VERIFICATION

STATE OF OHIO)
) **SS:**
COUNTY OF HAMILTON)

The undersigned, Bradley A. Seiter, Sr. Project Manager, being duly sworn, deposes and says that he has personal knowledge of the matters set forth in the foregoing data requests, and that they are true and correct to the best of his knowledge, information and belief.

Bradley A. Seiter Affiant

Subscribed and sworn to before me by Bradley A. Seiter on this 24th day of May, 2022.

NOTARY PUBLIC

My Commission Expires: July 8, 2022

EMILIE SUNDERMAN
Notary Public
State of Ohio
My Comm. Expires
July 8, 2022

VERIFICATION

STATE OF NORTH CAROLINA)
) SS:
COUNTY OF MECKLENBURG)

The undersigned, Brian Weisker, Sr. Vice President, Chief Operating Officer Natural Gas, being duly sworn, deposes and says that he has personal knowledge of the matters set forth in the foregoing data requests, and that they are true and correct to the best of his knowledge, information and belief.

Brian Weisker Affiant

Subscribed and sworn to before me by Brian Weisker on this 1st day of June, 2022.

NOTARY PUBLIC

SHANNON L. WALL
Notary Public, North Carolina
Mecklenburg County
My Commission Expires
June 28, 2022

My Commission Expires: 6/28/2022

KyPSC Case No. 2022-00084
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Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-001

REQUEST:

Refer to plans and specifications appended to the Application.

a. Identify any alternative designs or materials that could be used to comply with federal regulations.

b. Provide the estimated costs and useful lives of alternative pipeline designs or materials identified in the response to 1(a) above.

RESPONSE:

a. An alternative plan that was considered was the full replacement of the AM07 line as part of the first phase that included replacement of 4.5 miles of AM07 as opposed to the approximately 2 miles currently planned.

b. The full replacement of 4.5 miles of pipeline would cost approximately $63,300,000. This would be installed with new 24” coated steel pipe, comparable to what is currently planned.

PERSON RESPONSIBLE: Bradley A. Seiter

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-002

REQUEST:

Refer to the Application, paragraph 6.

a. Provide what "modem materials" the new pipelines will be constructed of, and how they differ from the current pipelines they will be replacing.

b. Provide the life expectancy of the new pipelines to be installed, and how long Duke Kentucky anticipates the new system to remain in service before other replacements or upgrades will be required through the filing of a future Certificate of Public Convenience and Necessity (CPCN).

RESPONSE:

a. The new pipeline will be constructed with high frequency electric resistant weld pipe with higher grade material and fusion bonded epoxy coating for better corrosion prevention.

b. The replacement steel pipe material will improve the safety and reliability of the existing vintage material. The existing pipeline contains A.O. Smith pipe which has a long history in the pipeline industry of crack susceptible hard spots and longitudinal seam failures. There is not a pre-determined life expectancy of the new pipeline. It will be operated and maintained as long it safely can.

PERSON RESPONSIBLE: Bradley A. Seiter

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-003

REQUEST:

Refer to the Application, paragraph 16.

a. Provide support for the annual ongoing cost of operation of less than $10,000 after the Project's completion.

b. Provide the expected annual costs of the required periodic inspections or testing that were not included in the estimated annual cost of operation of less than $10,000.

RESPONSE:

a. The annual ongoing cost of operation is based on the following activities that take place of an annual basis:

   1) Quarterly line inspections $2000 per inspection (4 times a year)
   2) Annual cathodic protection maintenance ($1000-$1500 once a year)
   3) Utility costs for facilities ($500-$1000 a year)

b. The annual ongoing cost of operation is inclusive of periodic testing/inspection. The only outlier to this is in-line inspection work that is done every seven years on the pipeline. That work is not included in the cost of annual operating costs.

PERSON RESPONSIBLE: Bradley A. Seiter

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-004

REQUEST:

Refer to the Direct Testimony of Brian R. Weisker (Weisker Testimony), page 5, lines 9-10. Mr. Weisker states that A.O. Smith pipe has a long history of failures due to hard spots in the pipe body along with failures on the longitudinal seam. Provide a published report or study supporting this statement.

RESPONSE:

Please see attached STAFF-DR-01-004 Attachment 1, STAFF-DR-01-004 Attachment 2, STAFF-DR-01-004 Attachment 2(a), and STAFF-DR-01-004 Attachment 2(b).

PERSON RESPONSIBLE: Brian Weisker

THE INGAA FOUNDATION, INC.

American Gas
Foundation

Integrity Characteristics of Vintage Pipelines

Prepared for The INGAA Foundation, Inc.,
in conjunction with American Gas Foundation by:
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201-2693

F-2002--50435

10 G Street, NE, Suite 700 • Washington, DC 20002 (202) 216-5900 • FAX (202) 216-0870 • www.ingaa.org

Final Report

on

Integrity Characteristics of Vintage Pipelines

Prepared for

Interstate Natural Gas Association of America

by

E. B. Clark and B. N. Leis
Battelle
and
R. J. Eiber
Robert J. Eiber, Consultant Inc.

October 2004

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Acknowledgements

This work was prepared under contract to the Interstate Natural Gas Association of America (INGAA), under the management of their working group on Integrity Management chaired on behalf of INGAA by Mr. Andy Drake of Duke Energy Gas Transmission (DEGT). Constructive suggestions from him and his team of project advisors notably Dr David L Johnson (CrossCountry Energy Services, LLC), Mr. T Boss (INGAA Staff), Mr Gary Vervake (DEGT), Mr S. C. Rapp (DEGT) and others too many to note are gratefully acknowledged. The project team at Battelle comprised the authors and others on staff that contributed to varying degrees, notably Dr Thomas Bubenik early in the project.

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Executive Summary

This report has evaluated vintage pipelines in reference to the historical evolution of the natural-gas pipeline system in the US, and the related evolution of steel and pipe making practices, and pipeline construction practices to meet the needs of that system. The potential for anomalies in this system has been characterized in reference to steel and pipe making practices, and pipeline construction practices. The potential importance of such anomalies to system integrity was assessed in terms of the response of anomalies to loadings experienced by pipelines. This analysis showed that the threat posed depends on a number of factors aside from the presence of an anomaly – the most important factors are the defect size, orientation, and severity, the mechanical properties of the pipe material, and the imposed loads. This report uses the term "defect" to identify anomalies that would be expected to fail at stress levels at the specified minimum yield stress and are becoming a practical concern.

Consideration of the characteristic defects in vintage pipeline systems and their possible impact on pipeline integrity leads to a number of important conclusions:

- Historic anomalies on vintage pipelines can be managed in reference to flowcharts developed for the anomalies most likely to threaten pipeline integrity – guidance is provided to determine when a defect may exist, conditions that can "activate" the defect, and practices used to mitigate the potential threat.
- Anomalies were introduced in historic steel- and pipe-making practices used by a small subset of pipe manufacturers, which have been tabulated in terms of the era the pipe was produced and its producer, which can be helpful in determining the potential that a defect is present.
- The most significant anomalies are inconsistent weld seam quality and hard spots. Of these, inconsistent weld quality is largely limited to the use of certain welding processes, such as specific forms of electric resistance welding and flash welding. Likewise, hard spots occurred only a limited number of line pipe types available from specific producers.
- Anomalies due to historic fabrication and construction practices are generally associated with certain girth weld practices and wrinklebends.
- Mitigation practices, including pressure testing, ILI, and improved operational controls can be effective in limiting growth of many historic anomalies.
- The use of pressure testing, which began on a widespread basis in the 1960s, serves to expose critical or near-critical defects and so can limit their significance.
- The design properties of pipeline steels do not diminish with time or aging of the system, there being no evidence to suggest pipe steels "wear out" – to the best of the authors' knowledge, no failure of a natural-gas pipeline has ever been attributed to aging of the line pipe steel.
- Data for the vintage system indicate that the rate of reportable incidents per volume of gas transported has gone down over many decades of service by as much as a factor of ten, even though the average age of the pipe is increasing. A decreasing trend likewise exists in terms of mileage, although not as dramatic. Thus, one could conclude the vintage system is viable and does not pose a unique threat to pipeline system safety.

Background

On December 15, 2004, the U. S. Department of Transportation issued a Final Rule that requires natural-gas pipeline operators to develop integrity management programs for high consequence areas (HCAs). The rules have been incorporated in Title 49 of the Code of Federal Regulations Part 192 (49CFR192) as Subpart O, Pipeline Integrity Management(1)*. This rule covers transmission pipelines that operate at or above 20-percent of the yield pressure.[1]

Before the integrity management rules were issued, the B31.8 Committee of the American Society of Mechanical Engineers (ASME) issued ASME B31.8S(2), "Managing System Integrity of Gas Pipelines". ASME B31.8S provides guidance on formulating and implementing integrity management programs for natural gas transmission pipelines. The final rule(1) incorporates many of the provisions contained in B31.8S, either directly or by reference.

One of the key components of ASME B31.8S is the use of technical information in the integrity management process (IMP). This report presents and discusses a rich set of information on vintage pipeline serviceability, which is described in Appendix A, along with research conducted over a period of years to establish trends and conclusions of value as part of the IMP process for vintage pipeline systems. Throughout, the focus of this report is pipeline systems transporting natural gas[2].

Definitions

Terms are introduced in pipe-related codes and specifications to describe abnormalities that may exist. To ensure consistent understanding of such terms, the following definitions[3] are adopted:

- Anomaly – Any deviation in the properties of the engineered product, typically found by nondestructive inspection. (The term indication is sometimes used in place of anomaly).
- Flaw – A deviation in the properties or function of the engineered product that is outside of the engineering specifications for the type of service anticipated in design.
- Imperfection – A flaw that an analysis shows does not lower the failure pressure below the specified minimum yield pressure or limit functionality of the engineered product.
- Defect – A flaw that an analysis shows could reduce the failure pressure to below the minimum specified yield pressure or limit functionality of the engineered product.
- Critical Defect – A flaw that an analysis predicts could fail below the pipeline's maximum allowable operating pressure (MAOP), or precludes in-service function.[4]
- Transmission Pipeline – By 49 CFR 192.3, these are pipelines operating at over 20-percent of the yield pressure. Typically, transmission pipelines are larger diameter steel lines operating at higher pressures transporting gas from a gathering line or storage facility to a distribution center, storage facility, or large volume customer. Pipelines that operate at pressures below 20% of the yield pressure are not addressed herein.

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[*] Numbers in superscript parenthesis refer to the list of references compiled at the end of this report.

[1] The pressure at which hoop stress equals the specified minimum yield stress (SMYS).

[2] This focus is specific to steels, line pipe making and pipeline construction practices used in this industry.

[3] These definitions are largely consistent with those adopted by ASME B31.8S

[4] The term critical defect is often used to identify a defect that will rupture. Such use is not implied here.

Objectives and Scope

This report has been developed to complement other work done under the auspices of the Interstate Natural Gas Association of America (INGAA) in cooperation with the Gas Technology Institute, and the Pipeline Research Council International, and others, to help formalize the IMP efforts of their member companies. Much of this work is summarized in References 3 through 20, with other work cited as it is introduced later in this report. Central in this effort was the consensus development of ASME B31.8S, whose provisions as noted above play an integral role in Title 49 of the Code of Federal Regulations Part 192 (49 CFR Part 192), Subpart O, Pipeline Integrity Management.

According to 49 CFR 192.917(a), gas pipeline operators must identify and evaluate potential threats to the integrity of each pipeline segment within HCAs. In this context, ASME B31.8S identifies 21 potential pipeline integrity threats in reference to work by Kiefner et al(3), and groups these threats into nine broad categories, as shown in Table 1. Such threats have been part of the incident reporting required U. S. Department of Transportation (DoT) Office of Pipeline Safety (OPS) starting in 2002.

Table 1. Categories of threats to integrity of natural-gas transmission pipelines

Threat Category		Time Based Behavior
1	External corrosion	Time Dependent
2	Internal corrosion	
3	Stress corrosion cracking	
4	Manufacturing defects	Stable unless activated by a change in service conditions
5	Fabrication and construction defects	
6	Equipment related defects	
7	Third party or mechanical damage	Time Independent or Random
8	Incorrect operations	
9	Weather and outside force related	

The threat categories in Table 1 can be differentiated by their time-based behavior, as indicated in column three. "Time Dependent" behavior indicates such threats can increase or decrease over time. Time-based inspection and maintenance practices can be effective in managing such threats. "Stable" behavior indicates such threats do not change over time, unless a change in the service conditions occurs, such as a pressure increase, which activates the threat. Once activated, the otherwise stable threat can become time dependent. One-time inspection and/or maintenance practices can be effective in managing stable threats. "Time Independent or Random" behavior indicates the occurrence of such threat cannot be correlated with the passage of time. Time-based-inspection and/or maintenance practices are ineffective in managing these threats, which are best managed by protecting against their occurring or limiting their consequences(e.g., see 4, 5).

The threat categories in Table 1 apply to all pipelines whether new or old. However, Categories 4 and 5 can be considered unique in the threat assessment of early pipelines, as much change has come over time in regard to the line pipe and its construction into pipelines. Thus, the objectives of this report are to identify 1) the types of anomalies produced by historic manufacturing, fabrication, and construction practices, 2) the conditions necessary to "activate" the anomalies, and 3) mitigation practices used to control the growth of the anomalies in reference to buried vintage pipelines. For the purposes of this report, pipe making and construction practices that are no longer used, including some early variations of current practices, are termed *historic*. *Vintage pipelines* are those built using pipe or construction practices made with such *historic* practices.

The report addresses threats due to anomalies introduced by historic steel-making, pipe-making, construction, and fabrication. The report does not address historic pipe and practices used in offshore pipelines, service lines, nor does it address pipelines not made of steel and operated above 20% of the yield pressure. Where possible, the report gives guidance on determining whether a given type of flaw is likely to be present on a pipeline, and if so, whether the flaw may grow or otherwise presents a current threat to integrity. Such guidance is specific to historic pipe manufacturing (Threat Category 4) and construction practices (Threat Category 5). This report does not address the remaining threat categories (i.e., external corrosion, internal corrosion, stress corrosion cracking, equipment related defects, third party or mechanical damage, or incorrect operations). These threats are not unique to vintage pipelines and addressed in References 6 through 19, and elsewhere, including coverage of issues unique to low-wall-stress pipelines(e.g. 20).

Finally, this report addresses questions raised regarding whether vintage pipelines deteriorate solely because of their age. Addressing this question can be confusing, in part due to terminology. The change in fundamental mechanical properties, such as yield strength, over time due to temperature or applied stresses or strains is referred to by metallurgists as "aging." This is different from possibly degraded load carrying capability of an engineered structure due to time-dependent processes such as corrosion. As noted above, time-dependent threat categories such as corrosion are addressed elsewhere for pipelines generally, and are not unique to vintage pipelines. However, as aging could be viewed as a problem unique to vintage pipeline systems, this report also considers whether pipeline integrity is affected by aging in reference to changes in material properties.

Report Organization

This report begins with a brief history of natural-gas pipelines, steel and pipe making practices, and pipeline construction practices. This section provides perspective for issues related to vintage pipelines in reference to threats for such systems in contrast to more modern systems, relying on incident data historically assembled under the auspices of the US Government. Thereafter, the conditions necessary for such incidents to occur are presented to help understand methods to avoid and manage causative factors. The historical perspective then shifts to consider pipeline design practices and the effects of aging on pipeline properties, with reference to Appendix C that deals with aging in detail. There it is evident that the aging of pipeline steel does not cause changes in properties that affect pipeline integrity, leading to the conclusion that pipe steels do not "wear out".

Next, historic anomalies that arise from manufacturing (steel and pipe making) and fabrication / construction process are considered. The report provides flowcharts that address the anomalies most likely to threaten pipeline integrity, that provide guidance for determining when an flaw may exist, conditions that can "activate" the flaw, and practices used to mitigate the potential threat. Finally, the report provides a summary of the conclusions drawn based on the results presented.

This report includes eight appendices that provide detailed support for the conclusions drawn in the body of the report for those readers concerned for broad consideration of the issues, while facilitating direct coverage of such topics in the body of the report for those readers more interested in topical coverage. Appendix A presents details of the databases used to characterize the transmission pipeline system and its historical evolution in terms of system safety, while Appendix B addresses issues unique to low-wall-stress pipelines. Appendix C considers issues related to the aging of the steel pipelines are made of, focusing on design properties. Appendix D details historic steel- and pipe-making practices while Appendices E and F present incident experience based on pipe vintage and seam type, and supplier respectively. Appendix G presents similar information in reference to vintage construction practices. Finally, Appendix H presents related historic timelines.

Historical Perspective

History of Natural-Gas Pipelines[5]

The first recorded use of natural gas in North America took place in the early 1600s, when explorers witnessed Native Americans lighting gas that seeped from the earth near Lake Erie. From that time and through the 1800s, natural gas was used almost exclusively for lighting, with most of the gas manufactured from coal rather than produced from wells.

In 1859, one of the first natural-gas pipelines was built, a two-inch line that ran from a natural gas well to Titusville, Pennsylvania. Early attempts at transporting gas included innovations such as wooden and wrought iron pipelines, neither of which proved practical for long-distance higher-pressure lines. It was not until leak-proof couplings were invented in 1890 that widespread natural-gas pipelines began to be constructed. By the late 1920s, advances in metallurgy and welding technologies led to the initial construction of a North American pipeline infrastructure. By the early 1930s, at least ten major gas transmission pipelines were in service in the United States.

Today, the natural gas pipeline infrastructure in the United States serves over 60 million customers and is comprised of roughly 300,000 miles of transmission pipelines, 569,000 miles of steel distribution mains, 577,000 miles of non-steel distribution mains, and 58 million miles of service lines.(21) Of the 300,000 miles of transmission pipelines, nearly 15,000 miles (about 5% of the total) was built before 1940, 185,000 miles (62% of the total) between 1940 and 1970, and the remainder since 1970. This distribution over time is evident in Figure 1. Unfortunately, a corresponding timeline cannot be developed for the construction of steel distribution mains, as the necessary data are not readily available.

There are several important differences between transmission pipelines and steel distribution mains. Most notably, steel distribution mains are of smaller diameter than transmission pipelines, as is evident in Figures 2 and 3.(21) Nearly all of the lines with diameters greater than 12 inches are transmission pipelines, while those with diameters between 4 and 12 inches are roughly split between distribution mains and transmission lines. Roughly 8 percent of the transmission pipelines have diameters less than 4 inches, while nearly 78 percent of the distribution lines are below 4 inches. This report focuses on pipe diameters greater than 4 inches. Consequently, it addresses nearly all of the transmission pipelines and slightly less than one quarter of the distribution mains.

Trends in Manufacturing, Fabrication, and Construction Threats

Consider now the relative importance of manufacturing, fabrication, and construction defects based on their contribution to incidents occurring in the pipeline infrastructure distributed as evident in Figures 1, 2, and 3.

Figure 4 summarizes the average annual number of incidents attributed to the ASME threat categories summarized in Table 1 for the period from 1984 through 2000. This figure specifically represents onshore natural-gas transmission pipelines. Figure 1 presents the frequency of incident occurrence per year for each of the threat categories in Table 1, and so indicates the relative importance of each threat category.

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[5] This section draws on material published in the Oil and Gas Journal and Pipeline News, , data assembled by the OPS(21), information gathered under the auspices of INGAA or the ASME(e.g. 22), and a related web search.

Categories 4 and 5, the focus of this report, each account for roughly two reportable incidents per year. These Category 4 and 5 incidents reflect the mileage for all pipelines in operation from 1984 through 2000 for both vintage and modern pipeline systems. While informative, this type of information only provides a snapshot of the likelihood of an incident, and does not consider the consequences of an incident. Insight on the consequences of a particular threat category can be found in reports prepared by Hartford Steam Boiler(4,6). This and other work(3), for example, indicates that Category 7, Third Party or Mechanical Damage, is responsible for more than 85% of the fatalities due to onshore natural-gas pipeline incidents(4-6). Significantly, data assembled in Appendix A for the vintage system indicate that the rate of reportable incidents per volume of gas transported has gone down over many decades of service by about a factor of ten, even though the average age of the infrastructure is increasing.

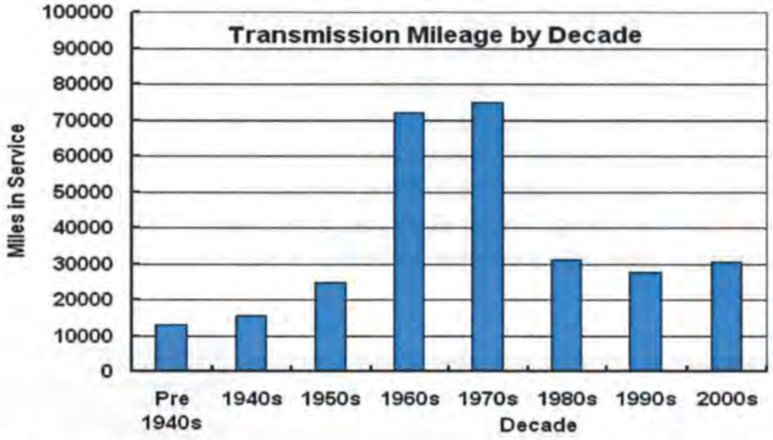

Figure 1. Mileage of transmission pipeline added by decade of construction (2002 OPS Annual Report)

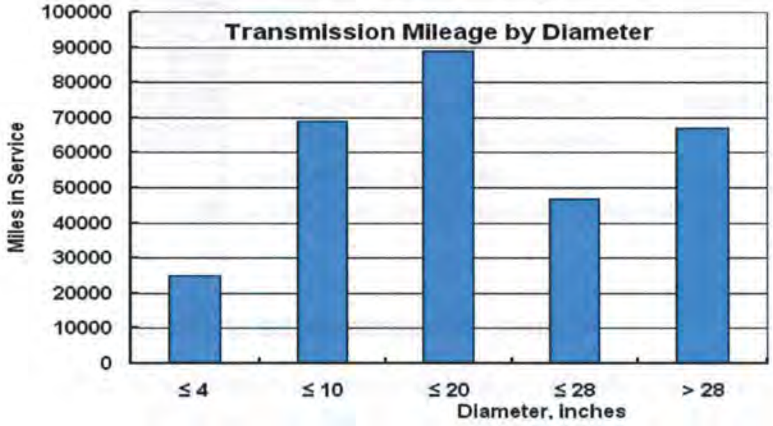

Figure 2. Mileage of transmission pipelines by diameter (2002 OPS Annual Report)

Relative to other causes of pipeline incidents, historic anomalies occur less frequently than most other causes. For example, in the 1985 through 2000 incident data reported to the Office of Pipeline Safety, there were 30 incidents attributed to material faults in the pipe body, while there were 359 incidents attributed to corrosion and 591 incidents attributed to outside force. The relative threat or number of incidents attributed to historic anomalies is an order of magnitude less than corrosion or outside force and has been reducing throughout the decades.

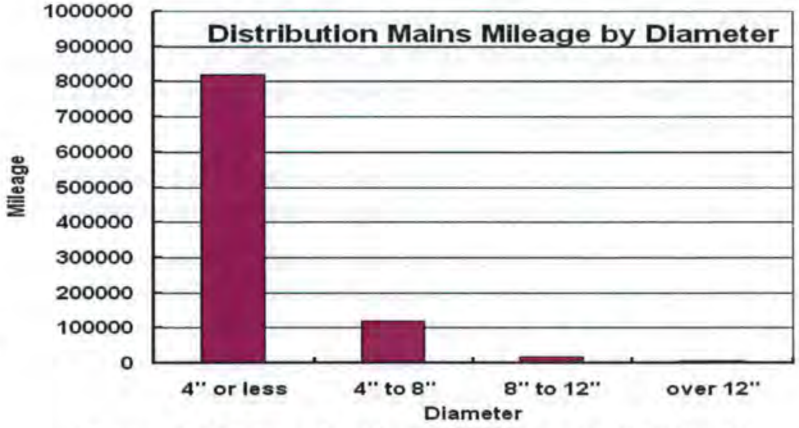

Figure 3. Mileage of steel distribution mains by diameter (2002 OPS Annual Report)

Historic Pipe-Making and Construction Practices

Differences in steel-making, pipe-making, and pipeline construction practices must be considered to fully understand how vintage versus modern pipeline systems contribute to the trends in incident frequency presented in Figure 4. In this regard it is instructive to examine the two threat categories considered in this report, specifically Categories 4 and 5. In regard to Figure 4 these two categories account for about two incidents each per year, of which some occurred on vintage pipe. While the available data preclude full evaluation of the incidents, it is reasonable to conclude that some of the Category 4 and 5 incidents involving vintage pipe occur at defects whose origin involves factors other than the vintage issues discussed in this report. From this perspective, complete mitigation of the vintage pipe issues considered herein would result in a reduction of perhaps one or two incidents per year.

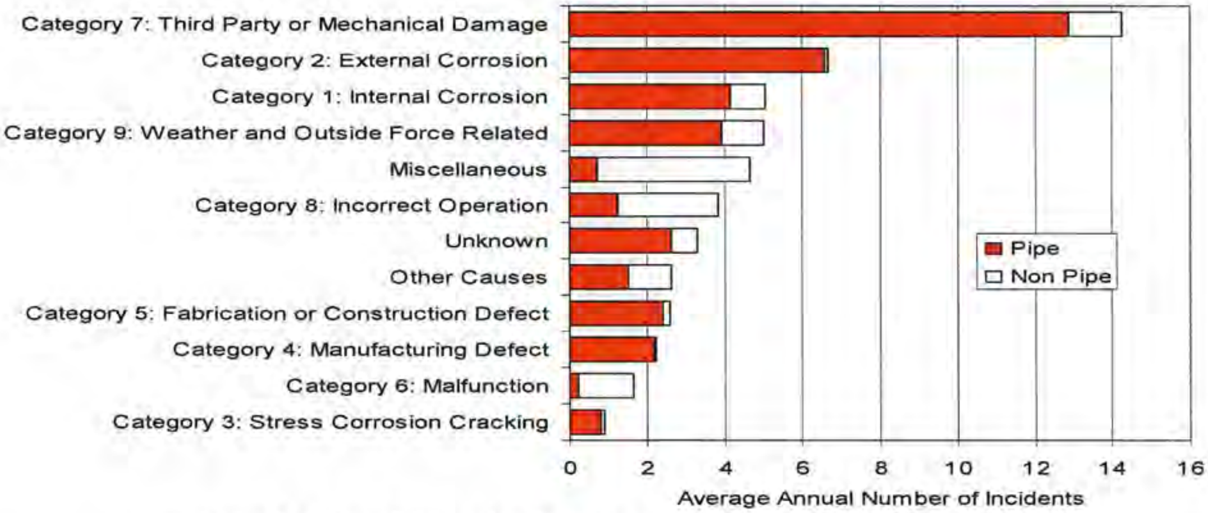

Figure 4. Reportable natural gas transmission incidents 1984-2000

Figure 5 presents pipe making processes and their period of use. Processes covered in Figure 5 include furnace butt-welding, continuous butt-weld, lap and hammer welding, low-frequency electric resistance welding (ERW), flash welding, single submerged arc welding, some early seamless (SMLS) variations, high-frequency ERW (HFERW), and double submerged arc welding (DSAW) as either straight seam or spiral seam. Of these processes, the continuous butt-weld SMLS, HFERW, and DSAW processes remain in widespread use today, and have so since early 1970, whereas the others were phased-out about 1970 or previously. Vintage processes are those used prior to 1970, and since abandoned, although as the dotted line indicates not all processes termed historic herein were abandoned in 1970.

New technology coupled with changing economics led to the introduction of new processes, the modification or improvement of existing processes, and abandonment of others.

Where these processes created pipe with variable characteristics throughout the longitudinal weld or the pipe body, such variability is classified as an anomaly. The acceptance for use of a product such as pipe is controlled by the engineering specifications and quality control procedures at the time the product is manufactured. These specifications are developed based on the parameters of the service that the pipe will be used. Quality control procedures such as visual and nondestructive inspection are used to verify that the anomalies remaining in the product meet the engineering specifications. Over time, more stringent engineering specifications and improved quality control procedures have

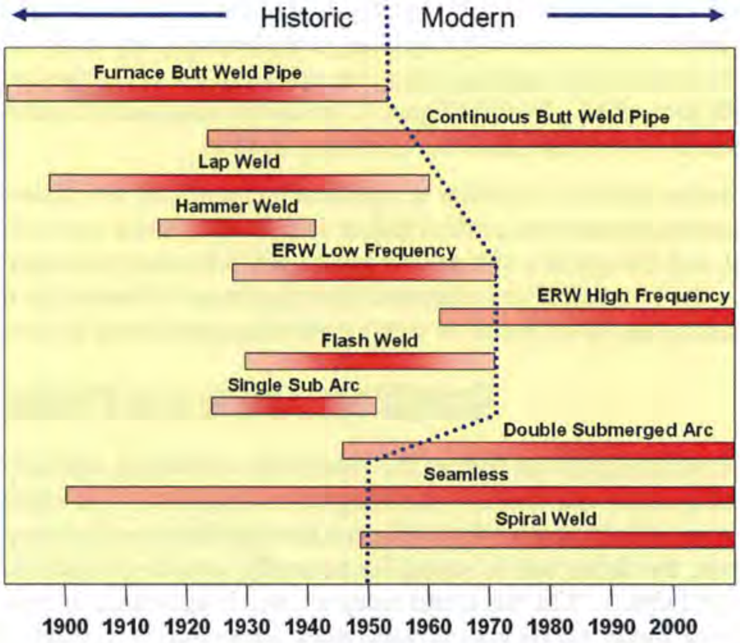

Figure 5. Pipe making practices

been developed as new knowledge was gained in the manufacture of a product such as steel line pipe. More stringent specifications were the driver for improved quality, while inspection and testing procedures were central to quality control. Some of these inspection and testing procedures can and have been applied to pipe already in service essentially improving the integrity of the pipe in service.

Fortunately, processes that produced pipe with anomalies that lead to incidents have largely been produced by a handful of pipe mills, generally over a limited time period. Specific types of anomalies are found to be characteristic of specific production processes. The development and adherence to specific quality control procedures has for the most part eliminated anomalies that did not satisfy engineering specifications. In some cases, additional knowledge gained after a product is put in service has resulted in a change of acceptable engineering specifications. A good example of this is the classic concern of the integrity of certain types of early low frequency electric resistance welded (ERW) pipe. After several years of service, recurrent performance problems with selected early ERW production indicated a need for process change, such that engineering specifications and accompanying quality control and acceptance procedures were modified for subsequent production. To ensure system safety, quality assurance and/or integrity assessment procedures, such as hydrostatic pressure testing[23], were implemented on pipe already in service. Tables that follow shortly and Appendices D through G provide details of the problems, and the changes in specification and production practices that alleviated these concerns.

The significance of both pipe-body and weld-seam anomalies on integrity vary with the mechanical properties of the pipeline as well as loads due to normal operations and abnormal loadings. Starting around 1960, mill inspection practices were significantly improved, as did typical material properties of the steel available for pipe making.

Figure 6 summarizes historic pipeline construction practices and the dates the processes were used in analogy to

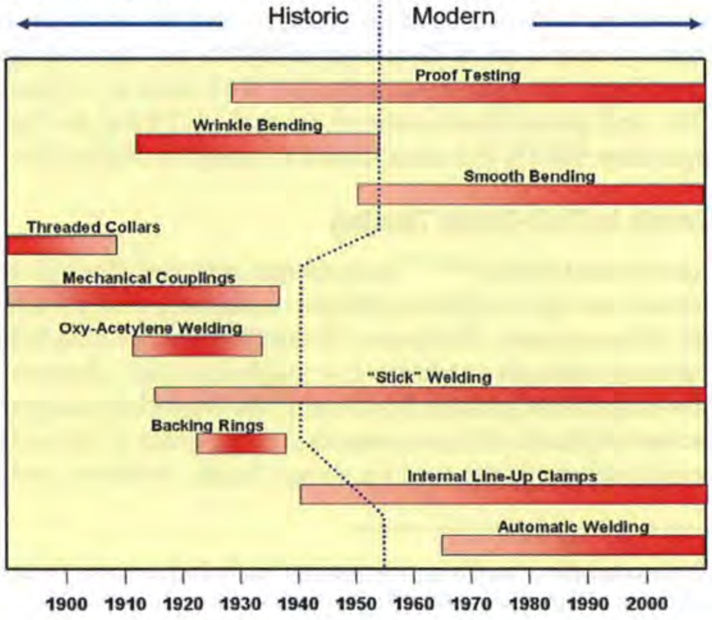

Figure 6. Pipeline construction practices

Figure 5 dealing with line pipe. Historic fabrication and construction practices include the use of threaded and mechanical couplings, wrinklebends, oxy-acetylene welding, and backing bars. As with historic pipe-making processes, not all of these vintage construction practices led to pipelines with anomalies. As with Figure 5, the dotted blue line indicates that not all processes considered historic were abandoned at a fixed date in time.

Whether or not an anomaly is significant depends on its influence on integrity. The next section identifies factors that control failure in reference to the sizes of defect that can cause a pipeline to fail, and the stresses that drive a failure subject to the properties of the line pipe. This next section lays the foundation to understand the importance of anomalies due to pipe making and pipeline construction in reference to vintage practices considered in subsequent sections of this report.

Conditions Leading to Pipeline Failures[6]

This section presents factors that determine whether an anomaly is also a defect, or can become a critical defect and threaten the integrity of a pipeline. The objective here is to illustrate causative factors and parameters that influence the significance of an anomaly. Given the objectives of this report, the focus here is anomalies normally considered stable in reference to categories four through six in Table 1. The last threat category also is addressed in reference to scenarios where weather and outside forces act on historic anomalies, imperfections, or defects.

Defect-Free Failure Response

Consider first the failure behavior of line pipe that is defect free, which is the reference condition to assess failure response of code-accepted failure criteria such as ASME B31G(26), and other such failure criteria for pipelines. Figure 7 characterizes the failure stress of defect-free pipes in grades from Gr. B through X65, which span the range of grades typically available prior to 1970, and includes a late 1960s vintage experimental X100 grade designated in the figure as EX100. Figure 7a shows, the defect free failure stress of end-capped pipe is on average characterized very well by the UTS[7]. The range of the ratio of UTS / actual failure stress for these data runs from 1.09 to 0.88, or data scatter of roughly ±10 percent uniformly around the one-to-one trend. Figure 7b contrasts the value of the UTS as a function of SMYS and the maximum allowable stress (MAS) for US pipelines, which by code is set at 72-percent of SMYS for Class I design that applies to cross-country pipelines. From Figure 7b it can be seen that the MAS leads to a factor of safety the order of (SMYS / (0.72)) = 1.39. And given failure occurs at about the UTS that for these vintage grades is about 25-percent larger than SMYS, the actual factor of safety for defect-free line pipe is about 1.74.

Trends in Full-Scale Testing

Experimental studies(e.g., 27) indicate that axial part-through-wall (PTW) defects in a pipeline under pressure can fail via plastic collapse or fracture, with growth through the wall occurring in a three-step failure process. Reference 28 details this three-step failure process and essential differences in hydrotest protocols to address low toughness steels, through moderate to high toughness steels. The three-step failure process described in the following paragraphs is central to understanding whether fracture or plastic collapse controls failure, which in turn reflects the evolution of steels that was strongly driven by the need for strong, tough, weldable steel for use in line pipe(29).

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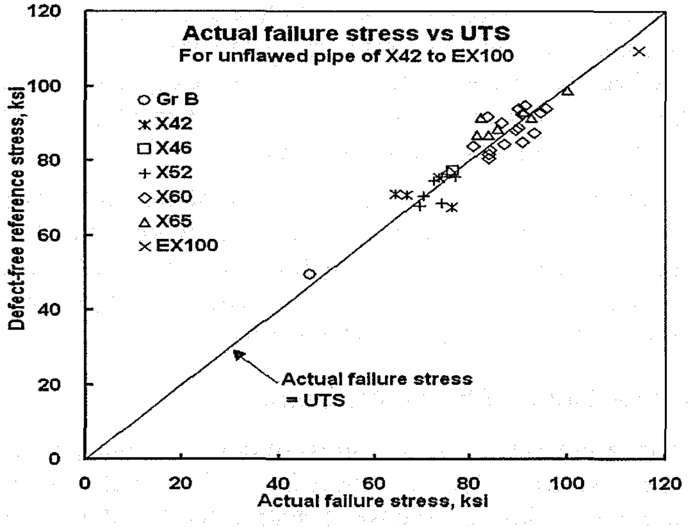
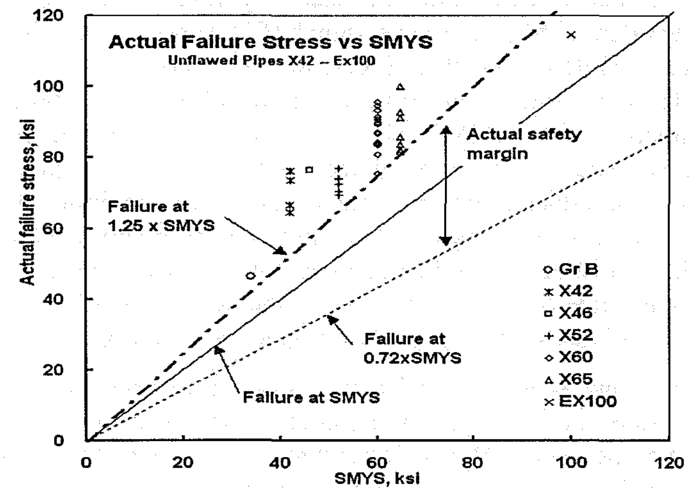
[6] This section draws heavily on concepts detailed in References 8, 17, 24, and 25. Appendix B of Reference 15 and Reference 17 provide perspective for their use and demonstrate their accuracy.

[7] The maximum load carrying capacity prior to failure of the material

Full-scale experiments indicate the first step in the failure process of sharp axially oriented defects involves gradual bulging of the pipe local to the defect as the pressure is increased. Such bulging becomes more evident as the pressure increases, which in tough steels can occur without measurable defect growth. For ductile thin-wall pipe and deep defects, bulging is noticeable to the unaided eye, but for heavier-wall pipe, shallow defects, or lower toughness steels, relatively less bulging occurs prior to failure. The second step involves nucleation of cracking and its possible stable extension into the wall and along the pipe that continues as the pressure increases. The final step involves initially stable time dependent crack extension at constant pressure, which eventually transitions to unstable crack growth, and rapid penetration into and through the wall thickness.



a) consolidation achieved via UTS



b) FoS inherent in WSD

Figure 7. Plastic-collapse in defect-free pipe

The amount and nature of the crack extension depends on the steel's fracture resistance, measured commonly in terms of the Charpy-vee-notch(30) fracture energy, with the most complex response developing for modern higher-toughness steels, and least for early vintage steels. Higher toughness steels experience blunting along their initially sharp crack fronts that makes them very resistant to fracture. In the same way tough steels blunt initially sharp defects, their growth involves the extension along a blunted crack-tip. An upper-bound toughness exists beyond which failure pressure ceases to increase as toughness increases, with little difference evident beyond this toughness level(17). Such behavior indicates the transition from toughness-controlled failure to plastic-collapse-controlled failure for a given line pipe geometry, although such behavior can occur at much lower toughness particularly for shorter defects, or very deep or very shallow defects. Whether the breach created in pipe wall as the crack transitions through-wall leads to a leak or a rupture (and fracture propagation along the length of the pipe) depends on the length of the break, the geometry of the line pipe and its mechanical and fracture properties, and the properties of the pressurizing media(17). Very short breaks are likely when hydrostatic testing very tough steels, which might be difficult to identify on pressure-volume plots under some test conditions.

Critical Defects

Defect sizes associated with failure at MAOP are considered critical defects in the definitions introduced at the start of this report. Analyses methods have been developed that accurately recreate the experimental trends in defect failure and accurately predict failure pressure, which facilitate calculating critical defect sizes for blunt defects(e.g., 31,32) as well as initially sharp defects(e.g., 24), which have been proven accurate across the range of toughness representing vintage through modern line pipe[8]. Such technology is used next to illustrate typical critical defect sizes and their dependence on the line pipe's properties and its loading.

Critical defect dimensions are a function of the type, magnitude, and manner in which loading is applied, the pipe geometry, and the material properties of the pipe steel. The most important line pipe properties affecting critical dimensions are the UTS and the toughness. Since there are property differences between vintage pipelines and modern pipelines, it is helpful that the reader understand this behavior as they develop their IMPs.

Critical Defect Sizes – An Example

Figure 8 presents the failure stress of defects in line pipe calculated using software developed at Battelle as detailed in References 24 and 25, which has been extensively validated. These trends represent the failure response of sharp crack-like defects in a 30-inch diameter pipeline made with a 0.312-inch-thick wall of X52 steel. Figure 8a represents results for X52 steel with full-size equivalent (FSE) Charpy vee-notch (CVN) energy (toughness) of 100 ft-lbs, which reflects modern steels, while the results in Figure 8b reflect critical defects in X52 line pipe with CVN energy of 10 ft-lb, which reflects the lower end typical for some vintage steels. The vertical axis is hoop stress as a fraction of the SMYS. The horizontal axis is the axial extent or length of the crack-like defect. The curved lines represent defect depth relative to the pipe's wall thickness (e.g., the curve labeled 70 percent deep represents defects that have a maximum depth 70-percent through the wall). The dashed horizontal lines correspond to low-wall stress operation (30 percent SMYS), operation in Class 3 (50 percent SMYS) and operation in Class 1 (72 percent SMYS). The horizontal line at the y-axis value of ~1.4 corresponds to the ratio of the UTS to SMYS for this X52 pipe, which indicates this steel has slightly improved properties as compared to the results shown in Figure 7b.

Each point along the labeled curves in Figure 8 represents a critical length and depth for a given pressure. For example, in reference to the higher toughness steel reflected in the trends in Figure 8a – at 50 percent SMYS, a defect that is 90 percent of the wall thickness deep and 3.7 inches long (point 1 in the figure) will fail, as will a defect that is 70 percent deep and about 13 inches long (point 2 in the figure). Similar values can be determined for other combinations of depth and pressure. At higher pressures, the critical defect sizes are smaller, and at lower pressures, they are larger.

While not evident from the information supplied in reference to Figure 8a, the trends for defect depths 40-percent and 90-percent through wall represent failures that are controlled by the strength of the pipeline steel. This occurs for these depths because the toughness supplied (at 100 ft-lb) leads to toughness independent failure, or plastic collapse. If the toughness were much lower (as occurs for some vintage pipelines), the failure response of some defect depths and lengths would be controlled by toughness rather than strength. This is the case in reference to Figure 8b, which represents CVN energy of 10 ft-lb. Notice first that for this lower-toughness steel that defect-free failure is indicated at a y-axis value of ~1.4, just as it did for the higher-toughness scenario in Figure 8a. Thus, defect-free lower-toughness pipe fails by plastic collapse.

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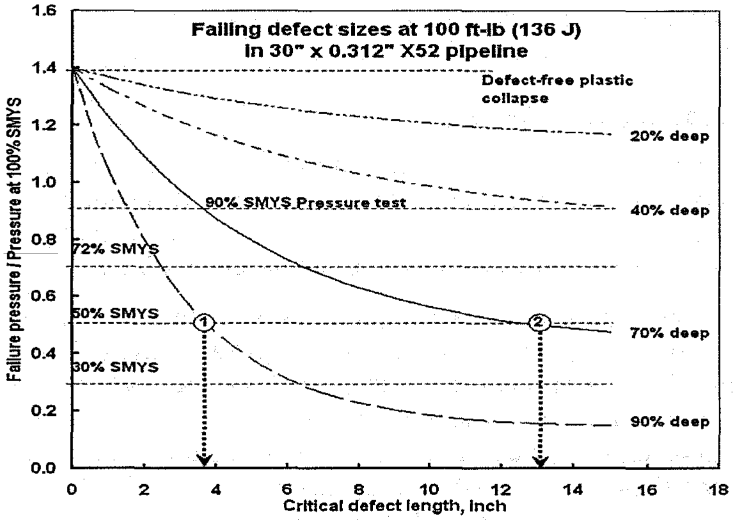
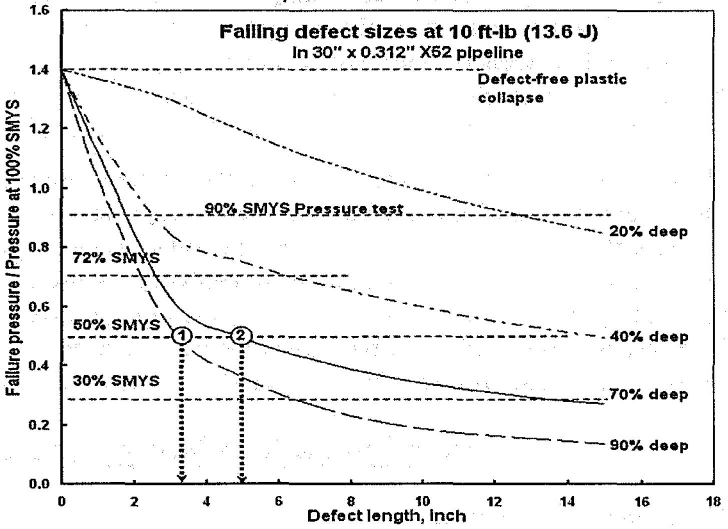
[8] For a summary of such work see Reference 33.

For the lower-toughness steel, Figure 8b indicates the critical defect length at 50 percent SMYS for a 90 percent deep defect is 3.3 inches long, while that for a 70 percent deep defect is ~4.8 inches long. In contrast to Figure 8a, lower toughness pipelines have smaller critical defect sizes, although there is little difference for very deep defects as these remain close to a plastic-collapse condition. Aside from somewhat smaller defect sizes and failure more often under fracture rather than collapse control, there is little difference in the performance between vintage pipelines and those made of modern steels.

Extensive analyses, similar to those discussed above, have been conducted over the years to determine when plastic collapse controls failure(e.g., see 15). The analyses indicate that plastic collapse controls for most defect geometries and steels, except for defects with moderate depths in lower-toughness steels. Plastic collapse is a preferred failure mode, as it involves widespread plastic deformation and capitalizes on the reserve strength of steel, which provides an additional safety margin, well beyond that implied in working stress design(WSD), as discussed further in Appendix D.



a) at 100 ft-lb FSE CVN



b) at 10 ft-lb FSE CVN

Figure 8. Failing defect sizes vs. toughness

Figure 8 shows that critical defect sizes for in-service failures are quite large, even for anomalies in the lower-toughness steels. With the exception of weld-seam anomalies, many historic anomalies are short and not critical unless they are very deep. In contrast, the dimensions of weld-seam anomalies cover a wide range of shapes and sizes. The most significant are usually longer and when located in lower toughness weld zones can be critical at shallower depths.

The curves in Figure 8 correspond to sharp axially aligned (i.e. defect length along the pipeline) anomalies. Blunt anomalies and those that are not axially aligned have much larger critical dimensions(e.g., see 15). A tolerance for relatively large defects, even in lower-toughness steels, implies that pipelines can operate safely with stable anomalies less than critical size. More importantly, use of high-pressure or code required hydrostatic testing would expose all defects whose size lies below the test pressure. Thus, even though as-produced vintage pipe contained anomalies, the use of pressure testing, which began on a widespread basis in the 1960s(e.g., see 23, 34, 35), served to expose critical or near-critical defects and so limit their significance.

Loading at Defects

Pipeline failures at critical defects can occur under the usual pressure loading or in response to unanticipated or unusual loading conditions. When failures occur, they are typically due to quasi-static loading.[9] Consequently, material properties that are taken under quasi-static conditions rather than dynamic conditions are relevant in determining critical defect dimensions and failures modes.

The primary stress on buried pipelines is due to internal pressure of the pipeline. For a given pressure, hoop stresses in the pipe wall are a function of the diameter-to-thickness ratio of the pipeline. As the diameter-to-thickness ratio increases, the hoop stress increases all else being equal. Under some conditions, historic anomalies can grow to critical dimensions by fatigue, or SCC. However, for typical gas pipeline operations few if any critical defects sizes lie above the threshold for fatigue crack growth and so remain inactive(20, 37). Likewise, most critical defect sizes fall below the threshold for continued growth by SCC, except for conditions favoring SCC would independently nucleate cracking. The chance of fatigue crack growth depends on pipe hoop stress, the extent to which it changes, and the number of cycles of that change. The chance of SCC is more complex, but includes a dependence on pressure cycling, temperature, and other electrochemical considerations. Neither fatigue nor SCC is covered in this report. Interested readers are referred to recently published work on fatigue (e.g., 36,37), or SCC(12, 38), and text books that address such topics(e.g., see 39, 40).

Unanticipated loadings and related secondary stresses are most commonly the result of earth movement (i.e. landslide, earthquake), heavy rains, or floods (see Table 1). Unintended events that increase the pressure above the normal operating pressure can also create unanticipated loads that lead to failure, but are rare because of redundant pressure controls. Depending on the magnitude of the loading, failure can initiate at a flaw in the pipe or a weld. In situations where very high external loads are imposed, failure of flaw free pipe can occur due to plastic collapse. As is usual, secondary loads should be addressed where they are known to occur or can otherwise be reasonably anticipated.

Pipeline Failure Modes and Consequences

Leak versus Rupture

Pipeline failures can occur as either a leak or a rupture, depending on the critical defect size and the loading on the defect(17). In a leak, the release of gas is small and controlled, and the consequences are generally less than in ruptures. This is a critical aspect in risk analyses of pipelines, which might be done as a part of a system-wide IMP.

Figure 9 depicts the calculated demarcation between leaks and ruptures for the two cases shown earlier in Figure 8. Below and to the left of each curve in Figure 9 the defect will fail as a leak, whereas defects that are above and to the right of the curves will rupture. Longer defects are more likely to rupture than shorter defects, but the effect of material toughness can be relatively small[10], particularly at higher stress. This is evident in Figure 9, where at stresses the order of high-pressure

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[9] Dynamic loading, from the perspective of pipeline failures, refers to loading that occurs on the order of milliseconds. Because of the compressibility of gas, pressure always is a quasi-static load. Loading due to weather and outside forces also are typically applied at a much slower rate.

[10] Toughness influences many aspects of fracture resistance, from fracture initiation through fracture propagation(e.g. 15,17). Thus, "can be rather small" is context specific and should not be taken beyond the specific scenario considered.

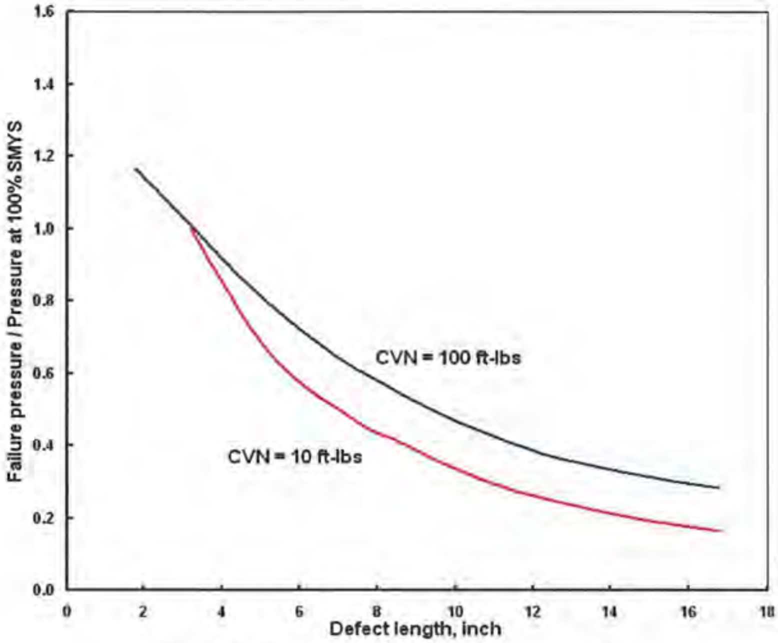

Figure 9. Leak versus rupture boundary

hydrotesting the trends for quite different toughness become coincident. As noted earlier, with the exception of weld-seam anomalies, most historic anomalies are short in length. Thus, these defects are more likely to fail by leaking than by rupturing. Weld-seam anomalies, which can be long, may fail by rupturing the pipe.

Likewise, lower pressure lines (e.g., lines in Class Locations 3 and 4) operated at their maximum allowable operating pressure (50 and 40%, respectively) can tolerate longer defects without rupturing as compared to higher-pressure pipelines. Consequently, pipelines operated at MAOP for Class Location 3 and 4 locations are more likely to leak than rupture for a given defect size as compared to the same scenario in lines operating at MAOP for Class Locations 1 and 2.

Brittle versus Ductile Fracture[11]

Whether pipe rupture behavior is brittle or ductile can affect the consequences of a failure if the failure propagates. Brittle fractures propagate more quickly along the pipeline than do ductile fractures. Propagating brittle fractures run at speeds higher than the acoustic velocity in the gas, which means the pressure ahead of the crack remains high and therefore arrest is unlikely. For this reason propagating brittle fractures can open long distances of a pipeline without arrest, and so are considered more serious than propagating ductile fracture because of the amount of pipe destroyed.

Public safety at a particular site along the right of way can be viewed in terms of the thermal exposure associated with a fracture. C-FER has developed a model [(41)] that has been widely accepted to estimate thermal exposure. The model assumes a full guillotine fracture with jet fires impinging from both ends of the rupture. This type of failure, if ignited at the time of the rupture, comprises the worst-case event as it results in the highest thermal exposure for the surrounding area. If the fracture propagated to where the ends of the pipe were separated by a significant distance (i.e. two single point locations), the resulting thermal exposure at either site will be significantly lower, because of the reduced fuel available. Thus, the potential thermal exposure is greater for shorter fracture lengths, because of the proximity of the fuel sources. Ductile fracture typically produces shorter splits than does brittle fracture all else being equal. Thus, the thermal exposure in such cases can be more intense as compared to brittle fracture propagation that significantly separates the fuel sources. While brittle fracture produces reduced thermal exposure, the downside is such exposure threatens

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[11] For a general overview of this topic and methods for control, see Reference 17.

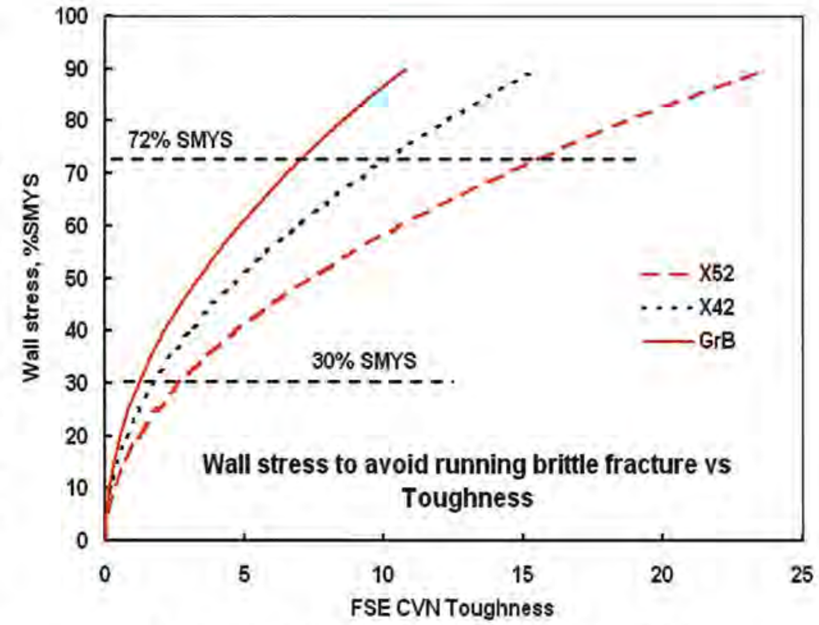

Figure 10. Arrest toughness for propagating brittle fractures

two sites. Retrofit arrestors are an option to control fracture propagation in such cases. Reference 42 reviews the issues in such applications and presents a design basis for arrestors.

The material property that controls whether a propagating fracture will stop is the arrest toughness of the line pipe steel. Figure 10 presents the minimum arrest toughness for steady-state running brittle fracture on the horizontal axis, as a function of wall stress plotted on the y-axis. The curves represent 16-inch diameter line pipe with a 0.250-inch thick wall made of one of three grades of steel – Grade B, X42, and X52. For this example, toughness equivalent to CVN energy of 2 to 3 ft-lbs provides sufficient resistance to arrest a running brittle fracture for operation at 30% SMYS. At 72% SMYS, somewhat higher toughness is needed: between 7 and 15 ft-lbs. Larger diameter or thinner wall pipelines require proportionally higher toughness.

Many early pipelines in Class Locations 3 and 4 were of smaller diameter and were built from materials with lower strength (typically Grades A, B, X42). In light of the trends in Figure 10 and typical toughness available for such steels, these pipelines operate with limited concern for propagating brittle fracture. Consequently, brittle propagation is not considered a significant issue in most vintage pipelines.

Early pipelines in Class Locations 1 and 2 tend to be made of higher strength material (Grades X42 and X52) and require a higher toughness to arrest a propagating brittle fracture. Some, but not all, early Class 1 and 2 pipelines have sufficient toughness to arrest propagating brittle fractures. Retrofit fracture arrestors are an option to control fracture propagation in such cases. Reference 42 reviews the issues in such applications and presents a design basis for such arrestors.

Pipe Diameter

The pipe diameter influences the consequences of a failure because it affects the maximum opening size, which in turn, controls the maximum exhaust rate. Reference 41 indicates the size of the region critically exposed during a rupture varies with the pressure in the pipeline and the square of its diameter. Thus, diameter is a key consideration in managing this issue when developing an IMP.

Failures that occur as leaks are generally consider less significant because they have smaller release volumes and rates as compared to ruptures. In a rupture, the full bore of the pipe is effectively open to the environment. As the gas exhausts, a decompression wave moves through the pipeline. After a very short period of time and at the opening, the exhaust pressure reaches a limiting state, where the gas flows at the speed of sound at the exhaust pressure. Larger diameter lines exhaust larger gas volumes that increase the fire damage radius as compared to smaller diameter lines.

Special Considerations

Low-Wall-Stress Pipelines

As discussed earlier, nearly all distribution mains are smaller in diameter than 8 inches and operate at lower pressures than transmission pipelines. However, many companies operate larger diameter trunk lines at pressures typically between 15 to 30-percent of SMYS, although a few operate at pressures up to less than 40-percent of SMYS.

Coupled with the increased likelihood that these lines will fail as a leak rather than a rupture when compared to transmission pipelines(20), the potential failure consequences are less than those in larger diameter and higher-pressure transmission lines. Consequently, in this report, two sets of assessment methodologies are given: one for lower pressure lines that are most likely to fail by leaking, and the other for higher pressure lines that could fail by either leaking or rupturing. The division for the two failure modes is taken as 30 percent of SMYS. Low-stress pipelines are discussed in more detail in Reference 20 and Appendix B.

Effect of Aging on Steel Properties

There is no evidence that the properties of steel are reduced as steel ages. Appendix C details the process of aging in steel, and evaluates its occurrence for present purposes. Other time dependent deterioration mechanisms such as corrosion are covered by other reports.

The results evaluated in Appendix C indicate that aging has no practical significance in reference to changes in the pipeline's design properties or its inherent integrity.

Historic Anomalies and Threat Assessment Procedure

Consider next guidance for determining when a historic flaw may be present on a pipeline, when it poses an increased threat to integrity, and which mitigation methods are most effective in controlling such threats. Prudence dictates independent consideration of the consequences of failure associated with this threat assessment procedure, particularly where the vintage pipeline passes through a high-consequence area.

Threat Assessment Approach

In assessing the impact of historic anomalies, several factors are important (see Figure 11):

- The likelihood the flaw is present,
- The impact of mitigation and control methods, and

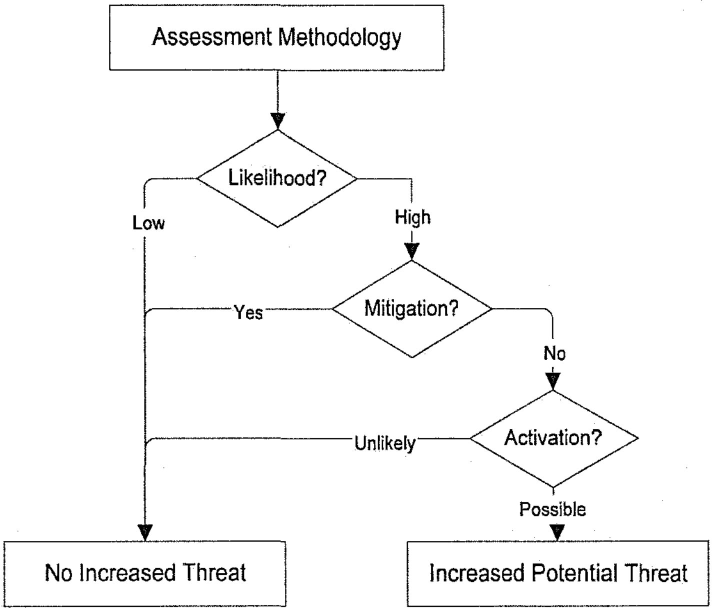

Figure 11. Generic assessment flowchart for historic flaws

- The presence of other conditions that increase or decrease the likelihood a flaw will grow or become "active".

Historic Pipe-Body And Weld-Seam Anomalies

Appendices D and E provide a brief history of steel- and pipe-making in the United States, and introduce the types of anomalies can be found in historic pipe. Further details on pipe making and anomalies can be found in Reference 43. Beyond the coverage of Reference 43, Appendices D and E identify pipe manufacturers and mills whose production is known to include these historic anomalies, and the time periods over which the pipe with these anomalies were known to occur. In addition, it identifies factors that increase or decrease the likelihood that an anomaly or defect will activate or grow in service. Table 2 summarizes historic pipe-body anomalies along with their potential impact on pipeline integrity.

Table 2. Pipe-body anomalies

Characteristic or Anomaly	Potential Integrity Impact	Comments
Fatigue cracks from cyclic stress created during shipment	Fatigue crack growth from in-service cyclic stress can result in a leak or a rupture	Most common in pipe with D/t ratios >70 produced prior to 1970. Can be detected by pressure test ILI or during field girth weld radiography.
High levels of impurities and non-metallic inclusions. (i.e. dirty steels)	Laminations often near the pipe wall centerline – can affect pipe strength depending on alignment	Not suitable for pipe in sour service. Can contribute to pipe production problems. Can produce in-line inspection signals that may be confused with critical defects.
Hard spots	Potential in-service cracking if exposed to atomic hydrogen resulting in a leak or a rupture	Susceptible to in-service diffusion and embrittlement by atomic hydrogen that occurs in sour service, high cathodic protection potentials, and other service environments.
Foreign bodies rolled into the steel or plate/skelp surfaces	Cavity results if foreign body works free during service resulting in wall thickness reduction and possible leak.	Foreign bodies can work free early in the life of a pipeline or during a hydrostatic pressure test. May be identified as corrosion metal loss by ILI tool.
Surface breaking anomalies (i.e., slivers, scabs, seams etc)	Minimal integrity concern. Possible site for preferential corrosion (uncommon)	Can adversely affect external coating integrity. Can produce in-line inspection signals that may be confused with other flaw types

Some of the other historic anomalies have also produced failures, but such failures are rare or very uncommon today. Of note, foreign bodies rolled into the pipe wall have typically caused leaks. Laminations rarely cause failures, but when they do it is either as a consequence of transporting sour gas[12] or the lamination is inclined to the pipe surface, which reduces the effective wall thickness.

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[12] Gathering lines (i.e., pipelines from a well to a central collection or processing location) sometimes carry sour gas. Transmission pipelines, as a rule, do not.

Similar to pipe-body anomalies, there are several types of anomalies that occur more frequently in historic weld seams than modern weld seams. Appendix D also covers the historic weld-seam anomalies, the time interval(s) over which the anomalies were produced, and factors that increase or decrease the likelihood that a flaw will activate or grow in service.

Consider now Table 3 that summarizes weld-seam anomalies as a function of pipe-making process.

Table 3. Weld-seam anomalies

Pipe Making Process	Flaw or Characteristic	Comments
Furnace Butt Welded, Continuous Butt Welded Pipe, Lap Welded and Hammer Welded Pipe	Oxides or foreign material trapped between weld surfaces; poor quality welds	Results from limited weld NDT and QA/QC capability. Reduced joint factor in 49CFR192 now accounts for weld quality
Electric Resistance Welded (ERW) and Flash Welded Pipe	Oxides or foreign material trapped between weld surfaces, poor quality welds	Results from limited weld NDT and QA/QC capability
	Stitched welds	More common in low-frequency ERW pipe. Hydrotest can expose near-critical defects.
	Hook cracks	More common in pipe produced from earlier steels with higher levels of impurities and inclusions. Not always detected during mill NDT and hydrotest .
	Excessive OD/ID ERW trim. Can be associated with offset skelp edges	Results in locally thinned zone in pipe wall.
	Arc burns (contact marks)	Very local hard spots produced by during ERW seam welding (see Table 5)
Single Arc Welded and Double Submerged-Arc Welded Pipe	Weld metal cracks, offset welds, toe cracks, lack of sidewall or inter-run fusion, inclusions, weld metal porosity or gas pockets, or undercut.	Can produce volumetric and planar defects that may adversely affect pipe integrity.
Any Welded Pipe	Transportation fatigue cracking in seam welds particularly DSAW due to the weld reinforcement.	Can produce cracks in the pipe body or pipe-ends that if large enough can be exposed in hydrotest or detected by x–ray of girth welds.

Data from failure analyses, the authors' experience, and the literature suggest that in-service failures due to historic pipe-body and weld-seam anomalies are most commonly due to:

- Cracking at dents that were introduced during pipe handling[13].
- Hook cracks, upturned inclusion cracks, and other cracks in or around the weld or at arc burns,

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[13] Prior mechanical damage is not covered in this report because such damage can occur on old or new lines. The impact of historic material properties on potential failure modes is discussed later in the report.

- Preferential corrosion in or near the weld.[14]
- Variable weld quality along the seam length in low frequency ERW seams,
- Transportation fatigue during shipping, and
- Hydrogen cracking at hard spots and arc strikes.

Transportation Fatigue

The most likely cause of failures due to historic pipe-body anomalies is fatigue cracking that occurs during transportation of pipe from a pipe mill to a job site. Transportation fatigue is considered in the flowchart in Figure 12.

Likelihood

Transportation fatigue results when pipe slides and contacts the ends of a railcar or when pipe is stacked and supported in a manner that subjects the weld seams to high cyclic stresses. Transportation fatigue typically occurs in pipe with a weld seam that protruded above the pipe surface (as occurs, for example, in flash welded and double-submerged arc welded pipe). The protruding weld seam serves as a stress concentrator, with the highest stresses near the edge of the weld itself. The conditions necessary to promote fatigue result from cyclic loading during shipment.

Transportation fatigue also has occurred in the pipe body from contact with rivet heads in rail car bottoms. Cracks have also formed in pipe without protruding weld seams at locations where pipe was in contact with rivet heads, foreign objects in a rail car, bearing strip misalignment, or insufficient support.

Transportation fatigue is most common in pipe with high diameter-to-thickness ratios shipped prior to 1970 on rail cars. Table 3 provides guidance on identifying pipe that may contain transportation fatigue cracking.

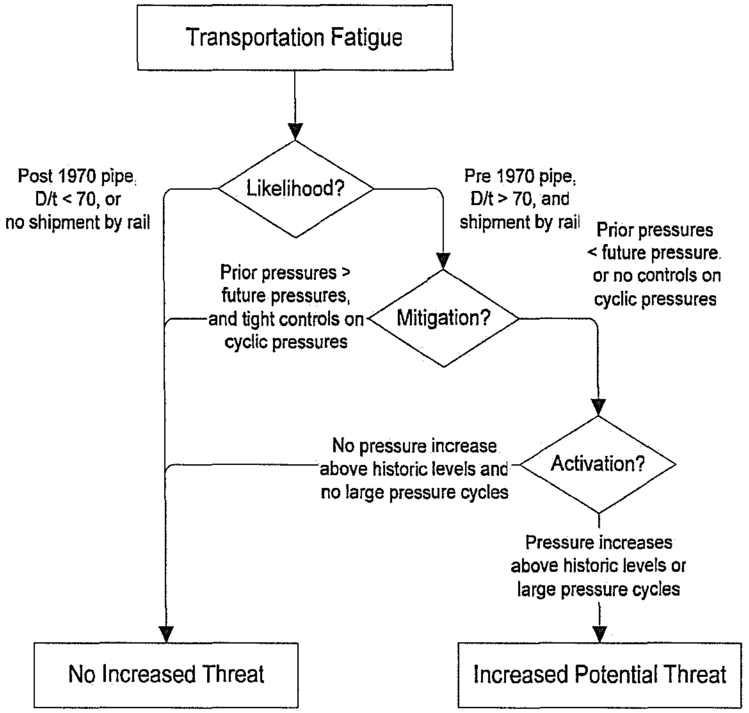

Figure 12. Flowchart for transportation fatigue

Mitigation

Transportation fatigue cracks have the potential to grow under cyclic pressure loading, especially if the pressure cycles are large and frequent. In addition, failures have occurred when the pressure was increased beyond historical levels. Potential mitigation methods include: (1) monitoring and controlling pressure cycles and (2) pressure testing significantly above the maximum operating pressure,

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[14] Corrosion is not covered herein, although the potential for preferential corrosion is briefly discussed later.

bell-hole inspection including NDT, and ultrasonic ILI. Pressure testing is most effective when pressure cycling is low amplitude and infrequent.

Table 4. Conditions related to transportation cracking

Parameter	Range	Comments
Diameter-to-thickness ratio	Above 70	Some transportation fatigue cracking has been found in pipe with lower diameter-to-thickness ratios, but the cracking is thought to be associated with unique situations that were not widely used.
Shipping dates	Pre-1970	API first issued a recommended practice for stacking pipe in 1965. Use of this and subsequent recommended practices has effectively eliminated the occurrence of transportation-induced cracking.
Shipping method	Rail	All of the reported cases of transportation fatigue were on pipe moved by rail. Somewhat similar loading conditions could occur in barge or over-the-road shipping, but no failure attributed to barge or over-the-road shipping has been reported. However, the authors are aware of documented but not openly published cases resulting from road shipment on pole trailers that supported only the ends of the pipe.

Activation

Transportation fatigue cracking that has remained dormant can be activated when pressure cycles increase significantly in magnitude or frequency, or when the pressure in the line exceeds historic levels.[15]

Assessment

The flowchart shown in Figure 12 can be used as a guide to assess the potential threat due to transportation fatigue, as follows:

1. Determine the age, diameter-to-thickness ratio, and transportation mode. If the pipe was produced after 1970, its diameter-to-thickness ratio is less than 70, or it was not shipped using rail cars, the likelihood of transportation fatigue cracking is relatively small. If the pipe was not shipped in accordance with API Recommended Practices for shipping, the likelihood of fatigue cracking is higher. Construction girth weld x-ray records may indicate the presence of cracks.
2. If transportation fatigue cracking may have occurred, determine whether the line was pressure tested or whether pressure cycling has been limited in frequency or magnitude. If these conditions are not met, transportation fatigue cannot be ruled out as a potential threat to integrity.
3. If a likelihood of transportation cracks exists and mitigation methods are not in place, determine if pressure has increased above historic levels, or large pressure cycles are anticipated in future. If so, there is an increased threat due to transportation fatigue.

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[15] Fatigue is not covered in this report, but the potential for crack growth due to pressure cycling is included here for completeness. For information on the effects of pressure cycling and fatigue, see References 36 and 37, or textbooks like References 39 and 40.

In assessing the potential for failure due to transportation cracking, it is important to note that the problem was largely confined to a short time period. Most failures due to transportation fatigue occurred early in the life of the pipeline or during its initial hydrostatic pressure test. Consequently, transportation fatigue cracking is no longer considered a significant threat to gas transmission pipeline integrity.

Hydrogen Stress Cracking - Arc Burns and Hard Spots

Hydrogen stress cracking (HSC) is associated with hard spots and arc burns. Arc burns and hard spots are not uncommon on early pipelines, but the likelihood of any one hard spot or arc burn failing due to hydrogen stress cracking is small relative to other threats to pipeline integrity. For example, the incident data discussed in Appendix A indicate that hydrogen stress cracking occurs at a frequency less than 1 percent of that for external corrosion. Hard spots and arc burns can and do safely exist on pipelines. Identifying which hard spots and arc burns are potential threats relies on identifying the potential for atomic hydrogen to form at or be available on the steel surface. Such conditions can be created by the cathodic protection system, with hardness level being a secondary consideration.

Archival failure analysis done at Battelle in the 1950s and 1960s indicates hard spots develop during hot rolling of a steel plate when an uncontrolled jet of water locally cools a portion of the plate too quickly. The water quenched areas form untempered martensite, with hardness levels locally much higher than the remainder of the pipe. The literature indicates HSC occurs at higher hardness levels, typically the order of R_c 35 or slightly harder(43,44), except in the presence of strongly sour environments. Likewise, where the hardness exceeds about 22 R_c or ~230 BHN, hydrogen embrittlement is possible, but as above requires the generation of atomic hydrogen on the pipeline's surface and conditions that promote its ingress.

Arc burns occur when a welding electrode arc occurs at the pipe surface outside of the weld preparation or from an arc at a grounding clamp. Arc burns (i.e., contact marks) can also occur during ERW pipe production due to arcing at the electrical contact on the steel during welding. When arcing occurs, a small zone is melted or heated well above the temperature at which the steel properties begin to change. Due to the much larger and cooler steel mass surrounding this area, rapid cooling results that can create a locally hardened zone.

Likelihood

For HSC to occur, three conditions must be satisfied concurrently. A hard spot must exist that is exposed to sufficient atomic hydrogen in the presence of sufficient stress. Hydrogen stress cracking at arc burns or hard spots appears to be associated with a handful of pipe mills over limited time periods. As shown in Table 5, the authors have identified 29 cases of HSC associated with a specific pipe mill. Twenty of these involved A. O. Smith pipe, of which 17 were produced in 1952. No other pipe manufacturer was identified as having more than two hydrogen stress cracking incidents. In addition, no incidents were identified that involved pipe produced after 1960. Consequently, the likelihood of hard spots appears higher than normal for A. O. Smith pipe produced in the early 1950s, and lower than normal for pipe produced after 1960. Such cases all involved hardness the order of R_c 35 or slightly higher.

Mitigation

There are two approaches to mitigating the potential risk of hydrogen cracking at hard spots and arc burns: coatings and cathodic protection controls. An undamaged coating with good adhesion prevents a hard spot or arc burn from being exposed to hydrogen. Most coating has some damage, though, but the amount of bare steel is small even in a poorly coated line. As a result, the likelihood that a given hard spot is exposed by coating degradation is not high.

The second mitigation method for hydrogen stress cracking is tight control of cathodic protection potentials. In order for cracks to form, the hard spot or arc burn must be exposed to an environment where diffusion of atomic hydrogen into steel can easily occur. On pipelines, hydrogen at the pipe surface can be generated when the cathodic protection potential is above (more negative than) -1.2 volts relative to a copper-copper sulfate electrode. A potential above (more negative than) -0.85 volts is typically used to control corrosion on pipelines.

Table 5. Hard spot incident summary

Pipe Seam Type	Pipe Manufacturer	Pipe Production Year	No. Of Incidents
Flash weld	A.O. Smith	1952	17
		1954	1
		1955	1
		1957	1
DSAW	Bethlehem	1957	2
	Kaiser	1955	1
	Republic	1949	2
		1957	1
ERW	Youngstown Sheet & Tube (YS&T)	1947	1
		1950	1
		1960	1

Activation

Two factors control whether hydrogen stress cracking will occur at a hard spot or arc burn at which diffusion of hydrogen into the steel can easily occur. The first is the hardness. Hydrogen stress cracking in service has occurred at hardness levels above approximately Rockwell C39[16]. If the hard spot or arc burn has hardness less than Rockwell C22, it is unlikely to crack.

The second factor is stress level. The hard spot or arc burn must be exposed to a stress that is high enough to form cracks. Since the dominant loading in pipelines is due to pressure, higher-pressure lines tend to be more prone to hydrogen stress cracking than lower pressure lines. To the authors' knowledge, hydrogen stress cracking at hard spots or arc burns has only occurred in Class 1 and 2 locations (i.e. higher stress designs).

One final factor impacts the significance of hydrogen stress cracks if they form: the size of the hard spot or arc burn. Hard spots have ranged from several inches in diameter, which is large enough to lead to a rupture in some pipeline steels (see later section on consequences), to the full circumference

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[16] Hard spots absent the threat from hydrogen-related mechanisms can and have failed in service. To the author's knowledge, such failures have not occurred at hardness levels below Rockwell C35 consistent with some literature data on hard spot failures (e.g., see Figure 3 of Reference 29 and References 43 and 44).

of the pipe over lengths of several inches. In contrast, arc burns can be long, short, or intermittent. For short or intermittent arc burns, there is a higher likelihood of a leak than at long arc burns.

Assessment[17]

The flowchart shown in Figure 13 can be used as a guide to assess the potential threat due to hydrogen stress cracking at hard spots or arc burns, as follows:

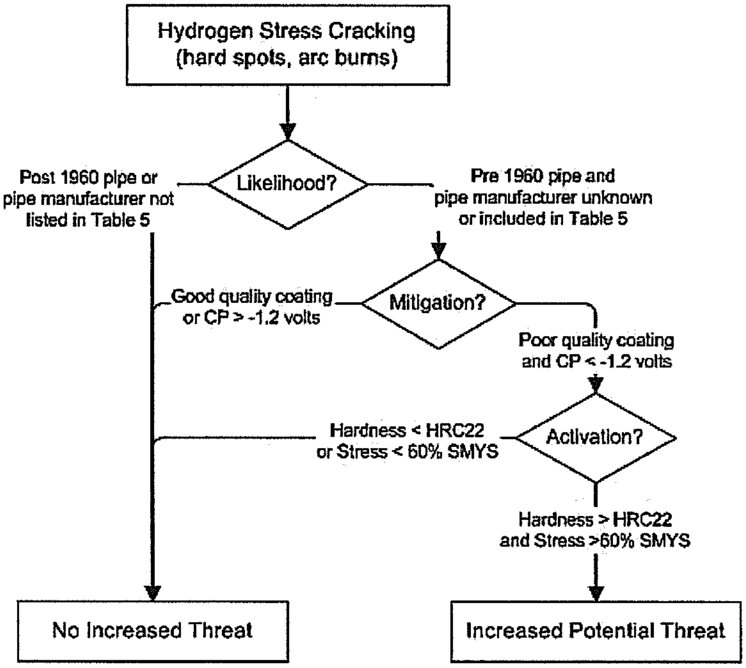

Figure 13. Flowchart for hydrogen stress cracking

1. Determine age and pipe manufacturer. If the pipe is newer than 1960 or not made by a manufacturer listed above, the likelihood hard spots or arc burns exist is relatively small.
2. If there is a likelihood that hard spots or arc burns exist, determine the history of coating problems to infer coating quality and the history of cathodic protection potentials. If the coating history indicates good adherence and few holidays or if the cathodic protection level is not more negative than -1.2 volts, the pipe is unlikely affected by hydrogen stress cracking.
3. If there is a likelihood hard spots or arc burns exist, and the coating is inferred to be of poor quality with cathodic protection levels uncontrolled and more negative than -1.2 volts, assess the stress in the pipe. If the stress is less than 60% SMYS, cracks are not likely to form. Otherwise, when hard spots are located on the pipeline, measure their hardness levels. If the hardness levels are at or above Rockwell C35[18], experience indicates hydrogen stress cracking is possible.

In assessing the potential for hydrogen stress cracking, it is necessary to recognize that a small percentage of the pipe surface is affected, and active degradation occurs only under a limited set of conditions. The use of an in-line inspection tool that is set up to detect hard spots and arc burns may help identify when hard spots are present. Practices such as inspecting exposed pipe surfaces for hard spots or arc burns and, if such locations are found, looking for evidence of coating damage, high local hardness levels, higher than normal cathodic protection potentials, and signs of cracking can be used to identify line segments that may have an elevated likelihood of cracking. Hard spots can be visually evident as local changes in the pipe surface curvature. However, similar changes in

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[17] As presented here, hard spots are considered in reference to a strong source of hydrogen generation, such as severe sour service as can occur in swamps or with microbiological activity. Differences between sources should be addressed to the extent they can be characterized. Where hard spots occur in conjunction with less aggressive sources of hydrogen, such as electrochemically generated hydrogen associated with corrosion and CP conditions, experience indicates R_c 35 or ~325 BHN are prone to HSC.

[18] This flowchart and assessment procedure reflect typical scenarios. Where there is a strong source of hydrogen generation, the hardness for susceptibility decreases.

curvature also can result from other pipe manufacturing problems that may not have a higher local hardness. Field hardness testing is a useful evaluation tool for such cases.

Cracking Near Seam Welds and Variable Weld Quality

Cracking near weld seams most commonly occurs as hook and other types of cracks associated with ERW or flash-welded pipe. Cracking near seam welds is most likely to occur in pipe made from earlier steels, where inclusions or lamination (typically impurities that are flattened and elongated during steel and pipe rolling) were more common.

Variable weld quality is considered along with other forms of weld cracking because both have a similar effect on pipeline integrity. In addition, the older incident datasets generally do not differentiate between the root cause of failures that involve the weld seam.

Likelihood

A number of welding processes have been used to produce the weld seam in pipe used to transport natural gas, including several forms of butt welding, lap welding, hammer welding, several forms of electric resistance welding, flash welding, single-sided submerged arc welding, double submerged arc welding, and others. While many pipe manufacturers used (or use) most of the weld processes, "problem pipe" is typically associated with a small subset of pipe manufacturers. For those manufacturers, though, not all individual pipe mills produced problem pipe, nor did they produce problem pipe at all time periods.

Table 6 is a list of pipe manufacturers that produced potentially problematic weld seams (see Appendices D, E, and F for more detailed listings). Pipe made by the listed manufacturers in the years noted appear to be more likely to contain cracking near the seam weld or pipe with variable weld quality than that produced by other manufacturers.

Table 6. Pipe manufacturers that produced pipe that failed due to weld-seam defects

Evaluation Criteria	Years	Most Frequently Reported Manufacturer(s)	Comments
Butt/Lap weld	Pre 1960	Armco, Republic	Reduced longitudinal joint factor required by 49 CFR 192
DSAW, SSAW, and other welded seams	Pre 1960	Kaiser, U. S. Steel	
Low frequency ERW	Pre 1971	Republic, Youngstown Sheet & Tube	Acero del Pacifica, Jones & Laughlin, Kaiser, and Lone Star also have higher incident rates than others manufacturers
High Frequency ERW	Pre 1980	Stupp	Kaiser, Jones &Laughlin, and Lone Star also have higher incident rates than others manufacturers
Flash weld		A. O. Smith	All

Mitigation

Cracking near seam welds and seam welds with variable quality are generally considered static. That is, once the pipeline has been in service and the larger defects have been exposed, the remaining defects, dormant over the early service, remain so unless historical loading conditions become more severe. A method of mitigating the risk due to cracking near seam welds and variable weld quality is to pressure test. Pressure testing can effectively prevent the anomalies from becoming critical.[19] ILI tools that can detect cracks also will be effective in locating cracking near/in weld seams.

Activation

As noted above, cracking near seam welds and variable seam weld quality do not grow or become more serious unless the line pressure exceeds historic levels. On the other hand, these anomalies can grow when the pipeline is subjected to large or frequent pressure cycles. As noted earlier, fatigue is not covered in this report. For information on the effects of pressure cycling and fatigue, see References 36 and 37, and textbooks that deal with this topic$^{(39,40)}$. If pressure levels are maintained below historic levels, the anomalies do not pose a large threat to pipeline integrity.[20]

Assessment

The flowchart shown in Figure 14 can be used to as a guide to assess the potential threat due to cracking near seam welds and pipe with variable weld seam quality, as follows:

1. Determine age and pipe manufacturer. If the pipe manufacturer and date of production are known but are not listed in Table 6, the likelihood of cracking near seam welds or pipe with variable weld quality is relatively small.
2. If there is a likelihood that cracking near seam welds or variable weld quality is present, determine whether the line was pressure tested. If the pressure test level exceeds future operating pressures and the pressure cycling history is within early

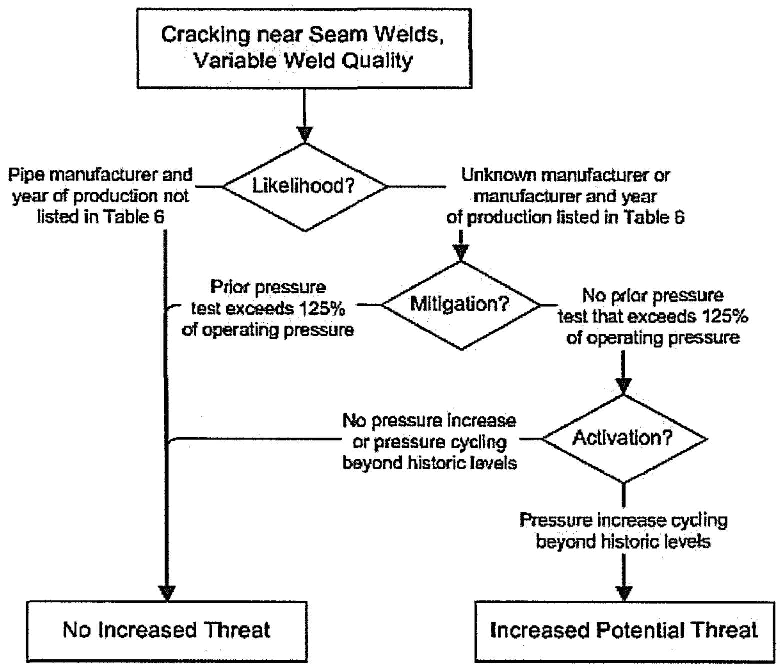

Figure 14. Flowchart for hook cracks and variable seam quality

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[19] The pressure level sufficient to prevent weld cracks from growing or becoming more serious depends on the type and size of the cracks. Pressure tests to 125% of the operating pressure are commonly used and are considered effective at mitigating most cracks. Pressure testing to 100% of the yield pressure is sometimes used for larger and more significant forms of damage, such as stress corrosion cracking.

[20] See prior footnote.

historic levels, the cracking if any and the seam welds can be considered stable.

3. If there is a likelihood cracking near seam welds or variable weld quality is present and the line has not been pressure tested to a level exceeding future operating pressures, determine if the recent or anticipated pressure history increases beyond historic operating pressures. If so, there is an increased potential threat due to hook cracking or variable seam welds.

Preferential Corrosion

As noted earlier, corrosion is not covered in this report. For completeness, though, it is important to recognize that preferential corrosion in the weld seam of some types of pipe has caused pipeline failures in some older pipelines. Preferential corrosion is most likely to occur in variable quality low-frequency ERW or flash weld seams or non-heat treated high-frequency ERW seams. Thus, the pipe manufacturers and dates listed in Table 6 may be useful in identifying pipe that is susceptible to preferential corrosion. Reference 45 provides further details.

Preferential corrosion on a pipeline can be an indicator of other seam welding problems. If preferential corrosion is found, there may be an increased threat due to cracking near the weld seam or inconsistent weld quality.

Historic Fabrication and Construction Anomalies

Appendix D E, and F provide a brief history of historic pipeline fabrication and construction practices in the United States, and it introduces the types of anomalies sometimes found in historic pipelines. It identifies practices whose production is known to include historic anomalies and the time periods over which they were used. Reference 46 addresses this topic in greater detail. Appendices D, consider factors that increase or decrease the likelihood that an historic fabrication or construction flaw will activate or grow in service.

Data from failure analyses, the authors' experience, and the literature suggest that in-service failures due to historic fabrication and construction anomalies are most commonly due to:

- Wrinklebends and other bend problems,
- Cracking at girth welds,
- Coupling failures, and
- Unconstrained dents were introduced during backfilling and testing.[21]

For buried pipelines, bends, girth welds, and couplings are not highly loaded during normal service. When failures occur, they are typically due to abnormal loading along the axis of the pipe from heavy rains or earth movement. Appendix G provides further details.

Wrinklebends and Other Bend Anomalies

One cause of failures due to historic fabrication or construction anomalies is problems associated with bending the pipe. Very early pipe bending methods may introduce a wide range of anomalies, some of which can be detrimental under certain loading scenarios. Generally, the anomalies are of most concern when they lead to cracking. They can also be of concern if the geometry of the bend

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[21] The difference between constrained and unconstrained dents is covered in the new pipeline integrity rule. See References 18 and 19 for guidance in severity assessment.

creates conditions susceptible to external or internal corrosion. Technology validated by full-scale testing that uses the wrinkle shape is available to assist in evaluating wrinkle severity and serviceability as a function of pipeline operation(47).

Likelihood

Identifying pipe with potential bending anomalies is relatively straightforward because such bends are known to exist in specific pipelines and are located at changes in pipeline elevation. Where pipelines can be pigged, such bends are also easily located. As with all potential critical defects, the larger features tend to be exposed early in the life of the pipeline, while the remaining less severe features lie dormant, and do so unless the loading changes. Clear evidence of this behavior exists for wrinklebends(47). Table 7 summarizes common bend anomalies and the years in which they were produced.

Table 7. Historic bending anomalies

Type	Years	Comments
Hot Wrinklebends	Pre 1952	Use of hot wrinkle-bending decreased through the 1940s
Miter bends	Pre 1940	Miter bends up to three degrees deflection are generally not a significant concern, with use limited per Part 192.233
Cold Wrinklebends	Pre 1955	Potential threat increases as the size of the wrinkles increases or their spacing decreases – see Reference 47 for details.

Mitigation

Mitigating growth of crack-like anomalies in bends consists of adequately restraining the pipe against axial forces and movement, and limiting its exposure to cyclic loadings. Historic crack-like anomalies in bends are not considered a threat in areas where landslides, settlement, and earthquakes are not a problem, where the pressure is steady and thermal cycling is absent (i.e., the bend is not exposed).

Activation

Wrinklebend anomalies can be activated by heavy rains, floods, earthquakes, and other causes of earth movement, and by the effects of pressure or thermal cycling. Nearby maintenance that disturbs soil restraint likewise is a potential concern(47).

Assessment

The flowchart shown in Figure 15 can be used as a guide to assess the

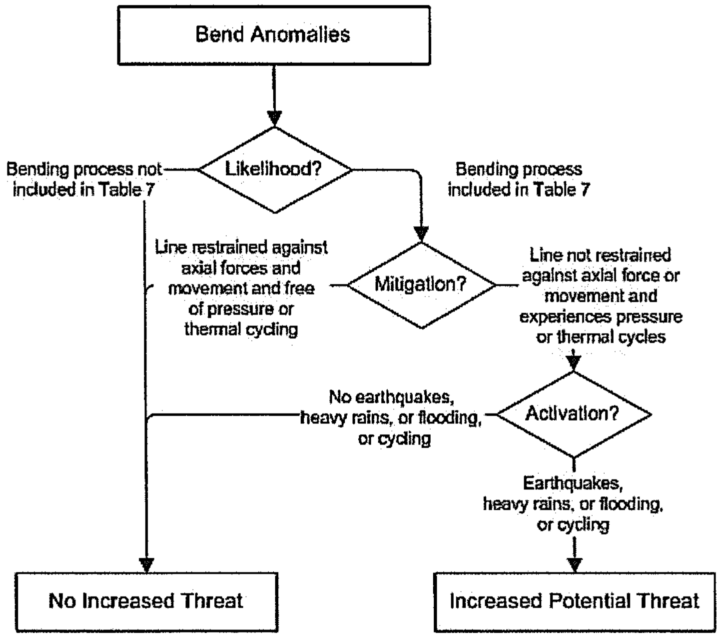

Figure 15. Flowchart for bend anomalies

potential threat due to bending anomalies, as follows:

1. Determine date of pipeline construction and bending method(s) used. If the pipe is newer than 1955 and bends were machine made, the likelihood of significant bend anomalies is relatively small.
2. If there is a likelihood that bend anomalies exist, evaluate the extent of cycling and restraint against pipe movement and axial forces. If the line is absent cycling, and is adequately restrained, the potential for bend-related problems is small.
3. If there is a likelihood that bending anomalies exist and the bends are not adequately restrained, evaluate the potential for earthquakes, heavy rains, and other events that have the potential to introduce large axial loads. If such events are likely, there is an increased chance of problems due to bend anomalies.

Acetylene Girth Welds

Another cause of failures due to historic fabrication or construction anomalies involves acetylene welds used to join pipe. Early vintage pipeline construction (~1915 – 1940) often utilized acetylene welds to join the pipe ends. While acetylene welds are not used today, the existence of acetylene welds alone does not pose an integrity issue. The presence of acetylene welds in conjunction with the potential for outside forces increases the likelihood of an event. Otherwise, the threat associated with acetylene welds is considered stable.

Likelihood

Identifying pipe with potential to contain acetylene welds is relatively straightforward because this is a feature that is typically well known to exist or not. Generally, any pipeline constructed with welded joints from ~1915 through the 1940's is likely to contain acetylene welds. The existence of acetylene welds usually can be ascertained by reviewing original construction records and/or historical maintenance and inspection records or exposing the pipe for visual inspection.

Mitigation

Mitigating against an event involving acetylene welds is a matter of ensuring that the pipeline is adequately restrained against axial forces and movement or eliminating the potential for soil movement altogether. Historically, acetylene welds do not pose an integrity threat in areas where landslides, settlement, flooding and earthquakes are not an issue. Mitigation can take the form of installing reinforcement sleeves over the acetylene welds, installing anchoring structures to eliminate movement of the pipeline or installing geotechnical surface structures to prevent soil movement and/or soil erosion which may cause external axial or lateral forces on the pipeline.

Activation

Heavy rains, floods, earthquakes, and other causes of earth movement can activate the potential threat associated with the existence of acetylene welds.

Assessment

The flowchart shown in Figure 16 can be used to assess the potential threat due to acetylene welds as follows:

1. Determine date of pipeline construction and whether or not acetylene welds are known to exist. If the pipe is newer than 1950, the likelihood that acetylene welds were used during pipeline construction is relatively small.
2. If there is a likelihood that acetylene welds exist, evaluate the restraint against pipe movement and axial forces. If the line is adequately restrained and/or weld reinforcements have been installed, the potential for acetylene weld related problems is small.
3. If there is a likelihood that acetylene welds exist and the acetylene welds have not been reinforced and pipeline in these areas is not anchored or restrained, evaluate the potential for earthquakes, heavy rains, and other events that have the potential to introduce large axial or lateral loads. If such events are likely, there is an increased risk due to the existence of acetylene welds.

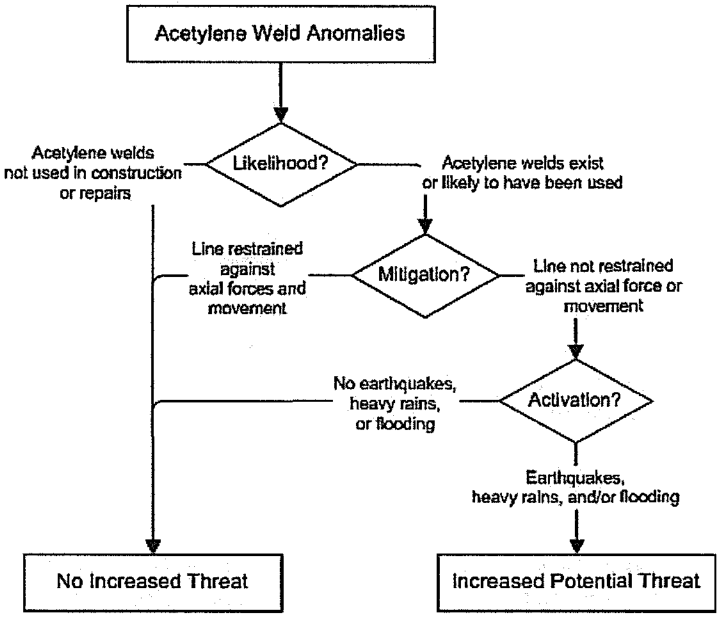

Figure 16. Flowchart for acetylene weld anomalies

Mechanical Couplings

The last cause of failures due to historic fabrication or construction flaws considered involves mechanical couplings used to join pipe. Early vintage pipeline construction (1890s – 1940) utilized mechanical couplings to join the pipe ends, in conjunction with oxyacetylene girth welds(e.g., see 112). Use of such couplings was typical for earlier construction in this period, and became infrequent toward the end. While mechanical couplings are not frequently used today, the existence of couplings alone does not pose an integrity issue. The presence of couplings in conjunction with the potential for outside forces increases the likelihood of an event due to pullout or leaking induced by severe misalignment. Such an event will typically manifest itself by the outside force causing a disengagement of the pipe from the coupling. Otherwise, the threat associated with couplings is considered stable.

Likelihood

Identifying pipe with potential to contain mechanical couplings is relatively straightforward because this is a feature that is typically well known to exist or not. Generally, pipelines constructed in the 1920's through the 1940's are likely to contain mechanical couplings. The existence of couplings can usually be ascertained by reviewing original construction records and/or historical maintenance and inspection records.

Mitigation

Mitigating against an event involving mechanical couplings is a matter of ensuring that the pipeline is adequately restrained against axial forces and movement or eliminating the potential for soil movement altogether. Historically, mechanical couplings do not pose an integrity threat in areas where landslides, settlement, flooding and earthquakes are not an issue. Mitigation can take the form of installing reinforcement sleeves over the couplings, which eliminates the potential for disengagement, installing anchoring structures to eliminate movement of the pipeline, or installing geotechnical surface structures to prevent soil movement and/or soil erosion, which may cause external axial or lateral forces on the pipeline.

Activation

Heavy rains, floods, earthquakes, and other causes of earth movement can activate the potential threat associated with the existence of mechanical couplings.

Assessment

The flowchart shown in Figure 17 can be used to assess the potential threat due to mechanical couplings in much the same manner discussed for acetylene welds, as follows:

1. Determine date of pipeline construction and whether or not couplings are known to exist. If the pipe is newer than 1960, the likelihood that mechanical couplings were used during pipeline construction is relatively small.
2. If there is a likelihood that mechanical couplings exist, evaluate the restraint against pipe movement and axial forces. If the line is adequately restrained and/or coupling reinforcements have been installed, the potential for coupling-related problems is small.
3. If there is a likelihood that couplings exist and the couplings have not been reinforced and pipeline in these areas is not anchored or restrained, evaluate the potential for earthquakes, heavy rains, and other events that have the potential to introduce large axial or lateral loads. If such events are likely, there is an increased risk due to the existence of couplings.

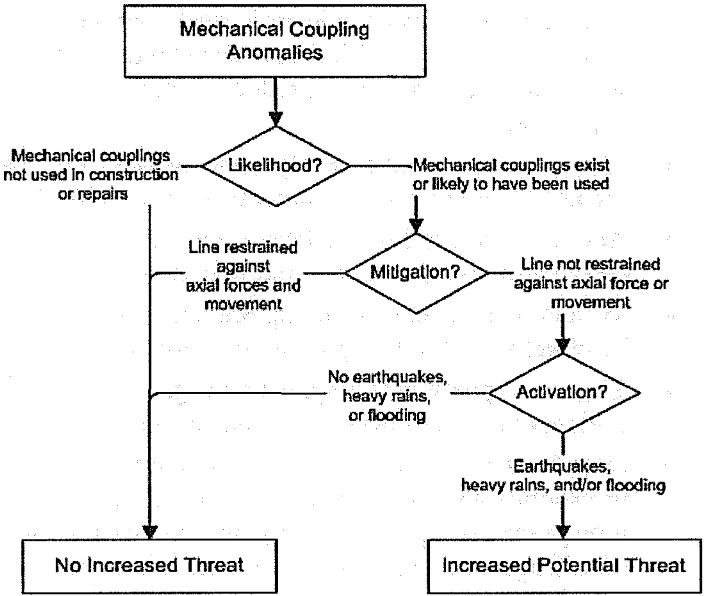

Figure 17. Flowchart for coupling anomalies

Summary and Conclusions

This report has evaluated vintage pipelines in reference to the historical evolution of the natural-gas pipeline system in the US, and the related evolution of steel and pipe making practices, and pipeline construction practices to meet the needs of that system. The potential of anomalies in this system has been characterized in reference to steel and pipe making practices, and pipeline construction practices. The potential importance of such anomalies to system integrity was assessed in terms of the response of anomalies to loadings experienced by pipelines. This analysis showed that the threat posed depends on a number of factors aside from the presence of the anomaly – the most important factors are the size, orientation, and severity of the defect, the mechanical properties of the pipe material, and the imposed loads.

Consideration of the characteristic defects in vintage pipeline systems and their possible impact on pipeline integrity leads to a number of important conclusions:

- The design properties of pipeline steels do not diminish with time or aging of the system, there being no evidence to suggest pipe steels "wear out" – to the best of the authors' knowledge, no failure of a natural-gas pipeline has ever been attributed to aging of the line pipe steel.
- Historic anomalies on vintage pipelines can be managed in reference to flowcharts developed for the anomalies most likely to threaten pipeline integrity – guidance is provided to determine when a defect may exist, conditions that can "activate" the defect, and practices used to mitigate the potential threat.
- Anomalies introduced in historic steel- and pipe-making practices used by a small subset of pipe manufacturers, which have been tabulated to simplify their identification. Identifying when and where pipe was produced can be helpful in determining the potential that a defect is present.
- The most significant anomaly is inconsistent weld seam quality, which is largely limited to the use of certain welding processes, such as electric resistance welding and flash welding.
- Anomalies due to historic fabrication and construction practices are generally associated with certain girth weld practices and wrinklebends.
- Mitigation practices, including pressure testing, ILI, and improved operational controls can be effective in limiting growth of many historic anomalies.
- The use of pressure testing, which began on a widespread basis in the 1960s, serve to expose critical or near-critical defects and so can limit their significance.
- Data for the vintage system indicate that the rate of reportable incidents per volume of gas transported has gone down over many decades of service by as much as a factor of ten, even though the average age of the pipe is increasing. A decreasing trend likewise exists in terms of mileage, although not as dramatic. Thus, one could conclude the vintage system is viable and does not pose a unique threat to pipeline system safety.

Historic pipe-body and weld-seam anomalies that have the highest potential to impact pipeline integrity are summarized in Table 8 (below), along with an indication of circumstances where such anomalies can develop. Flowcharts provided for each characteristic anomaly indicate when and where it might become active and so pose an increased threat to integrity. Likewise, these flowcharts indicate mitigation measures when needed that should provide adequate management of such features when embedded in a comprehensive IMP.

Table 8. Potentially significant historic anomalies

Threats Under Normal Loading	Threats Under Abnormal Loading
HSC at hard spots or arc burns	
Other forms of seam weld cracking and variable quality seam welds	
Preferential weld corrosion	
Wrinklebend cracking and corrosion	Wrinklebend cracking
	Girth weld cracking
	Coupling failures

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Appendix A: Incident Information Considered

Four incident datasets have been used in this study(3,21,48). Of these, Reference 21 is viewed as providing two distinct datasets with the demarcation beginning in 2002 and the introduction of much more detailed reporting.

Databases

The first dataset was collected by the United States Federal Power Commission (FPC) at the direction of the U. S. Senate(48). It covers incidents that occurred from January 1950 through June 1965[22] as reported by 63 natural gas transmission companies. This dataset covers onshore in-service incidents and includes the year of occurrence, cause, injuries and fatalities, diameter, wall thickness grade, pressure at the time of the incident, and maximum operating pressure. No information is provided as to whether the consequence was a leak or a rupture. This dataset contains records from 1,067 incidents.

The second dataset was collected under the auspices of the U. S. DoT Office of Pipeline Safety (OPS) and covers transmission pipelines and certain higher-pressure distribution mains from 1970 through mid 1984(3,21). This dataset contains reports from onshore incidents that met certain minimum reporting requirements and occurred during service, during a pre-service pressure test, or during a subsequent retest. The reporting requirements for this dataset are property damage equal to or above $5,000 or an injury/fatality. While this dataset contains all the data fields included in the FPC dataset, pipe diameter and wall thickness have only been reported for a limited number of incidents. The dataset includes a data field on whether a leak or rupture occurred and the cost of the property damage. In many cases, one or both of these fields were not entered. Data from 7,864 incidents are contained in this dataset.

The third dataset was also collected by the OPS(21) and covers transmission pipelines and certain higher pressure distribution mains during the period from mid 1984 through 2000. It contains both onshore and offshore reportable incidents but no pressure test or retest data. The reporting requirements for this dataset are property damage level of $50,000 or more or an injury or fatality. This dataset contains the data fields in the earlier OPS dataset. Pipe diameter and wall thickness are generally reported. Data from 1,318 incidents are contained in this dataset.

The fourth dataset was collected by OPS(21) and covers transmission pipelines from 2002-2003. The reporting requirements for this dataset are property damage level of $50,000 or more or an injury or fatality. This dataset contains most of the data fields in the earlier OPS dataset, plus the causal categories have been expanded permitting more in depth analysis. This information combined with the new annual reports by OPS give a clear picture of the distribution of vintages of pipe in service. As it is a recent change, few additional incidents are represented in this period.

Service data from failures are included in each dataset, but only one dataset contains data from pre-service pressure testing or retesting. In-service, pre-service, and re-test incidents are fundamentally different, and pressure test failures should be considered separately from in-service incidents. Pressure testing subjects the pipeline to a pressure that is higher than seen during operations. Pre-service pressure tests remove (fail) some anomalies that would not fail during service, and retests

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[22] These data were compiled from the results of a pipeline incident data questionnaire submitted to natural gas transmission operators by the Federal Power Commission in 1966.

remove anomalies that have already survived in service for a significant amount of time. Nonetheless, these data were used to identify types and sizes of anomalies that did not cause in-service failures. This data was also used to identify pipe mills that produced anomalies even though they did not similar to those that failed in service.

Finally, additional data from pipeline failure analyses and investigations conducted by the authors, proprietary data, and through public sources have been included to supplement the three incident data sources.

Database Limitations and Implications

There are some limitations to each of the datasets used. These include

- Incomplete, incorrect, or missing root causes. For example, a number of incidents are attributed to anomalies in the pipe body, but no additional information is given in the pre 2002 incidents to determine the mechanism of failure (e.g., hydrogen cracking). Another example is an incident that is attributed to the pipe body but the verbal description suggests a seam weld failure.
- Missing manufacturer data. Many records do not include information on the pipe supplier or the year in which the pipe was made, although the other parameters describing the pipe can help limit the number of manufacturers and the time it was produced.
- Variability in reporting requirements. In addition to the basic differences discussed above, some companies reported incidents that it considered "significant" even though they did not meet the other regulatory requirements, while others did not.
- Differences in service. Some incidents reflect gas transmission service, while others reflect distribution main service or gathering service.
- As noted above, service data are included in each dataset, but only one dataset contains data from pre-service pressure testing or retesting. In-service, pre-service, and retest incidents are fundamentally different, and failures that occur during pressure tests should be considered separately from in-service incidents. Pressure testing subjects the pipeline to a pressure that is higher than seen during operations allowing a safety factor between the operating pressure and the test pressure. So, pre-service tests remove (fail) anomalies with stable behavior that would not fail during service, and retests remove these same anomalies that have already survived in service if they have grown. Sometimes, the retest if conducted at a higher pressure level than the original test and it might remove stable behavior defects that passed the original test, but are now subjected to higher stress. Nonetheless, these data were used to identify types and sizes of anomalies to differentiate pipe that is subject to particular material and construction behavior.

Because of the above-noted limitations, and others, comparisons between the datasets are best made on a qualitative basis, and caution should be taken to not interpret the data in an absolute sense. Moreover, because these datasets typically contain first-to-occur incidents on unique pipeline segments each of which is operated slightly differently and is constructed at differing times of differing materials, such data cannot be pooled and analyzed to characterize "the US pipeline system".

Other Data Sources Used

A variety of databases(49-69) and analyses were used in this study to help in identifying flaw characteristics and assessing failure modes. Included here are U. S. incident datasets from liquid pipelines and a number of international datasets. Also included were data for hazardous liquid lines from the OPS(21) and North American and European data obtained from reports published by the Alberta Energy and Utilities Board(49,50), the Canadian National Energy Board(51), the Transportation Safety Board of Canada(52,69), the European Gas Pipeline Incident Data Group(53), CONCAWE(54,55), the United Kingdom Health and Safety Executive(56,57), and the United Kingdom Onshore Pipeline Operators' Association(58,59).

These data and information sources listed above were reviewed but not used in the statistical summaries because:

- Most do not contain information on the pipe manufacturer. As shown in this report, the likelihood of historic anomalies in the pipe body and weld seam varies significantly with pipe manufacturer.
- Some reflect foreign pipe manufacturers not commonly used to supply material in the United States.
- Many (international) datasets reflect younger pipelines. Construction of a pipeline infrastructure began sooner in the United States than it did in most other countries. As a result, data from other countries may not cover the range of pipeline characteristics seen in U. S. lines.
- Some reflect different operating characteristics. For example, liquid pipelines typically have larger pressure swings at higher frequencies than gas lines and are more likely to experience fatigue. Including such data could make some causes, such as construction transportation induced cracking, appear more significant relative to other causal types.

Other analyses of pipeline incident data were also reviewed. Included here are studies done for or by the American Petroleum Institute(60), the New Jersey Institute of Technology(61-63), Gas Piping Technology Committee(64), INGAA, the Gas Research Institute(65), and EFA Technologies(66,67).

Other Information Sources Considered

In addition, the authors reviewed a large number of confidential failure reports, as well as published failure analyses from around the world as part of this study. These reviews were used to provide additional insight into the causes of pipeline incidents, identify characteristics of anomalies that have led to failures, and identify the conditions under which anomalies are "activated." Of particular note, the authors reviewed:

- Reports by the U. S. National Transportation Safety Board (NTSB); from which 17 were selected for further analysis of historic anomalies on steel transmission lines(68).
- Failure analyses conducted by the Transportation Safety Board of Canada, from which four were reviewed in depth because they reflected historic anomalies(69).
- A number of proprietary failure reports related to historic anomalies provided by pipeline companies. (These reports are not explicitly identified other than by identifying where conclusions are supported or not supported by the reports)
- Reports on individual historic anomalies, on topics such as transportation fatigue, hydrogen stress cracking at hard spots, and ERW seam-weld defects(70).
- Studies of pipeline failures under unusual conditions, such as earthquake loading (see, for example, studies conducted by Texas A&M University(71,72)).

Some published failure analyses were located but not used in the study. Data from the former Soviet Union and elsewhere in the world were not used because the analyses did not provide sufficient information to shed light on the types or characteristics of historic anomalies that caused incidents.

Some Case-Specific Results

The FPC database and the several OPS databases facilitate trending failure rates for B31.8S Threat Categories 4 and 5 (see Table 1) as a function of time period. Without normalizing failure rates are found as follows:

Average number of incidents per mile 1950-1955 – 8.39×10^{-4}
Average number of incidents per mile 1956-1960 – 5.59×10^{-4}
Average number of incidents per mile 1961-1965 – 3.88×10^{-4}
Average number of incidents per mile 1998-2002 – 2.27×10^{-4}

This shows even though the average age of the pipeline infrastructure is greater, the rate of reportable incidents per mile is decreasing. Over the time interval for these data, the reduction is continuous, with roughly a factor-of-three decrease evident. Such reflects the fact that the larger defects in this population of line pipes fail rather quickly, eventually leaving an essentially dormant (stable) set of anomalies. It also might reflect differences in service conditions and other factors, although from a service perspective conditions are likely worse now as demand for gas continues to increase.

An alternative way to evaluate trends in failure rate is in reference to gas volume transported. The failure rate in this context is as follows:

Average number of incidents per mmcf/year 1950-1955 – 1.46×10^{-5}
Average number of incidents per mmcf/year 1956-1960 – 6.86×10^{-6}
Average number of incidents per mmcf/year 1961-1965 – 4.29×10^{-6}
Average number of incidents per mmcf/year 1998-2002 – 2.93×10^{-6}

From these results one can conclude that the rate of reportable incidents per amount of gas transported is decreasing over the time, even though the average age of the pipe is increasing. In this format, the reduction is again continuous over the interval, with the decline in rate greatest early on in service as would be expected if the quality of the line pipe introduced into the system was improving over time, and the larger defects in this population failed rather quickly, eventually leaving an essentially dormant (stable) set of anomalies. When viewed this way, the reduction in incident rate is the order of ten-fold[23].

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[23] There are many possible approaches to normalize such data. Two aspects complicate this. First, the amount of system-related information differs over the time intervals represented, and second the data reported and the detail and accuracy of reporting change over this interval. Given this, the significant observations include that the rate is reducing over time, and the process appears to reflect continuing improvement.

Appendix B. Low-Stress Pipelines

Because pressure drives both fracture initiation and fracture propagation(17,24), low-wall-stress pipelines have different failure characteristics than pipelines operating at high stress levels(20). Moreover, pressure is a key factor in determining leak versus rupture response in the event of fracture initiation(17). Finally, the extent of thermal exposure depends directly on pressure(41). For these reasons, critical defect sizes are large in low-wall-stress pipelines, most failures will result in leak rather than rupture. It takes a very large defect to initiate a leak or rupture and it is unlikely that fracture will propagate. These differences significantly reduce the potential likelihood and consequences of an incident for such pipelines in comparison to higher stressed pipelines.

This section considers differences between incident history and consequences for lower stress pipelines relative to higher stress lines. For present purposes, low-stressed pipelines are defined here as those lines that operate at 30% SMYS or lower.

Low-Stress Pipeline Incident Data

The three incident dataset introduced earlier were analyzed to assess the effects of operating pressure on the frequency at which incidents occur and on whether the incident was a leak or a rupture. In the FPC incident dataset, roughly seven percent of the sum of all incidents occurred on pipelines operating at or less than 30 percent SMYS.[24]

Table B-1 summarizes the FPC incidents attributed to historic anomalies. A little less than three percent of the incidents due to historic anomalies are from lines operating at or less than 30 percent of SMYS. The number of incidents associated with manufacturing, fabrication, and construction anomalies on low stress pipelines is very quite small relative to that for higher stressed lines.

Table B-1. Low and high stress incidents attributed to historic anomalies in the FPC 1950-65 database

Cause	Number <= 30% SMYS	Number > 30% SMYS
Manufacturing Related:		
Defects in the Pipe Body	1	23
Defects in the Seam Weld	3	101
Fabrication or Construction Related:		
Defects in Field Welds	1	88
Construction Damage	1	22
Total (All Threats)	**42**	**1024**

Table B-2 presents a similar comparison based on the onshore OPS reportable incident data between 1984 and 2000. For this comparison, the dataset was culled to include only incidents attributed to historic anomalies on onshore steel transmission pipelines. The number of manufacturing-related incidents attributed to historic manufacturing anomalies in low stress pipelines is similar to that

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[24] Unfortunately, the results tabulated in the databases considered here occasionally are not sufficient to calculate percent SMYS for all incidents. Consequently, the results tabulated must be viewed as an indicator of the situation evaluated, rather than exact measure.

from the FPC, but the number of due to fabrication and construction incidents anomalies is significantly higher.[25] This may be the result of increased use of small diameter lines in low stress service and difficulties associated with working around more heavily congested areas. Small diameter lines are more difficult to weld in the field due to the rapidly changing orientation of the weld itself. Conversely, the number of higher stress incidents is significantly less in the OPS data compared to the FPC data. Incidents attributed to defects in the seam weld are significantly lower, perhaps reflecting better quality control and testing requirements in the pipe mill.

Table B-2. Low and high stress incidents attributed to historic anomalies in the OPS 1984-2000 database

Cause	Number <= 30% SMYS	Number > 30% SMYS
Manufacturing Related:		
Defects in the Pipe Body	10	38
Defects in the Seam Weld	0	26
Fabrication or Construction Related:		
Defects in Field Welds	9	14
Construction Damage	0	0
Total (All Threats)	**242**	**744**

In Table B-2, most of the incidents at stresses below 30 percent of SMYS are described as a "leak" or "other" in the dataset, rather than as a rupture. In several cases, though, ruptures were indicated for which the length was reported as zero or a small length. A "no length" incident is, by definition, a leak as the product lost through a short opening is small. Only one of the 22 reported low-stress incidents corresponded to a true rupture: a 40-foot long rupture. That is and as expected, the data indicate the most likely outcome of an incident in a low stress pipeline is a leak.

Evaluations including burst tests were conducted by British Gas to support development of the pipeline design requirements in IGE/TD/1, "Steel Pipelines for High Pressure Gas Transmission"(73). The specifications of this standard confirm the expectation of a leak rather than a rupture in a pipeline operated at 30% SMYS or less.

In summary, very few incidents have been attributed to historical manufacturing defects in low-wall-stress pipelines. The number of low-stress incidents attributed to historic fabrication and construction anomalies is higher quite likely because construction of parallel pipelines in common rights-of-way has activated the larger features. For incidents attributed to either type of historic anomalies, leak are anticipated rather than ruptures(20).

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[25] The time periods covered by the OPS (16 years) and the Federal Power Commission (15 years) datasets are comparable.

Appendix C: Metallurgical Aging Issues

Background

Time dependent degradation that can reduce pipeline integrity can result from threats such as external corrosion or increased external loading that may cause growth of a pre-existing pipe or construction related flaw. These aspects along with re-inspection intervals are considered in other reports(e.g., see 9) as outlined in B31.8S. Time-temperature dependent reactions within the steel also are possible at sufficiently high temperature and can cause changes in steel properties under such circumstances. Because the working stress design (WSD) philosophy adopted in the U. S. pipeline design codes(e.g., 74)[26] assumes that material design properties remain constant over the operational life of the pipeline, the constancy of these properties is essential to assure long-term integrity. The possible time-dependence of pipeline integrity is considered in this appendix.

Code-Based Design Parameters and Other Important Factors

Reference 8 outlines WSD as applied to pipelines. WSD is based on elastic response under design conditions and is based on the long-recognized theory of elasticity, which is elaborated in detail in many textbooks(e.g., 78). Key parameters in WSD include the stiffness (of the line-pipe steel), termed the elastic modulus denoted E, and its specified minimum yield stress[27], denoted SMYS. For simple uniaxial tension, the stress, denoted here S, and strain, denoted here e, under elastic conditions are linearly related according to Hooke's law, which has the form:

$$S = E \circ e \,. \qquad \text{(C1)}$$

Thus, the elastic modulus, E, is a constant of proportionality between stress and strain and also the slope of the stress-strain curve in the linear region. This modulus also defines the stiffness (or rigidity) and so underlies the deformation resistance of a structure while the stresses are linear elastic. Thus, stiffness issues in design are resolved by design modifications rather than by metallurgical adjustments.

A design factor, DF, whose value is less than one(77) is applied to SMYS to provide a margin of safety to ensure the response remains elastic in service. On this basis, the maximum design stress (MAS) is defined as:

$$\text{MAS} = \text{DF} \circ \text{SMYS} \,. \qquad \text{(C2)}$$

Design factors whose value is less than 1.0 are specified to ensure the maximum stress in the pipe during operation remains safely within the elastic (linear) regime. The DF provides a margin of safety against unexpected or unusual loading as well as the presence of anomalies. Early pipeline designs used a single design factor(76), while later designs (e.g., 49CFR192) used three as follows:

- A class-location factor that accounts for population density near the line and ranges from 0.4 for pipelines in heavily populated areas to 0.72 for lines in less populated or rural areas;

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[26] See Reference 75 for the history and evolution of the U. S. codes since their initial appearance as consensus standards in 1935(76), and Reference 77 for discussion of related design factors.

[27] The term strength is typically used, which is a misnomer as strength has units of force whereas units of force per unit area are appropriate. As such units define stress it is used here in lieu of strength. The yield stress is defined in reference to permanent deformation, and typically is evaluated at an offset plastic strain of 0.002 or a total strain of 0.005. For details see Reference 8 or related textbooks.

- A longitudinal joint factor that accounts for seam welds that had a higher flaw frequency and ranges from 0.6 for early welding processes to 1.0; and
- A temperature de-rating factor, that applies for operating temperatures above 250 F (uncommon because gas transmission pipelines typically operate at 140 F and less).

Pipeline integrity also can involve material properties other than those associated with WSD. Parameters other than those involved in design become important when the pipe wall thickness specified in accordance with WSD is diminished locally because of corrosion or the presence of an anomaly. Parameters potentially important in such situations center around fracture resistance that is needed for fracture control.

For pipeline applications, the toughness required for resistance to fracture initiation and propagation has been typically specified in terms of Charpy V-Notch energy(30). With respect to fracture propagation resistance, the relationship of the ductile-brittle transition temperature (DBTT) to the pipeline operating temperature is also a concern[28].

Strain Aging Processes

Several types of metallurgical aging processes can occur. With respect to pipeline operating conditions, the major concern is strain aging that can occur during or after application of a plastic strain. Strain aging that occurs during plastic straining application is described as “dynamic strain aging”(79) and aging after strain application is referred to as “static strain aging”(80, 81). Either type of strain aging could occur in a pipeline, but dynamic strain aging would favor lower strain rates and typically higher temperatures that facilitate high rates of diffusion that are the order of the strain rate. In gas pipelines, room temperature aging is the primary concern for most of the pipeline, however near a compressor station discharge, higher temperatures can exist, but are typically bounded above by ~140 F.[29]

In line pipe, the plastic strain necessary to promote strain aging can result from several sources. During steel and pipe manufacturing, this includes lower temperature steel rolling, pipe forming, and local flow associated welding residual stress. Typically, the plastic strain level introduced during pipe forming is in the range of 1 to 2 percent for pipe with a diameter to thickness ratio between 50 and 100. Cold expansion is used for pipe sizing during some pipe manufacturing processes can introduce an additional 1 percent of plastic strain. Thus, pipe forming typically involves plastic strain levels of 2 to 3 percent. Plastic strain during construction can occur from welding (localized) and cold field bending. The plastic strain from cold field bending at 1.5 degrees per diameter is 1.3%. During operation, the likely sources of plastic strain are deformation from outside forces and mechanical damage, which in cases where the strains are large usually leads to replacement of the line pipe.

It should be noted that the strains resulting from pipe manufacturing and construction are not all applied in the same direction. Following strain aging, the response of steel to strain can be affected by the direction of the additional applied strain with respect to the pre-strain. This is discussed in a following section.

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[28] See Reference 17 for detailed discussion of the several parameters involved in characterizing fracture resistance.

[29] Tabulations of discharge temperatures for early SCC incidents(82) indicate temperatures less than this level were essential to avoid widespread SCC (high pH SCC is accelerated by temperature). This led to the use of after-coolers and controlled compression to keep temperatures below this level for many gas transmission systems. For this reason, 140 F can be taken as an upper bound to discharge temperatures.

General Effect of Strain Aging on Steels

Strain aging is a process that consists of plastic pre-strain and time period at an ambient or elevated temperature. Dislocations created during plastic deformation become locked or pinned due to the diffusion and concentrations of interstitial solute atoms (i.e., carbon, nitrogen) to the dislocations. Dislocations are effective nucleation locations that promote solute precipitation and impede additional dislocation movement. When dislocations become locked, an increased applied stress is required to further deform the material.

Strain aging has been described as a four step process(81,83-85). Step 1 involves the migration of solute atoms to dislocations effectively reducing their mobility or locking them. The quantity of solute atoms affecting dislocations increases and precipitates form on the dislocations during Step 2. The size of these precipitates increase in Step 3 and over-aging occurs in Step 4.

Material property alteration occurs during the different steps of the strain aging process. Table C-1 summarizes these effects. The aging step shown in Table C-1 indicates the stage during the strain aging process when the effect begins to occur. Typically, a yield strength increase, a ductile-to-brittle transition temperature (DBTT) shift to a higher temperature, and increased hardness are among the first detectable effects. Other changes including an ultimate tensile strength increase and an elongation to fracture change occur during later steps in the process. Unlike the other effects shown in Table C-1, elongation to fracture data indicate a variation of the change resulting from strain aging that can range from an increase to a decrease(83-86), but in either case the effect is not strong.

Table C-1. Aging effects

Property	Effect	Aging Step
Lower YP elongation (Luders)	Increase	1
Hardness	Increase	1,2
YS	Increase	1
UTS	Increase	2,3
DBTT	Increase	1
Elongation to fracture	Increase/Decrease	3

Other design related properties including the Charpy V-Notch energy absorption for a 100% shear fracture decreases during strain aging. None of the strain aging literature reviewed indicated any influence on the elastic modulus(80,81,83,87).

The two main solute atoms typically contained in steels that influence strain aging are carbon and nitrogen. Both carbon and nitrogen influence strain aging behavior since they both have a high solubility in ferrite, a high diffusion coefficient, and can readily restrict or prevent dislocation movement. At lower temperatures (< 212 deg. F), free nitrogen is the primary solute atom contributing to strain aging. This is due to the fact that at lower temperatures, nitrogen has a greater solubility in the ferrite matrix than carbon. Since the maximum operating temperature of gas pipelines is 140 F or less, nitrogen would be the primary solute affecting strain aging.

Above 212 deg. F, carbon starts to play a role. Carbon can induce strain aging in steels at temperatures above 212 deg. F and may have an effect at lower temperatures depending on the prior thermal history of the material. Very low levels of free carbon or nitrogen are sufficient for strain aging to occur and higher levels will result in an increased response(80,81,87, 88).

Alloy additions that tend to form stable nitrides (Al, Ti, and B) reduce the amount of free nitrogen within the matrix thus reducing strain aging propensity at lower temperatures. Other alloying elements such as V and Nb form stable nitrides and carbides that reduce both the free carbon and nitrogen. If a sufficient quantity of these elements are present, the levels of free carbon and nitrogen are reduced to the point that the strain aging propensity becomes limited but is not totally eliminated(84,85). Research has indicated that other typical steel alloying elements including silicon and manganese, under certain conditions, can retard strain aging(80,81).

Considering the impact of typical steel alloying elements, strain aging response can also be related to the steel manufacturing method. Steels that have been incompletely or partially deoxidized are more susceptible to strain aging while fully deoxidized and microalloyed steels tend to be less susceptible. Aging susceptibility can be related to the degree of deoxidation treatment and alloying additives in the steel being manufactured. The strain aging susceptibility of several steels used for pipe production is shown in Table C-2 below. They are listed in order of decreasing strain aging tendency(88-90).

Table C-2. Steel strain aging tendency

Rank	Type of Steel
1	Rimmed steels
2	Semi-killed steels
3	Silicon killed steels
4	Aluminum killed steels
5	Silicon-Aluminum killed steels
6	Killed Microalloyed steels (HSLA)

Literature on strain aging research frequently includes data from evaluations of rimmed steels. For pipeline applications, rimmed steels are not of particular interest. Rimmed steels contain little soluble Al or other nitride formers leaving most of the N in solid solution thereby available for strain aging. Therefore, they tend to be most susceptible to strain aging.

The other steel types shown in Table C-2 have been frequently used for line pipe steel production. Historically, most Grade B through Grade X56 pipe was manufactured from semi-killed steels that typically contained limited amounts of deoxidizers and other alloying elements with resultant higher levels of free solutes. Grade X60 and higher strength line pipe were typically manufactured from killed microalloyed steels that were deoxidized with either silicon, aluminum, or a combination of silicon and aluminum. Silicon killed steels are deoxidized with silicon that can also combine with nitrogen under certain conditions and retard strain aging. Aluminum is a commonly used deoxidizer and also a nitride former thus it reduces the level of free nitrogen(88).

HSLA steels are susceptible to strain aging and exhibit many of the same aging characteristics as plain carbon steels. These steels are typically produced by controlled rolling and cooling and contain additions of V, Nb, Ti, and other elements for development of higher strength through solution and precipitation hardening mechanisms. It has been found that strain aging activation energy for HSLA steels is higher than for killed or semi-killed steels so strain aging occurs at a slower rate. It should also be noted that in addition to HSLA steels, other steel types shown in Table C-2 including some semi-killed steels that were produced in the mid 1960s and later may have also contained Nb or V additions or both(83,87,91,92).

In addition to the effects of steel composition discussed above, other variables including the pre-strain direction and level, aging temperature, and prior material condition can influence strain aging response. The relationship of pre-strain direction prior to aging to the direction of any additional strain does affect material response. A material pre-strained, aged and then loaded in the same direction will exhibit a comparatively rapid return of the lower yield stress. Where the same material is pre-strained in compression or in tension perpendicular to a subsequently applied strain, the lower yield stress return is delayed. However, other properties including ultimate tensile strength and elongation are not affected by this strain direction relationship. It has also been shown that amount of tensile pre-strain (on the order of 2-7%) does not have a significant effect on that amount of yield strength increase(80,85).

Data from strain aging evaluations have indicated that steel property modifications can result from straining and aging. Pre-strain prior to aging can cause a significant proportion of the total change. This includes a significant fraction of the DBTT shift to higher temperatures that occurs in plain carbon and HSLA steels(80,83).

Strain Aging Results for Steels

Different test procedures have been used to evaluate the extent to which strain aging occurs including impact tests (Charpy V-Notch and similar), hardness tests, and tensile tests. Strain aging experiments often are conducted at elevated temperatures and high pre-strain levels to accelerate the process. These temperatures are often well above those experienced in operating pipelines. The results of such evaluations can be equated to lower aging temperatures and equivalent aging times. Methods have been developed based on the Arrhenius relationship to permit such comparisons under certain conditions(80,93).

Two of the methods that can be used to equate the results of strain aging evaluations to lower temperature equivalent aging times are shown as Equations C3 and C4. Equation C3 is only applicable to rimmed or plain carbon steels and should be used to predict the effect of aging temperature after application of a defined pre-strain. It is also based on the assumption that nitrogen is the major active solute and that the solute concentration does not change with temperature.

Also, Equation C3 does not account for the effects of carbon that can contribute to the aging effects at temperatures greater than 212 deg. F. Strain aging response estimates from tests conducted at higher temperatures can be a combination of nitrogen and carbon diffusion and precipitation. Therefore, the strain aging response indicated by such data may represent a more extreme effect when compared to typical pipeline operating temperatures(80,93).

$$\log\left(\frac{t_r}{t}\right) = 4000\left[\left(\frac{1}{T_r}\right) - \left(\frac{1}{T}\right)\right] - \log\left(\frac{T}{T_r}\right) \tag{C3}$$

where: t_r = Equivalent aging time at lower temperature

t = Time at aging temperature

T_r = Lower or room temperature (K)

T = Aging temperature (K)

For other steels with different strain aging activation energies, similar equations have been proposed to equate different temperatures and times required for aging following a pre-strain. For instance, Equation C4 has been proposed for application to HSLA steels as follows(92):

$$\log\left(\frac{t_r}{t}\right) = 7500\left[\left(\frac{1}{T_r}\right) - \left(\frac{1}{T}\right)\right] \qquad (C4)$$

Equation C4 is valid up to 400 F aging temperatures and the definitions of terms are as described above for Equation C3.

Evaluation of Strain Aging Data

Strain aging data from the literature has been reviewed and evaluated to determine trends and illustrate the expected effects on pipeline integrity. The available data represent a wide variety of carbon steel materials subjected to various strain aging treatments. This review has focused on data illustrating the performance of carbon steels subjected to pre-strains less than 5% and lower temperature aging conditions, as these are more representative of strain aging in operating gas pipelines.

An evaluation described in Reference 94 included data from a semi-killed, low carbon steel that was partially deoxidized with silicon. The material was pre-strained between 2.3 and 18.5% followed by aging at 250 deg. C for one hour. Although the aging temperature is high in reference to any gas-transmission pipeline, the lower end of the range of pre-strains considered is similar to that for line pipe. Figure B-1 illustrates the variation in yield and tensile strengths due to a 2.3 to 9.25% pre-strain and pre-strain plus an aging treatment. The yield and tensile strengths shown at zero percent strain represent the initial material properties. These data illustrate one example where the pre-strain accounted for all of the yield and tensile strength increase shown. Straining plus aging resulted in a slightly decreased response.

The effect of long term aging (21 years) at room temperature on an aluminum killed steel following a 0.5% temper rolling treatment was described Reference 95. The results of this work have been summarized in Figure B-1. Very little yield strength, tensile strength, or hardness variation occurred over this period. In this case, the percent elongation (not shown) increased slightly during this period. Other data reviewed, however, have demonstrated that the change in percent elongation does not exhibit a consistent trend, nor is there evidence of a significant effect(86).

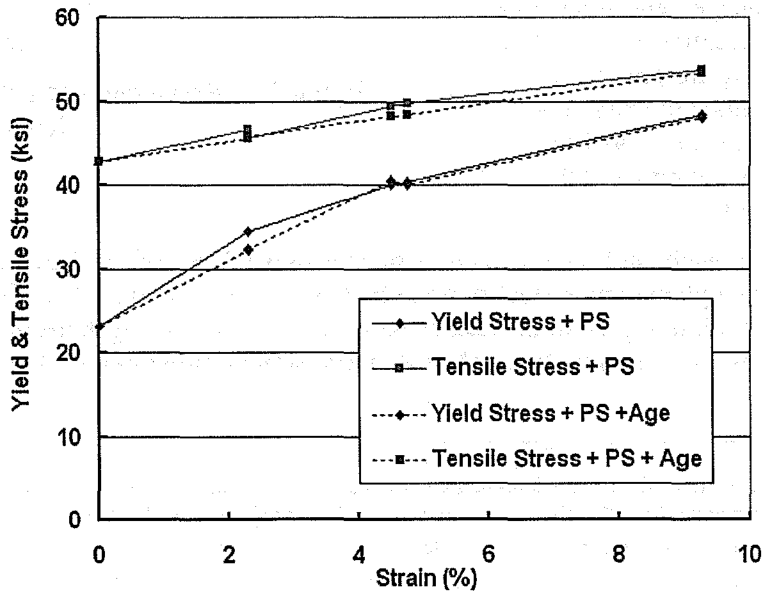

Figure C-1 Strain aging data compiled from Reference 94

One of the more extensive evaluations of line pipe steel strain aging behavior was conducted by United States Steel(85) (USS). The objective of this evaluation was to determine the effects of heating cycles from application of fusion bonded epoxy coatings on line pipe. A 3% pre-strain was used to simulate the pipe manufacturing induced plastic strain in large diameter double submerged-arc welded (DSAW) line pipe formed by the U-O-E[30] process(86).

Except for a rimmed steel, the USS evaluation included the different types of steel listed in Table C-2. Seven fully killed and semi-killed steels with several containing microalloying elements were included. Steels were finished in the hot rolled condition (1800F) and two controlled rolling schedules using 1550 or 1330 F as a finishing temperature. Aging was conducted at 250 F and 475 F (0.5 hr.) with the latter temperature included to simulate fusion bonded coating applications. Data collected included yield strength, tensile strength, elongation, reduction of area, Charpy vee-notch (CVN) upper shelf energy (USE), and Charpy 50% shear area transition temperature (SATT)(86).

Figures 3 and 4 present comparable sets of data generated as part of the USS study that indicate the extent of aging effects on steel, including those used in vintage pipelines. Figure 3 presents results for a semi-killed plain carbon steel while Figure 4 presents results for a Si-Al killed steel. In all cases results for the as-rolled (AR) condition are contrasted to the effects of pre-strain, whose effect on steel fracture resistance characterized by several different resistance measures is well known, as is the effect of pre-strain on integrity and integrity management of pipelines[31]. Thereafter, the effects of aging are presented in contrast to unaged, with results presented for aging aging at either 250 F or 475 F[32].

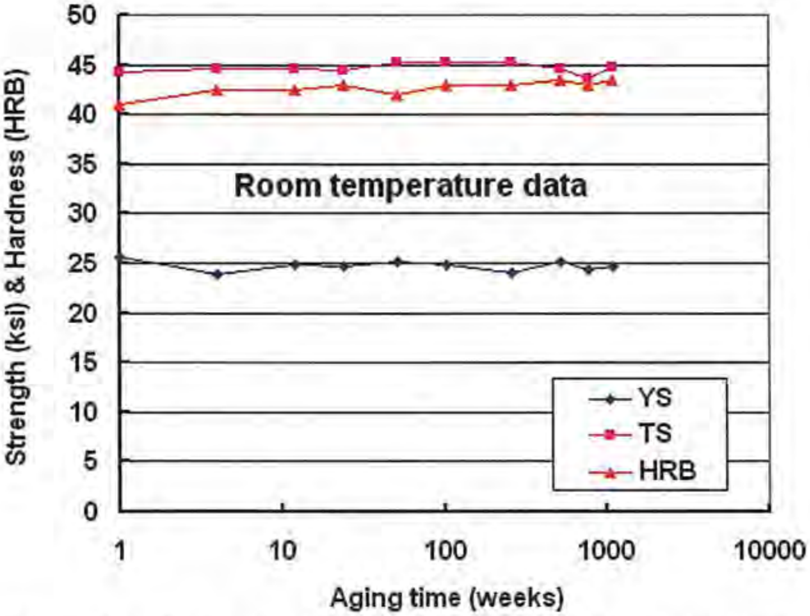

Figure C-2. Room temperature strain aging data compiled from Reference 95

The results in Figure C-3a illustrate the dependence of yield and tensile strength changes the semi-killed plain carbon steel finished by hot rolling at 1800 F. This figure contrasts the as-rolled (AR) condition to pre-strain without aging, and then following aging at either 250 F or 450 F. The tensile stress was essentially unaffected by pre-strain or after aging. The yield stress can be seen to increase

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[30] The "U-O-E" process indicates a particular pipe manufacturing method typically used to produce DSAW pipe. Plate is formed into a "U" shape, then into a cylinder ("O-shape"), welded, and then cold expanded ("E").

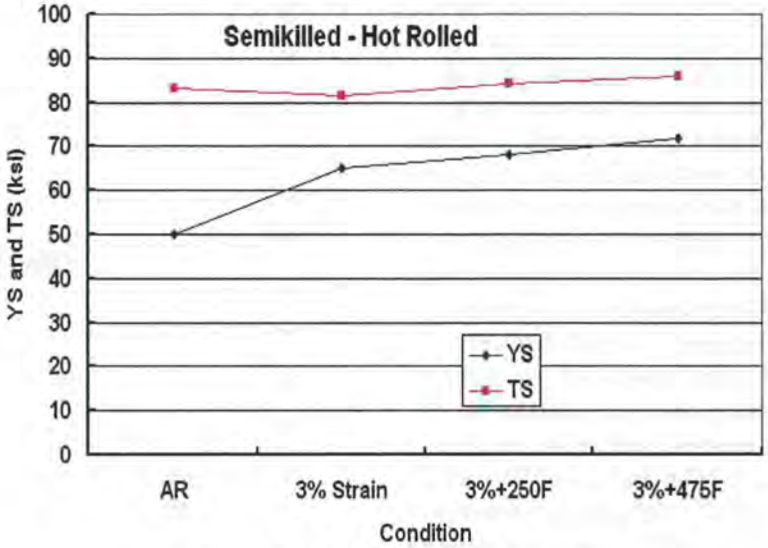
[31] See for example the extensive references cited in Reference 5 or Reference 19, and the related discussion.

[32] Aging in reference to 250 F involves a temperature well beyond that encountered in gas transmission pipeline service. As noted earlier herein, a temperature of about 140F can be considered an upper bound for such service after the late 1960s when the tie between higher service temperature and SCC was identified. Before then, compressor discharge temperatures as high as 170 F had been recorded, with slightly higher temperatures being plausible. As such, results for 250 F or 450 F are of academic interest in reference to accelerating the effects of aging, which was the focus of such research.

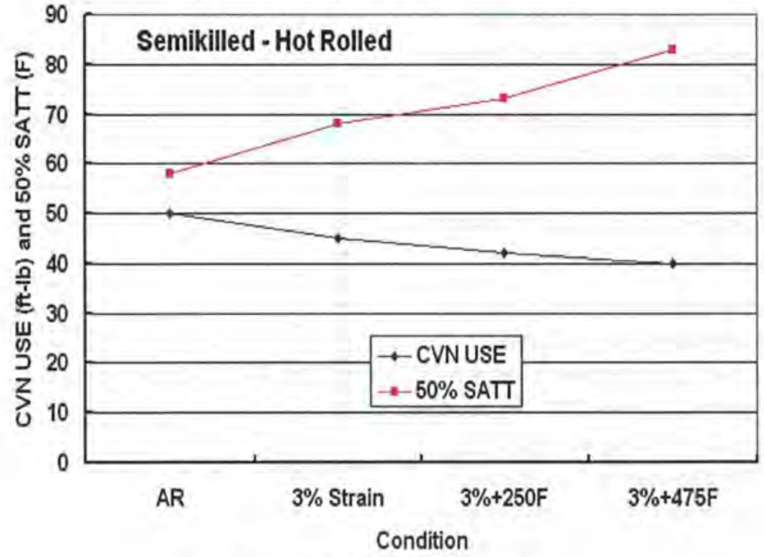
due to pre-strain and thereafter to a lesser extent due to the subsequent aging even for the higher temperature.

The variation of Charpy USE and 50% SATT for the same semi-killed steel are shown in Figure C-3b. A reduction in Charpy USE is evident due to the effects of pre-strain that accounts for more than half of the overall reduction when the effects of aging are included. This difference in energy is of the same order as the typical variability in this parameter within a joint of pipe so such differences are not of great practical significance. The Charpy 50% SATT increased somewhat beyond that due to pre-straining, but again such differences are not of great practical significance in contrast to variability within a pipe joint.

All steels evaluated that are typical of those available for use in vintage pipelines show trends in yield and ultimate stress comparable to those shown in Figure C-3a. While similarities exist in stress response with pre-strain and aging, significant differences are evident in the fracture resistance in comparison to that in Figure C-3b. This is evident in Figures C-4a and C-4b, which present results from a Si-Al fully killed steel included in the USS evaluation.



a) variation in yield and tensile stress



b) variation in CVN properties

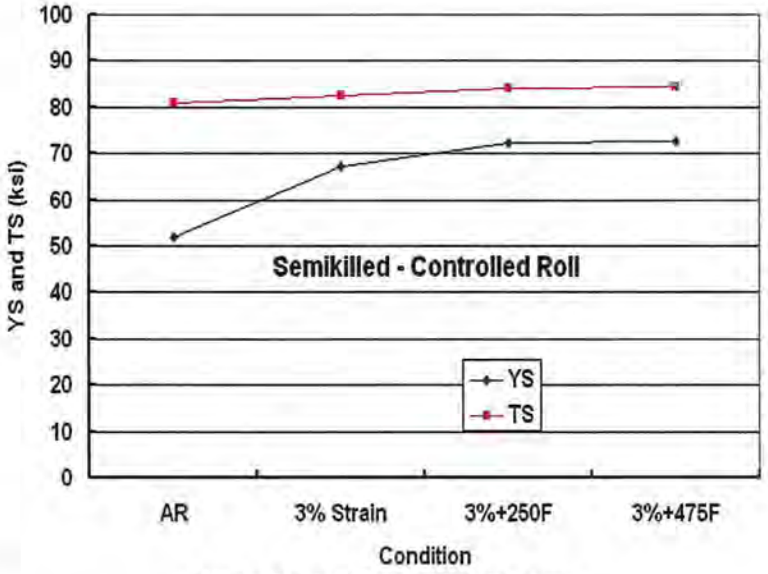
Figure C-3. Effect of aging on a semi-killed steel

Comparing the trends in Figures C3a and C4a indicates that the tensile stress for both is largely independent of thermal or mechanical history. The yield stress for the controlled-roll steel shows the expected effects of strain hardening, as evident in the increase due to the pre-strain. Aging results in a further beneficial increase in the yield stress as compared to SMYS.

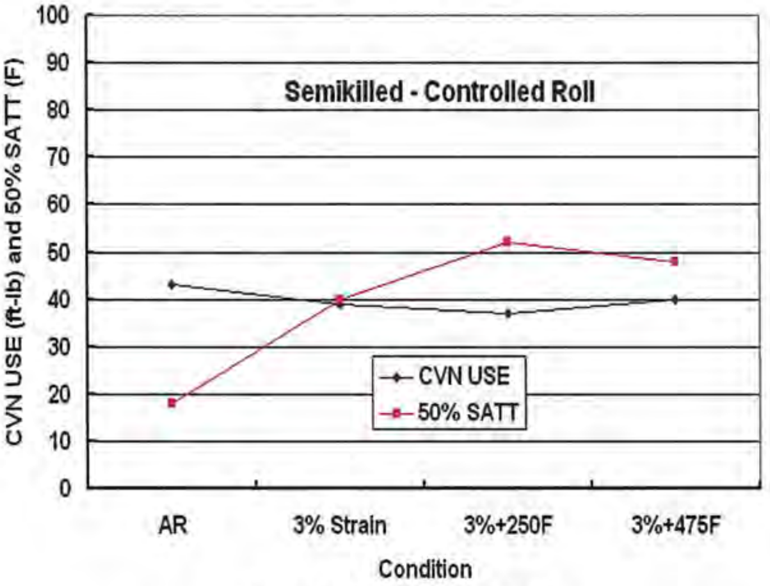
As shown in Figure C-4b, Charpy USE changes little in reference to typical scatter in a joint of line pipe, while the Charpy 50% SATT shows an increase with pre-strain, with the subsequent aging having less effect. But, regardless of the change in SATT, the temperature remains well below typical service temperatures for cross-country pipelines.

Figures C-3 and C-4 represent two of the seven steels included in the USS study and of these reflect two of the six rolling schedules considered. To better capture the influence of aging on properties important to design and integrity the results of all seven steels in each of the three rolling schedules have been evaluated. The USS study included results for yield and tensile stress in addition t o elongation, reduction in area, CVN USE and CVN 50-percent SATT[33]. Of these parameters, yield stress is central to pipeline design, while elongation or reduction in area, serve as measures of fracture initiation resistance as can CVN USE via correlation to parameters like J-integral, and CVN USE and CVN 50-percent SATT serve as measures of fracture propagation resistance.

The yield stress as well as the tensile stress for all cases behaved as the trends shown in Figures C-3 and C-4. In no case was the yield stress after pre-strain and aging less than the initial yield stress, and in most cases the resulting yield stress after this history was significantly larger than the initial value.



a) variation in yield and tensile stress



b) variation in CVN properties

Figure C-4. Effect of aging on a Si-Al killed steel

Results for elongation, reduction in area, CVN USE and CVN 50-percent SATT are somewhat more complex in their behavior such that figures are used to represent these trends. As the tendency for elongation and reduction in area are similar as anticipated, only data for reduction in area are presented. Figure C-5 presents these results in terms of the cumulative distribution of percent reduction, CVN USE, and 50-percent SATT in parts a through c respectively. Each part of this figure presents the cumulative frequency on the y-axis and the corresponding parameter value on the x-axis. In each case the figure contrasts the result after the pre-strain to the

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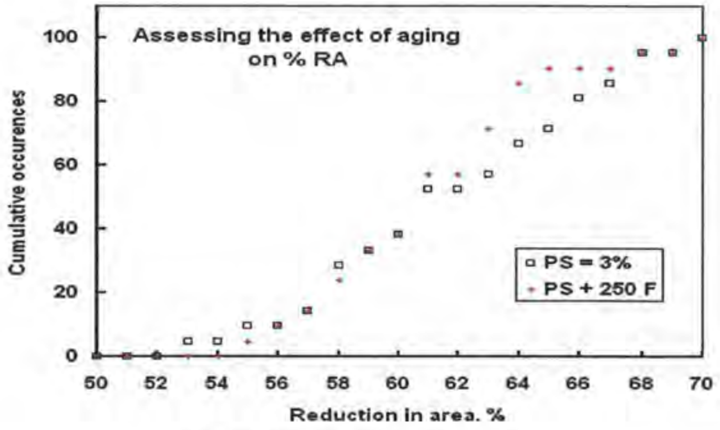
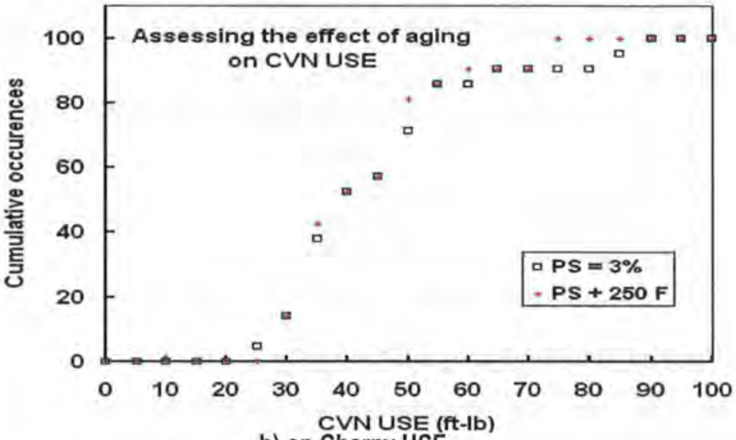
[33] That modulus is not considered points to their awareness that it is independent of such effects over their range of interest

corresponding result after the hold-time at 250 F, which represents the influence of the thermal aging. Results for the pre-strain condition prior to aging are shown as the open squares in each view, while the results after the hold at 250 F are shown as the + symbols. The result after the hold at 250 F is used for this comparison rather than the data for the hold at 475 F as the lesser of these temperatures is an upper bound to the circumstances that might occur in pipelines.

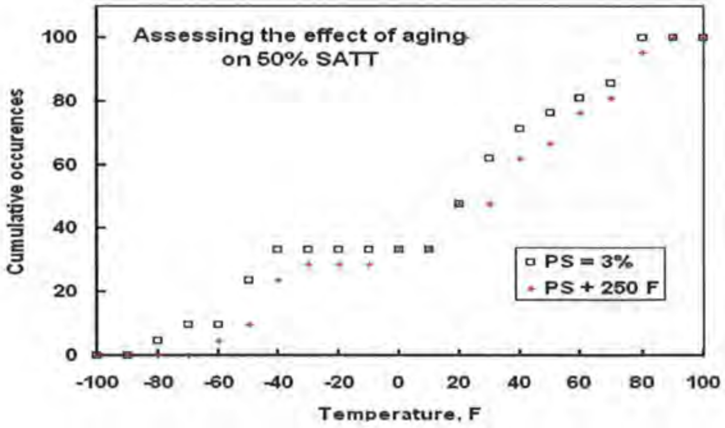
Figure C-5a presents the results for percent reduction in area, which here serves as a surrogate for fracture initiation resistance. In the format of this plot, values of area reduction that are less than that prior to the hold time indicate a reduction in resistance to fracture initiation. In many cases the result is unchanged by the aging, while in others it increased or decreased slightly, the extent to which is magnified for this figure by the selection of the scale that begins at 50 percent. As the variation shows no clear trend and the scatter is the order of that typical in this parameter, the data do not indicate aging has a detrimental influence on fracture initiation resistance assessed in terms of this surrogate.



a) on percent reduction in area



b) on Charpy USE



c) on 50-percent SATT

Figure C-5. Effect of aging on seven steels

Consider now Figure C-5a which presents results for CVN USE, which can serve as a surrogate for fracture initiation resistance, and is a measure of fracture propagation resistance. In the format of this plot, values of CVN USE that are less than that prior to the hold time indicate a reduction in resistance to fracture initiation. The figure shows that in many cases the result is unchanged by aging, while in others it increased or decreased slightly, the extent to which is well within the scatter typical of this parameter. As the variation shows no clear trend and the scatter is the order of that typical in this parameter, the data do not indicate aging has a detrimental influence on fracture initiation resistance assessed in terms of this surrogate, or fracture propagation resistance.

Finally, consider Figure C-5c, which presents the results for 50-percent SATT, which here is an indicator of possible change in the ductile to brittle fracture that serves as an indirect measure of fracture propagation consequences. In the format of this plot, values of SATT that are greater than that prior to the hold time indicate an increased tendency for brittle fracture in situations where the actual SATT lies above the pipeline's service temperature. In some cases the result is unchanged by the aging, while in others it increased slightly by as much as 20 F, although at the higher transition temperatures the shift appears to be diminishing. In the transition regime, a shift of up to 20 F lies within the range of variability in this parameter. More importantly, while the variation does show a trend that leis within the scatter typical in this parameter, the data do not indicate SATT whose level lies at or appreciably above the service temperatures of cross-country pipelines. Consequently, its influence on fracture mode is not practically significant.

In summary, the results for the comprehensive USS steel study of aging effects leads to similar trends across the full range of steels and rolling schedules considered, as follows:

- Yield strength increased with pre-strain,
- Pre-strain alone accounted the same incremental increase as due to aging, or more,
- Tensile strength either remained essentially constant or increased slightly,
- The CVN USE was largely invariant for aging at 250 F, but tended to decrease at 475 F,
- The CVN 85% SATT increased, but even then was below the operating temperatures experienced in cross-country pipelines,
- Ductility was largely invariant of aging at 250 F.

Effect of Strain Aging on Integrity

The strain aging data reviewed indicate that pre-strain and aging do affect the properties of line pipe steels typical of those used in vintage pipelines. Changes in three properties have a potential impact on fracture initiation and propagation, the data trends show increase in DBTT, and a decrease in both CVN USE and elongation to fracture. The reason for concern over these changes lies in the fact that fracture control depends on these parameters. Consequently, where fracture control plans have been developed for vintage pipelines, the values CVN USE and DBTT used to establish the required toughness to provide for fracture initiation and propagation resistance of line pipe are diminished somewhat by aging. While a potential concern, fracture control did not become a design consideration until the advent of fracture mechanics, which in a practical context for many structures dates to the 1970s. Significantly, even today most pipeline codes don't require fracture control plans. On this basis, a change in such parameters compared to their design requirements is a moot point for vintage pipelines.

While fracture control plans are not an issue, a consequential decrease in fracture resistance is a factor for vintage pipelines. Because quasi-static or dynamic fracture initiation is the necessary precursor to propagation, preventive measures and adequate fracture initiation resistance are central in reducing the chance propagating fracture could occur. Of the parameters characterized, no measure or surrogate for quasi-static initiation resistance was found to be degraded due to aging at 250 F, which is an upper bound to temperatures that might be experienced in pipelines. Given that initiation is minimized by toughness levels that maximize pipe defect tolerance, the likelihood of fracture propagation is likewise minimized.

As noted above, initiation resistance characterized in reference to both ductility (reduction in area) and CVN USE were both invariant of aging at 250 F. Therefore, in reference to fracture initiation, strain aging can be anticipated to have a minor effect if any. Likewise, as CVN USE was invariant of aging at 250 F, there is little change anticipated in susceptibility to fracture propagation due to aging. The observed increase in CVN 50% SATT was small, but even after this change was typically less than the operating temperatures experienced in cross-country pipelines, which again indicates that aging has little practical significance in reference to fracture mode.

It follows that aging constitutes a comparatively minor influence, with any change due strain aging being a second order effect with little practical influence on fracture initiation and propagation behavior. Consistent with this, the authors are not aware of any pipeline failure attributable to strain aging effects on an in-service gas transmission pipeline.

Modulus of Elasticity

As noted earlier in reference to Equation C1, the elastic modulus is central to pipeline design. The value of this modulus is determined by atomic binding forces and the crystalline structure of the material involved, which is steel for the vintage transmission system. These binding forces and crystallography cannot be changed without modifying the basic nature of the steel. For this reason, within a given class of materials such as steel the elastic modulus is among the most microstructure invariant mechanical properties. It can be marginally affected by alloying additions, heat treatment, and cold work. Other factors including crystallographic defects such as vacancies, dislocations, or polycrystalline features like grain size also have a minimal effect on the elastic modulus(96-98).

Depending on their concentration, alloy additions in solid solution with alpha iron can either increase or decrease the elastic modulus. However, at the levels typically used in steels, such changes are minimal. For instance, heat treated alloy steel may have a higher elastic limit and yield strength but the elastic modulus is the same(99,100).

In single crystals and small aggregates of crystals the elastic modulus varies with crystallographic orientation and structure. For example, if the elastic modulus is determined along different crystallographic directions, different values will result that range from about 18 to 41×10^6 psi in iron. The typically used steel elastic modulus value for steels (i.e., 30×10^6 psi) represents an averaged or mean value of a randomly oriented polycrystalline structure(101,102).

One of the most significant factors affecting the elastic modulus is temperature. The elastic modulus decreases with increasing temperature but within the typical natural gas pipeline operating temperature range (40 deg. F to < 140 deg. F), it is essentially constant. Figure A-5 illustrates the variation of elastic modulus based on data typical set for a structural steel. It was evident from the literature reviewed that elastic modulus determinations have been made using a variety of static and dynamic methods. This has contributed to the variation of values reported(97,103).

Summary

This review indicates that strain aging can affect material properties whose detrimental effects occur at aging temperatures well above that experienced on operating pipelines. Trends developed in a comprehensive evaluation of seven steels each involving three rolling schedules led to the following trends:

- Yield strength increased with pre-strain,
- Pre-strain alone accounted the same incremental increase as due to aging, or more,
- Tensile strength either remained essentially constant or increased slightly,

- The CVN USE was largely invariant for aging at 250 F, but tended to decrease at 475 F,
- The CVN 85% SATT increased, but even then was below the operating temperatures experienced in cross-country pipelines, and,
- Ductility was largely invariant of aging at 250 F.

These results lead to the conclusion that aging is unlikely to be a factor in the performance of vintage pipelines.

Regarding design parameters that underlie WSD as used for pipelines, this review indicates that strain aging does not adversely affect the design basis, as follows:

- The elastic modulus remains a constant for normal gas pipeline operating conditions, and,
- The yield strength increases with aging during the initial steps and may decrease later in the process but not below initial levels.

Appendix D: Historic Steel- and Pipe-Making Processes

As noted in the background section, anomalies that lead to the threats addressed by this report include manufacturing-related and welding/fabrication-related features. This appendix considers historic steel and pipe-making practices, and where appropriate describes the types of anomalies they produced.

Steel-Making Processes

Pipe steels have been made using a variety of steel-making processes as outlined on the timeline in Figure D-1. Steel-making processes affect the steel's grain structure and the presence and location of impurities or undesirable constituents

Steel manufacturing in the United States began with the introduction of the Bessemer process in 1865. Pipe manufacturers began using Bessemer steel for production of butt welded, lap welded, and seamless pipe. Introduction of the open hearth steel making process quickly followed (1870s-1880s) and evolved as the primary steel producing method in the world in the early 1900s. These developments were followed by other processes including electric furnace and basic oxygen processes. Electric furnace steel production began between 1900 and 1910. In the mid 1950s, basic oxygen steel making was implemented, and by 1969 accounted for nearly half of the annual steel production.

The major steel manufacturing processes used for steel production for line pipe applications through the 1960s included the open hearth, basic oxygen, and Bessemer processes. Some electric furnace steel was used for line pipe in limited quantities. Prior to the 1960s, ingot casting and hot rolling were typically used to produce plate and skelp[34] for line pipe production. Partially deoxidized[35] (semi-killed) and fully deoxidized (killed) steels

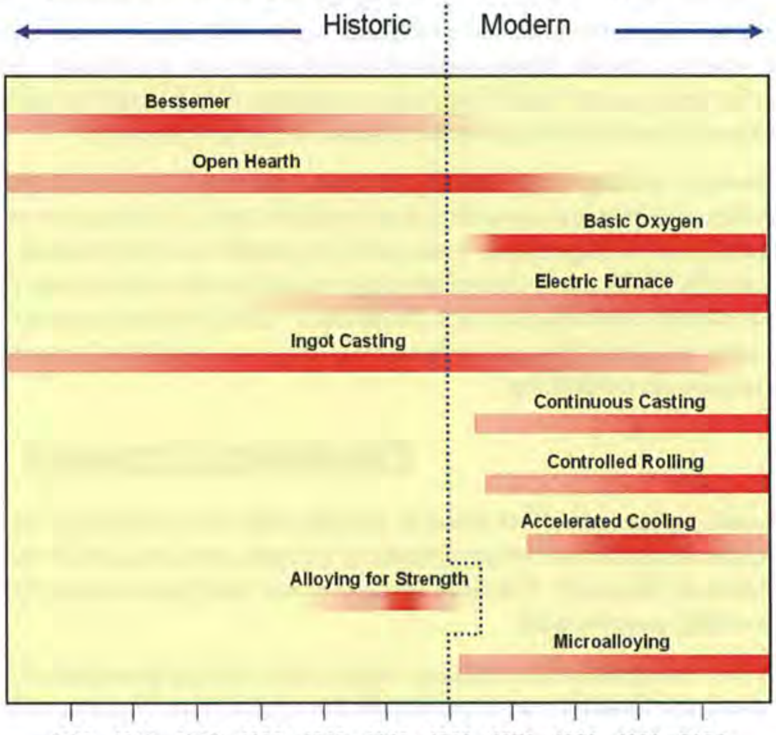


Figure D-1. Steel production history

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[34] Skelp, as used in this report, refers to a continuous strip of steel that is coiled by the steel maker. For pipe, the skelp is unrolled and either cut followed by forming and welding or formed and welded in a continuous process, then cut to length.

[35] Oxygen in combination of other elements forms nonmetallic inclusions, which are considered impurities. Sulfide inclusions were also common.

were used for line pipe production. Depending on the steel deoxidation practice used, ingot structural soundness varied. During the same period, higher yield strength materials began being used for line pipe. The primary method for producing higher strength steels was increased alloying element contents (typically carbon and manganese), which tended to reduce the weldability[36] of the material based on the welding techniques in use.

Pre-1960 steels have higher residual impurity levels and more frequent internal anomalies than later steels. In many cases, these impurities are aligned in planes that are parallel to the pipe surfaces. Impurities are not necessarily detrimental to pipeline integrity, but they can act as initiation sites for some forms of corrosion or cracking.

In the 1960s and into the 1970s, major steel manufacturing and plate/skelp rolling improvements were implemented. Microalloyed steels with additions of niobium, vanadium, and other elements coupled with improved steel rolling practices (controlled rolling) and improved impurity controls (desulfurization, inclusion shape control, vacuum degassing) resulted in "cleaner" steels with higher yield strengths, increased toughness levels[37], and improved weldability. This allowed engineering specifications for newer pipe to change. Continuous casting began to be used in the same time period, further improving steel quality and providing more efficient production.

Additional steel manufacturing developments occurred in the 1970s and 1980s through control of steel microstructures, additional rolling method improvements (accelerated cooling), and chemical additions. These methods have resulted in pipe with higher yield strengths (stronger pipe for the same wall thickness), fewer impurities, and improved weldability. More sophisticated steel manufacturing controls and improved nondestructive inspection systems have also resulted in a reduction of steel related anomalies found in modern line pipe(104-107).

In summary, vintage steel-making processes produced steels that are more likely to contain impurities and internal anomalies than modern steels, but these are not necessarily detrimental. Weldability of vintage steels varies and is typically less than that of modern steels. By the 1960s, and into the 1970s, steel manufacturing matured to the point where these improved steel materials were routinely available for pipe production. Steel production processes included the controls to limit inherent impurities and reduce alloy levels to consistently produce higher specification steels with improved weldability.

Pipe-Making Processes

Pipe-making processes[38] evolved in concert with steel-making processes(46). Pipe making can introduce anomalies or create anomalies through interaction with existing imperfections and anomalies in the steel. The final form of a flaw after pipe making typically depends on the forming and welding process used.

Table D-1 summarizes the primary major pipe-making processes for line pipe, the dates each process was used, the diameter range produced, the typical pipe lengths, and identifying characteristics. Note that several of the manufacturing processes have been discontinued.

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[36] Weldability typically refers to the ease with which a weld can be made without cracking. It is typically evaluated based on the alloy content of steel.

[37] Toughness refers to a material's resistance to crack initiation and propagation.

[38] Several pipe-making processes described here were also used to produce iron pipe, which is not covered in this report. Many of these processes also were used to produce pipe for other applications, such as water systems.

Table D-1. Pipe-making processes and dates

Process	Process Dates		Common Diameters (inch)	Max Length (feet)	Unique Identifying Characteristic(s)
	Start	End			
Furnace Butt Weld (FBW)	1832	1954	1/8 –3	20	No visible weld; relatively short joint length
Continuous Butt Weld (CBW)	1923	Current	1/8 – 4-1/2	40	Uniform wall thickness with no visible weld
Lap Weld	1887	1962	1-1/4 – 30	22-26	Waffle-like pattern over the weld seam
Hammer Weld	1917-1921	1942 (or later)	20-96	30	
Electric Resistance Welded (ERW)	1928	Current	1-1/2 – 24	80	Occasional "trim tool marks" near the weld zone
Flash weld (EFW)	1930	1972	8-5/8 – 36	40	Square weld bead shape on the ID and OD
Single Sided Arc Weld	1925	1952 (or later)	To 96	30	Elliptical weld bead on the outside diameter
Double Submerged-Arc Weld (DSAW)	1946	Current	16 - 48	40	Elliptical weld bead on the inside and outside diameters
Seamless	1890 1899 1938	Current	To 6 To 16 To 26	40	Surface roughness, and helical variation in wall thickness
Spiral Weld	1948	Current	To 56	40	Helical weld seam

The following paragraphs provide a general description of each pipe-making process.

Furnace Butt[39] and Continuous Butt Welded Pipe[40]

Furnace butt welding was among the earliest manufacturing processes used to produce line pipe in the United States. Furnace butt welding began in 1832, prior to the use of steel materials. Pipe was produced by pulling furnace pre-heated lengths of skelp through a bell shaped die to form the pipe and create a forged weld without the addition of a filler material. Production rates were low, and this process was replaced by continuous butt welding in 1923.

Continuous butt welded pipe uses a coiled skelp (product of the steel making process) that is continuously formed into a pipe. The skelp is preheated prior to forming, after which a forged weld is produced through a series of rolls, again without filler material. Continuous butt welding is still used to produce a limited number of lower yield strength API and ASTM pipe grades.

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[39] Furnace butt-welded pipe has no easily identifiable characteristic other than a short joint length.

[40] Continuous butt welded pipe also has no easily identifiable characteristic. It can sometimes be distinguished from seamless pipe by its relatively consistent wall thickness.

Lap and Hammer Welded Pipe[41]

Lap and hammer welding are related processes that were among the earliest used in the United States. Lap welding was used to produce a wide range of pipe diameters, whereas hammer welding was only used for large diameter pipe. In both processes, pipe was produced from a steel plate with both edges sheared or "scarfed" to produce a tapered welding surface. For lap welding, the plate was heated and formed into a pipe, with the tapered edges "forge welded" between a ball on the inside of the pipe and a roll on the outside of the pipe. With hammer welding, a forged weld was produced by successive hammer impacts on the outside against an anvil inside the pipe. Both processes did not use filler material in the weld.

Electric Resistance[42] and Flash Welded Pipe[43]

Electric-resistance welded (ERW) pipe is produced by a continuous forming process in which coils of skelp are formed into pipe through a series of rolls and the edges are heated to produce a solid state bond without a filler metal. Metal that is extruded from the weld zone is trimmed, after which the weld zone (or entire pipe) may be subjected to a normalizing heat treatment. Pipe is then cut to the desired length.

Early ERW pipe was produced from single lengths of steel plate, single coils of steel, or coils sequentially welded together during the production process. Welding heat was typically achieved with low frequency alternating-current (i.e., 60-360 Hz) electric-resistance welders. In some cases, the weld zones in early ERW pipe were incompletely normalized or not heat treated at all. This creates slightly different characteristics in the weld zone (i.e. near the seam weld). If certain operating conditions exist, these anomalies can cause defects to appear.

Conversion from low to high frequency welding in existing ERW mills began in the 1960s with the last mills converted in 1970. Today, ERW pipe is produced from sequentially welded coils, with welding achieved by high frequency (i.e., 350-500 kHz) electric resistance or induction coils, and most manufacturers normalize their weld seams.

Flash welded pipe is similar to ERW as it was made without a filler metal and used localized electric resistance (direct current) heating and forging to produce a solid-state bond. The primary difference between ERW pipe and flash weld is that the entire length of a flash weld was produced at one time. Like ERW, flash welding left metal extruded from the weld line on the pipe surfaces. Typically, the extruded metal was trimmed with a characteristic small upset left on the inside and outside surfaces.

Single-Side Arc and Double Submerged-Arc Welded Pipe

This category refers to a number of pipe making processes that involve arc welding with a filler material. Single side arc welding (SSAW) encompasses a group of now discontinued welding processes including single sided automatic welded, manual submerged-arc welding, and other arc welding processes, such as manual and automated applications of the shielded metal-arc welding

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[41] Lap welded pipe can often be identified by a waffle-like pattern that is frequently visible on the outside surface over this scarf weld. This pattern is created by serrations on surface of the external rolls used in the welding process.

[42] ERW pipe usually has little to no visible weld reinforcement on the inside or outside surfaces. Any flash (metal extruded from the fusion zone during the welding process) is removed after welding. Sometime, longitudinal marks left by the trim tools are visible on the pipe surface.

[43] Flash welded pipe typically has a characteristic square weld profile left when the flash was trimmed (flash welded pipe was not trimmed down to the pipe surface). The remaining flash typically projects about 1/16-inch above the inside and outside pipe surfaces.

(SMAW) process. Single side arc welding was largely discontinued after double submerged-arc welded (DSAW) pipe began production.

DSAW is an automated, multi-wire application of the submerged-arc welding process with at least one weld bead made on the inside and outside surfaces of a preformed plate. DSAW pipe has a characteristic elliptical weld bead projecting above the inside and outside pipe surfaces.

Most commonly (in DSAW pipe mills), the pipe is formed from plate whose edges are crimped[44], pressed to a U-shape, and then pressed to an O-shape. Less common line pipe forming methods include pyramid roll bending, where a plate is bent as it moves back and forth between three rollers. In all cases, after the weld is made, the pipe may be expanded using an internal mechanical or hydraulic expander.

Spiral-Welded Pipe

Spiral-welded pipe has been produced in United States since 1948. Pipe is made from a coiled skelp or sequentially welded plates that are continuously formed to produce a helical seam and then welded or tack welded on the forming stand. Most domestic spiral pipe has been produced for water pipelines and uses other than natural gas and petroleum-products transmission pipelines.

Spiral-welded pipe was made using several welding processes including hammer welding and ERW. Later, several manufacturers produced spiral-welded pipe using double submerged-arc welding. Very little DSAW spiral-welded pipe has been used in natural gas pipelines in the United States, most of which was produced by foreign pipe manufacturers. None of the records and data reviewed identifies a reportable incident including spiral-welded pipe. Spiral pipe is, however, broadly used in Canada and Europe. Like all line pipe, spiral-welded pipe produced in a proven mill with quality controls on the skelp and pipe production leads to a quality pipe.

Seamless Pipe

Seamless is another pipe manufacturing process that has been used for line pipe production beginning in 1890 whose basic concept continues in use today. The seamless pipe-making process is fundamentally different from that used for welded pipe. Several different methods have been used to produce seamless pipe. Most commonly, a billet (a solid round of steel) is pierced and then rolled to produce the desired diameter and wall thickness. This manufacturing process inherently results in pipe with wall thickness variations around the circumference and along the length of the pipe. This is typically not found in welded pipe design. In general, these variations have no significant effect on pipeline integrity since the design specification is based on the minimum wall thickness of the pipe.

Summary of Pipe Production Processes

In summary, pipe specifications improved with the introduction of the DSAW process and again in the 1960s and early 1970s. Most of the earlier pipe production practices were phased out at this time or were in the process of being modified (i.e., low to high frequency ERW pipe) to compete.

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[44] Locally bent to the radius of the pipe.

Pipe Specifications and Quality Standards

Early Specifications and Quality Control Methods

Pipe quality standards were first developed in the early 1900s and continue to evolve today. In the early days of pipe production, quality control was largely based on visual inspection and hydrostatic testing of finished pipe products. Welding quality was controlled by the welding operator, whose experience and judgment were essential to the quality of the product and so an essential aspect of the pipe production process.

Prior to the introduction and application of American Petroleum Institute (API) pipe manufacturing specifications, pipe quality requirements were often specified and controlled by the purchaser[45]. Methods included company pipe specifications, manufacturing inspection by company personnel, third party inspection contractors, or a combination of these methods. Another quality control method included the application of pipe production procedures established by the manufacturer and formally adopted by the purchaser in the pipe purchase agreement. Such procedures were often amended to suit the particular pipe order requirements.

One of the key specifications associated with the manufacture of pipe is its strength. Two conditions are generally measured for pipe, which include the UTS and the yield stress, YS[46].

API Specifications 5L and 5LX[47]

Most of the line pipe in service today was manufactured in accordance with API Specifications 5L or 5LX. These specifications, which are regularly updated, provide minimum requirements for pipe used in natural gas and hazardous liquid lines. The specifications typically provide requirements for chemical composition, mechanical properties, pressure testing, dimensions, weights, end preparation, inspection, and quality criteria. Even when the API specifications were used, though, many pipeline operators chose to provide additional requirements in proprietary specifications. These additional requirements have often been predicated on the intended pipeline service environment and/or the fluids to be transported.

The evolution of the API specifications provides useful insight into pipe characteristics and quality. With respect to vintage line pipe, the most significant criteria are those related to strength, inspection, destructive testing, and hydrostatic pressure testing.

Strength or Grade

From their first editions of the API specification through the present, yield and tensile strength requirements have increased on a regular basis, reflecting advancements in steel- and pipe-making processes. For example, one of the original pipe grades (Grade A) has specified minimum yield strength[48] of 25 ksi (i.e. thousands of pounds per square inch), while the most recently added grade (X80) calls for yield strength of 80 ksi. In addition, requirements for grades with 100 ksi (X100) and

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[45] Many companies have the records of the pipe specifications and quality control procedures and the compiled results of those efforts.

[46] These terms are defined earlier in this report.

[47] The first edition of API Specifications 5L and 5LX were published in 1928 and 1948, respectively, with "X" grade used to designate higher strength grades. These two documents along with API 5LS (for spiral welded pipe) were combined as API 5L in March 1983.

[48] Recall earlier discussion noting that strength here is a misnomer, as the units involved are those of stress. Nevertheless, this section continues the historical notation.

also 120 ksi (X120) yield stress are actively being developed for use in future API Specifications. This increase in strength of the pipe has allowed the pressure containing capacity to increase while using the same pipe wall thickness.

Inspection

From their first editions through 1962, the API pipe inspection requirements addressed workmanship and flaws. Workmanship criteria covered pipe surface appearance, while critical manufacturing anomalies were defined as any flaw that exceeded a specified fraction of the wall thickness (typically 12.5%) and certain types of weld defects. Pipe lengths that did not meet the workmanship criteria or contained critical manufacturing anomalies were to be repaired or rejected.

In the early 1960s, a more definitive list of critical manufacturing anomalies appeared in API specifications. The list included all anomalies that exceeded 12.5% of the pipe wall thickness plus cracks, leaks, dents with depth exceeding 0.25-inch, offset plate edges, out-of-line weld beads, excessive weld reinforcement, improper trimming of flash, hard spots, surface breaking laminations and inclusions, arc burns, and weld undercut. Non-destructive inspections of seam welds were also added in the 1960s. Depending on the weld type, the entire weld was required to be inspected using radiological, ultrasonic, or electromagnetic techniques. In addition, magnetic particle inspection of each pipe end was required to locate partial or incomplete welds, intermittent welds, cracks, seams, and slivers. End inspection is also used to locate nonmetallic inclusions or steel delamination that intersects with the weld bevel surface that could affect girth welding.

Destructive Tests

API specifications require destructive testing (typically one set of tests per 100 or 200 pipe joints) to evaluate the strength and ductility the steel and weld seams. In the earliest API specifications, destructive tests[49] were used to demonstrate the pipe body met strength and elongation requirements and the weld seam could withstand high strains without cracking. By the early 1960s, weld tensile and ductility tests[50] were included. Fracture toughness testing used to be at the discretion of the purchaser, but recently a minimum level was imposed.

Hydrostatic Pressure Testing[51]

Hydrostatic pressure testing is used to detect (fail) anomalies in the pipe body and weld that are critical at the test conditions (pressure levels significantly higher than operational pressures). In the earliest versions of API 5L, pressure tests were largely used to ensure leak tightness. As the minimum test pressure increased, the maximum remaining flaw size remaining after the hydrostatic pressure test decreased. Figure D-2 shows the maximum API 5L and 5LX pressure test requirements as a function of the manufacture year for large diameter pipe.

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[49] Destructive tests verify the integrity of the pipe by exposing the pipe samples to significantly higher stresses than occurs in pipeline operation. The difference in the actual yield stress measured in such tests and the specified minimum yield strength reflect the additional conservatism.

[50] Sample pipe joints are selected and coupons (small representative section of pipe) are cut from the pipe and various destructive tests are conducted to determine the characteristics of the pipe.

[51] References 14, 15, 23, 27, 28, 82, and 110 provide comprehensive coverage that validates the use of this practice, identifies where it is beneficial, and indicates viable test protocols for various concerns such as SCC and approaches to limit pressure reversals.

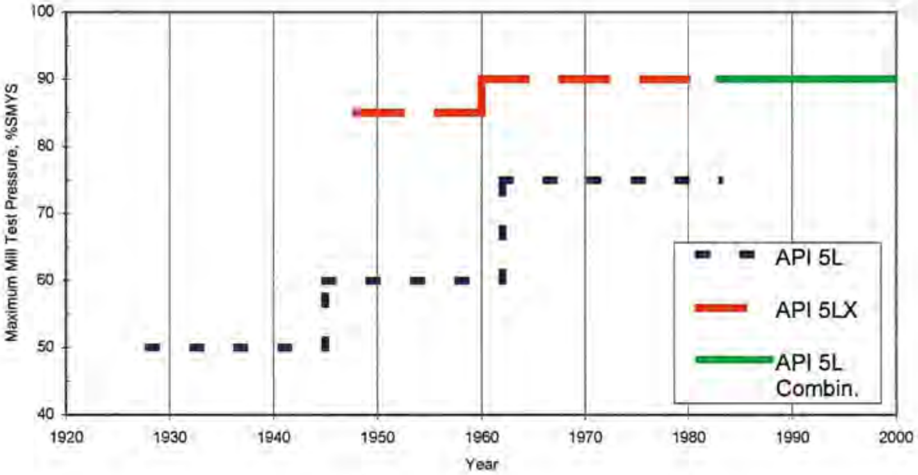

Figure D-2. History API hydrotest requirements

In API 5L, the maximum hydrostatic test pressures increased from 40 to 50% of the SMYS in 1928 to 60 to 75% SMYS in 1970. In API 5LX, the maximum pressures increased from 85% SMYS to 90% SMYS, well above operating stress levels. Current test pressures of 60 to 75% are required for pipe diameters below 8 inches and 85 to 90% is required for larger diameters.

Construction and Fabrication Practices

Pipeline construction methods evolved as more and more pipelines were laid. American Society Mechanical Engineers (ASME) Code B31.1.8 was issued in 1935, which provided consensus standards requirements for pipeline construction. ASME B31.8(74) was issued in 1955 and reflected industry consensus standards that had evolved since 1935(76), which formed the basis for pipeline design and construction. B31.8 became mandatory under the Federal Pipeline Safety Act in 1968.

Pipeline construction encompasses a wide range of activities. Typical activities include clearing and grading a right of way, trenching, stringing the pieces of pipe along the right of way, bending the pipe, when needed to conform with the terrain, welding or otherwise connecting pipe pieces together, coating the pipe[52] and field welds, lowering the welded sections into the trench, backfilling around the assembled pipe sections, testing the completed pipeline, and restoring the right of way. Several other activities are required for special circumstances, such as when crossing a river, road, or wetland area. The activities that have the greatest potential impact on pipeline integrity are:

1. Joining,
2. Bending,
3. Backfilling, and depending on pipe production history and specifications
4. Pre-service pressure testing or retesting.

The others have less impact and are not discussed further in this report.

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[52] Modern pipe is coated prior to transportation to the right of way.

Joining[53]

Many early pipelines were constructed from cast and wrought iron pipe assembled with caulked joints and threaded collars. As Bessemer steel became available in 1865, line pipe production transitioned to steel rather than continue with iron pipe, and the use of threaded collars continued. A recurring problem with threaded couplings was leaking, which led to the development of mechanical couplings. Mechanical couplings began to replace threaded collars in 1891. Couplings were not as leak prone as threaded collars but also leaked in some circumstances.

Mechanical couplings began to be replaced by oxy-acetylene welded joints in the early 1900s. Around 1915, oxy-acetylene welding was used to fabricate the first long-distance pipeline and early SMAW ("stick electrode") was applied to pipelines. In 1925, the SMAW process using electrodes coated with extruded cellulose was applied to pipelines. The quality of field welds made with oxy-acetylene and early SMAW processes were sometimes inconsistent.

Additional evolution of stick welding occurred, and in 1930, all position[54] SMAW became practical. By about 1933, SMAW was used instead of oxy-acetylene welding for all but small diameter pipe. The first standardized welder qualifications were required in the early 1930s and included destructive testing of sample welds. Some company welding specifications were also being used at that time.

The "stove pipe" pipeline construction technique was first used in the early 1930s and became the preferred construction method in the 1940s. Internal line-up clamps were first used in 1945. Both of these modifications of pipeline construction techniques favorably impacted welding quality. Pipeline weld inspection quality further increased with the application of radiography and weld acceptance standards in the late 1940s. API 1104 (Welding of Pipelines and Related Facilities), issued in 1949 and currently in its 19th edition) was immediately adopted for pipeline construction. More extensive development of field radiography and its field use followed in the early 1950s. In about 1960, field radiography of girth welds had become a pipeline construction requirement, with field-proven value.

Initially, welding was used to fabricate branch connections and other components, which often included fillet welds that can be difficult to inspect and can for high carbon-equivalent steels can be prone to cold cracking. Recognizing this, methods to produce fittings evolved from field fabrications (common prior to the mid 1950s) to shop production where quality control was easier as was quality assurance via mature NDE techniques. Other construction improvements including double jointing and the use of internal line-up clamps occurred in the 1940s. Pipeline radiographic methods further improved with the introduction of the first successful internal X-ray crawler in 1965.

Bending

To accommodate necessary direction and elevation changes along a pipeline route, several methods have been used. Vintage pipe laying practices include the use of bent pipe sections provided by pipe manufacturers, miter bends, angled mechanical couplings, hot/cold wrinkle-bending and smooth bends. Small changes in direction were easy to accommodate in vintage construction where couplings were used, or through the elastic flexibility of the pipe string, a practice that continues in use today.

Miter bends consisted of adjacent pipe sections cut at an angle and welded together to produce locally abrupt changes in direction. Depending on the direction change required, miter bends could

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[53] This section draws on material published over the years in the Oil and Gas Journal, Pipeline News, and other early industry magazines in Battelle's archives, and a web search.

[54] Pipe can be welded on the top, sides, and bottom of the pipe without rotating pipe.

consist of one or more such welds. Miter bends have been prohibited by many construction specifications since the late 1940s and early 1950s.

Various wrinkle-bending[55] processes were used on pipelines constructed in the mid 1950s and earlier. Earlier wrinkle-bending methods (~1930s and earlier) often included heating the pipe by various methods prior to bending. Pipeline construction bending methods entered a transitional period in the 1940s. Development of improved bending equipment capable of producing smooth field bends in large diameter thin wall pipe was stimulated by requirements for the construction of the War Emergency Pipelines. The first of these bending machines was used for pipeline construction in 1942-1943.

Wrinkle-bending continued to be used through the 1940s and into the early 1950s. In the late 1940s, many pipeline construction specifications prohibited hot (wrinkle) bending. By the early 1950s, hot/cold wrinkle-bending was still a viable option along with hydraulic bending machines. Wrinkle-bending was phased out in the early 1950s. External bending shoes for producing smooth bends in smaller diameter pipe (~12-inch diameter) began to be used in about 1944.

Hot bends were field fabricated wherein a piece of pipe was heated, after which the pipe was bent, or shop bent usually the pipe was packed with sand to support the wall thickness during bending. Hot bends where used today are made in dedicated bending shops that rely on practices and controls to produce quality bends. Like miter bends, field-made hot bends have been prohibited by many construction specifications since the late 1940s and early 1950s.

Cold field bending began its evolution to the controlled process in use today when controlled bending machines of various forms began to appear in the 1940. Uncontrolled vintage cold bending techniques introduced anomalies such as buckles, wrinkles, ripples, and variable strength and wall thickness. Such processes have evolved such that the pipe is stretched and bent around a shoe with an internal mandrel, which facilitates control of the bend in the pipe and limits anomalies to inconsequential levels(108).

Backfilling

After a pipeline has been welded and lowered into a trench, the line is backfilled. During backfilling, several types of anomalies can be introduced. In historic construction practices, the material removed from the trench was used to backfill without removing rocks, possibly resulting in coating damage, scrapes, and dents. In severe cases, sand and other soil was brought in to pad the pipeline. In addition, pipe was sometimes laid on rock ledges, also leading to dents as the pipe settled. Recently, machines have been designed to separate fine soil from large rocks permitting segregated material to be backfilled on the pipeline minimizing the possibility of coating damage. Further discussion of this topic can be found in Reference 109.

Post Construction Pressure Testing

Post construction pressure testing also evolved over time. Prior to the early 1950s, gas pressure testing was frequently done. Hydrostatic pressure testing was investigated in the late 1940s and began to be applied in the early 1950s as its merits were published(e.g., see 57). From the early 1950s through 1960s, pressure tests were conducted with both gas and water. The practice of gas testing ended in the 1950s as a result of a long-running brittle fracture during such testing. Beginning in

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[55] So-called "wrinklebends" are not uncommon in vintage pipelines. For examples and a history, see Appendix A of Reference 47. Such bends are considered in more detail here in Appendix G.

early 1960s, hydrostatic testing was widespread, and with the enactment of the Pipeline Safety Act in 1968 became mandatory.

Before, 1950, pressure testing was conducted at pressures ranging from near the maximum allowable operating pressure, to 110% of the maximum operating pressure, or 50 to 100 psig above the maximum operating pressure. Such pressures were typically used in gas pressure testing. After 1960, hydrostatic pressure testing was commonly performed at pressures of 125% of the maximum allowable operating pressure. This is the minimum level cited in U. S. regulations for pressure-based strength testing of pipelines. More recently, pressure testing to SMYS or above has been used as a strength test to demonstrate a high-pressure-carrying capacity. Much has been done to refine hydrostatic testing practices recently, including the introduction of the "spike test"(110), which is now recognized in various forms in some recommended practices and standards(e.g., 13, 111). This spike test capitalizes on the observation that leak-tightness testing can be effective at pressures less than required for strength testing(15). As a strength test it imposes a short-term high pressure on the pipe to expose near-critical defects without unnecessary growth of anomalies during the test.

In summary, pipeline construction practices evolved along with steel and pipe making practices. By the late 1940s through the early 1950s, many of the modern construction practices were either adopted or began to be applied. This included improved welding, more sophisticated inspection methods, and higher pressure hydrostatic testing that began selectively in the 1970s and is now recommended in some practices(13).

Quality Requirements

This topic has been covered in more detail under the same heading in Appendix D. Suffice it here to note that several industry specifications were written to provide minimum requirements for pipeline welding and construction. The most significant is API Recommended Practice 1104 for field welding, which was first issued in 1949 and continues to be revised almost annually as new information and practices become available. In reference to this appendix, API 1104 called for nondestructive testing of welds, along with acceptance criteria. Also relevant here is the observation that welder qualification, which included destructive testing, became common in the 1930s.

Relative Significance and Summary

Fabrication and construction anomalies tend to be of less concern to pipeline integrity than most other threats. The most significant fabrication and construction anomalies from the perspective of pipeline integrity are girth-weld problems, coupling problems, wrinkles, and dents.

Girth-Weld Problems, Coupling Problems, and Wrinkles

Anomalies at girth welds, couplings, and wrinkles are generally benign unless the pipeline is acted upon by unusual or high axial tensile or bending loads. Under axial tensile and bending loads, historic girth-weld anomalies can become active, couplings can leak or pull apart, and wrinkles can flex, leading to fatigue cracking. In addition, wrinkling can sometimes damage the coating on a pipeline or become a site for moisture to accumulate, leading to corrosion.

Potential failures due to defects in pipeline girth and fabrication welds are a function of the type of welding and the era in which the welds were made. Welding processes and techniques were initially crude but improved with time. By the early 1940s, the processes and techniques had been significantly improved and inspection techniques had been developed to further improve the overall quality of girth welds. Potentially problematic processes include oxyacetylene welding and vintage stick welding.

Vintage hot bending and various wrinkle-bending processes were used on pipelines constructed up through the mid 1950s. Depending on methods used and care exercised, wrinklebend quality can vary widely. As noted above, wrinklebend problems are associated with locations where external loading is high and/or a cyclic stress environment exists. Increased external loading and or cyclic stress can interact with the wrinklebend geometry creating the conditions necessary for fatigue. Metal loss in a wrinkle resulting from external and/or internal corrosion can also increase the local stress in a wrinkle thus increasing the chance of fatigue.

Mechanical couplings are a potential threat anywhere settlement or soil movement provides the loads needed to induce a leak or separate the pipe from the coupling. A 1.5 degree bend is considered sufficient to cause coupling leaks or separation.

Dents

Dents that form when a pipe settles on a rock or rock ledge can become a threat to integrity if cracks form and grow in service. Rock dents are typically constrained, which if fully effective precludes the re-rounding needed to initiate and grow cracks. Consequently, rock dents are often of little concern to pipeline integrity. On the other hand, dents formed from the weight of the hydrostatic testing water can be subject to cracking in operation due to the removal of the water and subsequent re-rounding that occurs. Further on the relative significance of dents can be found in Reference 113, with criteria to assess such features presented in various forms in References 18 and 19.

Related problems at or near rocks and rock ledges include coating damage and, under selected conditions, shielding of the cathodic protection current.

Appendix E: Experience with Historic Pipelines

The following sections present incident data, pipe manufacturing processes, and pipe manufacturers. In each section, incidents attributed to a defect in the pipe body and those due to a problem in the seam weld are included. Note that only one of the datasets (the OPS data from 1970 through mid 1984) includes incidents that occurred during pre-service and subsequent pressure testing. Neither of the other two datasets includes test data. The data on pre-service testing and retest are included because, while not directly related to service failures, they provide an indication of when anomalies were produced.

The data are also grouped by year for each manufacturer when the incidents occurred in periods separated by one year or less. The data should be taken as an indication of the time periods when anomalies were experienced.

Butt Welded Pipe

Butt welded pipe is prone to anomalies related to weld strength and reliability. When anomalies are present, the weld seam may be weaker than the pipe body. 49CFR192 includes a longitudinal joint factor (described earlier) of 0.6 for butt welded pipe to account for the potential that defective welds can be weaker than the body of the pipe. Very little, if any, butt welded pipe has been used for high pressure transmission lines since about 1940.

Reference 46 lists 19 manufacturers of furnace or continuous butt-welded pipe from 1911 through present.[56] These 19 manufacturers operated 40 mills, producing pipe from ¼ inch to 4.5 inches in diameter. Of these, the incident data identify five manufacturers for which incidents are attributed to anomalies in the pipe body or seam weld.

Reference 46 summarizes reported pipe-body and seam-weld incidents. A total of 7 pipe body incidents have been reported for butt-welded pipe, six of which occurred in service. A much larger number of seam-weld incidents were reported, but none of these occurred in service.[57]

Reference 46 shows that relatively few pipe-body incidents have occurred in butt-welded pipe. There is no apparent trend in terms of year of production. Pipe produced by Youngstown Sheet & Tube may be somewhat more prone to pipe-body problems, but the data are too sparse to make a definitive conclusion. The small number of service incidents attributed to defects in the body of butt-welded pipe may reflect the amount of pipe in service: butt-welded pipe is produced in small diameters, which is not widely used in transmission pipelines. The number may also reflect that most incidents may have occurred well before the dates for which incident reporting began (1950) and that much of the potentially defective pipe has since been replaced or retired.

A much larger number of seam-weld incidents have been reported. Both Armco and Republic Steel show many retest failures due to seam-weld anomalies. In each case, the incidents are on a single pipeline and from pipe made during a single year, suggesting a lapse in quality assurance. The relatively large number of incidents raises questions about the effectiveness of quality assurance programs for these suppliers. Armco (in 1949) and Republic Steel (in 1931) account for over 90

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[56] Reference 46 lists manufacturers of API-stamped pipe. These lists are necessarily incomplete, especially for earlier pipe-making processes. Butt-welded pipe was available well before 1911.

[57] The occurrence of failures in-service is distinguished from those when not in service because the latter occur during pressure testing that are done at much higher pressure, or under other circumstances designed to expose potentially deleterious anomalies prior to their causing problems during operations.

percent of the reported incidents on vintage natural-gas pipelines based on the data assembled in Appendix A, which is summarized in Table E-1.

Table E-1. Incidents attributed to butt welded pipe

Pipe Manufacturer	Year Made	Pipe Body			Seam Weld		
		Pre-Service	Retest	Service	Pre-Service	Retest	Service
A. O. Smith[58]	'50		1				
Armco	'49					49	
Bethlehem	'42			1			
Republic	'31					11	
	'52					1	
	'57					1	
	'81[59]			1			
Youngstown Sheet & Tube	'28-30			2			
	'53			1			
	'58			1			
Totals		0	1	6	0	62	0

Lap and Hammer Welded Pipe

Lap and hammer welded pipe were prone to weld defects resulting from slag or oxides present on the welding surfaces or because the weld was "burnt" (overheated). Proper welding temperatures and weld quality depend on the process controls used during welding. Like butt welded pipe, 49CFR192 accounts for lap and hammer weld defects with a longitudinal joint factor or through the use of an effective yield stress determined by full-scale burst tests.

Reference 46 lists 12 manufacturers of lap- or hammer-welded pipe from around 1920 through 1969. These 12 manufacturers operated 23 mills, producing pipe from 1-¼ to 36 inches in diameter. Of these, the incident data identify two manufacturers for which incidents are attributed to anomalies in the pipe body or seam weld.

Table E-2 summarizes reported pipe-body and seam-weld incidents. A total of 26 pipe body incidents have been reported for lap and hammer welded pipe, four of which occurred in service. A total of 58 seam-weld incidents were reported, of which 17 occurred in service. Only two manufacturers are included in the list, with U. S. Steel accounting for the vast majority of the reported incidents. The predominance of U. S. Steel in Table E-2 suggests recurrent quality control problems with that mill.

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[58] There are a number of apparent errors in the published incident datasets used in this study. For example, A. O. Smith is listed as the manufacturer of butt-welded pipe that failed during a retest, but Reference 46 does not include A. O. Smith as a producer of butt-welded pipe. The data in the tables in this appendix include the pipe manufacturers identified in the incident datasets, regardless of whether the manufacturers are listed in Reference 46.

[59] Reference 46 states that Republic Steel stopped producing butt-welded pipe in 1964.

Table E-2. Incidents attributed to lap and hammer welded pipe

Pipe Manufacturer	Year Made	Pipe Body			Seam Weld		
		Pre-Service	Retest	Service	Pre-Service	Retest	Service
U. S. Steel (National Tube, National Supply)	’29-31		17	4		27	14
	‘35						1
	‘43		3			12	
	‘55		2				1
Youngstown Sheet & Tube		0				2	1
Totals			22	4		41	17

Electric Resistance and Flash Welded Pipe

Regardless of when or how ERW pipe was (is) made, good quality welds can be (are) made with proper process controls. Nonetheless, historic ERW welds can be more prone to the following types of anomalies:

1. Lack of fusion and oxides along the bond line, generally due to poor process controls,
2. Stitched welds (alternating complete and incompletely fused or partially fused areas) due to uneven heating (generally associated with low-frequency ERW processes),
3. Hook-cracks near the bond line caused by inclusions in the plane of the wall thickness at the edge of the skelp that are upset or turned toward the pipe surface in the forging process,
4. Excessive trim or grooving (wall thickness reduction), and
5. Arc burns resulting from poor or intermittent welding electrode contact adjacent to the weld.

As the ERW process evolved in conjunction with mill inspections and quality controls, the likelihood of ERW seam defects decreased. For example, ERW pipe manufacturers began converting from low to high frequency (alternating current) welding in the early 1960s. This modification essentially eliminated “stitched welds” as a quality concern. During this same period, pipe steel quality also improved, reducing the incidence of hook cracks. The anomalies in flash welded seam are the same as found in low frequency ERW seams.

Reference 46 lists 72 manufacturers of ERW pipe from 1929 through present. Of these, 25 continue to produce ERW pipe. These manufacturers operated 86 mills (per Reference 46, 42 are currently in operation), producing pipe from 1/2 to 36 inches in diameter (per Reference 46, the current range is 1/2 to 24 inches). Of these, the incident data identify 12 manufacturers – one out of six manufacturers – for which incidents are attributed to anomalies in the pipe body or seam weld.

Table E-3 summarizes the reported low frequency ERW pipe-body and seam-weld incidents, while Table E-4 summarizes the comparable results for high frequency ERW pipe[60]. The incident datasets

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[60] Production practices in high-frequency ERW have evolved since this process was first introduced, as have mill inspection practices, which has led to much improved pipe quality. Nevertheless, pre-service hydrotesting periodically expose seam defects in this product, even from so-called quality mills.

did not identify low versus high frequency pipe. Consequently, data separated in these tables reflects the use of Reference 46 and personal experience to cull data from the incident databases. Nine out of the 12 manufacturers have incidents reported for both low frequency and high frequency ERW pipe; two have reports for low frequency only, and one has reports for high frequency only.

The number of incidents listed for low frequency ERW pipe is significantly larger than that for high frequency ERW pipe. Given the amount of ERW produced, the numbers of pipe body incidents are reasonably consistent with those for the other pipe manufacturing methods discussed above and with improvements in steel-making practices and in API inspection specifications.

Table E-3. Incidents attributed to low frequency ERW pipe

Pipe Manufacturer	Year(s) Made	Pipe Body			Seam Weld		
		Pre-Service	Retest	Service	Pre-Service	Retest	Service
Acero Del Pacifica	’51-52					17	8
American Steel Pipe	‘37[61]			1			
Bethlehem	’57-58					3	1
	‘69			1			
Cal Metal	‘57					2	
Jones & Laughlin	’57-64		1	1		17	2
Kaiser	’51-56	1	1			13	1
	’60-63			1	2	3	2
Lone Star	’59-65			7		17	2
Republic	’31-32			1			2
	’38-62	3		5		118	8
Stupp	‘40			1			
U. S. Steel	‘31				1		1
	‘61						1
	‘65						1
Youngstown Sheet & Tube	‘19					20	
	‘31						3
	‘40-59	1	6	20		92	54
	’66-67		1	1			
	‘71	1					
Totals		6	9	39	3	302	86

Both low and high frequency ERW shows test and retest incidents. The retest data are typically from programs aimed at removing potentially weak ERW seams from service. The low frequency pipe shows significantly more in-service seam-weld incidents, which is expected.

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[61] According to Reference 46, ACIPCO did not begin producing ERW pipe until 1963.

Several pipe manufacturers dominate the number of reported incidents for both low and high frequency pipe. For low frequency pipe, Republic and Youngstown Sheet & Tube account for 70 percent of the reported incidents, while Acero del Pacifica, Jones & Laughlin, Kaiser, and Lone Star account for over 20 percent more.

For the high frequency pipe, American Steel Pipe, Stupp, and U. S. Steel dominate, accounting for nearly 75 percent of the total. Nearly all of the incidents attributed to Stupp pipe occurred during a relatively short period – from 1970 to 1977. Kaiser (~4 percent), Jones & Laughlin (~7 percent), and Lone Star (~6 percent) are also notable.

Table E-4. Incidents attributed to high frequency ERW pipe

Pipe Manufacturer	Year Made	Pipe Body			Seam Weld		
		Pre-Service	Retest	Service	Pre-Service	Retest	Service
American Steel Pipe	'70-78	6		2		28	
Bethlehem	'73			1		3	
Cal Metal	'70					1	1
	'77					1	
Jones & Laughlin	'70-73	6			8		
	'79-80						2
Kaiser	'71-75		1		6		
	'83				1		
Lone Star	'70-76			1	11		
Republic	'70	1					
	'81			1			
Stupp	'70-77	3	3		30		1
	'81-82	1			3		2
Tex Tube	'70				1		
	'74				1		
	'78				1		
	'82						8
U. S. Steel	'68-82	13		4	52		11
Totals		30	4	9	114	33	25

Table E-5 summarizes reported pipe-body and seam-weld incidents for flash welded pipe. Only one manufacturer, A. O. Smith, produced flash welded pipe. A total of 276 incidents are evident in this table, with most being attributed to the weld. Problematic pipe appears to have been made in nearly every year for which flash-welded pipe was produced. One of the problems with flash welded pipe is that the weld seam was not heat treated.

A number of retest failures in A. O. Smith flash welded pipe have occurred after 1984[62], as the pipeline industry instituted programs to excise defective flash welded pipe from their systems.

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[62] In mid 1984, OPS stopped collected data on pre-service and retest failures.

Pressure testing above the maximum allowable operating pressure is an effective way of removing defective flash welded (and ERW) pipe.

Table E-5. Incidents attributed to flash welded pipe

Pipe Manufacturer	Year Made	Pipe Body			Seam Weld		
		Pre-Service	Retest	Service	Pre-Service	Retest	Service
A.O Smith	'28-31		5			3	2
	'37			1			
	'40-43					29	4
	'46-65		8	18		162	37
	'67						2
	'69-71	2				2	1
Totals		2	13	19	0	196	46

Single-Sided Arc and Double Submerged-Arc Welded Pipe

Single arc and double submerged-arc welds are not particularly prone to anomalies. There have been isolated occurrences of the following anomalies:

1) weld metal cracks,
2) toe cracks at the edge of the weld reinforcement,
3) lack of sidewall or inter-run fusion,
4) inclusions,
5) weld metal porosity,
6) offset welds, and
7) undercut.

These anomalies are much more prevalent in vintage single arc and double submerged-arc welded pipe than they are in modern production.

Reference 46 lists 22 manufacturers of arc welded or double submerged-arc welded pipe from 1940 through present. Of these, 8 manufacturers continue to produce double submerged-arc welded pipe. These manufacturers operated 30 mills, 11 of which are still in operation, currently producing pipe from 16 to 120 inches in diameter. Of these, the incident data identify 8 manufacturers – roughly one out of three manufacturers – for which incidents are attributed to anomalies in the pipe body or seam weld.

Table E-6 summarizes the reported arc welded and double submerged-arc welded pipe-body and seam-weld incidents. Again, several manufacturers dominate the reported incidents, with Kaiser accounting for nearly half and U. S. Steel accounting for nearly 20 percent of the total.

A more detailed examination of the incident data for double submerged-arc welded pipe shows a strong dependence on age. Over 44 percent of the incidents are attributed to pipe produced in 1950, with another 17 percent in 1949, 1951, or 1952. These years represent the time period in which double submerged-arc welded pipe was gaining widespread acceptance in the United States.

Table E-6. Incidents attributed to arc welded and double submerged-arc welded pipe

Pipe Manufacturer	Year Made	Pipe Body			Seam Weld		
		Pre-Service	Retest	Service	Pre-Service	Retest	Service
Acero Del Paci	’52-53						8
ARMCO	‘52			1			
	’73-74	5			4		
	‘79				1		
Bethlehem	‘52					1	
	’57-62		1	1		5	4
	’71-72		2				
	‘75						1
Claymont	‘51					5	2
Consolidated Western	‘47					2	
	‘50		8	2		6	3
	’54-56			2			3
Kaiser	’49-56		51	2		57	6
	‘60			1			
	’70-73	1			3		
	‘76				2		
	’79-81				1		1
Republic	’48-50		4	1			
	‘67		1				
	‘73		5	1			
US Steel	‘31						1
	’49-51		3			3	1
	’54-62		5	7		6	9
	’65-66			2			
	’69-71	2		2		4	
	’77-82			1			3
Totals		8	80	24	11	89	42

Spiral-Welded Pipe

There are two basic processes by which spiral welded pipe can be made. Small amounts of vintage spiral-welded pipe were made by hammer welding and ERW processes, mostly for the water industry. Later, several foreign manufacturers produced spiral-welded pipe using double submerged-arc welding. None of the incident records examined by the authors identify spiral-welded pipe as the type of pipe that led to incidents.

Seamless Pipe

Irregularities that have occurred in seamless pipe include scabs, blisters, slivers, seams, laps, laminations, pits, roll-ins, hot tears, and plug scores. Surface imperfections, such as blisters, slivers, seams, pits, plug scores and laps, arise from the twisting, upsetting and abrading of the surface during pipe formation. Hot tears result from the working of the metal with an insufficient temperature for rewelding of torn material. Laminations typically result from imperfections and insufficient ingot cropping.

Reference 46 lists 18 manufacturers of seamless pipe operating 30 pipe mills from 1895 through present. These manufacturers produced pipe in diameters from 1/4 to 26 inches. Of these, the incident data identify only one manufacturer – U. S. Steel – for which incidents are attributed. Table E-7 summarizes the data.

Table E-7. Incidents attributed to seamless pipe

Pipe Manufacturer	Year Made	Pre-Service	Retest	Service
US Steel	‘30			2
	‘33		1	
	‘38		2	
	’43-53		15	7
	‘56			1
	‘59			4
	’64-65		1	1
	’70-74	9		
	’77-78		3	
Totals		9	22	15

Upsets in Pipe Making and Pipeline Construction

This section considers the occurrence of problems that occurred during the process of pipe making or pipeline construction that created anomalies prevalent across a range of product types or suppliers. There are two generic categories of such anomalies – arc burns and hardspots that are a potential source for hydrogen stress cracking, and transportation-induced fatigue cracking.

Hydrogen Stress Cracking - Arc Burns and Hard Spots

Hydrogen stress cracking on gas transmission pipelines transporting sweet dry gas is nearly always associated with arc burns, hard spots, with such cracking also possible in high-hardness ERW seams.

The presence of arc burns and hard spots is not, by itself, sufficient to indicate cracking will occur. In order for cracking to occur several other conditions must co-exist. First, the hard spot or arc burn must be exposed to the environment where diffusion of atomic hydrogen into steel can occur. On pipelines, such conditions can be created in the presence of higher than normal cathodic protection potentials that liberate hydrogen at the exposed metal surfaces. A second condition for HSC requires that the hard spot be exposed, typically as a result of coating degradation[63]. While coating degradation is not uncommon, the amount of bare steel in a poorly coated line is typically small. Last, the hard spot must be sufficiently hard. Hydrogen stress cracking occurs at hardness at or above about Rockwell C22(43,44), with lower hardness levels being associated with strong sources of hydrogen, such as can occur with sour service.

Table E-8. Hard spot incident summary

Pipe Seam Type	Pipe Manufacturer	Pipe Production Year	No. Of Incidents
Flash weld	A.O. Smith	1952	17
		1954	1
		1955	1
		1957	1
DSAW	Bethlehem	1957	2
	Kaiser	1955	1
	Republic	1949	2
		1957	1
ERW	Youngstown Sheet & Tube (YS&T)	1947	1
		1950	1
		1960	1

Transportation Damage

Line pipe with weld seam reinforcement that protrudes above the pipe surface (i.e., FW, DSAW) has experienced shipping fatigue cracks due to the seams contacting rail car bottoms or other pipes, with cracks forming at the edge of the weld reinforcement bead(e.g., se 70). Fatigue cracks have also formed in all types of line pipe due to rivet heads, projections in rail cars contacting the pipe body or pipe ends, foreign objects in a rail car, bearing strip misalignment, or insufficient support(e.g., se 70). In these cases, the conditions necessary to promote fatigue cracking result from vibration during shipment.

Transportation fatigue often occurred in pipe with high diameter/thickness ratios in the period prior to 1970. Between 1957 and 1962, 32 field failures were recorded. This included pipe with diameter/thickness (D/t) ratios that ranged from 54 to 91. Full-scale tests to measure actual pipe stress (D/t range: 88-128) were conducted during this same period. Field failures and test data prompted development of a pipe loading Recommended Practice for rail transportation by the API (American Petroleum Institute) first issued in 1965 as API RP 5L. This was followed by similar recommended practices for pipe shipment in vessels (API RP 5L5, 1975) and inland waterways (API RP 5L6, 1979). The requirements contained in these documents have reduced the frequency of transportation related damage.

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[63] It is also possible for the stress fields due to pipe forming and service pressure to nucleate and grow cracks in hard spots. While this is plausible, such cracking would either be severe enough to be exposed early in service, or otherwise exposed in pressure testing. Remaining cracks would lie dormant unless changes in service due to pressure increase activated them.

Requirements for pipe transportation by rail have been included 49CFR192 since 1973. Any pipe with a D/t ratio of 70 or higher to be operated at a hoop stress of 20% SMYS or greater must be transported in accordance with API 5L1. For pipe transported prior to November, 1970, a proof test commensurate with the class location must be conducted.

Quality Requirements

A number of specifications were developed to establish minimum requirements for pipe used in transmission pipelines. Commonly used pipe specifications are API Specifications 5L and 5LX. These specifications provide requirements on composition, mechanical properties, pressure testing, dimensions, weights, end preparation, inspection, and other quality components with toughness recently being included. The requirements on pressure (hydrostatic) testing and inspection have the largest effects on pipeline integrity.

It should be noted that not all pipelines were constructed from pipe manufactured in accordance with API specifications. Prior to the introduction of API specifications, quality requirements were established by each purchaser. Methods included company pipe specifications, manufacturing inspections by company personnel, and third party inspections by contractors, individually or in combination. Additional measures included defined pipe production procedures established by a pipe manufacturer, as amended and/or agreed to by the purchaser to suit particular requirements.

The API specifications provided an industry-wide basis for pipe specifications and standardized many of the pipe making practices. In time, they largely replaced the requirements developed by individual purchasers. Nonetheless, many pipeline operators chose (and continue to choose) to add requirements in proprietary specifications. These additions are typically predicated on the intended pipeline service environment and/or the fluids to be transported.

The evolution of pipe quality control requirements contained in the API specifications provides useful insight into pipe characteristics and quality. From their first editions through the present, yield and tensile strength requirements have increased on a regular basis, reflecting improvements in steel- and pipe-making processes. For example, one of the original pipe grades (Grade A) has a minimum yield strength of 25 ksi, while the most recently added grade (X80) calls for a yield strength of 80 ksi. In addition, requirements for 100 ksi (X100) and 120 ksi (X120) steels are actively being developed for future API Specifications. In addition, mechanical testing requirements have been added. Typical destructive testing requirements include bend and strength tests of production welds to ensure they are at least as strong as the pipe body.

Pressure testing and inspections are important quality assurance methods used in the API specifications. In the earliest versions of API 5L, pressure tests were largely used to ensure leak tightness, not strength, with minimum hydrostatic pressures of 40 to 50% SMYS. By 1970, the API 5L pressure requirements had increased to 60 to 75% SMYS – comparable to the maximum stress levels in Class 1 and 2 locations.

The API 5LX pressure requirements are generally higher (60 to 75% pipe diameters below 8 inches and 85 to 90% for larger diameters). For pipe diameters greater than 8 inches, the mill hydrostatic tests produce stresses well above operating stress levels.

From the earliest API specifications, destructive tests were required on pipe and weld samples (typically one set of tests per 100 or 200 pipe joints). Typically tests were used to demonstrate the pipe body met the strength and elongation requirements while bending tests were used to demonstrate the weld seam could withstand high strain levels without cracking. Early workmanship requirements stated that the pipe should be free of "injurious defects", including defective welds, pits, blisters, slivers, and laminations. Injurious defects were further defined as those defects greater than 12.5% of the wall thickness. Additional visual inspections to identify injurious defects were at the discretion of the purchaser.

By the early 1960s, more destructive tests were required, including weld tensile and ductility tests. Fracture toughness testing was at the discretion of the purchaser. The list of workmanship defects had been expanded to address a wide variety of conditions, including dents, offset of plate edges, out-of-line weld beads, excessive weld reinforcement, improper trimming of flash, and hard spots. Other defect types were identified, including all cracks and leaks, surface breaking laminations and inclusions, arc burns, weld undercut, arc burns, and any other imperfection having a depth greater than 12.5% of the wall thickness.

Non-destructive inspections of welds were also added in the 1960s. Depending on the weld type, the entire weld was required to be inspected using radiological, ultrasonic, or electromagnetic techniques. In addition, magnetic particle inspection of each pipe end was required to locate open welds, partial or incomplete welds, intermittent welds, cracks, seams, and slivers.

In summary, since 1928, API specifications have evolved to ensure minimum pipe quality, with their evolution reflecting changes in steel- and pipe-making practices, and the expanding capabilities of real-time nondestructive inspection. By the early 1960s, the specifications began to significantly reduce the historic pipe body and weld seam anomalies discussed above. Because of this impact, quality control and quality assurance have become central to the pipe production and supply specifications in use throughout the industry.

Relative Significance of Anomalies

Tables E-9 and E-10 summarize these process and production anomalies and their characteristics, while the ensuing paragraphs consider their potential impact on integrity. These tables and the

Table E-9. Weld-seam anomalies

Pipe-Making Process	Defect or Characteristic	Comments
Furnace Butt Welded, Continuous Butt Welded Pipe, Lap Welded and Hammer Welded Pipe	Oxides trapped between weld surfaces; inconsistent quality welds	Addressed in 49CFR192 with longitudinal joint factor, or by use of an effective yield stress
Electric Resistance Welded (ERW) and Flash Welded Pipe	Oxides trapped in weld, inconsistent quality welds	Welding controls and inspection practices have largely eliminated these types of anomalies
	Stitched welds	More common in low-frequency ERW pipe
	Hook cracks	More common in earlier steels with higher levels of impurities and inclusions
	Excessive trim	Rare in modern line pipe
	Arc burns and hard weld zones	Like hard spots (see Table E-8)
Single Arc Welded and Double Submerged-Arc Welded Pipe	Weld metal cracks, toe cracks, lack of sidewall or inter-run fusion, undercut inclusions, porosity, offset welds,.	Rare

following discussion rely on the author's personal experience and/or published data to identify the most significant anomalies, where possible. This approach is necessary for two reasons. First, as compared to other incident causes, pipe body and seam weld anomalies are a much less frequent cause, as was evident in the introduction to this report. Thus, the potential database available for trending or statistical analysis is limited. Second, the reporting requirements for OPS data did not motivate reporting details of the type of pipe-body or weld-seam defect that led to an incident, which precludes conclusively determining anomalies of greatest concern. The same was true for the FPC database. In spite of this, there is a significant literature that can be used to better understand the cause – effect relationship between defects and incidents.

Table E-10. Summary of pipe-body and weld-seam anomalies

Evaluation Criteria	Years	Most Frequently Reported Manufacturer(s)	Comments
Pipe Specific			
Butt/Lap weld	Pre 1960	Armco, Republic	Use of a longitudinal joint factor reduces loading on weld
DSAW, SSAW, and other welded seams	Pre 1960	Kaiser, U. S. Steel	
Low frequency ERW	Pre 1971	Republic, Youngstown Sheet & Tube	Acero del Pacifica, Jones & Laughlin, Kaiser, and Lone Star also have higher incident rates than others manufacturers
High Frequency ERW	Pre 1980	Stupp	Kaiser, Jones &Laughlin, and Lone State also have higher incident rates than others manufacturers
Flash weld		A. O. Smith	All
Seamless	1940s and early 50s; 1970s	U. S. Steel	
Defect Specific			
Cracking in Hard Spots or Arc Burns	1950s	A. O. Smith	
Transportation Fatigue	Pre 1970		Double submerged-arc and flash welded pipe are more susceptible than other types of pipe; High diameter-to-thickness ratios are more prone to damage
Mechanical Damage	Vintage pipe is more likely to have experienced mechanical damage due to handling than later pipe		Thin walled pipe and pipe with high diameter-to-thickness ratios are more prone to some forms of cracking in mechanical damage

Important information sources include the five-page tabulation and analysis of historical defects causing pre-service and hydrostatic retest failures that comprises Table A1-3 in Appendix A of Reference 15. These tables reflect input from Europe via Mr. Peter Peters, then retired but recently manager of Mannesmann Mulheim Works, and the U.S. and elsewhere via Dr Malcolm Gray, a principal of MicroAlloying International. This information was supplemented by results in archived Battelle failure reports developed to assess and characterize defects that caused failures in hydrotesting during the era such failures were reported but not as in-service incidents. Another key source was the quite extensive evaluation of failure causes documented on behalf of the PRCI as Reference 70. Finally, the extensive literature selected in regard to historic pipelines and organized here as Reference 68 was useful, although somewhat more topical that is typically needed to meet the needs here.

When the process of assembling the data and evaluating causes was completed, the data from failure analyses, the authors' experience, and the literature indicate that incidents originating at a defect in the weld seam are most commonly due to cracks in or around the weld, inconsistent quality welds, or preferential corrosion in or near the weld. Other causes are much less important as compared to this to this one.

Cracking

The most common form of cracking in seam welds is hook cracks associated with ERW or flash-welded pipe. Hook cracks are most likely in pipe made from earlier steels. Hook cracks are generally stable up to the maximum pressure to which the pipe has been exposed, unless the pipe is exposed to large pressure cycles.

Inconsistent Quality Seam Welds

Inconsistent quality seam welds are potential anomalies for all of the earlier pipe-making processes. While most pipe manufacturers succeeded in making pipe of consistent quality, there are several notable exceptions:

- Acero del Pacifica (low frequency ERW pipe),
- American Steel Pipe (high-frequency ERW pipe),
- A. O. Smith (flash-welded pipe),
- Armco (butt-welded pipe),
- Jones & Laughlin (low- and high-frequency ERW pipe),
- Kaiser (low- and high- frequency ERW pipe, arc or double submerged-arc welded pipe),
- Lone Star (low- and high- frequency ERW pipe),
- Republic (butt-welded pipe, low-frequency ERW pipe),
- Stupp (high-frequency ERW pipe),
- U. S. Steel (lap welded pipe, high-frequency ERW pipe, arc or double submerged-arc welded pipe, seamless pipe), and
- Youngstown Sheet & Tube (low-frequency ERW pipe).

Inconsistent quality welds are considered stable up to the maximum pressure to which the pipe has been exposed in prior service. Pressure testing of pipelines with seam defects opens the door to pressure reversals.

Appendix F. Pipe Body Incidents by Pipe Manufacturer

Figures F-1 through F-17 present data from the three databases used in this study to identify those pipe manufacturers and years in which incidents occurred in the pipe body. All figures are shown on the same scales, save for Figure F because the incident rate there differs significantly from the others.

The incidents are broken down into three categories:

- Pre-service – such incidents occurred during a pre-pressure test done prior to commissioning a pipeline, at a pressure that is a multiple of the maximum allowable operating pressure.
- Service – such incidents occurred during normal revenue operation at a pressure corresponding to design limitations driven by demand.
- Retest – such incidents occurred during a pressure retest conducted after a pipeline is put into service, at a pressure that is a multiple of the maximum allowable operating pressure.

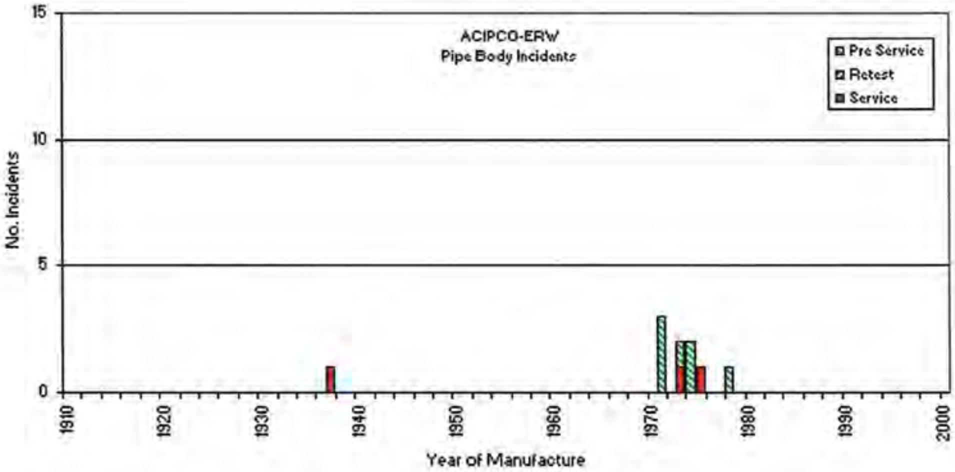


Figure F1. ACIPCO-ERW pipe body incidents by year

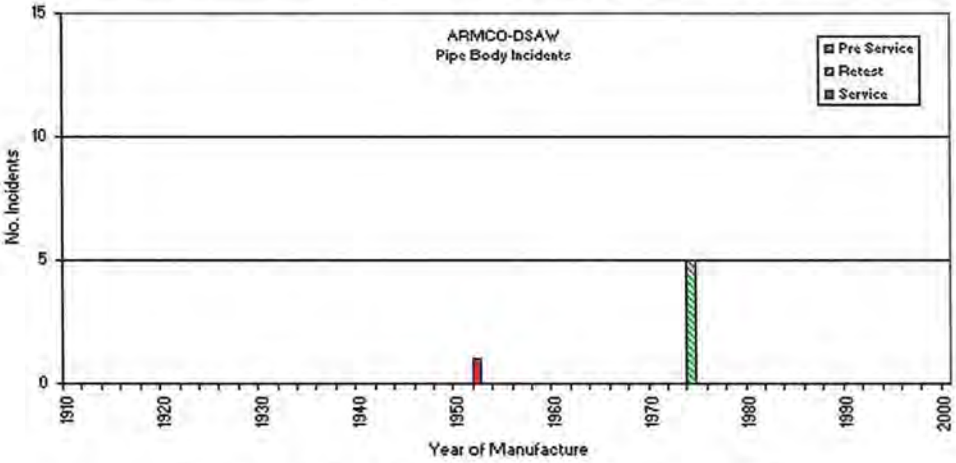


Figure F2. ARMCO DSAW pipe body incidents by year

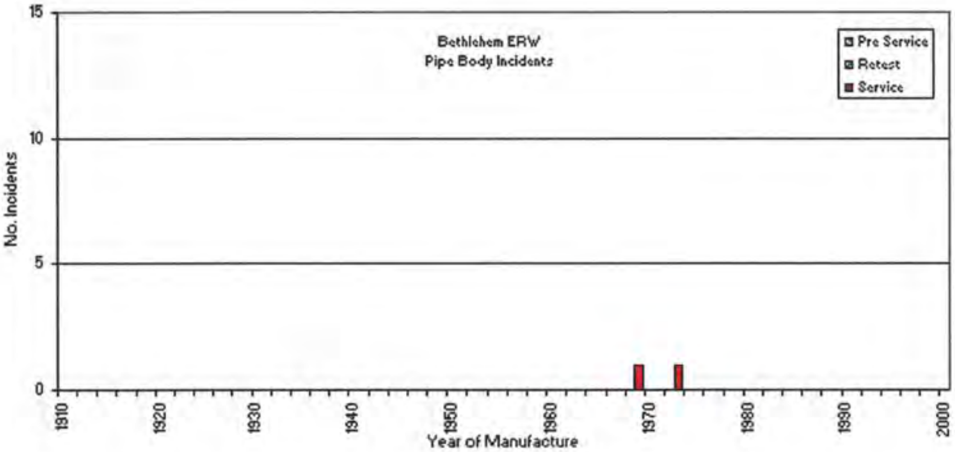


Figure F3. Bethlehem ERW pipe body incidents by year

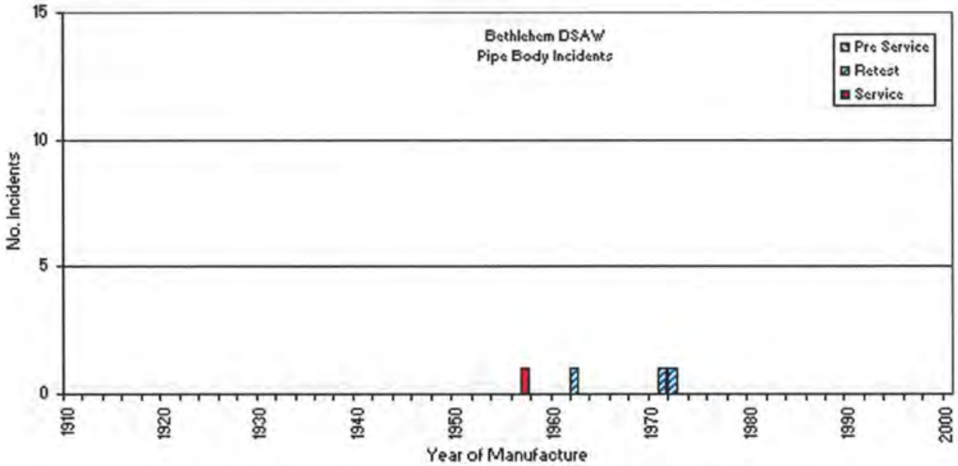


Figure F4. Bethlehem DSAW pipe body incidents by year

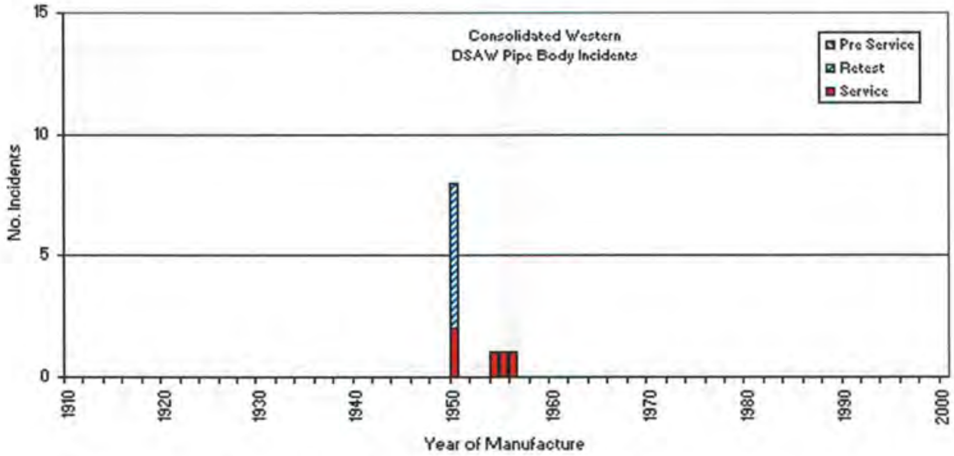


Figure F5. Consolidated Western DSAW pipe body incidents by year

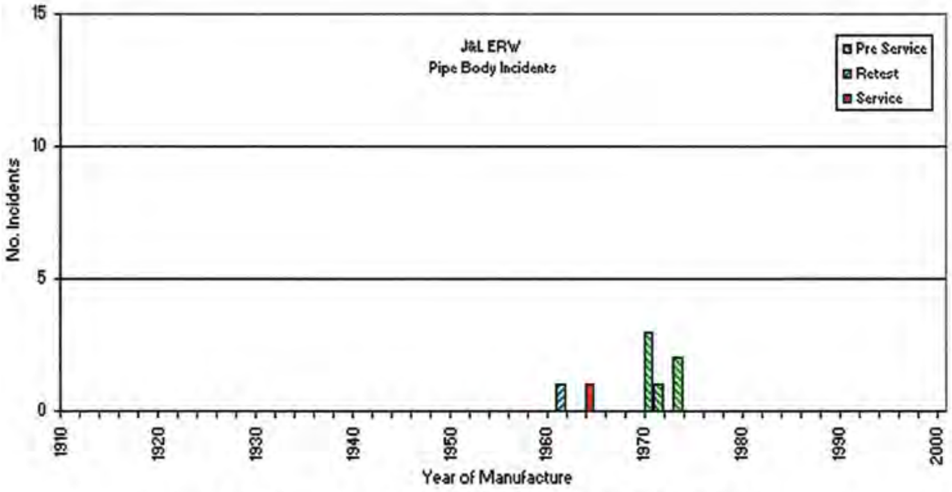


Figure F6. J&L ERW pipe body incidents by year

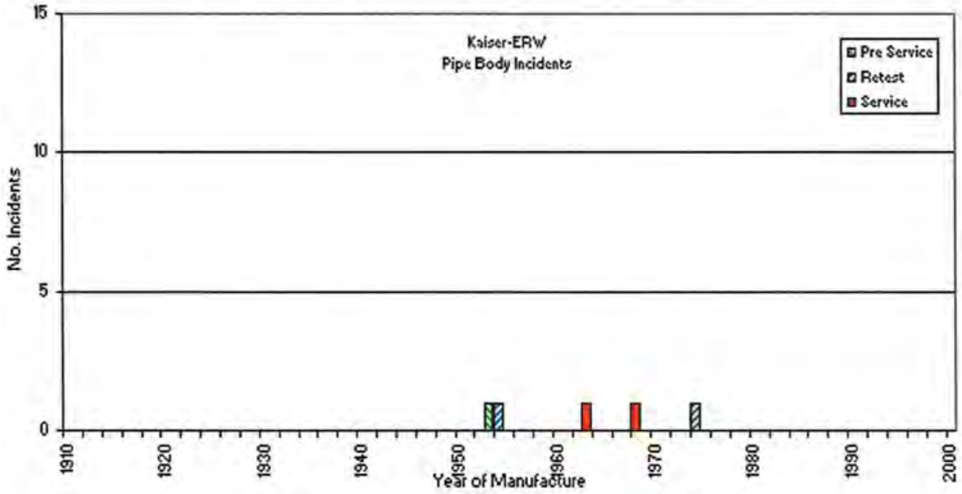


Figure F7. Kaiser ERW pipe body incidents by year

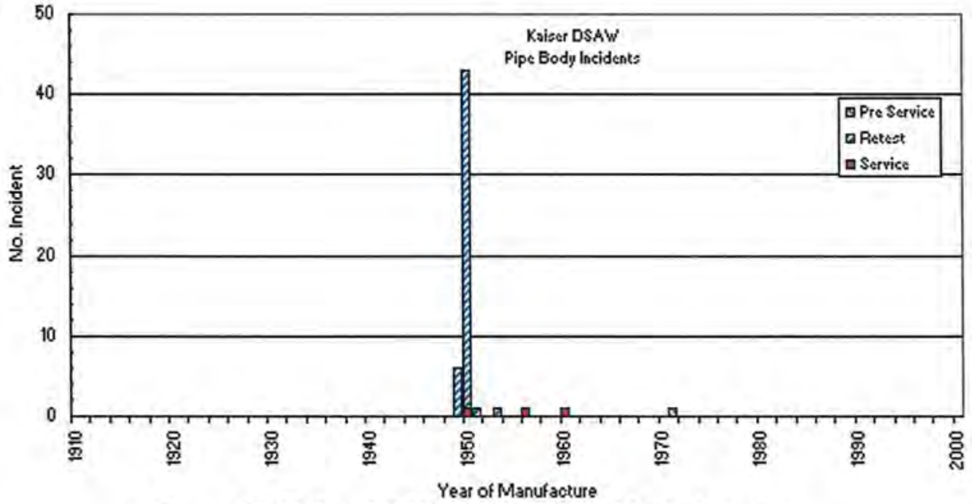


Figure F8. Kaiser DSAW pipe body incidents by year

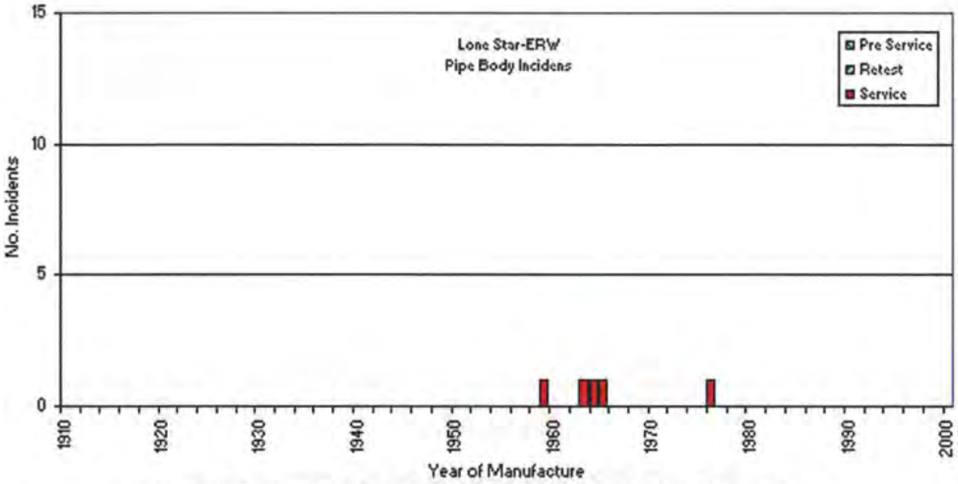


Figure F9. Lone Star ERW pipe body incidents by year

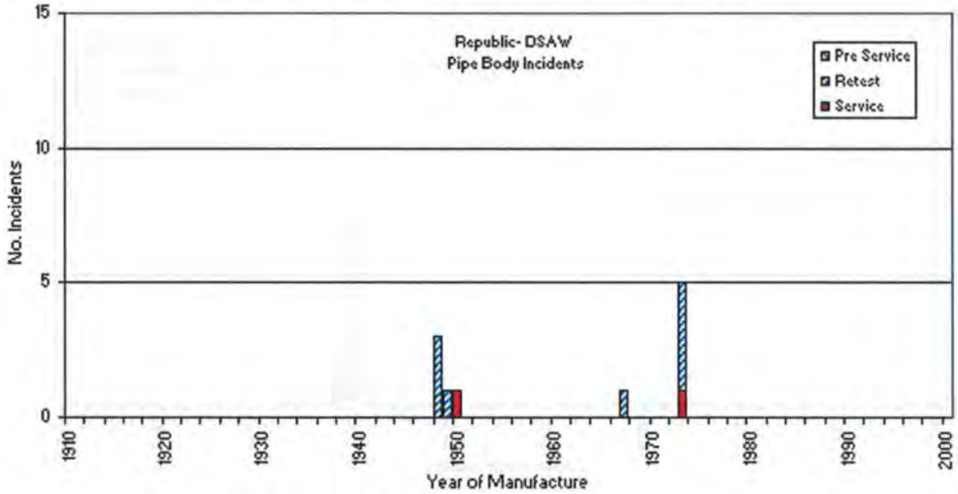


Figure F10. Republic DSAW pipe body incidents by year

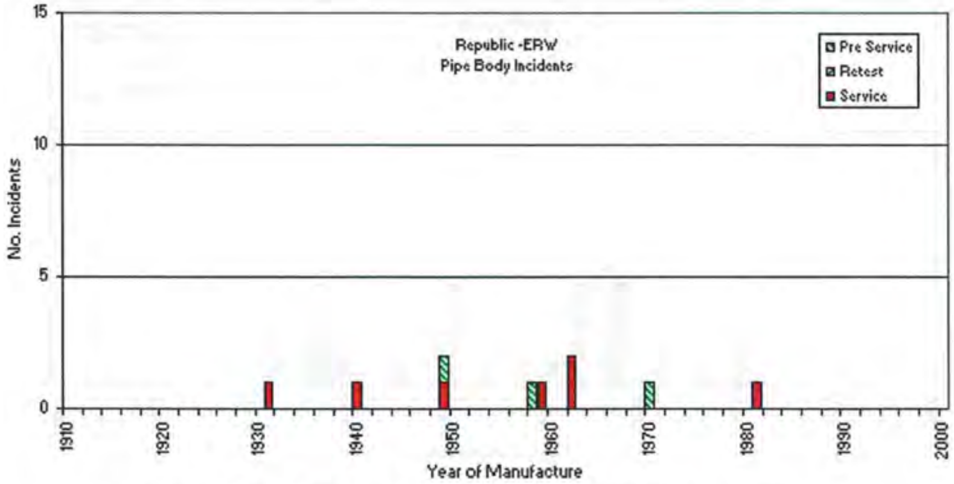


Figure F11. Republic ERW pipe body incidents by year

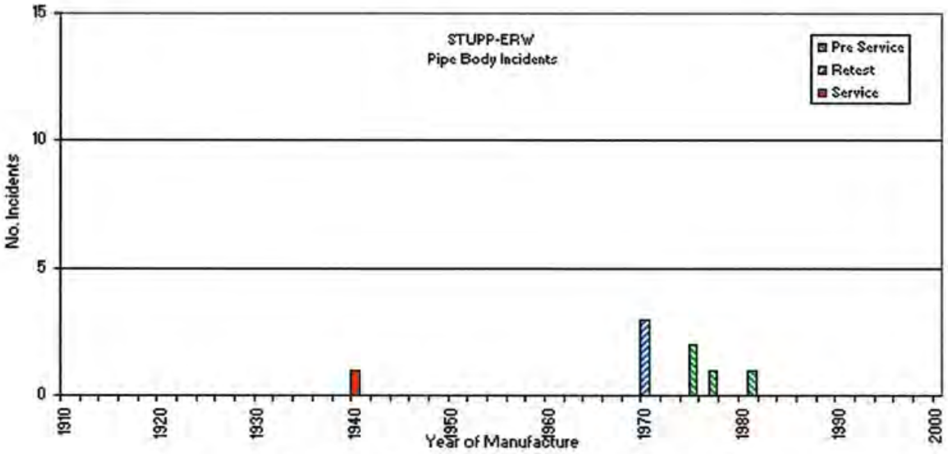


Figure F12. STUPP ERW pipe body incidents by year

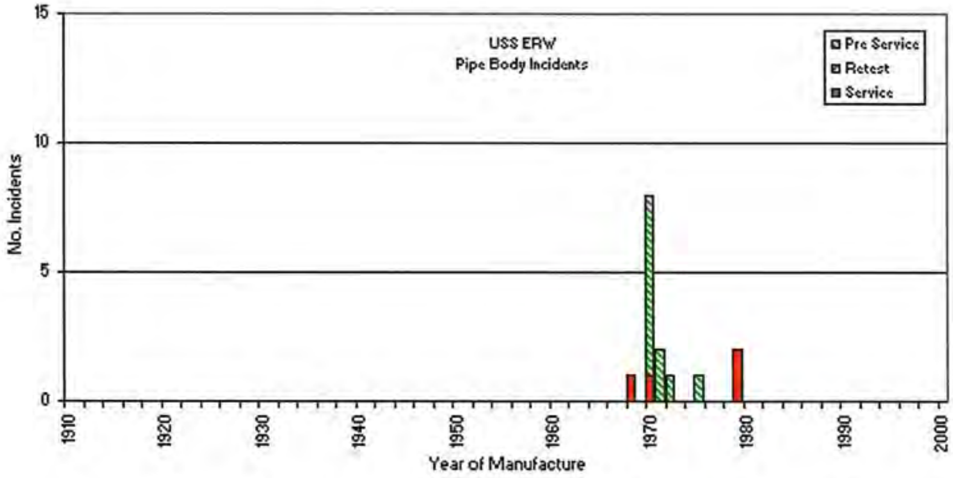


Figure F13. US Steel ERW pipe body incidents by year

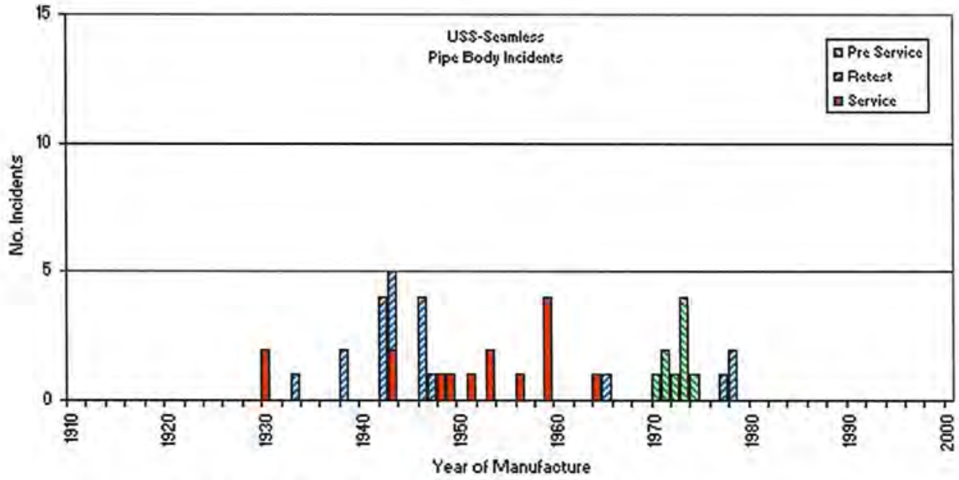


Figure F14. US Steel Furnace Seamless pipe body incidents by year

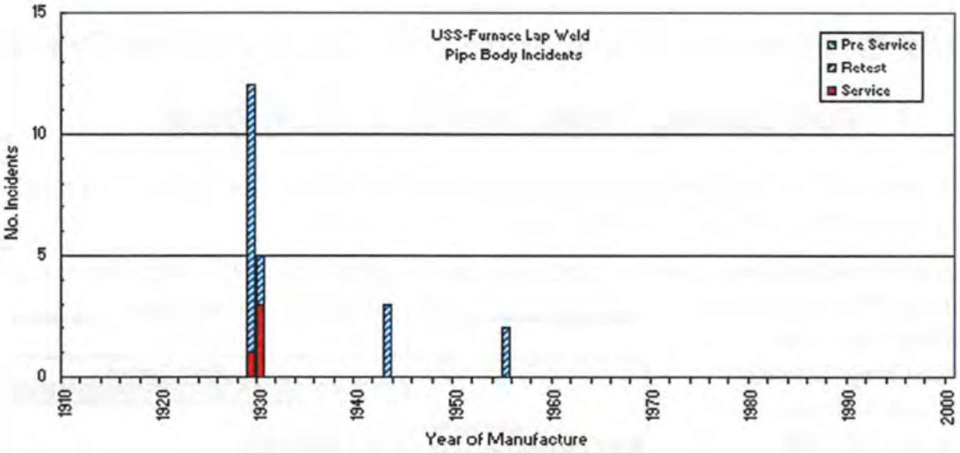


Figure F15. US Steel Furnace Lap Weld pipe body incidents by year

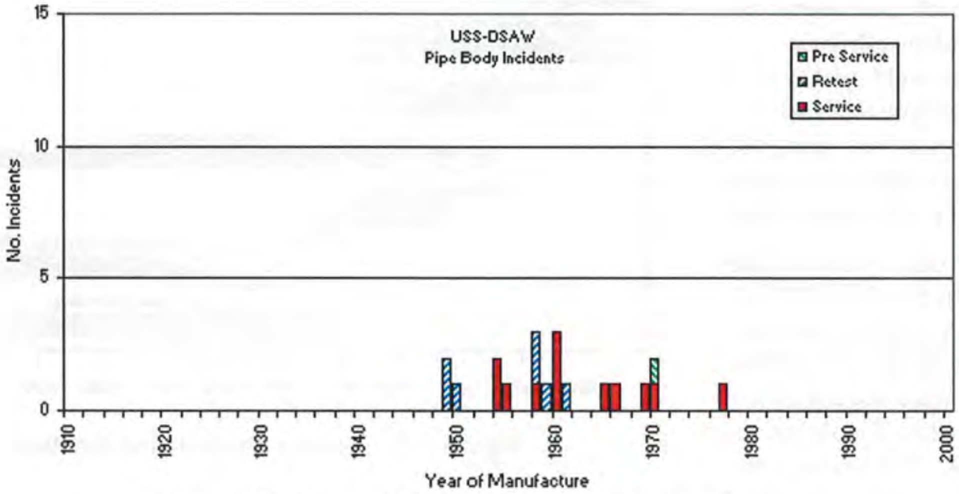


Figure F16. US Steel DSAW pipe body incidents by year

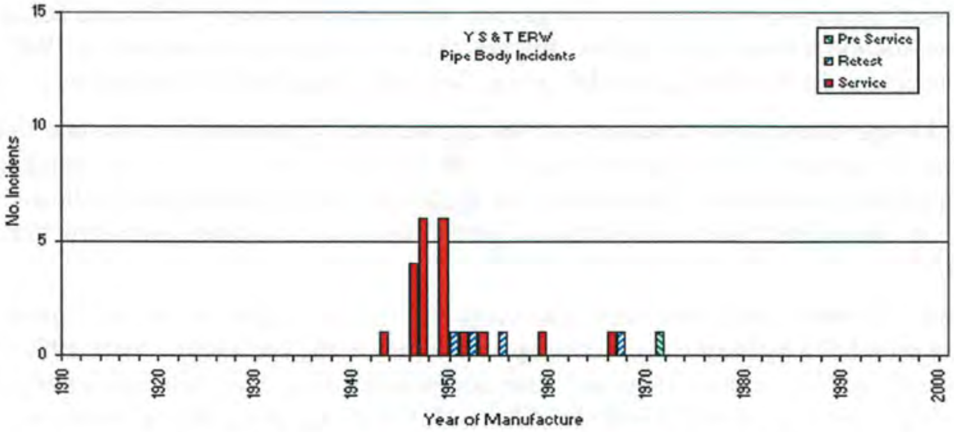


Figure F17. YS&T ERW pipe body incidents by year

Appendix G: Historic Fabrication and Construction Practices

Pipe Joining – Girth and Fabrication Welds

As Figure G-1 indicates, several different welding practices have been used to join line pipe. These processes have evolved significantly over the timeline shown there.

Application of early welding processes on pipelines started in the early 1900s with the oxy-acetylene process. In about 1914-1916, oxy-acetylene welding was used to fabricate the first long distance pipeline. At about this time, early shielded-metal-arc (SMAW, "stick electrode") welding was first applied to pipelines. In 1925, the first SMA welding was done on pipelines, which used electrodes with an extruded cellulosic coating. Field weld quality using both oxy-acetylene and early SMAW processes was marginal at best. Visual examination was the primary field inspection method.

Additional evolution of the SMA process resulted and in 1930 all position SMA welding became practical. By about 1933, SMA welding was used instead of oxy-acetylene welding for all but small diameter pipe. The first welder qualifications were required in the early 1930s that included destructive testing. Some company welding specifications were also being used at that time.

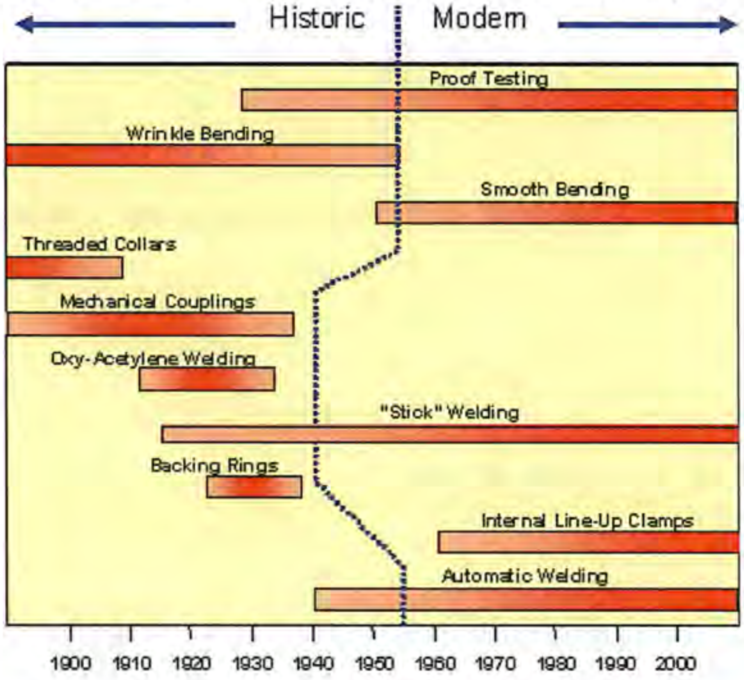


Figure G-1. Pipeline construction practices

The "stove pipe" pipeline construction technique was first used in the early 1930s and became the preferred construction method in the 1940s. Internal line-up clamps were first used in 1945. Both of these pipeline construction technique modifications favorably impacted welding quality.

Pipeline weld inspection quality increased with the application of radiography in the late 1940s and weld acceptance standards were being developed. API 1104 was issued in 1949 and immediately adopted for pipeline construction. More extensive application of field radiography followed in the early 1950s. In about 1960, field radiography of girth welds became a pipeline construction requirement.

Field fabrication of bends and components also evolved. The use of miter bends and field hot bending were prohibited by most construction specifications in the late 1940s – early 1950s. Other components such as branch connections and other components were often field fabricated prior to the mid 1950s. These fabrications often included fillet welds that were difficult to properly inspect without the availability more mature NDE techniques.

Along with the evolution of welding and nondestructive inspection processes, materials used for line pipe and components also improved. In the 1960s, line pipe manufacture with lower carbon steels (i.e., microalloyed steels) began with a result being generally improved weldabilty. Prior to this time, many girth and fabrication welds were made on relatively high carbon equivalent materials (IIW CE> ~ 0.45) that tended to be more sensitive to cracking.

Appendix C presents additional information and more details concerning many of the events applicable to welding processes and quality shown in Figure G-1. Considering the pipeline welding/inspection related items evident in Figure G-1, ~1950 tends to be a defining point in time. The following occurred in about 1950, all of which lead to improved weld quality:

- SMA welding had become a more mature field welding process.
- The "stove pipe" pipeline construction was the preferred method in the 1940s
- Internal line-up clamp use began in 1945.
- Gamma/X-ray radiography of welds was implemented in the mid 1940s
- Welder qualification methods had been implemented earlier by some and became a requirement in API 1104 in 1949.
- Weld acceptance criteria had been implemented on some pipeline construction and became a requirement in 1949 as API 1104 was adopted.
- Pipeline construction SAW double jointing was implemented about 1957.

Historical data on the number of girth weld incidents included in the three historical databases between 1950 and 2000 is summarized in Figures G-2a and G-2b. Figure G-2a includes a timeline for some of the key events in girth-weld practices. In Figure G-2a it is apparent that there are peaks for girth welds in the 1930s and in the 1950s that tend to coincide with the peaks in line pipe production and pipeline construction.

Figure G-2a indicates a relatively high girth weld incident rate in the early 1950s although several pipeline welding and construction improvements discussed above were already in place. Figure G-2a also illustrates that the most significant girth weld incident rate decline began in the late 1960s although it was relatively low throughout the 1960s. Additional girth welding improvements occurred in the 1960s through use of microalloyed steels with improved weldability and increased requirements for girth weld radiography. Additional historical data pertaining to other incidents pertaining to field welds is provided in Figure G-2b. However, no useful trends are indicated by these data.

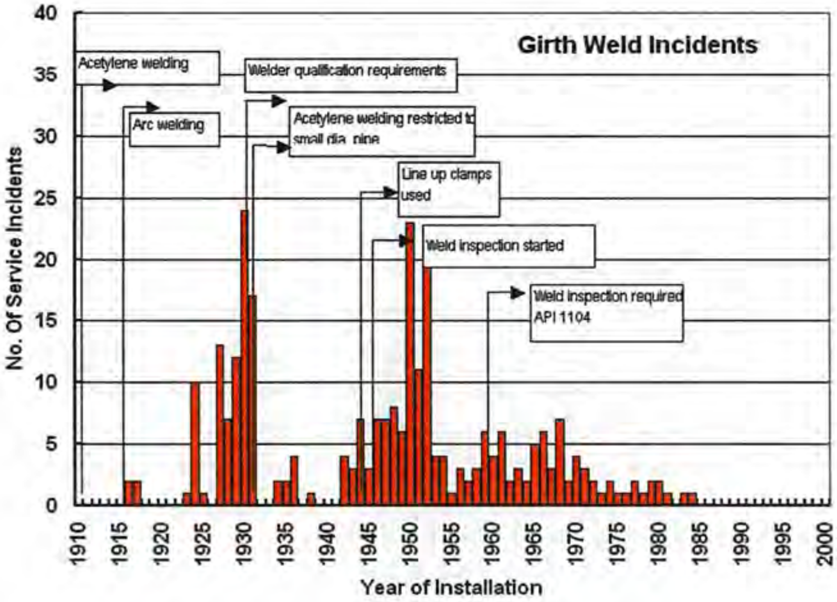
The events related to welding quality in the welding construction timeline and the historical incident data discussed in reference to Figure G-2a suggest that the interval from 1955-1960 can be viewed as the period defining a reduction in defective girth/fabrication welds and the related threat. It also represents the period when the use of field-fabricated components such as branch connections was declining. In general, this period coincides with a transition in welding methods, pipeline construction techniques, and inspection quality/frequency that resulted in significant welding related improvements. The threat associated with welds produced after this period is low compared to earlier years.

Pipe Joining – Mechanical Couplings

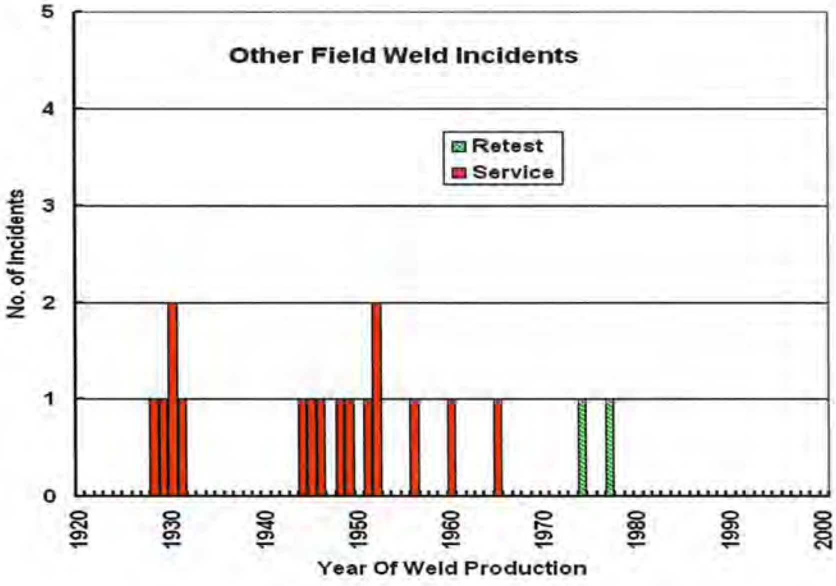
Pipelines were joined using various methods including mechanical couplings prior to the development of suitable field welding methods. Caulked joints and threaded collars were used on very early pipelines and the Dresser coupling was first used in 1891. By the late 1920s mechanical coupling applications were decreasing as welding became the preferred pipe joining method[64]. However, their use in welded pipelines continued into the 1930s to allow for in-service axial pipe expansion.

Mechanical couplings are sensitive to external loading. Their application in early pipelines was often on 20-foot pipe lengths and shallow burial depths. As pipeline pressures and diameters began to increase, the lateral restraint needed to assure pipeline stability became a concern. It was recognized that deeper burial and longer pipe lengths would be required achieve improved pipeline stability. Improved pipeline welding practices reduced the need for couplings at short intervals.

External loading sufficient to create about a 1.5-degree bend through a mechanical coupling can a separation to occur. Similarly, backfill removal adjacent to a coupling under a lateral load may allow previously restrained pipe to bend thus allowing a coupling separation.



a) girth welds



b) other field welds

Figure G-2. Trends in the failure of field welds through 2000

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[64] See Reference 112 for discussion of typical vintage construction practices wherein couplings were often used between welded double joints of line pipe. This reference also discusses rehabilitation of vintage construction.

Where mechanical couplings are present, any loading condition that may deform a pipeline should be considered as a potential threat. A coupling threat should be assumed at locations where earth movement and heavy rains/floods could interact with a coupled pipeline. In assessing a coupling threat, the pipe burial depth and coupling frequency should also be considered.

Wrinklebends and Buckles[65]

Pipe bending practices used during early pipeline construction practices typically resulted in circumferential pipe deformation or wrinkles centered at the bend radius. This deformation occurred at each bending location. The number of wrinkles in a given bend depended on the total angle bend angle required. Thus, a "wrinklebend" could contain various numbers of individual wrinkle locations. Depending on methods used (and care exercised), wrinklebend quality varied widely[66]. It ranged from severe buckles to almost no visible wrinkle or local deformation at the bend intrados.

Various wrinkle-bending processes were used on pipelines constructed in the mid 1950s and earlier. Earlier wrinkle-bending methods (~1930s) often included heating the pipe prior to bending. Pipeline construction bending methods entered a transitional period in the 1940s. Development of improved bending equipment capable of producing smooth field bends in large diameter thin wall pipe was stimulated by requirements for the War Emergency pipelines. In 1942-1943, the first improved bending machine was used for pipeline construction. Wrinkle-bending, however, continued to be used through the 1940s. In the late 1940s, many pipeline construction specifications prohibited hot (wrinkle) bending. By the early 1950s, hot/cold wrinkle-bending was still being considered a viable option along with hydraulic bending machines. Wrinkle-bending was phased out in the early 1950s. If no information is available to the contrary, it should be assumed that any pipeline constructed in 1955 or earlier contains wrinklebends.

It should be noted that wrinkle-bending process described above were most likely focused on larger pipe diameters (i.e., 16 inch and larger). Historical records indicate that nominal 12-inch OD pipe was bent with external shoes as early as 1944. Wrinkle bent pipe of diameters 8 and 12-inch have been removed from service.

The geometric discontinuity created by wrinkle formation develops a local bend that is sensitive to external loading that causes it to flex. When in service within the WSD limits under conditions that do not flex this area, the associated anomalies are stable. However, at locations where external loading has increased and/or a cyclic stress environment exists, wrinklebend integrity can become an issue. Increased external loading and/or cyclic stress can interact with the wrinklebend geometry creating the conditions that could promote time-dependent degradation. Metal loss in a wrinkle resulting from external and/or internal corrosion can cause additional local stress in a wrinkle thus increasing the chance of time dependent degradation. Reference 47 provides criteria that facilitate IMPs involving wrinklebends.

Buckles in pipelines are similar to wrinklebends except they are typically formed in-service due to external loading. Locations with confirmed threats including earth movement and heavy rains/floods can potentially create the conditions that can initiate time-dependent degradation. Once a buckle is formed, operational cyclic stress can also lead to fatigue cracking in a buckle. Assessment and corrective action, as needed, can be facilitated via Reference 47.

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[65] Reference 47 provides a comprehensive review of wrinklebend practices and criteria that facilitate IMPs.

[66] See Appendix A of Reference 47 for a complete history of such processes and examples of bend quality.

Valves and Other Components

The incident data contains minimal information that can be used as a basis to meaningfully evaluate the performance of pipeline components. Some information, however, is available on valve incidents, which forms the basis for this appendix.

Figure G-3 illustrates the distribution of valve related incidents with time. Unfortunately, the valve related data do not provide the specific failure cause. It is evident From Figure G-3 that the number of incidents has remained low and essentially constant over a long period. This trend indicates that valve failure resulting in a reportable incident has not been a significant issue, with no incidents reported since the mid 1980s.

Table G-1. Valve incidents by supplier

Valve Manufacturer	Number of Incidents	Valve Manufacturer	Number of Incidents
Fisher	2	Balon	1
Crane	4	WKM	1
Darling	1	M&J	1
Grove	3	Orbit	1
Rockwell	4	Rockwell	1
Wheatley	9 (8 in 1982)	Misc	3
Walworth	2		

Table G-1 presents the data available that included manufacturer, which represents about half of such incidents, and indicates the number of incidents associated with each. From this manufacturer data, it is evident that incidents have included a wide variety of valve types including, ball, gate, plug, and check valves. Overall, the incident data was divided reasonably equally between the manufacturers represented with the exception of Wheatley. Among other products, Wheatley produced check valves that were commonly used in pipelines. Some valve designs, particularly gate valves can be impacted by external loading that distorts the body thereby impeding normal operation. External loading has also promoted gate valve failures in the weld joining the pipe to the valve body.

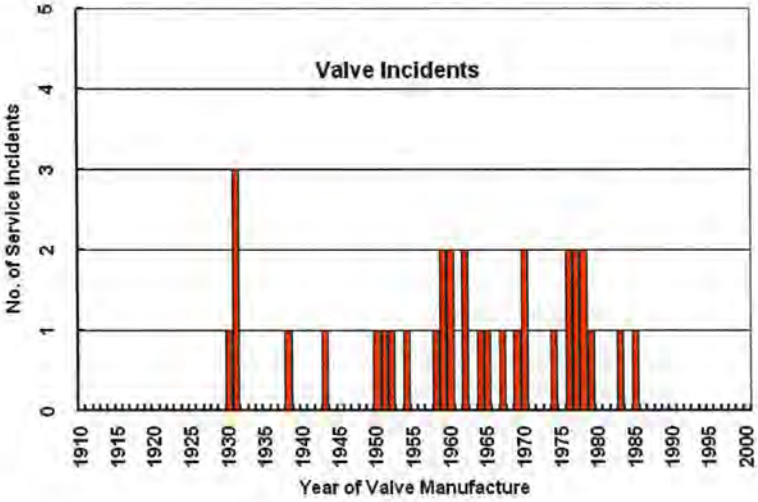


Figure G-3. Valve incidents

Appendix H: Pipeline Construction Timelines

Table H-1. Timeline for construction methods

Date(s)	Event
1800s	Threaded collars used to join pipe up to 12 inch OD.
Late 1800s	Maximum of 8-10 inch OD pipe; threaded joints
1887	Wrought iron pipe up to 24-inch OD used for pipelines. Bessemer steel began to replace wrought for lap welded pipe.
1891	Dresser couplings first used.
1899	First 30-inch lap welded pipe produced. First 20-inch OD seamless pipe produced.
1907	Coated welding electrodes developed.
1911	First oxy-acetylene process pipeline welding. First portable electric welding machine developed.
1914 -1916	Oxy-acetylene welding first used on long distance pipelines. Improved SMAW welding electrodes becoming available.
1917	First application of SMA electrodes on pipelines. Use of pipe coatings considered essential. Painting used for pipe protection in some cases.
1920	Commercial production of "electric welded" pipe began. Steel lap welded pipe up to 24 inch OD available.
1922	Ditching machine first used for pipeline construction Some pipeline welding with bare "stick" electrodes. Backing rings required for early "stick" electrode welding on pipelines. Oxy-acetylene process roll welding of 5 pipe lengths together to improve production rates, improved quality; method used for next 10-12 years.
1924	First all welded (14, 16, 18-inch OD) pipeline completed.
1925	First extruded cellulosic SMAW electrodes produced; field weld quality was poor. Rapid flux development and pipeline use followed. A.O. Smith started production of welded pipe made from plate with an automated shielded electrode process – 16 to 24-inch OD. Pipe flashwelding process being developed.
Late 1920s	Mechanical couplings still used in all welded pipelines to allow for thermal expansion. All field girth welds visually inspected and some field NDT was used. Bell/ spigot joint developed to reduce weld leakage and use of backing rings
1926	Introduction of large diameter, thin wall seamless pipe with improved quality
1927	Lincoln introduced Fleetweld 5 SMAW coated electrode.
1928	First long distance, electric welded pipeline (155 miles, 8-inch OD). Bell/ spigot joints made with two passes. Motor driven electric welding machines used. First use of aerial photography for pipeline location. First edition of API 5L published.
1929	Additional use of electric welding of bell/spigot joints on pipelines. 45 weld failures the first year.
1930	All position SMA welding without backing rings became practical. First use of coated electrodes for pipeline field welding. Use of Dresser couplings for 18-20 foot pipe lengths in shallow ditch considered

	unreliable due to limited lateral support. Longer distance between couplings and deeper ditch needed. Protection of coupled pipelines against outside forces difficult to achieve. Initial use of welder qualifications. 1000 mile pipeline constructed primarily with SMAW; some oxy-acetylene and mill welded double joints. Backing rings used initially and then discontinued during project.
~ 1930	Lap welded, Bessemer steel pipe up to 24-inch OD is most common line pipe. Depression era reduced pipeline activity for about 7 years.
Early 1930s	First welder qualification requirements. Test welds destructively evaluated per company specifications. Modified oxy-acetylene welding with multiple tips to increase production rates.
1933	Oxy-acetylene welding only used for small diameter pipe. First SMAW pipeline welding without backing rings. First use of "stove pipe" pipeline construction method.
1935	American Standard Code for Pressure Piping issued by ASME.
1936	More extensive use of "stove pipe" pipeline construction method.
1940	Various cold bending methods. Used tractors, cables; some done with external bending shoe.
1940s	"Stove pipe" becomes preferred pipeline construction method.
1941	Automatic welding first attempted; not successful.
1942	Double coat/wrap field coating introduced.
1942-1943	First use of thin wall, large OD pipe on War Emergency liquid pipelines. Smooth bends for such liquid service required development of bending machines; provided to construction contractors.
1943	Large diameter cold bending machine in use.
1945	Use of internal line-up clamps began.
1946	First use of X-ray radiography (18-inch OD pipe). First use of large OD (30-inch) DSAW pipe (214 miles) Company pipe, field welding, construction specifications applied. Gamma RT specification applied. Weld defect acceptance criteria used by Standard Oil.
1948	Girth weld gamma RT initially required cutting hole in pipe to insert source and then began using double wall technique from outside. Gamma RT weld acceptance standards still in developmental stages. Acceptance based on inspector opinion. First hydraulic pipe bending machine. DSAW process preferred for large OD pipe production. High pressure pipeline hydrotesting begins. API 5LX issued.
1949	Radiograph interpretation still not mature. Training aids published. RT specified on most new gas pipelines and to a lesser extent on liquids pipelines. X-ray radiography used for => 20 inch pipe.
~ 1949	API 1104 published and immediately adopted for pipeline construction. Wrinkle-bending still used for pipeline bending. Miter bends and hot field bending prohibited by most pipe construction specifications.
1949-1950	More extensive use of girth weld X-ray radiography (1/3 of welds examined) Early attempt to use automated field SAW double jointing; equipment too bulky for ROW use.
Early 1950s	Production of line pipe at high level compared to previous years.

1952	Hot/cold wrinkle-bending and hydraulic bending considered viable for pipeline construction.
1955	Gas pipeline construction code issued by ASME and immediately adopted.
1957	First application of portable, automated SAW double joining process used for pipeline construction
1958	Automated GMA welder used by H.C. Price; skilled operator required; too slow to complete entire weld.
1960	Girth weld RT a proven practice a generally required for pipeline construction. CRC/ER&E/Battelle developed automatic GMA welder; used on 6 inch OD pipe, CO2 shielding; semi-automatic GMA repairs.
1960s	Use of microalloyed pipeline steels began.
1963	First application of semi-automatic GMA process for pipeline welding.
1965	First successful automatic crawler for pipeline X-ray radiography. Automatic/semi-automatic GMA welding on Grade X100 pipe.
1968	Federal Pipeline Safety Act: B31.8 now mandatory.

Table H-2. Timeline for construction, joining and field welding, and nondestructive inspection methods

Date(s)	Event
Earlier	Use of threaded collars/couplings to join pipe.
1910s	Continued use of collars and couplings. First oxy-acetylene welding on long distance pipelines. First shielded metal arc welding on pipelines.
1920s	Continued use of collars and couplings, oxy-acetylene welding, and shielded metal arc welding. First roll welding with oxy-acetylene process. First shielded metal arc welding with extruded cellulosic electrodes. First bare “stick” welding. Backing rings required – 45 weld failures the first year. First bell/spigot joints. First requirements for visual inspections of all field girth welds. First use of aerial photography for pipeline location. First use of ditching machine for pipeline construction.
1930s	Reduction in use of couplings, especially for short (18 to 20 foot) pipe lengths. Reduction in use of oxy-acetylene welding. First modified oxy-acetylene welding with multiple tips; process used for small diameters only. Widespread use of all-position shielded metal arc welding without backing rings. Initial welder qualification requirements; test welds destructively evaluated. First use of “stove pipe” pipeline construction method. American Standard Code for Pressure Piping issued by ASME.

Date(s)	Event
1940s	Little or no use of couplings. Widespread use of all-position shielded metal arc welding. First use of automatic welding; not successful. First use of internal line-up clamps. Stove pipe" becomes preferred pipeline construction method. Company pipe, field welding, construction specifications applied. First use of gamma ray inspections of girth welds. By the end of the decade, radiographic inspection was required on most new gas pipelines and to a lesser extent on liquids pipelines. First X-ray inspections. Various cold bending methods in use. First use of hydraulic and large-diameter bending machines. API 1104 published and immediately adopted for pipeline construction.
1950s	First automated gas metal arc welding; skilled operator required; too slow to complete entire weld. First application of portable, automated submerged arc welding double joining process used for pipeline construction. Hot/cold wrinkle-bending and hydraulic bending considered viable for pipeline construction. Gas pipeline construction code issued by ASME and immediately adopted.
1960s	Radiographic inspection a proven practice and generally required for pipeline construction. Automatic welding began to be successfully implemented. First application of semi-automatic GMA process for pipeline welding. First successful automatic crawler for pipeline X-ray radiography. Automatic/semi-automatic GMA welding on Grade X100 pipe. Federal Pipeline Safety Act: B31.8 now mandatory.

Appendix A – Task 1

Catalog of Early Generation Pipe and Weld Properties

Pipe background information

Nominal diameter	8-inch	203 mm
Nominal wall thickness	0.250-inch	6.4 mm
Pipe manufacturer	Bethlehem Steel Co., Yoder Mill	
Year of manufacture	1963	
Seam weld type	LF ERW, post tempered seam	
Reported pipe grade	API 5LX-46, non-expanded	

Base metal tensile test results*

Tensile strength	70,500 psi	486 MPa
Yield strength	49,700 psi	343 MPa
Elongation, %	29.0	
Reduction of area, %	42.0	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

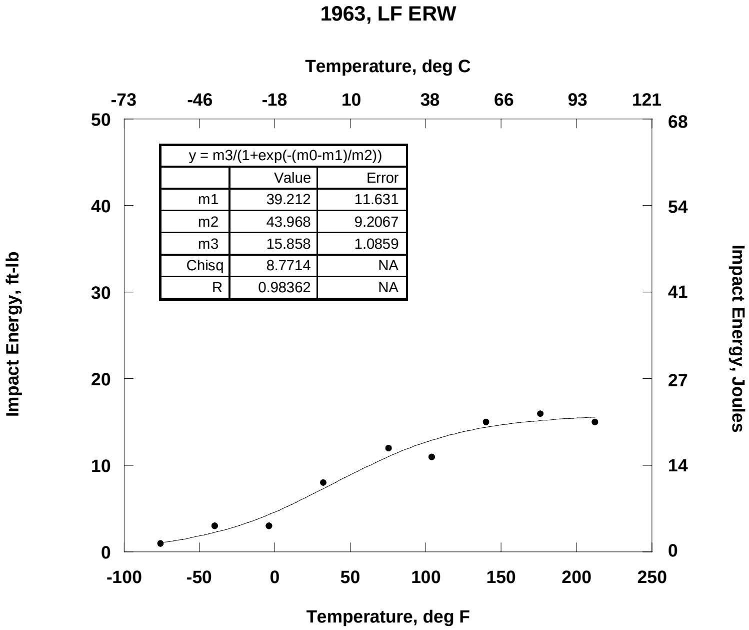
Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.253	0.310
Manganese (Mn)	0.844	1.350
Phosphorus (P)	0.007	0.040
Sulphur (S)	0.020	0.050
Silicon (Si)	0.009	
Copper (Cu)	0.051	
Tin (Sn)	0.004	
Nickel (Ni)	0.054	
Chromium (Cr)	0.040	
Molybdenum (Mo)	0.021	
Aluminum (Al)	0.003	
Vanadium (V)	0.002	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0004	
Cobalt (Co)	0.007	
CE = C + (Mn/6)	**0.3937**	
V + Nb + Ti	**0.007**	

Bondline Charpy V-notch impact test results

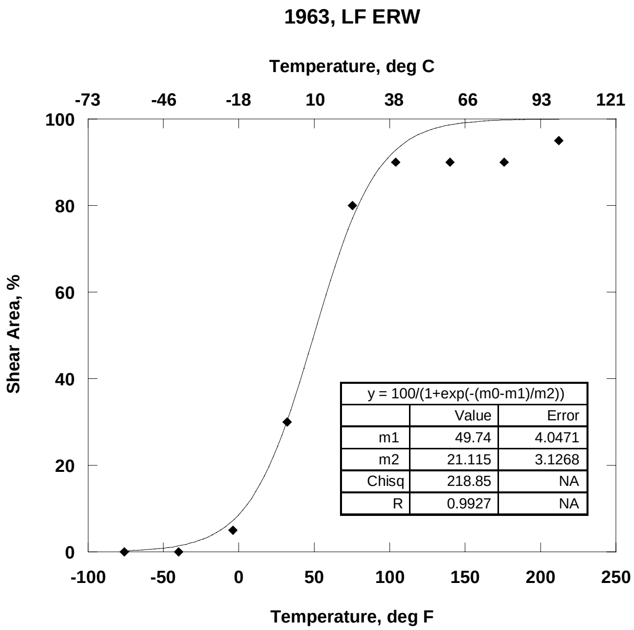
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-76	-60	1	1	0	2	0.05
-40	-40	3	4	0	2	0.05
-4	-20	3	4	5	2	0.05
32	0	8	11	30	8	0.20
75.2	24	12	16	80	14	0.36
104	40	11	15	90	15	0.38
140	60	15	20	90	18	0.46
176	80	16	22	90	19	0.48
212	100	15	20	95	22	0.56

Transition temperature, 85% shear area for specimen	100	°F	38	°C
Charpy upper shelf energy, (full size specimen)	13	ft-lbs	18	Joules



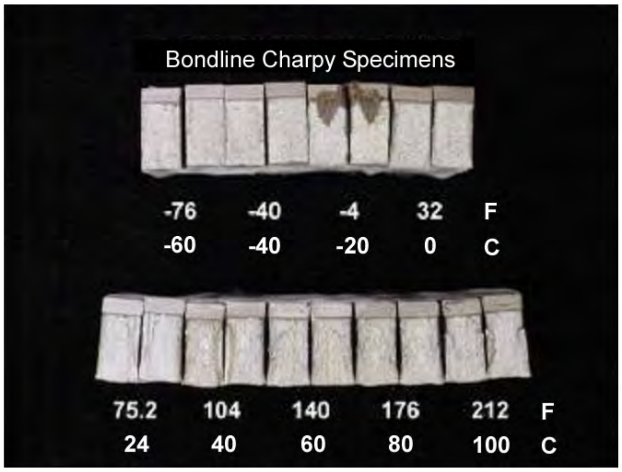
1963, LF ERW

y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	39.212	11.631
m2	43.968	9.2067
m3	15.858	1.0859
Chisq	8.7714	NA
R	0.98362	NA



1963, LF ERW

y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	49.74	4.0471
m2	21.115	3.1268
Chisq	218.85	NA
R	0.9927	NA



Ring flattening test results N/A

General notes and observations for this pipe section:

ID connected lack of fusion (LOF) defect observed on one Charpy specimen. This pipe was used for natural gas transmission.

Pipe background information

Nominal diameter	Unknown	Plate section
Nominal wall thickness	0.250-inch	6.4 mm
Pipe manufacturer	Unknown	
Year of manufacture	1957	
Seam weld type	LF ERW	
Reported pipe grade	Assumed API 5LX-42, non-expanded	

Base metal tensile test results*

Tensile strength	65,500 psi	452 MPa
Yield strength	49,200 psi	339 MPa
Elongation, %	28.0	
Reduction of area, %	41.0	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Bondline and HAZ chemical analysis results

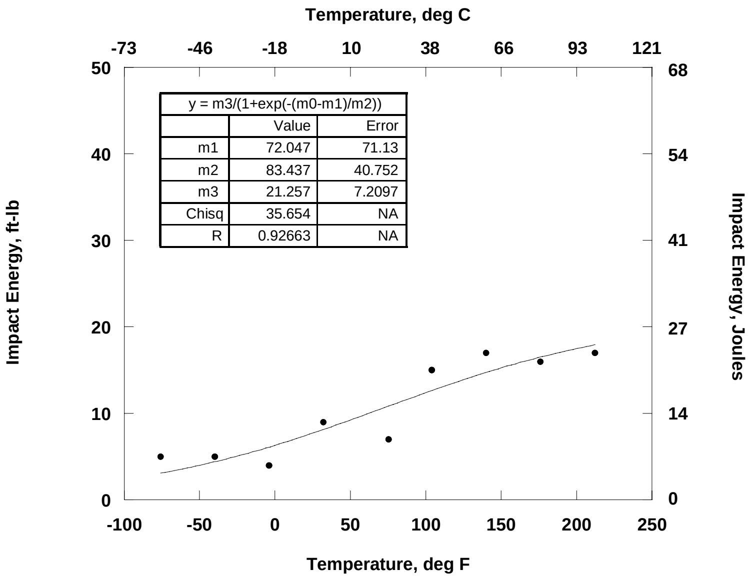
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.249	0.280
Manganese (Mn)	0.799	1.250
Phosphorus (P)	0.016	0.040
Sulphur (S)	0.028	0.050
Silicon (Si)	0.007	
Copper (Cu)	0.125	
Tin (Sn)	0.006	
Nickel (Ni)	0.022	
Chromium (Cr)	0.015	
Molybdenum (Mo)	0.005	
Aluminum (Al)	0.011	
Vanadium (V)	0.002	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.033	
CE = C + (Mn/6)	**0.3822**	
V + Nb + Ti	**0.007**	

Bondline Charpy V-notch impact test results

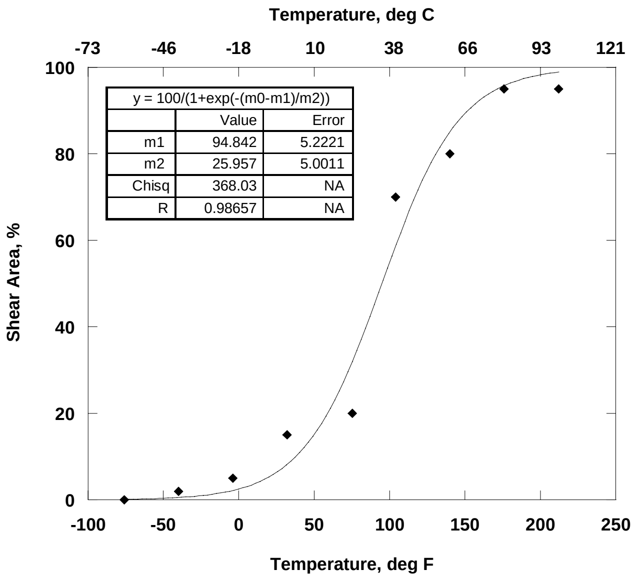
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-76	-60	5	7	0	3	0.08
-40	-40	5	7	2	1	0.03
-4	-20	4	5	5	4	0.10
32	0	9	12	15	12	0.30
75.2	24	7	9	20	8	0.20
104	40	15	20	70	15	0.38
140	60	17	23	80	17	0.43
176	80	16	22	95	17	0.43
212	100	17	23	95	18	0.46

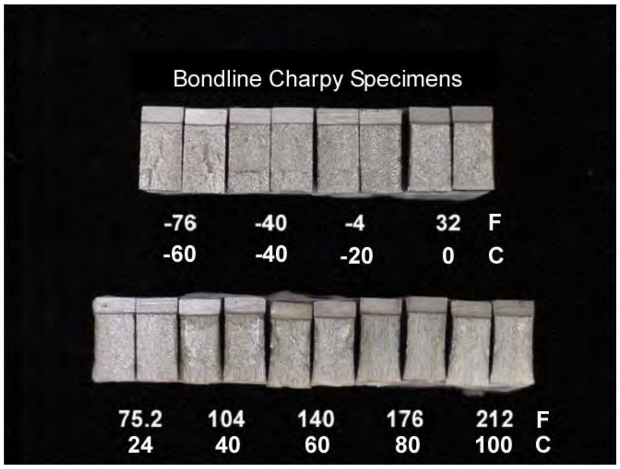
Transition temperature, 85% shear area for specimen	140	°F	60	°C
Charpy upper shelf energy, (full size specimen)	16	ft-lbs	22	Joules

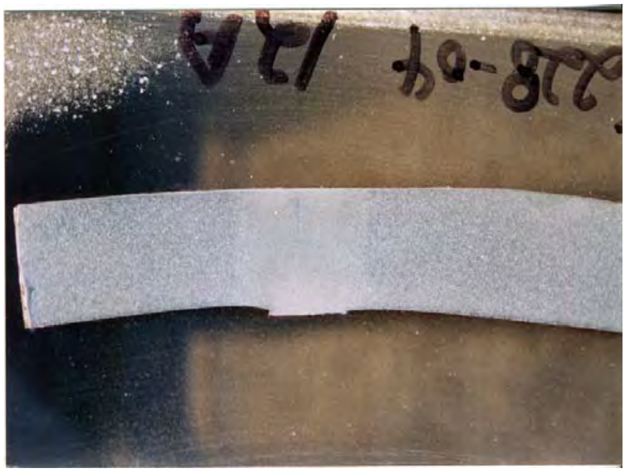
1957, LF ERW



1957, LF ERW







Vickers hardness testing results

Remote from Seam			HAZ		Weld Metal or Fusion Line			
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID
164	151	158	ID	187		231	229	210
			Midwall	190				
			OD close to fusion line	238				
			OD	203				
			ID close to fusion line	226				
			midwall close to fusion line	246				

Ring flattening test results N/A

General notes and observations for this pipe section:

Plate specimen submitted by anonymous donor. 275 psig MAOP

Pipe background information

Nominal diameter	8-inch	203 mm
Nominal wall thickness	0.233-inch	5.9 mm
Pipe manufacturer	Unknown	
Year of manufacture	1926	
Seam weld type	LF ERW	
Reported pipe grade	Unknown	

Base metal tensile test results*

Tensile strength	68,800 psi	474 MPa
Yield strength	50,300 psi	347 MPa
Elongation, %	24.4	
Reduction of area, %	45.4	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Bondline and HAZ chemical analysis results

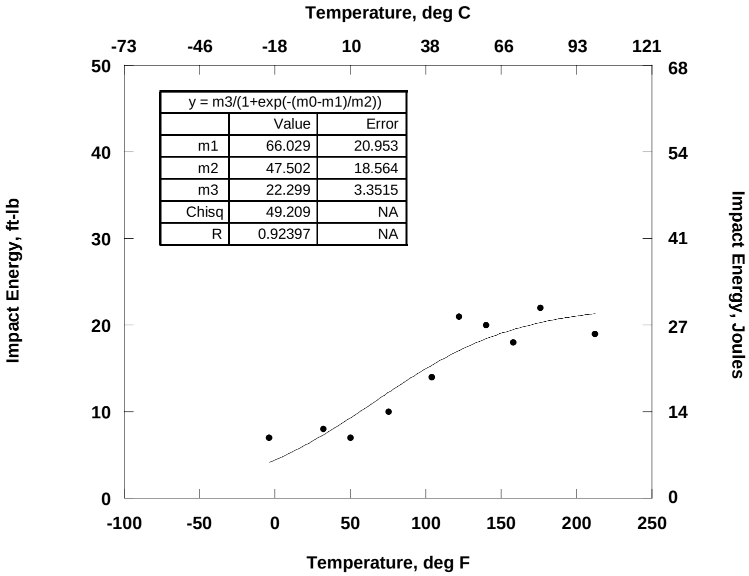
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.243	Unknown pipe grade
Manganese (Mn)	0.698	
Phosphorus (P)	0.008	
Sulphur (S)	0.022	
Silicon (Si)	0.048	
Copper (Cu)	0.091	
Tin (Sn)	0.002	
Nickel (Ni)	0.013	
Chromium (Cr)	0.017	
Molybdenum (Mo)	0.005	
Aluminum (Al)	0.004	
Vanadium (V)	0.002	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.025	
CE = C + (Mn/6)	**0.3593**	
V + Nb + Ti	**0.006**	

Bondline Charpy V-notch impact test results

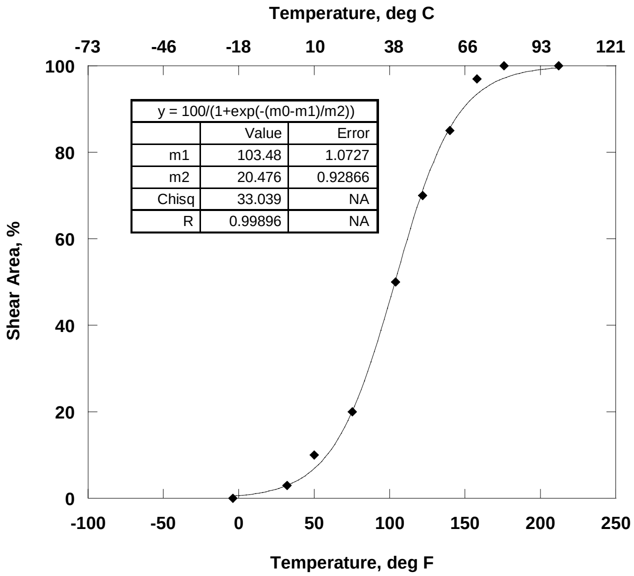
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-4	-20	7	9	0	8	0.20
32	0	8	11	3	9	0.23
50	10	7	9	10	11	0.28
75.2	24	10	14	20	15	0.38
104	40	14	19	50	17	0.43
122	50	21	28	70	24	0.61
140	60	20	27	85	21	0.53
158	70	18	24	97	22	0.56
176	80	22	30	100	25	0.64
212	100	19	26	100	23	0.58

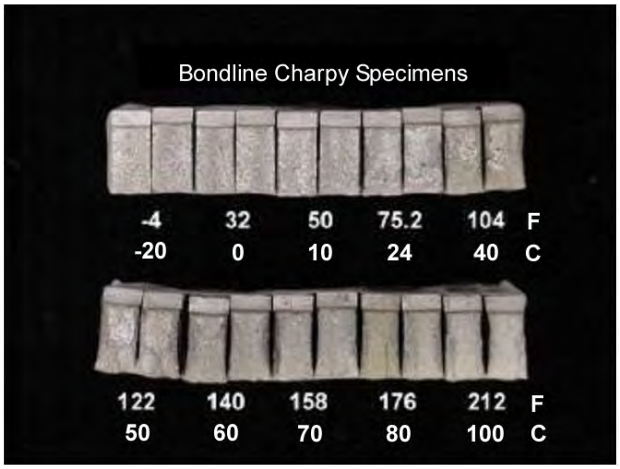
Transition temperature, 85% shear area for specimen	100	°F	38	°C
Charpy upper shelf energy, (full size specimen)	13	ft-lbs	18	Joules

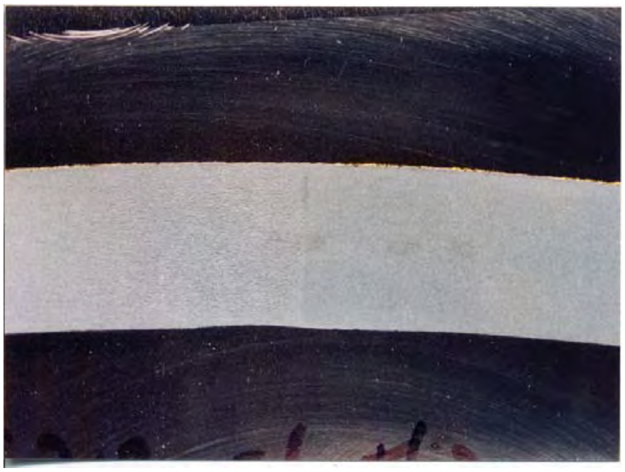
1926, LF ERW



1926, LF ERW







Ring flattening test results N/A

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor with ID misalignment of the seam weld

Pipe background information

Nominal diameter	18-inch	457 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	Unknown	
Year of manufacture	1967	
Seam weld type	LF ERW	
Reported pipe grade	API 5LX-42, non-expanded	

Base metal tensile test results*

Tensile strength	67,300 psi	464 MPa
Yield strength	51,900 psi	358 MPa
Elongation, %	26.2	
Reduction of area, %	48.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

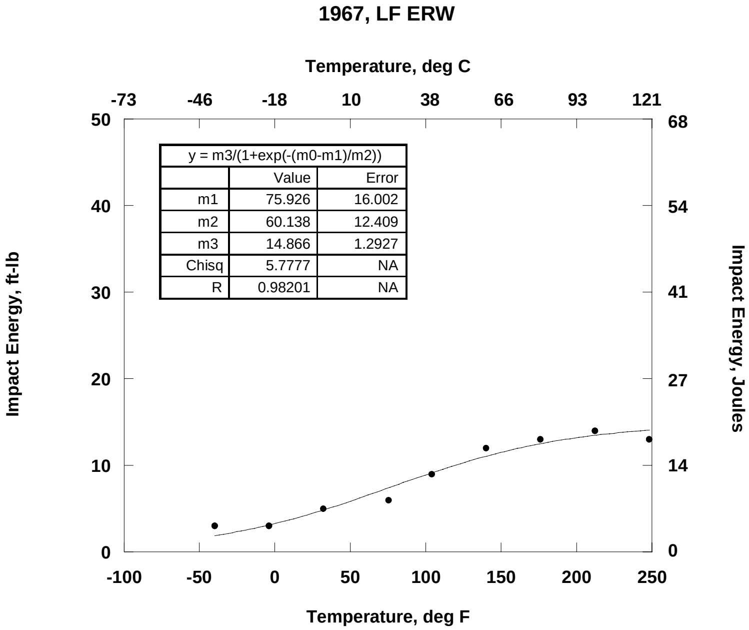
Bondline and HAZ chemical analysis results

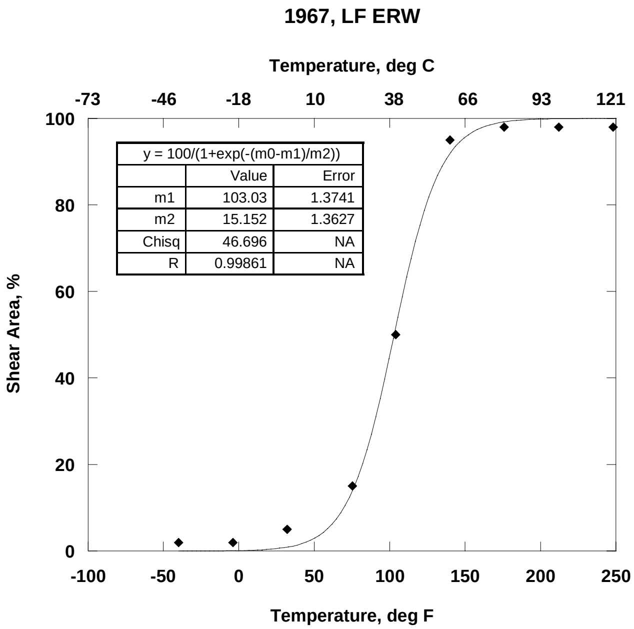
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.231	0.300
Manganese (Mn)	0.861	1.350
Phosphorus (P)	0.011	0.040
Sulphur (S)	0.022	0.050
Silicon (Si)	0.006	
Copper (Cu)	0.100	
Tin (Sn)	0.010	
Nickel (Ni)	0.042	
Chromium (Cr)	0.046	
Molybdenum (Mo)	0.019	
Aluminum (Al)	0.021	
Vanadium (V)	0.001	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.007	
CE = C + (Mn/6)	**0.3745**	
V + Nb + Ti	**0.005**	

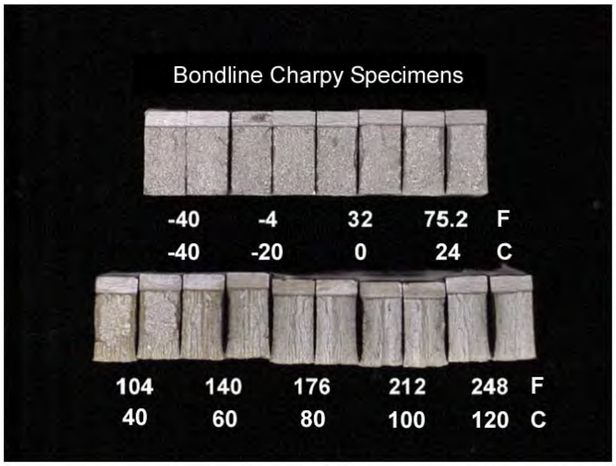
Bondline Charpy V-notch impact test results

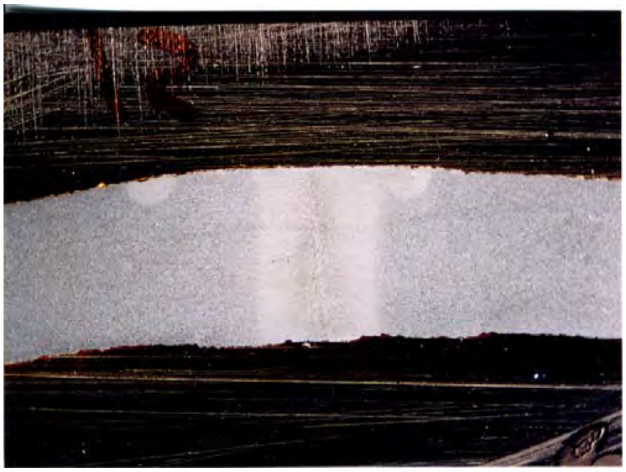
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-40	-40	3	4	2	3	0.08
-4	-20	3	4	2	5	0.13
32	0	5	7	5	4	0.10
75.2	24	6	8	15	8	0.20
104	40	9	12	50	19	0.48
140	60	12	16	95	17	0.43
176	80	13	18	98	17	0.43
212	100	14	19	98	19	0.48
248	120	13	18	98	18	0.46

Transition temperature, 85% shear area for specimen	150	°F	66	°C
Charpy upper shelf energy, (full size specimen)	13	ft-lbs	18	Joules









Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	Yes	Seam

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. 360 psig MAOP.

Pipe background information

Nominal diameter	34-inch	864 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	A. O. Smith Corp., Houston facility	
Year of manufacture	1962	
Seam weld type	Flash Weld	
Reported pipe grade	API 5LX-42, cold-expanded	

Base metal tensile test results*

Tensile strength	55,750 psi	384 MPa
Yield strength	45,100 psi	311 MPa
Elongation, %	30.0	
Reduction of area, %	40.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

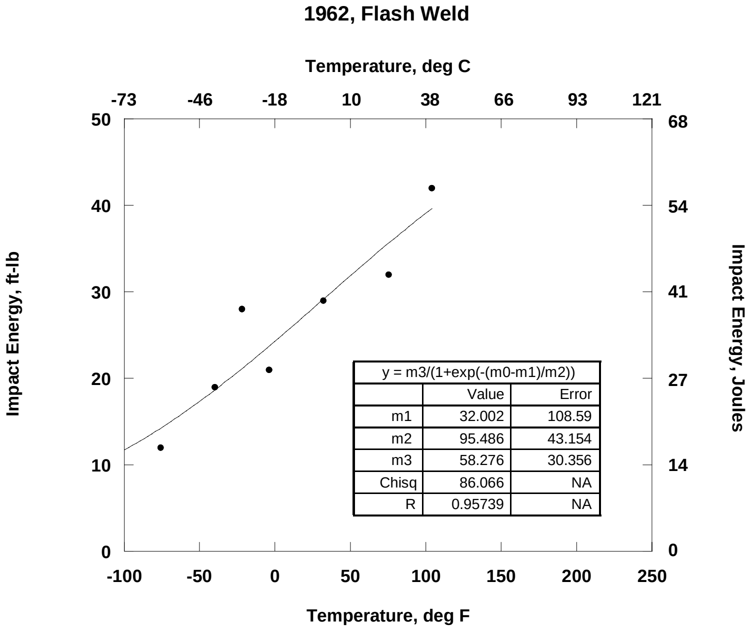
Flash and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.252	0.280
Manganese (Mn)	1.290	1.250
Phosphorus (P)	0.019	0.040
Sulphur (S)	0.015	0.050
Silicon (Si)	0.025	
Copper (Cu)	0.016	
Tin (Sn)	0.002	
Nickel (Ni)	0.009	
Chromium (Cr)	0.032	
Molybdenum (Mo)	0.010	
Aluminum (Al)	0.003	
Vanadium (V)	0.003	
Niobium (Nb)	0.004	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.006	
CE = C + (Mn/6)	**0.4670**	
V + Nb + Ti	**0.009**	

Flash centerline Charpy V-notch impact test results

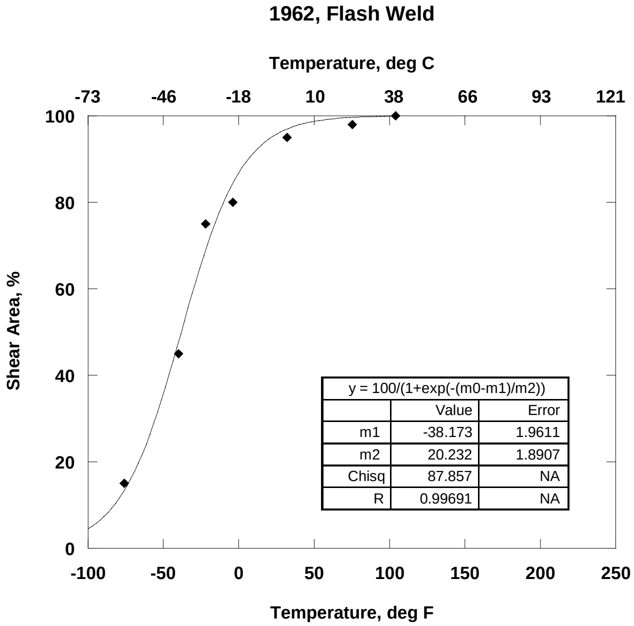
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-148	-100	9	12	0	8	0.20
-103	-75	9	12	0	9	0.23
-76	-60	12	16	15	13	0.33
-40	-40	19	26	45	15	0.38
-22	-30	28	38	75	32	0.81
-4	-20	21	28	80	25	0.64
32	0	29	39	95	36	0.91
75.2	24	32	43	98	37	0.94
104	40	42	57	100	46	1.17

Transition temperature, 85% shear area for specimen	15	°F	-9	°C
Charpy upper shelf energy, (full size specimen)	27	ft-lbs	37	Joules



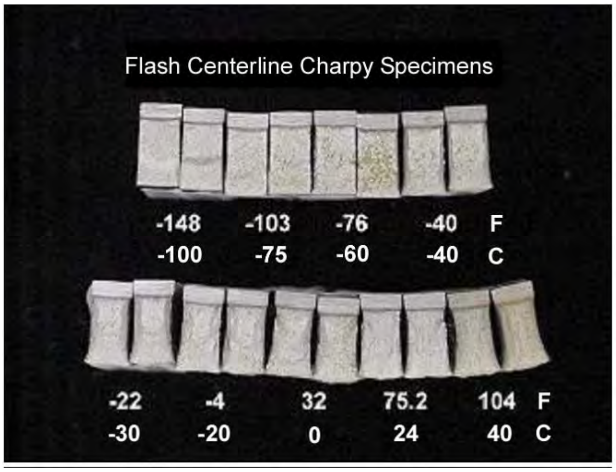
y = m3/(1+exp(-(m0-m1)/m2))

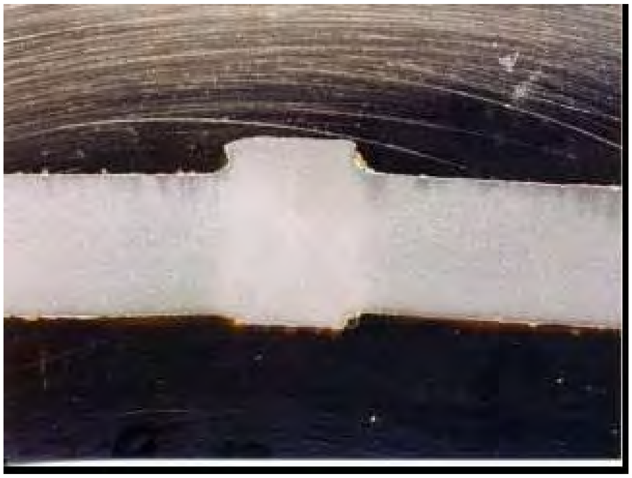
	Value	Error
m1	32.002	108.59
m2	95.486	43.154
m3	58.276	30.356
Chisq	86.066	NA
R	0.95739	NA



y = 100/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	-38.173	1.9611
m2	20.232	1.8907
Chisq	87.857	NA
R	0.99691	NA





Vickers hardness testing results

Remote from Seam			HAZ		Weld Metal or Fusion Line				
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID	comments
172	176	187	at ID corner of flash upset	202		192			approx. even with OD surface
		190	ID low temp	202			195		
			midwall low temp	191				202	approx. even with ID surface
			OD high temp	180	198				between midwall and OD
			OD low temp	178					
			midwall close to fusion line	199					

Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	Yes	Seam

General notes and observations for this pipe section:

6-inch long, ID connected Hook Crack located several inches upstream of material property testing locations. This pipe was used for crude oil transmission.

Pipe background information

Nominal diameter	20-inch	508 mm
Nominal wall thickness	0.375-inch	9.5 mm
Pipe manufacturer	Republic Steel Corp., Gasden, AL	
Year of manufacture	1955	
Seam weld type	SSAW	
Reported pipe grade	API 5LX-56, cold-expanded	

Base metal tensile test results*

Tensile strength	77,250 psi	533 MPa
Yield strength	59,550 psi	411 MPa
Elongation, %	28.0	
Reduction of area, %	39.0	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Weld metal chemical analysis results

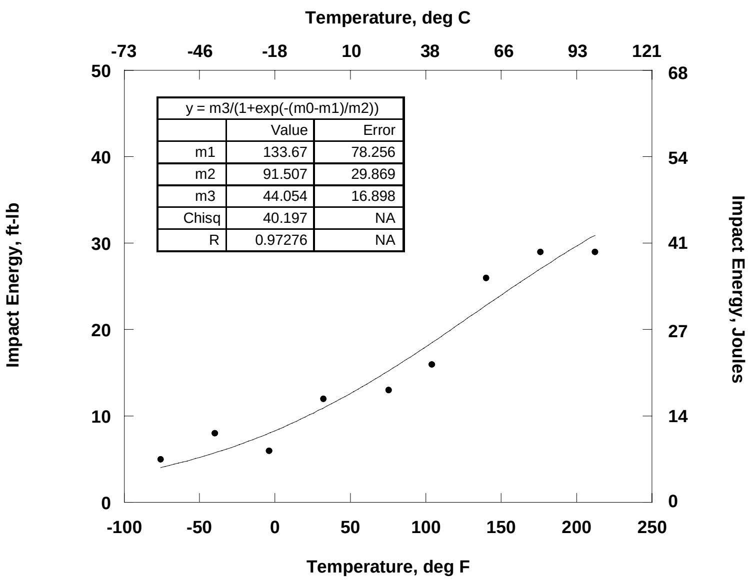
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.184	0.310
Manganese (Mn)	1.100	1.350
Phosphorus (P)	0.021	0.040
Sulphur (S)	0.036	0.050
Silicon (Si)	0.262	
Copper (Cu)	0.123	
Tin (Sn)	0.013	
Nickel (Ni)	0.036	
Chromium (Cr)	0.018	
Molybdenum (Mo)	0.159	
Aluminum (Al)	0.002	
Vanadium (V)	0.004	
Niobium (Nb)	0.004	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0.0002	
Calcium (Ca)	0.0002	
Cobalt (Co)	0.024	
CE = C + (Mn/6)	**0.3673**	
V + Nb + Ti	**0.010**	

Weld metal Charpy V-notch impact test results

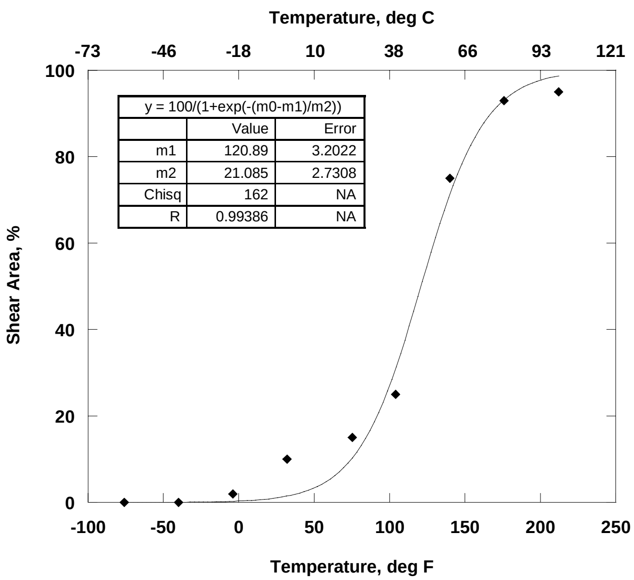
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-76	-60	5	7	0	4	0.10
-40	-40	8	11	0	7	0.18
-4	-20	6	8	2	6	0.15
32	0	12	16	10	15	0.38
75.2	24	13	18	15	18	0.46
104	40	16	22	25	21	0.53
140	60	26	35	75	32	0.81
176	80	29	39	93	34	0.86
212	100	29	39	95	35	0.89

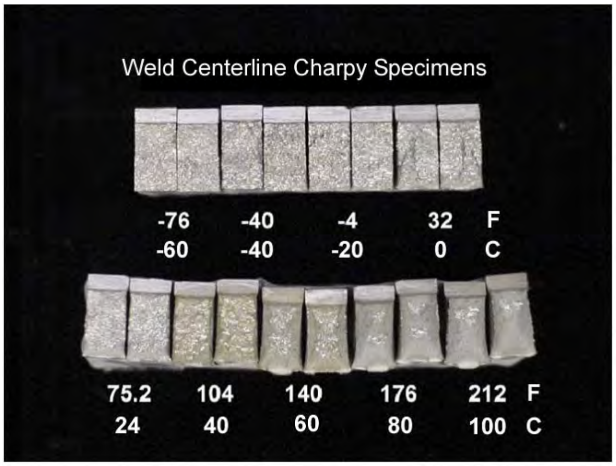
Transition temperature, 85% shear area for specimen	160	°F	71	°C
Charpy upper shelf energy, (full size specimen)	27	ft-lbs	37	Joules

1955, SSAW



1955, SSAW





Ring flattening test results N/A

General notes and observations for this pipe section:

It was reported that this pipe section was removed from service when transit fatigue cracks were found at the toe of the weld

Pipe background information

Nominal diameter	22-inch	559 mm
Nominal wall thickness	0.375-inch	9.5 mm
Pipe manufacturer	National Tube Co., McKeesport, PA	
Year of manufacture	1930	
Seam weld type	Lap Weld	
Reported pipe grade	API 5L Gr. B, non-expanded	

Base metal tensile test results*

Tensile strength	53,750 psi	371 MPa
Yield strength	38,300 psi	264 MPa
Elongation, %	26.0	
Reduction of area, %	42.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in Lap @ 51,000 psi	352 MPa
#2	Failed in Lap @ 47,800 psi	330 MPa

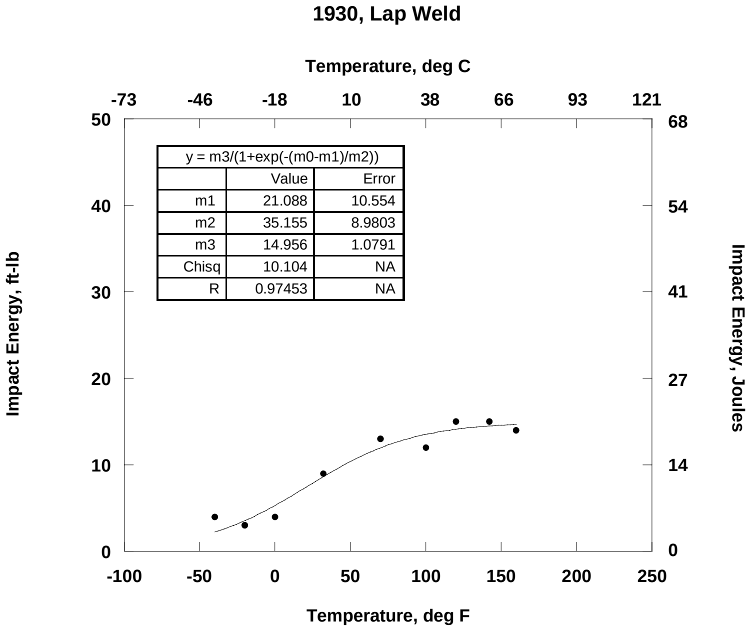
Lap area chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.240	0.300 (for Gr. B seamless only, 1930)
Manganese (Mn)	0.750	0.300 – 0.600
Phosphorus (P)	0.014	0.045 ?
Sulphur (S)	0.022	0.060 ?
Silicon (Si)	0.040	
Copper (Cu)	0.056	
Tin (Sn)	0.004	
Nickel (Ni)	0.009	
Chromium (Cr)	0.039	
Molybdenum (Mo)	0.008	
Aluminum (Al)	0.018	
Vanadium (V)	0.002	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.01	
CE = C + (Mn/6)	**0.3150**	
V + Nb + Ti	**0.006**	

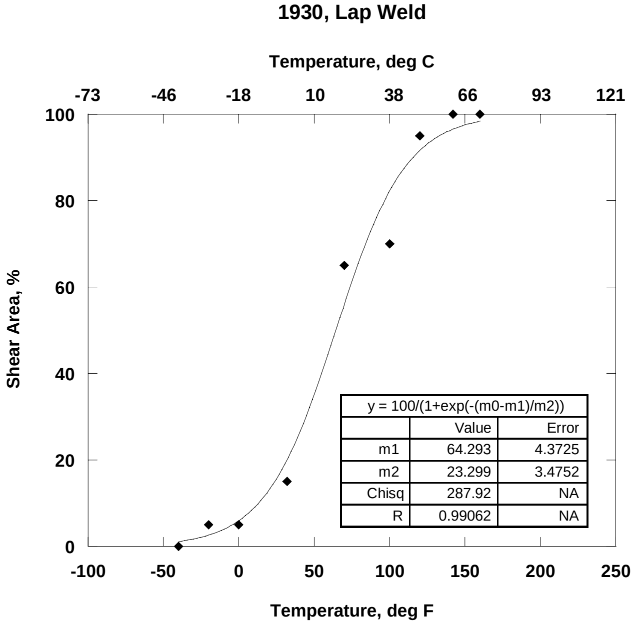
Lap mid-point Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-40	-40	4	5	0	2	0.05
-20	-29	3	4	5	2	0.05
0	-18	4	5	5	4	0.10
32	0	9	12	15	6	0.15
70	21	13	18	65	13	0.33
100	38	12	16	70	14	0.36
120	49	15	20	95	17	0.43
142	61	15	20	100	18	0.46
160	71	14	19	100	17	0.43

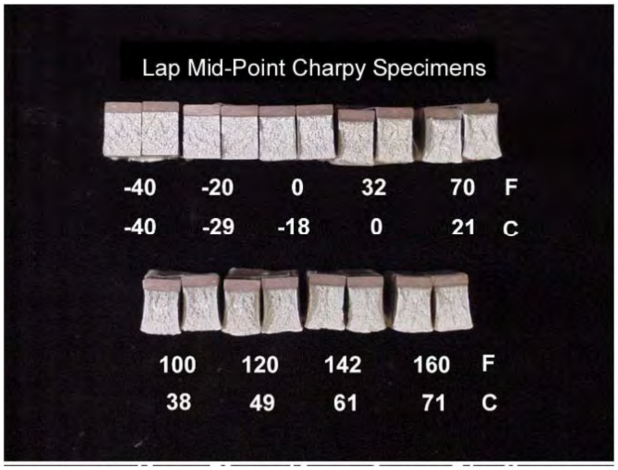
Transition temperature, 85% shear area for specimen	118	°F	48	°C
Charpy upper shelf energy, (full size specimen)	14	ft-lbs	19	Joules



y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	21.088	10.554
m2	35.155	8.9803
m3	14.956	1.0791
Chisq	10.104	NA
R	0.97453	NA



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	64.293	4.3725
m2	23.299	3.4752
Chisq	287.92	NA
R	0.99062	NA



Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	Yes	-
90°	No	-	Yes	Lap	-	-

General notes and observations for this pipe section:

It was reported that this pipe section was removed due to a hydrostatic test failure in the Lap Weld. Failure pressure is not known. Material property testing was conducted 3-feet downstream of the failure

Pipe background information

Nominal diameter	20-inch	508 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	A. O. Smith Corp., Houston facility?	
Year of manufacture	1959	
Seam weld type	Flash Weld	
Reported pipe grade	Not reported. Probably API 5LX-46	

Base metal tensile test results*

Tensile strength	67,700 psi	467 MPa
Yield strength	49,300 psi	340 MPa
Elongation, %	24.0	
Reduction of area, %	40.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 68,000 psi	469 MPa
#2	Failed in HAZ @ 48,000 psi	331 MPa

Flash and HAZ chemical analysis results

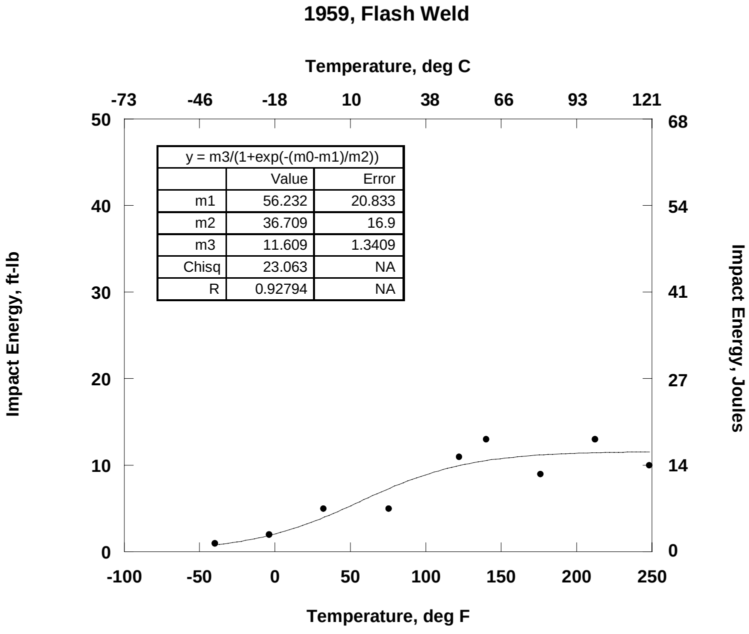
Element	Weight % of sample	Base metal **max. allow (Wt %)
Carbon (C)	0.199	0.280
Manganese (Mn)	0.990	1.250
Phosphorus (P)	0.014	0.040
Sulphur (S)	0.019	0.050
Silicon (Si)	0.029	
Copper (Cu)	0.022	
Tin (Sn)	0.002	
Nickel (Ni)	0.017	
Chromium (Cr)	0.045	
Molybdenum (Mo)	0.008	
Aluminum (Al)	0.046	
Vanadium (V)	0.003	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.006	
CE = C + (Mn/6)	**0.3640**	
V + Nb + Ti	**0.008**	

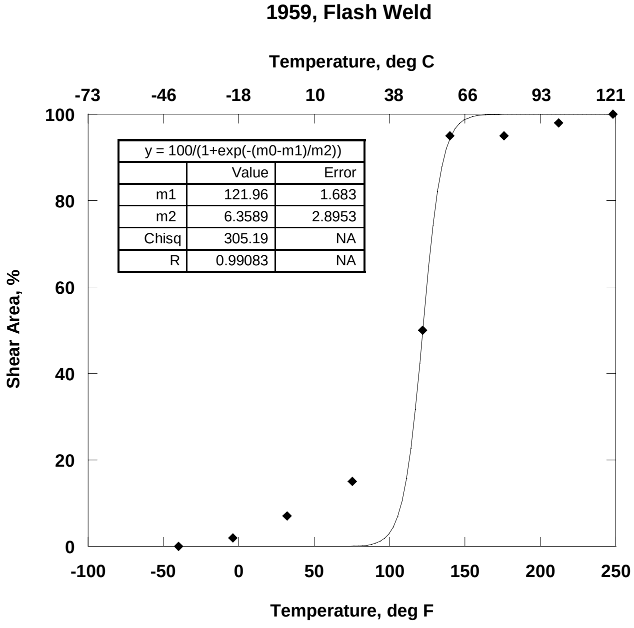
** API 5LX-46, cold expanded, 1958 API code

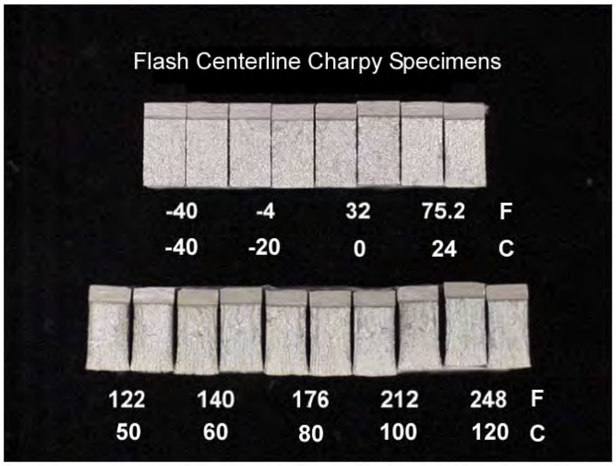
Flash centerline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-40	-40	1	1	0	1	0.03
-4	-20	2	3	2	2	0.05
32	0	5	7	7	8	0.20
75.2	24	5	7	15	8	0.20
122	50	11	15	50	17	0.43
140	60	13	18	95	13	0.33
176	80	9	12	95	13	0.33
212	100	13	18	98	18	0.46
248	120	10	14	100	14	0.36

Transition temperature, 85% shear area for specimen	135	°F	48	°C
Charpy upper shelf energy, (full size specimen)	57	ft-lbs	15	Joules



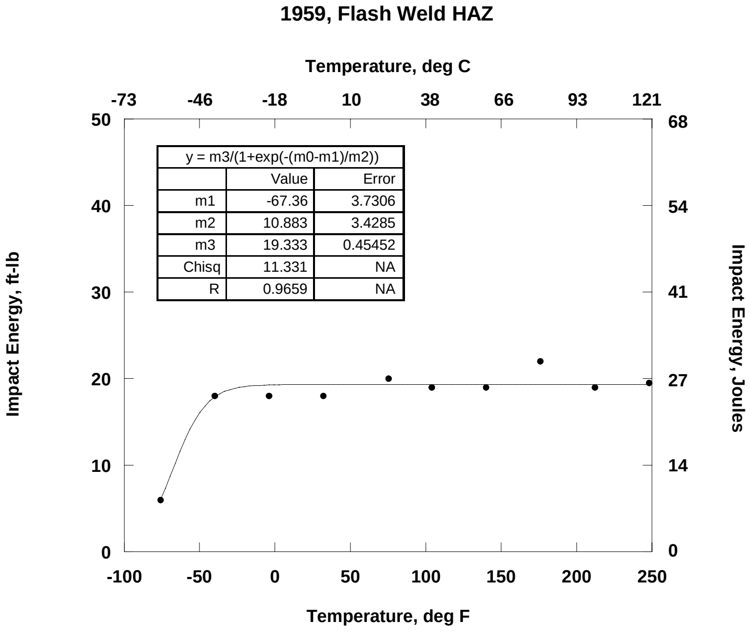


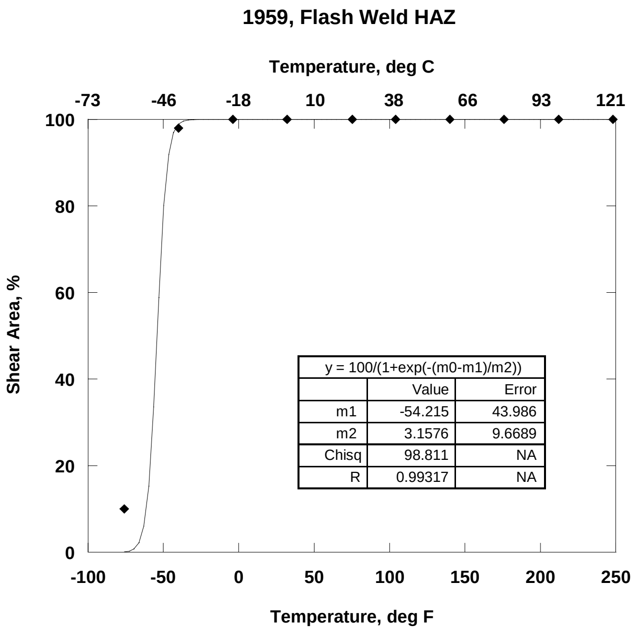


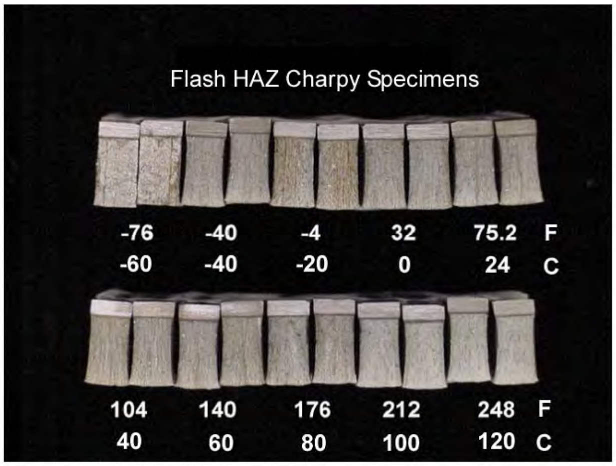
HAZ Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-76	-60	6	8	10	6	0.15
-40	-40	18	24	98	19	0.48
-4	-20	18	24	100	20	0.51
32	0	18	24	100	23	0.58
75.2	24	20	27	100	24	0.61
104	40	19	26	100	23	0.58
140	60	19	26	100	26	0.66
176	80	22	30	100	21	0.53
212	100	19	26	100	26	0.66
248	120	19.5	26	100	24	0.61

Transition temperature, 85% shear area for specimen	-55	°F	-48	°C
Charpy upper shelf energy, (full size specimen)	18	ft-lbs	24	Joules







Vickers hardness testing results

Remote from Seam			HAZ		Weld Metal or Fusion Line				
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID	comments
194	205	197	at ID corner of flash upset	203			201	203	Cracked through
	197		ID low temp	204					fusion line at OD
			ID low temp	191					
			midwall low temp	207					
			OD high temp	226					
			OD low temp	187					
			midwall close to fusion line	226					
			ID high temp	219					
			1/3T from OD near fusion line	213					
			OD high temp, HAZ side of crack	205					

Ring flattening test results

Weld Location, degrees	**Opening observed when flattened to**					
	2/3 D		**1/3 D**		**Walls Meeting**	
	Cracks	**Location**	**Cracks**	**Location**	**Cracks**	**Location**
0°	No	-	No	-	No	-
90°	No	-	No	-	Yes	HAZ

General notes and observations for this pipe section:

This pipe section reportedly had MnS inclusions at the bondline. There was also a 7-inch long, ID connected hook crack downstream from the area of material property testing. This pipe was used for natural gas transmission.

Pipe background information

Nominal diameter	26-inch	660 mm
Nominal wall thickness	0.281-inch	7.1 mm
Pipe manufacturer	A. O. Smith Corp.	
Year of manufacture	1957	
Seam weld type	Flash Weld	
Reported pipe grade	Not reported. Probably API 5LX-42	

Base metal tensile test results*

Tensile strength	62,200 psi	429 MPa
Yield strength	44,000 psi	303 MPa
Elongation, %	30.0	
Reduction of area, %	39.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 64,000 psi	441 MPa
#2	Failed in base metal @ 61,900 psi	427 MPa

Flash and HAZ chemical analysis results

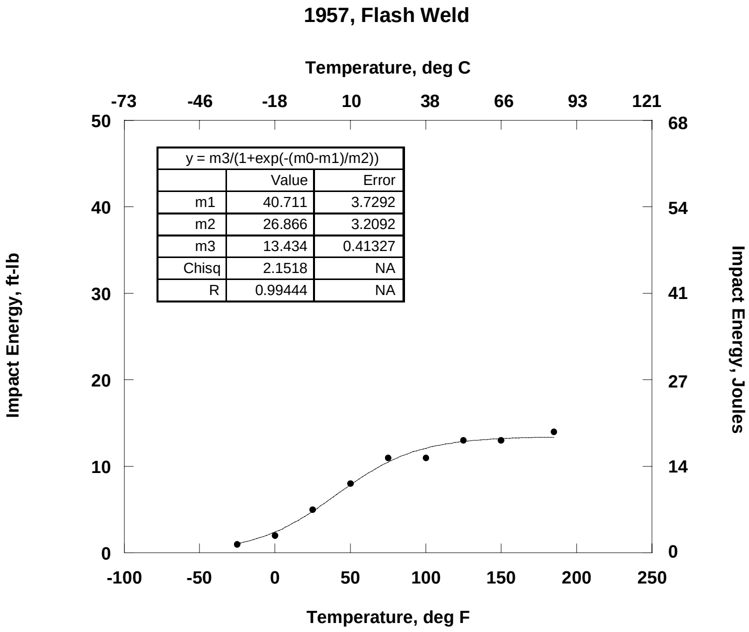
Element	Weight % of sample	Base metal **max. allow (Wt %)
Carbon (C)	0.202	0.280
Manganese (Mn)	0.900	1.250
Phosphorus (P)	0.014	0.040
Sulphur (S)	0.019	0.050
Silicon (Si)	0.054	
Copper (Cu)	0.062	
Tin (Sn)	0.009	
Nickel (Ni)	0.017	
Chromium (Cr)	0.029	
Molybdenum (Mo)	0.008	
Aluminum (Al)	0.03	
Vanadium (V)	0.003	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.006	
CE = C + (Mn/6)	**0.3520**	
V + Nb + Ti	**0.008**	

** API 5LX-42, cold expanded, 1957 API code

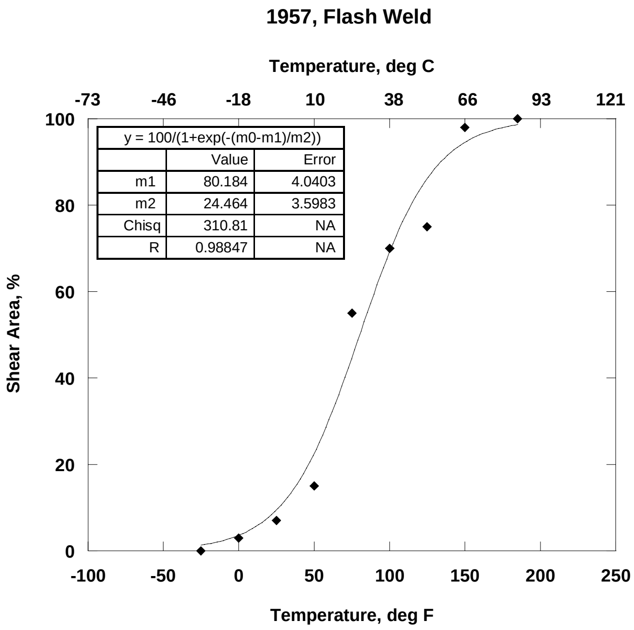
Flash centerline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-25	-32	1	1	0	2	0.05
0	-18	2	3	3	2	0.05
25	-4	5	7	7	5	0.13
50	10	8	11	15	5	0.13
75	24	11	15	55	13	0.33
100	38	11	15	70	12	0.30
125	52	13	18	75	17	0.43
150	66	13	18	98	18	0.46
185	85	14	19	100	21	0.53

Transition temperature, 85% shear area for specimen	130	°F	54	°C
Charpy upper shelf energy, (full size specimen)	13	ft-lbs	18	Joules


1957, Flash Weld

y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	40.711	3.7292
m2	26.866	3.2092
m3	13.434	0.41327
Chisq	2.1518	NA
R	0.99444	NA


1957, Flash Weld

y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	80.184	4.0403
m2	24.464	3.5983
Chisq	310.81	NA
R	0.98847	NA

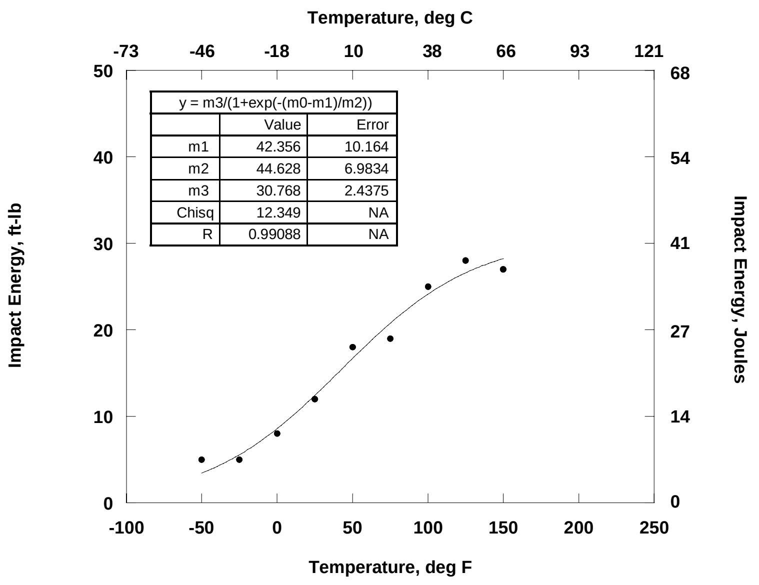
Charpy specimens were not returned for photo documentation

HAZ Charpy V-notch impact test results

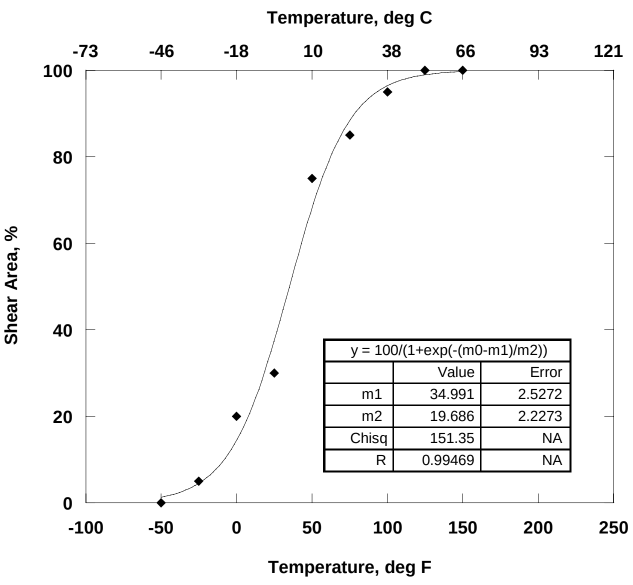
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-50	-46	5	7	0	5	0.13
-25	-32	5	7	5	4	0.10
0	-18	8	11	20	10	0.25
25	-4	12	16	30	11	0.28
50	10	18	24	75	18	0.46
75	24	19	26	85	23	0.58
100	38	25	34	95	29	0.74
125	52	28	38	100	30	0.76
150	66	27	37	100	32	0.81

Transition temperature, 85% shear area for specimen	75	°F	24	°C
Charpy upper shelf energy, (full size specimen)	19	ft-lbs	26	Joules

1957, Flash Weld HAZ



1957, Flash Weld HAZ



Charpy specimens were not returned for photo documentation

Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

General notes and observations for this pipe section:

No defects were associated with this pipe section. Conflicting information was reported about which mill manufactured this pipe, therefore it may have come from Milwaukee or Houston.

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.250-inch	6.4 mm
Pipe manufacturer	Lone Star	
Year of manufacture	1955	
Seam weld type	LF ERW	
Reported pipe grade	API 5LX-42, non-expanded	

Base metal tensile test results*

Tensile strength	66,100 psi	456 MPa
Yield strength	46,200 psi	319 MPa
Elongation, %	31.0	
Reduction of area, %	42.0	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

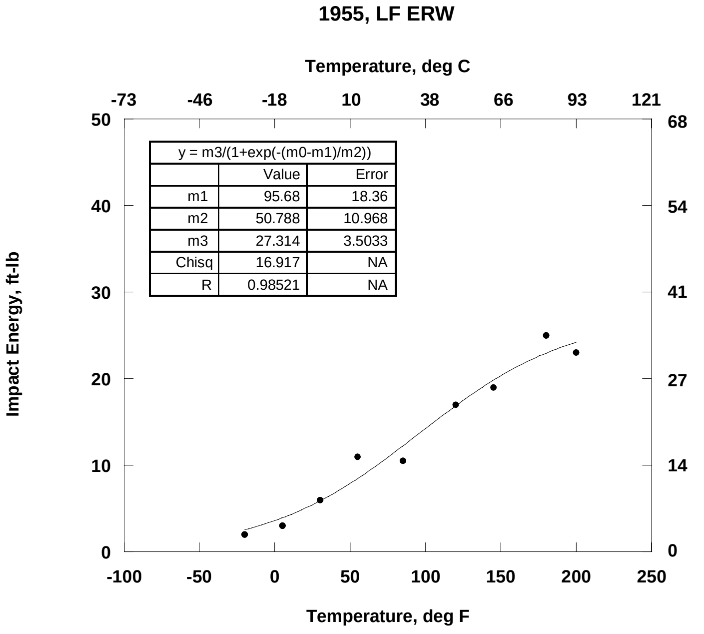
Bondline and HAZ chemical analysis results

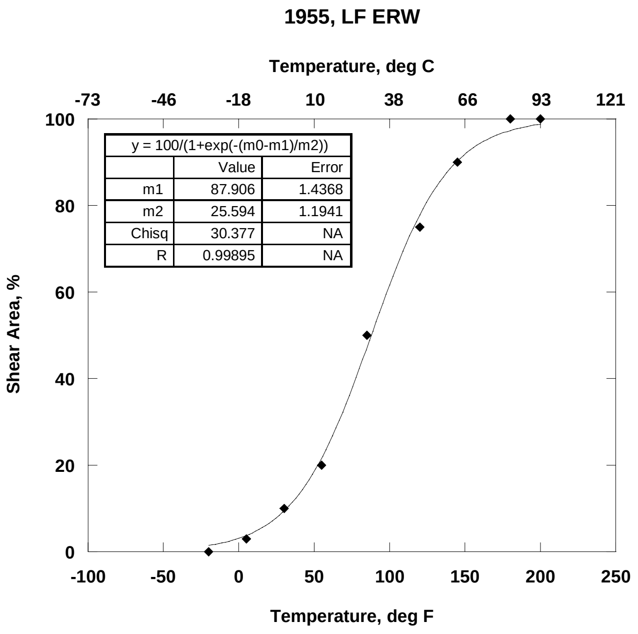
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.212	0.300
Manganese (Mn)	1.103	1.350
Phosphorus (P)	0.008	0.040
Sulphur (S)	0.020	0.050
Silicon (Si)	0.107	
Copper (Cu)	0.060	
Tin (Sn)	0.009	
Nickel (Ni)	0.030	
Chromium (Cr)	0.021	
Molybdenum (Mo)	0.008	
Aluminum (Al)	0.03	
Vanadium (V)	0.001	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0002	
Cobalt (Co)	0.005	
CE = C + (Mn/6)	**0.3958**	
V + Nb + Ti	**0.006**	

Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	Percent	mils	mm
-20	-29	2	3	0	5	0.13
5	-15	3	4	3	8	0.20
30	-1	6	8	10	12	0.30
55	13	11	15	20	13	0.33
85	29	10.5	14	50	16	0.41
120	49	17	23	75	19	0.48
145	63	19	26	90	20	0.51
180	82	25	34	100	23	0.58
200	93	23	31	100	21	0.53

Transition temperature, 85% shear area for specimen	130	°F	54	°C
Charpy upper shelf energy, (full size specimen)	18	ft-lbs	24	Joules





Photographs of Charpy specimens were not found in this record

Ring flattening test results N/A

Remote from Seam			HAZ		Weld Metal or Fusion Line			
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID
168	157	167	ID near fusion line	191		230	213	193
	161		midwall near fusion line	209				
			OD near fusion line	227				
			ID low temp	179				
			1/3T from OD low temp	194				
			midwall low temp	185				
			1/3T from OD lower temp	193				
			OD low temp	220				

General notes and observations for this pipe section:

This pipe section was reported to have stitching in the ERW seam, downstream from the area of material property testing.

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.266-inch	6.8 mm
Pipe manufacturer	Unknown. Possibly Republic Steel	
Year of manufacture	1930	
Seam weld type	LF ERW	
Reported pipe grade	Not reported. Probably API 5L Gr. B, non-expanded	

Base metal tensile test results*

Tensile strength	65,800 psi	454 MPa
Yield strength	44,600 psi	308 MPa
Elongation, %	30.2	
Reduction of area, %	54.4	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 64,900 psi	447 MPa
#2	Failed in base metal @ 66,900 psi	461 MPa

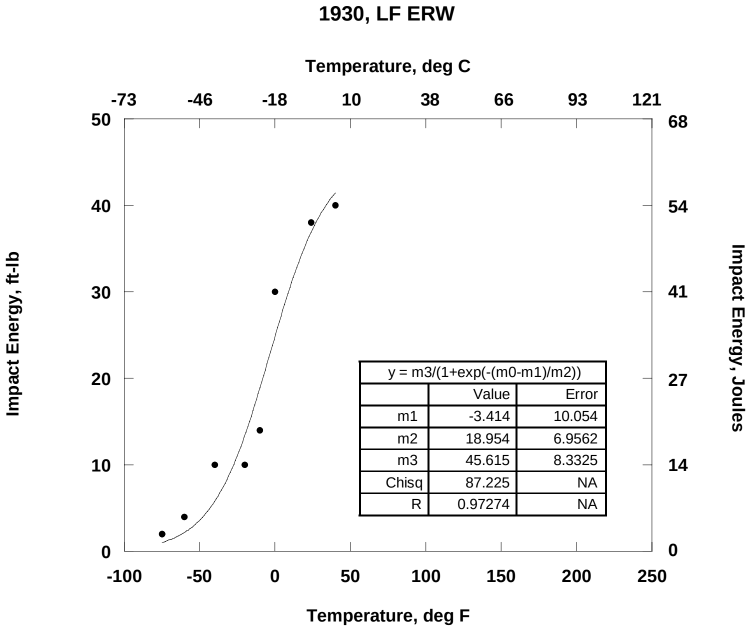
Bondline and HAZ chemical analysis results

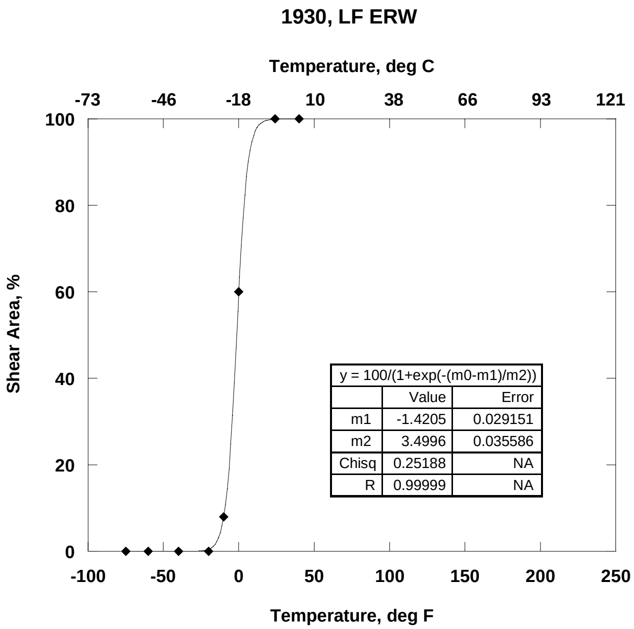
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.235	0.300 (for Gr. B seamless only, 1930)
Manganese (Mn)	0.490	0.300 – 0.600
Phosphorus (P)	0.008	0.045 ?
Sulphur (S)	0.018	0.060 ?
Silicon (Si)	0.007	
Copper (Cu)	0.051	
Tin (Sn)	0.006	
Nickel (Ni)	0.060	
Chromium (Cr)	0.054	
Molybdenum (Mo)	0.010	
Aluminum (Al)	0.002	
Vanadium (V)	0.001	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0	
Cobalt (Co)	0.006	
CE = C + (Mn/6)	**0.3167**	
V + Nb + Ti	**0.005**	

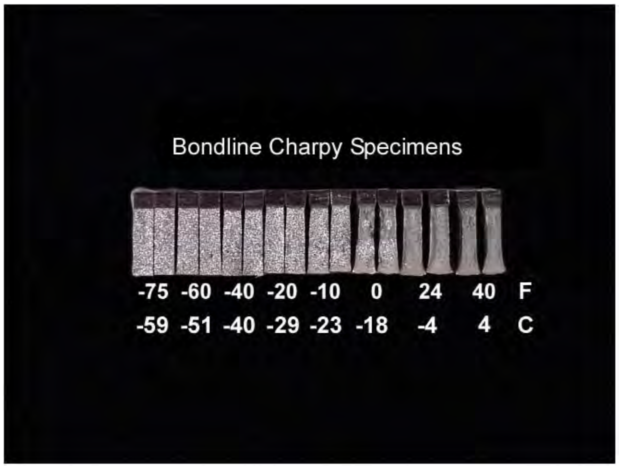
Flash centerline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-75	-59	2	3	0	0	0
-60	-51	4	5	0	6	0.15
-40	-40	10	14	0	8	0.20
-20	-29	10	14	0	6	0.15
-10	-23	14	19	8	15	0.38
0	-18	30	41	60	26	0.66
24	-4	38	52	100	34	0.86
40	4	40	54	100	30	0.76

Transition temperature, 85% shear area for specimen	20	°F	-7	°C
Charpy upper shelf energy, (full size specimen)	37	ft-lbs	50	Joules





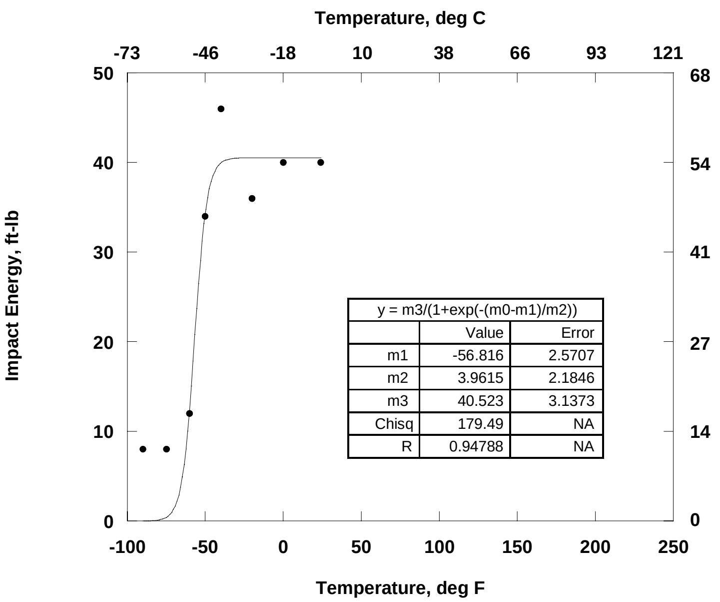


HAZ Charpy V-notch impact test results

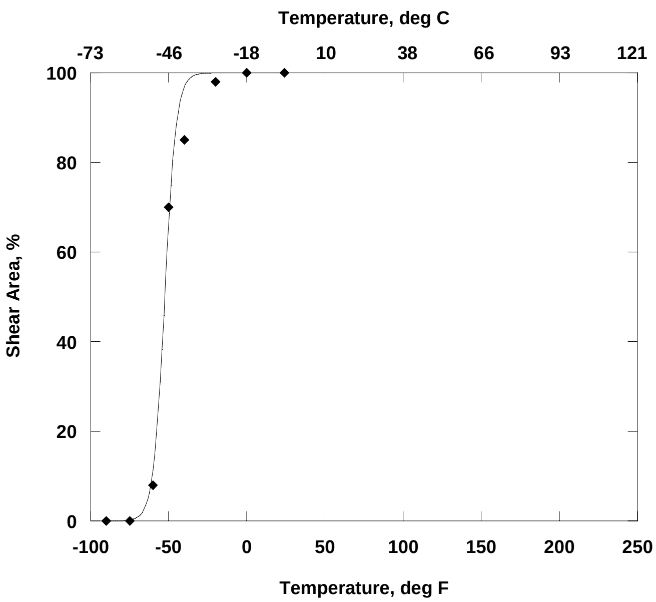
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-90	-68	8	11	0	8	0.20
-75	-59	8	11	0	7	0.18
-60	-51	12	16	8	12	0.30
-50	-46	34	46	70	33	0.84
-40	-40	46	62	85	31	0.79
-20	-29	36	49	98	34	0.86
0	-18	40	54	100	33	0.84
24	-4	40	54	100	36	0.91

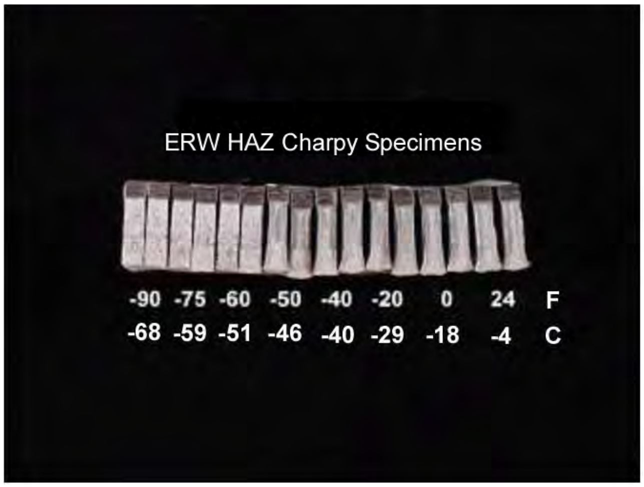
Transition temperature, 85% shear area for specimen	-40	°F	-40	°C
Charpy upper shelf energy, (full size specimen)	46	ft-lbs	62	Joules

1930, LF ERW HAZ



1930, LF ERW HAZ





Vickers hardness testing results

Remote from Seam			HAZ		Weld Metal or Fusion Line				
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID	comments
164	161	161	OD low temp	173		181	175	164	
			OD low temp	164	177				between OD and midwall
			midwall low temp	164					
			ID low temp	167					
			ID low temp	151					
			OD near fusion line	180					
			High CE banding	191					
			midwall near fusion line	176					

Ring flattening test results

Weld Location, degrees	**Opening observed when flattened to**					
	2/3 D		**1/3 D**		**Walls Meeting**	
	Cracks	**Location**	**Cracks**	**Location**	**Cracks**	**Location**
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. Offset skelp edges at the seam and inadequate trim of the upset at the ID

Pipe background information

Nominal diameter	8-inch	203 mm
Nominal wall thickness	0.188-inch	4.8 mm
Pipe manufacturer	Cal-metal Pipe Corporation	
Year of manufacture	1963	
Seam weld type	HFC ERW	
Reported pipe grade	API 5LX-46, non-expanded	

Base metal tensile test results*

Tensile strength	62,200 psi	429 MPa
Yield strength	53,200 psi	367 MPa
Elongation, %	26.0	
Reduction of area, %	45.0	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 71,000 psi	490 MPa
#2	Failed in base metal @ 64,300 psi	443 MPa

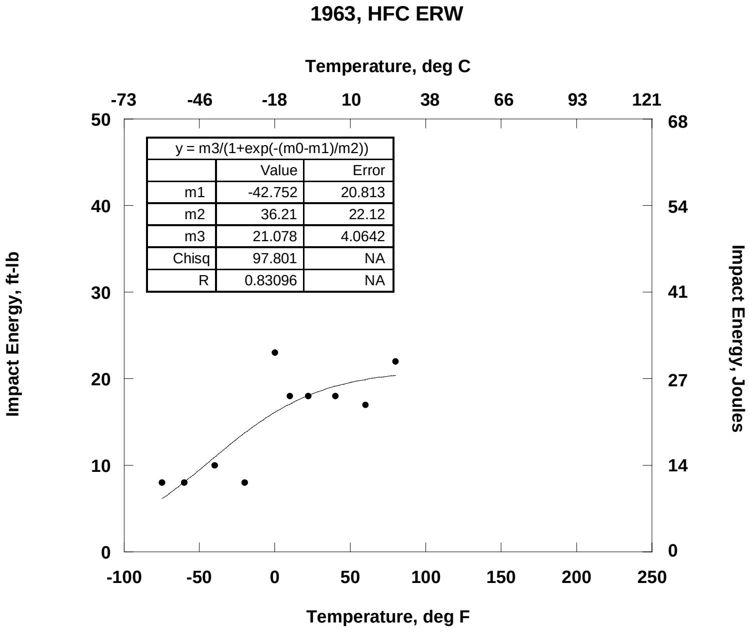
Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.213	0.300
Manganese (Mn)	0.695	1.350
Phosphorus (P)	0.009	0.040
Sulphur (S)	0.016	0.050
Silicon (Si)	0.012	
Copper (Cu)	0.125	
Tin (Sn)	0.020	
Nickel (Ni)	0.039	
Chromium (Cr)	0.024	
Molybdenum (Mo)	0.007	
Aluminum (Al)	0	
Vanadium (V)	0.001	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0	
Cobalt (Co)	0.018	
CE = C + (Mn/6)	**0.3288**	
V + Nb + Ti	**0.005**	

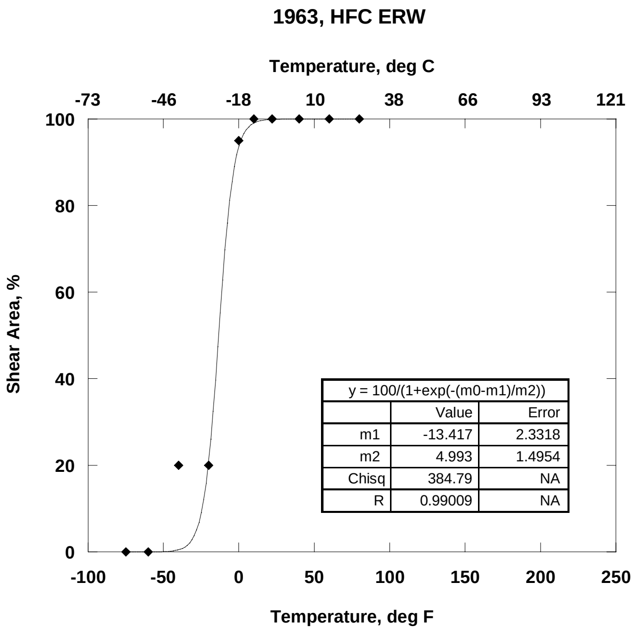
Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-75	-59	8	11	0	9	0.23
-60	-51	8	11	0	7	0.18
-40	-40	10	14	20	13	0.33
-20	-29	8	11	20	16	0.41
0	-18	23	31	95	26	0.66
10	-12	18	24	100	24	0.61
22	-6	18	24	100	24	0.61
40	4	18	24	100	27	0.69
60	16	17	23	100	25	0.64
80	27	22	30	100	29	0.74

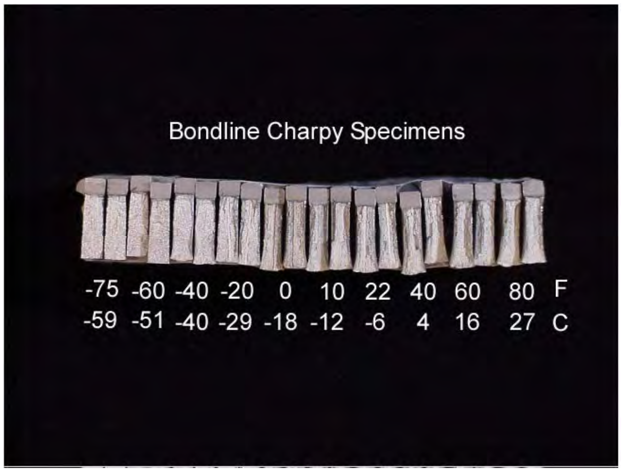
Transition temperature, 85% shear area for specimen	-5	°F	-21	°C
Charpy upper shelf energy, (full size specimen)	20	ft-lbs	27	Joules

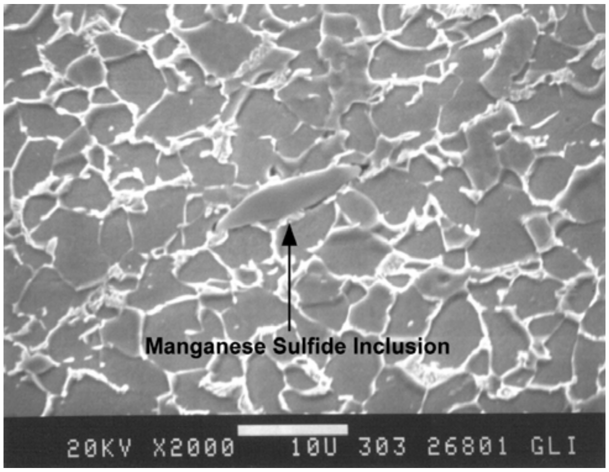


y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	-42.752	20.813
m2	36.21	22.12
m3	21.078	4.0642
Chisq	97.801	NA
R	0.83096	NA



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	-13.417	2.3318
m2	4.993	1.4954
Chisq	384.79	NA
R	0.99009	NA





Ring flattening test results N/A

General notes and observations for this pipe section:

This pipe section was removed after rupturing during a hydrostatic test. The rupture occurred because of a 7-inch long hook crack in the seam weld. MnS inclusions were found in the HAZ near the hook crack. The rupture occurred at 1,655 psig. Material property testing was conducted several inches away from the rupture. This pipe was used for natural gas transmission.

Pipe background information

Nominal diameter	8-inch	203 mm
Nominal wall thickness	0.322-inch	8.2 mm
Pipe manufacturer	Unknown	
Year of manufacture	1932	
Seam weld type	Lap Weld	
Reported pipe grade	Probably API 5L Gr. B, non-expanded	

Base metal tensile test results*

Tensile strength	49,400 psi	341 MPa
Yield strength	35,600 psi	245 MPa
Elongation, %	24.0	
Reduction of area, %	39.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 41,000 psi	214 MPa
#2	Failed in base metal @ 47,900 psi	261 MPa

Lap area chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.193	0.300 (for Gr. B seamless only, 1930)
Manganese (Mn)	0.550	0.300 – 0.600
Phosphorus (P)	0.032	0.045 ?
Sulphur (S)	0.019	0.060 ?
Silicon (Si)	0.031	
Copper (Cu)	0.049	
Tin (Sn)	0.004	
Nickel (Ni)	0.007	
Chromium (Cr)	0.037	
Molybdenum (Mo)	0.010	
Aluminum (Al)	0.028	
Vanadium (V)	0.002	
Niobium (Nb)	0.008	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.01	
CE = C + (Mn/6)	**0.2847**	
V + Nb + Ti	**0.010**	

Ring flattening test results

Weld Location, degrees	**Opening observed when flattened to**					
	2/3 D		**1/3 D**		**Walls Meeting**	
	Cracks	**Location**	**Cracks**	**Location**	**Cracks**	**Location**
0°	No	-	Yes	Lap	-	-
90°	No	-	Yes	Lap	-	-

General notes and observations for this pipe section:

It was reported that this pipe section had entrapped oxide layers in the Lap Weld, downstream from the area of material property testing. Tensile tests across the seam both failed in the Lap. Insufficient material remained for Charpy impact tests.

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	US Steel, bought by Camp Hill Corp.	
Year of manufacture	Unknown	
Seam weld type	HFC ERW, Thermatool	
Reported pipe grade	API 5LX-52, possibly cold-expanded	

Base metal tensile test results*

Tensile strength	72,900 psi	503 MPa
Yield strength	56,100 psi	387 MPa
Elongation, %	31.6	
Reduction of area, %	46.4	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.262	Unknown year of manufacture
Manganese (Mn)	1.250	Applicable code not known
Phosphorus (P)	0.012	
Sulphur (S)	0.020	
Silicon (Si)	0.037	
Copper (Cu)	0.013	
Tin (Sn)	0.004	
Nickel (Ni)	0.010	
Chromium (Cr)	0.030	
Molybdenum (Mo)	0.009	
Aluminum (Al)	0.004	
Vanadium (V)	0.002	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.005	
CE = C + (Mn/6)	**0.4703**	
V + Nb + Ti	**0.006**	

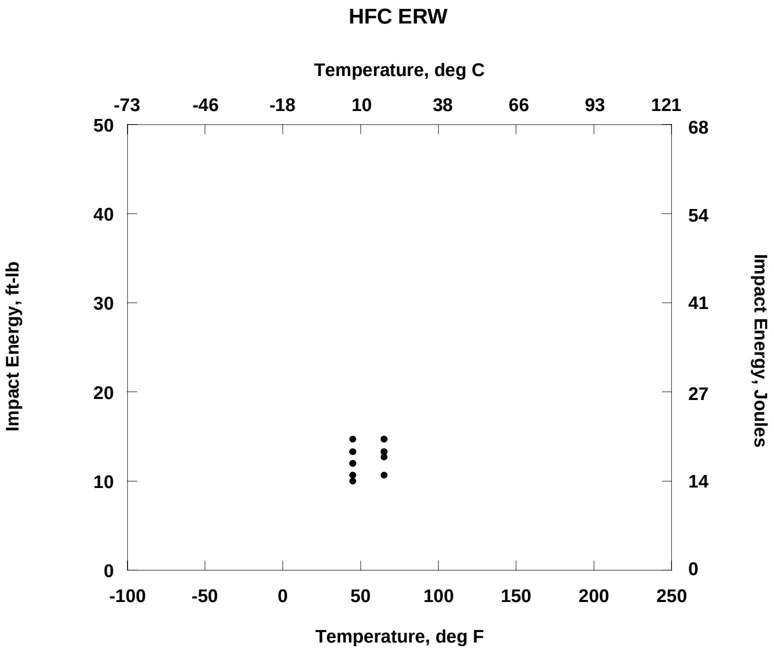
Bondline Charpy V-notch impact test results

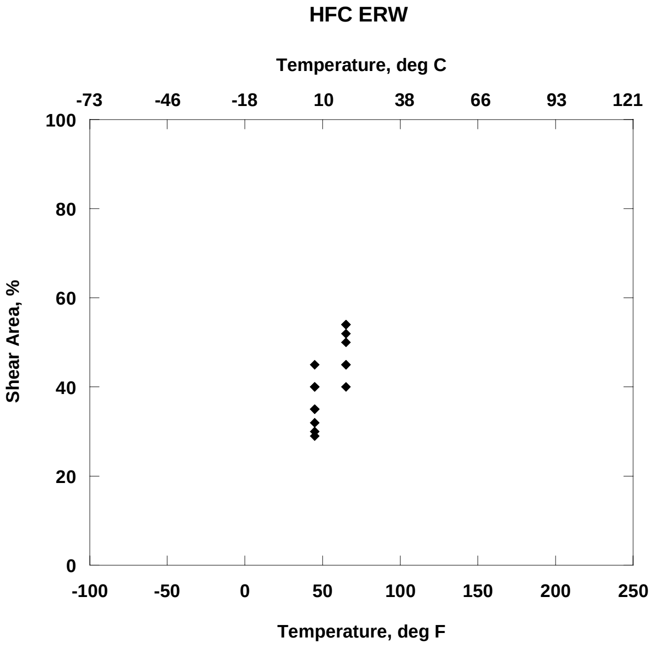
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	Percent	mils	mm
45	7	13	18	32	16	0.23
45	7	12	16	35	12	0.18
45	7	10.5	14	29	15	0.33
45	7	12	16	30	14	0.41
45	7	10	14	40	16	0.66
45	7	14.5	20	35	19	0.61
45	7	10.5	14	40	12	0.61
45	7	13.5	18	45	13	0.69
Average value		12	16	36	15	0.46

Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
65	18	13.5	18	54	17	0.43
65	18	14	19	52	20	0.51
65	18	14.5	20	50	19	0.48
65	18	10.5	14	45	15	0.38
65	18	13	18	40	17	0.43
65	18	12.5	17	40	17	0.43
65	18	13	18	45	15	0.38
65	18	14.5	20	54	16	0.41
Average value		13.2	18	48	17	0.43

Transition temperature, 85% shear area for specimen N/A
Charpy upper shelf energy, (full size specimen) N/A





Ring flattening test results	N/A
General notes and observations for this pipe section:	Pipe section submitted by anonymous donor

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	US Steel, bought by Camp Hill Corp.	
Year of manufacture	Unknown	
Seam weld type	HFC ERW, Thermatool	
Reported pipe grade	API 5LX-52, possibly cold-expanded	

Base metal tensile test results*

Tensile strength	75,000 psi	517 MPa
Yield strength	57,000 psi	393 MPa
Elongation, %	34.0	
Reduction of area, %	45.0	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1 Failed in base metal @ 83,000 psi 572 MPa

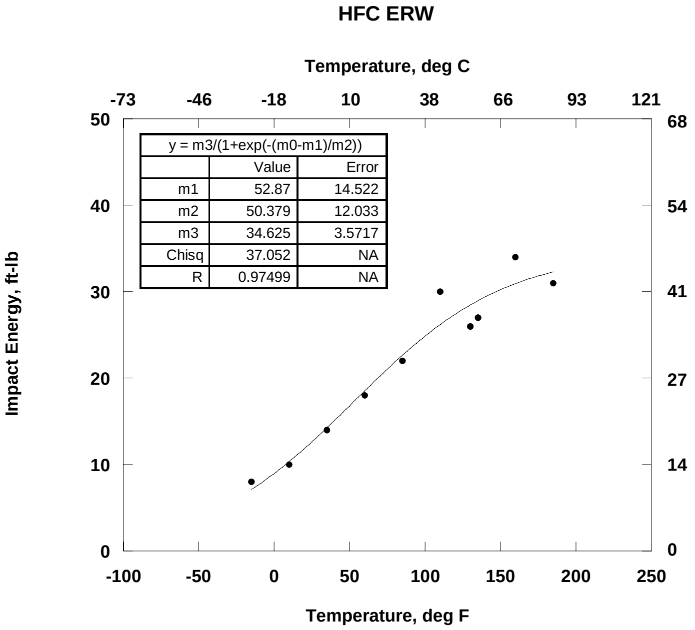
Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.253	Unknown year of manufacture
Manganese (Mn)	1.220	Applicable code not known
Phosphorus (P)	0.008	
Sulphur (S)	0.018	
Silicon (Si)	0.038	
Copper (Cu)	0.012	
Tin (Sn)	0.009	
Nickel (Ni)	0.072	
Chromium (Cr)	0.032	
Molybdenum (Mo)	0.008	
Aluminum (Al)	0.004	
Vanadium (V)	0.003	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.005	
CE = C + (Mn/6)	**0.4558**	
V + Nb + Ti	**0.008**	

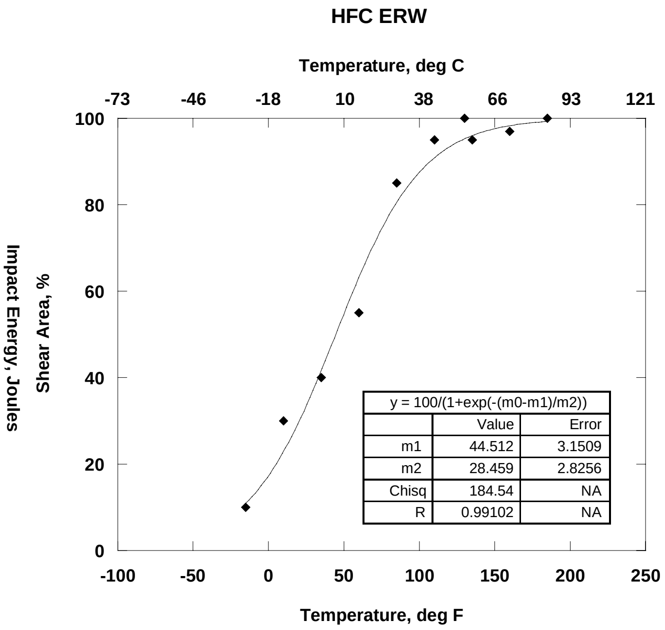
Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-15	-26	8	11	10	8	0.20
10	-12	10	14	30	10	0.25
35	2	14	19	40	20	0.51
60	16	18	24	55	24	0.61
85	29	22	30	85	26	0.66
110	43	30	41	95	33	0.84
130	54	26	35	100	25	0.64
135	57	27	37	95	29	0.74
160	71	34	46	97	36	0.91
185	85	31	42	100	35	0.89

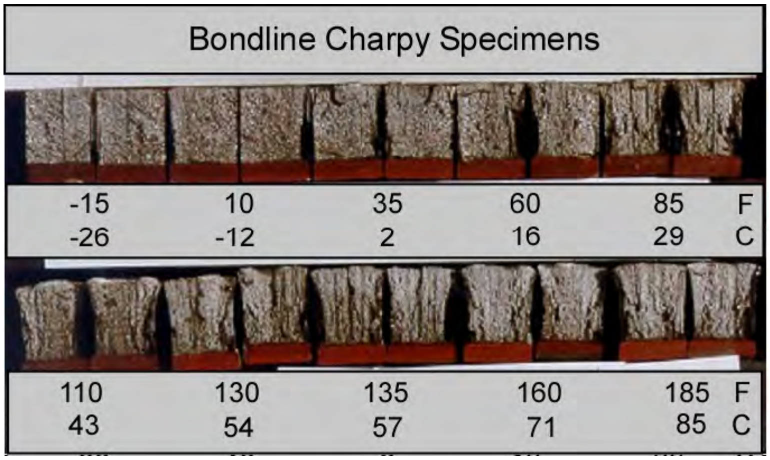
Transition temperature, 85% shear area for specimen	90	°F	32	°C
Charpy upper shelf energy, (full size specimen)	27	ft-lbs	27	Joules



y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	52.87	14.522
m2	50.379	12.033
m3	34.625	3.5717
Chisq	37.052	NA
R	0.97499	NA



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	44.512	3.1509
m2	28.459	2.8256
Chisq	184.54	NA
R	0.99102	NA



Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	Yes	Pipe wall lamination
90°	No	-	No	-	Yes	Seam weld

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	US Steel, bought by Camp Hill Corp.	
Year of manufacture	Unknown	
Seam weld type	HFC ERW, Thermatool	
Reported pipe grade	API 5LX-52, possibly cold-expanded	

Base metal tensile test results*

Tensile strength	73,550 psi	507 MPa
Yield strength	57,050 psi	393 MPa
Elongation, %	33.2	
Reduction of area, %	48.3	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.268	Unknown year of manufacture
Manganese (Mn)	1.205	Applicable code not known
Phosphorus (P)	0.009	
Sulphur (S)	0.018	
Silicon (Si)	0.036	
Copper (Cu)	0.014	
Tin (Sn)	0.015	
Nickel (Ni)	0.013	
Chromium (Cr)	0.038	
Molybdenum (Mo)	0.010	
Aluminum (Al)	0.004	
Vanadium (V)	0.003	
Niobium (Nb)	0.003	
Zirconium (Zr)	0.001	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.006	
CE = C + (Mn/6)	**0.4688**	
V + Nb + Ti	**0.009**	

Bondline Charpy V-notch impact test results

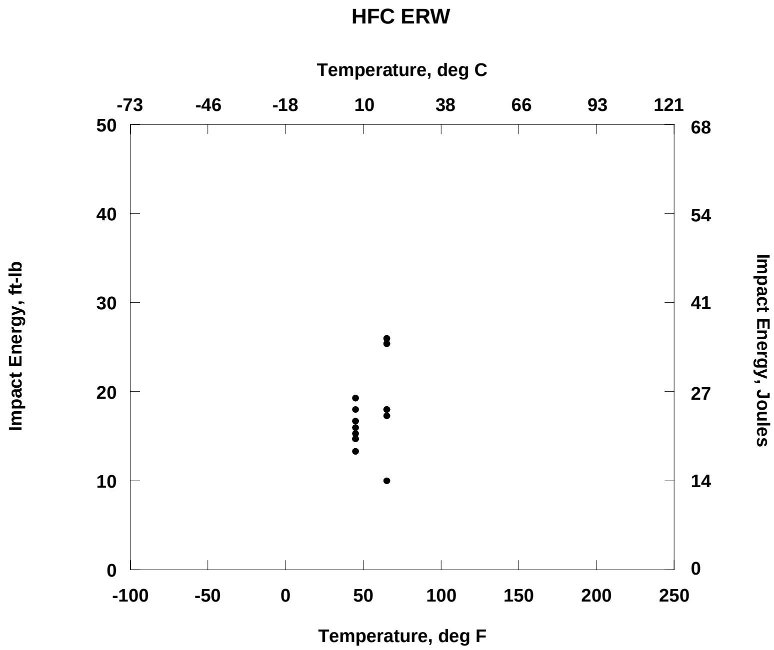
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
45	7	14.5	20	40	19	0.48
45	7	16	22	35	16	0.41
45	7	16.5	22	36	17	0.43
45	7	15	20	36	18	0.46
45	7	14.5	20	30	18	0.46
45	7	19	26	58	24	0.61
45	7	18	24	48	20	0.51
45	7	13.5	18	48	17	0.43
Average value		15.9	22	41	19	0.47

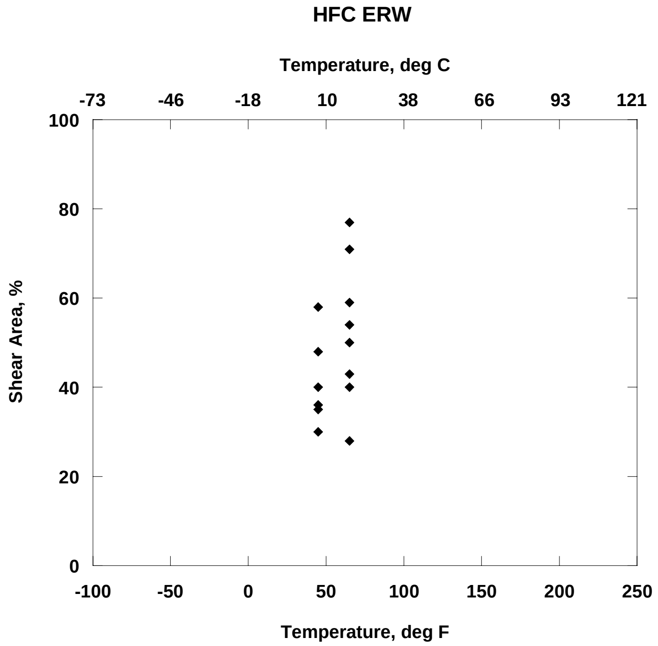
Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
65	18	18	24	28	21	0.53
65	18	18	24	50	22	0.56
65	18	26	35	71	26	0.66
65	18	25	34	77	26	0.66
65	18	10	14	43	17	0.43
65	18	18	24	59	20	0.51
65	18	18	24	40	20	0.51
65	18	17	23	54	22	0.56
Average value		19	26	53	22	0.55

Transition temperature, 85% shear area for specimen N/A

Charpy upper shelf energy, (full size specimen) N/A





Photographs of Charpy specimens were not found in this record

Ring flattening test results	N/A
General notes and observations for this pipe section:	Pipe section submitted by anonymous donor. This pipe was used for liquid natural gas transmission.

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	US Steel, bought by Camp Hill Corp.	
Year of manufacture	Unknown	
Seam weld type	HFC ERW	
Reported pipe grade	API 5LX-52, possibly cold-expanded	

Base metal tensile test results*

Tensile strength	71,500 psi	493 MPa
Yield strength	55,500 psi	383 MPa
Elongation, %	34.0	
Reduction of area, %	45.0	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1 Failed in base metal @ 86,000 psi 593 MPa

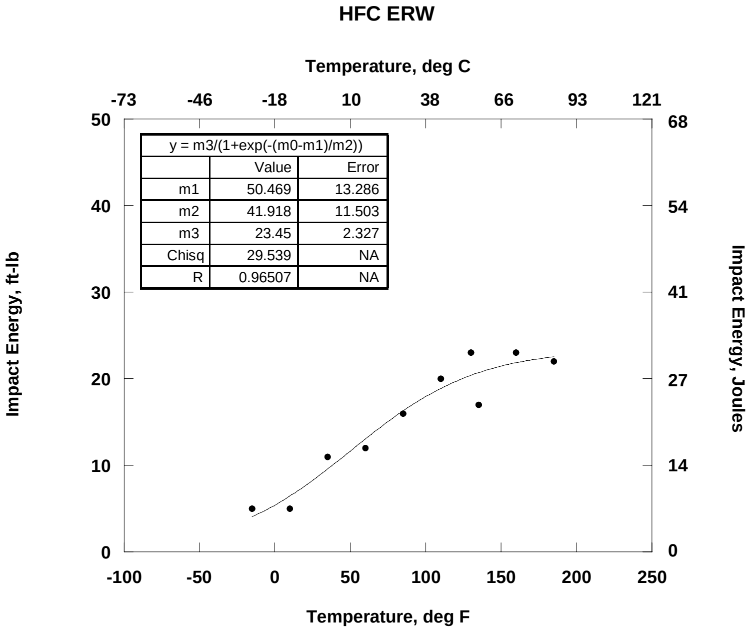
Bondline and HAZ chemical analysis results

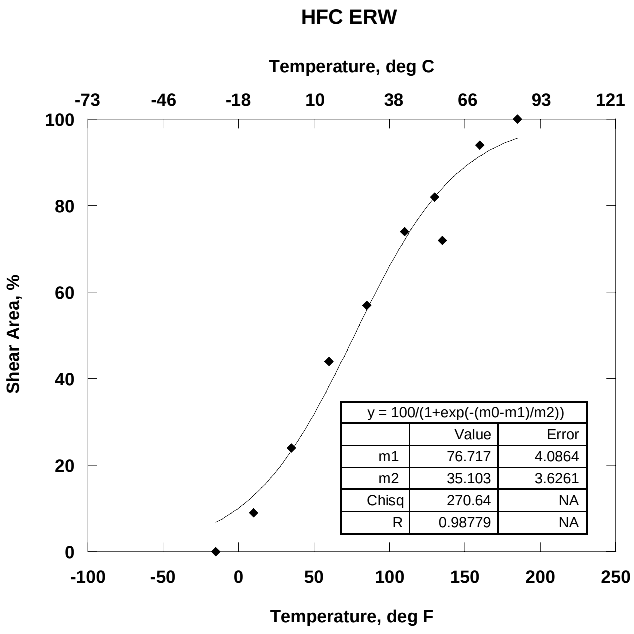
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.259	Unknown year of manufacture
Manganese (Mn)	1.115	Applicable code not known
Phosphorus (P)	0.009	
Sulphur (S)	0.016	
Silicon (Si)	0.035	
Copper (Cu)	0.014	
Tin (Sn)	0.002	
Nickel (Ni)	0.010	
Chromium (Cr)	0.042	
Molybdenum (Mo)	0.006	
Aluminum (Al)	0.006	
Vanadium (V)	0.003	
Niobium (Nb)	0.003	
Zirconium (Zr)	0.000	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0002	
Cobalt (Co)	0.005	
CE = C + (Mn/6)	**0.4448**	
V + Nb + Ti	**0.008**	

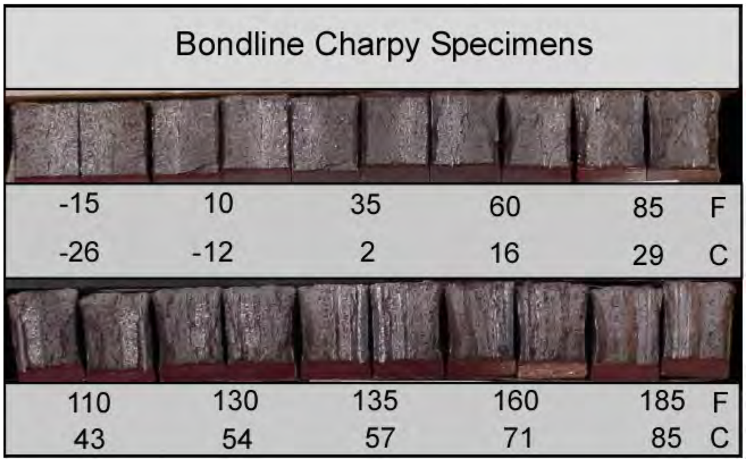
Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-15	-26	5	7	0	2	0.05
10	-12	5	7	9	2	0.05
35	2	11	15	24	9	0.23
60	16	12	16	44	12	0.30
85	29	16	22	57	14	0.36
110	43	20	27	74	20	0.51
130	54	23	31	82	22	0.56
135	57	17	23	72	19	0.48
160	71	23	31	94	24	0.61
185	85	22	30	100	22	0.56

Transition temperature, 85% shear area for specimen	142	°F	61	°C
Charpy upper shelf energy, (full size specimen)	21	ft-lbs	28	Joules







Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	Yes	Pipe wall lamination
90°	No	-	No	-	Yes	Seam weld

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. This pipe was used for liquid natural gas transmission.

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	US Steel, bought by Camp Hill Corp.	
Year of manufacture	Unknown	
Seam weld type	HFC ERW, Thermatool	
Reported pipe grade	API 5LX-52, possibly cold-expanded	

Base metal tensile test results*

Tensile strength	71,150 psi	491 MPa
Yield strength	56,600 psi	390 MPa
Elongation, %	32.2	
Reduction of area, %	48.6	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1 Failed in base metal @ 78,700 psi 543 MPa

Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.266	Unknown year of manufacture
Manganese (Mn)	1.133	Applicable code not known
Phosphorus (P)	0.010	
Sulphur (S)	0.021	
Silicon (Si)	0.035	
Copper (Cu)	0.037	
Tin (Sn)	0.003	
Nickel (Ni)	0.017	
Chromium (Cr)	0.047	
Molybdenum (Mo)	0.010	
Aluminum (Al)	0.005	
Vanadium (V)	0.003	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.006	
CE = C + (Mn/6)	**0.4543**	
V + Nb + Ti	**0.008**	

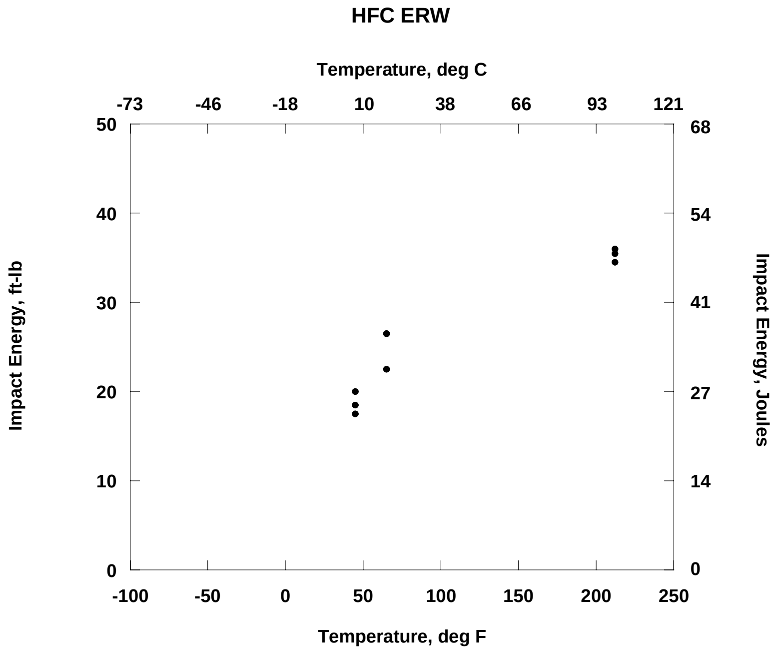
Bondline Charpy V-notch impact test results

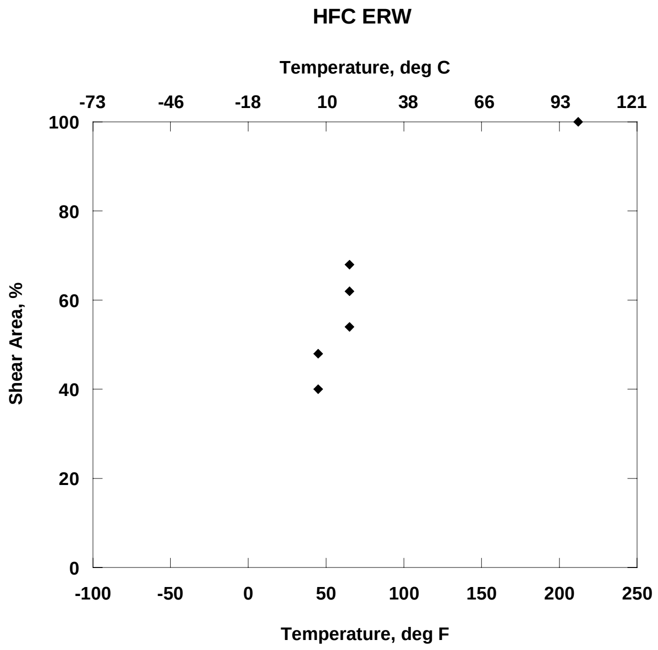
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
45	7	20	27	40	25	0.64
45	7	18.5	25	40	22	0.56
45	7	17.5	23	48	23	0.58
Average value		18.7	25	43	23	0.59
65	18	22.5	31	68	28	0.71
65	18	26.5	36	54	32	0.81
65	18	26.5	36	62	26	0.66
Average value		25.2	34	61	29	0.73

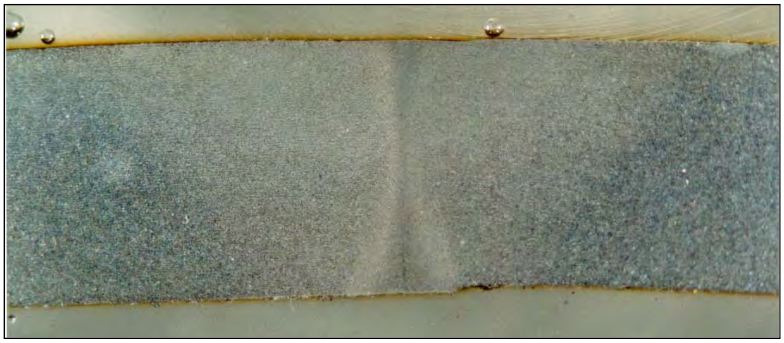
Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
212	100	36	49	100	39	0.99
212	100	34.5	47	100	36	0.91
212	100	35.5	48	100	45	1.14
Average value		35.3	48	100	40	1.01

Transition temperature, 85% shear area for specimen N/A
Charpy upper shelf energy, (full size specimen) N/A







Photographs of Charpy specimens were not found in this record

Ring flattening test results

Weld Location, degrees	**Opening observed when flattened to**					
	2/3 D		**1/3 D**		**Walls Meeting**	
	Cracks	**Location**	**Cracks**	**Location**	**Cracks**	**Location**
0°	No	-	No	-	No	-
90°	No	-	No	-	Yes	Seam weld, OD

General notes and observations for this pipe section:

This pipe section failed in the seam weld during a hydrostatic test, upstream from the area of material property testing. Failure pressure was not reported.

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	Lone Star, Yoder Mill	
Year of manufacture	Unknown	
Seam weld type	LF ERW	
Reported pipe grade	API 5LX-52, non-expanded	

Base metal tensile test results*

Tensile strength	78,500 psi	541 MPa
Yield strength	59,100 psi	407 MPa
Elongation, %	30.1	
Reduction of area, %	44.9	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.277	Unknown year of manufacture
Manganese (Mn)	1.220	Applicable code not known
Phosphorus (P)	0.027	
Sulphur (S)	0.020	
Silicon (Si)	0.014	
Copper (Cu)	0.345	
Tin (Sn)	0.010	
Nickel (Ni)	0.040	
Chromium (Cr)	0.040	
Molybdenum (Mo)	0.015	
Aluminum (Al)	0.005	
Vanadium (V)	0.004	
Niobium (Nb)	0.004	
Zirconium (Zr)	0.001	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.013	
CE = C + (Mn/6)	**0.4803**	
V + Nb + Ti	**0.010**	

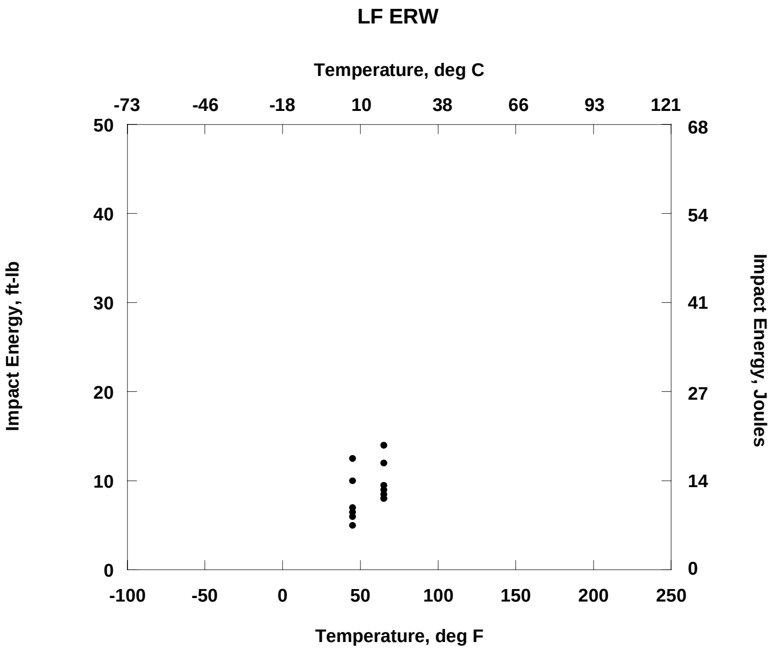
Bondline Charpy V-notch impact test results

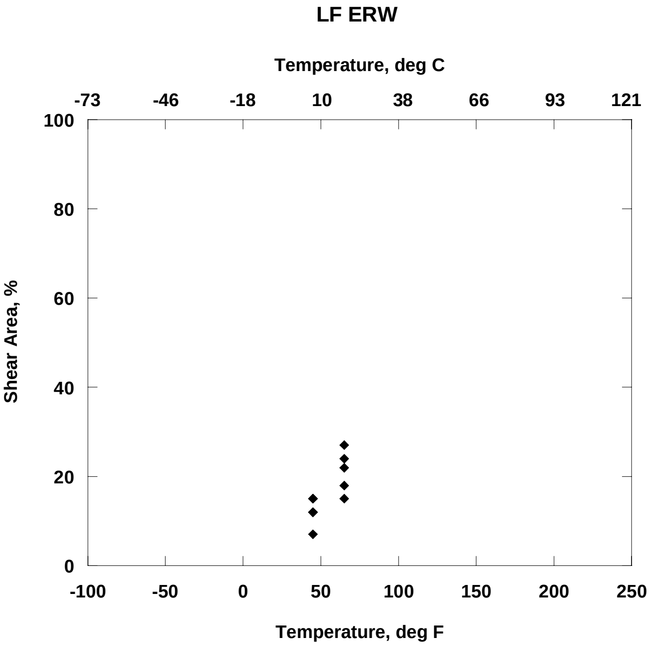
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
45	7	6.5	9	7	7	0.18
45	7	7	9	15	8	0.20
45	7	6	8	15	7	0.18
45	7	10	14	12	11	0.28
45	7	5	7	15	8	0.20
45	7	12.5	17	12	16	0.41
45	7	12.5	17	15	16	0.41
45	7	12.5	17	12	16	0.41
Average value		9	12	13	11	0.28

Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
65	18	14	19	22	18	0.46
65	18	14	19	24	16	0.41
65	18	8	11	15	12	0.30
65	18	9.5	13	15	11	0.28
65	18	9	12	27	13	0.33
65	18	8	11	18	12	0.30
65	18	8.5	12	18	11	0.28
65	18	12	16	18	16	0.41
Average value		10.4	14	20	14	0.35

Transition temperature, 85% shear area for specimen N/A
Charpy upper shelf energy, (full size specimen) N/A





Photographs of Charpy specimens were not found in this record

Ring flattening test results N/A

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. This pipe was used for liquid natural gas transmission.

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	Lone Star, Yoder Mill	
Year of manufacture	Unknown	
Seam weld type	LF ERW	
Reported pipe grade	API 5LX-52, non-expanded	

Base metal tensile test results*

Tensile strength	85,720 psi	591 MPa
Yield strength	66,250 psi	457 MPa
Elongation, %	27.5	
Reduction of area, %	42.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1 Failed in base metal @ 81,000 psi 558 MPa

Bondline and HAZ chemical analysis results

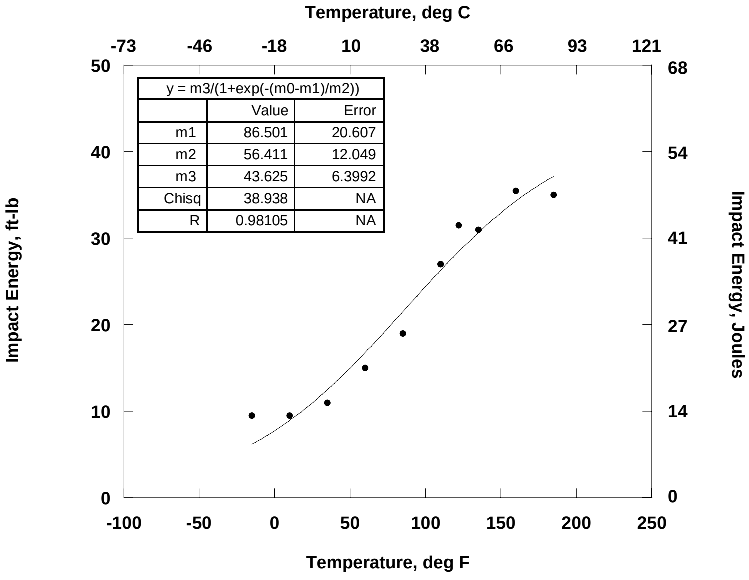
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.376	Unknown year of manufacture
Manganese (Mn)	1.240	Applicable code not known
Phosphorus (P)	0.030	
Sulphur (S)	0.018	
Silicon (Si)	0.015	
Copper (Cu)	0.402	
Tin (Sn)	0.013	
Nickel (Ni)	0.050	
Chromium (Cr)	0.030	
Molybdenum (Mo)	0.015	
Aluminum (Al)	0.002	
Vanadium (V)	0.003	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0.000	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.014	
CE = C + (Mn/6)	**0.5822**	
V + Nb + Ti	**0.008**	

Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-15	-26	9.5	13	0	5	0.13
10	-12	9.5	13	5	3	0.08
35	2	11	15	15	12	0.30
60	16	15	20	30	8	0.20
85	29	19	26	45	16	0.41
110	43	27	37	60	22	0.56
122	50	31.5	43	80	22	0.56
135	57	31	42	95	27	0.69
160	71	35.5	48	98	27	0.69
185	85	35	47	98	28	0.71

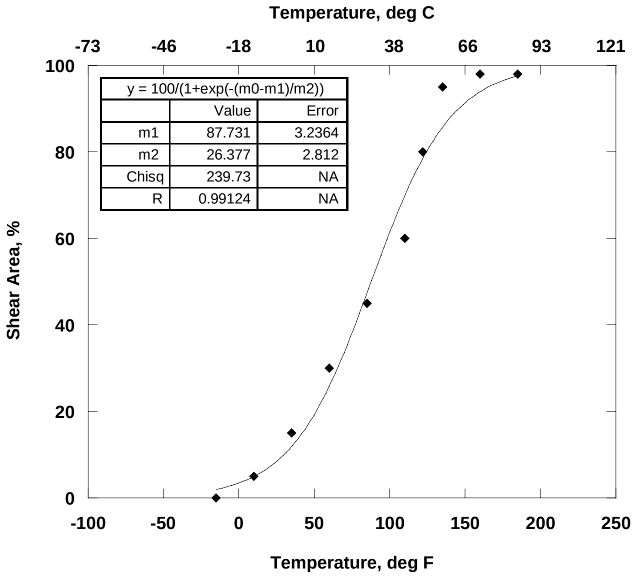
Transition temperature, 85% shear area for specimen	128	°F	53	°C
Charpy upper shelf energy, (full size specimen)	31	ft-lbs	42	Joules

LF ERW



y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	86.501	20.607
m2	56.411	12.049
m3	43.625	6.3992
Chisq	38.938	NA
R	0.98105	NA

LF ERW



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	87.731	3.2364
m2	26.377	2.812
Chisq	239.73	NA
R	0.99124	NA

Photographs of Charpy specimens were not found in this record

Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. This pipe section was removed from service when SCC colonies were found in the base metal.

Pipe background information

Nominal diameter	16-inch	406 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	Lone Star, Yoder Mill	
Year of manufacture	Unknown	
Seam weld type	LF ERW	
Reported pipe grade	API 5LX-52, non-expanded	

Base metal tensile test results*

Tensile strength	89,000 psi	614 MPa
Yield strength	65,500 psi	452 MPa
Elongation, %	31.0	
Reduction of area, %	44.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1 Failed in base metal @ 91,000 psi 627 MPa

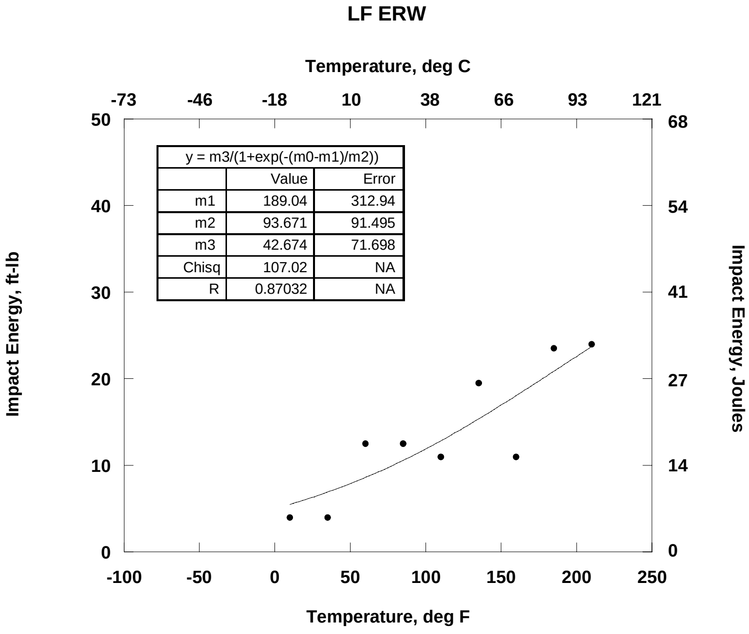
Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.263	Unknown year of manufacture
Manganese (Mn)	1.195	Applicable code not known
Phosphorus (P)	0.036	
Sulphur (S)	0.015	
Silicon (Si)	0.014	
Copper (Cu)	0.338	
Tin (Sn)	0.009	
Nickel (Ni)	0.050	
Chromium (Cr)	0.050	
Molybdenum (Mo)	0.017	
Aluminum (Al)	0.004	
Vanadium (V)	0.003	
Niobium (Nb)	0.003	
Zirconium (Zr)	0.000	
Titanium (Ti)	0.002	
Boron (B)	0.000	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.013	
CE = C + (Mn/6)	**0.4687**	
V + Nb + Ti	**0.009**	

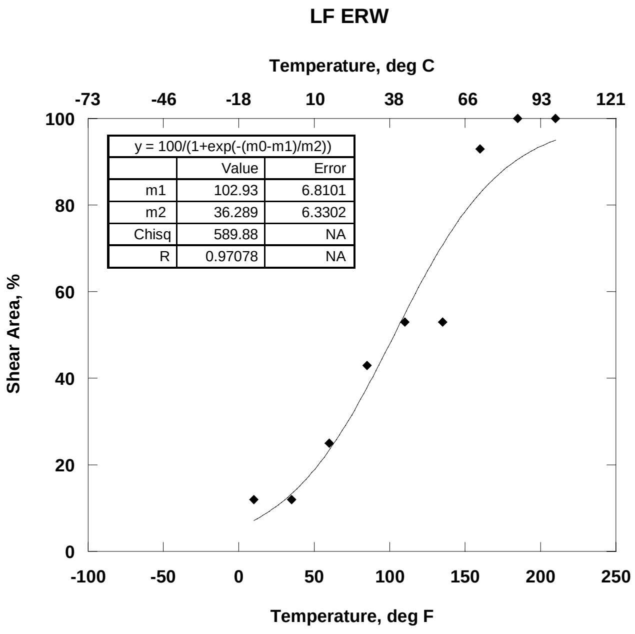
Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
10	-12	4	5	12	2	0.05
35	2	4	5	12	3	0.08
60	16	12.5	17	25	12	0.30
85	29	12.5	17	43	12	0.30
110	43	11	15	53	12	0.30
135	57	19.5	26	53	18	0.46
160	71	11	15	93	26	0.66
185	85	23.5	32	100	27	0.69
210	99	24	33	100	26	0.66

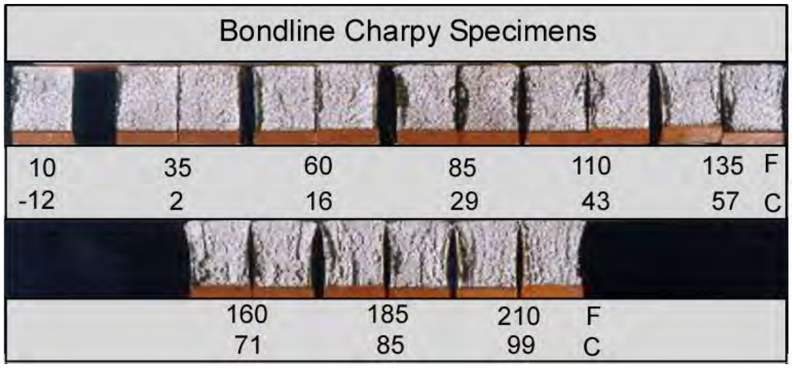
Transition temperature, 85% shear area for specimen	155	°F	68	°C
Charpy upper shelf energy, (full size specimen)	20	ft-lbs	27	Joules



y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	189.04	312.94
m2	93.671	91.495
m3	42.674	71.698
Chisq	107.02	NA
R	0.87032	NA



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	102.93	6.8101
m2	36.289	6.3302
Chisq	589.88	NA
R	0.97078	NA



Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	Yes	Seam weld

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor.

Pipe background information

Nominal diameter	20-inch	508 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	A. O. Smith Corp.	
Year of manufacture	1951-1952	
Seam weld type	Flash Weld	
Reported pipe grade	API 5LX-52, cold-expanded	

Tensile test results

Base metal tensile testing was conducted on this pipe sample by the client to determine if the pipe section met API 5LX-52 yield and tensile strength requirements. Tensile testing across the seam weld was also conducted. These results were not presented to CC Technologies.

Chemical analysis results

Base metal chemical analysis was conducted on this pipe sample by the client to determine if the pipe section met the requirements for API 5LX-52, cold-expanded pipe for the applicable year of manufacture. These results were not presented to CC Technologies.

Flash centerline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
25	-4	1.5	2	6	Not reported	
50	10	3	4	9		
75	24	3.5	5	16		
100	38	7	9	31		
125	52	7.5	10	47		
150	66	8.5	12	68		
175	79	11.5	16	83		
200	93	14.5	20	94		
225	107	13	18	98		

Transition temperature, 85% shear area for specimen	175	°F	79	°C
Charpy upper shelf energy, (full size specimen)	12	ft-lbs	16	Joules

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HAZ Charpy V-notch impact test results

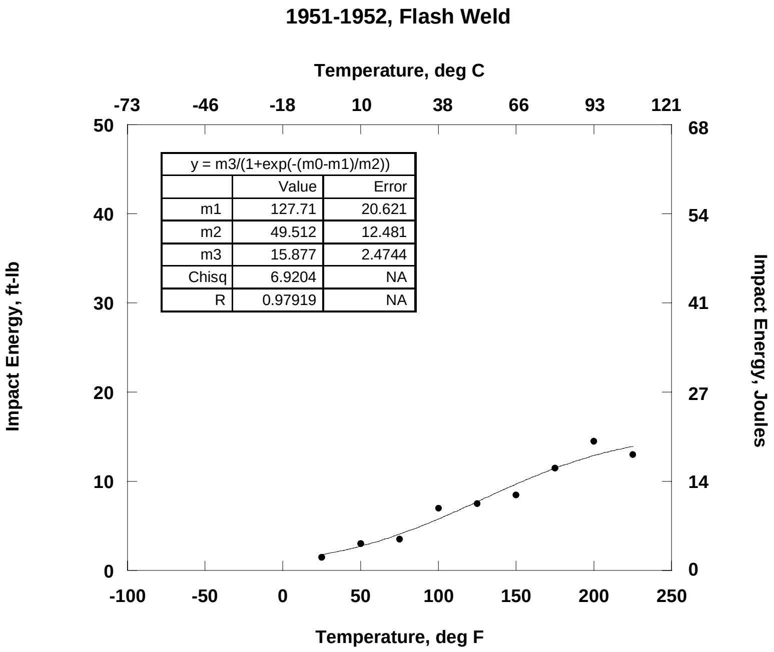
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-25	-32	4	5	0	Not reported	
0	-18	4.5	6	6		
25	-4	3	4	27		
50	10	3.5	5	30		
75	24	7	9	37		
100	38	10	14	54		
125	52	10	14	88		
150	66	11.5	16	89		
175	79	10	14	96		
200	93	14.5	20	100		

Transition temperature, 85% shear area for specimen	125	°F	52	°C
Charpy upper shelf energy, (full size specimen)	10	ft-lbs	14	Joules

Base metal Charpy V-notch impact test results

Test temperature °F	Test temperature °C	Impact Energy, Ratio for full size, 10mm x 10mm specimen ft-lbs	Impact Energy, Ratio for full size, 10mm x 10mm specimen Joules	Shear area percent	Lateral expansion mils	Lateral expansion mm
-25	-32	6	8	0	Not reported	
0	-18	4.5	6	6		
25	-4	10.5	14	16		
50	10	11	15	35		
75	24	16.5	22	71		
100	38	20.5	28	83		
125	52	22	30	97		
150	66	23	31	99		
175	79	22	30	100		

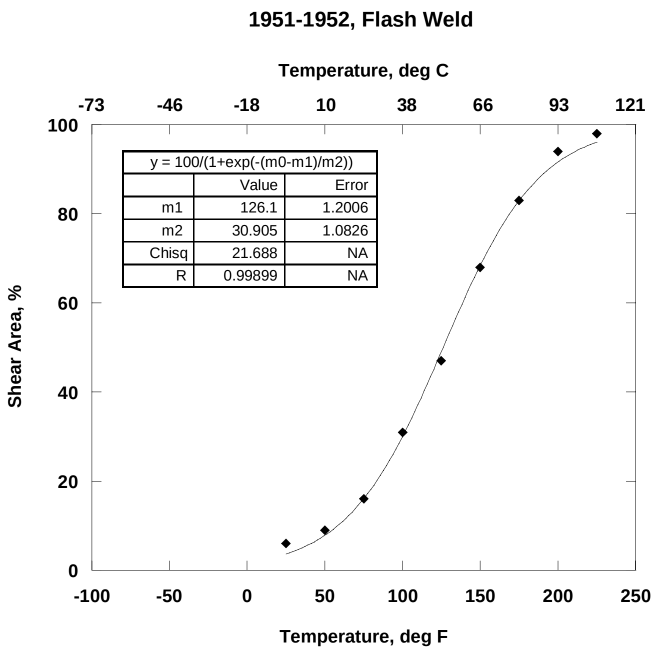
Transition temperature, 85% shear area for specimen	110	°F	43	°C
Charpy upper shelf energy, (full size specimen)	21	ft-lbs	28	Joules



1951-1952, Flash Weld

y = m3/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	127.71	20.621
m2	49.512	12.481
m3	15.877	2.4744
Chisq	6.9204	NA
R	0.97919	NA

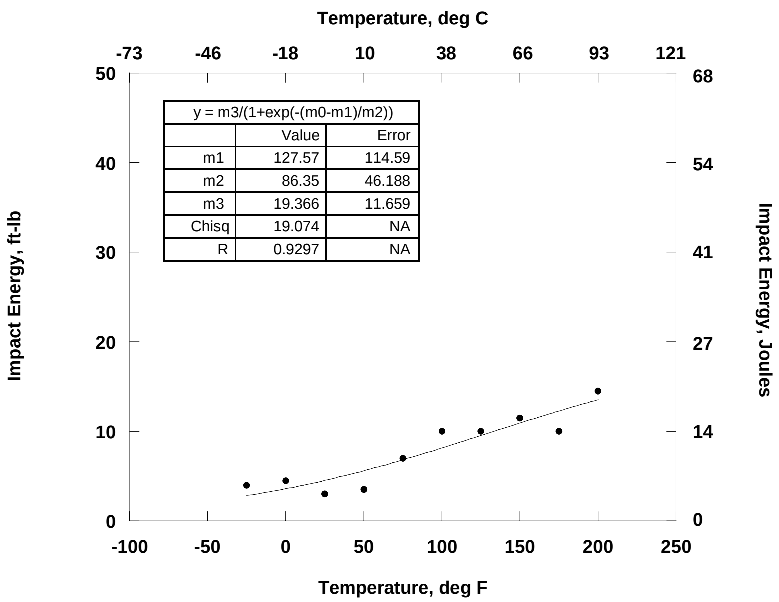


1951-1952, Flash Weld

y = 100/(1+exp(-(m0-m1)/m2))

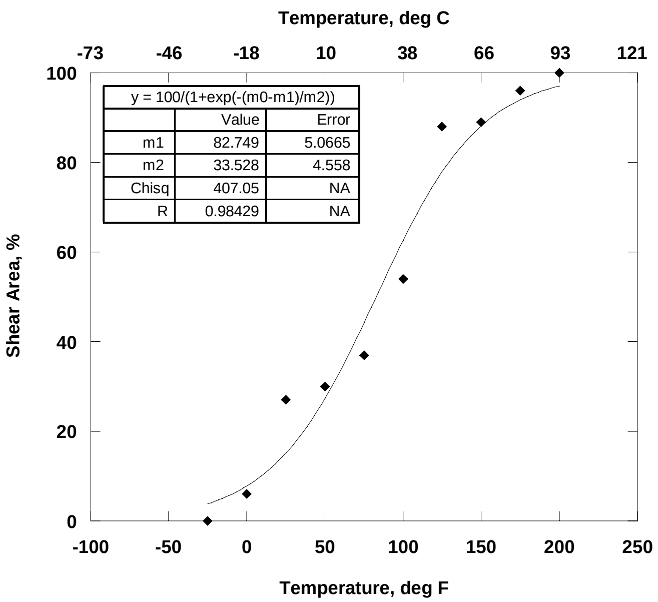
	Value	Error
m1	126.1	1.2006
m2	30.905	1.0826
Chisq	21.688	NA
R	0.99899	NA

1951-1952, Flash Weld HAZ



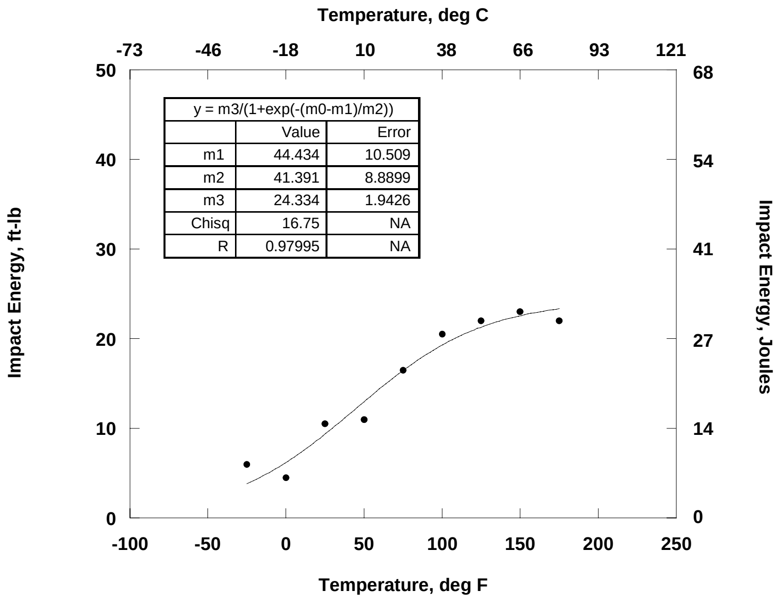
y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	127.57	114.59
m2	86.35	46.188
m3	19.366	11.659
Chisq	19.074	NA
R	0.9297	NA

1951-1952, Flash Weld HAZ



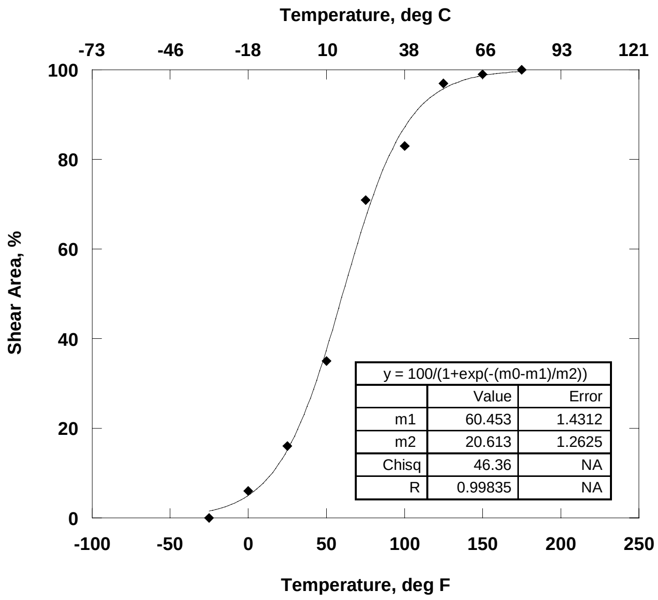
y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	82.749	5.0665
m2	33.528	4.558
Chisq	407.05	NA
R	0.98429	NA

1951-1952, Flash Weld Base Metal



y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	44.434	10.509
m2	41.391	8.8899
m3	24.334	1.9426
Chisq	16.75	NA
R	0.97995	NA

1951-1952, Flash Weld Base Metal



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	60.453	1.4312
m2	20.613	1.2625
Chisq	46.36	NA
R	0.99835	NA

Charpy specimens were not returned for photo documentation

Ring flattening test results	N/A
General notes and observations for this pipe section:	The background information and testing results for this pipe section were the result of a collaborative effort between several industry clients and CC Technologies.

Pipe background information

Nominal diameter	20-inch	508 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	Kaiser Steel Corporation	
Year of manufacture	Early 1960's	
Seam weld type	SSAW	
Reported pipe grade	API 5LX-52, non-expanded	

Tensile test results

Base metal tensile testing was conducted on this pipe sample by the client to determine if the pipe section met API 5LX-52 yield and tensile strength requirements. Tensile testing across the seam weld was also conducted. These results were not presented to CC Technologies.

Chemical analysis results

Base metal chemical analysis was conducted on this pipe sample by the client to determine if the pipe section met the requirements for API 5LX-52, cold-expanded pipe for the applicable year of manufacture. These results were not presented to CC Technologies.

Weld metal Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
10	-12	2.5	3	0	Not reported	
35	2	4	5	2		
60	16	12	16	14		
85	29	16	22	17		
110	43	20	27	38		
135	57	29	39	72		
160	71	30.5	41	76		
185	85	34.5	47	89		
205	96	35	47	100		
230	110	35	47	100		

Transition temperature, 85% shear area for specimen	175	°F	79	°C
Charpy upper shelf energy, (full size specimen)	33	ft-lbs	45	Joules

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HAZ Charpy V-notch impact test results

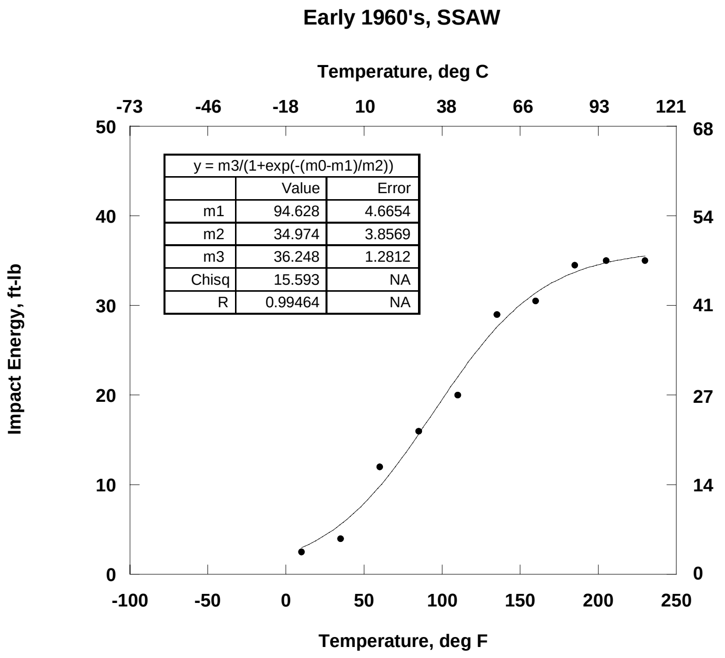
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
10	-12	9	12	0	Not reported	
35	2	10	14	14		
60	16	17.5	24	17		
85	29	19	26	21		
110	43	23	31	29		
135	57	25	34	40		
160	71	38	52	40		
185	85	42	57	97		
205	96	42	57	100		
230	110	43	58	100		

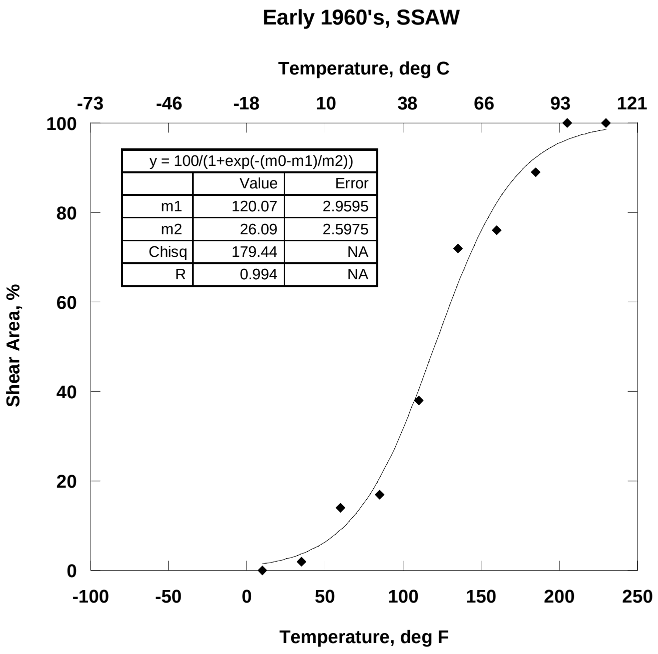
Transition temperature, 85% shear area for specimen	175	°F	79	°C
Charpy upper shelf energy, (full size specimen)	41	ft-lbs	56	Joules

Base metal Charpy V-notch impact test results

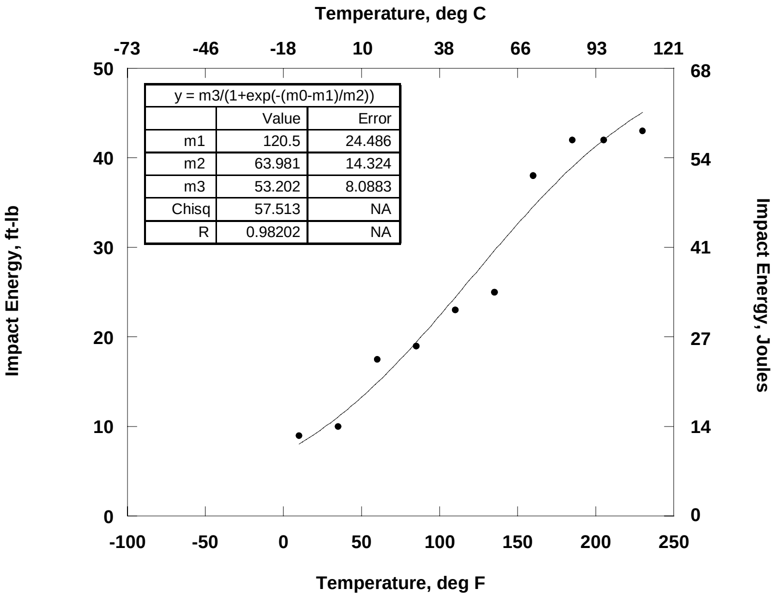
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-10	-23	7	9	0	Not reported	
10	-12	9	12	0		
35	2	10.5	14	10		
60	16	15	20	17		
85	29	18	24	26		
110	43	30	41	84		
135	57	32	43	100		
160	71	34	46	100		
185	85	33.5	45	100		

Transition temperature, 85% shear area for specimen	110	°F	43	°C
Charpy upper shelf energy, (full size specimen)	27	ft-lbs	37	Joules



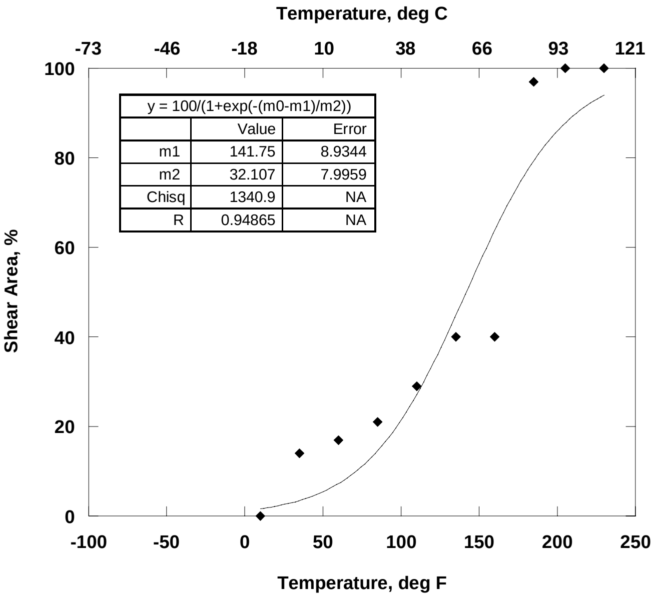


Early 1960's, SSAW HAZ



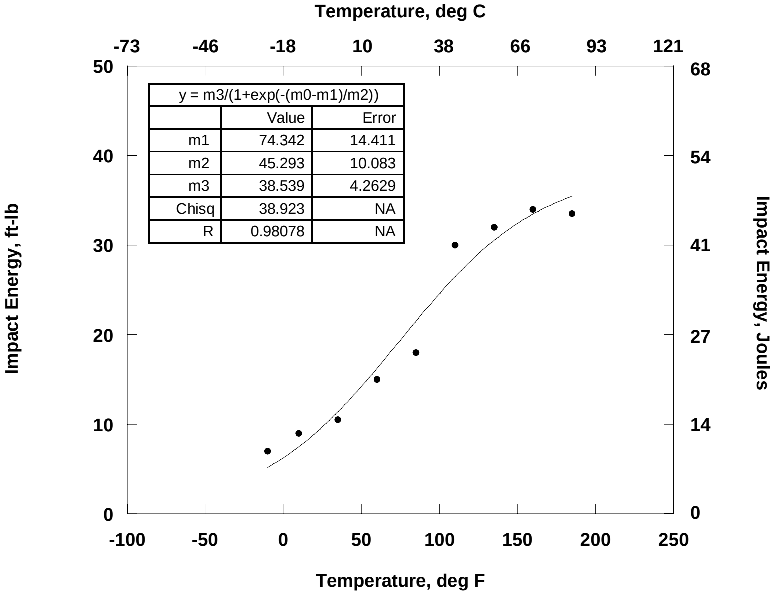
y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	120.5	24.486
m2	63.981	14.324
m3	53.202	8.0883
Chisq	57.513	NA
R	0.98202	NA

Early 1960's, SSAW HAZ



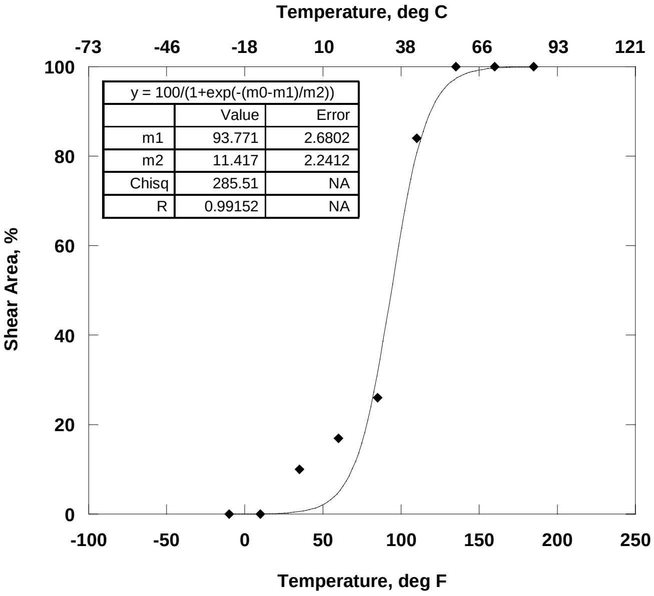
y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	141.75	8.9344
m2	32.107	7.9959
Chisq	1340.9	NA
R	0.94865	NA

Early 1960's, SSAW Base Metal



y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	74.342	14.411
m2	45.293	10.083
m3	38.539	4.2629
Chisq	38.923	NA
R	0.98078	NA

Early 1960's, SSAW Base Metal



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	93.771	2.6802
m2	11.417	2.2412
Chisq	285.51	NA
R	0.99152	NA

Charpy specimens were not returned for photo documentation

<u>Ring flattening test results</u> <u>N/A</u>

<u>General notes and observations for this pipe section:</u>

The background information and testing results for this pipe section were the result of a collaborative effort between several industry clients and CC Technologies.

Pipe background information

Nominal diameter	20-inch	508 mm
Nominal wall thickness	0.312-inch	7.9 mm
Pipe manufacturer	Youngstown Steel & Tube, Final mill	
Year of manufacture	1951-1952	
Seam weld type	d.c. ERW	
Reported pipe grade	API 5LX-52, probably cold-expanded	

Tensile test results

Base metal tensile testing was conducted on this pipe sample by the client to determine if the pipe section met API 5LX-52 yield and tensile strength requirements. Tensile testing across the seam weld was also conducted. These results were not presented to CC Technologies.

Chemical analysis results

Base metal chemical analysis was conducted on this pipe sample by the client to determine if the pipe section met the requirements for API 5LX-52, cold-expanded pipe for the applicable year of manufacture. These results were not presented to CC Technologies.

Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
10	-12	3	4	0	Not reported	
35	2	4.5	6	31		
60	16	6	8	42		
85	29	7	9	49		
110	43	5.5	7	62		
135	57	8.5	12	65		
160	71	10	14	70		
185	85	7	9	77		
205	96	7	9	87		
230	110	7	9	94		

Transition temperature, 85% shear area for specimen	185	°F	85	°C
Charpy upper shelf energy, (full size specimen)	7	ft-lbs	9	Joules

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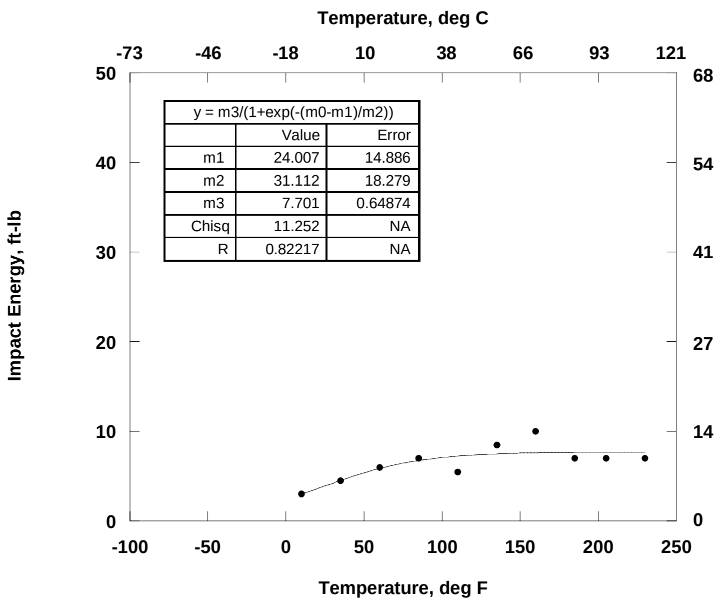
Base metal Charpy V-notch impact test results

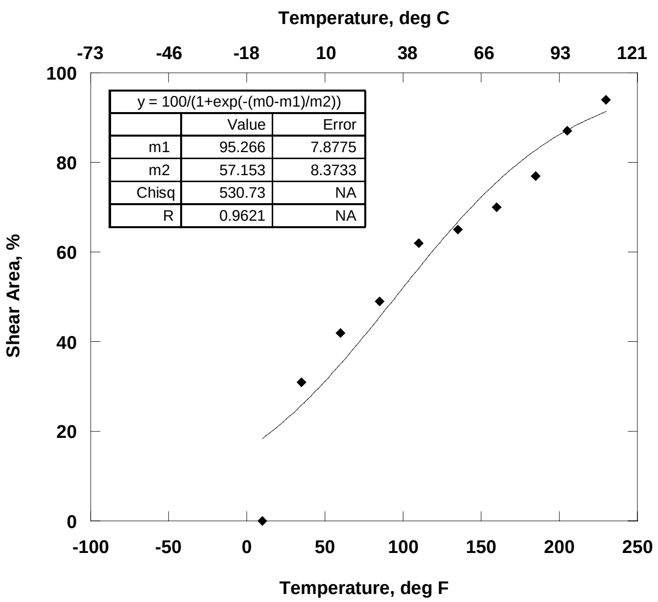
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-60	-51	1	1	0	Not reported	
-40	-40	1.5	2	0		
-15	-26	3	4	17		
10	-12	4	5	33		
16	-9	8	11	74		
22	-6	10.5	14	88		
35	2	10.5	14	100		
60	16	13.5	18	100		
85	29	14.5	20	100		

Transition temperature, 85% shear area for specimen	20	°F	-7	°C
Charpy upper shelf energy, (full size specimen)	11	ft-lbs	15	Joules


1951-1952, d.c. ERW

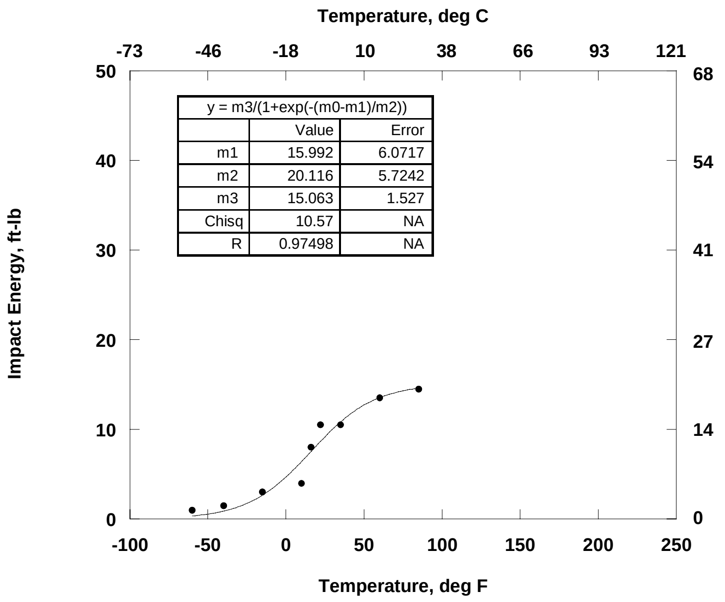
y = m3/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	24.007	14.886
m2	31.112	18.279
m3	7.701	0.64874
Chisq	11.252	NA
R	0.82217	NA


1951-1952, d.c. ERW

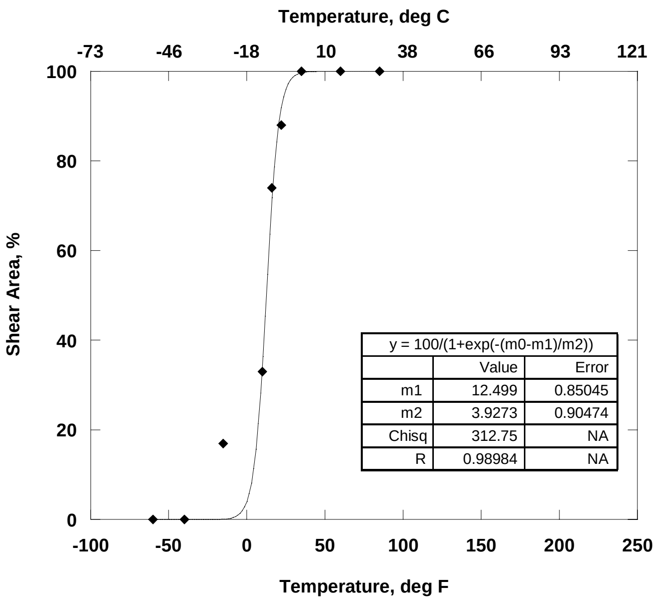
y = 100/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	95.266	7.8775
m2	57.153	8.3733
Chisq	530.73	NA
R	0.9621	NA


1951-1952, d.c. ERW Base Metal

y = m3/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	15.992	6.0717
m2	20.116	5.7242
m3	15.063	1.527
Chisq	10.57	NA
R	0.97498	NA


1951-1952, d.c. ERW Base Metal

y = 100/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	12.499	0.85045
m2	3.9273	0.90474
Chisq	312.75	NA
R	0.98984	NA

Charpy specimens were not returned for photo documentation

Ring flattening test results	N/A
General notes and observations for this pipe section:	The background information and testing results for this pipe section were the result of a collaborative effort between several industry clients and CC Technologies.

Pipe background information

Nominal diameter	8-inch	203 mm
Nominal wall thickness	0.250-inch	6.4 mm
Pipe manufacturer	Youngstown Sheet & Tube	
Year of manufacture	Reported as early 1940's	
Seam weld type	Lap Weld	
Reported pipe grade	API 5L Gr. B, non-expanded	

Base metal tensile test results*

Tensile strength	51,800 psi	357 MPa
Yield strength	36,100 psi	249 MPa
Elongation, %	30.0	
Reduction of area, %	44.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in Lap @ 49,050 psi	338 MPa
#2	Failed in Lap @ 42,350 psi	292 MPa

Lap area chemical analysis results

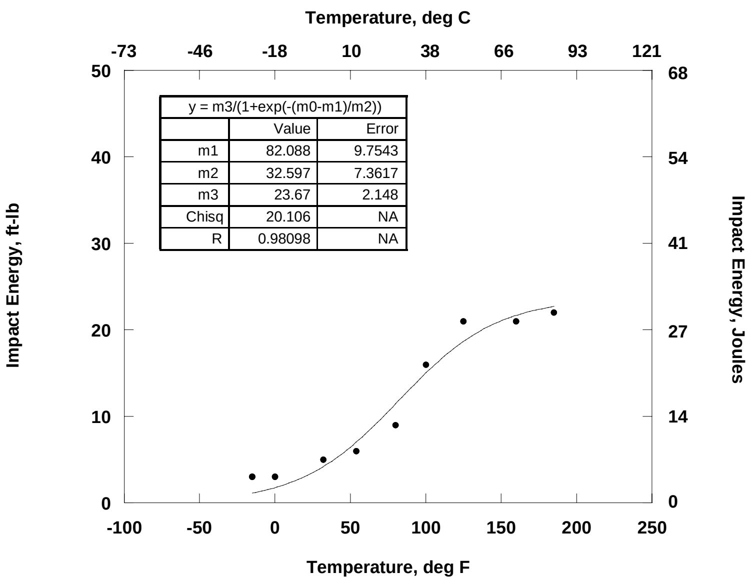
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.190	Unknown year of manufacture
Manganese (Mn)	0.980	Applicable code not known
Phosphorus (P)	0.034	
Sulphur (S)	0.020	
Silicon (Si)	0.032	
Copper (Cu)	0.060	
Tin (Sn)	0.004	
Nickel (Ni)	0.008	
Chromium (Cr)	0.021	
Molybdenum (Mo)	0.010	
Aluminum (Al)	0.018	
Vanadium (V)	0.002	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.001	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.01	
CE = C + (Mn/6)	**0.3533**	
V + Nb + Ti	**0.005**	

Lap mid-point Charpy V-notch impact test results

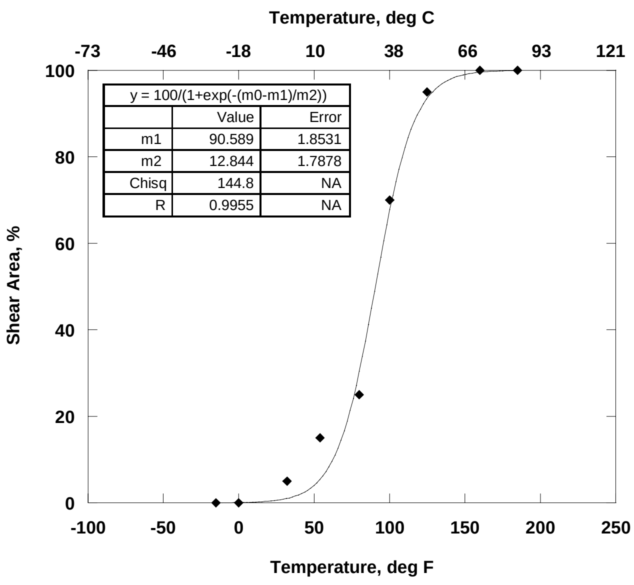
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-15	-26	3	4	0	2	0.05
0	-18	3	4	0	2	0.05
32	0	5	7	5	4	0.10
54	12	6	8	15	6	0.15
80	27	9	12	25	12	0.30
100	38	16	22	70	18	0.46
125	52	21	28	95	18	0.46
160	71	21	28	100	22	0.56
185	85	22	30	100	21	0.53

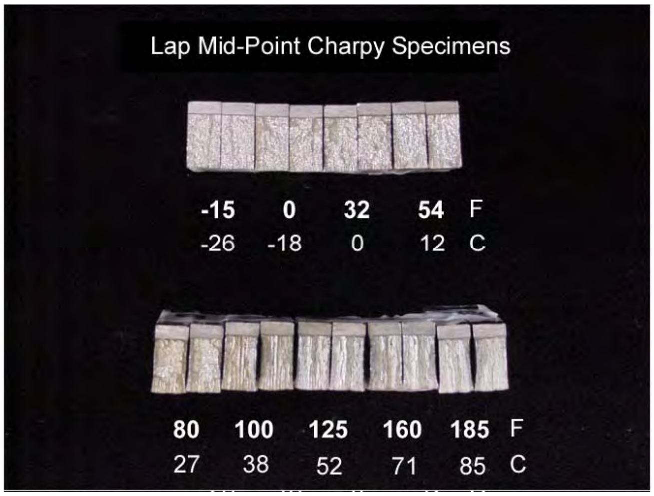
Transition temperature, 85% shear area for specimen	120	°F	49	°C
Charpy upper shelf energy, (full size specimen)	20	ft-lbs	27	Joules

Early 1940's Lap Weld



Early 1940's, Lap Weld





Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	Yes	Lap

General notes and observations for this pipe section:

This pipe section was removed downstream from a rupture. The rupture occurred in the Lap during a hydrostatic test. Failure pressure was not reported and the failed section was not submitted.

Pipe background information

Nominal diameter	12-inch	305 mm
Nominal wall thickness	0.233-inch	5.9 mm
Pipe manufacturer	Unknown	
Year of manufacture	1925 – 1928	
Seam weld type	Lap Weld	
Reported pipe grade	Probably API 5L Gr. B	

Base metal tensile test results*

Tensile strength	51,900 psi	358 MPa
Yield strength	32,200 psi	222 MPa
Elongation, %	15.5	
Reduction of area, %	18.4	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 52,750 psi	364 MPa
#2	Failed in Lap @ 48,900 psi	337 MPa

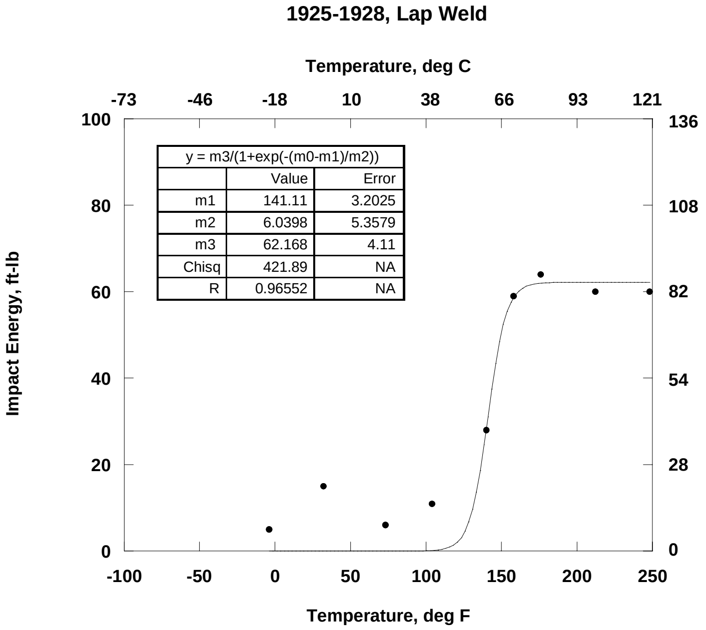
Lap area chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.097	Unknown year of manufacture
Manganese (Mn)	0.434	Applicable code not known
Phosphorus (P)	0.029	
Sulphur (S)	0.037	
Silicon (Si)	0.022	
Copper (Cu)	0.013	
Tin (Sn)	0.002	
Nickel (Ni)	0.006	
Chromium (Cr)	0.007	
Molybdenum (Mo)	0.003	
Aluminum (Al)	0.012	
Vanadium (V)	0	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.005	
CE = C + (Mn/6)	**0.1693**	
V + Nb + Ti	**0.004**	

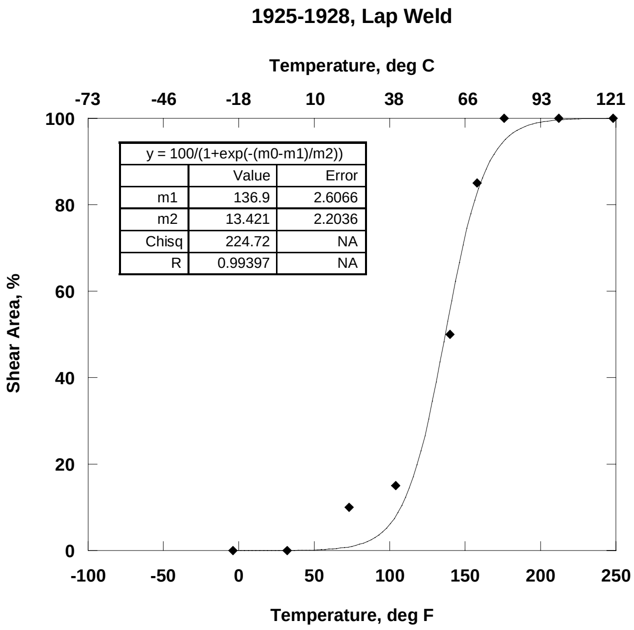
Lap mid-point Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-4	-20	5	7	0	10	0.25
32	0	15	20	0	4	0.10
73	23	6	8	10	14	0.36
104	40	11	15	15	24	0.61
140	60	28	38	50	47	1.19
158	70	59	80	85	70	1.78
176	80	64	87	100	76	1.93
176	80	64	87	100	69	1.75
212	100	60	81	100	65	1.65
248	120	60	81	100	76	1.93

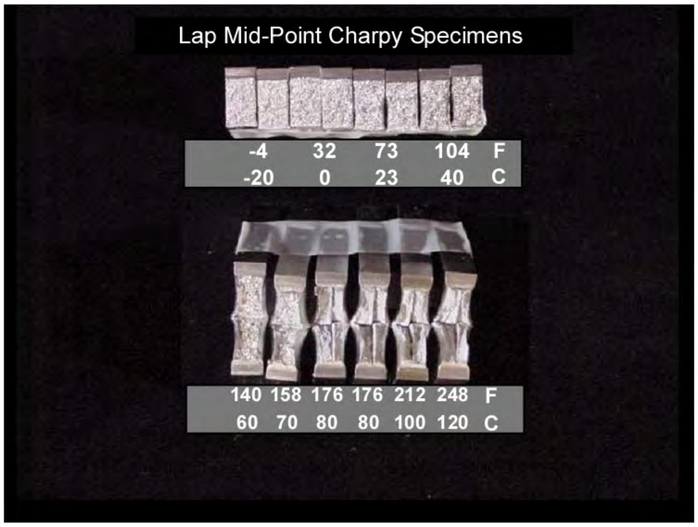
Transition temperature, 85% shear area for specimen	150	°F	66	°C
Charpy upper shelf energy, (full size specimen)	60	ft-lbs	81	Joules

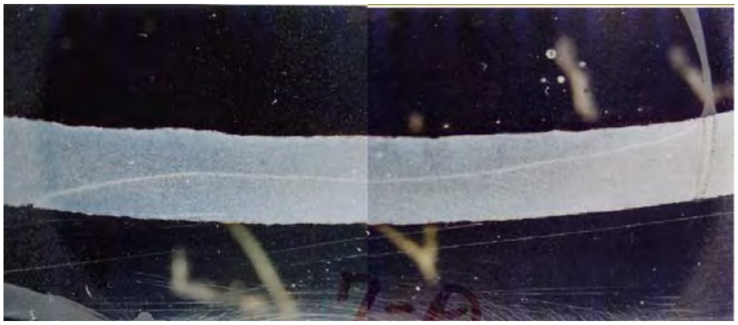


y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	141.11	3.2025
m2	6.0398	5.3579
m3	62.168	4.11
Chisq	421.89	NA
R	0.96552	NA



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	136.9	2.6066
m2	13.421	2.2036
Chisq	224.72	NA
R	0.99397	NA





Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	Yes	Lap

Vickers hardness testing results

Remote from Seam			HAZ		Weld Metal or Fusion Line			
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID
97.1	98.6	99.6	OD between ID & OD lap edges	97.6		103	104	103
			OD between ID & OD lap edges	101				
			ID between ID & OD lap edges	97.8				
			ID between ID & OD lap edges	97.6				

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. 345 psig MAOP. The Charpy graph has been modified to reflect the high impact energy values

Pipe background information

Nominal diameter	10-inch	254 mm
Nominal wall thickness	0.250-inch	6.4 mm
Pipe manufacturer	Unknown	
Year of manufacture	1925	
Seam weld type	Lap Weld	
Reported pipe grade	Probably API 5L Gr. B	

Base metal tensile test results*

Tensile strength	49,400 psi	341 MPa
Yield strength	36,800 psi	254 MPa
Elongation, %	12.3	
Reduction of area, %	25.4	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1 Failed in Lap @ 51,900 psi 358 MPa

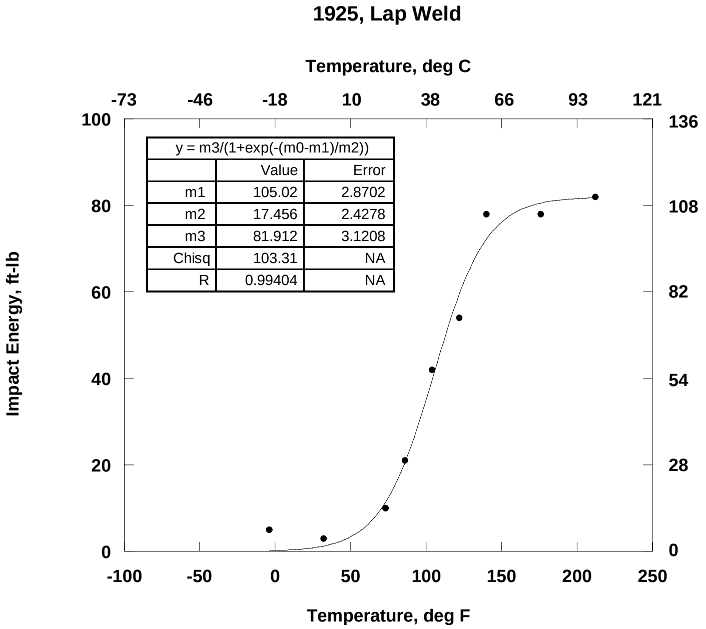
Lap area chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.033	API 5L, 1st edition was not issued until 1928.
Manganese (Mn)	0.330	
Phosphorus (P)	0.056	
Sulphur (S)	0.024	
Silicon (Si)	0.004	
Copper (Cu)	0.008	
Tin (Sn)	0.001	
Nickel (Ni)	0.004	
Chromium (Cr)	0.005	
Molybdenum (Mo)	0.003	
Aluminum (Al)	0.004	
Vanadium (V)	0.003	
Niobium (Nb)	0.004	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0	
Cobalt (Co)	0.004	
CE = C + (Mn/6)	**0.0880**	
V + Nb + Ti	**0.009**	

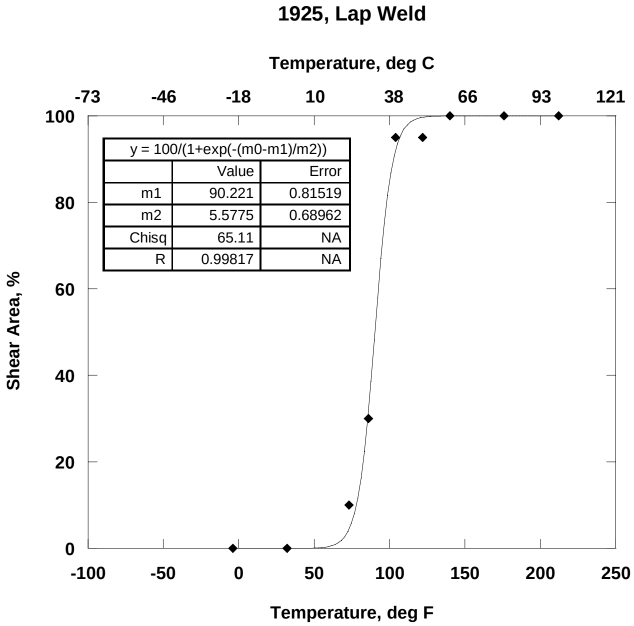
Lap mid-point Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-4	-20	5	7	0	4	0.10
32	0	3	4	0	6	0.15
73	23	10	14	10	20	0.51
86	30	21	28	30	35	0.89
104	40	42	57	95	57	1.45
122	50	54	73	95	68	1.73
140	60	78	106	100	80	2.03
176	80	78	106	100	84	2.13
212	100	82	111	100	83	2.11

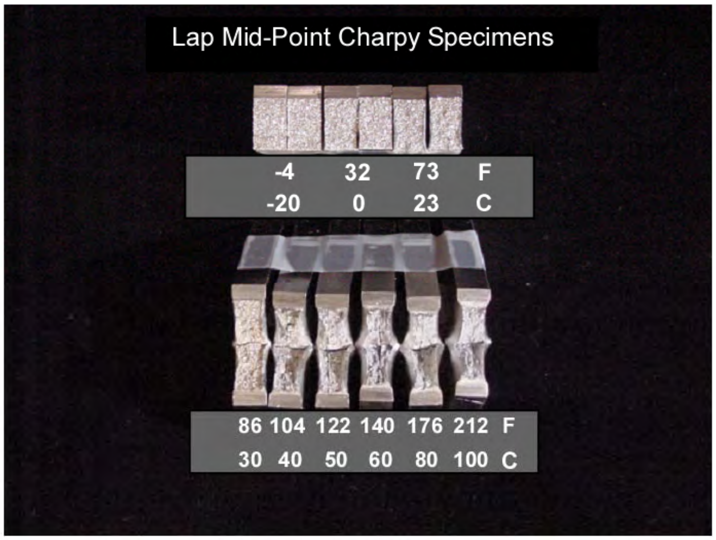
Transition temperature, 85% shear area for specimen	93	°F	34	°C
Charpy upper shelf energy, (full size specimen)	78	ft-lbs	106	Joules



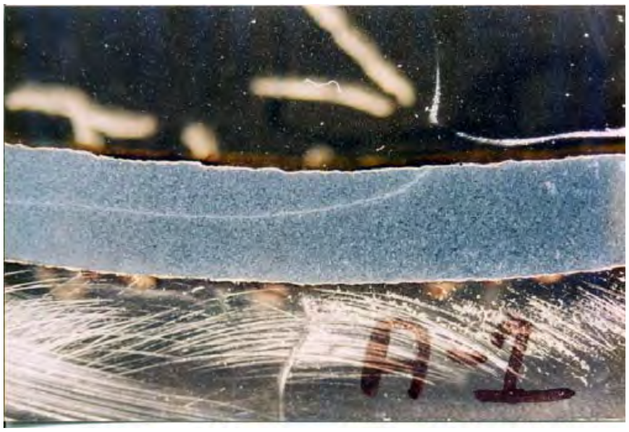
y = m3/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	105.02	2.8702
m2	17.456	2.4278
m3	81.912	3.1208
Chisq	103.31	NA
R	0.99404	NA



y = 100/(1+exp(-(m0-m1)/m2))		
	Value	Error
m1	90.221	0.81519
m2	5.5775	0.68962
Chisq	65.11	NA
R	0.99817	NA



Lap Mid-Point Charpy Specimens



Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

Vickers hardness testing results

Remote from Seam			HAZ		Weld Metal or Fusion Line			
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID
113	101	99.7	OD between ID & OD lap edges	105		101	104	101
128	101	113	ID between ID & OD lap edges	97.1		100		103
128		104						

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. 200 psig MAOP. The Charpy graph has been modified to reflect the high impact energy values

Pipe background information

Nominal diameter	6-inch	152 mm
Nominal wall thickness	0.219-inch	5.6 mm
Pipe manufacturer	Cal-Metal Pipe Corporation	
Year of manufacture	1957	
Seam weld type	Reported as an electric "fusion" weld	
Reported pipe grade	Reported as API 5L Gr. B	

Base metal tensile test results*

Tensile strength	67,700 psi	467 MPa
Yield strength	53,100 psi	366 MPa
Elongation, %	22.9	
Reduction of area, %	48.3	
Mode of failure	Ductile	

*Average between two longitudinal tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 69,000 psi	476 MPa
#1	Failed in base metal @ 66,300 psi	457 MPa

Weld metal chemical analysis results

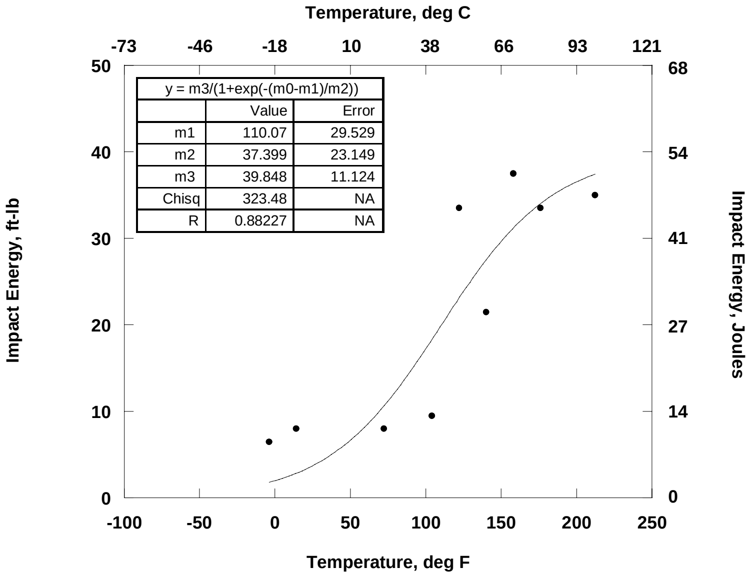
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.172	0.260
Manganese (Mn)	0.904	1.350
Phosphorus (P)	0.016	0.040
Sulphur (S)	0.020	0.050
Silicon (Si)	0.259	
Copper (Cu)	0.112	
Tin (Sn)	0.013	
Nickel (Ni)	0.030	
Chromium (Cr)	0.025	
Molybdenum (Mo)	0.009	
Aluminum (Al)	0.002	
Vanadium (V)	0.002	
Niobium (Nb)	0.003	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.007	
CE = C + (Mn/6)	**0.3227**	
V + Nb + Ti	**0.007**	

Weld metal Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-4	-20	6.5	9	0	5	0.13
14	-10	8	11	0	5	0.13
72	22	8	11	24	13	0.33
104	40	9.5	13	39	12	0.30
122	50	33.5	45	90	37	0.94
140	60	21.5	29	79	28	0.71
158	70	37.5	51	100	45	1.14
176	80	33.5	45	100	40	1.02
212	100	35	47	100	41	1.04

Transition temperature, 85% shear area for specimen	142	°F	61	°C
Charpy upper shelf energy, (full size specimen)	30	ft-lbs	41	Joules

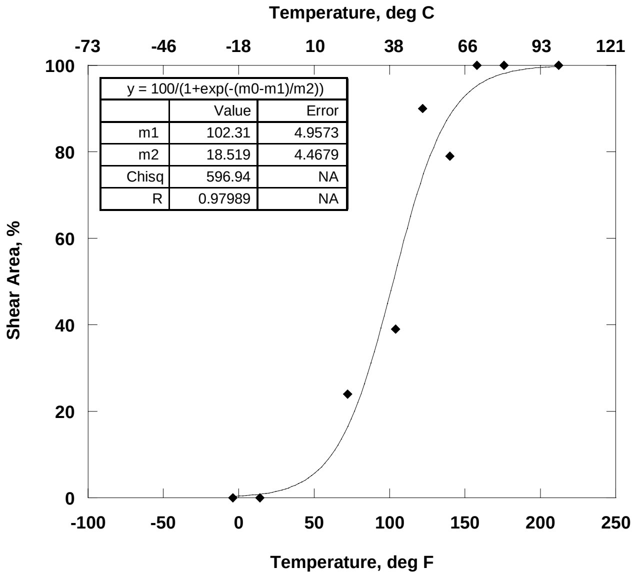
1957, Electric Fusion Weld



y = m3/(1+exp(-(m0-m1)/m2))

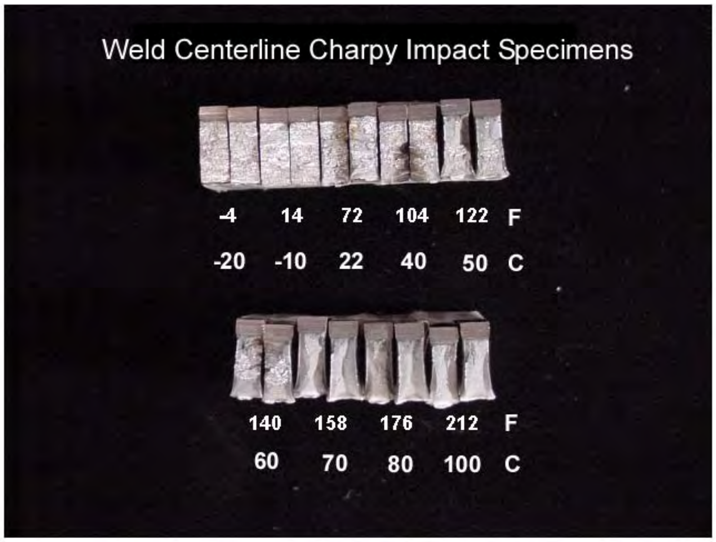
	Value	Error
m1	110.07	29.529
m2	37.399	23.149
m3	39.848	11.124
Chisq	323.48	NA
R	0.88227	NA

1957, Electric Fusion Weld



y = 100/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	102.31	4.9573
m2	18.519	4.4679
Chisq	596.94	NA
R	0.97989	NA



Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

Vickers hardness testing results

Remote from Seam			HAZ		Weld Metal or Fusion Line			
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID
176	167	180	OD high temp	215		204	212	203
	171		mid high temp	185				
			ID high temp	184				
			OD low temp	213				
			OD low temp	217				
			OD lower temp	204				
			midwall low temp	186				
			ID low temp	179				

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. Seam weld was reported as an electric “fusion” weld with filler metal

Pipe background information

Nominal diameter	10-inch	254 mm
Nominal wall thickness	0.250-inch	6.4 mm
Pipe manufacturer	Republic Steel Corporation	
Year of manufacture	1948	
Seam weld type	LF ERW	
Reported pipe grade	API 5L Gr. B, non-expanded	

Base metal tensile test results*

Tensile strength	63,400 psi	437 MPa
Yield strength	46,200 psi	319 MPa
Elongation, %	29.1	
Reduction of area, %	48.5	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 64,700 psi	446 MPa
#1	Failed in base metal @ 66,000 psi	455 MPa

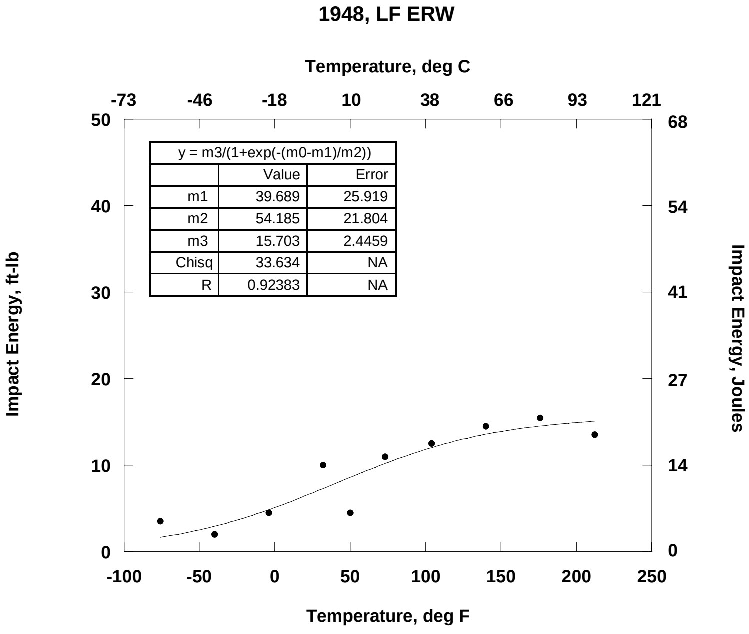
Bondline and HAZ chemical analysis results

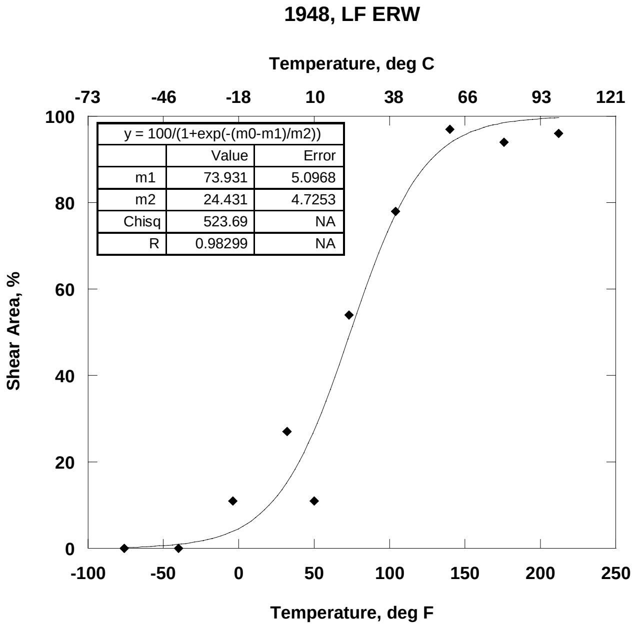
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.198	0.300
Manganese (Mn)	0.685	1.500
Phosphorus (P)	0.008	0.045
Sulphur (S)	0.022	0.060
Silicon (Si)	0.022	
Copper (Cu)	0.013	
Tin (Sn)	0.002	
Nickel (Ni)	0.004	
Chromium (Cr)	0.016	
Molybdenum (Mo)	0.003	
Aluminum (Al)	0.004	
Vanadium (V)	0.002	
Niobium (Nb)	0.002	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.025	
CE = C + (Mn/6)	**0.3122**	
V + Nb + Ti	**0.006**	

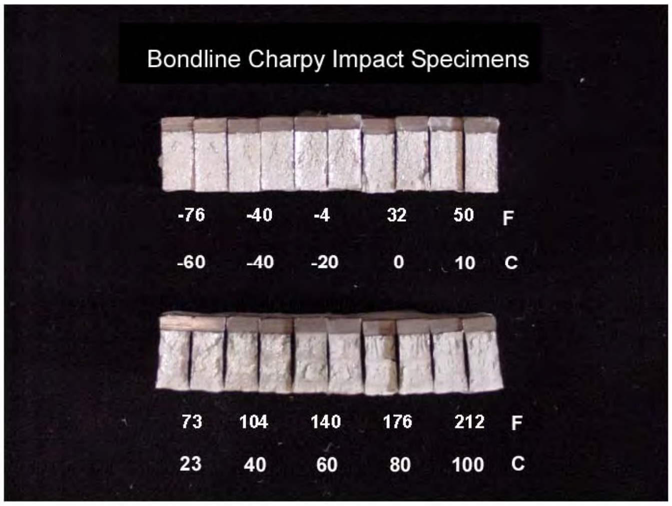
Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	Mils	mm
-76	-60	3.5	5	0	6	0.15
-40	-40	2	3	0	4	0.10
-4	-20	4.5	6	11	6	0.15
32	0	10	14	27	15	0.38
50	10	4.5	6	11	7	0.18
73	23	11	15	54	13	0.33
104	40	12.5	17	78	16	0.41
140	60	14.5	20	97	20	0.51
176	80	15.5	21	94	19	0.48
212	100	13.5	18	96	17	0.43

Transition temperature, 85% shear area for specimen	125	°F	52	°C
Charpy upper shelf energy, (full size specimen)	13	ft-lbs	18	Joules







Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. This pipe was used for crude oil transmission.

Pipe background information

Nominal diameter	14-inch	356 mm
Nominal wall thickness	0.219-inch	5.6 mm
Pipe manufacturer	Lone Star Steel, Yoder Mill?	
Year of manufacture	1966	
Seam weld type	Probably LF ERW	
Reported pipe grade	API 5LX-52, non-expanded	

Base metal tensile test results*

Tensile strength	79,300 psi	547 MPa
Yield strength	56,700 psi	391 MPa
Elongation, %	20.2	
Reduction of area, %	52.0	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 77,000 psi	531 MPa
#1	Failed in base metal @ 80,800 psi	557 MPa

Bondline and HAZ chemical analysis results

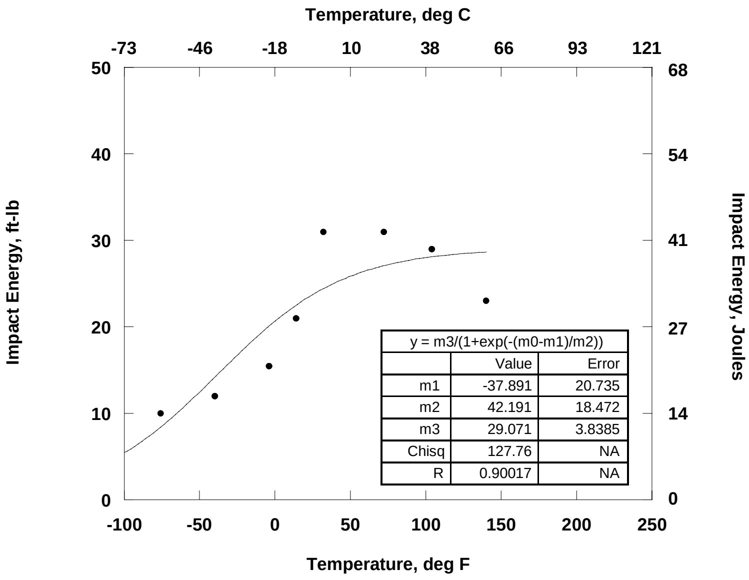
Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.220	0.300
Manganese (Mn)	0.960	1.350
Phosphorus (P)	0.012	0.040
Sulphur (S)	0.017	0.050
Silicon (Si)	0.022	
Copper (Cu)	0.033	
Tin (Sn)	0.004	
Nickel (Ni)	0.015	
Chromium (Cr)	0.029	
Molybdenum (Mo)	0.005	
Aluminum (Al)	0.004	
Vanadium (V)	0.002	
Niobium (Nb)	0.004	
Zirconium (Zr)	0	
Titanium (Ti)	0.002	
Boron (B)	0.0003	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.006	
CE = C + (Mn/6)	**0.3800**	
V + Nb + Ti	**0.008**	

Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	Mils	mm
-103	-75	7.5	10	0	6	0.15
-76	-60	10	14	0	8	0.20
-40	-40	12	16	10	13	0.33
-4	-20	15.5	21	25	18	0.46
14	-10	21	28	75	25	0.64
32	0	31	42	100	34	0.86
72	22	31	42	100	37	0.94
104	40	29	39	100	37	0.94
140	60	23	31	100	28	0.71

Transition temperature, 85% shear area for specimen	20	°F	-7	°C
Charpy upper shelf energy, (full size specimen)	25	ft-lbs	34	Joules

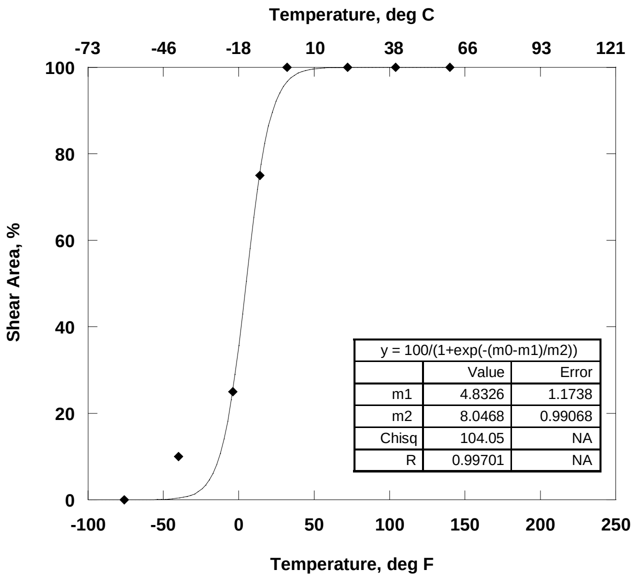
1966, LF ERW



y = m3/(1+exp(-(m0-m1)/m2))

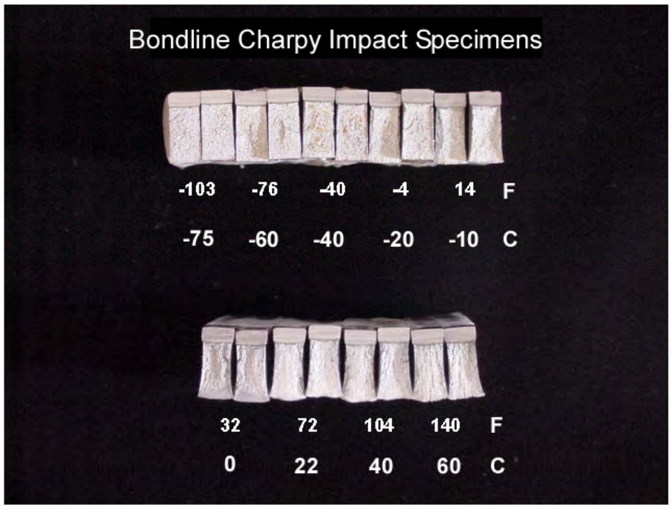
	Value	Error
m1	-37.891	20.735
m2	42.191	18.472
m3	29.071	3.8385
Chisq	127.76	NA
R	0.90017	NA

1966, LF ERW



y = 100/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	4.8326	1.1738
m2	8.0468	0.99068
Chisq	104.05	NA
R	0.99701	NA



Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor. Lone Star Steel converted from a LF ERW mill to a HFC mill around the time that this pipe was manufactured.

Pipe background information

Nominal diameter	8-inch	203 mm
Nominal wall thickness	0.250-inch	6.4 mm
Pipe manufacturer	Consolidated Western Steel	
Year of manufacture	1951	
Seam weld type	LF ERW	
Reported pipe grade	API 5LX-42, non-expanded	

Base metal tensile test results*

Tensile strength	66,300 psi	457 MPa
Yield strength	50,700 psi	350 MPa
Elongation, %	17.5	
Reduction of area, %	40.8	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 65,000 psi	448 MPa
#1	Failed in base metal @ 68,400 psi	472 MPa

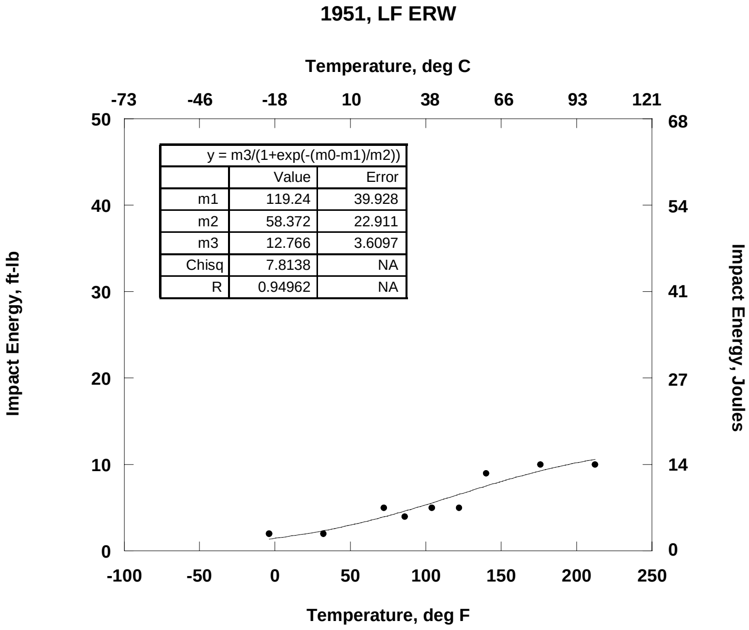
Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.254	0.300
Manganese (Mn)	0.485	1.250
Phosphorus (P)	0.011	0.045
Sulphur (S)	0.038	0.060
Silicon (Si)	0.072	
Copper (Cu)	0.104	
Tin (Sn)	0.014	
Nickel (Ni)	0.068	
Chromium (Cr)	0.018	
Molybdenum (Mo)	0.007	
Aluminum (Al)	0.003	
Vanadium (V)	0.001	
Niobium (Nb)	0.003	
Zirconium (Zr)	0.000	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0002	
Cobalt (Co)	0.023	
CE = C + (Mn/6)	**0.3348**	
V + Nb + Ti	**0.006**	

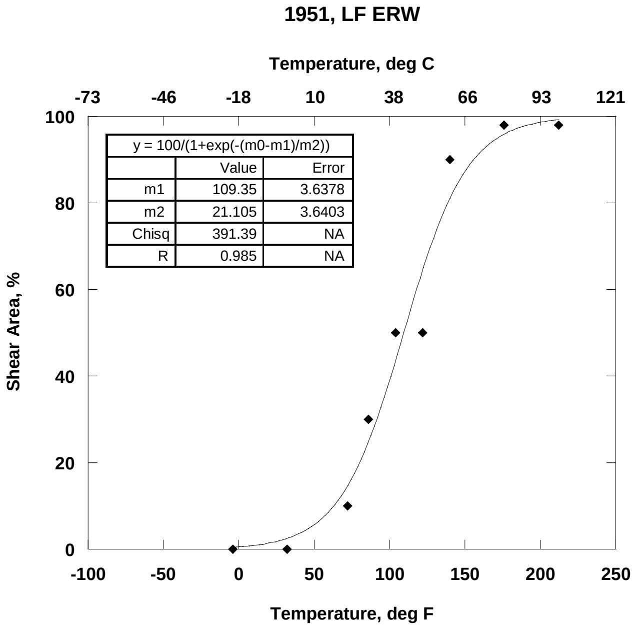
Bondline Charpy V-notch impact test results

Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	mils	mm
-4	-20	2	3	0	2	0.05
32	0	2	3	0	2	0.05
72	22	5	7	10	5	0.13
86	30	4	5	30	9	0.23
104	40	5	7	50	9	0.23
122	50	5	7	50	11	0.28
140	60	9	12	90	15	0.38
176	80	10	14	98	16	0.41
212	100	10	14	98	17	0.43

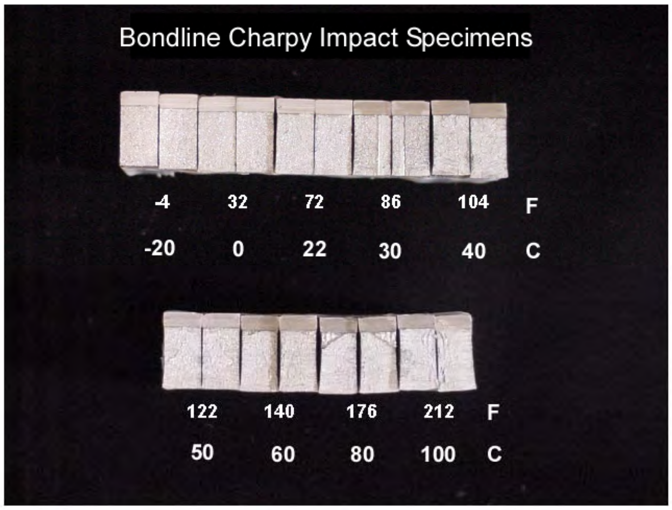
Transition temperature, 85% shear area for specimen	142	°F	61	°C
Charpy upper shelf energy, (full size specimen)	9	ft-lbs	12	Joules

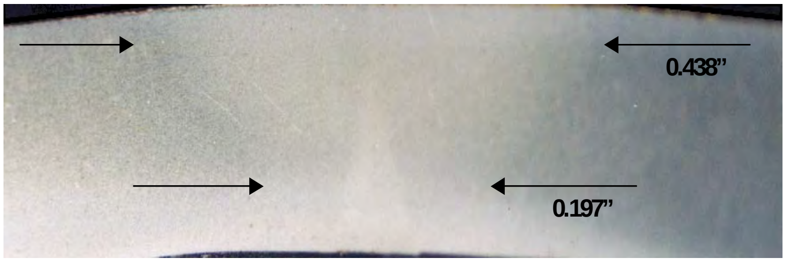


y = m3/(1+exp(-(m0-m1)/m2))	Value	Error
m1	119.24	39.928
m2	58.372	22.911
m3	12.766	3.6097
Chisq	7.8138	NA
R	0.94962	NA



y = 100/(1+exp(-(m0-m1)/m2))	Value	Error
m1	109.35	3.6378
m2	21.105	3.6403
Chisq	391.39	NA
R	0.985	NA





Ring flattening test results

Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

Vickers hardness testing results

Remote from Seam			HAZ		Weld Metal or Fusion Line			
OD	Midwall	ID	Location	Hardness	other	OD	Midwall	ID
164	156	162	OD	210		212	194	192
160	155	165	Mid	182				
			ID	178				
			OD near fusion line	198				
			Midwall near fusion line	186				
			ID near fusion line	183				

General notes and observations for this pipe section:

Pipe section submitted by anonymous donor

Pipe background information

Nominal diameter	8-inch	203 mm
Nominal wall thickness	0.250-inch	6.4 mm
Pipe manufacturer	Kaiser, Fontana, CA mill	
Year of manufacture	1954	
Seam weld type	LF ERW	
Reported pipe grade	API 5L X-46, non-expanded	

Base metal tensile test results*

Tensile strength	68,500 psi	472 MPa
Yield strength	50,700 psi	350 MPa
Elongation, %	24.9	
Reduction of area, %	36.9	
Mode of failure	Ductile	

*Average between two transverse tensile tests.

Transverse seam weld tensile test results

#1	Failed in base metal @ 70,200 psi	484 MPa
#1	Failed in base metal @ 68,800 psi	474 MPa

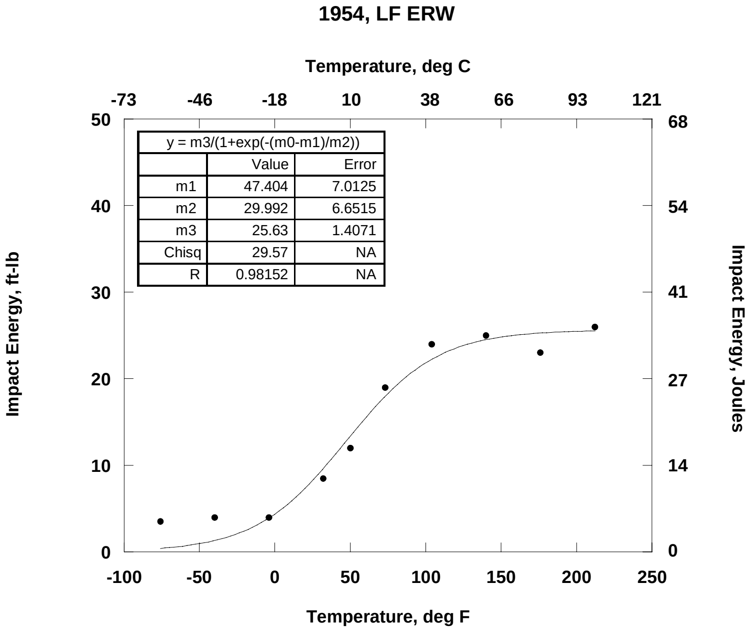
Bondline and HAZ chemical analysis results

Element	Weight % of sample	Base metal max. allow (Wt %)
Carbon (C)	0.227	0.310
Manganese (Mn)	0.754	1.350
Phosphorus (P)	0.009	0.040
Sulphur (S)	0.031	0.050
Silicon (Si)	0.006	
Copper (Cu)	0.158	
Tin (Sn)	0.010	
Nickel (Ni)	0.056	
Chromium (Cr)	0.022	
Molybdenum (Mo)	0.012	
Aluminum (Al)	0.006	
Vanadium (V)	0.002	
Niobium (Nb)	0.003	
Zirconium (Zr)	0.000	
Titanium (Ti)	0.002	
Boron (B)	0	
Calcium (Ca)	0.0001	
Cobalt (Co)	0.034	
CE = C + (Mn/6)	**0.3527**	
V + Nb + Ti	**0.007**	

Bondline Charpy V-notch impact test results

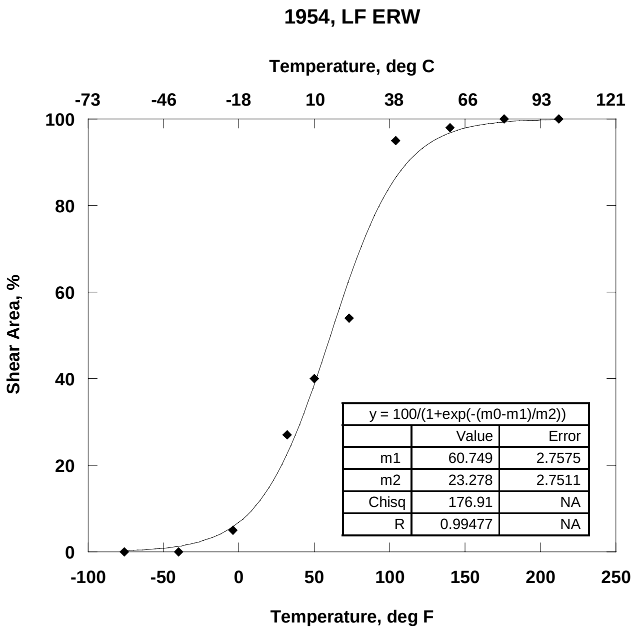
Test temperature		Impact Energy, Ratio for full size, 10mm x 10mm specimen		Shear area	Lateral expansion	
°F	°C	ft-lbs	Joules	percent	Mils	mm
-76	-60	3.5	5	0	3	0.08
-40	-40	4	5	0	5	0.13
-4	-20	4	5	5	4	0.10
32	0	8.5	12	27	10	0.25
50	10	12	16	40	12	0.30
73	23	19	26	54	13	0.33
104	40	24	33	95	18	0.46
140	60	25	34	98	25	0.64
176	80	23	31	100	19	0.48
212	100	26	35	100	21	0.53

Transition temperature, 85% shear area for specimen	100	°F	38	°C
Charpy upper shelf energy, (full size specimen)	24	ft-lbs	34	Joules



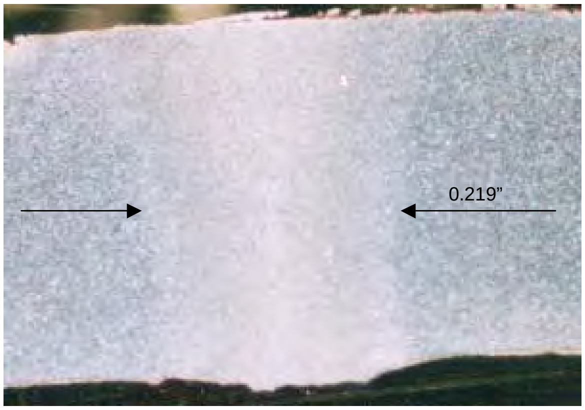
y = m3/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	47.404	7.0125
m2	29.992	6.6515
m3	25.63	1.4071
Chisq	29.57	NA
R	0.98152	NA



y = 100/(1+exp(-(m0-m1)/m2))

	Value	Error
m1	60.749	2.7575
m2	23.278	2.7511
Chisq	176.91	NA
R	0.99477	NA



Ring flattening test results

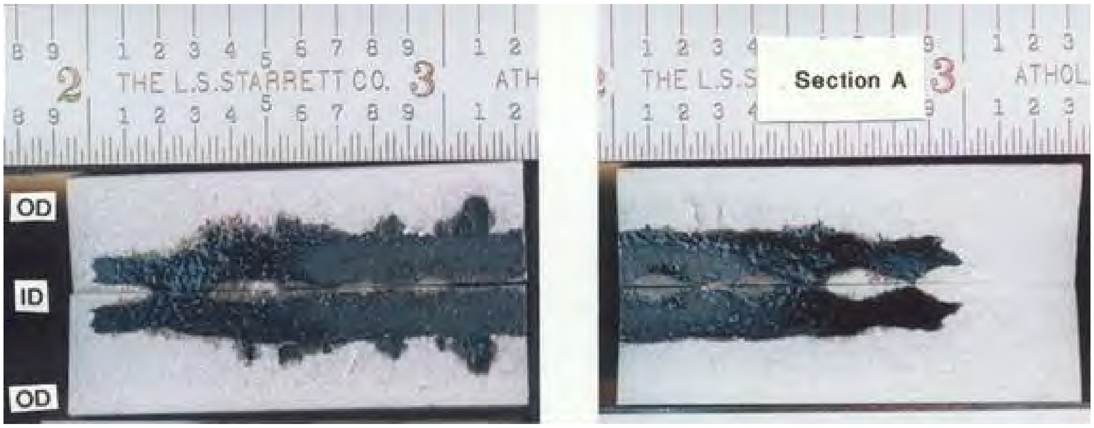
Weld Location, degrees	Opening observed when flattened to					
	2/3 D		1/3 D		Walls Meeting	
	Cracks	Location	Cracks	Location	Cracks	Location
0°	No	-	No	-	No	-
90°	No	-	No	-	No	-

General notes and observations for this pipe section:

LF ERW seam weld exhibits a HF ERW hourglass shape.

Appendix B – Task 2

Catalog of Seam Weld Defect Types



Photograph of Fracture Surfaces.

Catalog #:	30
Report #:	3
Defect #:	13

Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	60%, 3.5 inch (89 mm) ID crack
Seam Type:	LF-ERW	Visual:	ID Hook Crack
Grade:	X52	L	2.21 inch (56.1 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	71%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.240 inch (6.10 mm)
t_{pipe}	0.319 inch (8.10 mm)	t_{weld}	0.340 inch (8.64 mm)
Failure:	None		

Photograph of Fracture Surface.

Catalog #:	134		
Report #:	12		
Defect #:	68C		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	99%, 2.25 inch (57.2 mm) OD-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	OD Hook Crack
Grade:	API 5L X42	L	> 2.7 inch (69 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	52%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.130 inch (3.30 mm)
t_{pipe}	Not Determined	t_{weld}	0.248 inch (6.30 mm)
Failure:	N/A		

Photographs of Metallographic Section and Fracture Surface.

Catalog #:	135		
Report #:	12		
Defect #:	71A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	60%, 8.5 inch (216 mm) ID & Mid-wall Non-Fusion
Seam Type:	LF-ERW	Visual:	Mid-wall Void + Laminations + ID Hook Crack
Grade:	API 5L X42	L	> 2 inch (51 mm) (ID Hook Crack)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	48% (ID Hook Crack)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.122 inch (3.10 mm)
t_{pipe}	Not Determined	t_{weld}	0.251 inch (6.38 mm)
Failure:	N/A		

Photograph of Fracture Surface.

Catalog #:	122		
Report #:	12		
Defect #:	58A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	52%, 8 inch (203 mm) OD-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	OD Hook Crack
Grade:	API 5L X42	L	> 7 inch (178 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	46%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.120 inch (3.05 mm)
t_{pipe}	Not Determined	t_{weld}	0.260 inch (6.60 mm)
Failure:	N/A		

Photograph of Fracture Surface.

Catalog #: 142
Report #: 12
Defect #: 79A

Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	64%, 4.3 inch (109 mm) Intermittent Non-Fusion
Seam Type:	LF-ERW	Visual:	OD Hook Crack
Grade:	API 5L X42	L	> 6.575 inch (167 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	44%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.108 inch (2.74 mm)
t_{pipe}	Not Determined	t_{weld}	0.248 inch (6.30 mm)
Failure:	N/A		

Photograph of Fracture Surfaces.

Catalog #:	22		
Report #:	2		
Defect #:	421		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	50%, 7 inch (178 mm) crack like
Seam Type:	ERW	Visual:	ID Hook crack
Grade:	X52	L	5.5 inch (140 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	43%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.150 inch (3.81 mm)
t_{pipe}	0.326 inch (8.28 mm)	t_{weld}	0.344 inch (8.74 mm)
Failure:	Burst test rupture at 2,200 psig (15.17 MPa) (136% of SMYS)		

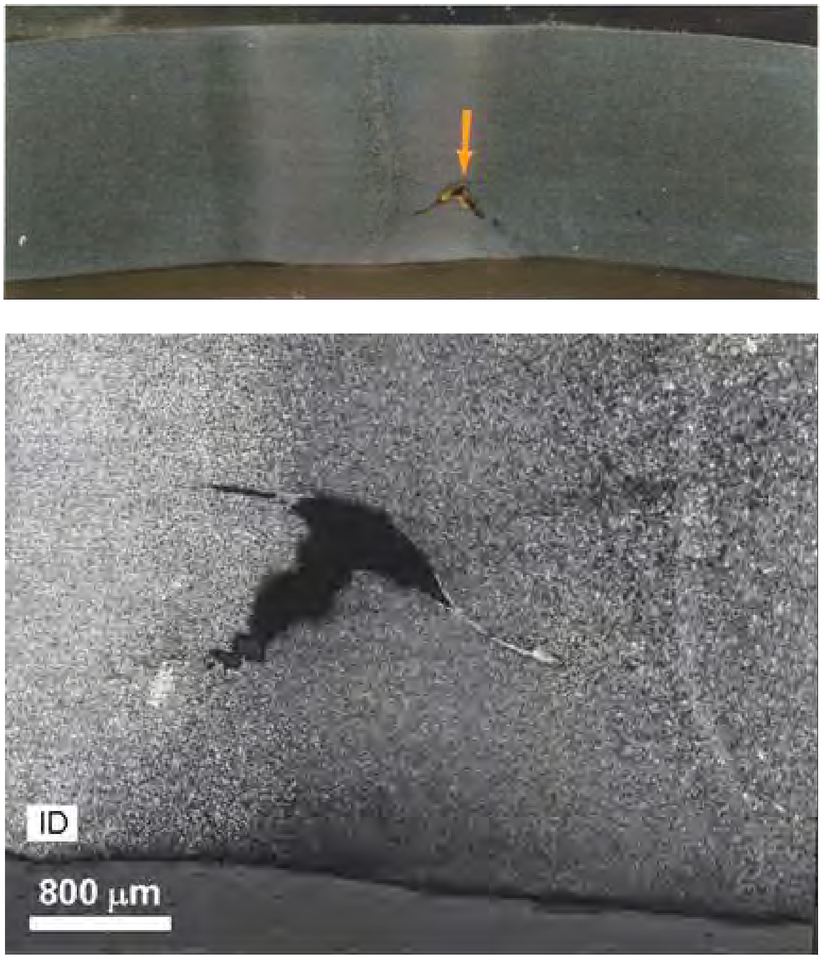
Photograph of Fracture Surface.

Catalog #:	126
Report #:	12
Defect #:	67A

Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	80%, 6 inch (152 mm) ID-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	OD Hook Crack
Grade:	API 5L X42	L	5.4 inch (137 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	43%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.106 inch (2.69 mm)
t_{pipe}	Not Determined	t_{weld}	0.147 inch (3.73 mm)
Failure:	N/A		

Photograph Fracture Surface.

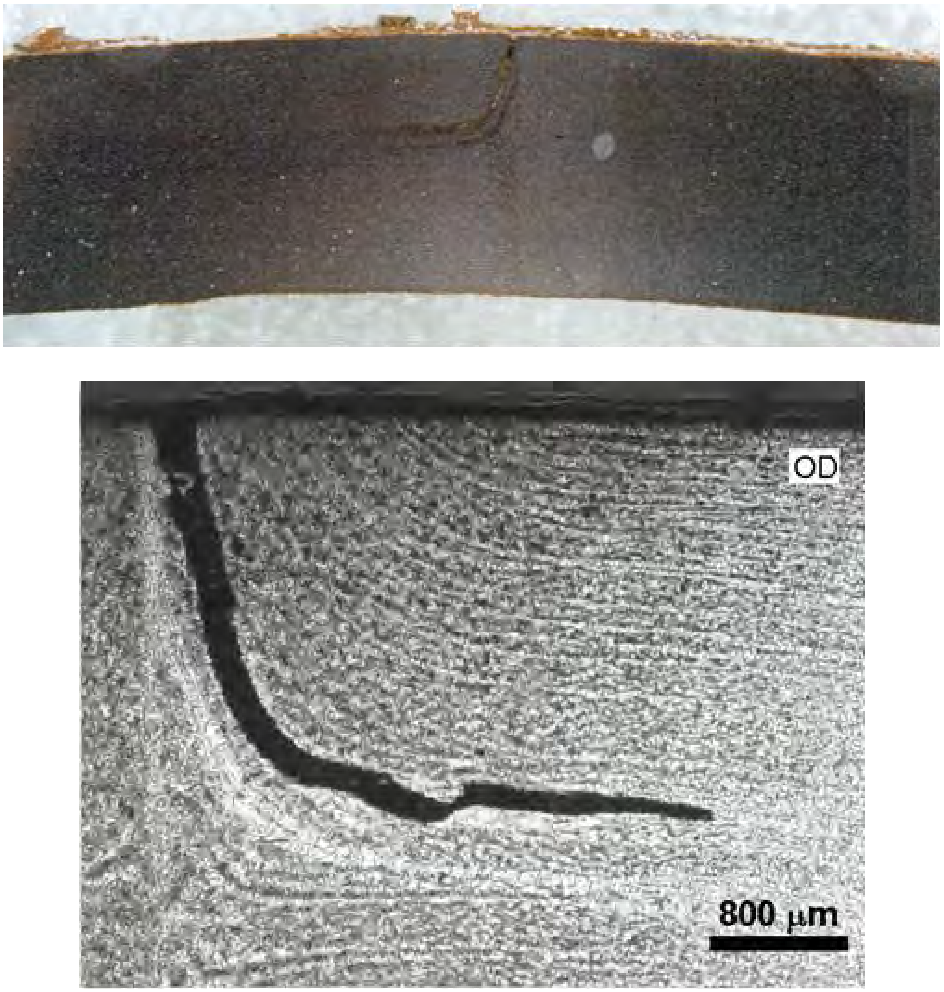
Catalog #:	124		
Report #:	12		
Defect #:	60A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	84%, 7 inch (178 mm) OD-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	OD Hook Crack
Grade:	API 5L X42	L	> 7.0 inch (178 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	40%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.105 inch (2.67 mm)
t_{pipe}	Not Determined	t_{weld}	0.265 inch (6.73 mm)
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

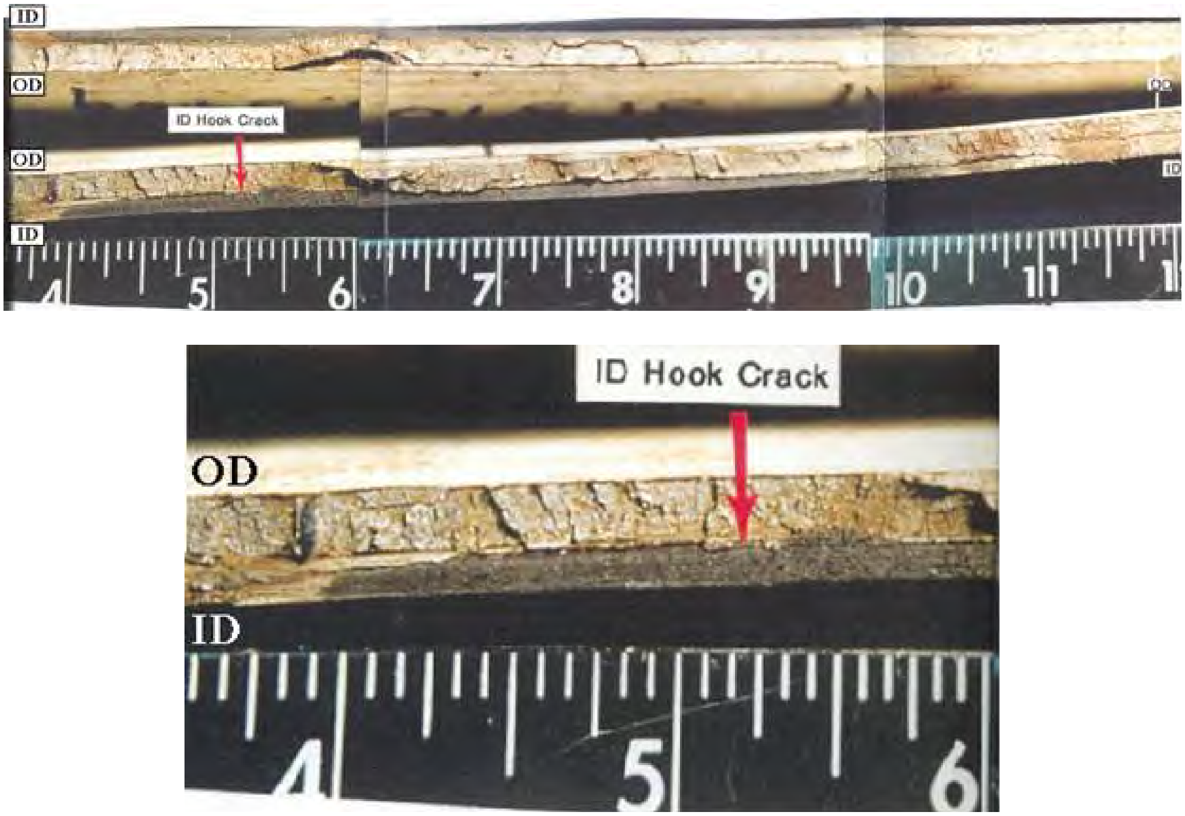
Catalog #:	104
Report #:	11
Defect #:	3B

Pipe		**Defect**	
Vintage:	1953	NDE technique(s):	Fast UT
Manufacturer:	Unknown	NDE result(s):	40%, 3 inch (76 mm) ID Crack
Seam Type:	LF-ERW	Visual:	ID Hook Crack Mid-wall Void
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	39.6% (ID Hook Crack)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

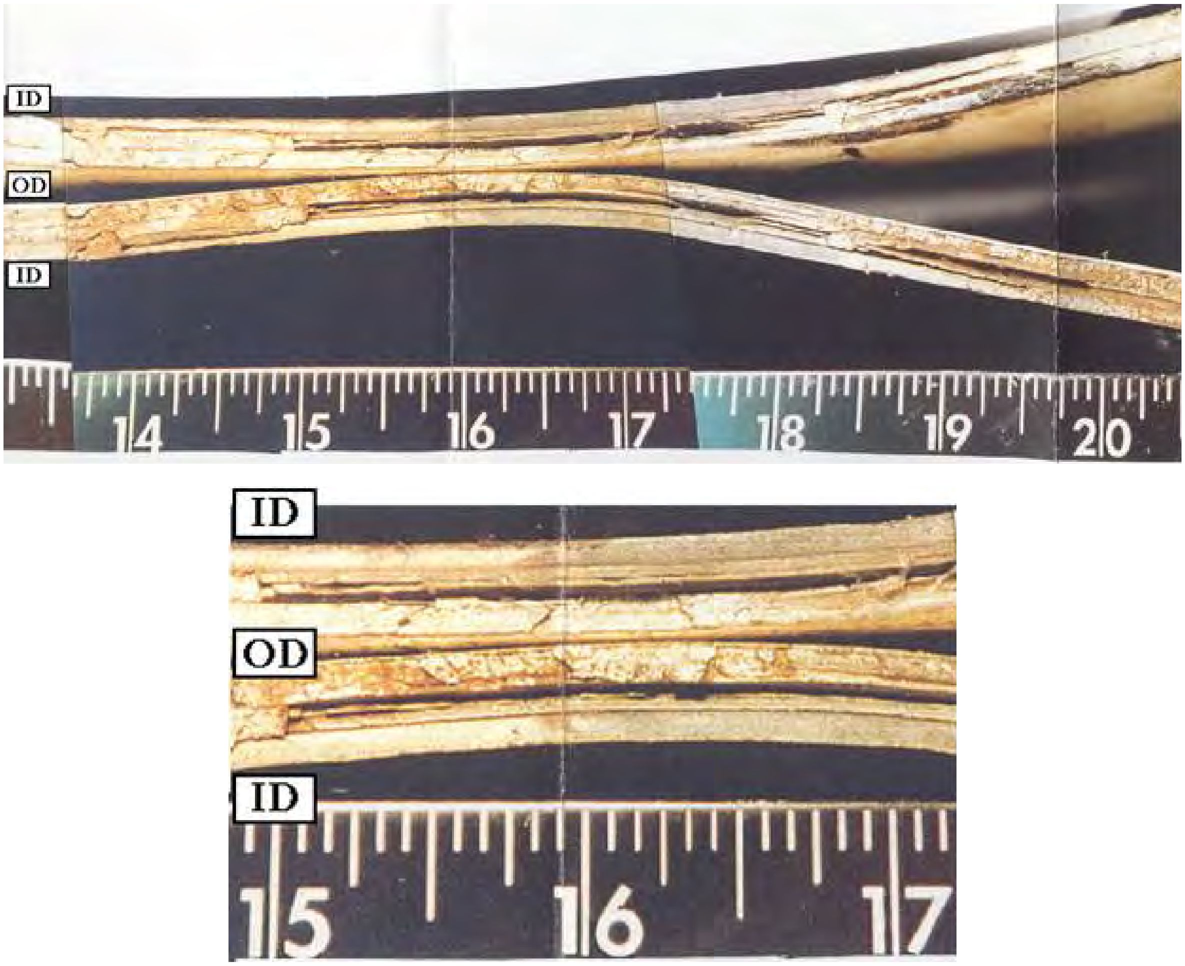
Catalog #:	140		
Report #:	12		
Defect #:	73D		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	48%, 6.5 inch (165 mm) OD-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	OD Hook Crack
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	38%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.090 inch (2.29 mm)
t_{pipe}	Not Determined	t_{weld}	0.236 inch (5.99 mm)
Failure:	N/A		



Photographs of Fracture Surfaces.

Catalog #:	23		
Report #:	2		
Defect #:	551-38.8.b		
Pipe		**Defect**	
		NDE technique(s):	UT
Vintage:	circa 1950	NDE result(s):	20%, 2.5 inch (64 mm) ID crack like
Manufacturer:	Youngstown	Visual:	ID Hook crack
Seam Type:	ERW	L	6.0 inch (152 mm)
Grade:	X52	depth/t_{weld}	35%
$D_{nominal}$	20 inch (508 mm)	depth:	0.120 inch (3.05 mm)
$t_{nominal}$	0.312 inch (7.92 mm)	t_{weld}	0.346 inch (8.79 mm)
t_{pipe}	0.332 inch (8.43 mm)		
Failure:	Burst test rupture(*) at 2,200 psig (15.17 MPa) (116% of SMYS)		

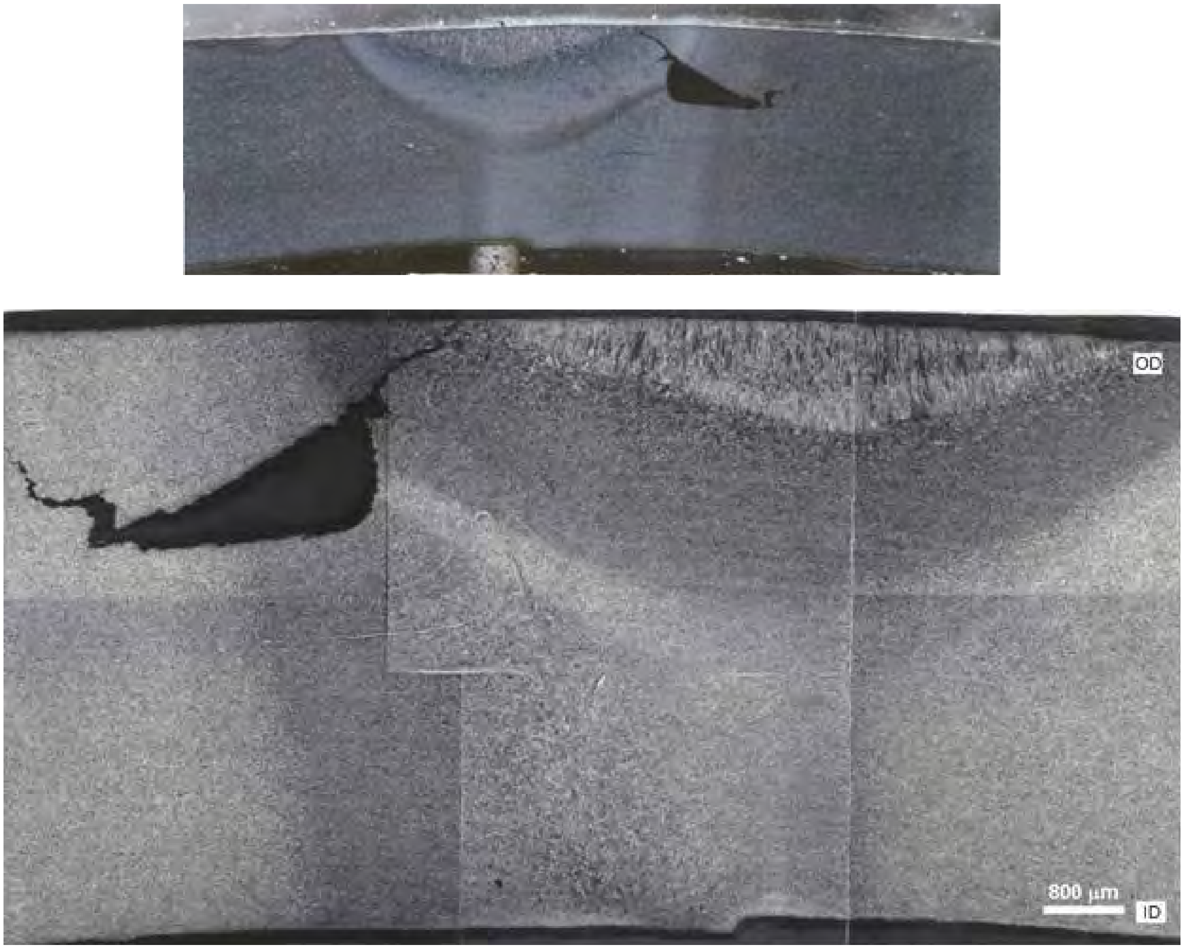
(*) Burst test failed two adjacent hook cracks at one pressure.



Photographs of Fracture Surfaces.

Catalog #:	24		
Report #:	2		
Defect #:	551-39.6.b		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	80%, 5.5 inch (140 mm) ID crack like
Seam Type:	ERW	Visual:	ID Hook crack
Grade:	X52	L	7.0 inch (178 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	35%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.120 inch (3.05 mm)
t_{pipe}	0.332 inch (8.43 mm)	t_{weld}	0.346 inch (8.79 mm)
Failure:	Burst test rupture(*) at 2,200 psig (15.17 MPa) (116% of SMYS)		

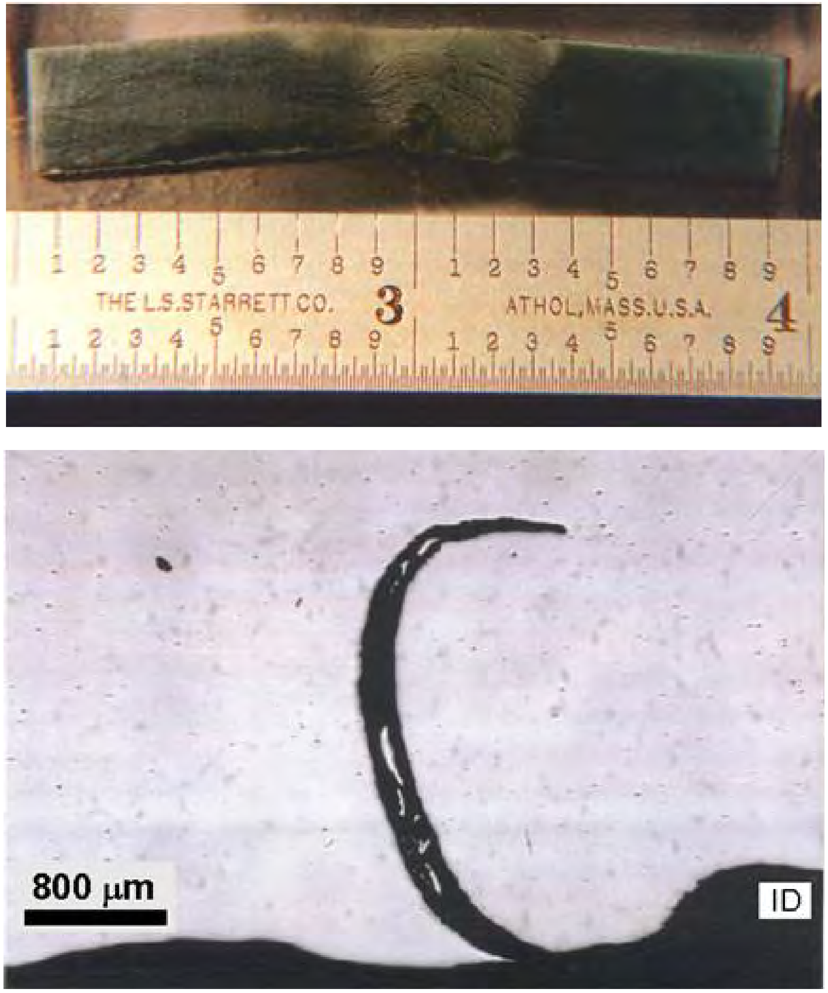
(*) Burst test failed two adjacent hook cracks at one pressure.



Photograph and Photomicrograph of Metallographic Section.

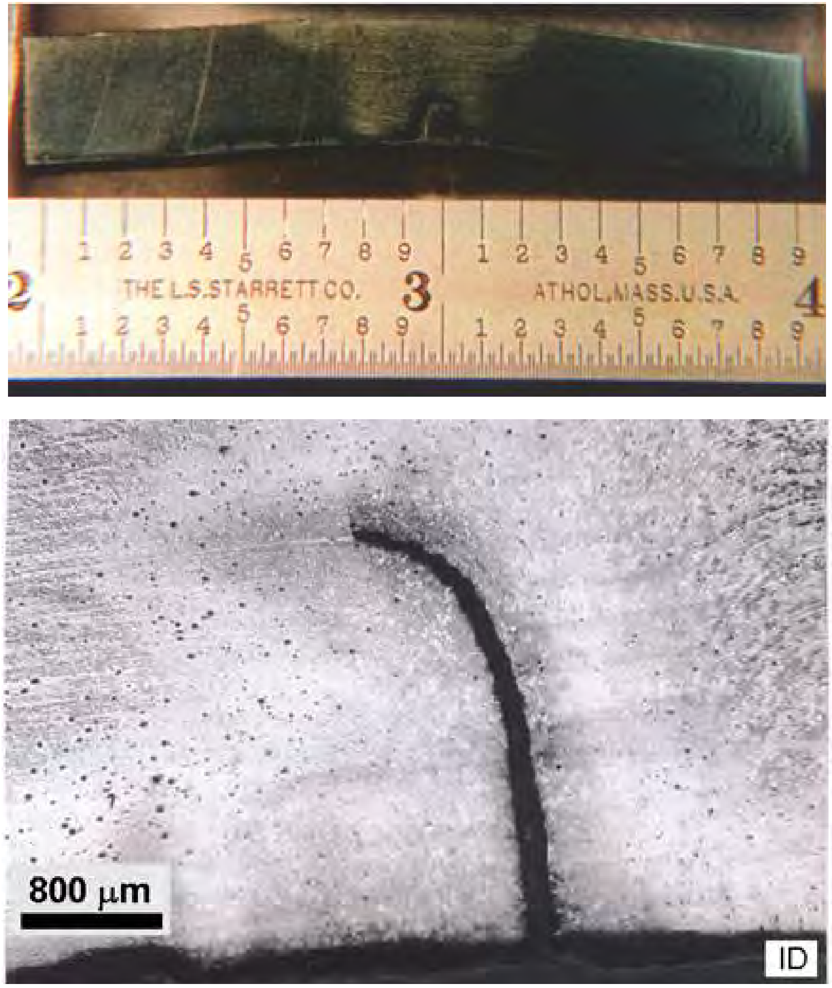
Catalog #: 108
Report #: 11
Defect #: 4A

Pipe		**Defect**	
Vintage:	1953	NDE technique(s):	Fast UT
Manufacturer:	Unknown	NDE result(s):	40%, 3.5 inch (89 mm) OD Crack
Seam Type:	LF-ERW	Visual:	OD Hook Crack + Mid-Wall Void + OD Weld Repair
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	33.5% (OD Hook Crack)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



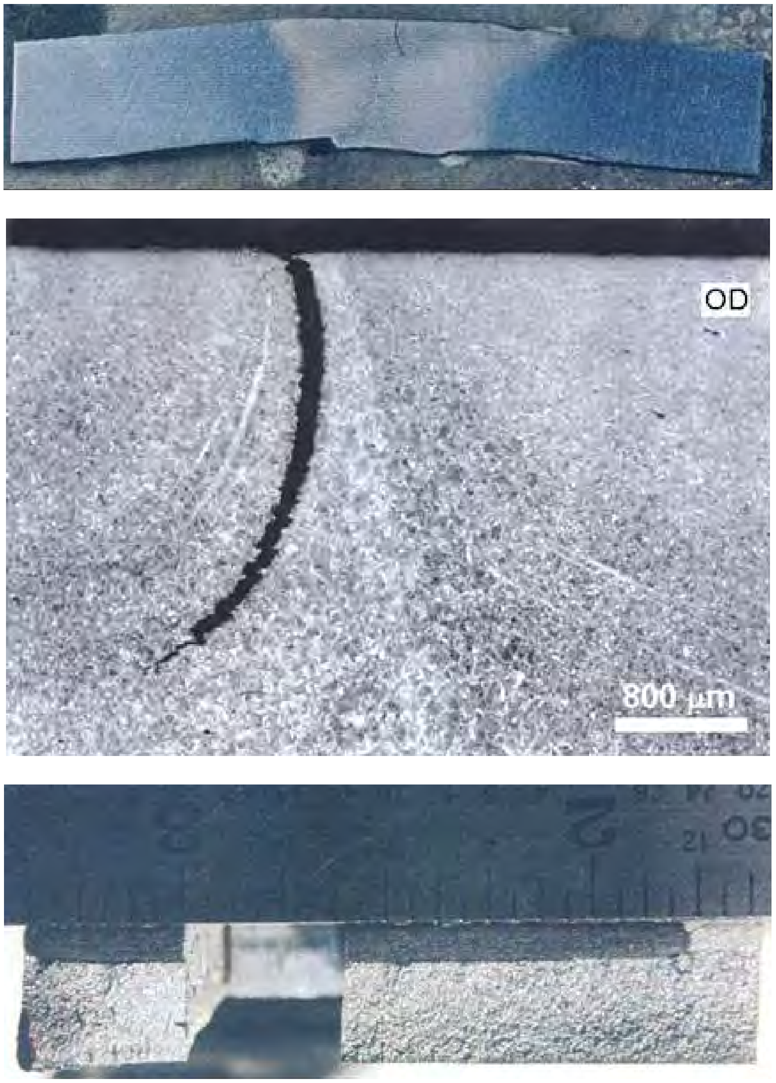
Photograph and Photomicrograph Metallographic Section.

Catalog #:	9		
Report #:	1		
Defect #:	469		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	30% x 2.5 inch (63.5 mm) ID crack
Seam Type:	ERW	Visual:	ID hook crack
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	29%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.096 inch (2.44 mm)
t_{pipe}	0.309 inch (7.85 mm)	t_{weld}	0.330 inch (8.38 mm)
Failure:	None at 2,175 psig (15.00 MPa) (134% of SMYS)		



Photograph and Photomicrograph of Metallographic Section.

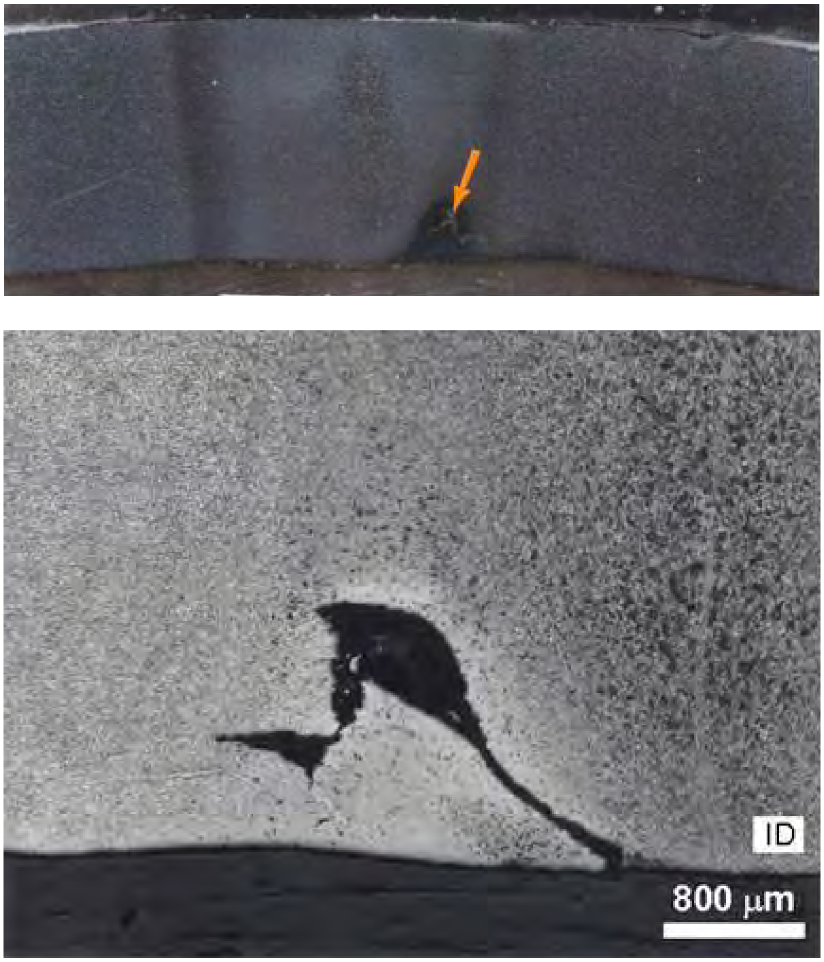
Catalog #:	7		
Report #:	1		
Defect #:	415		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	<10% x 2.4 inch (61 mm) grind area on seam
Seam Type:	ERW	Visual:	ID hook crack
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	27.9%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.092 inch (2.34 mm)
t_{pipe}	0.330 inch (8.38 mm)	t_{weld}	0.330 inch (8.38 mm)
Failure:	Yielding at 2,100 psig (14.48 MPa) (129% of SMYS)		



Photographs and Photomicrograph of Metallographic Section and Fracture Surface.

Catalog #: 98
Report #: 10
Defect #: CY-7

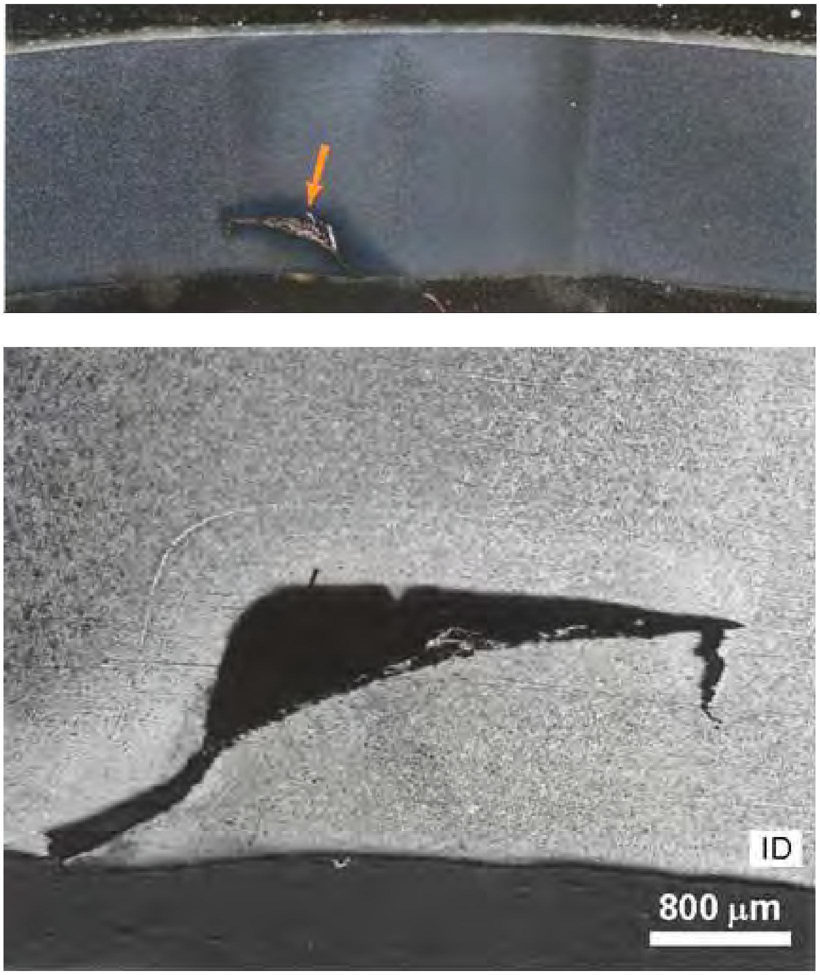
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	OD Hook Crack
Grade:	X52	L	1.6 inch (41 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	27.5 %
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.100 inch (2.54 mm)
t_{pipe}	Not Determined	t_{weld}	0.363 inch (9.22 mm)
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

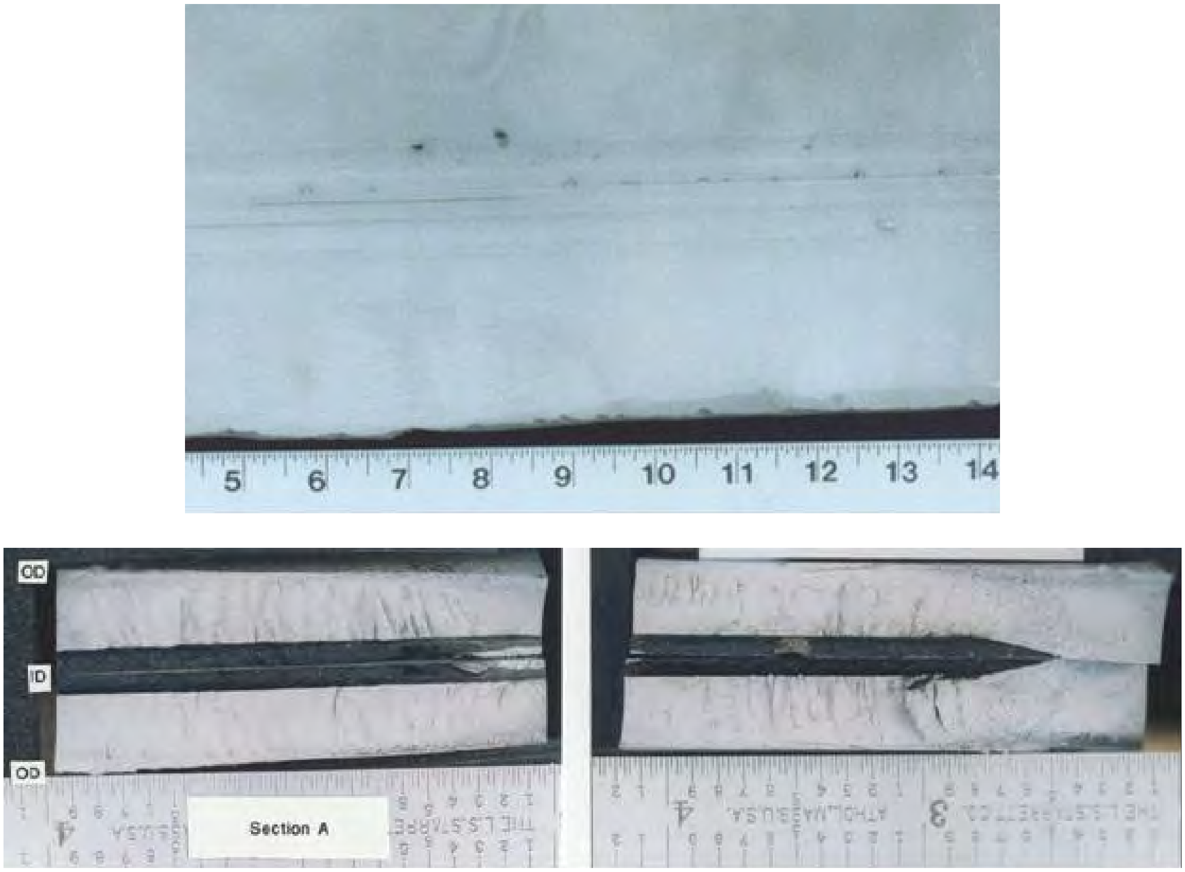
Catalog #:	106
Report #:	11
Defect #:	3D

Pipe		**Defect**	
Vintage:	1953	NDE technique(s):	Fast UT
Manufacturer:	Unknown	NDE result(s):	30%, 2.5 inch (63 mm) ID Crack
Seam Type:	LF-ERW	Visual:	ID Hook Crack Mid-wall Void
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	24.2% (ID Hook Crack)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



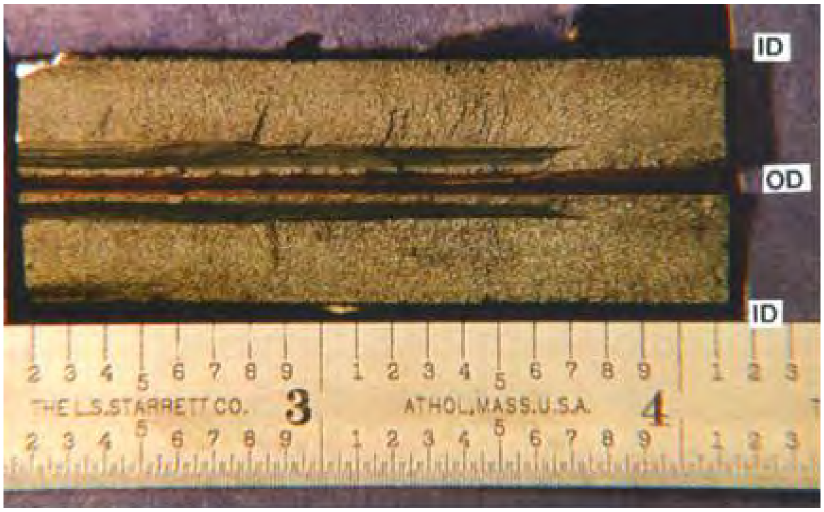
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	103		
Report #:	11		
Defect #:	3A		
Pipe		**Defect**	
Vintage:	1953	NDE technique(s):	Fast UT
Manufacturer:	Unknown	NDE result(s):	25%, 4 inch (102 mm) ID Crack
Seam Type:	LF-ERW	Visual:	ID Hook Crack Mid-Wall Void
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	24% (ID Hook Crack)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



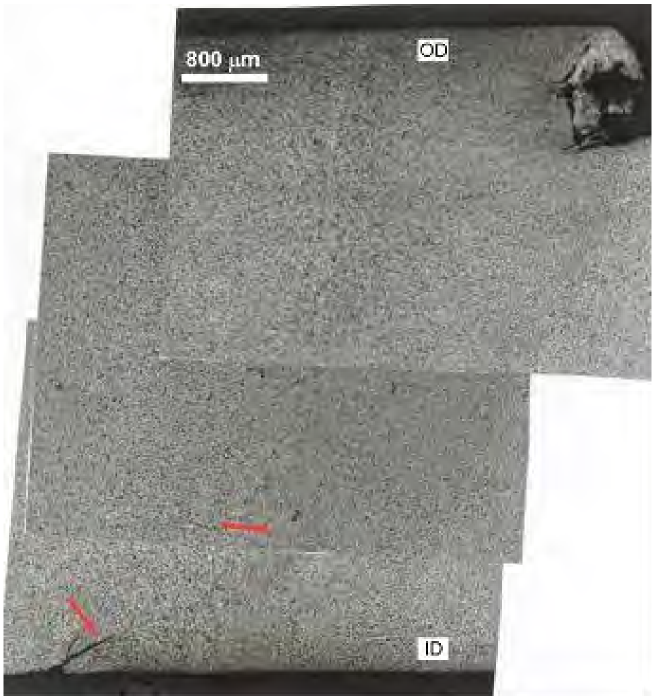
Photographs of ID Pipe Surface and of Fracture Surfaces.

Catalog #:	32		
Report #:	3		
Defect #:	16		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	40%, 4 inch (102 mm) ID hook crack
Seam Type:	LF-ERW	Visual:	ID Hook crack
Grade:	X52	L	>3.64 inch (92.5 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	23%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.083 inch (2.1 mm)
t_{pipe}	0.335 inch (8.51 mm)	t_{weld}	0.365 inch (9.27 mm)
Failure:	None		



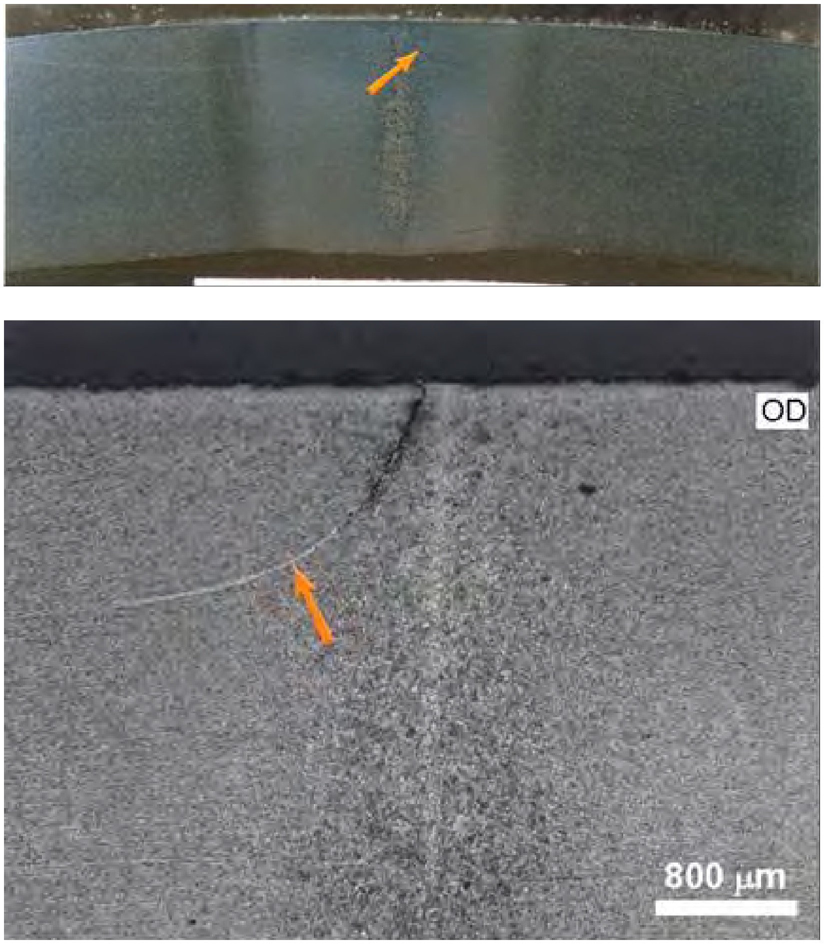
Photograph of Fracture Surfaces.

Catalog #:	10		
Report #:	1		
Defect #:	490		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	30% x 2.63 inch (66.7 mm) OD crack
Seam Type:	ERW	Visual:	OD hook crack
Grade:	X52	L	~ 3.1 inch (79 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	23%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.096 inch (2.44 mm)
t_{pipe}	0.320 inch (8.13 mm)	t_{weld}	0.340 inch (8.64 mm)
Failure:	None at 2,300 psig (15.86 MPa) (142% of SMYS)		



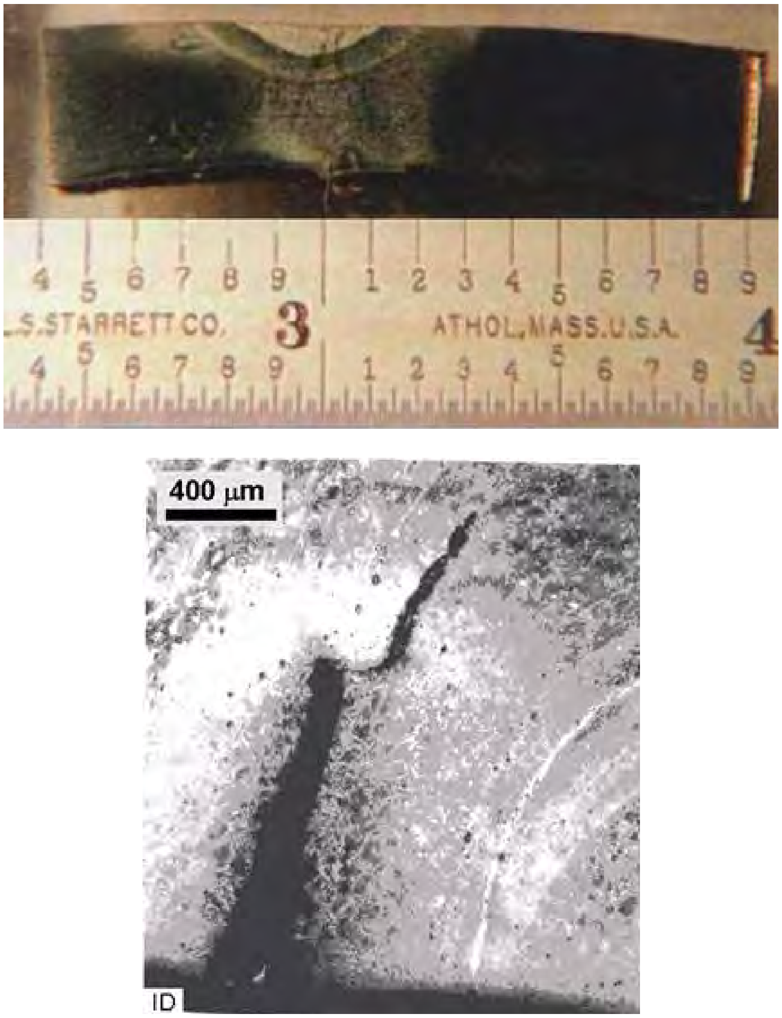
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	125		
Report #:	12		
Defect #:	62A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	16%, 8 inch (203 mm) Non-Fusion or Lamination
Seam Type:	LF-ERW	Visual:	Misalignment + Hook Crack + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	19% (Misalignment)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.049 inch (1.24 mm)
t_{pipe}	Not Determined	t_{weld}	0.257 inch (6.53 mm)
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

Catalog #:	105		
Report #:	11		
Defect #:	3C		
Pipe		**Defect**	
Vintage:	1953	NDE technique(s):	Fast UT
Manufacturer:	Unknown	NDE result(s):	15%, 2 inch (51 mm) OD Crack
Seam Type:	LF-ERW	Visual:	OD Hook Crack
Grade:	API 5L X42	L	2 inch (51 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	16.5%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

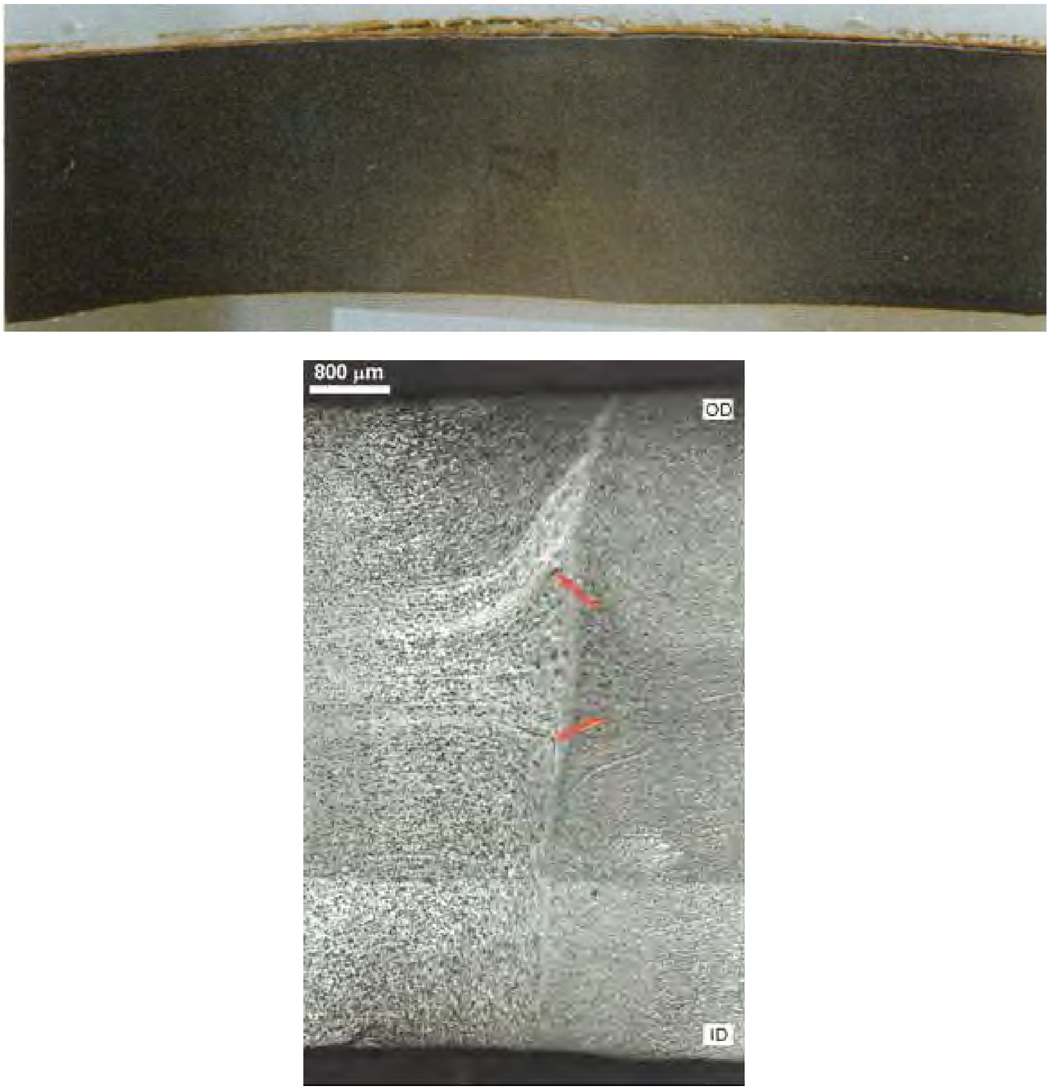


Photograph and Photomicrograph of Metallographic Section.

Catalog #:	8		
Report #:	1		
Defect #:	451		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	7% x 2.5 inch (63 mm) grind area on seam
Seam Type:	ERW	Visual:	ID hook crack
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	4.3%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.0136 inch (0.35 mm)
t_{pipe}	0.330 inch (8.38 mm)	t_{weld}	0.319 inch (8.10 mm)
Failure:	None at 2,250 psig (15.51 MPa) (139% of SMYS)		

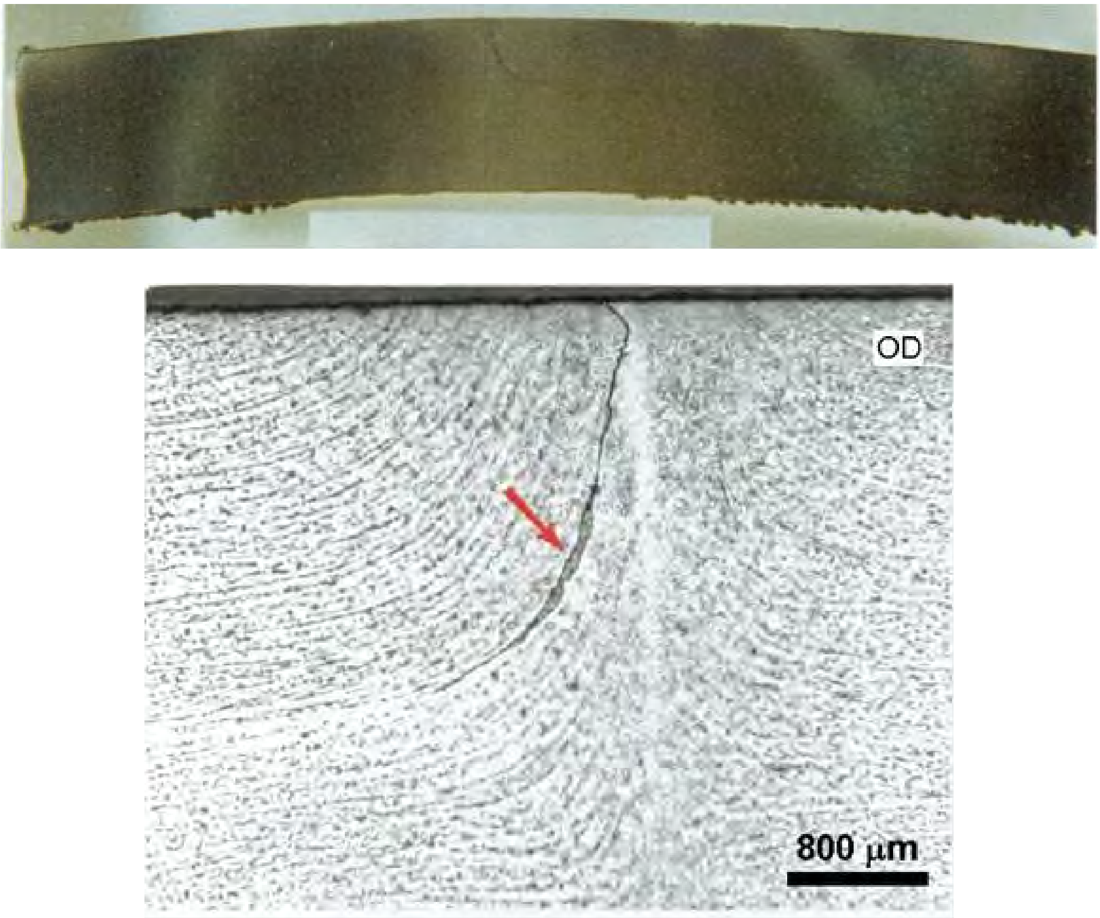
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	114		
Report #:	12		
Defect #:	46B-D		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	60%, 3.75 inch (95.3 mm) ID-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	Hook Crack
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



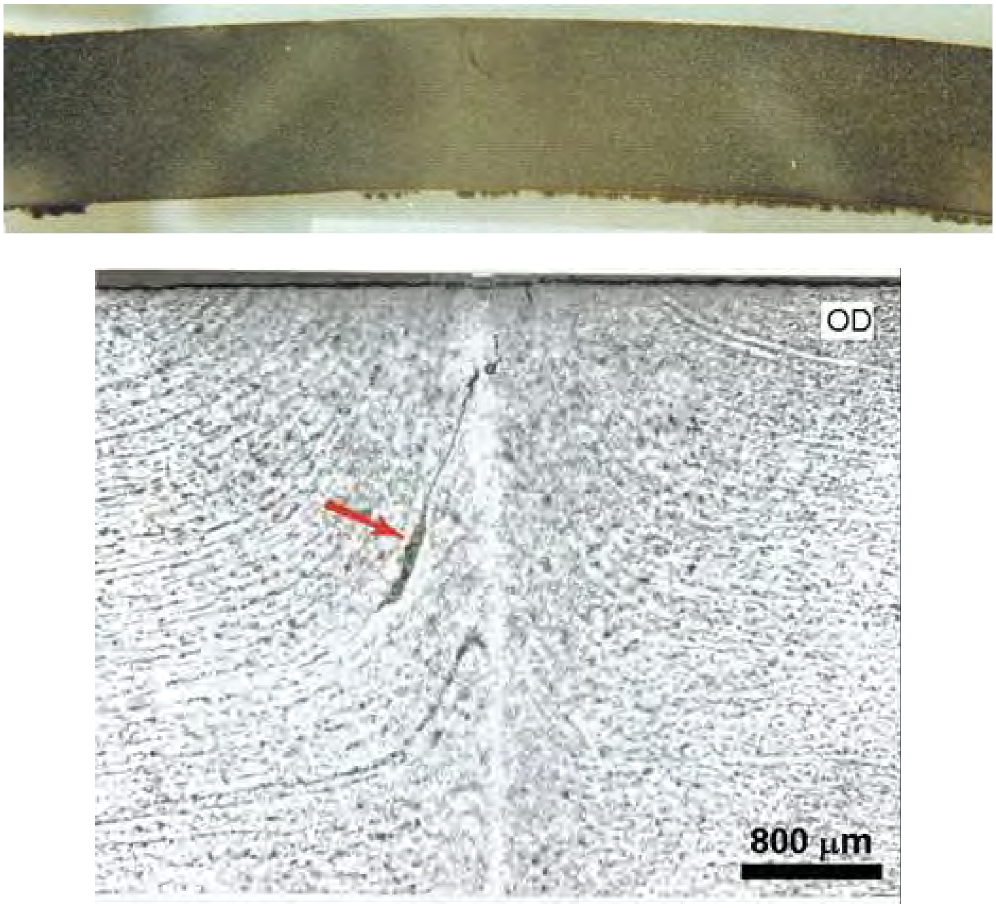
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	112		
Report #:	12		
Defect #:	46B-B		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	N/A
Seam Type:	LF-ERW	Visual:	Hook Crack + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



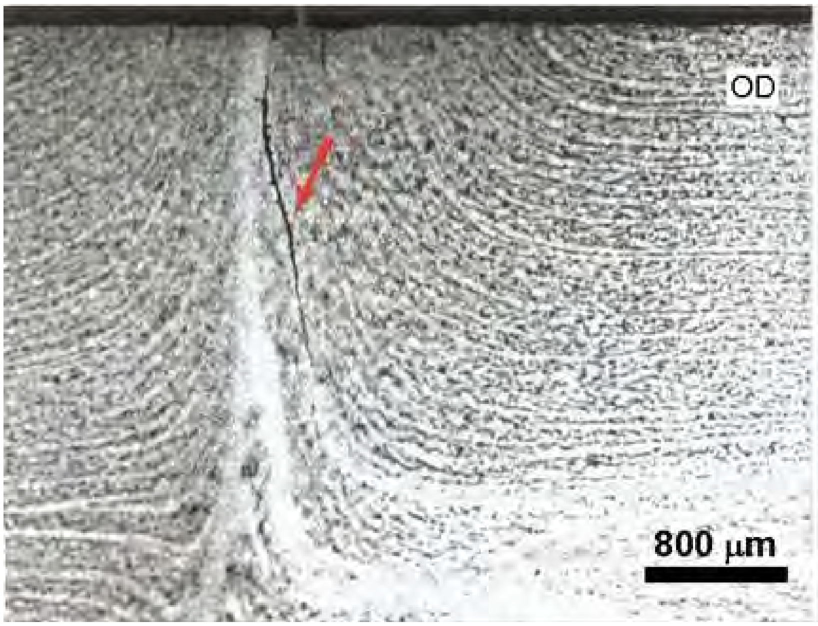
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	143		
Report #:	12		
Defect #:	79B		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	N/A
Seam Type:	LF-ERW	Visual:	Hook Crack + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



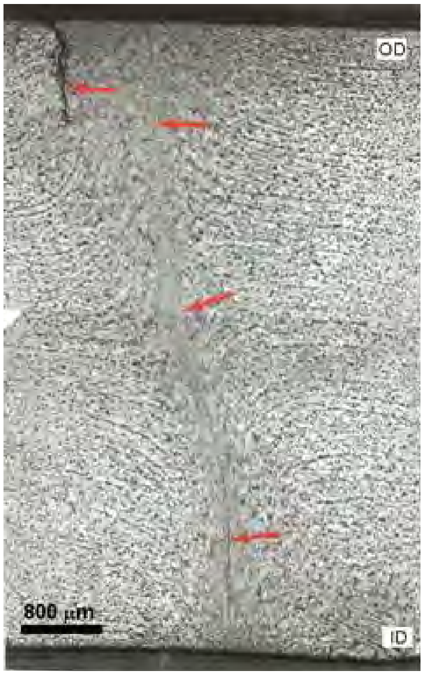
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	144		
Report #:	12		
Defect #:	79C		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	52%, 2.7 inch (69 mm) OD Non-Fusion
Seam Type:	LF-ERW	Visual:	Hook Crack + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

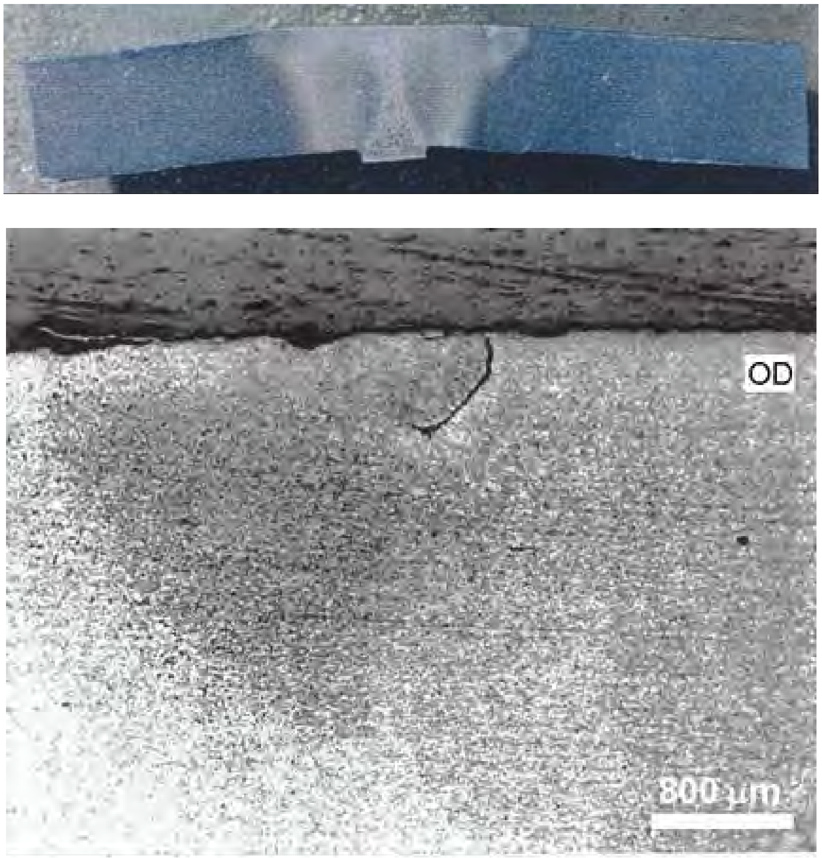
Catalog #:	141		
Report #:	12		
Defect #:	73E		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	52%, 2.5 inch (63 mm) OD-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	OD Hook Crack + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

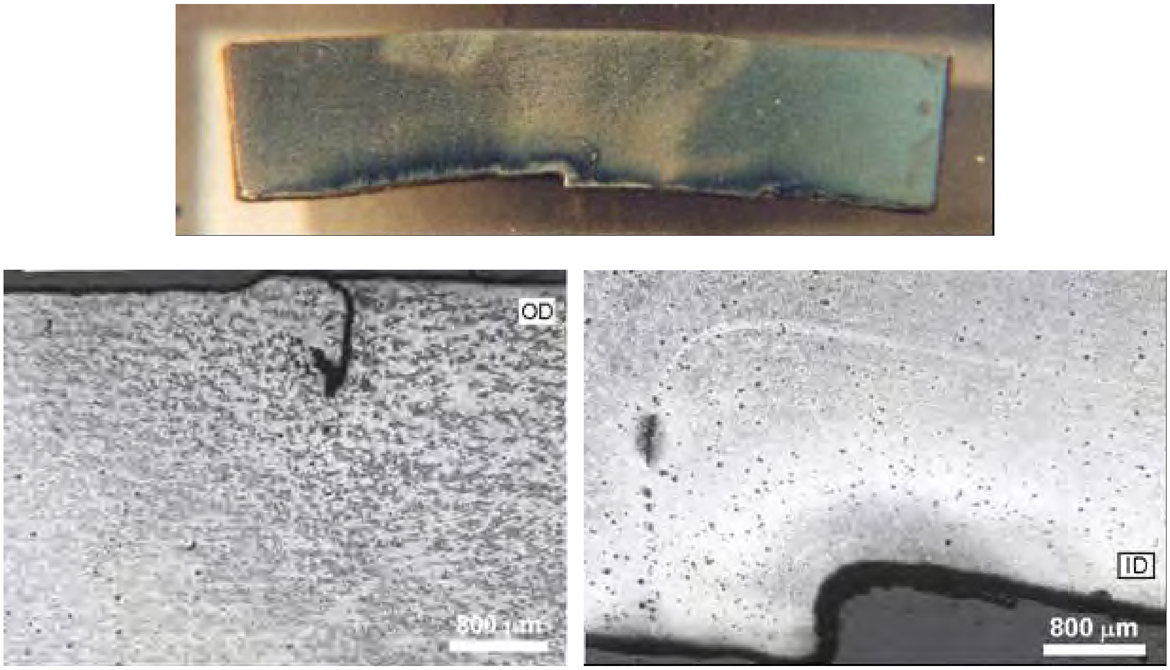
Catalog #: 145
Report #: 12
Defect #: 80A

Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	92%, 4.8 inch (122 mm) Non-Fusion
Seam Type:	LF-ERW	Visual:	Weld Area Crack, Weld Crack + Misalignment + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



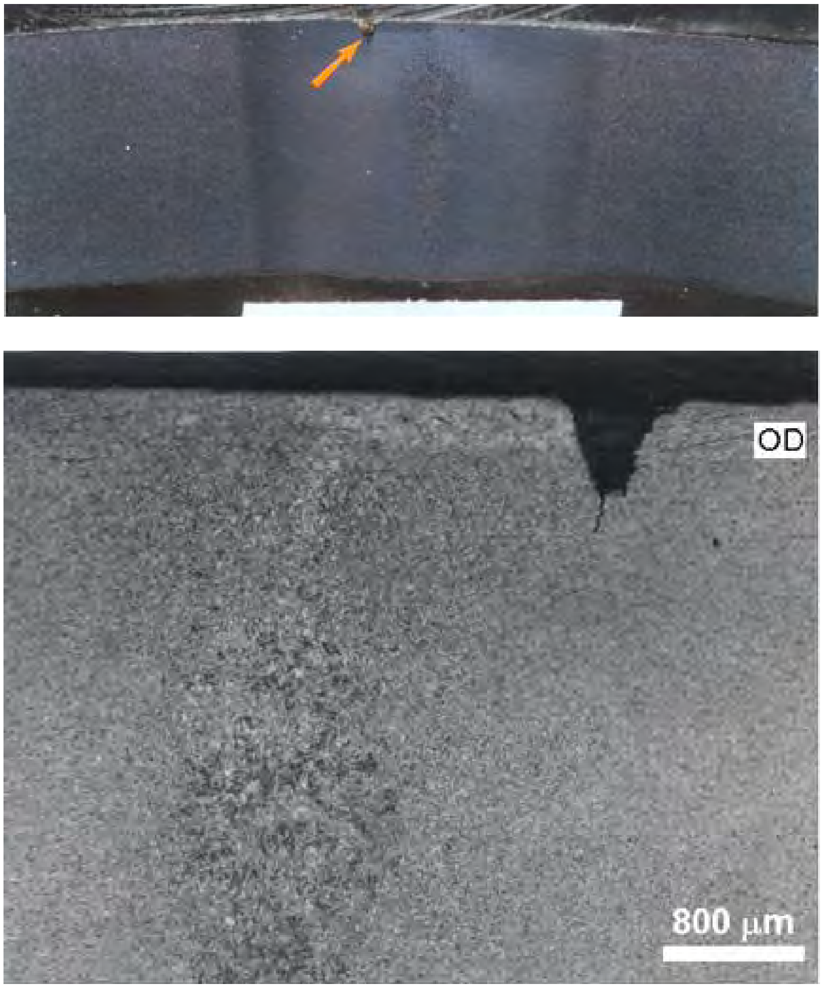
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	100		
Report #:	10		
Defect #:	CY-9		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	OD Crack at Contact Mark + ID Under-trim
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	< 7.0% (OD Crack)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	< 0.024 inch (0.61 mm)
t_{pipe}	Not Determined	t_{weld}	0.344 inch (8.74 mm)
Failure:	N/A		



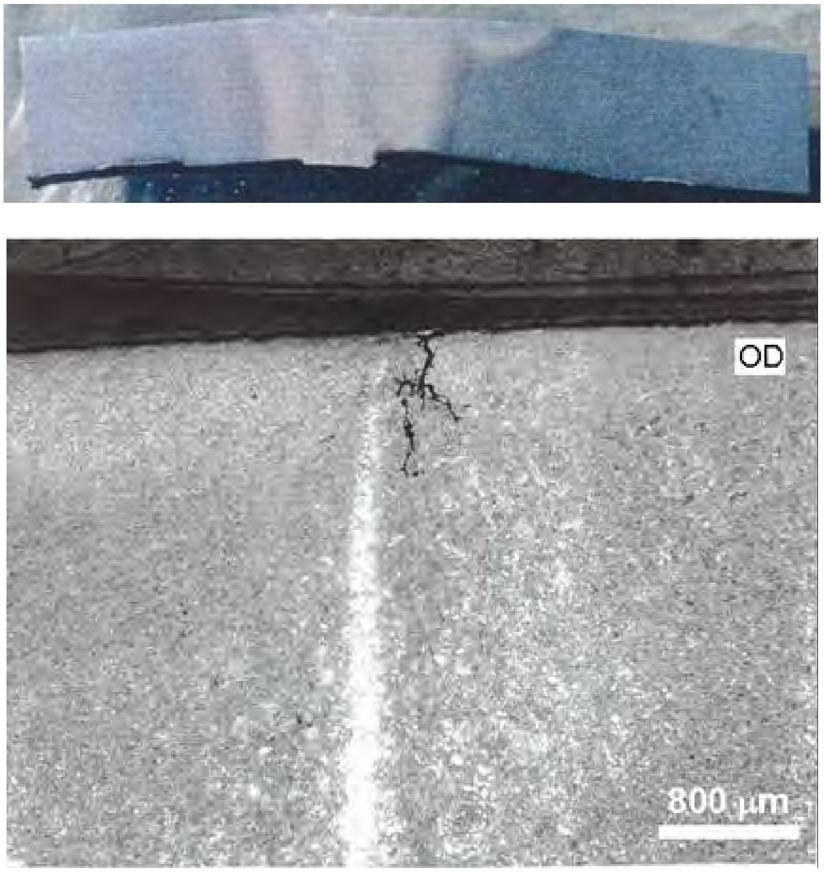
Photograph and Photomicrographs of Metallographic Section.

Catalog #:	63		
Report #:	7		
Defect #:	432-4.09		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	Youngstown	NDE result(s):	No Anomaly Revealed
Seam Type:	ERW	Visual:	OD Crack + ID Outbent fiber + Contact Marks
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	11% (OD Crack)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.036 inch (0.91 mm) (OD Crack)
t_{pipe}	Not determined	t_{weld}	0.319 inch (8.10 mm)
Failure:	N/A		



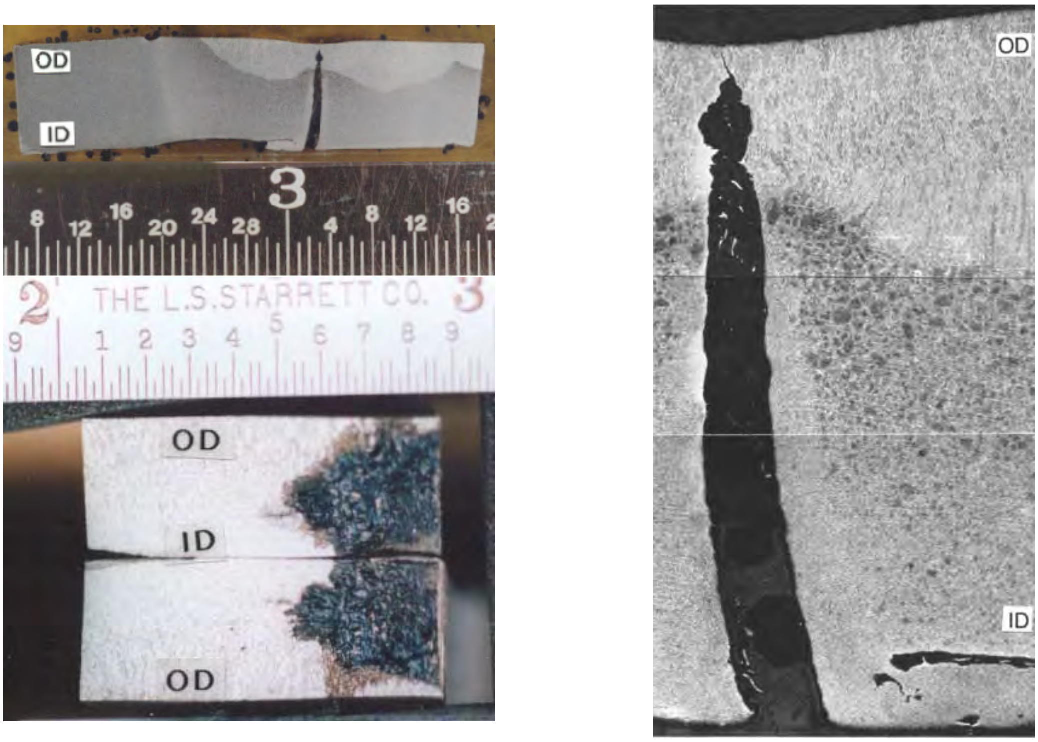
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	107		
Report #:	11		
Defect #:	3E		
Pipe		**Defect**	
Vintage:	1953	NDE technique(s):	Fast UT
Manufacturer:	Unknown	NDE result(s):	50%, 5 inch (127 mm) OD Crack
Seam Type:	LF-ERW	Visual:	OD Crack
Grade:	API 5L X42	L	5 inch (127 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	9.2%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

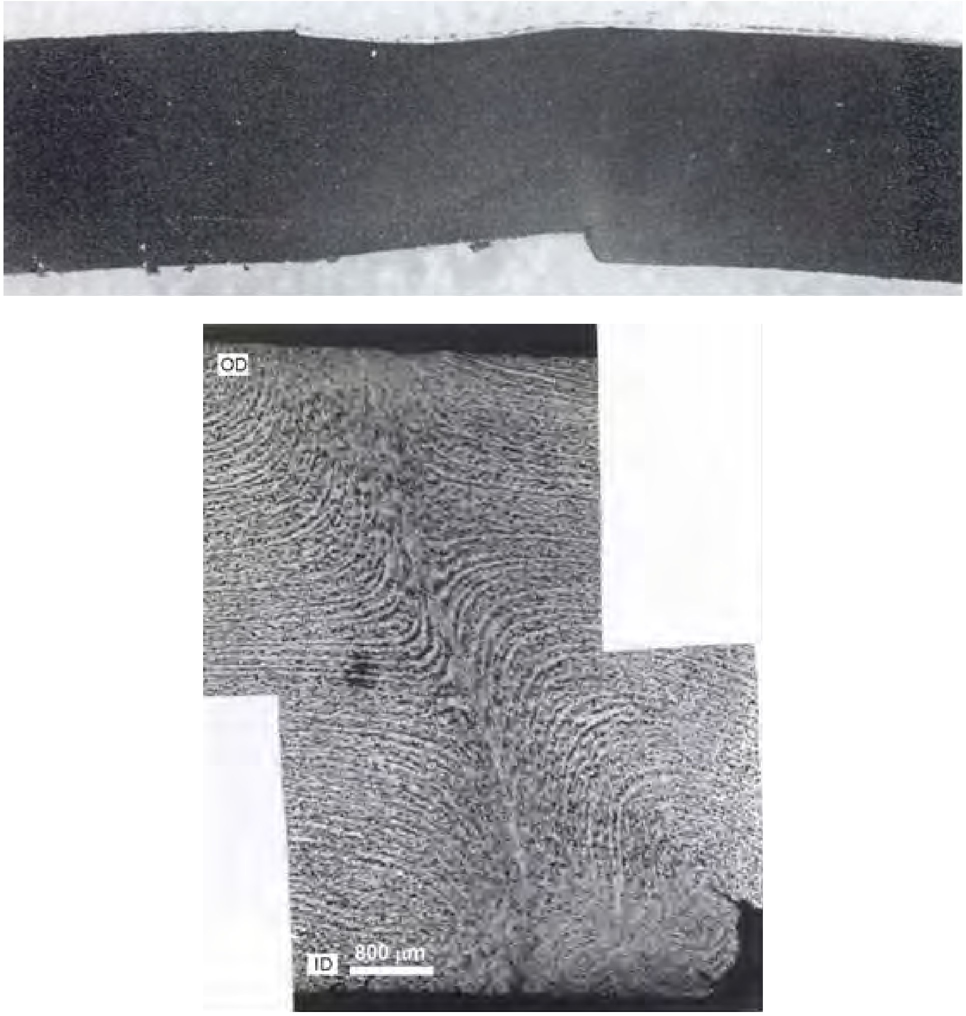
Catalog #:	93		
Report #:	10		
Defect #:	CY-2		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	OD Crack
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	8.8%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.031 inch (0.79 mm)
t_{pipe}	Not Determined	t_{weld}	0.353 inch (8.97 mm)
Failure:	N/A		



Photographs and Photomicrograph of Metallographic Section, and Fracture Surfaces.

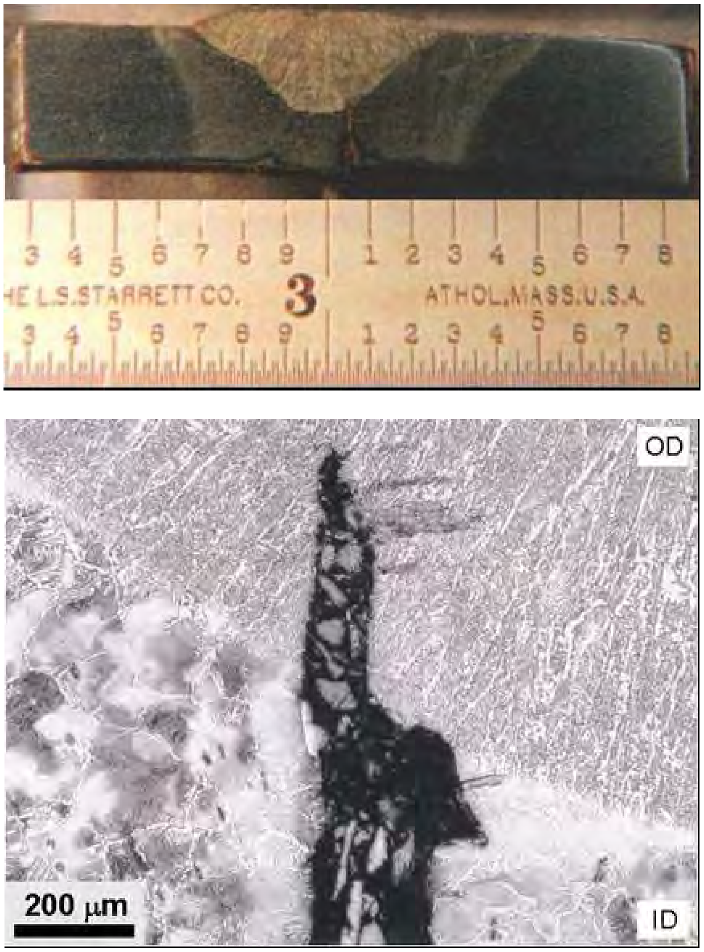
Catalog #: 29
Report #: 3
Defect #: 12A

Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT, MT, and Fast UT
Manufacturer:	Youngstown	NDE result(s):	12 x 7 inch (305 x 178 mm) OD seam grind area (UT) + 11 x 1.0 inch (280 x 25.4 mm) OD weld repair (UT) + 0.4 x 0.1 inch (10.2 x 2.5 mm) OD grind area (UT) + 0.25 inch (6.35 mm) OD crack (MT) + 100%, 1.9 inch (48.3 mm) ID hook crack (Fast UT)
Seam Type:	LF-ERW	Visual:	ID Lack of Fusion & Small crack
Grade:	X52	L	1.9 inch (48 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	99%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.317 inch (8.05 mm)
t_{pipe}	0.320 inch (8.13 mm)	t_{weld}	0.332 inch (8.43 mm)
Failure:	None		



Photograph and Photomicrograph of Metallographic Section.

Catalog #:	139		
Report #:	12		
Defect #:	73B		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	48%, 2 inch (51 mm) Non-Fusion
Seam Type:	LF-ERW	Visual:	ID Extrusion Cracks + Alloy Segregation + Misalignment
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	16% (Misalignment)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.043 inch (1.1 mm)
t_{pipe}	Not Determined	t_{weld}	0.262 inch (6.65 mm)
Failure:	N/A		



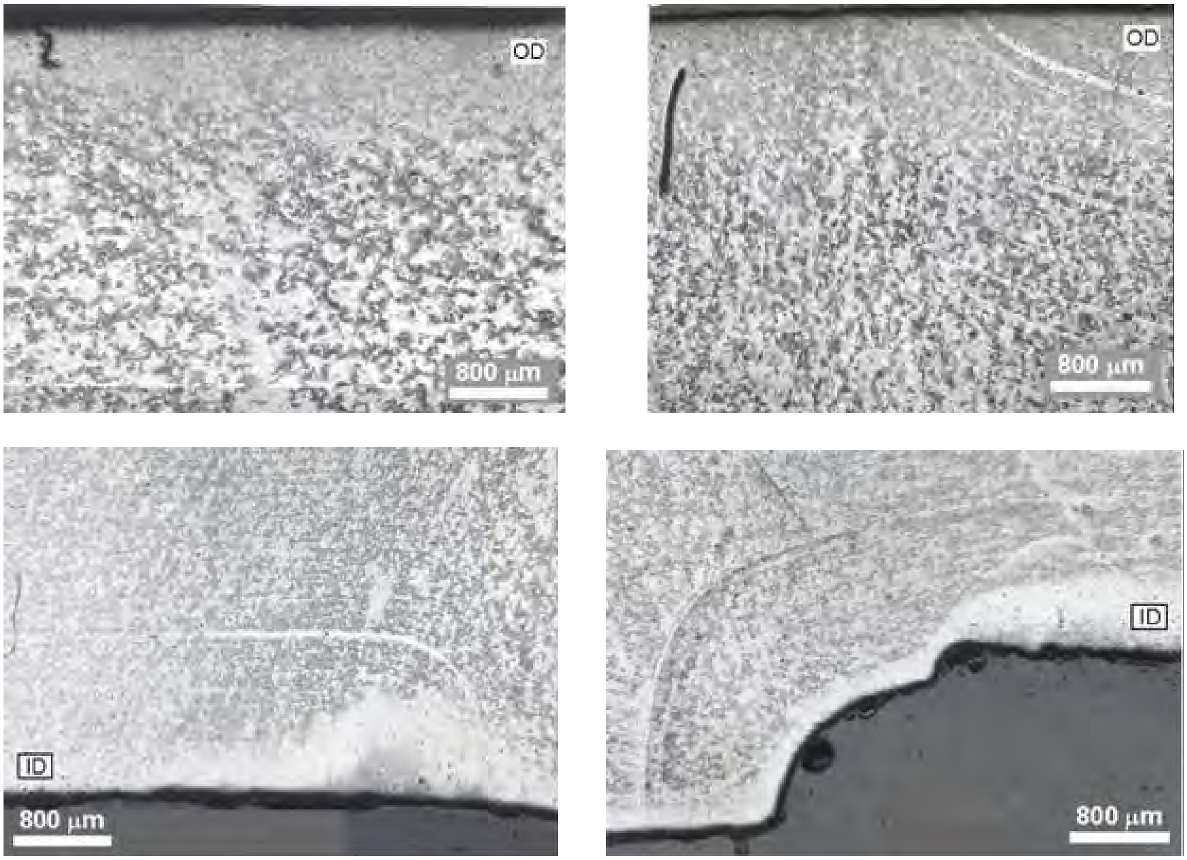
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	13
Report #:	1
Defect #:	574

Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	75% x 5.6 inch (142 mm) ID crack
		Visual:	ID crack + OD repair weld
Seam Type:	ERW	L	N/A
Grade:	X52	depth/t_{weld}	42%
$D_{nominal}$	20 inch (508 mm)	depth:	0.200 inch (5.08 mm)
$t_{nominal}$	0.312 inch (7.92 mm)	t_{weld}	0.427 inch (10.9 mm)
t_{pipe}	0.330 inch (8.38 mm)		
Failure:	None at 2,300 psig (15.86 MPa) (142% of SMYS)		

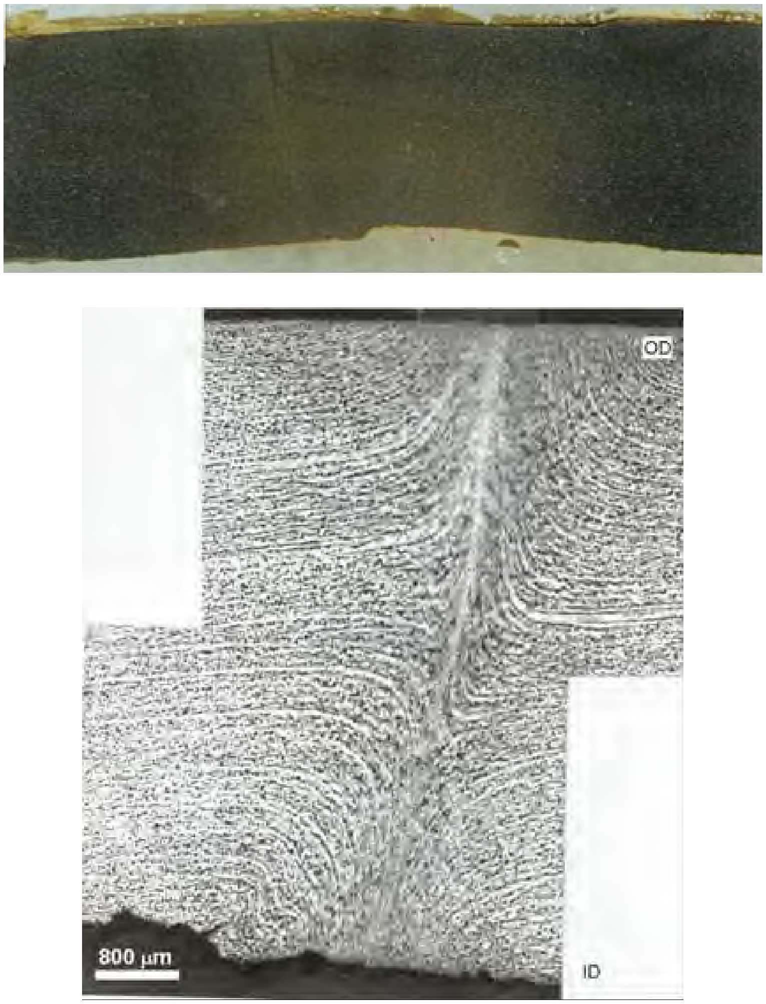
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	101		
Report #:	10		
Defect #:	CY-10		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	ID Crack + ID Under-trim
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	4.2% (ID Crack)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.015 inch (0.38 mm)
t_{pipe}	Not Determined	t_{weld}	0.350 inch (8.89 mm)
Failure:	N/A		



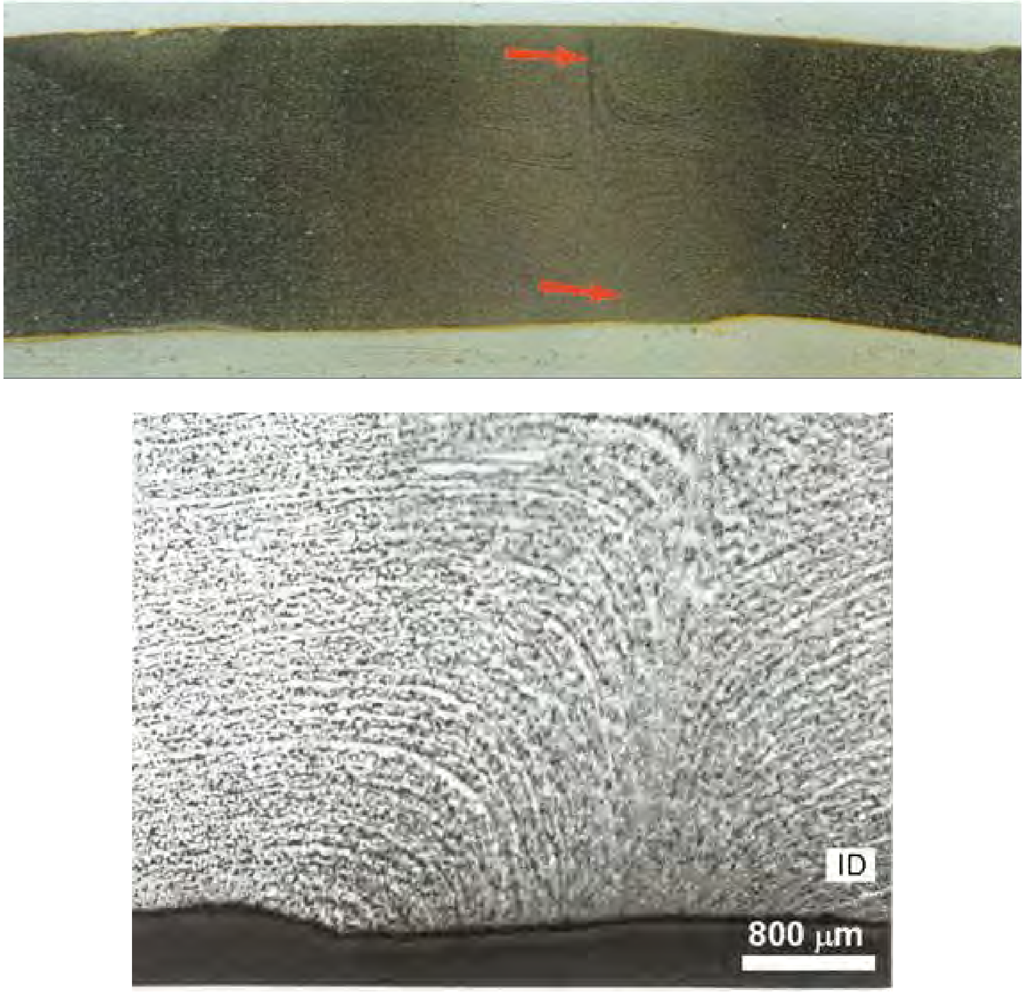
Photomicrographs of Metallographic Sections.

Catalog #:	64		
Report #:	7		
Defect #:	432-23/32/36/48		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	Youngstown	NDE result(s):	No Anomaly Revealed
Seam Type:	ERW	Visual:	ID & OD Outbent fibers + OD Crack + Contact Marks
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	N/A
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	N/A
t_{pipe}	Not determined	t_{weld}	0.319 inch (8.1 mm)
Failure:	N/A		



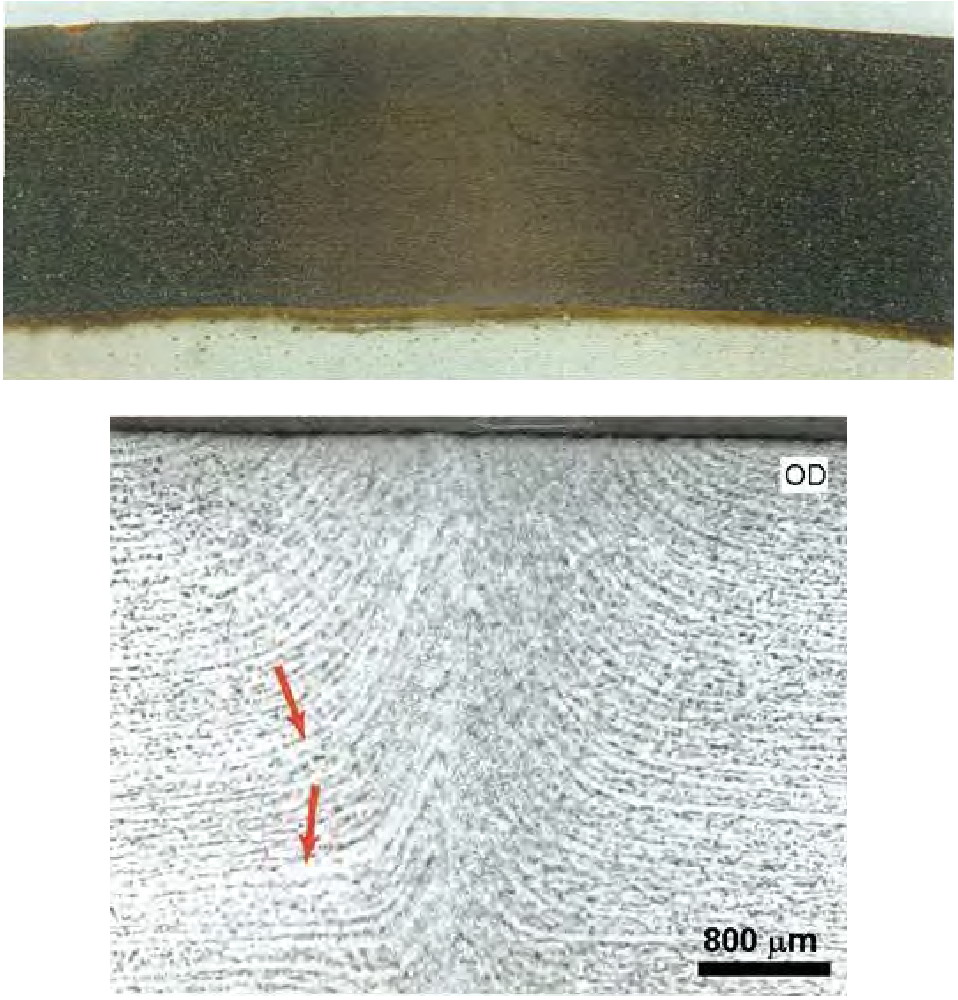
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	130		
Report #:	12		
Defect #:	67E		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	44%, 3.5 inch (89 mm) Mid-Wall Non-Fusion
Seam Type:	LF-ERW	Visual:	Misalignment + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	8.26%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.0195 inch (0.50 mm)
t_{pipe}	Not Determined	t_{weld}	0.236 inch (5.99 mm)
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

Catalog #:	129		
Report #:	12		
Defect #:	67D		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	28%, 1 inch (25 mm) ID-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	Misalignment + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

Catalog #:	131		
Report #:	12		
Defect #:	67F		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	20%, 1.1 inch (28 mm) Mid-Wall Non-Fusion
Seam Type:	LF-ERW	Visual:	Misalignment + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

Photograph of Metallographic Section.

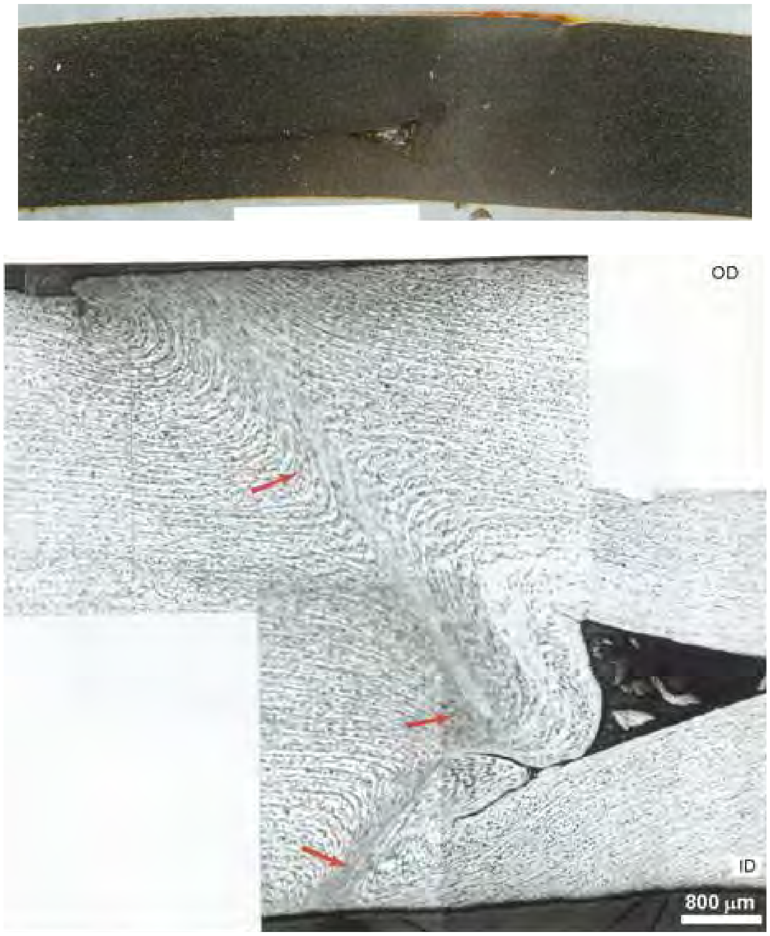
Catalog #:	127		
Report #:	12		
Defect #:	67B		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	80%, 5.25 inch (133 mm) ID-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	Mid-wall Void + Laminations + Misalignment + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

Photograph of Metallographic Section.

Catalog #:	128		
Report #:	12		
Defect #:	67C		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	74%, 4 inch (102 mm) ID-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	Mid-wall Void + Laminations + Misalignment + Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

Photograph of Metallographic Section.

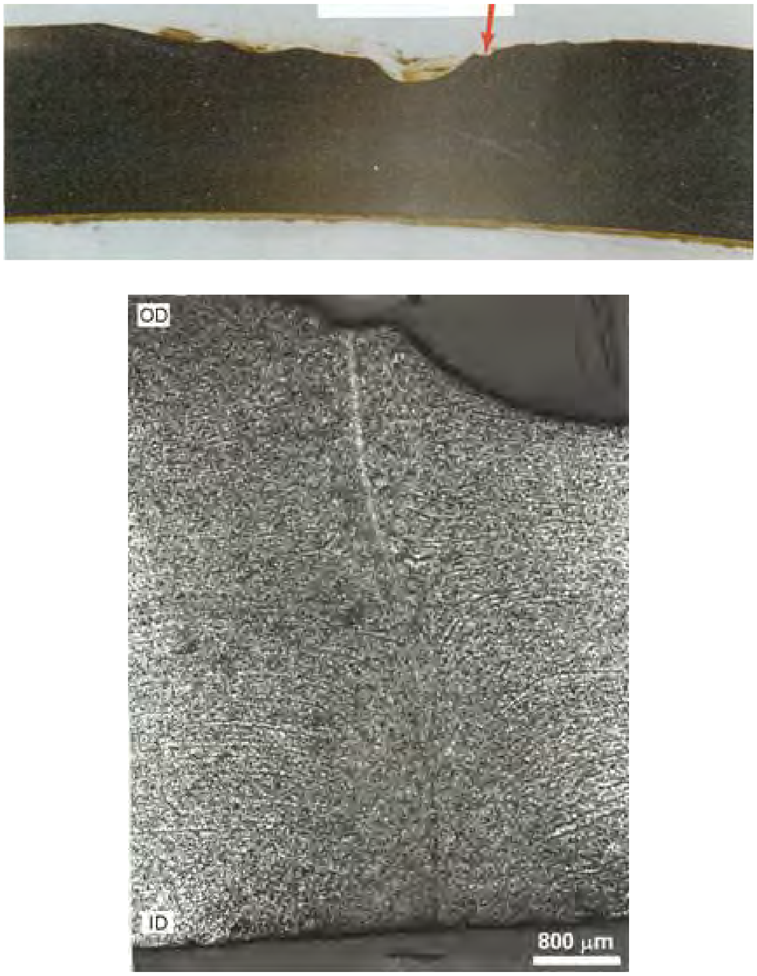
Catalog #:	132		
Report #:	12		
Defect #:	68A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	72%, 3 inch (76 mm) OD-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	Mid-Wall Void + Laminations + Alloy Segregation + Misalignment
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

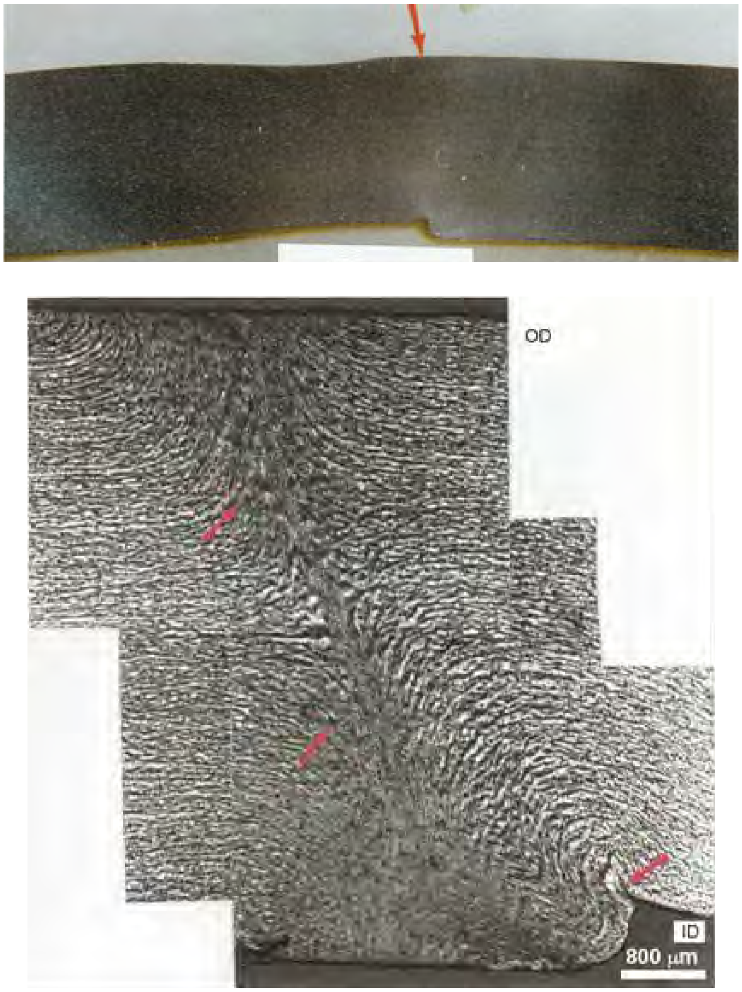
Catalog #: 117
Report #: 12
Defect #: 52B

Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	48%, 7.25 inch (184 mm) + Non-Fusion (ID to Mid-wall)
Seam Type:	LF-ERW	Visual:	Mid-wall Non-Fusion + Laminations, Misalignment, Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

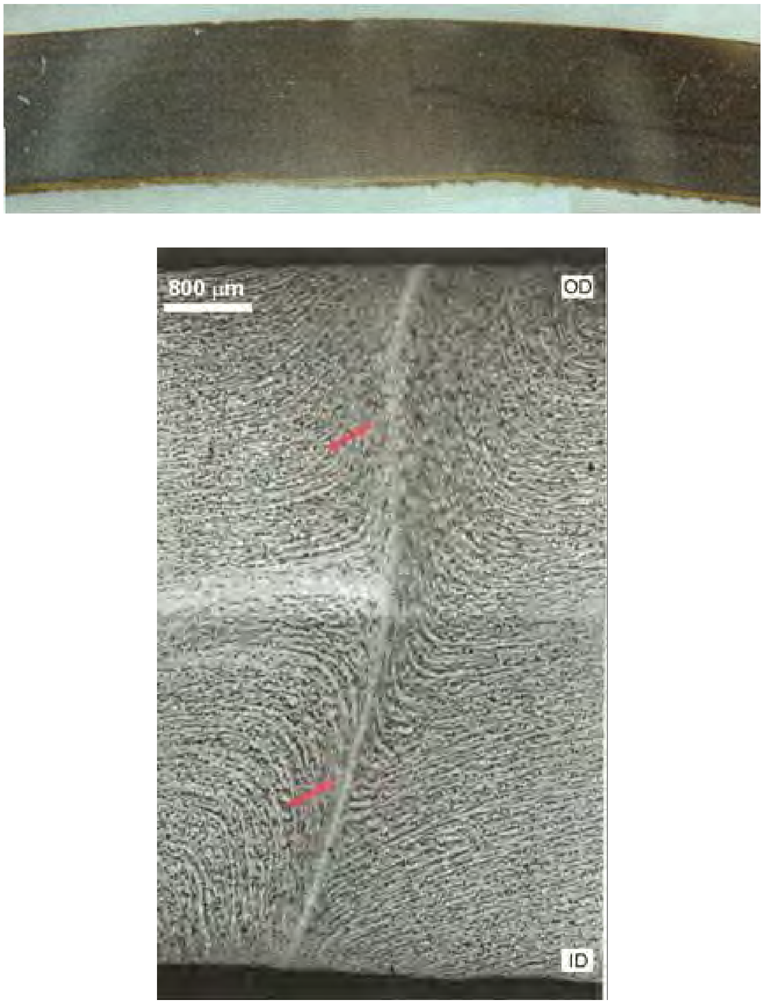
Catalog #:	119		
Report #:	12		
Defect #:	53A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	30%, 2 inch (51 mm) Metal Loss
Seam Type:	LF-ERW	Visual:	External Corrosion on Seam + Alloy Segregation + Misalignment
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	29% (Corrosion)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.075 inch (1.9 mm)
t_{pipe}	Not Determined	t_{weld}	0.257 inch (6.98 mm)
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

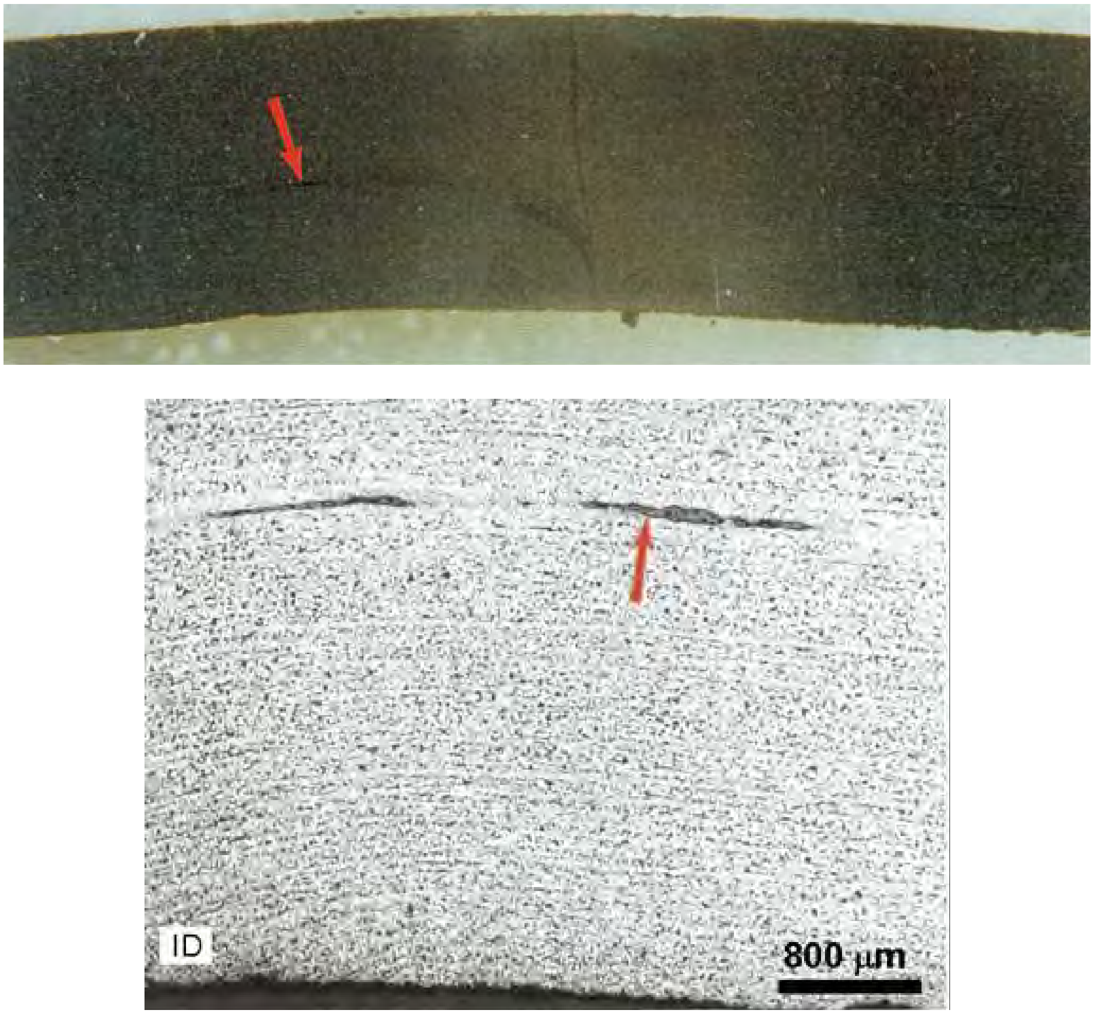
Catalog #: 121
Report #: 12
Defect #: 57B

Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	12%, 10 inch (254 mm) Gouge (Near Seam)
Seam Type:	LF-ERW	Visual:	Alloy Segregation + Misalignment
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	14%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.038 inch (0.96 mm)
t_{pipe}	Not Determined	t_{weld}	0.263 inch (6.68 mm)
Failure:	N/A		



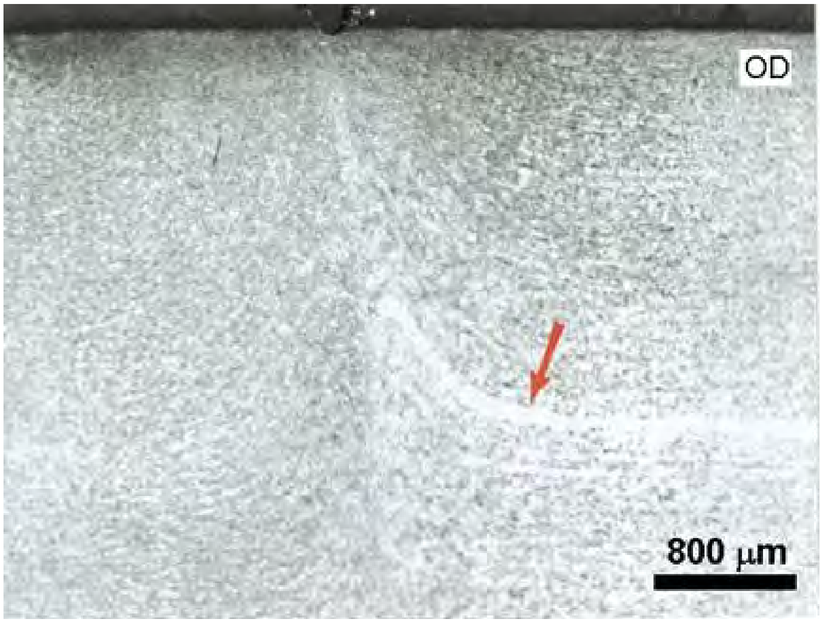
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	116		
Report #:	12		
Defect #:	52A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	8%, 9 inch (229 mm) OD & ID-connected Non-Fusion
Seam Type:	LF-ERW	Visual:	Alloy Segregation + Misalignment
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



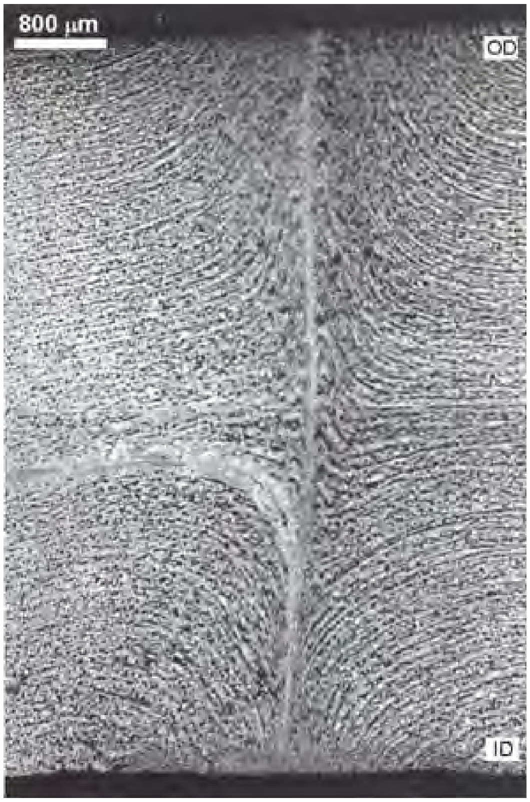
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	133		
Report #:	12		
Defect #:	68B		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	72%, 1.5 inch (38 mm) Non-Fusion
Seam Type:	LF-ERW	Visual:	Alloy Segregation + Misalignment
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



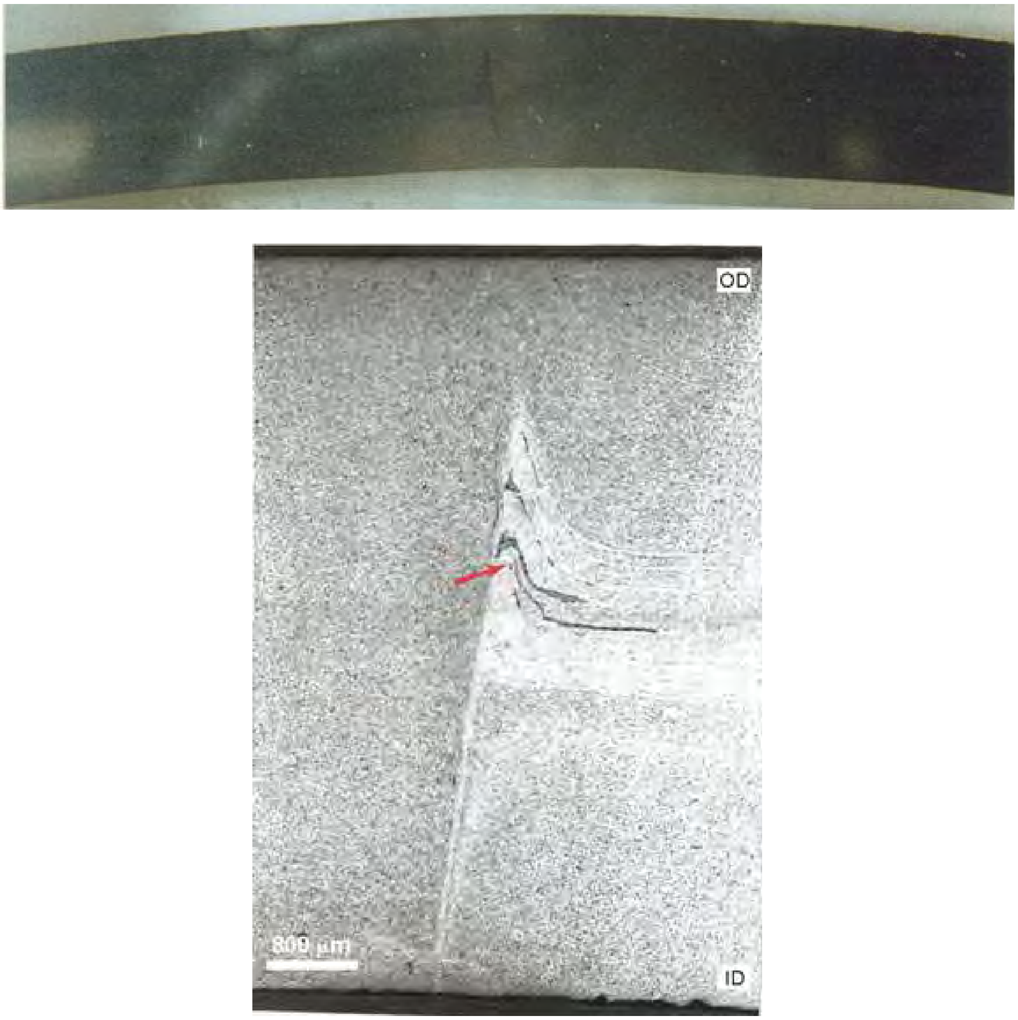
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	113		
Report #:	12		
Defect #:	46B-C		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	N/A
Seam Type:	LF-ERW	Visual:	Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

Catalog #:	118		
Report #:	12		
Defect #:	52C		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	N/A
Seam Type:	LF-ERW	Visual:	Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



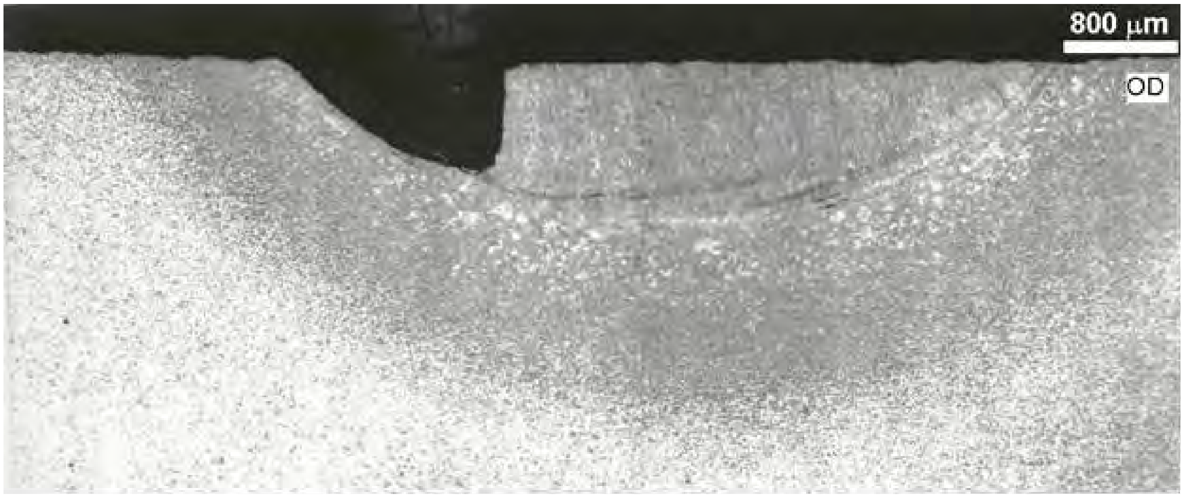
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	137		
Report #:	12		
Defect #:	72C		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	20%, 4 inch (102 mm) ID-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	Alloy Segregation
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

xxx

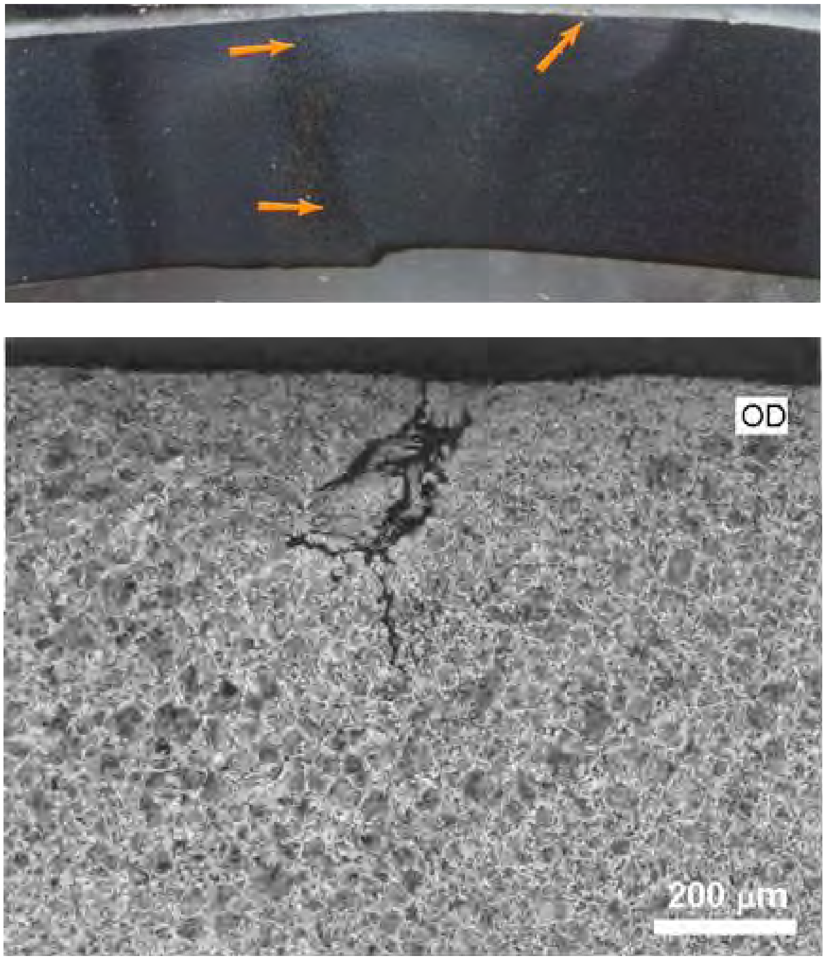
Photograph of Metallographic Section.

Catalog #:	95		
Report #:	10		
Defect #:	CY-4		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	Offset Plate Edges + OD Notch
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	0.280 inch (7.11 mm) (at offset)	t_{weld}	Not Determined
Failure:	N/A		



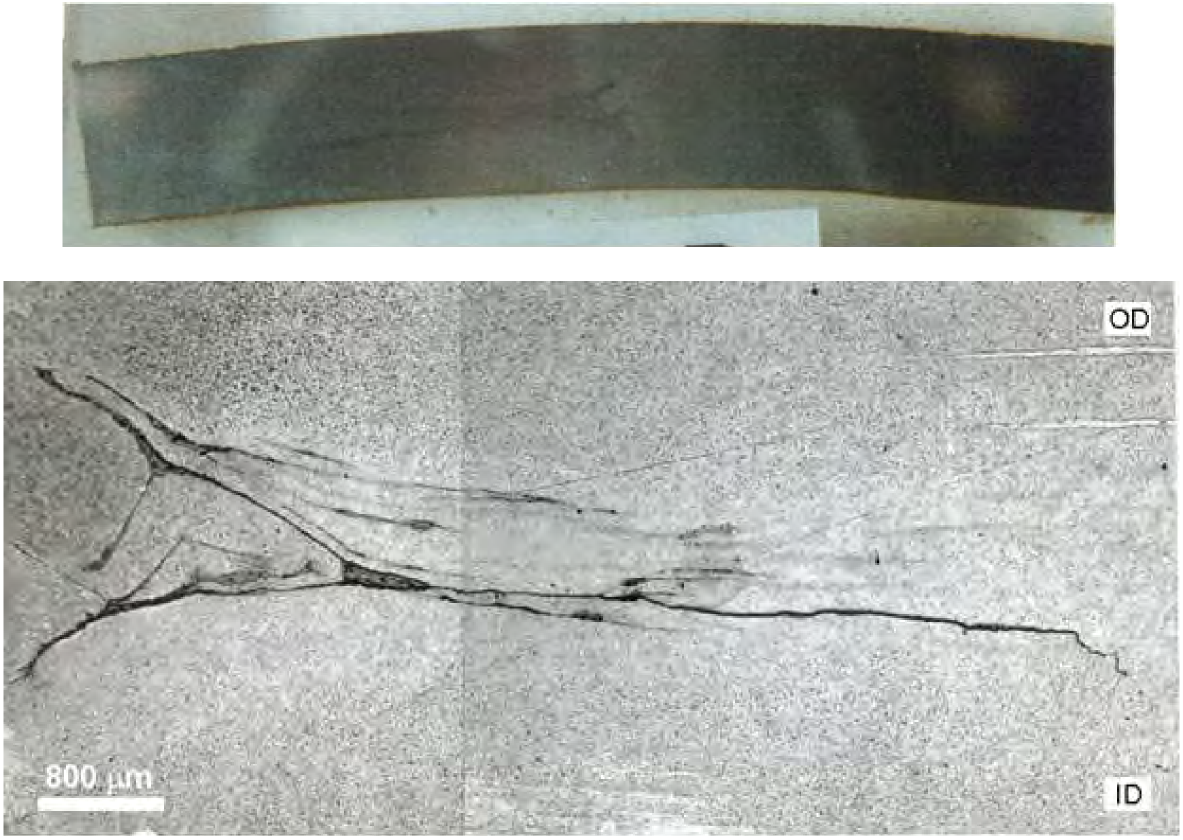
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	96		
Report #:	10		
Defect #:	CY-5		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	Offset Plate Edges + OD Notch
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	0.260 inch (6.60 mm) (at offset)	t_{weld}	Not Determined
Failure:	N/A		



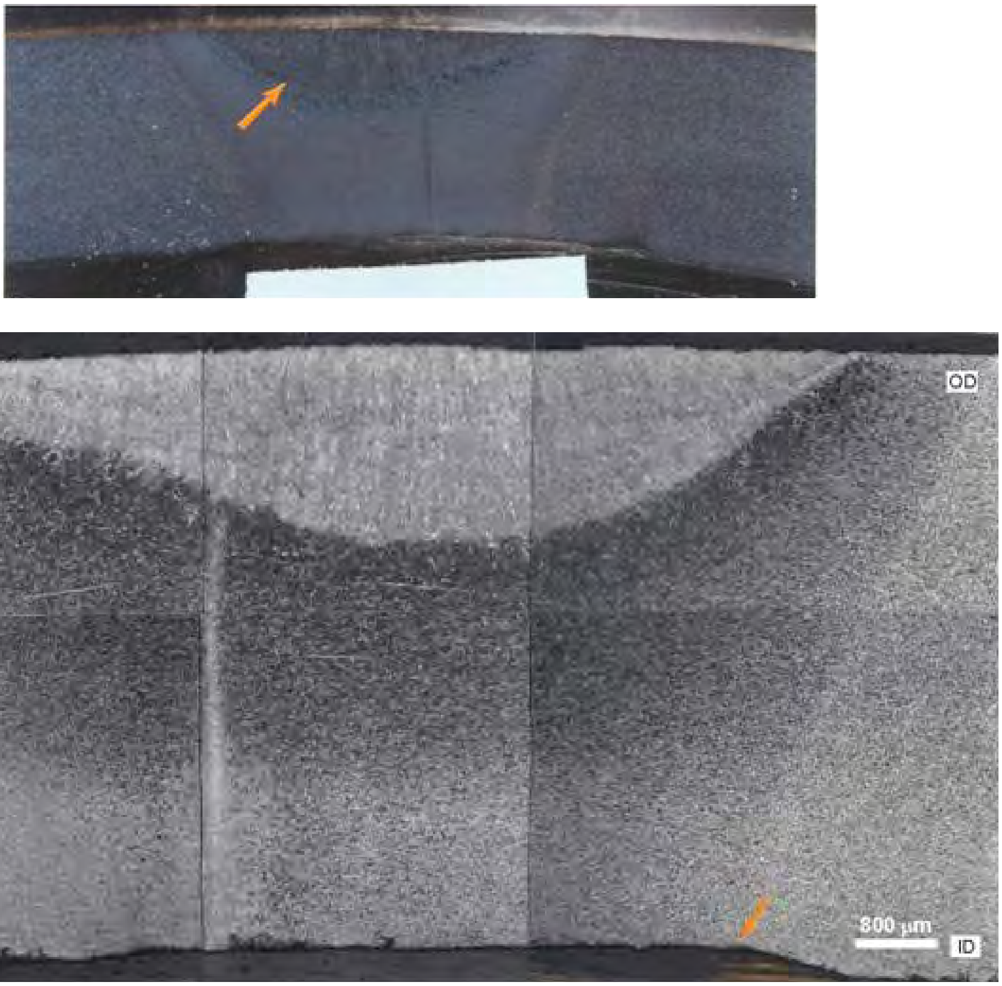
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	102		
Report #:	11		
Defect #:	2A		
Pipe		**Defect**	
Vintage:	1953	NDE technique(s):	Fast UT
Manufacturer:	Unknown	NDE result(s):	< 10%, 1.5 (38 mm) inch ID Gouge
Seam Type:	LF-ERW	Visual:	Misalignment Contact Mark
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	9.2% (Contact Mark)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

Catalog #:	138		
Report #:	12		
Defect #:	72D		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	72%, 15 inch (381 mm) Mid-Wall Non-Fusion
Seam Type:	LF-ERW	Visual:	Mid-wall Void + Lamination
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

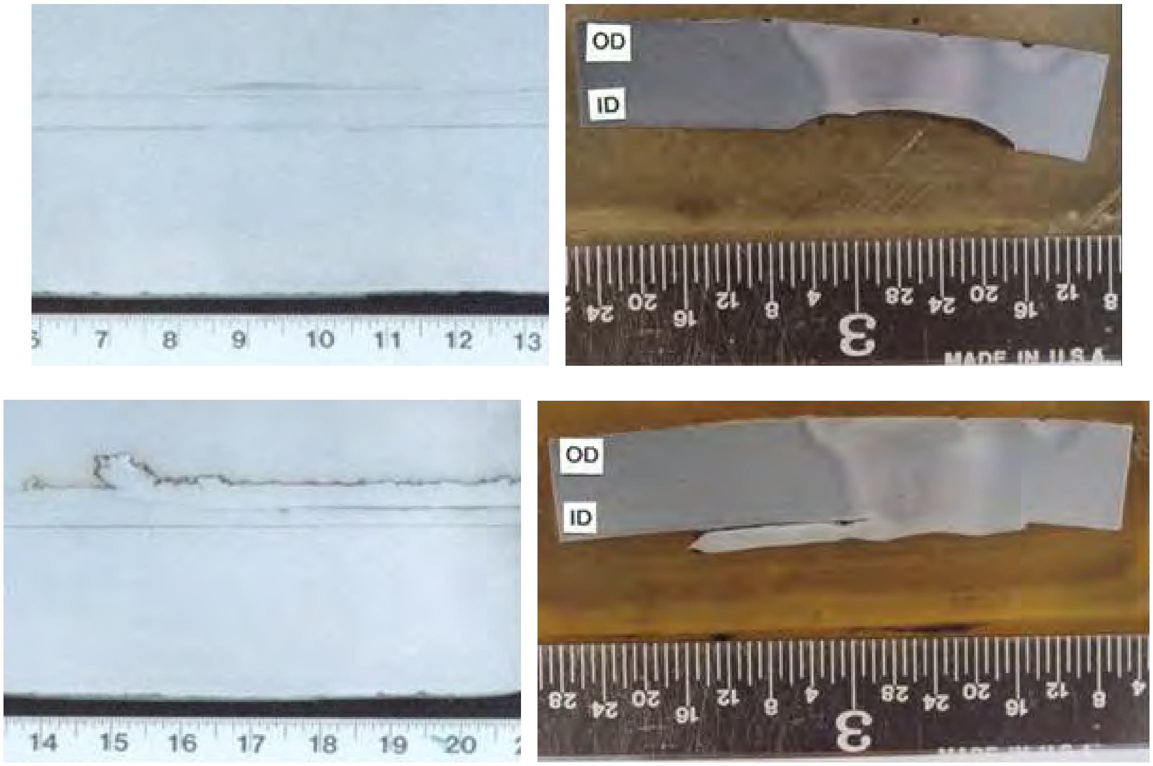
Catalog #:	109		
Report #:	11		
Defect #:	5A		
<u>Pipe</u>		**<u>Defect</u>**	
Vintage:	1953	NDE technique(s):	Fast UT
Manufacturer:	Unknown	NDE result(s):	15%, 4 inch (102 mm) ID Gouge
Seam Type:	LF-ERW	Visual:	ID Over-trim + OD Weld Repair
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	8.3% (Over-Trim) + 45% (Weld Repair)
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

Photograph of Metallographic Section.

Catalog #:	92		
Report #:	10		
Defect #:	CY-1		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	ID Under-trim + Weld Repair
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	55% (Weld Repair)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

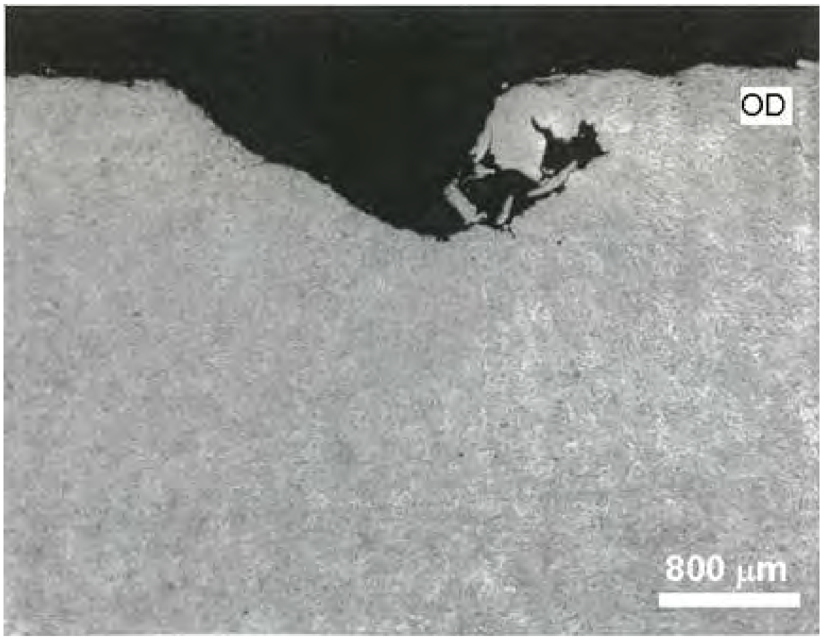
Photograph of Metallographic Section.

Catalog #:	99		
Report #:	10		
Defect #:	CY-8		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	ID Under-trim + OD Weld Repair
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	45% (Weld Repair)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photographs of ID Pipe Surface and Metallographic Sections.

Catalog #:	31		
Report #:	3		
Defect #:	15A/B		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT & HiLo MT
Manufacturer:	Youngstown	NDE result(s):	5.5 x 0.5 inch (140 x 12.7 mm) ID Gouge from Overtrim (UT) + 12 inch OD (HiLo MT)
Seam Type:	LF-ERW	Visual:	ID gouge (Overtrim)
Grade:	X52	L	5.5 inch (140 mm)
$D_{nominal}$	20 inch (508 mm)	Width:	0.5 inch (12.7 mm)
$t_{nominal}$	0.312 inch (7.92 mm)	depth/t_{weld}	26%
t_{pipe}	0.318 inch (8.08 mm)	depth:	0.084 inch (2.13 mm)
Failure:	None	t_{weld}	0.234 inch (5.94 mm)



Photograph and Photomicrograph of Metallographic Section.

Catalog #:	94		
Report #:	10		
Defect #:	CY-3		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	ID Under-trim + OD Notch at Contact mark
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

Photograph of Metallographic Section.

Catalog #:	97		
Report #:	10		
Defect #:	CY-6		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	Youngstown	NDE result(s):	N/A
Seam Type:	ERW	Visual:	ID Under-trim + OD Notch
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.031 inch (0.79 mm)
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

Photograph and Photomicrograph of Metallographic Section.

Catalog #:	12		
Report #:	1		
Defect #:	573-14.8		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	30% x 0.7 inch (17.8 mm) OD crack
Seam Type:	ERW	Visual:	OD lack of fusion + OD repair weld
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	37.2%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.128 inch (3.25 mm)
t_{pipe}	0.311 inch (7.9 mm)	t_{weld}	0.344 inch (8.74 mm)
Failure:	None at 2,275 psig (15.69 MPa) (140% of SMYS)		

Photograph of Metallographic Section.

Catalog #:	11		
Report #:	1		
Defect #:	573-5.1		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	10% x 2 inch (51 mm) grind area on seam
Seam Type:	ERW	Visual:	OD repair weld
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	N/A
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	N/A
t_{pipe}	0.330 inch (8.38 mm)	t_{weld}	0.330 inch (8.38 mm)
Failure:	None at 2,275 psig (15.69 MPa) (140% of SMYS)		

Photograph of Metallographic Section.

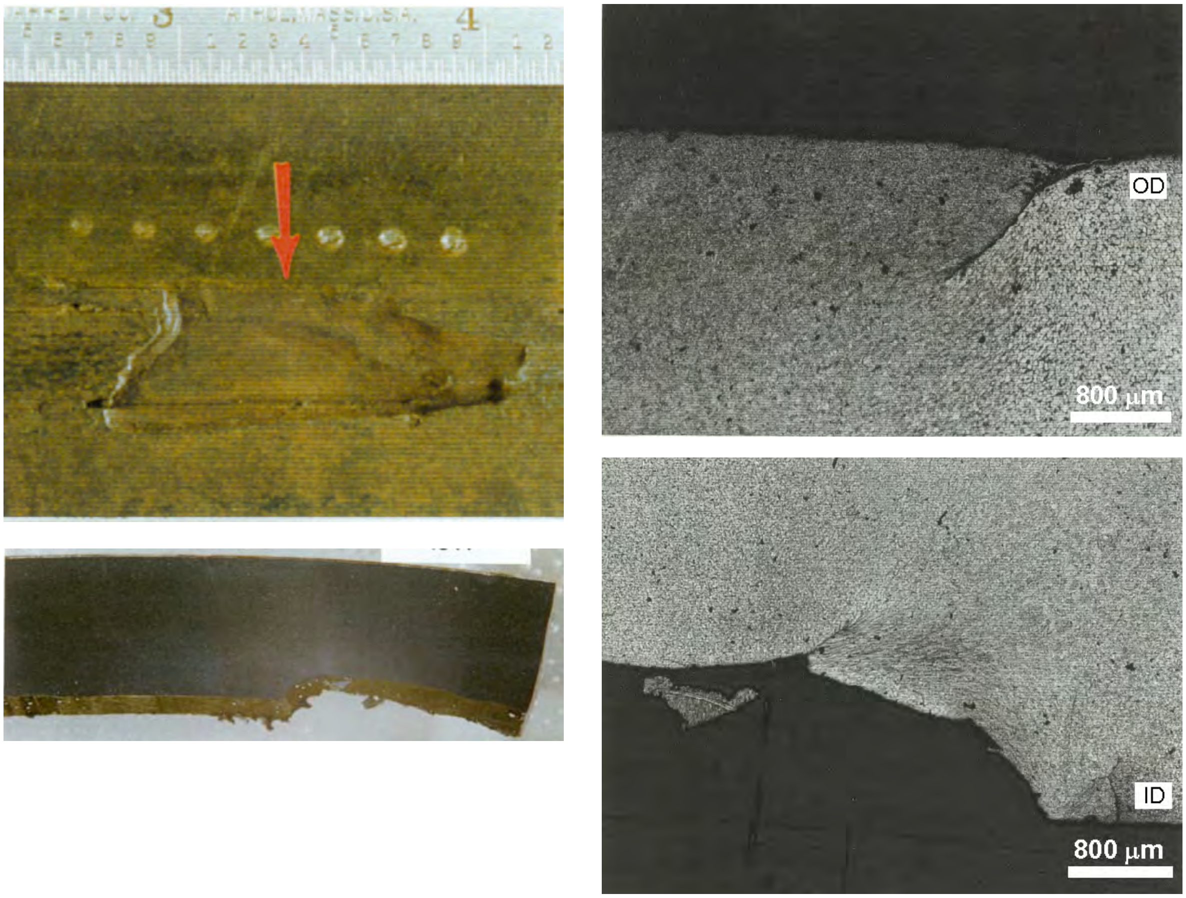
Catalog #:	14		
Report #:	1		
Defect #:	598		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	Youngstown	NDE result(s):	<10% multiple minor cracks at weld toe
Seam Type:	ERW	Visual:	OD repair weld
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	N/A
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	N/A
t_{pipe}	0.330 inch (8.38 mm)	t_{weld}	0.330 inch (8.38 mm)
Failure:	None at 2,100 psig (14.48 MPa) (129% of SMYS)		

Photograph of ID Pipe Surface Near Seam Weld.

Catalog #:	111		
Report #:	12		
Defect #:	45A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	24%, 1.25 inch (31.7 mm) ID Gouge (Metal Loss)
Seam Type:	LF-ERW	Visual:	ID Pit
Grade:	API 5L X42	L	1.15 inch (29.2 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	28%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.068 inch (1.73 mm)
t_{pipe}	Not Determined	t_{weld}	0.245 inch (6.22 mm)
Failure:	N/A		

Photograph of ID Pipe Surface Near Seam Weld.

Catalog #:	115		
Report #:	12		
Defect #:	49A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	24%, 0.6 inch (15.2 mm) ID Gouge (Metal Loss)
Seam Type:	LF-ERW	Visual:	ID Pit
Grade:	API 5L X42	L	1 inch (25.4 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	22%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.058 inch (1.47 mm)
t_{pipe}	Not Determined	t_{weld}	0.258 inch (6.55 mm)
Failure:	N/A		



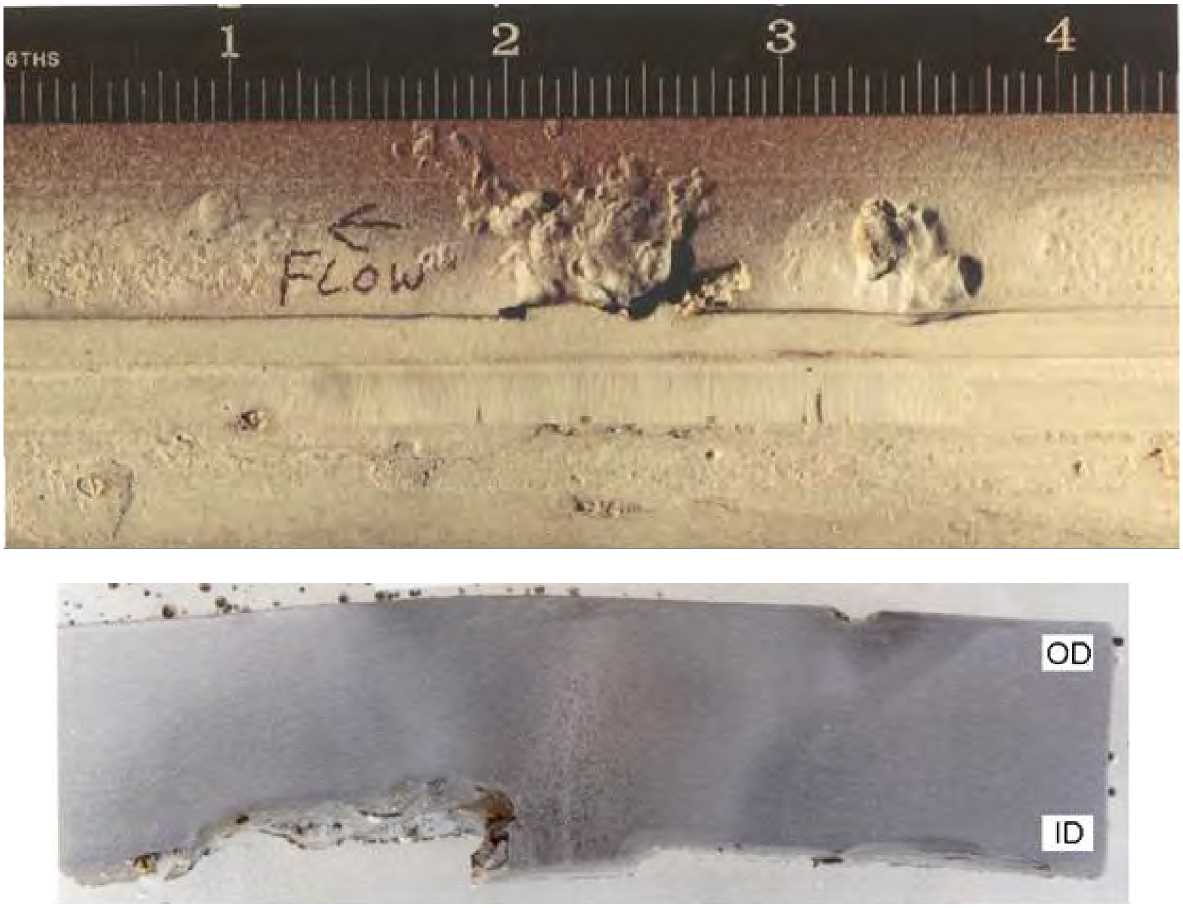
Photographs and Photomicrographs of Pipe Seam ID Surface and Metallographic Sections.

Catalog #:	110
Report #:	12
Defect #:	43A

Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	Fast UT, MPI
Manufacturer:	Unknown	NDE result(s):	88%, 3 inch (76 mm) ID & OD-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	ID Pit
Grade:	API 5L X42	L	1.72 inch (43.7 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	17%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.046 inch (1.17 mm)
t_{pipe}	Not Determined	t_{weld}	0.266 inch (6.76 mm)
Failure:	N/A		

Photographs of Pipe Seam ID Surface and Metallographic Section.

Catalog #:	123		
Report #:	12		
Defect #:	59A		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	44%, 2 inch (51 mm) ID-Connected Non-Fusion
Seam Type:	LF-ERW	Visual:	ID Pit
Grade:	API 5L X42	L	1 inch (25.4 mm)
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	15%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.037 inch (0.94 mm)
t_{pipe}	Not Determined	t_{weld}	0.252 inch (6.4 mm)
Failure:	N/A		

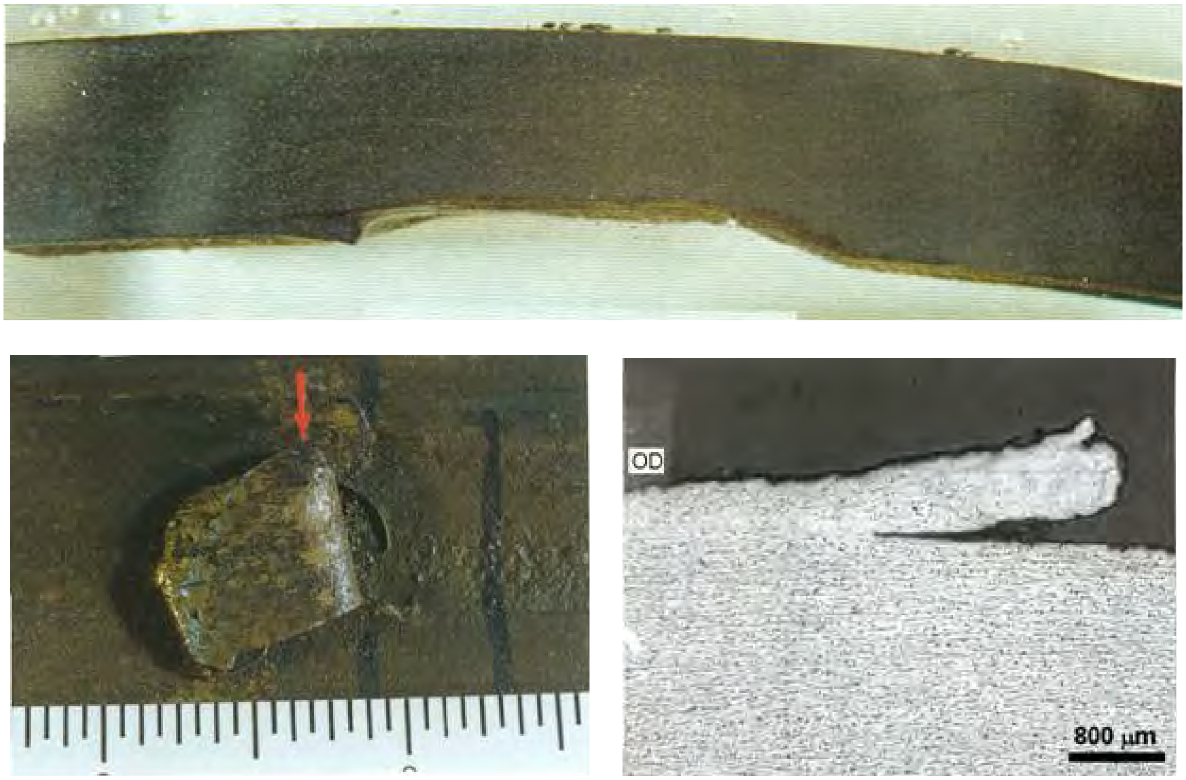


Photographs of Weld Seam ID Surface and Metallographic Section.

Catalog #:	73		
Report #:	7		
Defect #:	1084		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	Youngstown	NDE result(s):	ID Gouges
Seam Type:	ERW	Visual:	ID Plate Edge Defect (Roll-in) + Contact Location Arc
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	0.349 inch (8.86 mm)
Failure:	N/A		

Photograph of Metallographic Section.

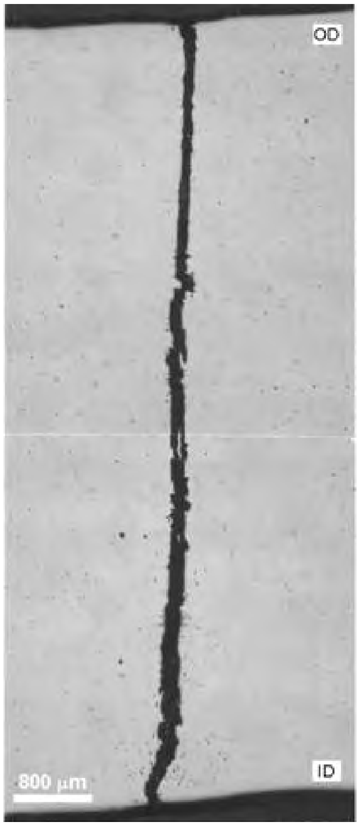
Catalog #:	136		
Report #:	12		
Defect #:	72B		
Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	48%, 1.25 inch (31.7 mm) OD Hook Crack
Seam Type:	LF-ERW	Visual:	Roll-in
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	6%
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	0.017 inch (0.43 mm)
t_{pipe}	Not Determined	t_{weld}	0.262 inch (6.65 mm)
Failure:	N/A		



Photograph and Photomicrograph of Pipe Seam ID Surface and Metallographic Section.

Catalog #:	120
Report #:	12
Defect #:	54B

Pipe		**Defect**	
Vintage:	Unknown	NDE technique(s):	TOFD, MPI
Manufacturer:	Unknown	NDE result(s):	24%, 2 inch (51 mm) ID Gouge
Seam Type:	LF-ERW	Visual:	ID Scab
Grade:	API 5L X42	L	Not Determined
$D_{nominal}$	12.75 inch (324 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.250 inch (6.35 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

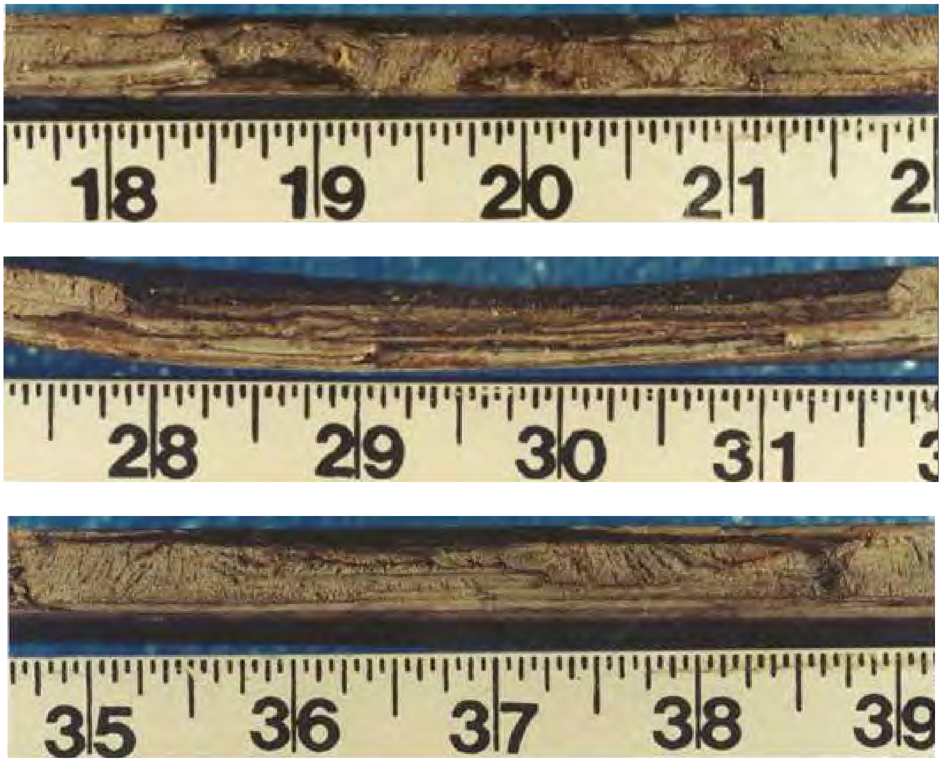
Catalog #:	65		
Report #:	7		
Defect #:	553		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Seeper found during dig
Manufacturer:	Youngstown	NDE result(s):	100%, 0.25 inch (6.35 mm) (Seeper)
Seam Type:	ERW	Visual:	Lack of Fusion
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	100%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.330 inch (8.38 mm)
t_{pipe}	Not Determined	t_{weld}	0.330 inch (8.38 mm)
Failure:	N/A		

Photograph of Weld Seam ID Surface.

Catalog #:	82		
Report #:	7		
Defect #:	1640		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	Youngstown	NDE result(s):	20% ID Non-Fusion + Irregular weld root geometry along entire joint
Seam Type:	ERW	Visual:	Not Determined
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

Photograph of Weld Seam ID Surface.

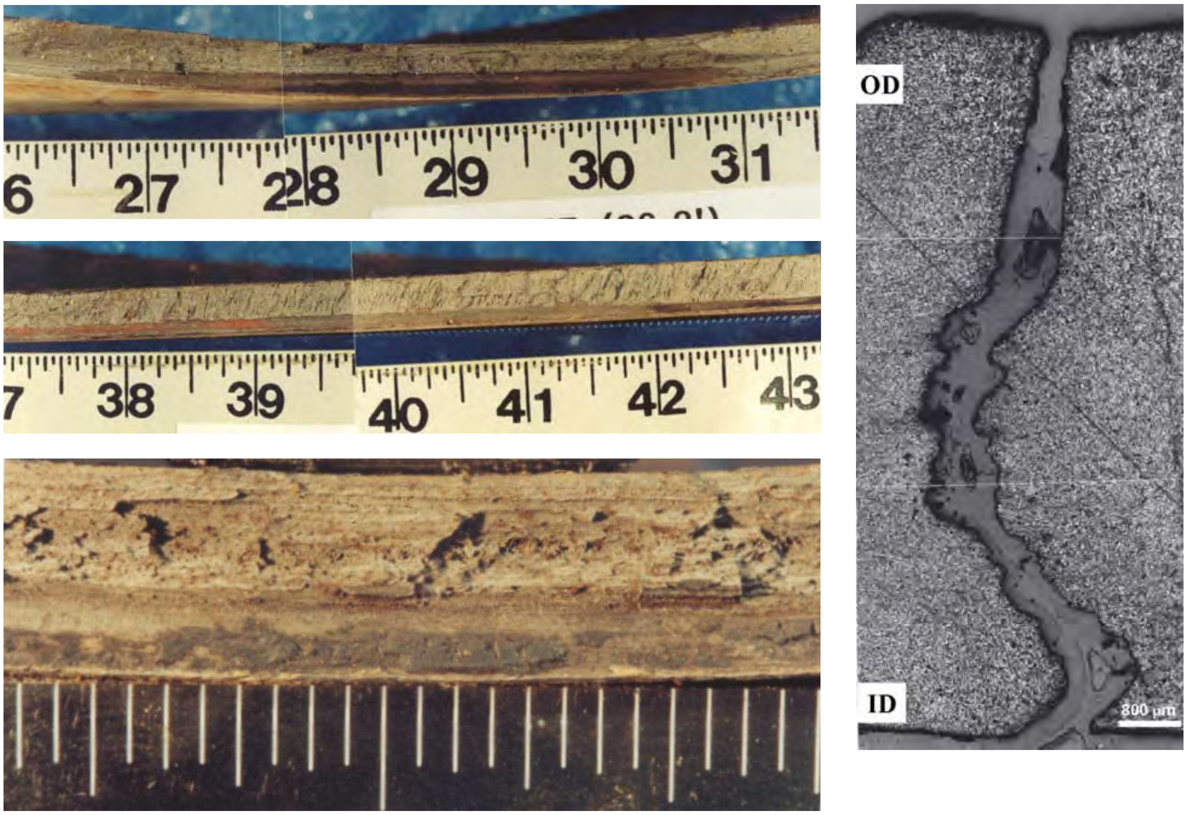
Catalog #:	83		
Report #:	7		
Defect #:	1668		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	Youngstown	NDE result(s):	25% ID Gouge
Seam Type:	ERW	Visual:	Not Determined
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



Photographs of Fracture Surfaces.

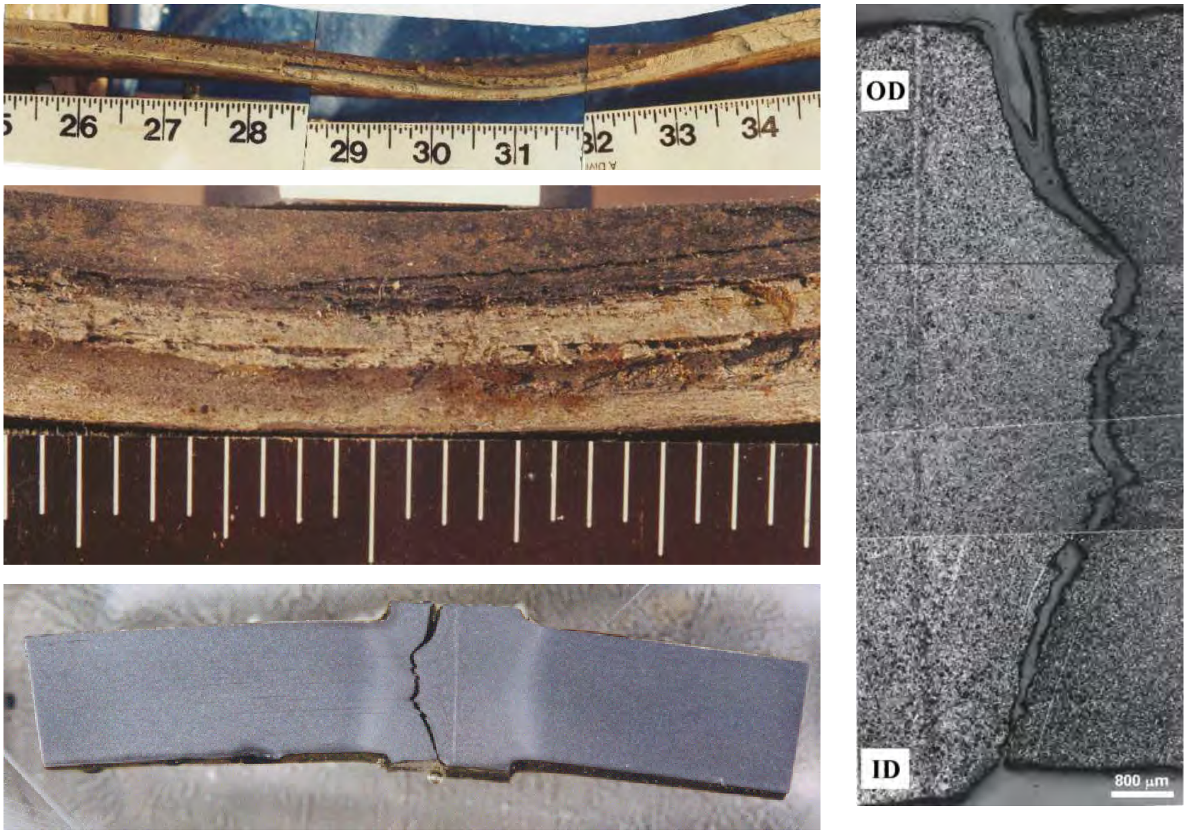
Catalog #:	61		
Report #:	6		
Defect #:	1012		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	50% ID + 20% OD Crack
Seam Type:	FW	Visual:	3 ID + 1 OD Hook Cracks
Grade:	X52	L	> 2 inch (51 mm) (ID Crack #1) + > 4 inch (102 mm) (ID Crack #2) + > 4 inch (ID Crack #3)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	43% (ID Crack #1) + 31% (ID Crack #2) + 31% (ID Crack #3) + 11% (OD Crack)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.171 inch (4.34 mm) (ID Crack #1) + 0.125 inch (3.17 mm) (ID Crack #2) + 0.125 inch (ID Crack #3) + 0.044 inch (1.19 mm) (OD Crack)
t_{pipe}	Not Determined	t_{weld}	0.397 inch (10.1 mm)
Failure:	Burst test failure at 1,825 psig (12.58 MPa) (112% of SMYS)		

FW ***Two OD Hook Cracks***



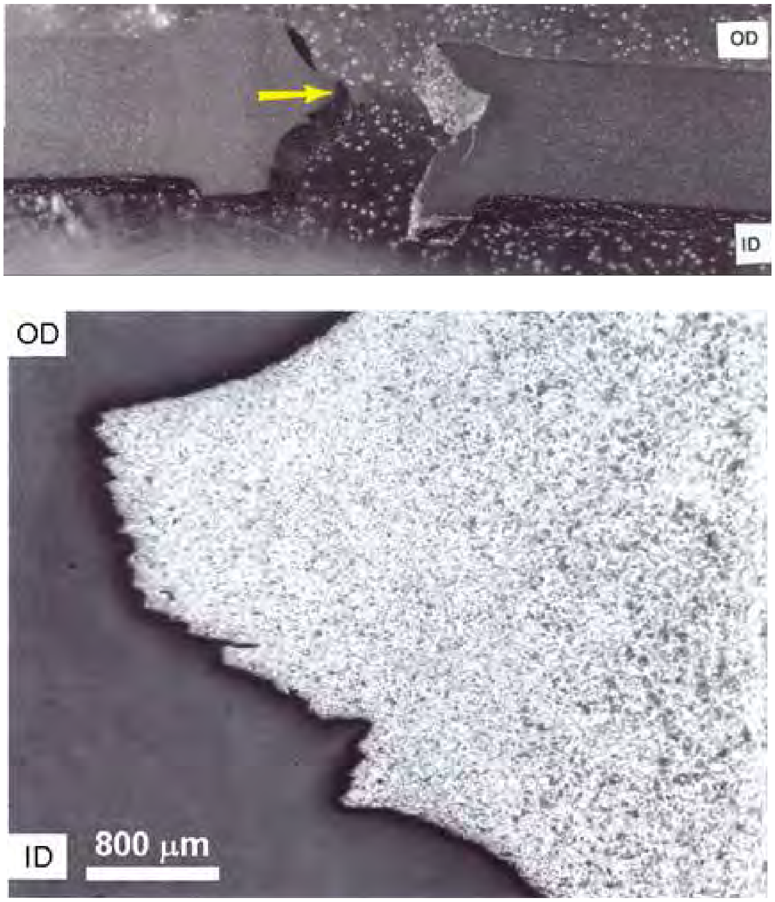
Photographs of Fracture Surface and Photomicrograph of Metallographic Section.

Catalog #:	56		
Report #:	6		
Defect #:	757		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	65% OD Crack
Seam Type:	FW	Visual:	Two OD Hook cracks
Grade:	X52	L	4.5 inch (114 mm) (Crack #1) + 12 inch (305 mm) (Crack #2)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	40% (Crack #1) (incl. 5% fatigue growth) + 28% (Crack #2)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.156 inch (3.96 mm) (Crack #1) (incl. 0.020 inch (0.51 mm) fatigue) + 0.109 inch (2.77 mm) (Crack #2)
t_{pipe}	Not Determined	t_{weld}	0.390 inch (9.91 mm)
Failure:	Burst test failure at 1,875 psig (12.93 MPa) (116% of SMYS)		



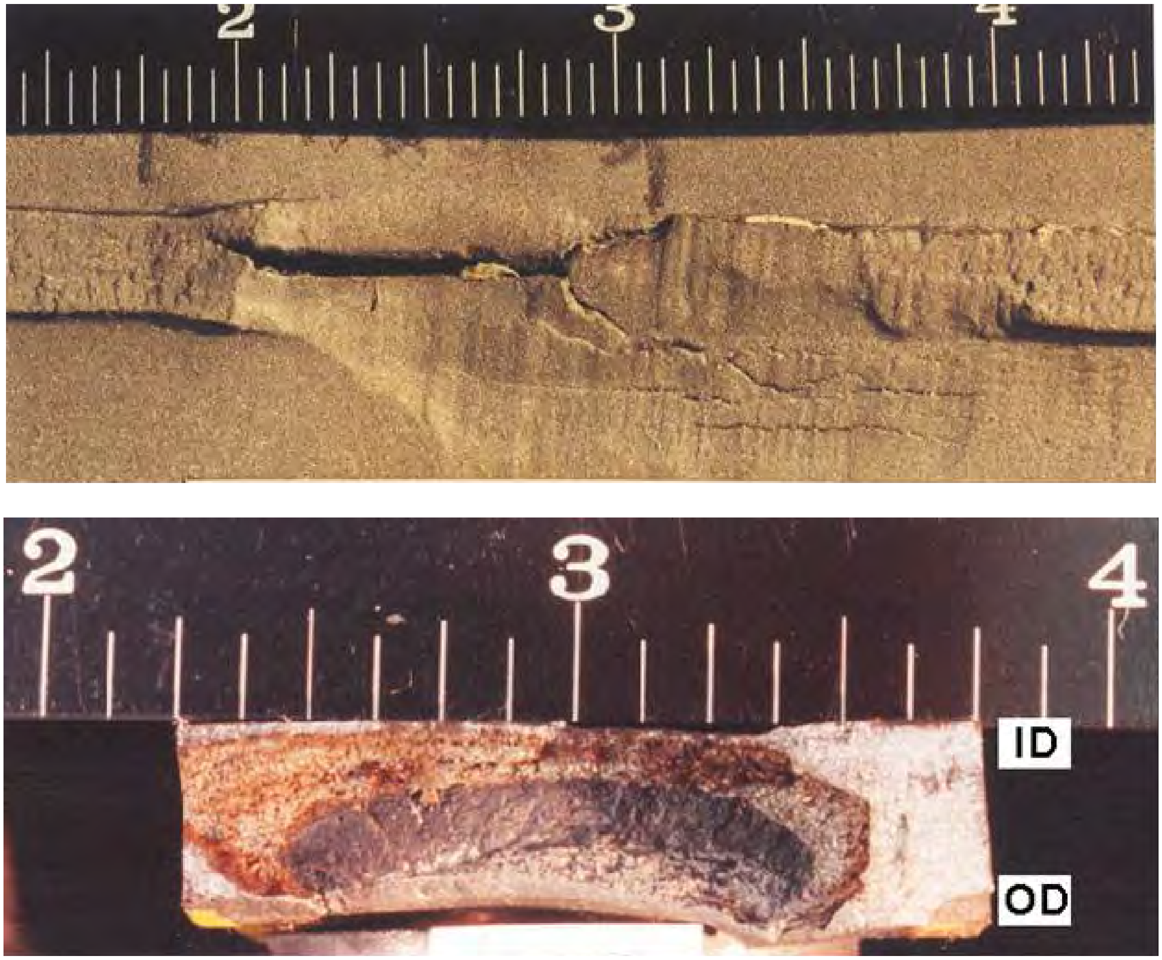
Photographs and Photomicrograph of Metallographic Section and Fracture Surfaces.

Catalog #:	59		
Report #:	6		
Defect #:	939		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	40% ID Crack
Seam Type:	FW	Visual:	Two ID Hook Cracks
Grade:	X52	L	4 inch (102 mm) (Crack #1) + > 8 inch (203 mm) (Crack #2)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	24% (Crack #1) + 40% (Crack #2)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.093 inch (2.36 mm) (Crack #1) + 0.156 inch (3.96 mm) (Crack #2)
t_{pipe}	Not Determined	t_{weld}	0.388 inch (9.85 mm)
Failure:	Burst test failure at 2,050 psig (14.13 MPa) (126% of SMYS		



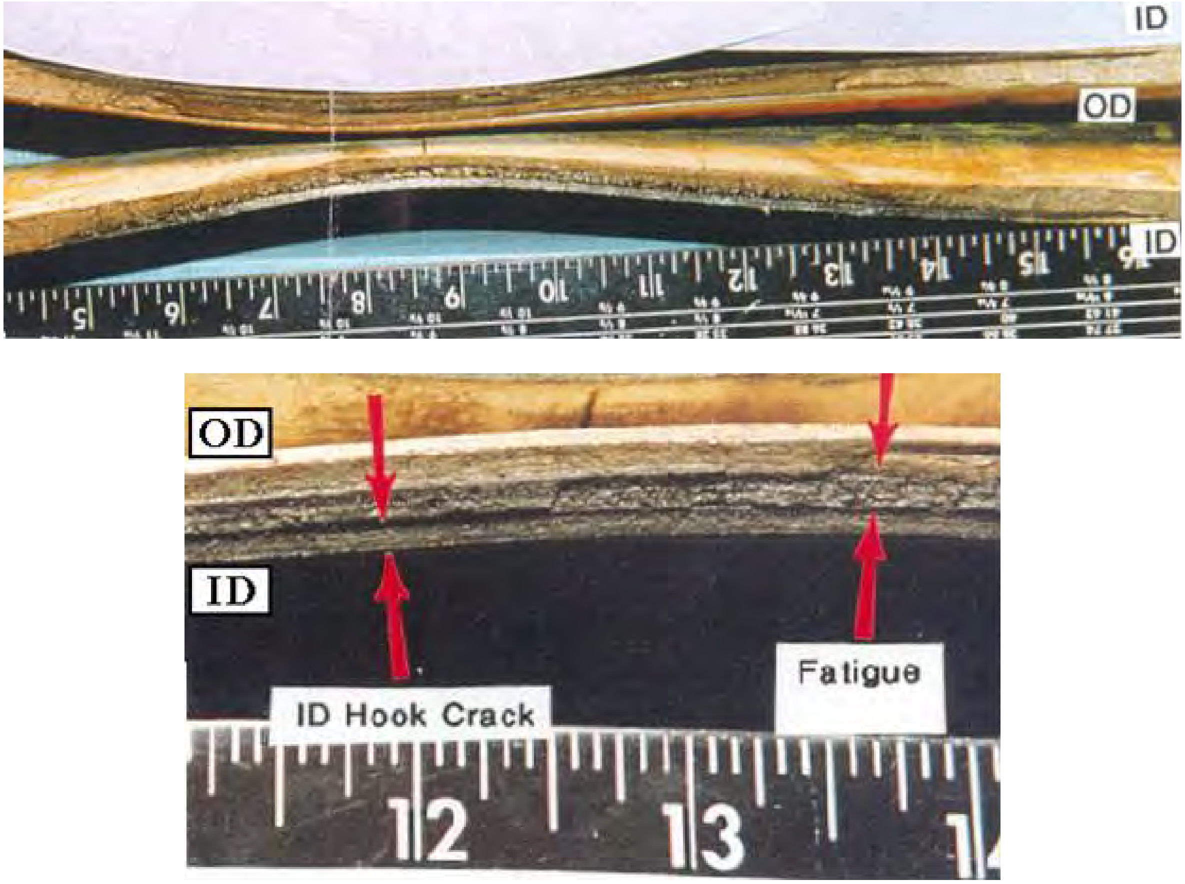
Photographs and Photomicrograph of Metallographic Section and Fracture Surfaces.

Catalog #:	44		
Report #:	5		
Defect #:	22		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	2 overlapping cracks: 85%, 10.5 inch (267 mm) total length
Seam Type:	FW	Visual:	ID & OD hook cracks
Grade:	X52	L	14 to 19 inch (356 to 483 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	75% (33% OD + 42% ID)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.129 inch (3.28 mm) (OD) + 0.164 inch (4.17 mm) (ID)
t_{pipe}	0.309 inch (7.85 mm)	t_{weld}	0.390 inch (9.91 mm)
Failure:	Burst Test Failure at 2,050 psig (14.13 MPa) (126% of SMYS)		



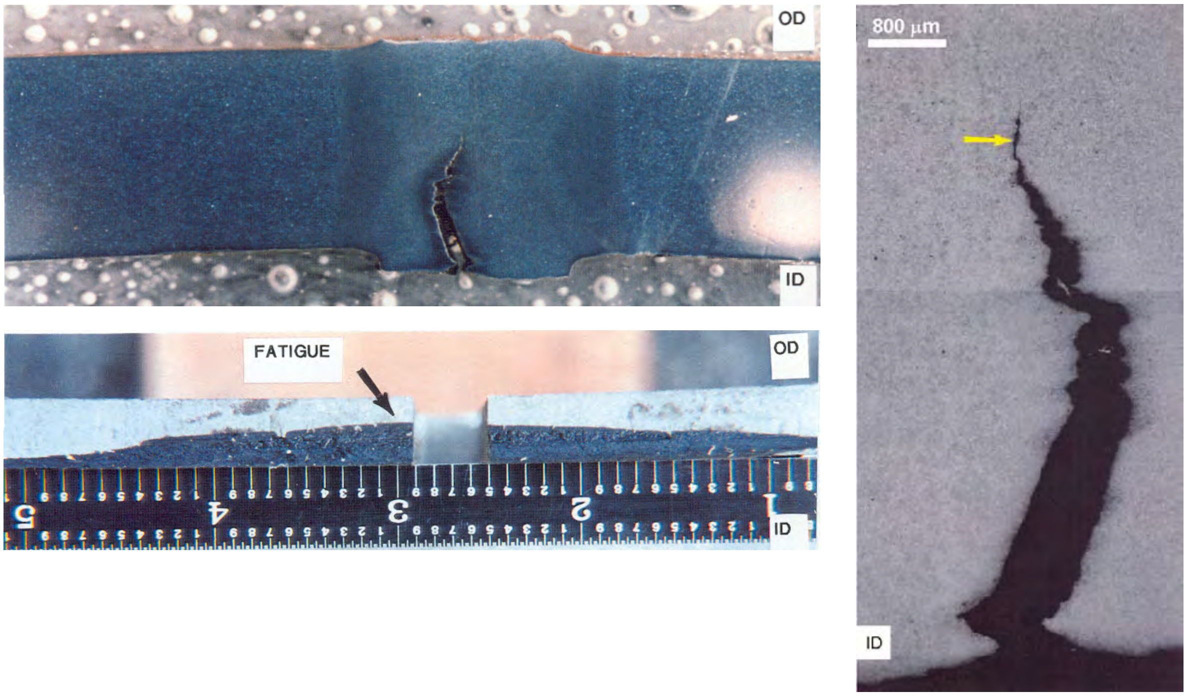
Photographs/Micrographs of Weld Seam OD Surface and Fracture Surface.

Catalog #:	62		
Report #:	6		
Defect #:	1450		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	0.300 inch (7.62 mm) RDI Mechanical Damage + 70%, 1 inch (25.4 mm) OD Crack
Seam Type:	FW	Visual:	Dent and Hook Crack
Grade:	X52	L	1 inch (25.4 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	70%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.312 inch (7.92 mm)
t_{pipe}	Not Determined	t_{weld}	0.445 inch (11.3 mm)
Failure:	Leak at 2,250 psig (15.51 MPa) (138% of SMYS)		



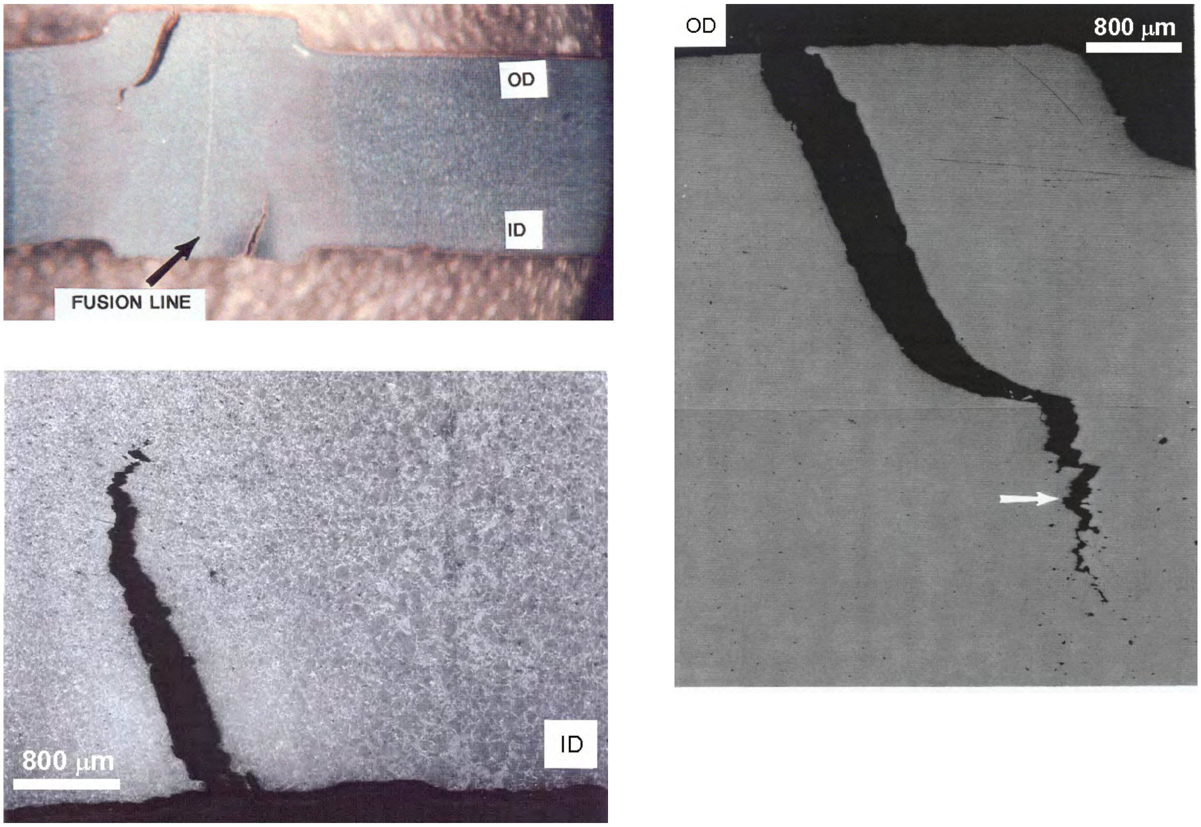
Photographs of Fracture Surfaces.

Catalog #:	26		
Report #:	2		
Defect #:	640		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	50% ID Crack like
Seam Type:	FW	Visual:	ID Hook crack
Grade:	X52	L	12.0 inch (305 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	63% (30% hook + 33% fatigue)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.250 inch (6.35 mm)
t_{pipe}	0.315 inch	t_{weld}	0.394 inch (10.1 mm)
Failure:	Burst test rupture at 1,550 psig (10.69 MPa) (95% of SMYS)		



Photographs and Photomicrograph of Metallographic Section and Fracture Surfaces.

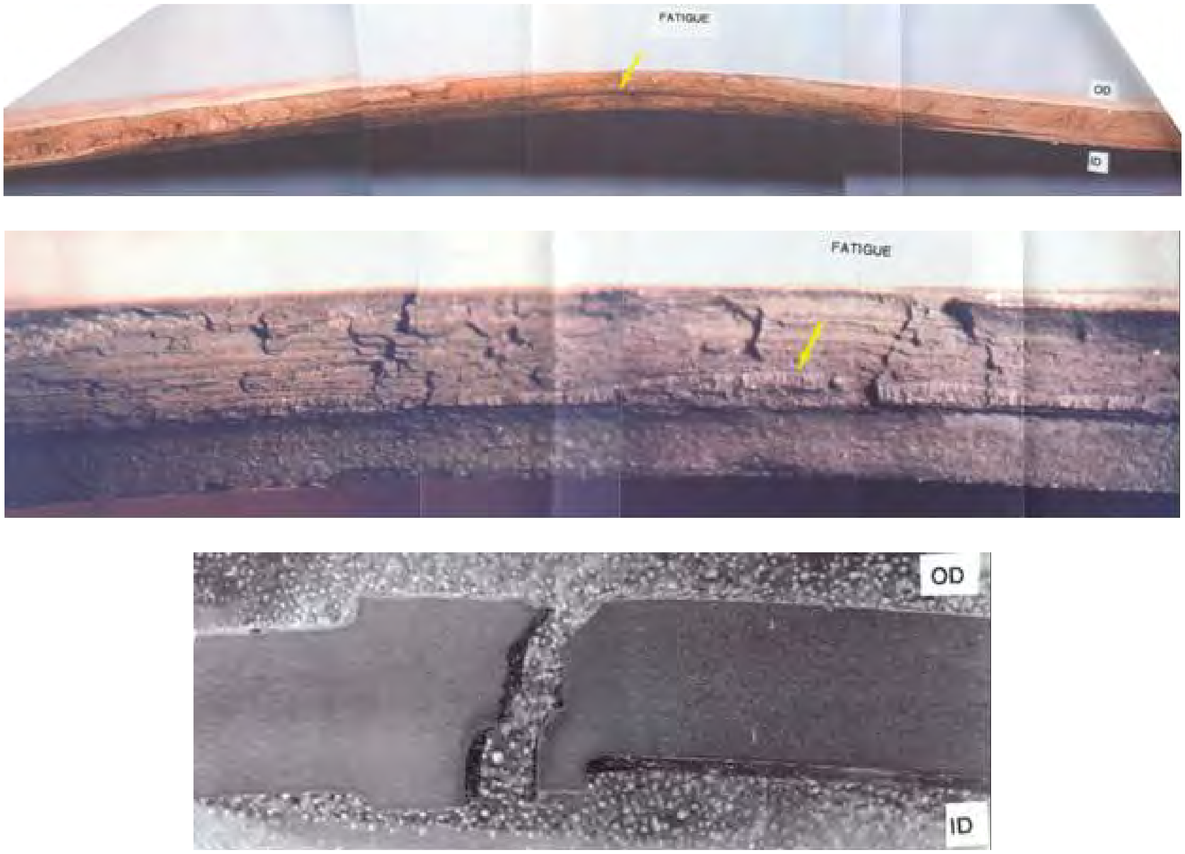
Catalog #:	37		
Report #:	5		
Defect #:	C9		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT, MT, and Fast UT
Manufacturer:	AO Smith	NDE result(s):	ID-connected crack-like (UT) + Intermittently dispersed minor inclusions (UT) + Crack-like (UT) + OD Sub-surface crack-like (MT) + NF with associated crack-like (Fast UT)
Seam Type:	FW	Visual:	ID hook crack (with crack extension)
Grade:	X52	L	> 4.25 inch (108 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	62%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.227 inch (5.77 mm) (incl. 0.020 inch (0.51 mm) crack extension)
t_{pipe}	0.320 inch (8.13 mm)	t_{weld}	0.366 inch (9.3 mm)
Failure:	None		



Photographs and Photomicrograph of Metallographic Section and Fracture Surfaces.

Catalog #:	35
Report #:	5
Defect #:	C5A

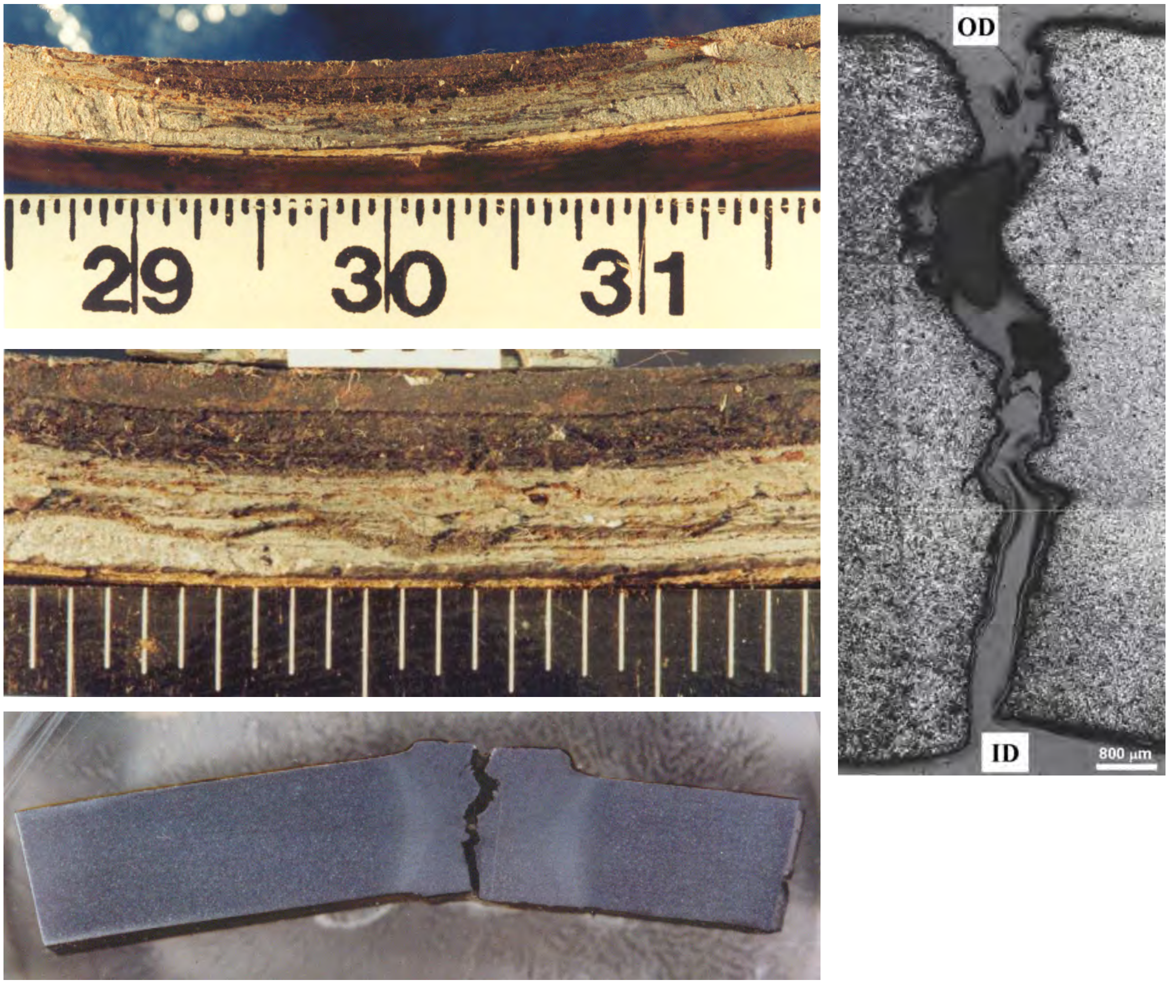
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT, MT, and Fast UT
Manufacturer:	AO Smith	NDE result(s):	ID Connected, Crack like (UT) + OD Crack-like (MT) + ID Connected, Crack-like + Some LOF (Fast UT)
Seam Type:	FW	Visual:	ID & OD Hook Cracks
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	57% (32 + 25%)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.204 inch (5.18 mm) (0.115 + 0.089 inch) (2.92 mm + 2.26 mm)
t_{pipe}	0.320 inch (8.13 mm)	t_{weld}	0.358 inch (9.09 mm)
Failure:	Burst Test: No failure at 2,000 psig (13.79 MPa) (123% of SMYS)		



Photographs of Fracture Surface and Metallographic Section.

Catalog #: 51
Report #: 5
Defect #: 49

Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	35%, 8 inch (203 mm), ID-connected crack-like + 2 inch (51 mm) inclusions
Seam Type:	FW	Visual:	ID Hook Crack + Crack extension
Grade:	X52	L	> 19.5 inch (495 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	54% (incl. 15% fatigue)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	< 0.218 inch (5.54 mm) (incl. 0.061 inch (1.55 mm) fatigue)
t_{pipe}	0.306 inch (7.77 mm)	t_{weld}	0.404 inch (10.3 mm)
Failure:	Burst test rupture at 1,750 psig (12.07 MPa) (108% of SMYS)		



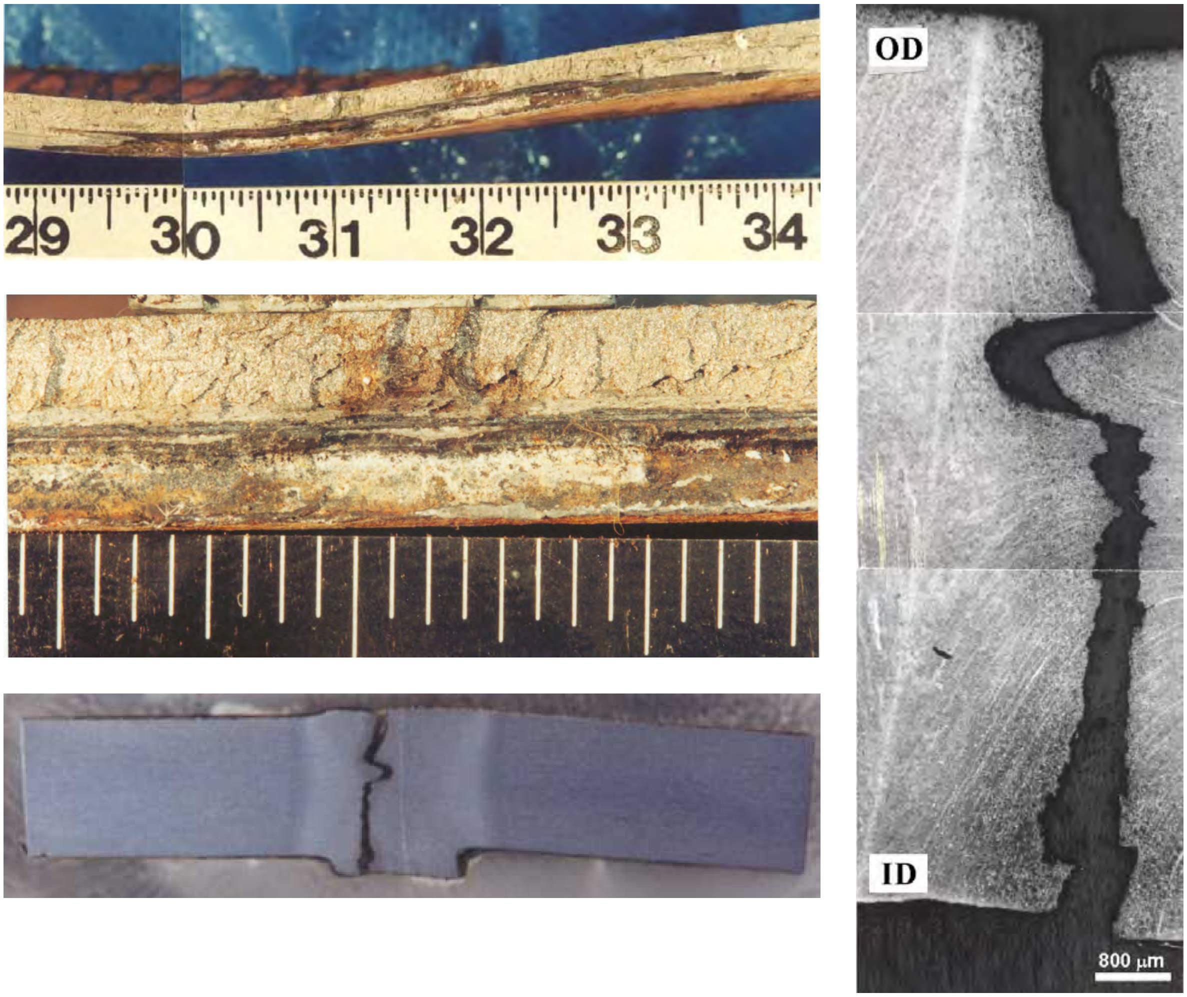
Photographs of Weld Seam ID Surface and Metallographic Section.

Catalog #: 58
Report #: 6
Defect #: 858

Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	75% ID Crack
Seam Type:	FW	Visual:	ID Hook Crack
Grade:	X52	L	2.25 inch (57.1 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	50%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.187 inch (4.75 mm)
t_{pipe}	Not Determined	t_{weld}	0.377 inch (9.58 mm)
Failure:	Burst test failure at 2,275 psig (15.69 MPa) (140% of SMYS)		

Photograph of Fracture Surface.

Catalog #:	48		
Report #:	5		
Defect #:	44		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	13.5 inch (343 mm) intermittent NF 2(1.6)5.3(.5)4.1 inch (gap)
Seam Type:	FW	Visual:	ID Hook Crack (evidence of crack extension)
Grade:	X52	L	> 12 inch (305 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	48% (incl. 11% crack extension)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.189 inch (4.8 mm) (incl. 0.043 inch (1.09 mm) crack extension)
t_{pipe}	0.312 inch (7.92 mm)	t_{weld}	0.394 inch (10.1 mm)
Failure:	Burst test failure at 1,950 psig (13.44 MPa) (120% of SMYS)		



Photographs and Photomicrograph of Fracture Surface and Metallographic Section.

Catalog #: 55
Report #: 6
Defect #: 707

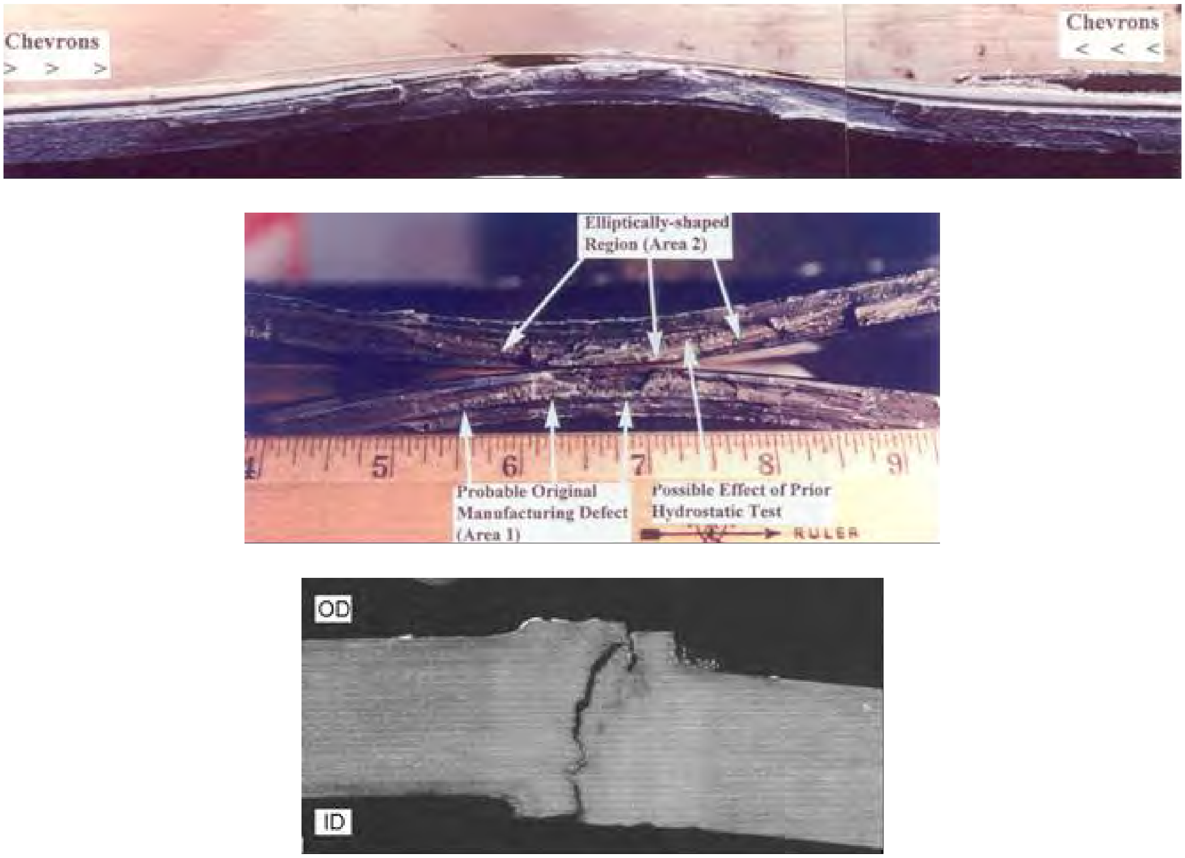
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	75% OD Crack
Seam Type:	FW	Visual:	OD Hook Crack
Grade:	X52	L	> 5 inch (127 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	47%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.187 inch (4.75 mm)
t_{pipe}	Not Determined	t_{weld}	0.400 inch (10.2 mm)
Failure:	Burst test failure at 1,675 psig (11.55 MPa) (103% of SMYS)		

Photograph of Fracture Surfaces.

Catalog #:	6		
Report #:	1		
Defect #:	299		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	60% x 6.0 inch (152 mm) ID crack
Seam Type:	FW	Visual:	ID hook crack
Grade:	X52	L	> 2.8 inch (71 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	43%
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	0.1875 (3/16 inch) (4.76 mm)
t_{pipe}	0.345 inch (8.76 mm)	t_{weld}	0.435 inch (11.1 mm)
Failure:	None at 2,300 psig (15.86 MPa) (129% of SMYS)		

Photograph of Fracture Surface.

Catalog #:	45		
Report #:	5		
Defect #:	24		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	2.4 inch (61 mm) long, 50% crack-like
Seam Type:	FW	Visual:	ID Hook Crack
Grade:	X52	L	> 5 inch (127 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	40%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.158 inch (4.01 mm)
t_{pipe}	0.310 inch (7.87 mm)	t_{weld}	0.394 inch (10.1 mm)
Failure:	Burst Test: No failure at 2,200 psig (15.17 MPa) (136% of SMYS) + Yielding at 2,175 psig (15.00 MPa) (134% of SMYS)		



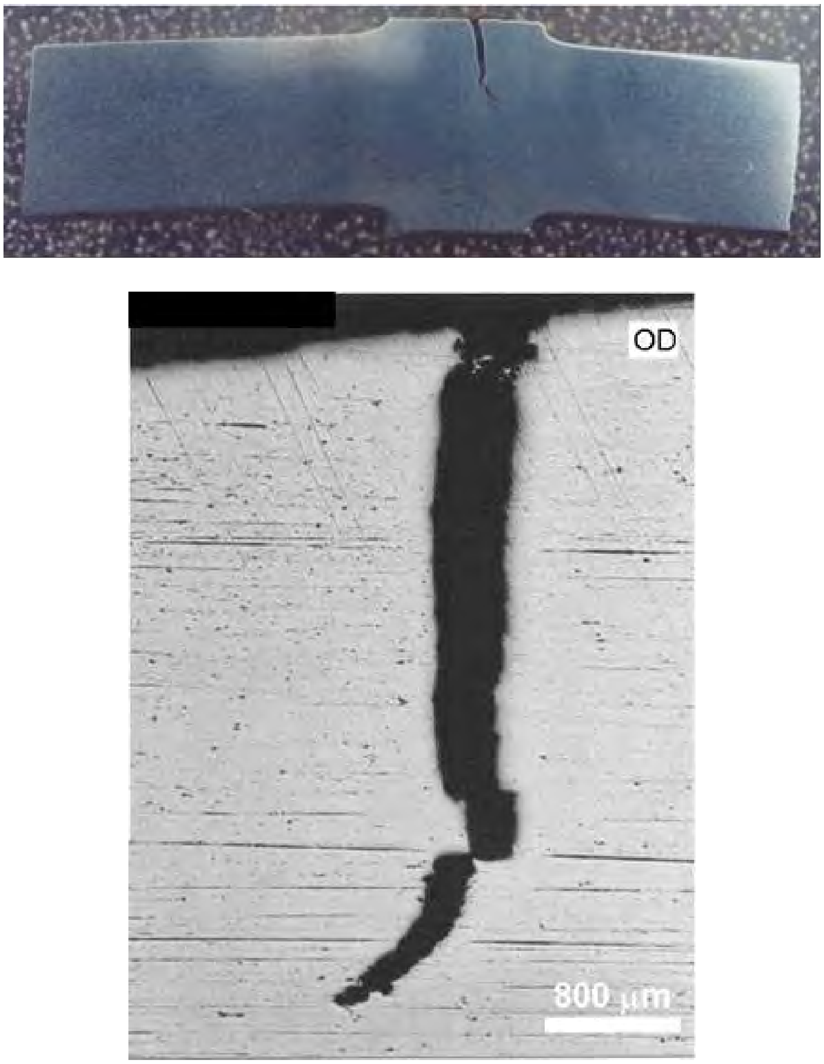
Photographs of Fracture Surfaces and Metallographic Section.

Catalog #:	84		
Report #:	4		
Defect #:	964+53		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	N/A
Manufacturer:	AO Smith	NDE result(s):	N/A
Seam Type:	FW	Visual:	ID Overtrim + ID Hook Crack + Fatigue Crack
Grade:	X52	L	11 feet long, 5.875 inch (149 mm) wide
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	40% (Hook Crack)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.162 inch (4.11 mm)
t_{pipe}	0.321 inch (8.15 mm)	t_{weld}	0.405 inch (10.3 mm)
Failure:	In-Service rupture at 897 psig (6.18 MPa) (55% of SMYS) Hydrotested at 1,460 psig (10.07 MPa) (90% of SMYS) 32 to 35 years earlier		

Photograph of Fracture Surface.

Catalog #:	49		
Report #:	5		
Defect #:	45B		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	65%, 14 inch (356 mm) crack-like
Seam Type:	FW	Visual:	OD Hook crack
Grade:	X52	L	6.63 inch (168 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	40%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.156 inch (3.96 mm)
t_{pipe}	0.308 inch (7.82 mm)	t_{weld}	0.390 inch (9.91 mm)
Failure:	Burst test rupture at 2,150 psig(*) (14.82 MPa) (133% of SMYS)		

(*) This and a nearby hook crack together produced the failure at this pressure.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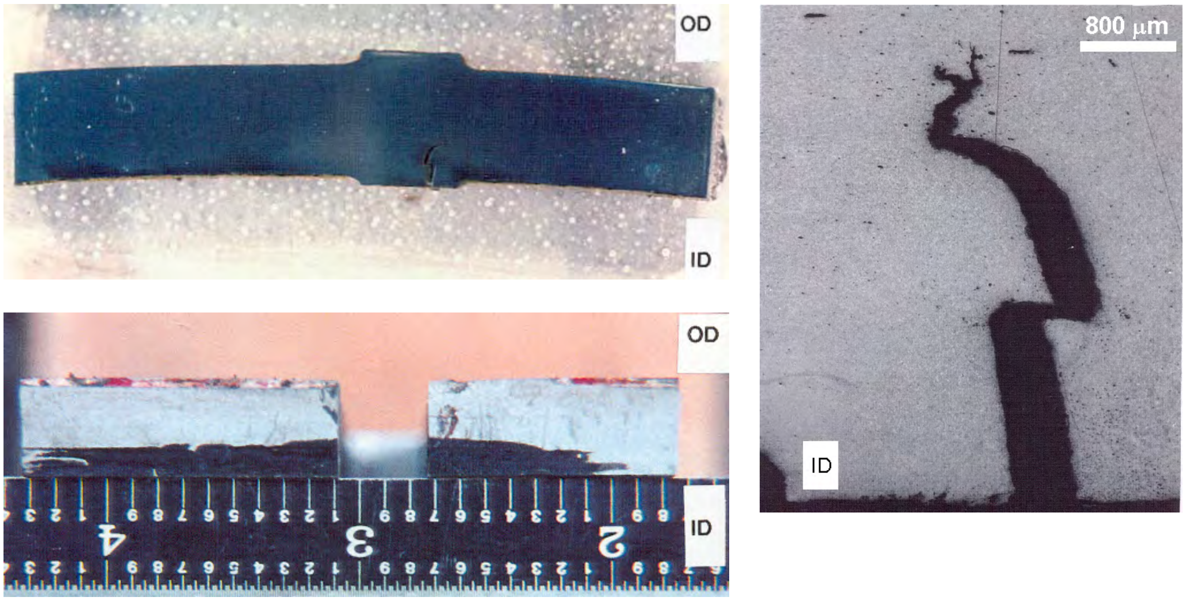
Photograph and Photomicrograph of Metallographic Section.

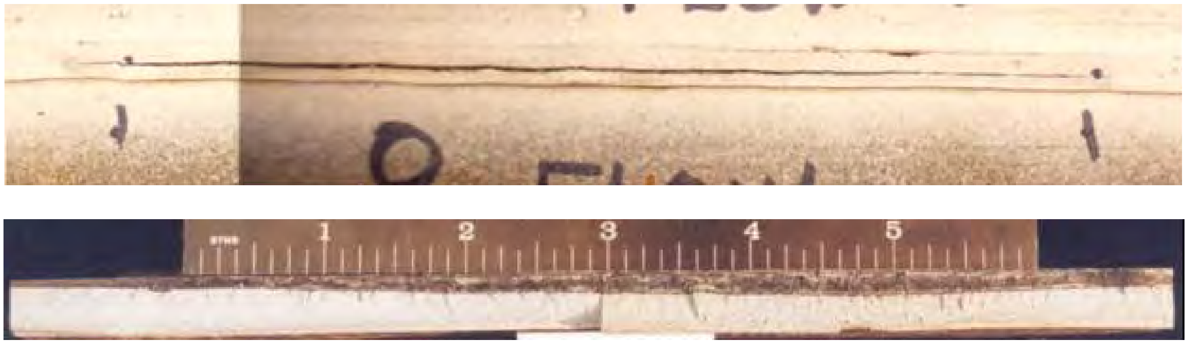
Catalog #:	76		
Report #:	7		
Defect #:	1328		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	40% (0.158 inch (4.01 mm)) OD Crack
Seam Type:	FW	Visual:	OD Hook Crack
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	39%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.155 inch (3.94 mm)
t_{pipe}	0.318 inch (8.08 mm)	t_{weld}	0.398 inch (10.1 mm)
Failure:	N/A		

FW — ***ID Hook Crack (with Crack Extension)***



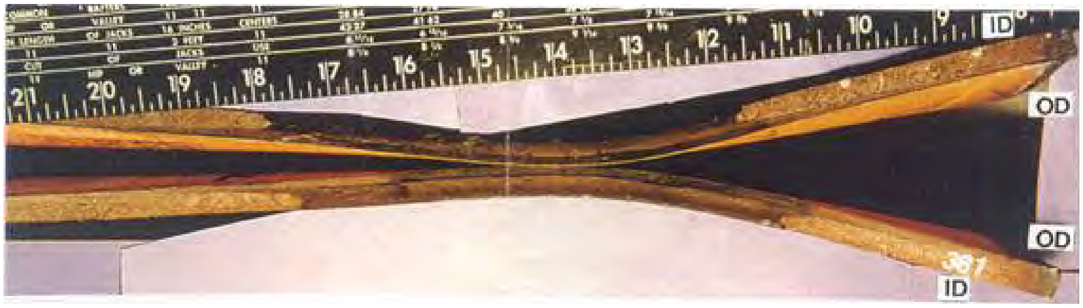
Photographs and Photomicrograph of Metallographic Section and Fracture Surfaces.

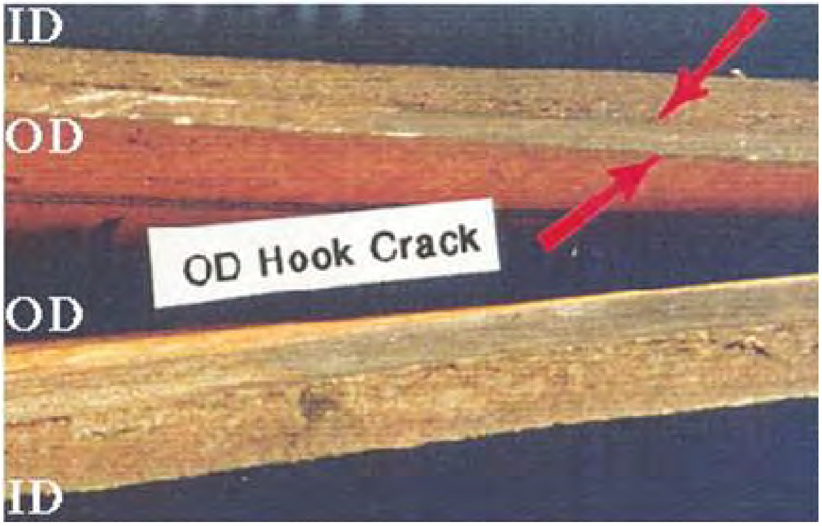
Catalog #:	38		
Report #:	5		
Defect #:	C10		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT & Fast UT
Manufacturer:	AO Smith	NDE result(s):	Minor Inclusions (UT) + Minor Inclusions (Fast UT) + Crack-like (Fast UT)
Seam Type:	FW	Visual:	ID hook crack (with crack extension)
Grade:	X52	L	> 2.5 inch (63 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	38%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.148 inch (3.76 mm) (incl. 0.028 inch (0.71 mm) crack extension)
t_{pipe}	0.321 inch (8.15 mm)	t_{weld}	0.390 inch (9.91 mm)
Failure:	None		



Photographs of Weld Seam ID Surface and Fracture Surface.

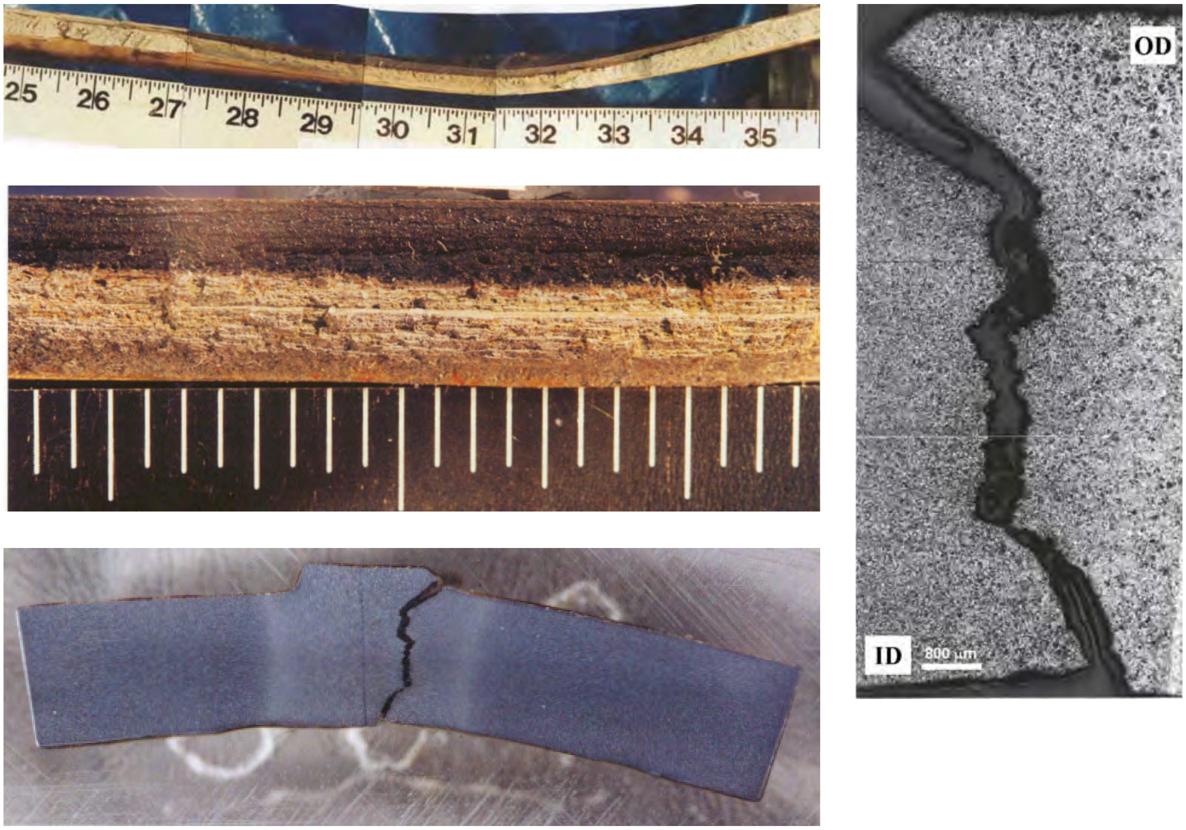
Catalog #:	67		
Report #:	7		
Defect #:	841		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	40% (0.170 inch (4.32 mm)) ID Crack
Seam Type:	FW	Visual:	ID Hook Crack
Grade:	X52	L	> 8 inch (203 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	37%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.156 inch (3.96 mm)
t_{pipe}	Not Determined	t_{weld}	0.425 inch (10.8 mm)
Failure:	N/A		





Photographs of Fracture Surfaces.

Catalog #:	21		
Report #:	2		
Defect #:	361		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	30%, 8.5 inch (216 mm) OD crack like
Seam Type:	FW	Visual:	OD Hook crack
Grade:	X52	L	10.5 inch (267 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	36%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.140 inch (3.56 mm)
t_{pipe}	0.303 inch (7.7 mm)	t_{weld}	0.389 inch (9.88 mm)
Failure:	Burst test rupture at 1,925 psig (13.27 MPa) (119% of SMYS)		



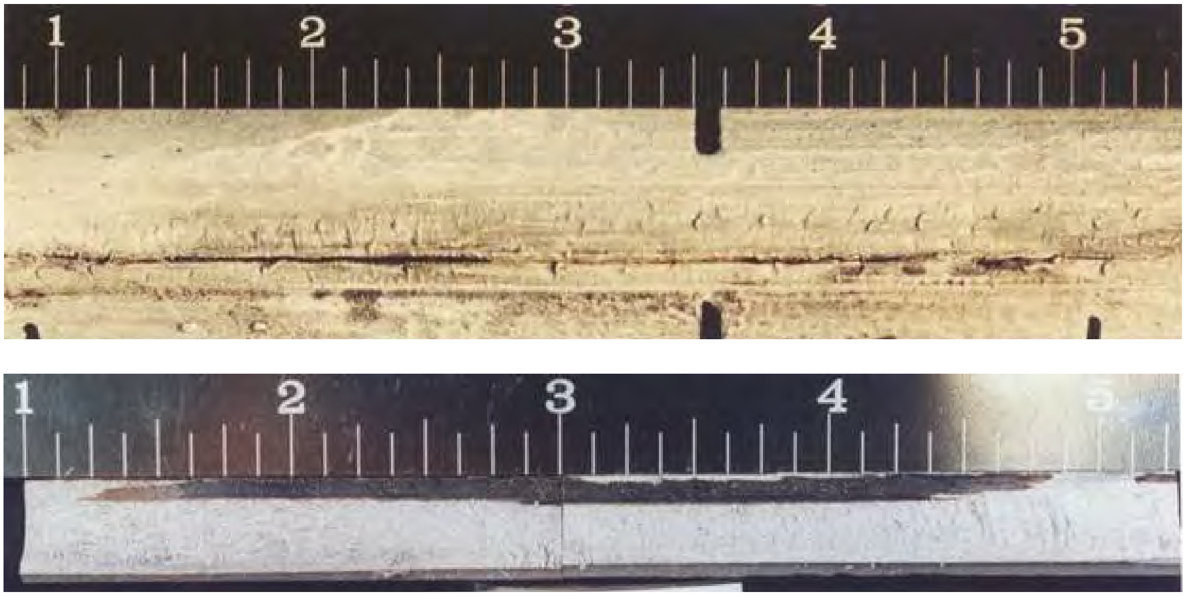
Photographs and Photomicrograph of Metallographic Section and Fracture Surfaces.

Catalog #:	60
Report #:	6
Defect #:	968

Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	65% ID Crack
Seam Type:	FW	Visual:	ID Hook Crack
Grade:	X52	L	8.25 inch (210 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	34%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.125 inch (3.17 mm)
t_{pipe}	Not Determined	t_{weld}	0.371 inch (9.42 mm)
Failure:	Burst test failure at 1,950 psig (13.44 MPa) (120% of SMYS)		

Photograph and Photomicrograph of Metallographic Section.

Catalog #:	78		
Report #:	7		
Defect #:	1381		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	30% (0.128 inch (3.25 mm)) OD Crack-Like
Seam Type:	FW	Visual:	OD Hook Crack
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	34%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.145 inch (3.68 mm)
t_{pipe}	0.306 inch (7.77 mm)	t_{weld}	0.425 inch (10.8 mm)
Failure:	N/A		

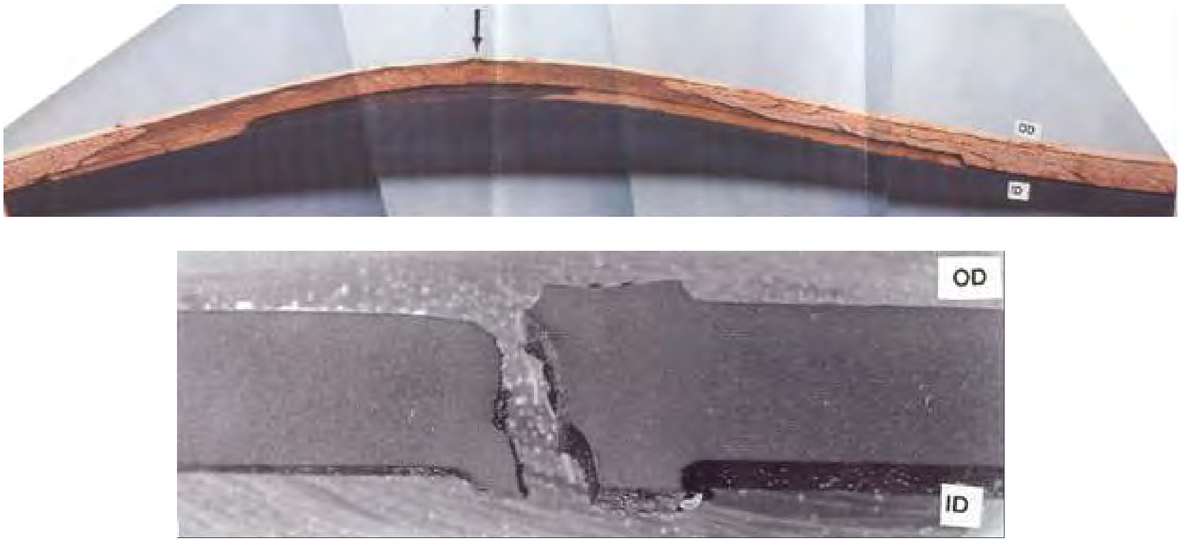


Photographs of Weld Seam ID Surface and Fracture Surface.

Catalog #:	72		
Report #:	7		
Defect #:	1017		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	30% ID Crack
Seam Type:	FW	Visual:	ID Hook Crack
Grade:	X52	L	3.5 inch (89 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	32%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.116 inch (2.95 mm)
t_{pipe}	Not Determined	t_{weld}	0.365 inch (9.27 mm)
Failure:	N/A		

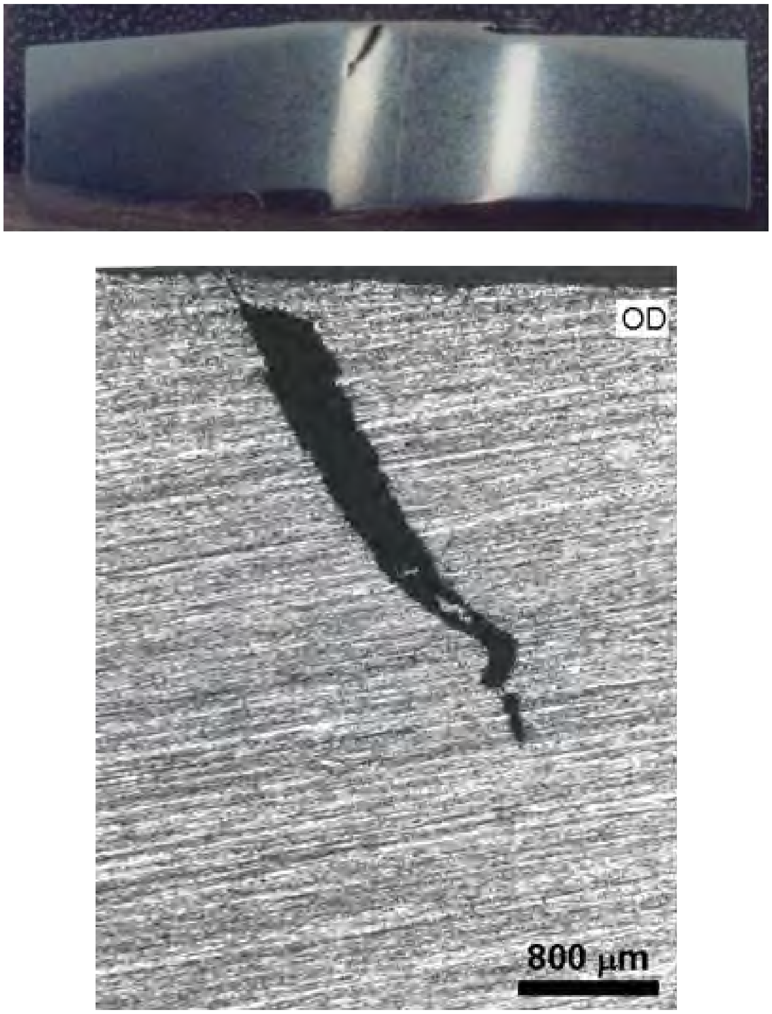
Photographs of Fracture Surface.

Catalog #:	57		
Report #:	6		
Defect #:	808		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	65% OD Crack
Seam Type:	FW	Visual:	OD Hook Crack + inclusions
Grade:	X52	L	5 inch (127 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	32%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.125 inch (3.17 mm)
t_{pipe}	Not Determined	t_{weld}	0.385 inch (9.78 mm)
Failure:	Burst test failure at 1,900 psig (13.10 MPa) (117% of SMYS)		



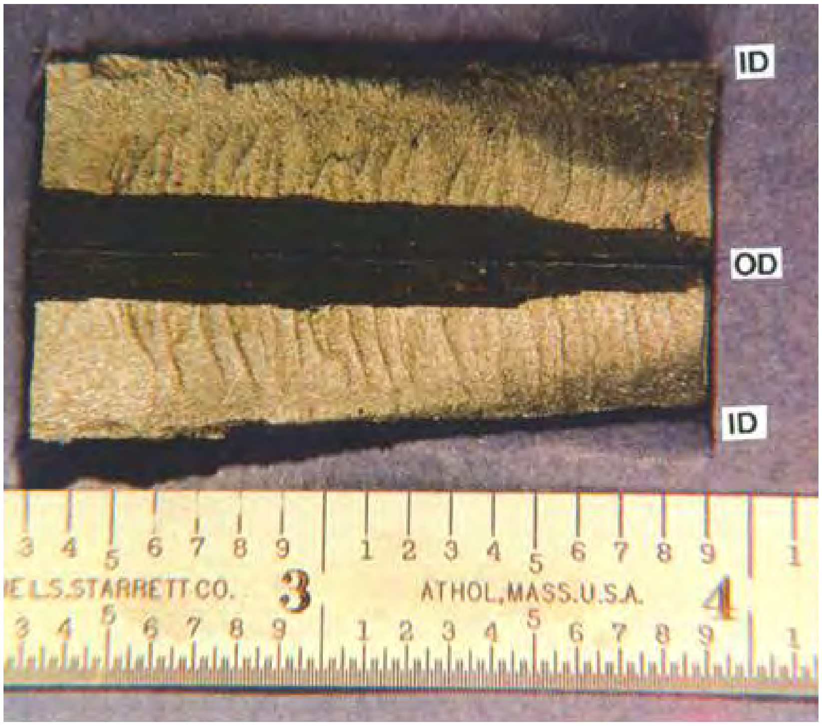
Photographs of Fracture Surface and Metallographic Section.

Catalog #:	50		
Report #:	5		
Defect #:	46		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	4.8 inch (122 mm) crack-like, ID connected
Seam Type:	FW	Visual:	ID Hook crack
Grade:	X52	L	> 9 inch (229 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	31%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.124 inch (3.15 mm)
t_{pipe}	0.314 inch (7.98 mm)	t_{weld}	0.400 inch (10.2 mm)
Failure:	Burst test rupture at 2,250 psig (15.51 MPa) (139% of SMYS)		



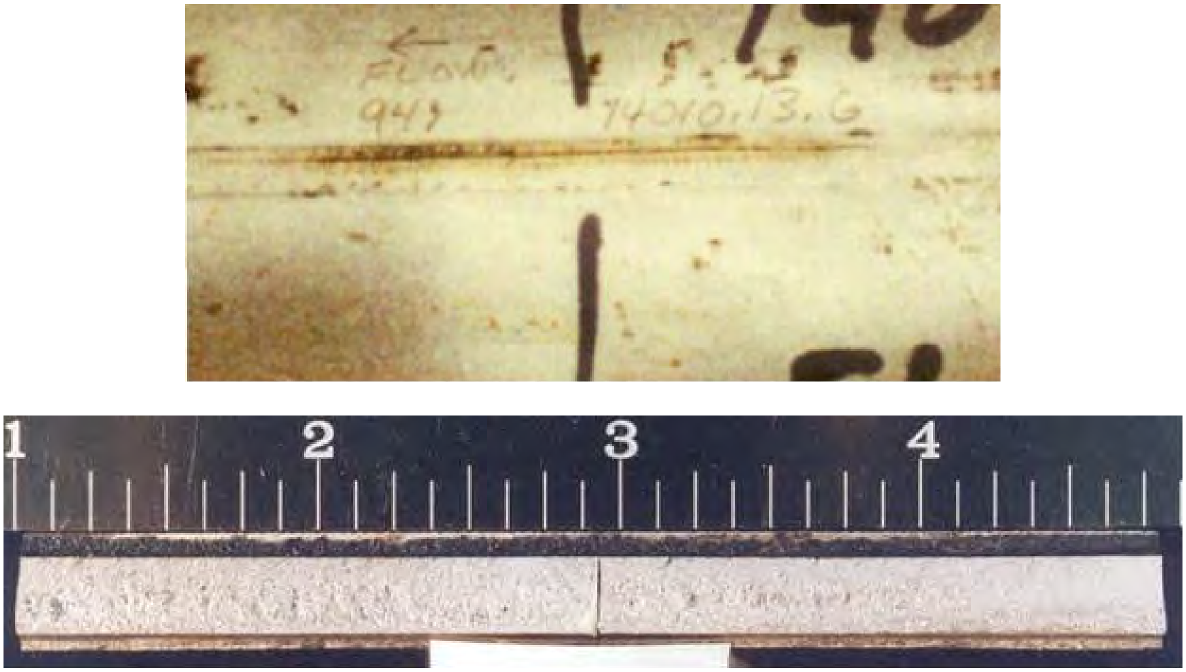
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	77		
Report #:	7		
Defect #:	1339		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	30% (0.105 inch (2.67 mm)) OD Crack-like
Seam Type:	FW	Visual:	OD Hook Crack
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	29%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.100 inch (2.54 mm)
t_{pipe}	0.306 inch (7.77 mm)	t_{weld}	0.349 inch (8.86 mm)
Failure:	N/A		



Photograph of Fracture Surfaces.

Catalog #:	5		
Report #:	1		
Defect #:	282		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	66% x 3.5 inch (89 mm) OD crack
Seam Type:	FW	Visual:	OD hook crack
Grade:	X52	L	~ 3.4 inch (86 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	27.7%
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	0.125 (1/8 inch (3.17 mm))
t_{pipe}	0.341 inch (8.66 mm)	t_{weld}	0.450 inch (11.4 mm)
Failure:	None at 2,300 psig (15.86 MPa) (129% of SMYS)		



Photographs of Weld Seam ID Surface and Fracture Surface.

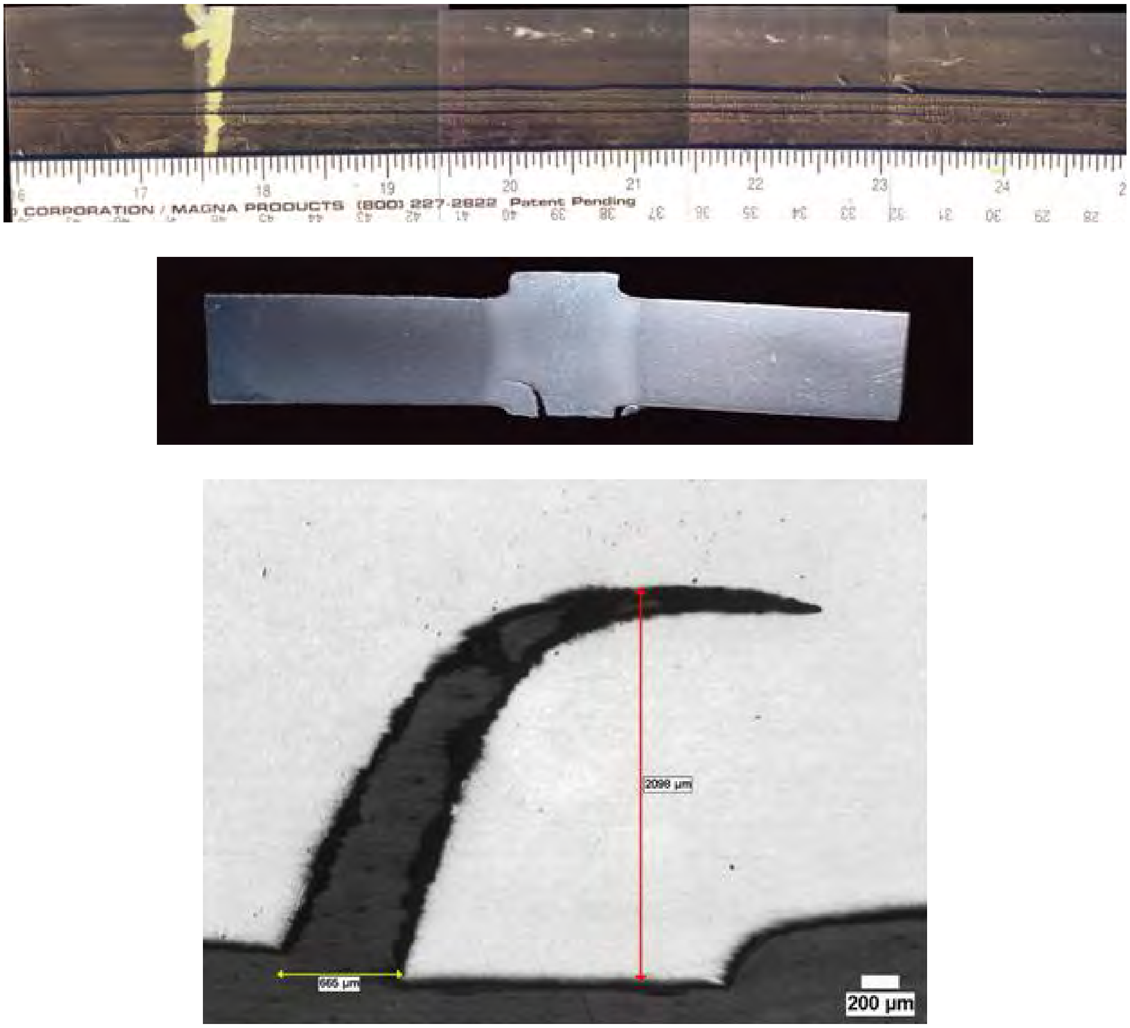
Catalog #:	69		
Report #:	7		
Defect #:	941		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	20% ID Crack
Seam Type:	FW	Visual:	ID Hook Crack
Grade:	X52	L	> 5 inch (127 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	25%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.086 inch (2.18 mm)
t_{pipe}	Not Determined	t_{weld}	0.344 inch (8.74 mm)
Failure:	N/A		

Photograph of Fracture Surfaces.

Catalog #:	4		
Report #:	1		
Defect #:	169		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	40% x 5.5 inch (140 mm) crack
Seam Type:	FW	Visual:	ID hook crack
Grade:	X52	L	> 6 inch (152 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	24.4%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.09375 (3/32 inch (2.38 mm))
t_{pipe}	0.310 inch (7.87 mm)	t_{weld}	0.384 inch (9.75 mm)
Failure:	None at 2,275 psig (15.69 MPa) (140% of SMYS)		

Photograph of Fracture Surfaces.

Catalog #:	16		
Report #:	1		
Defect #:	643		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	50% x 5.0 inch (127 mm) ID crack
Seam Type:	FW	Visual:	ID hook crack
Grade:	X52	L	~ 3.4 inch (86 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	23.4%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.09375 inch (3/32) (2.38 mm)
t_{pipe}	0.315 inch (8.00 mm)	t_{weld}	0.400 inch (10.2 mm)
Failure:	None at 2,300 psig (15.86 MPa) (140% of SMYS)		

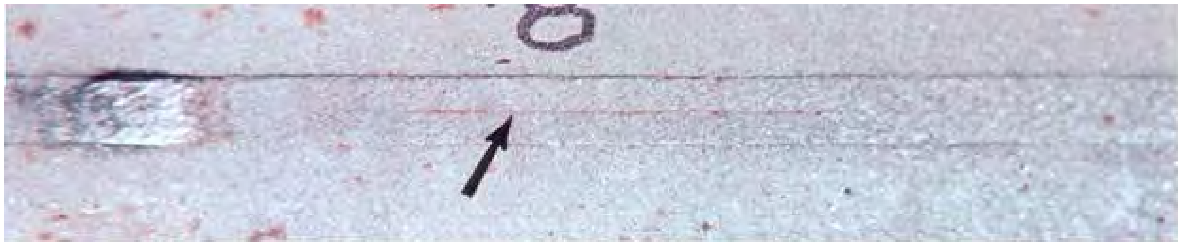


Photographs and Photomicrograph of Pipe ID Surface and Metallographic Section.

Catalog #:	17		
Report #:	13		
Defect #:	1		
Pipe		**Defect**	
Vintage:	1954	NDE technique(s):	Shear wave UT
Manufacturer:	AO Smith	NDE result(s):	30% x 8.1 inch (206 mm) ID-connected crack
Seam Type:	FW	Visual:	ID hook crack
Grade:	API 5L X52	L	~ 7 inch (178 mm)
$D_{nominal}$	26 inch (660 mm)	Width:	0.026 inch (0.66 mm)
$t_{nominal}$	0.281 inch (7.14 mm)	depth/t_{weld}	22.6%
t_{pipe}	0.275 inch (6.98 mm)	depth:	0.083 inch (2.1 mm)
Failure:	N/A	t_{weld}	0.365 inch (9.27 mm)
MOP:	809 psig (5.58 MPa)		

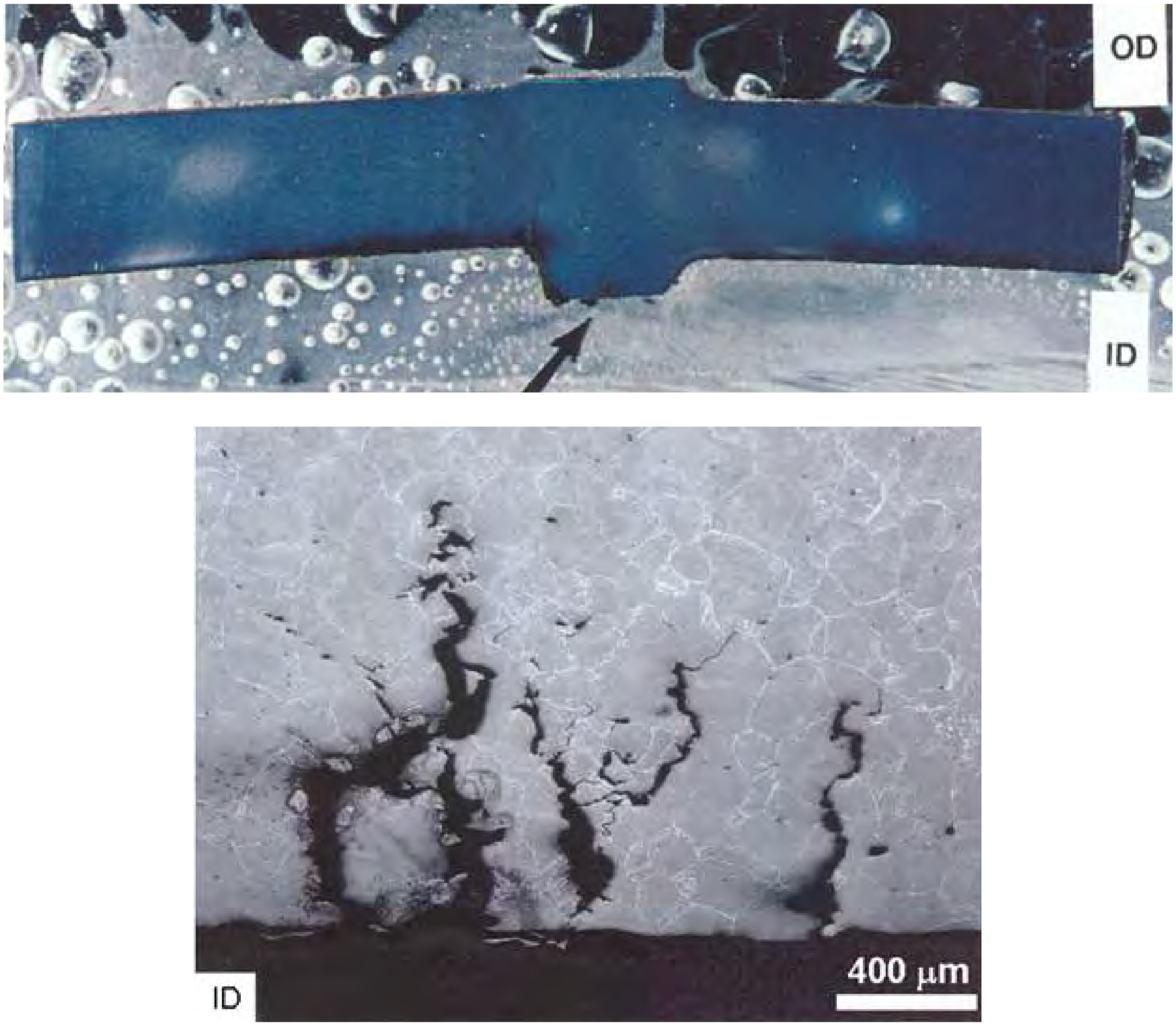
Photograph of Weld Seam ID Surface.

Catalog #:	40		
Report #:	5		
Defect #:	3		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	2 interacting, ID-connected crack-like indications: combined L = 3.6 inch (91 mm), 25% radial extent
Seam Type:	FW	Visual:	ID hook crack (surmised, defect not exposed)
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	0.309 inch (7.85 mm)	t_{weld}	0.380 inch (9.65 mm)
Failure:	Burst test: No failure at 2,250 psig (15.51 MPa) (139% of SMYS) + Yielding at 2,175 psig (15.00 MPa) (134% of SMYS)		



Photograph of Weld Seam OD Surface.

Catalog #:	41		
Report #:	5		
Defect #:	8		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	50%, 3.7 inch (94 mm) crack-like, OD-connected
Seam Type:	FW	Visual:	OD hook crack (surmised, defect not exposed)
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	0.327 inch (8.31 mm)	t_{weld}	0.404 inch (10.3 mm)
Failure:	Burst Test: No failure at 2,300 psig (15.86 MPa) (142% of SMYS) + Yielding at 2,250 psig (15.51 MPa) (139% of SMYS)		

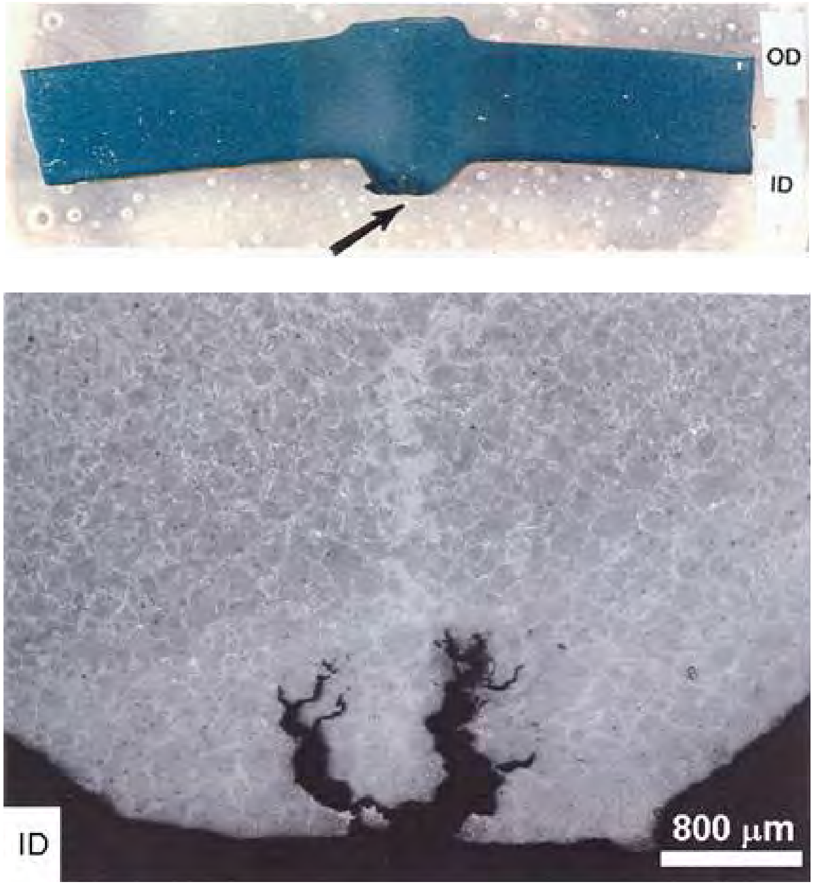


Photograph and Photomicrograph of Metallographic Section.

Catalog #:	36		
Report #:	5		
Defect #:	C7		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT & Fast UT
Manufacturer:	AO Smith	NDE result(s):	No anomaly revealed (UT) + Minor inclusions (Fast UT)
Seam Type:	FW	Visual:	ID Shrinkage Crack
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	< 12%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	< 0.052 inch (1.32 mm)
t_{pipe}	0.312 inch (7.92 mm)	t_{weld}	0.436 inch (11 mm)
Failure:	None		

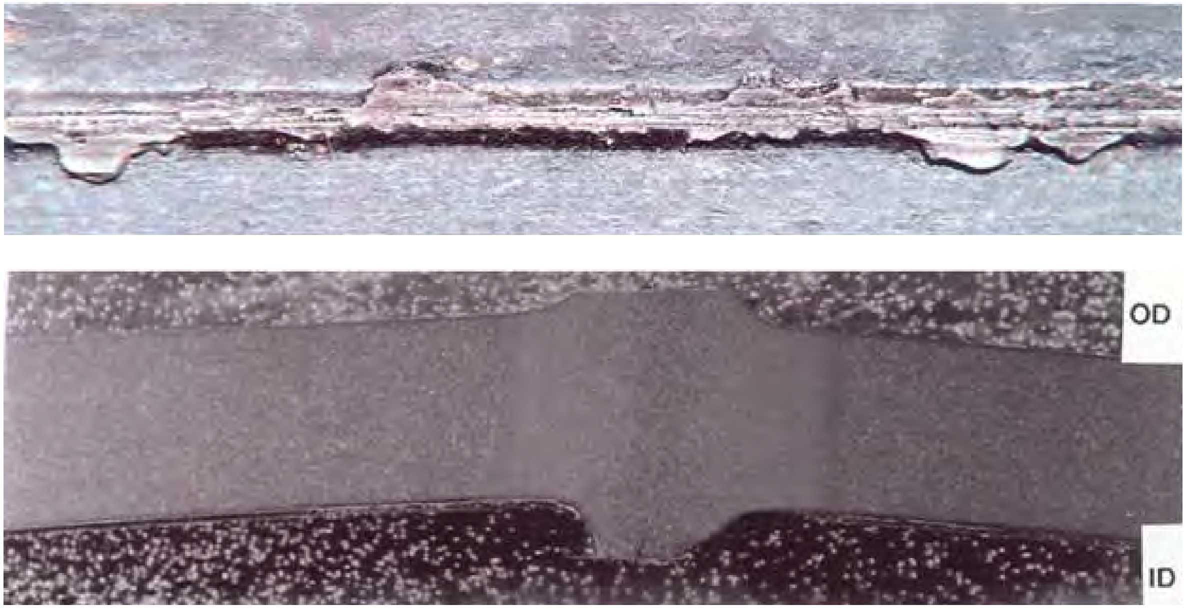
Photograph and Photomicrograph of Metallographic Section.

Catalog #:	68		
Report #:	7		
Defect #:	904		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	20% OD Crack-Like
Seam Type:	FW	Visual:	OD Shrinkage Crack
Grade:	X52	L	Not Determined
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	10%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.040 inch (1.02 mm)
t_{pipe}	Not Determined	t_{weld}	0.396 inch (10.1 mm)
Failure:	N/A		



Photograph and Photomicrograph of Metallographic Section.

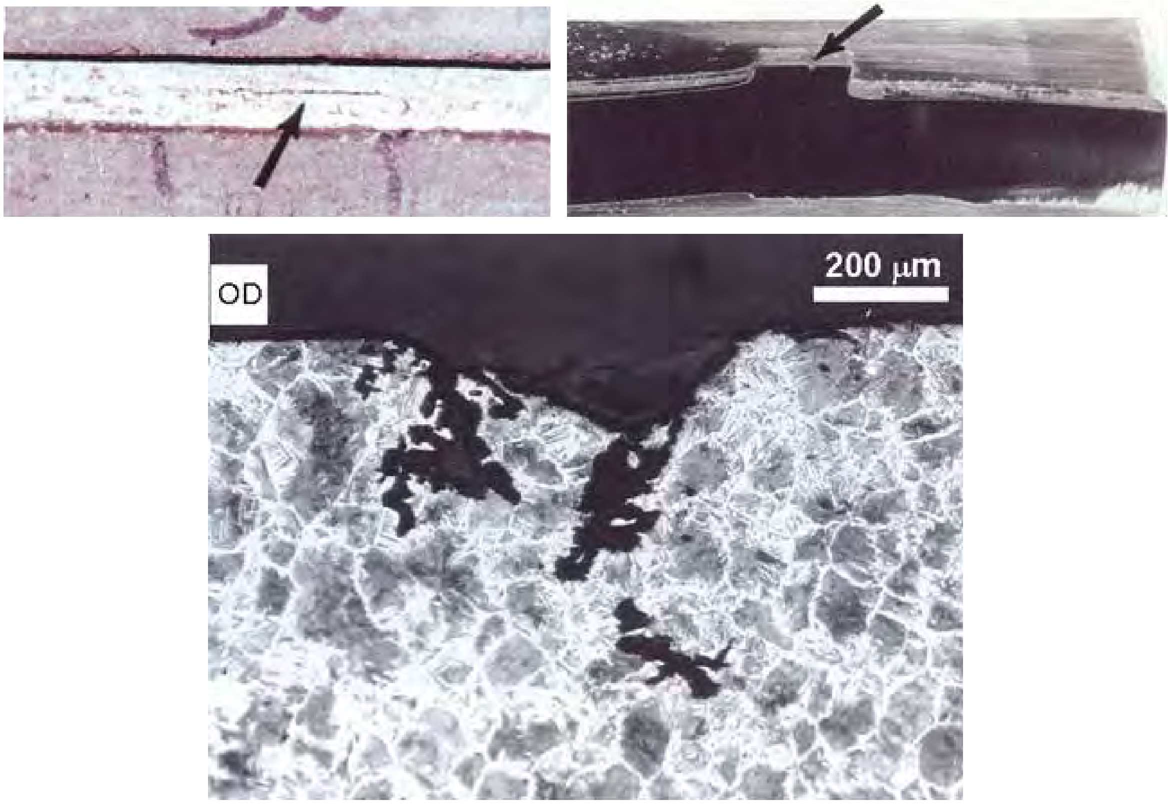
Catalog #:	33		
Report #:	5		
Defect #:	C1		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	Minor indication from ID surface
Seam Type:	FW	Visual:	Shrinkage Crack (Weld trim defect)
Grade:	X52	L	> 9 inch (229 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	< 10%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	< 0.047 inch (1.19 mm)
t_{pipe}	0.306 inch (7.77 mm)	t_{weld}	0.475 inch (12.1 mm)
Failure:	None		



Photographs of Weld Seam ID Surface and Metallographic Section.

Catalog #: 39
Report #: 5
Defect #: 1

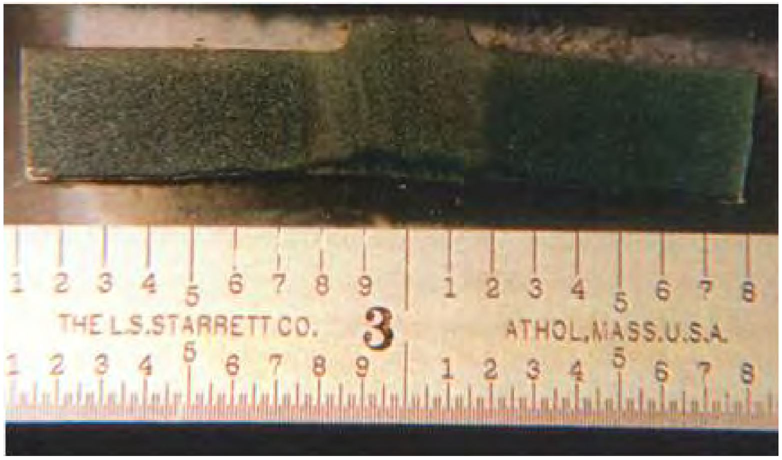
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	1.0 (25.4 mm) and 1.5 inch (38.1 mm) (long, 30% radial extent NF at Mid-wall
Seam Type:	FW	Visual:	ID Shrinkage Crack (Under-trim)
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	< 7%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	< 0.033 inch (8.38 mm)
t_{pipe}	0.313 inch (7.95 mm)	t_{weld}	0.470 inch (11.9 mm)
Failure:	Burst test: No failure at 2,250 psig (15.51 MPa) + Yielding at 2,250 psig (15.51 MPa) (139% of SMYS)		

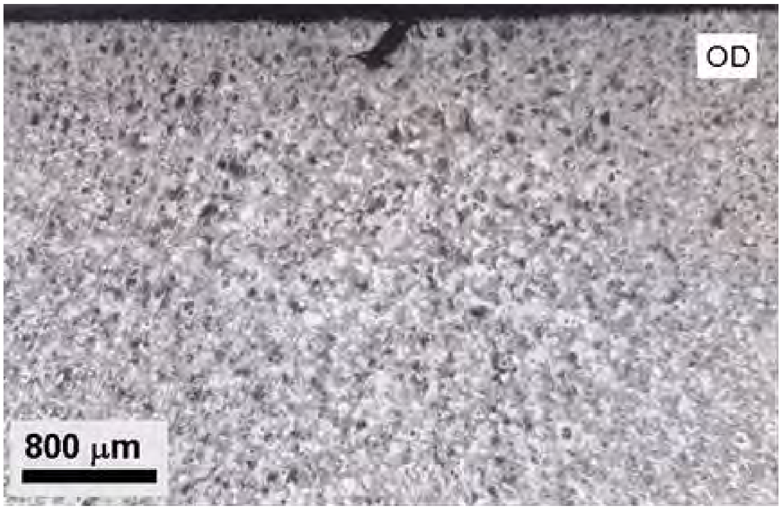


Photographs/Micrographs of Weld Seam OD Surface and Metallographic Section.

Catalog #: 47
Report #: 5
Defect #: 26

Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	<10%, 3.75 inch (95 mm) crack-like, OD-connected
Seam Type:	FW	Visual:	OD shrinkage crack (inadequate trim)
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	< 5%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.020 inch (0.51 mm)
t_{pipe}	0.316 inch (8.03 mm)	t_{weld}	0.390 inch (9.91 mm)
Failure:	Burst test: No failure at 2,200 psig (15.17 MPa) (136% of SMYS) + Yielding at 2,000 psig (13.79 MPa) (123% of SMYS)		



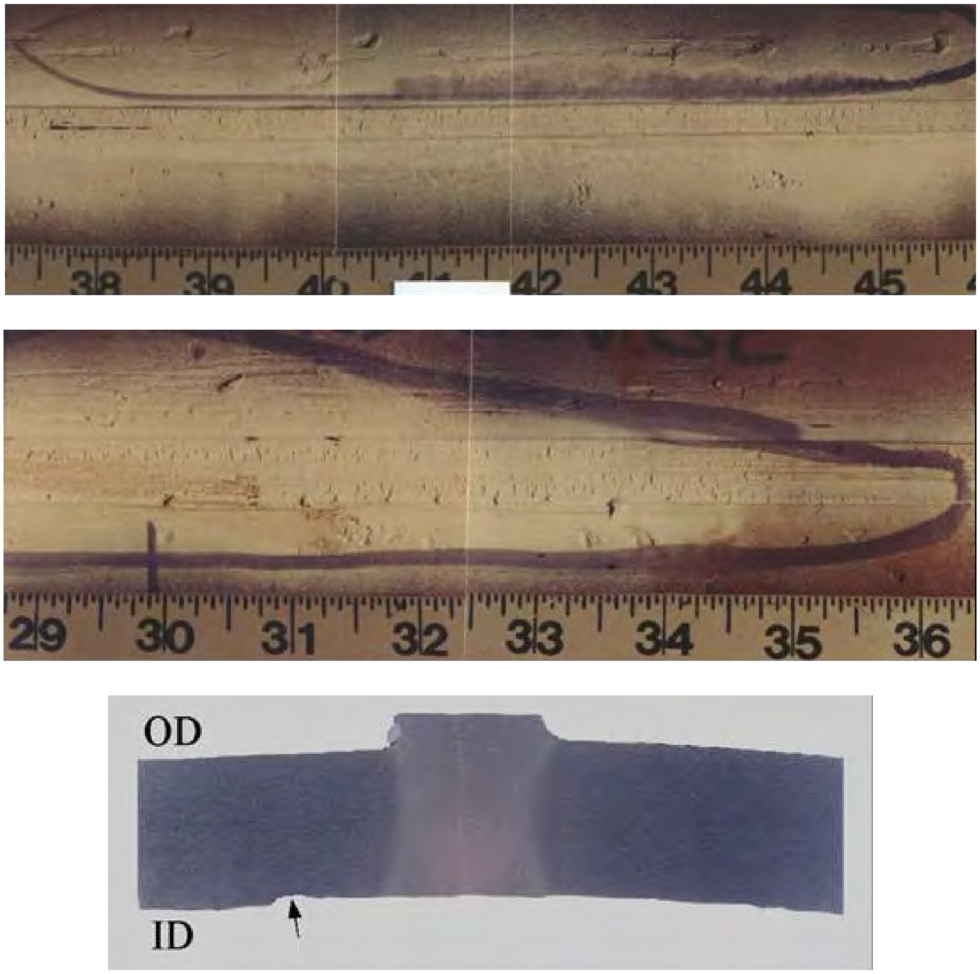


Photograph and Photomicrograph of Metallographic Section.

Catalog #:	15		
Report #:	1		
Defect #:	624		
Pipe		**Defect**	
Vintage:	1950s	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	<10% x 5.5 inch (140 mm) crack
Seam Type:	FW	Visual:	OD crack
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	3.1%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.012 inch (0.31 mm)
t_{pipe}	0.303 inch (7.7 mm)	t_{weld}	0.385 inch (9.78 mm)
Failure:	None at 2,300 psig (15.86 MPa) (142% of SMYS)		

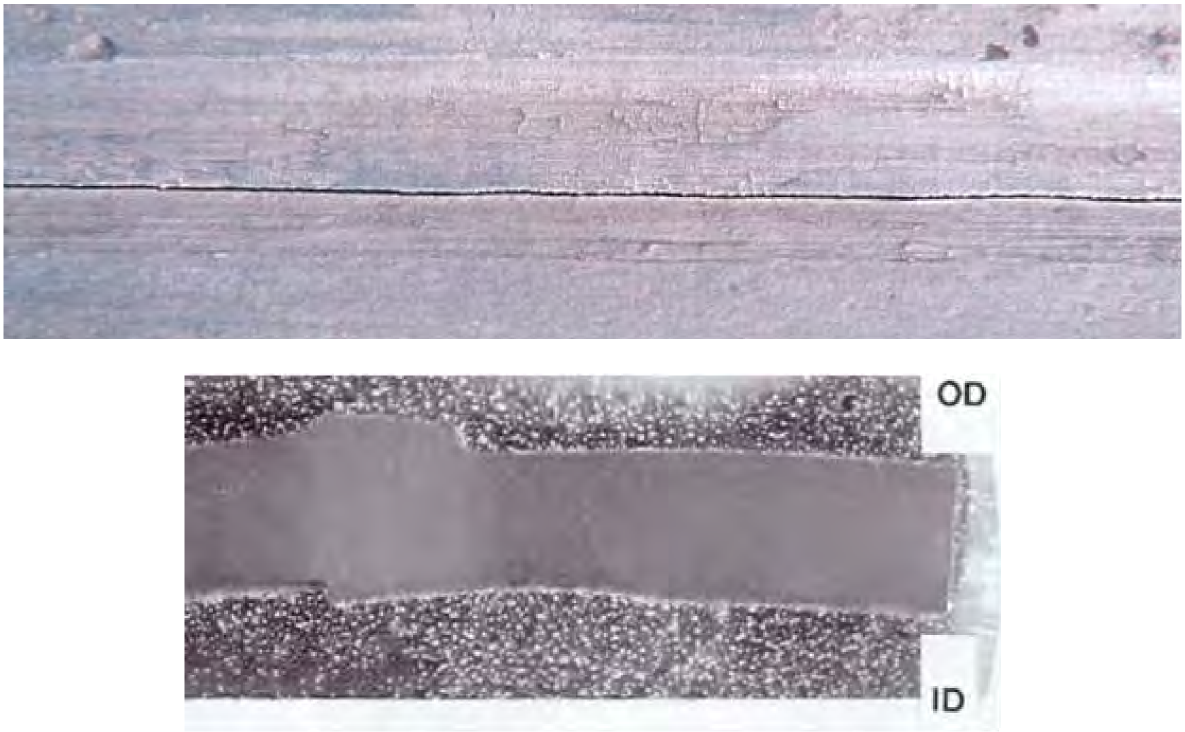
Photograph of Weld Seam OD Surface.

Catalog #:	79		
Report #:	7		
Defect #:	1422		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Visual
Manufacturer:	AO Smith	NDE result(s):	OD Weld repair
Seam Type:	FW	Visual:	OD Weld repair + No cracking visible from ID surface
Grade:	X52	L	0.5 inch (12.7 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	N/A
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	N/A
t_{pipe}	Not Determined	t_{weld}	N/A
Failure:	N/A		



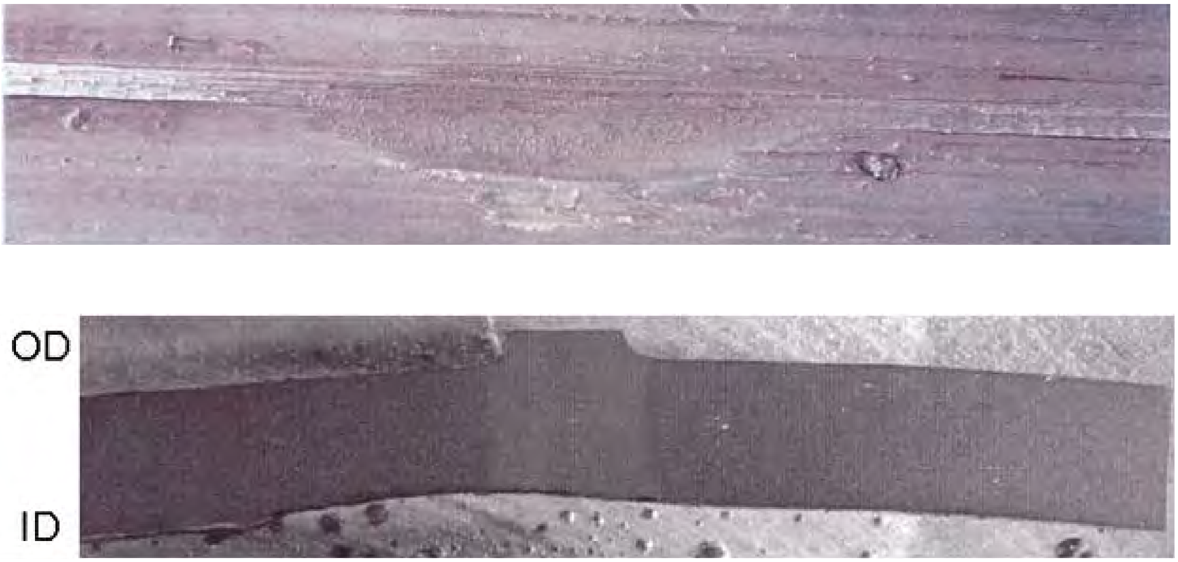
Photographs of Weld Seam ID Surface and Metallographic Section.

Catalog #:	71		
Report #:	7		
Defect #:	1003		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	< 10% ID Gouge + < 0.060 inch (1.52 mm) RDI Dent
Seam Type:	FW	Visual:	3 ID Gouges + Weld Over-trim
Grade:	X52	L	5 inch, 7 inch, 8 inch (127, 178, 203 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



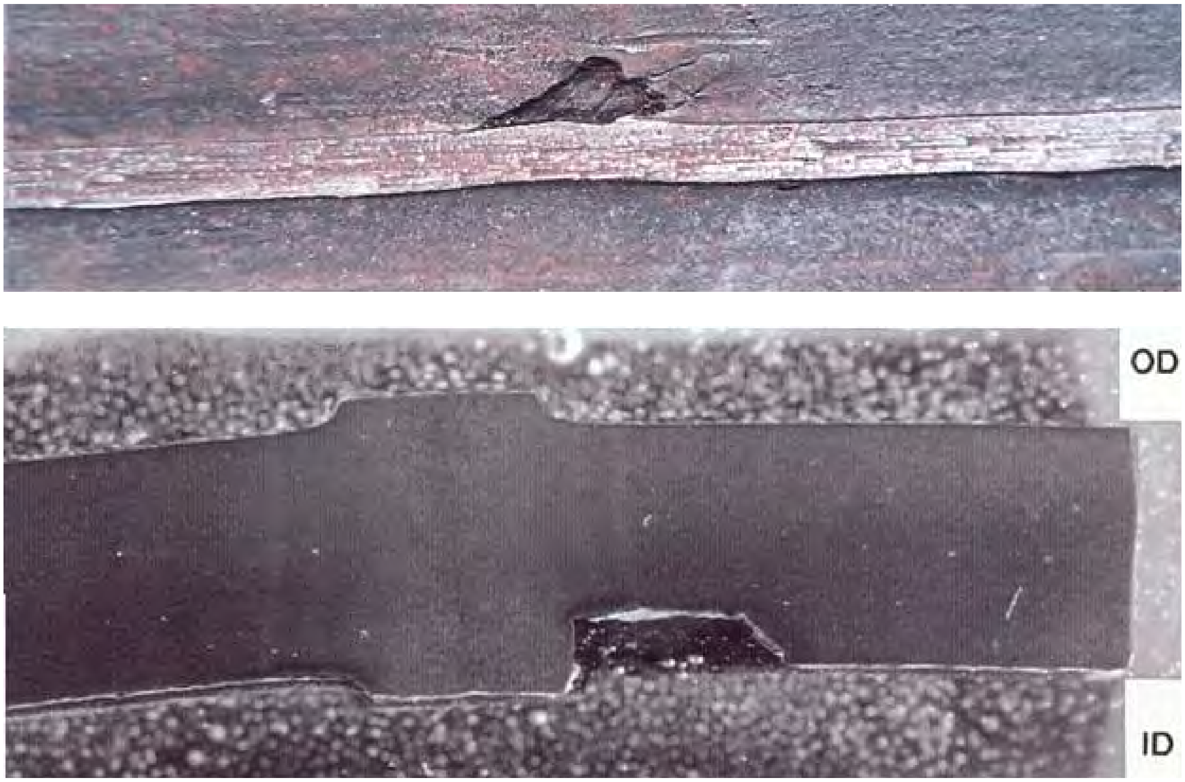
Photographs of Weld Seam ID Surface and Metallographic Section.

Catalog #:	52		
Report #:	5		
Defect #:	53		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	MT
Manufacturer:	AO Smith	NDE result(s):	9.2 inch (234 mm) linear indications + < 5% two small cracks 0.1"(1.6")0.3" (1.54 mm(41 mm)7.6mm)
Seam Type:	FW	Visual:	ID Over-trim (scrape)
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	N/A
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	N/A
t_{pipe}	0.307 inch (7.8 mm)	t_{weld}	0.383 inch (9.73 mm)
Failure:	Burst test: No failure at 2,300 psig (15.86 MPa) (142% of SMYS) + Yielding at 2,000 psig (13.79 MPa) (123% of SMYS)		



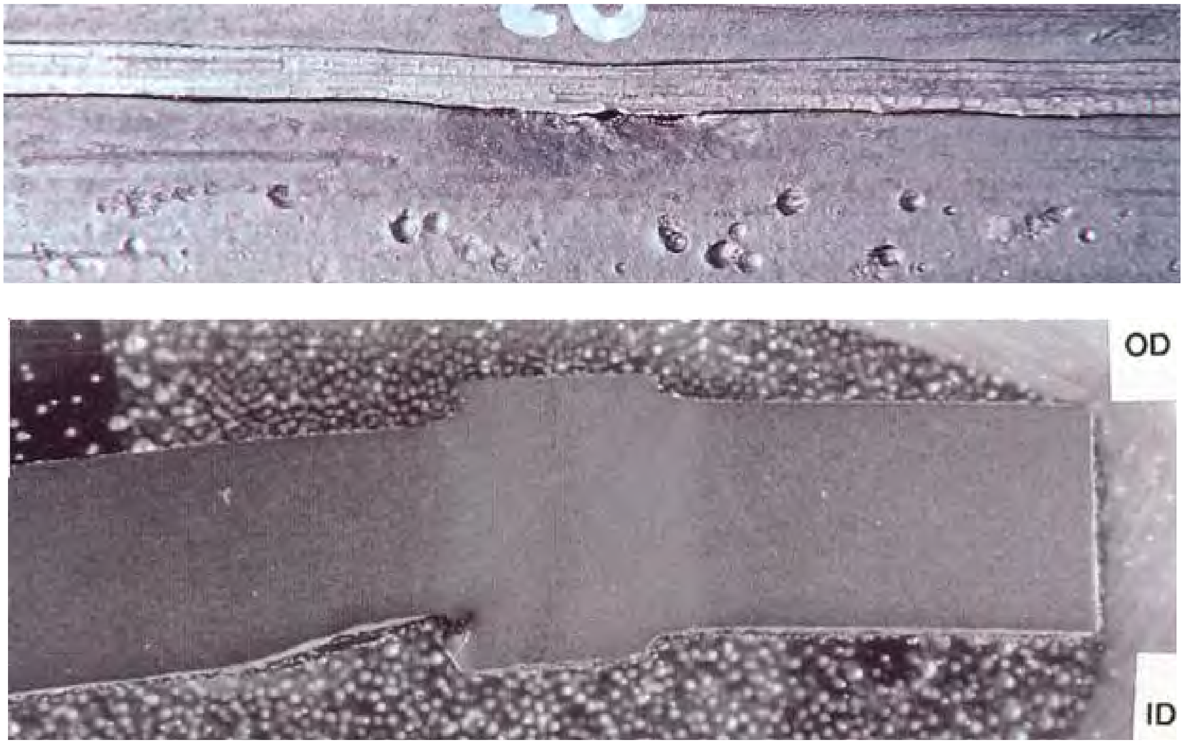
Photographs of Weld Seam ID Surface and Metallographic Section.

Catalog #:	53		
Report #:	5		
Defect #:	56		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	< 5%, 3.1 inch (79 mm) OD crack-like + 1.4 inch (36 mm) NF + 10%, 7.8 inch (198 mm) linear indications (over 9.5 inches (241 mm))
Seam Type:	FW	Visual:	ID Over-trim (scrape)
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	N/A
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	N/A
t_{pipe}	0.316 inch (8.03 mm)	t_{weld}	0.411 inch (10.4 mm)
Failure:	Burst test: No failure at 2,300 psig (15.86 MPa) (142% of SMYS)		



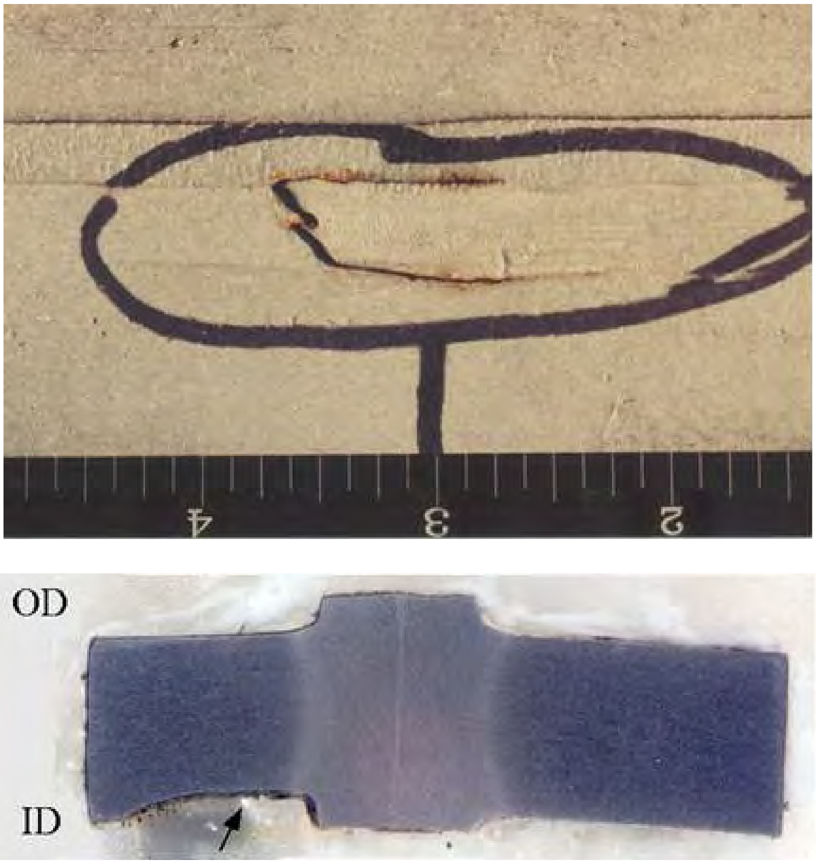
Photographs of Weld Seam ID Surface and Metallographic Section.

Catalog #:	46		
Report #:	5		
Defect #:	26		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	50%, 1.25 inch (31.7 mm) ID-connected
Seam Type:	FW	Visual:	Plate roll-in
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	40%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.167 inch (4.24 mm)
t_{pipe}	0.319 inch (8.1 mm)	t_{weld}	0.417 inch (10.6 mm)
Failure:	Burst test: No failure at 2,300 psig (15.86 MPa) (142% of SMYS) + Yielding at 2,175 psig (15.00 MPa) (134% of SMYS)		



Photographs of Weld Seam ID Surface and Metallographic Section.

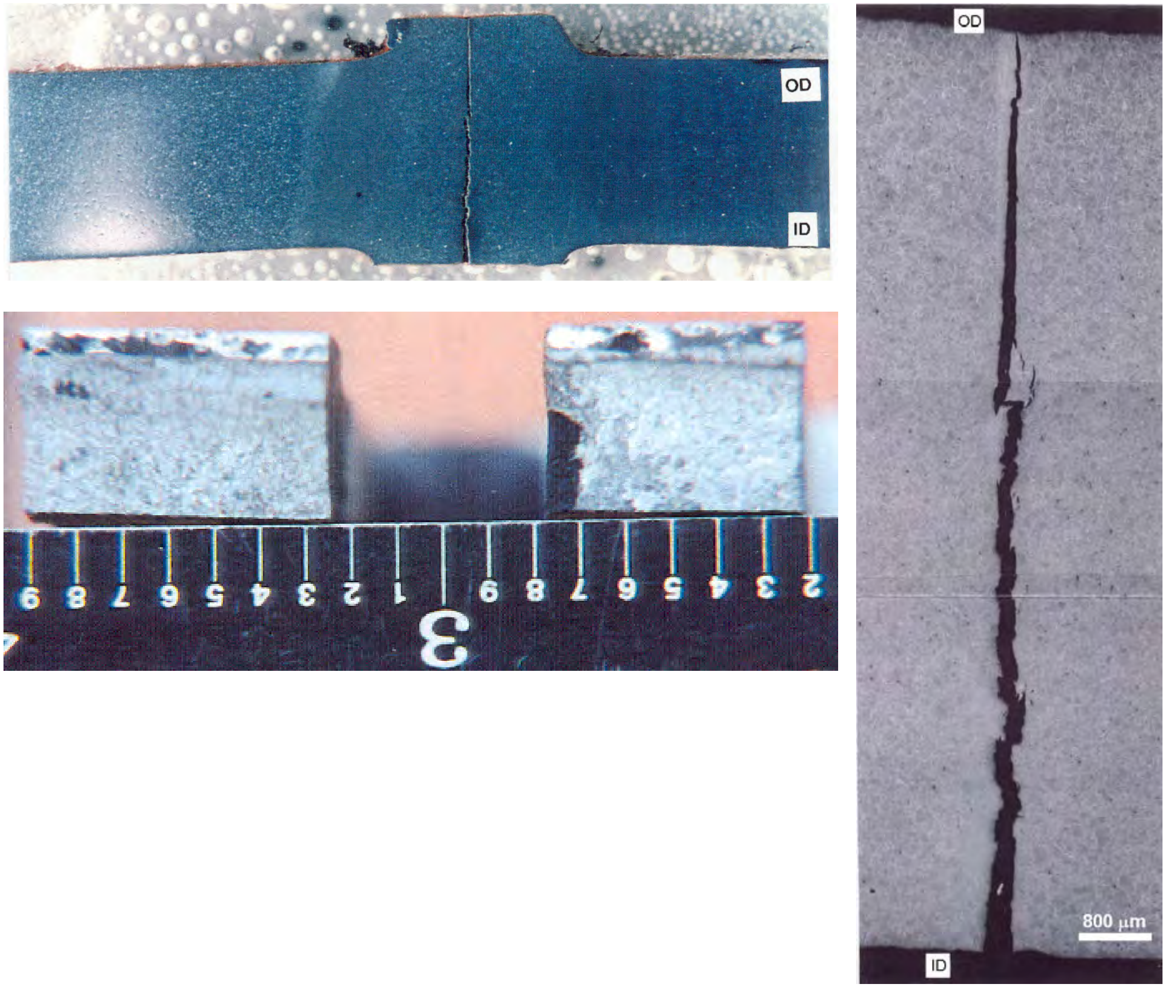
Catalog #:	43		
Report #:	5		
Defect #:	20		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	5%, 2.4 inch (61 mm) NF
Seam Type:	FW	Visual:	Plate roll-in
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	33%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.129 inch (3.28 mm)
t_{pipe}	0.312 inch (7.92 mm)	t_{weld}	0.394 inch (10.1 mm)
Failure:	Burst Test: No failure at 2,250 psig (51.51 MPa) (139% of SMYS) + Yielding at 2,200 psig (15.17 MPa) (136% of SMYS)		



Photographs of Weld Seam ID Surface and Metallographic Section.

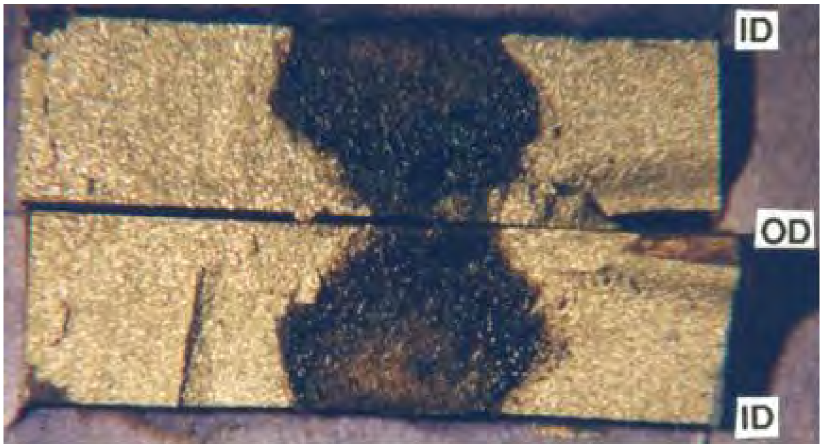
Catalog #:	70		
Report #:	7		
Defect #:	981		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	20% Mid-Wall Crack + < 10% ID Gouge
Seam Type:	FW	Visual:	ID Plate Edge Defect (Roll-in)
Grade:	X52	L	1.1 inch (27.9 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		

FW ***Lack of Fusion***



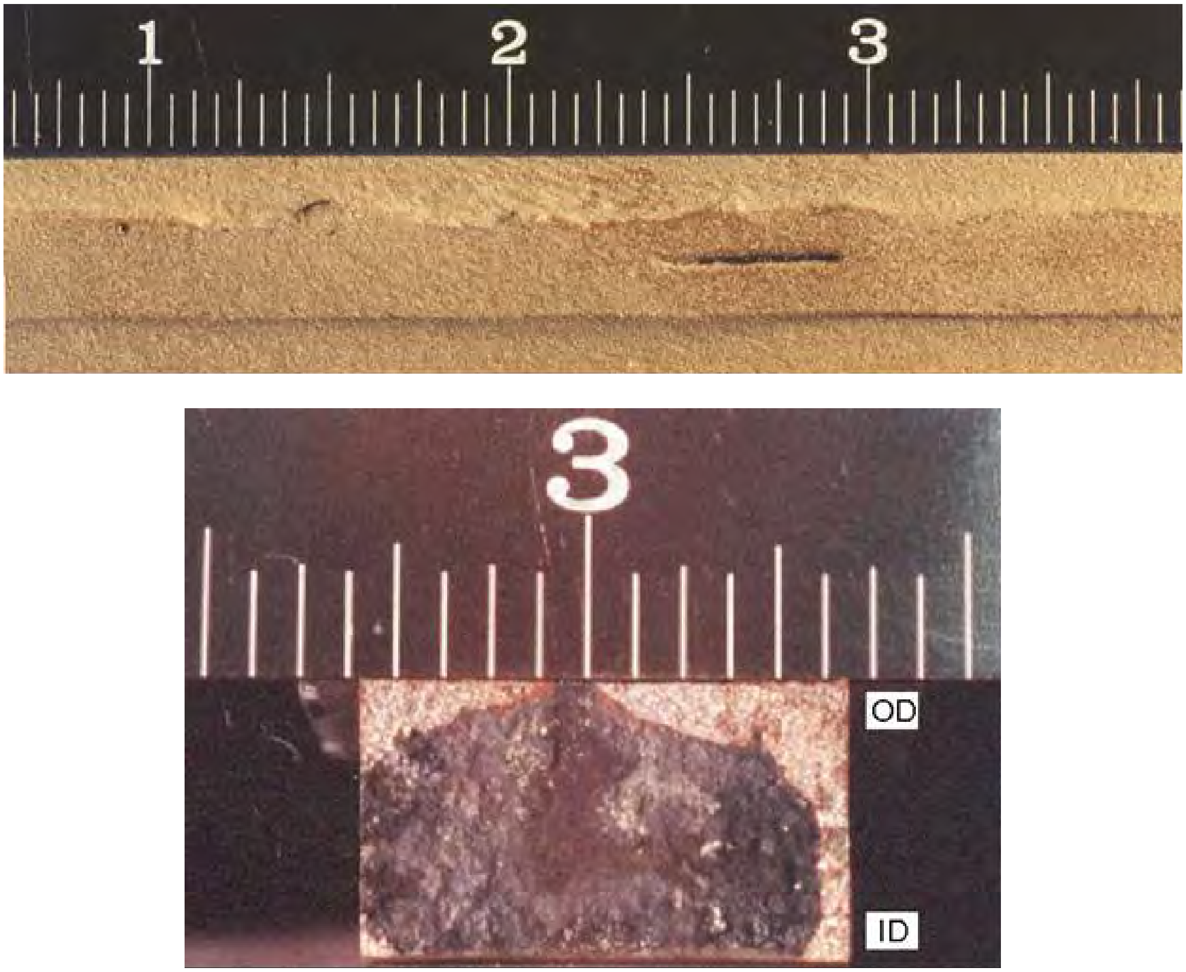
Photographs and Photomicrograph of Metallographic Section and Fracture Surfaces.

Catalog #:	34		
Report #:	5		
Defect #:	C5		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT & Fast UT
Manufacturer:	AO Smith	NDE result(s):	ID connected crack-like (UT) + NF with associated crack-like (Fast UT) + Narrow band of NF (Fast UT)
Seam Type:	FW	Visual:	Lack of Fusion
Grade:	X52	L	< 0.5 inch (12.7 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	100%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.422 inch (10.7 mm)
t_{pipe}	0.312 inch (7.92 mm)	t_{weld}	0.422 inch (10.7 mm)
Failure:	No leak		



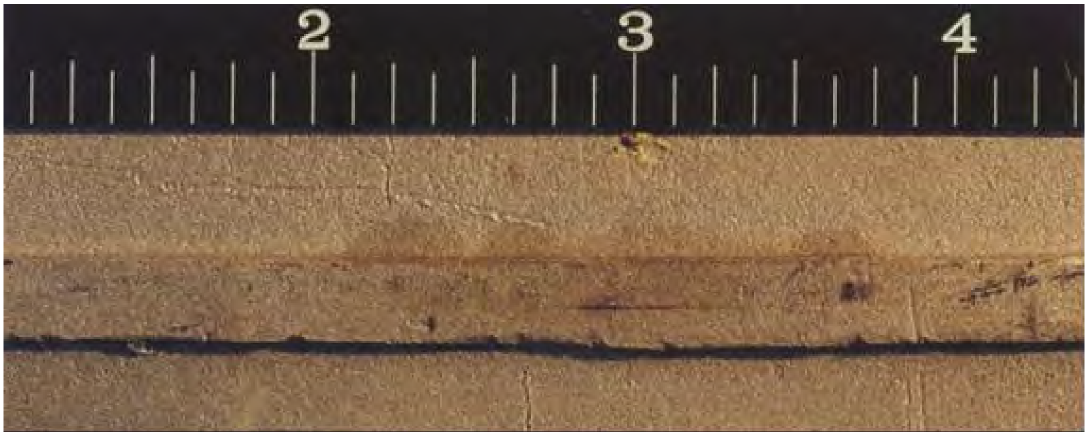
Photograph of Fracture Surface.

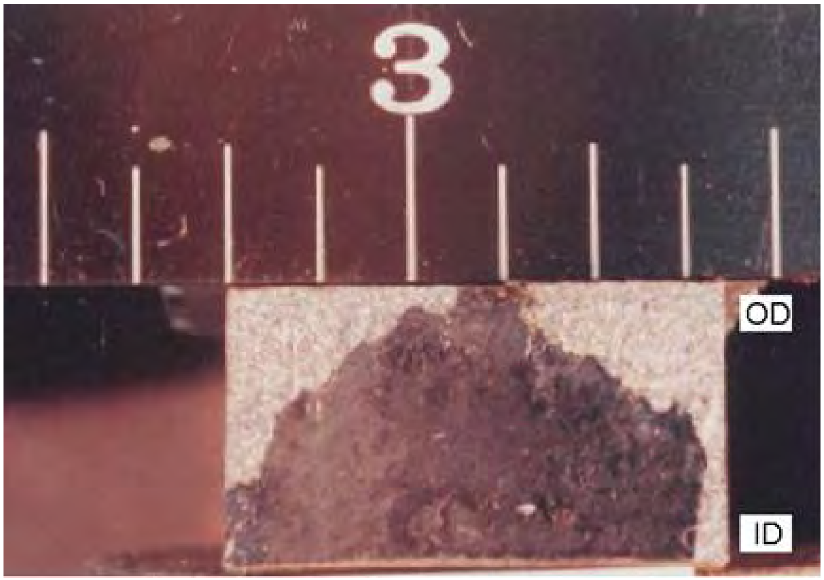
Catalog #:	66		
Report #:	7		
Defect #:	831		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	100% (Seeper)
Seam Type:	FW	Visual:	Lack of Fusion
Grade:	X52	L	0.55 inch (13.8 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	100%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.400 inch (10.2 mm)
t_{pipe}	Not Determined	t_{weld}	0.400 inch (10.2 mm)
Failure:	N/A		



Photographs of Weld Seam OD Surface and Fracture Surface.

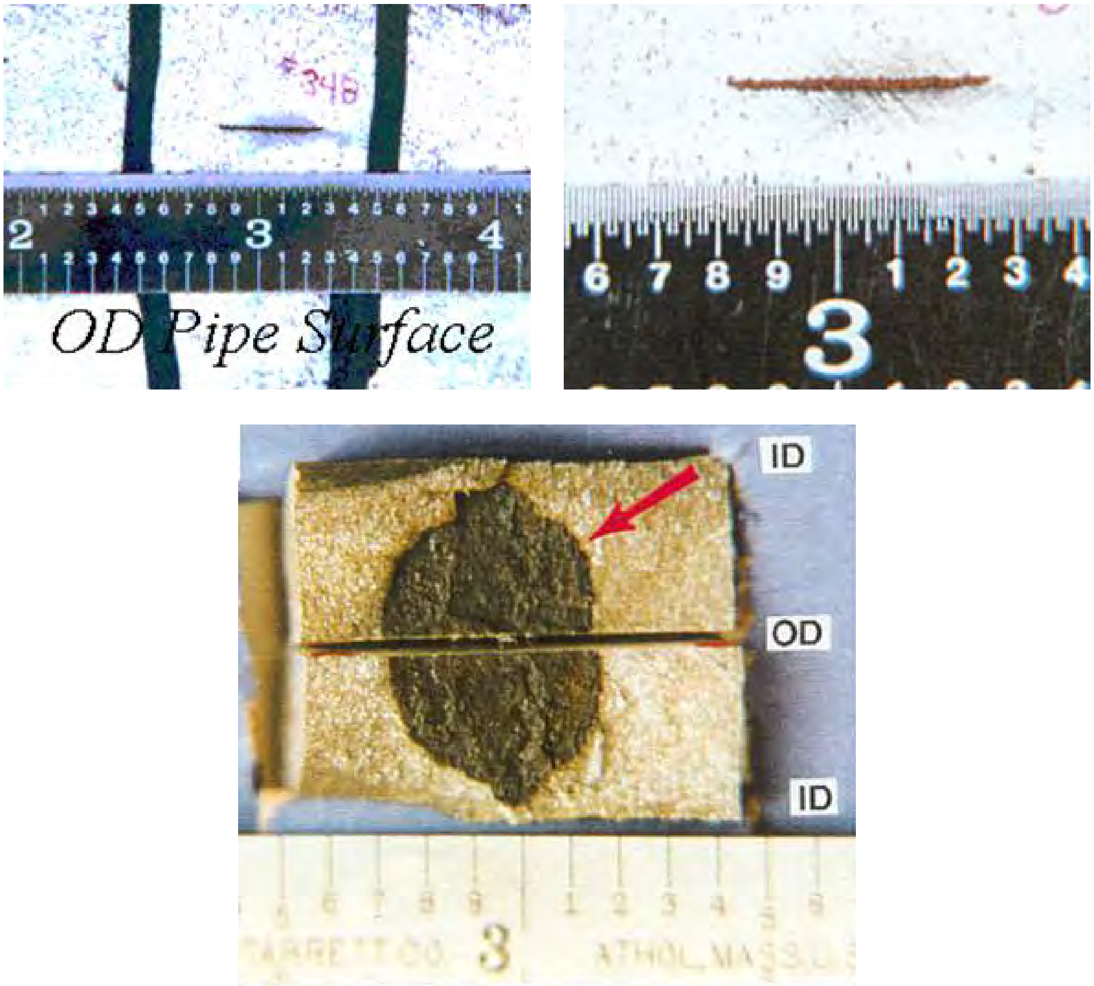
Catalog #:	80		
Report #:	7		
Defect #:	1573.1		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Visual
Manufacturer:	AO Smith	NDE result(s):	100% (Seeper)
Seam Type:	FW	Visual:	Lack of Fusion
Grade:	X52	L	0.63 inch (16 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	100%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		





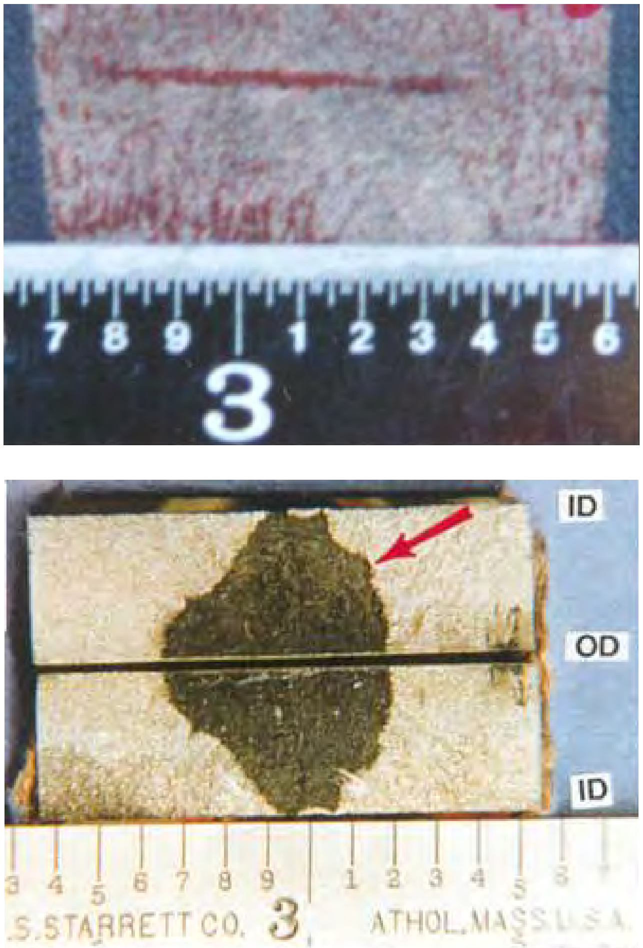
Photographs of Weld Seam OD Surface and Fracture Surface.

Catalog #:	81		
Report #:	7		
Defect #:	1577.1		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Visual
Manufacturer:	AO Smith	NDE result(s):	100% (Seeper)
Seam Type:	FW	Visual:	Lack of Fusion
Grade:	X52	L	0.66 inch (16.8 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	100%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	N/A		



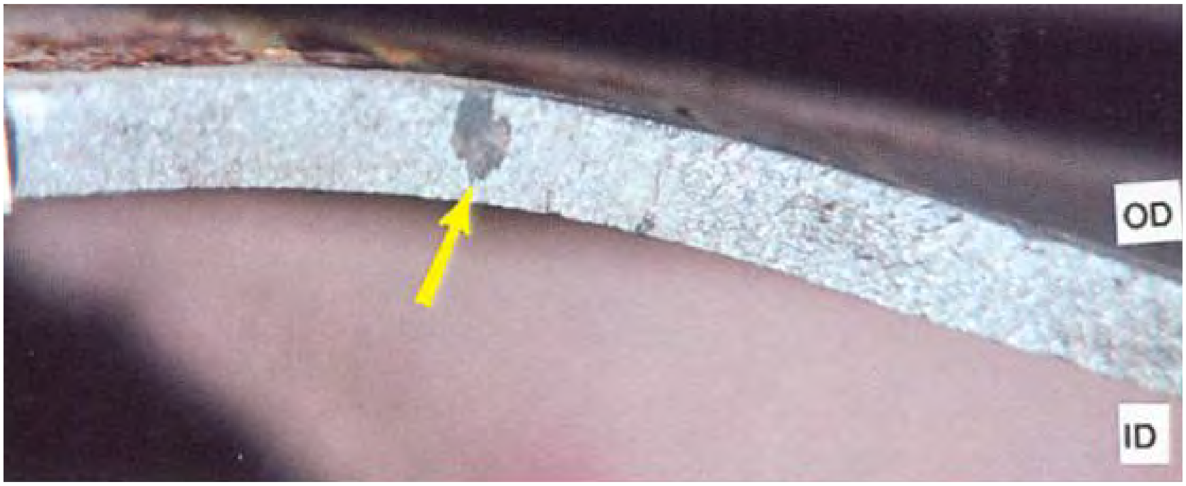
Photographs of Magnetic Particle Indication on Pipe OD Surface and of Fracture Surfaces.

Catalog #:	19		
Report #:	2		
Defect #:	348		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	MPI / UT
Manufacturer:	AO Smith	NDE result(s):	Through-wall, 1 inch (25.4 mm) long non-fusion / crack
Seam Type:	FW	Visual:	OD Lack of Fusion
Grade:	X52	L	0.42 inch (10.7 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	91%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.320 inch (8.13 mm)
t_{pipe}	0.312 inch (7.92 mm)	t_{weld}	0.350 inch (8.89 mm)
Failure:	No burst test done		



Photograph of Magnetic Particle Indication on Pipe OD Surface and of Fracture Surfaces.

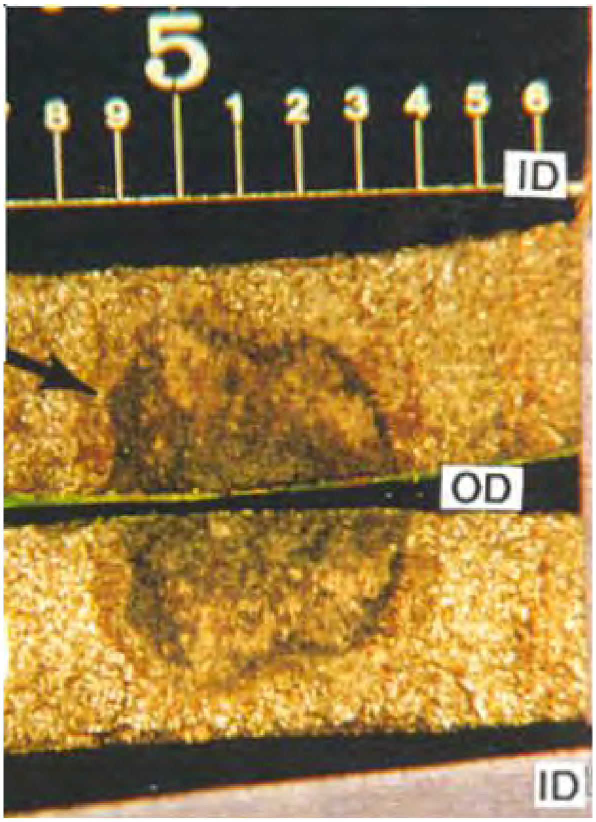
Catalog #:	20		
Report #:	2		
Defect #:	356		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	MPI / UT
Manufacturer:	AO Smith	NDE result(s):	1 inch long ID crack like
Seam Type:	FW	Visual:	OD Lack of Fusion
Grade:	X52	L	0.53 inch (13.5 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	91%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.320 inch (8.13 mm)
t_{pipe}	0.312 inch (7.92 mm)	t_{weld}	0.350 inch (8.89 mm)
Failure:	No burst test done		



Photograph of Fracture Surface.

Catalog #: 42
Report #: 5
Defect #: 16

Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	3 NF indications: 10%, 1.5 inch (38 mm) + 10%, 2.0 inch (51 mm) + 30%, 0.75 inch
Seam Type:	FW	Visual:	OD Lack of Fusion
Grade:	X52	L	< 0.25 inch (6.3 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	84%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.312 inch (7.92 mm)
t_{pipe}	0.308 inch (7.82 mm)	t_{weld}	0.372 inch (9.45 mm)
Failure:	Burst Test Failure at 2,125 psig (14.65 MPa) (131% of SMYS)		



Photograph of Fracture Surfaces.

Catalog #:	18		
Report #:	2		
Defect #:	220		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	AO Smith	NDE result(s):	>80%, 1 inch (25.4 mm) long crack like
Seam Type:	FW	Visual:	OD Lack of Fusion
Grade:	X52	L	0.52 inch (13.2 mm)
$D_{nominal}$	20 inch (508 mm)	Width:	N/A
$t_{nominal}$	0.312 inch (7.92 mm)	depth/t_{weld}	75%
t_{pipe}	0.312 inch (7.92 mm)	depth:	0.300 inch (7.62 mm)
Failure:	Burst test rupture at 2,225 psig (15.34 MPa) (137% of SMYS)	t_{weld}	0.396 inch (10.1 mm)
MAOP:	400 psig (2.76 MPa)		
Coating:	Coal tar + paper wrap		
CP:	Yes		

Photographs of Fracture Surface.

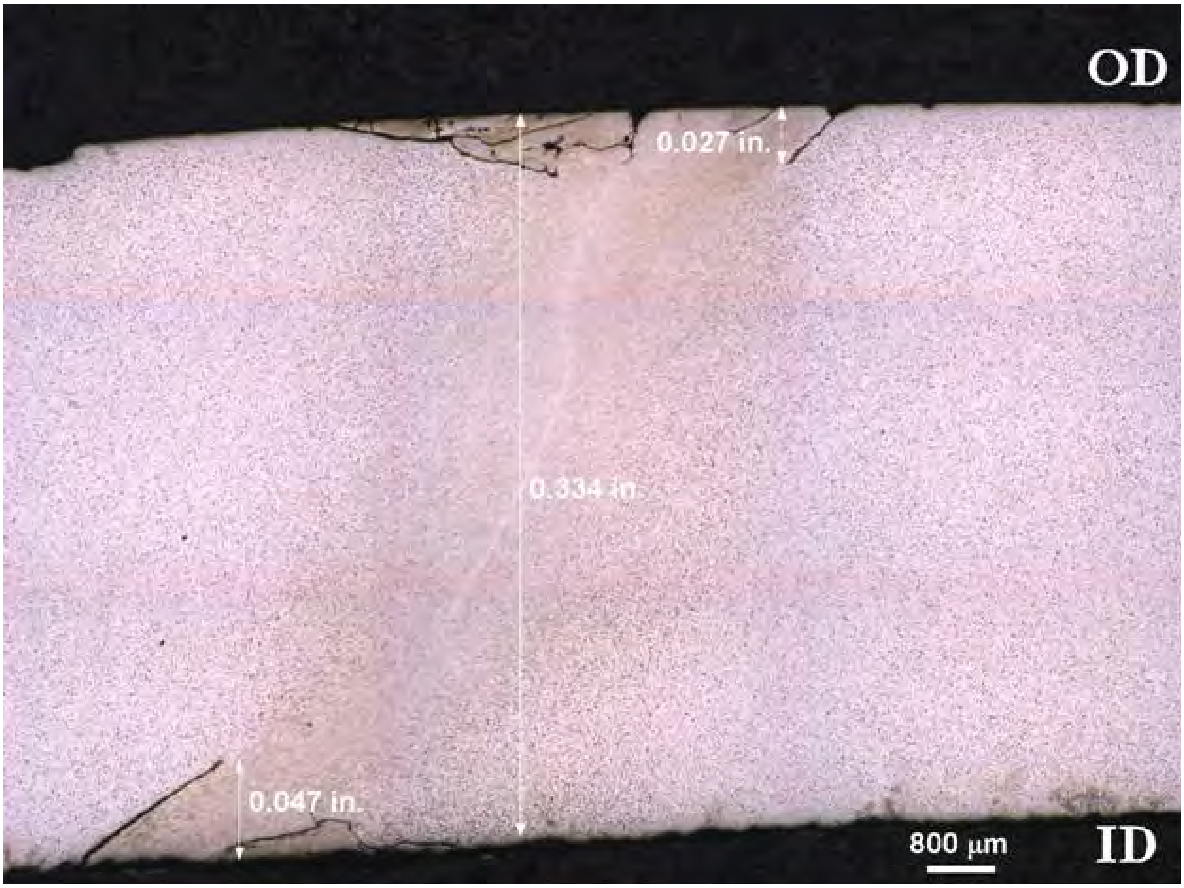
Catalog #:	54		
Report #:	6		
Defect #:	685		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	70% (0.300 inch (7.62 mm)) ID Crack + 30% (0.128 inch (3.25 mm)) OD Crack
Seam Type:	FW	Visual:	ID & Hook Cracks + Lack of Fusion
Grade:	X52	L	8.5 inch (216 mm) (ID Crack) + 4.0 inch (102 mm) (OD Crack)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	44% (22% ID + 22% OD)
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.094 inch (23.9 mm) (ID Crack) + 0.094 inch (23.9 mm) (OD Crack)
t_{pipe}	Not determined	t_{weld}	0.428 inch (10.9 mm)
Failure:	Burst test failure at 2,050 psig (14.13 MPa) (126% of SMYS)		

Photograph and Photomicrograph of Metallographic Section.

Catalog #:	74		
Report #:	7		
Defect #:	1097		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	30% OD Crack-like
Seam Type:	FW	Visual:	OD Outbent Fiber
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	33%
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	0.145 inch (3.68 mm)
t_{pipe}	Not determined	t_{weld}	0.433 inch (11 mm)
Failure:	N/A		

Photograph of Metallographic Section.

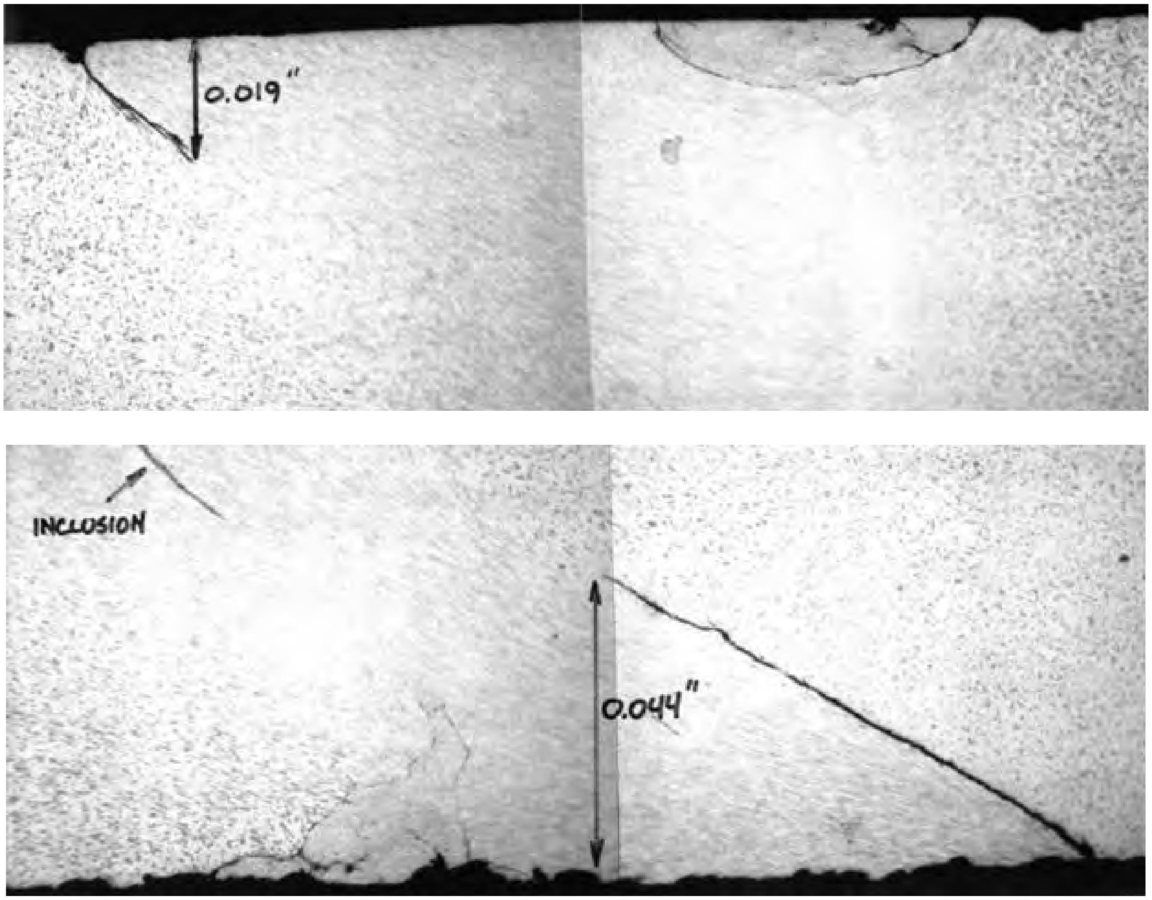
Catalog #:	75		
Report #:	7		
Defect #:	1105		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Fast UT
Manufacturer:	AO Smith	NDE result(s):	<10% OD Crack-like
Seam Type:	FW	Visual:	No Anomaly Revealed
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	N/A
$t_{nominal}$	0.312 inch (7.92 mm)	depth:	N/A
t_{pipe}	0.336 inch (8.53 mm)	t_{weld}	0.468 inch (11.9 mm)
Failure:	N/A		



Photomicrograph of Metallographic Section.

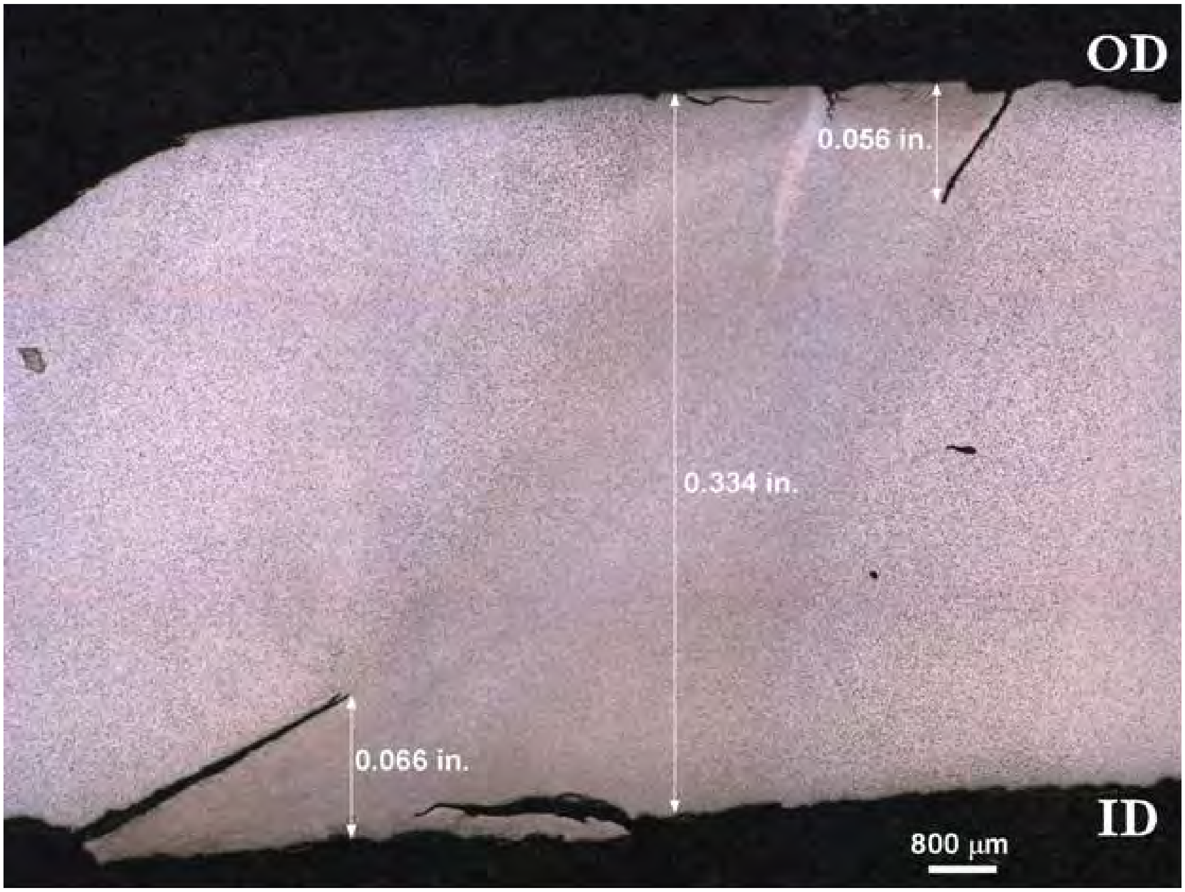
Catalog #:	3		
Report #:	8		
Defect #:	TS95		
Pipe		**Defect**	
Vintage:	1932	NDE technique(s):	MPI on OD surface
Manufacturer:	Republic Steel	NDE result(s):	Crack visible
Seam Type:	Lap Weld	Visual:	OD & ID Lack of Fusion
Grade:	A25	L	N/A
$D_{nominal}$	12.75 inch (324 mm)	Width:	N/A
$t_{nominal}$	0.250 inch (6.35 mm)	depth/t_{weld}	22.2% (LOF combined)
t_{pipe}	0.259 inch (6.58 mm)	depth:	0.027 inch (0.69 mm) (OD) + 0.047 inch (1.19 mm) (ID)
Failure:	No failure history	t_{weld}	0.334 inch (8.48 mm)
MAOP:	400 psig (2.76 MPa)		
Coating:	Coal tar + paper wrap		
CP:	Yes		

Lap Weld ***OD, Mid-Wall and ID Lack of Fusion***



Photomicrographs of Lack of Fusion at OD and ID Surfaces and Near Mid-Wall.

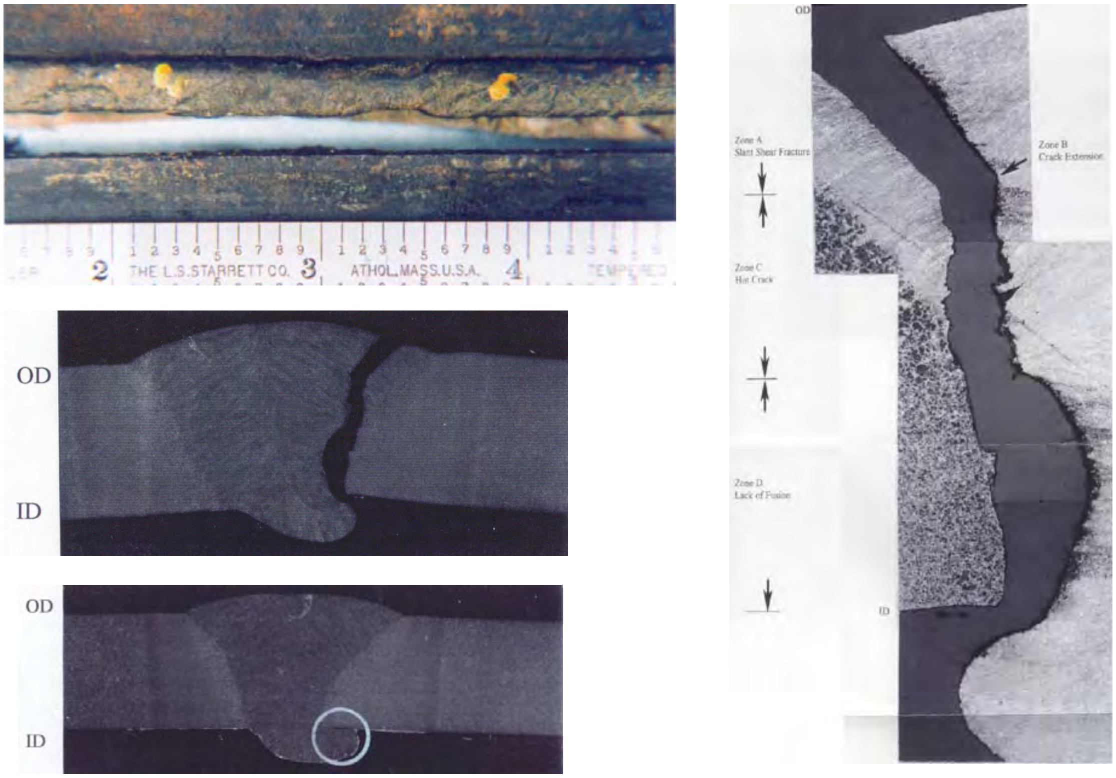
Catalog #:	1		
Report #:	8		
Defect #:	Not Specified		
Pipe		**Defect**	
Vintage:	1932	NDE technique(s):	MPI on OD surface
Manufacturer:	Republic Steel	NDE result(s):	Crack visible
Seam Type:	Lap Weld	Visual:	OD, Mid-wall & ID Lack of Fusion
Grade:	A25	L	N/A
$D_{nominal}$	12.75 inch (324 mm)	Width:	N/A
$t_{nominal}$	0.250 inch (6.35 mm)	depth/t_{weld}	30.8% (all LOF combined)
t_{pipe}	0.259 inch (6.58 mm)	depth:	OD: 0.019 inch (0.48 mm) + Mid-wall: 0.017 inch (0.43 mm) + ID: 0.044 inch (1.12 mm)
Failure:	No failure history	t_{weld}	0.259 inch (6.58 mm)
MAOP:	400 psig (2.76 MPa)		
Coating:	Coal tar + paper wrap		
CP:	Yes		



Photomicrograph of Metallographic Section.

Catalog #: 2
Report #: 8
Defect #: L1026

Pipe		**Defect**	
Vintage:	1932	NDE technique(s):	MPI on OD surface
Manufacturer:	Republic Steel	NDE result(s):	Crack visible
Seam Type:	Lap Weld	Visual:	OD, Mid-wall & ID Lack of Fusion
Grade:	A25	L	N/A
$D_{nominal}$	12.75 inch (324 mm)	Width:	N/A
$t_{nominal}$	0.250 inch (6.35 mm)	depth/t_{weld}	36.5%
t_{pipe}	0.259 inch (6.58 mm)	depth:	0.056 inch (1.42 mm) (OD) + 0.066 inch (1.68 mm) (ID)
Failure:	No failure history	t_{weld}	0.334 inch (8.48 mm)
MAOP:	400 psig (2.76 MPa)		
Coating:	Coal tar + paper wrap		
CP:	Yes		

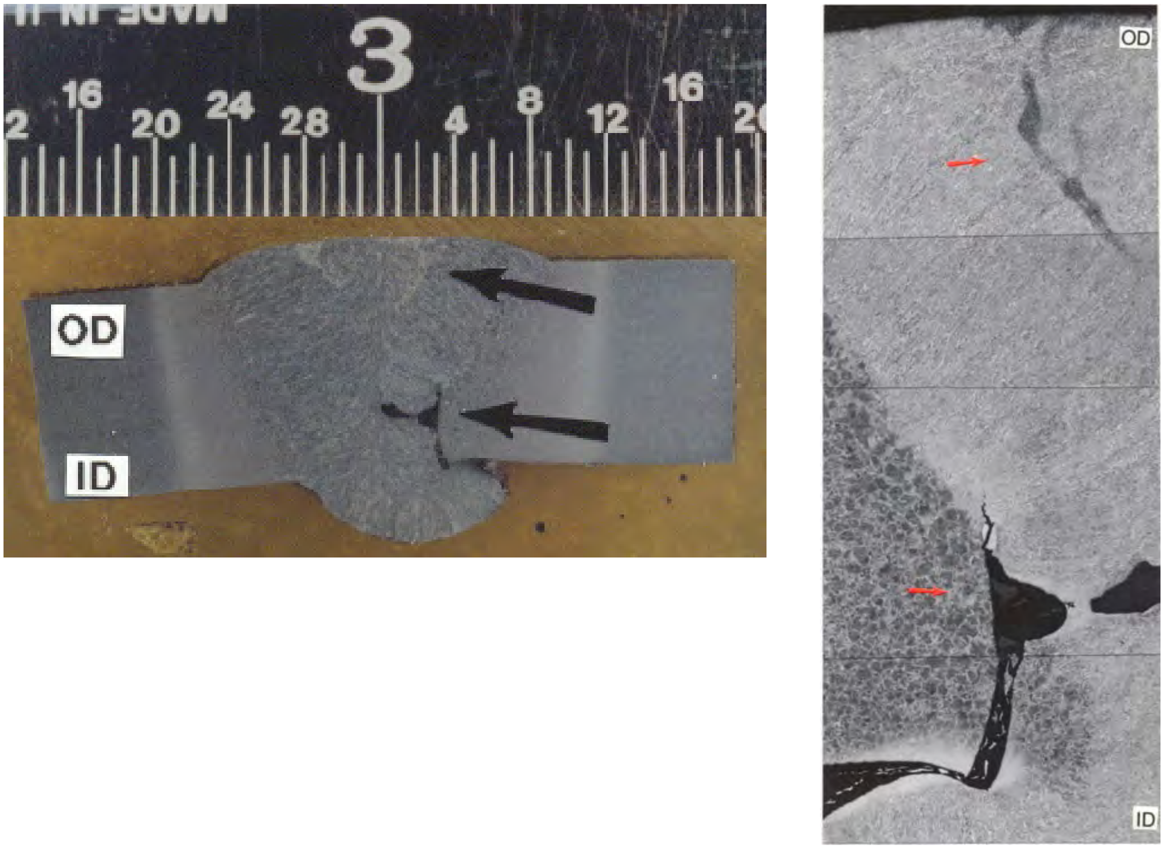


Photographs and Photomicrograph of Pipe Seam OD Surface and Metallographic Sections.

Catalog #: 85
Report #: 9
Defect #: 4-1

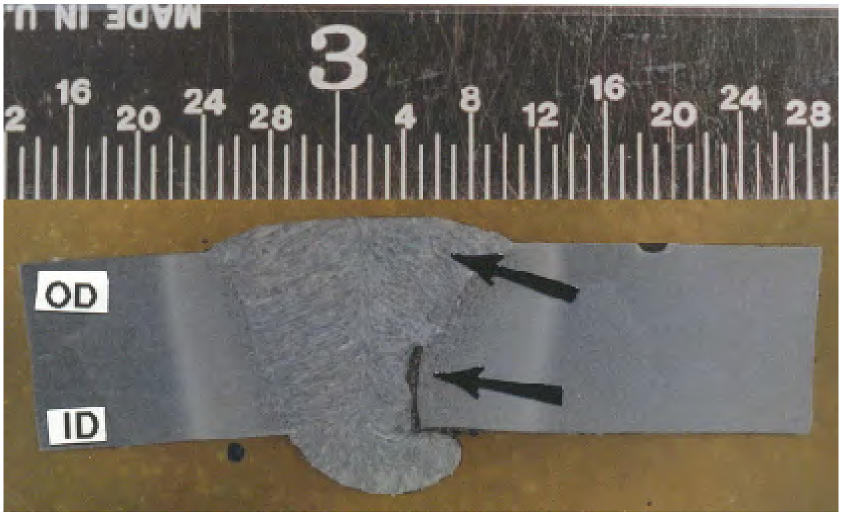
Pipe		**Defect**	
Vintage:	circa 1952	NDE technique(s):	N/A
Manufacturer:	Kaiser	NDE result(s):	N/A
Seam Type:	SSAW	Visual:	Weld Penetration + Lack of Fusion + Hot Crack
Grade:	API 5L X52	L	5 ft-9 inch (1.8 m) long Seam split
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	50% (LOF) + 30% (Hot crack)
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	0.177 inch (4.5 mm) (LOF) + 0.106 inch (2.69 mm) (Hot crack)
t_{pipe}	0.354 inch (8.99 mm)	t_{weld}	0.354 inch (8.99 mm) (At crack location)
Failure:	Hydrotest Rupture at 1,520 psig (10.48 MPa) (85% of SMYS)		

SSAW ***ID Lack of Fusion + ID Crack + OD Slag Inclusion***



Photograph and Photomicrograph of Metallographic Section.

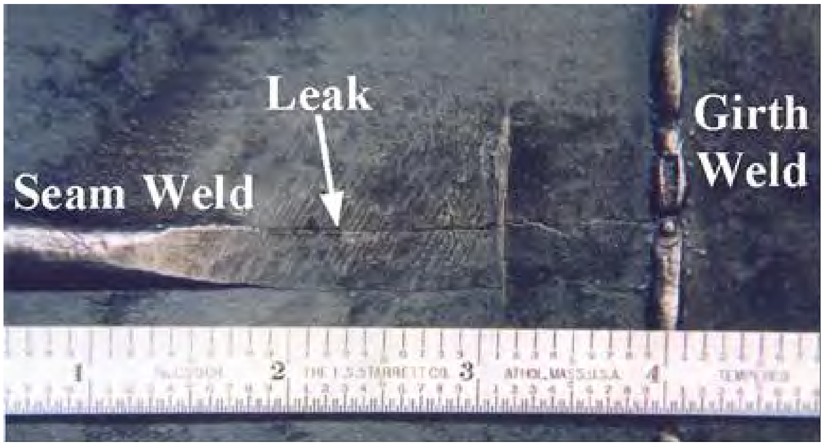
Catalog #:	27		
Report #:	3		
Defect #:	11A		
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Shearwave UT
Manufacturer:	Kaiser	NDE result(s):	1.5 inch (38 mm) Linear Inclusion at 0.235 to 0.291 inch depth
Seam Type:	SSAW	Visual:	ID Lack of Fusion + ID Crack + OD Slag Inclusion
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	21% ID Lack of Fusion + 6% ID Crack + 24% OD Slag Inclusion
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	0.106 inch (2.69 mm) ID Lack of Fusion + 0.030 inch (0.76 mm) ID Crack + 0.124 inch (3.15 mm) OD Slag Inclusion
t_{pipe}	0.344 inch (8.74 mm)	t_{weld}	0.516 inch (13.1 mm)
Failure:	None		

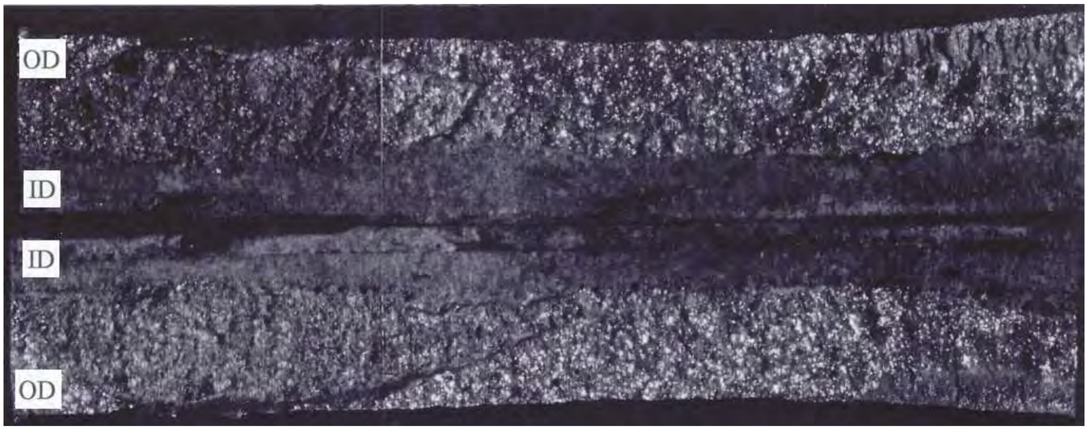


Photograph and Photomicrograph of Metallographic Section.

Catalog #: 28
Report #: 3
Defect #: 11C

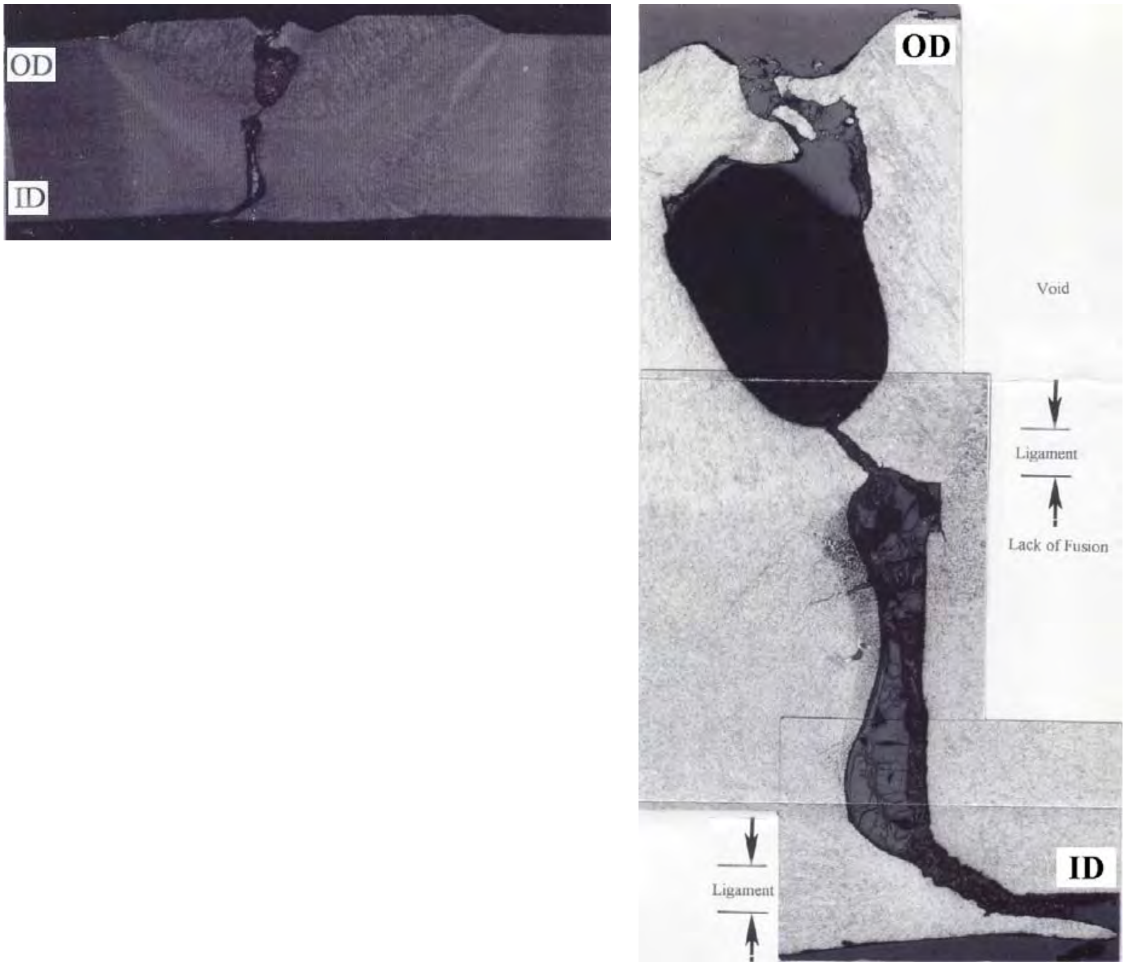
Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	Shearwave UT
Manufacturer:	Kaiser	NDE result(s):	5 inch Linear inclusion at 0.290 (7.37 mm) to 0.308 inch (7.82 mm) depth + suspected ID LOF
Seam Type:	SSAW	Visual:	ID Lack of Fusion + OD Slag Inclusion
Grade:	X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	29% ID Lack of Fusion + 29% OD Slag Inclusion
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	0.154 inch (3.91 mm) ID Lack of Fusion + 0.154 inch (3.91 mm) OD Slag Inclusion
t_{pipe}	0.344 inch (8.74 mm)	t_{weld}	0.525 inch (13.3 mm)
Failure:	None		





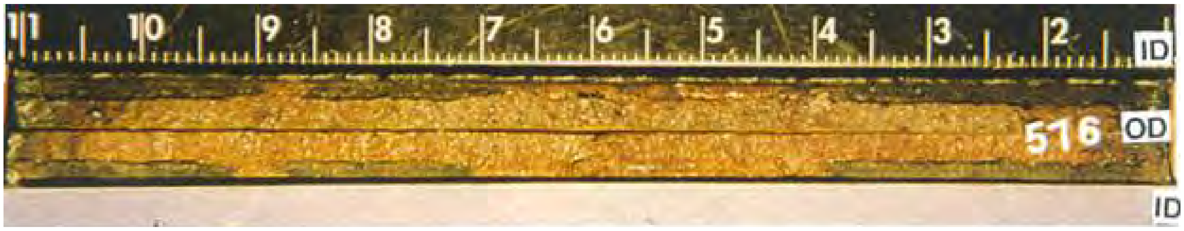
Photographs of Pipe Seam ID Surface and Fracture Surfaces.

Catalog #:	88		
Report #:	9		
Defect #:	4-3		
Pipe		**Defect**	
Vintage:	circa 1952	NDE technique(s):	N/A
Manufacturer:	Kaiser	NDE result(s):	N/A
Seam Type:	SSAW	Visual:	Through-wall flaw + ID seam ground flush + Lack of fusion
Grade:	API 5L X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	100% (Leak) + 30% (LOF)
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	Hydrotest Leak at 1,517 psig (10.46 MPa) (85% of SMYS)		



Photograph and Photomicrograph of Metallographic Section.

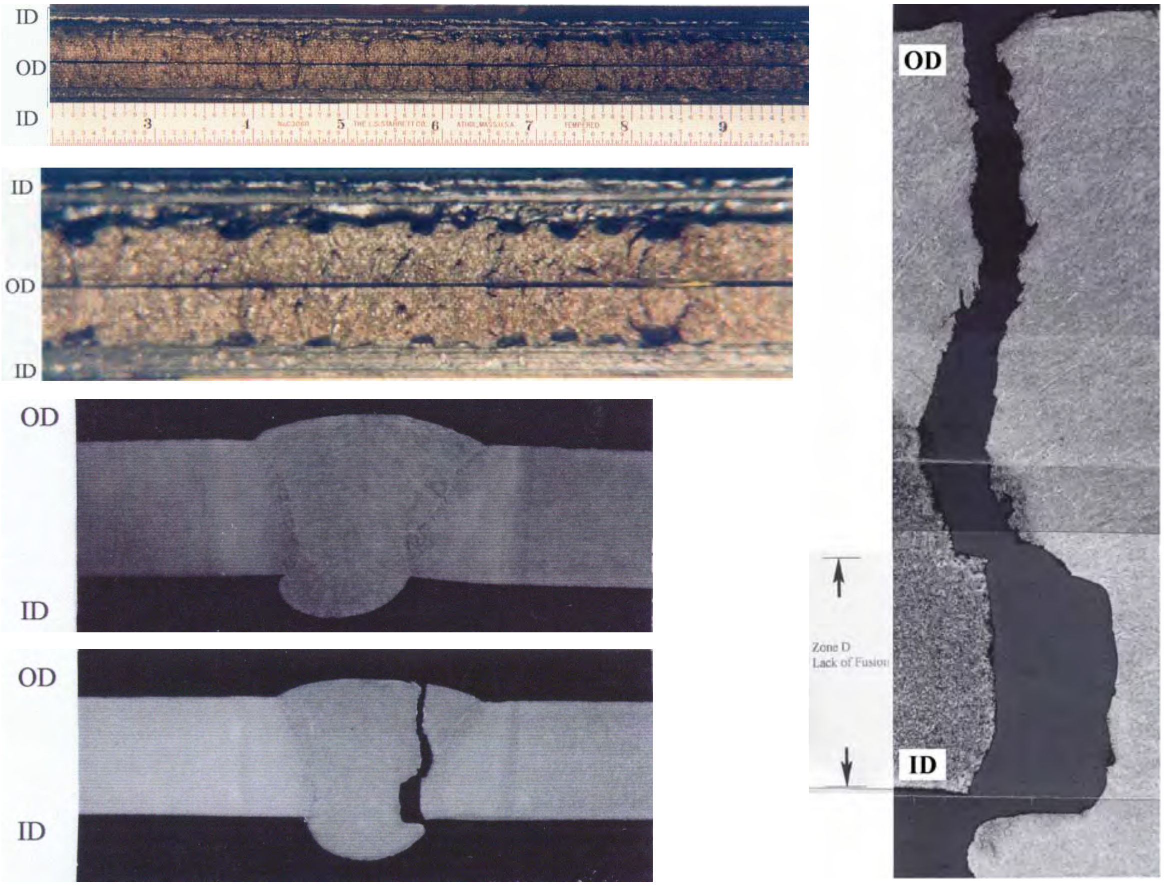
Catalog #:	89		
Report #:	9		
Defect #:	5-4		
Pipe		**Defect**	
Vintage:	circa 1952	NDE technique(s):	N/A
Manufacturer:	Kaiser	NDE result(s):	N/A
Seam Type:	SSAW	Visual:	Lack of fusion + Void
Grade:	API 5L X52	L	N/A
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	85%
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	45% (LOF) + 40% (Void)
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	Hydrotest Leak at 1,559 psig (10.75 MPa) (87% of SMYS)		



Photograph of Fracture Surfaces.

Catalog #: 25
Report #: 2
Defect #: 576

Pipe		**Defect**	
Vintage:	circa 1950	NDE technique(s):	UT
Manufacturer:	Kaiser	NDE result(s):	20%, 9.4 feet long (2.9 m) ID crack like
Seam Type:	SSAW	Visual:	Intermittent ID Lack of Fusion
Grade:	X52	L	Entire joint, in photo: 2.0, 1.75 & 2.9 inch (51, 44.5 & 74 mm)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	45%
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	0.150 inch (38 mm)
t_{pipe}	0.342 inch (8.69 mm)	t_{weld}	N/A
Failure:	Burst test rupture at 2,075 psig (14.31 MPa) (116% of SMYS)		



Photographs and Photomicrograph of Fracture Surfaces and Metallographic Section.

Catalog #:	86		
Report #:	9		
Defect #:	5-1		
Pipe		**Defect**	
Vintage:	circa 1952	NDE technique(s):	N/A
Manufacturer:	Kaiser	NDE result(s):	N/A
Seam Type:	SSAW	Visual:	Weld Penetration + Lack of Fusion
Grade:	API 5L X52	L	15 ft-4 inch (4.7 m) long Seam split
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	44% (LOF)
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	0.150 inch (38 mm) (LOF)
t_{pipe}	Not Determined	t_{weld}	0.341 inch (8.66 mm) (At crack location)
Failure:	Hydrotest Rupture at 1,483 psig (10.22 MPa) (83% of SMYS)		

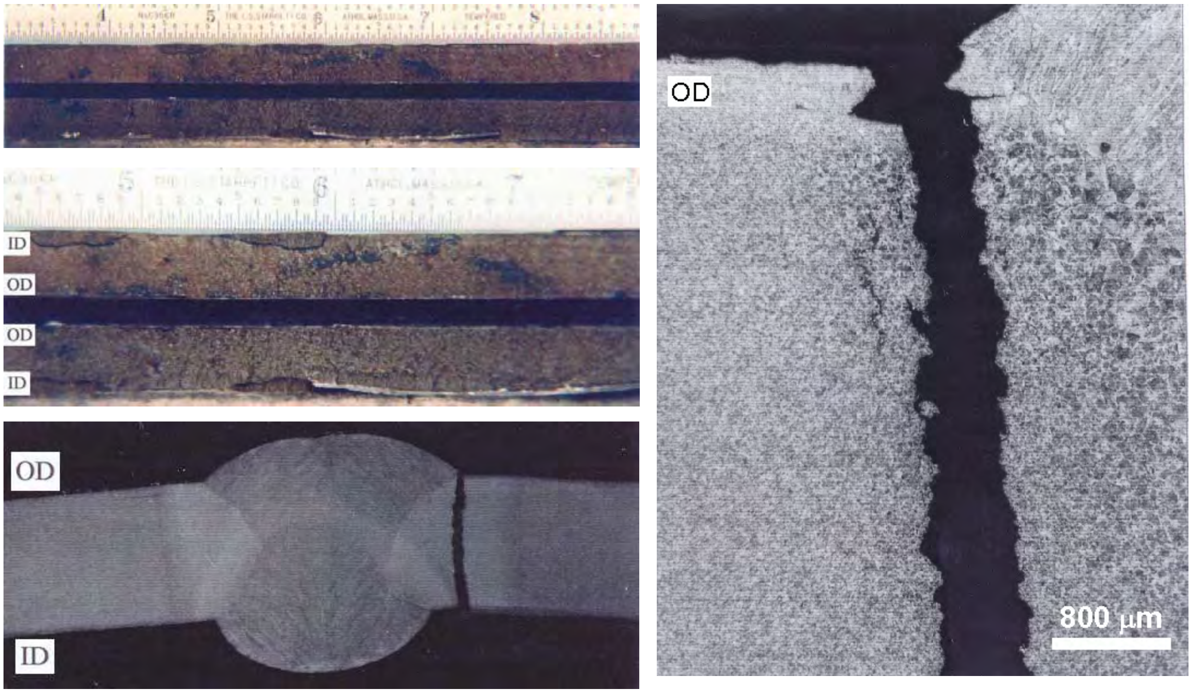
Photograph of Pipe Outside Surface.

Catalog #:	90		
Report #:	9		
Defect #:	5-2		
Pipe		**Defect**	
Vintage:	circa 1952	NDE technique(s):	N/A
Manufacturer:	Kaiser	NDE result(s):	N/A
Seam Type:	SSAW	Visual:	Seam Split
Grade:	API 5L X52	L	19 ft-5 inch (5.9 m)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	Hydrotest Leak at 1,570 psig (10.82 MPa) (88% of SMYS)		

Photographs of Pipe Outside Surface.

Catalog #:	91		
Report #:	9		
Defect #:	5-5		
Pipe		**Defect**	
Vintage:	circa 1952	NDE technique(s):	N/A
Manufacturer:	Kaiser	NDE result(s):	N/A
Seam Type:	SSAW	Visual:	Seam split
Grade:	API 5L X52	L	12 ft-8 inch (3.9 m)
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	Not Determined
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	Hydrotest Leak at 1,615 psig (11.14 MPa) (90% of SMYS)		

DSAW *Initiation at Toe of OD Weld Bead + Small OD Cracks Parallel to Main Fracture*



Photographs and Photomicrograph of Fracture Surfaces and Metallographic Section.

Catalog #:	87		
Report #:	9		
Defect #:	5-3		
Pipe		**Defect**	
Vintage:	circa 1952	NDE technique(s):	N/A
Manufacturer:	Kaiser	NDE result(s):	N/A
Seam Type:	DSAW	Visual:	Initiation at toe of OD weld bead + Small OD cracks parallel to main fracture
Grade:	API 5L X52	L	39 ft-3 inch (12 m) long Seam split
$D_{nominal}$	20 inch (508 mm)	depth/t_{weld}	100%
$t_{nominal}$	0.344 inch (8.74 mm)	depth:	Not Determined
t_{pipe}	Not Determined	t_{weld}	Not Determined
Failure:	Hydrotest Rupture at 1,538 psig (10.60 MPa) (86% of SMYS)		

FINAL REPORT
R3017-01R

UNDER JOINT FUNDING FROM DOT/OPS AND PRCI
DOT/OPS PROJECT DTRS56-03-T-0002

EARLY GENERATION SEAM WELDS

Prepared For

PIPELINE RESEARCH COUNCIL INTERNATIONAL, INC.
DEPARTMENT OF TRANSPORTATION/OFFICE OF PIPELINE SAFETY

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EXECUTIVE SUMMARY

Mechanical property data for early-generation seam welds are not commonly available, and when limited data are found, they often do not contain information needed to conduct structural integrity evaluations. The same is true for typical anomalies in early seams. Pipeline companies that operate older systems need these data to reliably assess integrity.

The U. S. Department of Transportation Office of Pipeline Safety and the PRCI (formerly Pipeline Research Council International) recognized the need for reliable data on early generation seam welds and contracted with CC Technologies to assemble a comprehensive database of material properties and seam-weld anomalies and to develop guidelines for assessing the anomalies. Three tasks were conducted:

- Task 1 compiled and evaluated the unique properties of early generation pipeline weld seams,
- Task 2 compiled a catalog of anomaly types, and
- Task 3 developed guidelines and recommendations for evaluating seam-weld anomalies and their severities to determine whether pipeline integrity has been compromised.

The first task was funded by the PRCI, while the second and third tasks were funded by the Office of Pipeline Safety. Work on the first task is continuing under separate PRCI sponsorship. This follow-on work will be reported at a later date.

This report summarizes the results of the project, which focus primarily on anomalies and material properties of lap-welded pipe, low frequency ERW seam pipe, and flash weld pipe. Limited data were available and are reported for early single submerged arc welds, double submerged arc welds, and high-frequency ERW.

The main body of this report summarizes the development of the material-property database and summarizes the types of seam-weld anomalies identified in this program. It also provides guidance on analyzing seam-weld anomalies and makes recommendations for future efforts.

Appendix A provides information on the material properties of early generation seam welds. While not extensive, this appendix provides a basis for estimating material properties and their variations. Appendix B illustrates many of the anomalies present in early generation seam welds. This appendix can be used by subject matter experts to assess the validity of various inspection techniques and as an aid in selecting and using integrity analyses. Additional work is needed to characterize typical inspection signals as a function of anomaly type and dimensions.

The data reported here do not represent the full range of pipe manufactured and in use today. Continuing efforts are needed to obtain more complete material property and seam weld anomaly data for use by pipeline companies in their integrity management programs.

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LIST OF ABBREVIATIONS

CD	Crack Detection
CP	Cathodic Protection
DSAW	Double Submerged Arc Weld
ERW	Electric Resistance Weld
FW	Flash Weld
HF-ERW	High-Frequency Electric Resistance Weld
ILI	In-Line Inspection
LF-ERW	Low-Frequency Electric Resistance Weld
LW	Lap Weld
MAOP	Maximum Allowable Operating Pressure
MOP	Maximum Operating Pressure
MPI	Magnetic Particle Inspection
NDE	Non-Destructive Examination
PRCI	Pipeline Research Council International
SAW	Submerged Arc Weld
SMYS	Specified Minimum Yield Strength
SSAW	Single Submerged Arc Weld
SWA	Seam-weld anomaly
TFI	Transverse Field Inspection
TOFD	Time of Flight Diffraction
UT	Ultrasonic Testing

INTRODUCTION

Pipeline operators have often managed the integrity of early generation seam welds through hydrostatic testing. More recently, in-line inspection (ILI) technologies have emerged as another option to identify seam-weld anomalies that could affect pipeline integrity. However, the methods for evaluating the severity of seam-weld anomalies are still evolving. The current industry practice is to repair any ‘crack-like’ seam-weld anomaly, rather than following a protocol with formal assessment criteria. This practice has likely resulted in the unnecessary repair of numerous seam-weld anomalies.

Mechanical property data for the seam welds are not commonly available and when limited data are found, they do not usually contain the information needed to conduct structural integrity evaluations. Pipeline companies that operate older pipeline systems need these data to reliably assess the integrity of their systems. The U. S. Department of Transportation Office of Pipeline Safety, along with the PRCI, recognized the need for reliable data for early generation seam welds and contracted with CC Technologies to assemble a comprehensive database of material properties and seam-weld anomalies and to develop guidelines for assessing the anomalies.

Objectives

The objectives of the current project are to (Task 1) compile and evaluate the unique properties of early generation pipeline weld seams, (Task 2) compile a catalog of anomaly types, and (Task 3) develop guidelines and recommendations for evaluating seam-weld anomalies and their severities to determine whether pipeline integrity has been compromised.

Background

Pipeline operators are developing and implementing integrity management programs that include hydrostatic testing, direct assessment, and in-line inspection. Inspection technologies have improved over the past several years, resulting in an ability to detect seam-weld anomalies that have been in service for over 30 years, without leaks or failures. Pipeline operators are using these technologies to identify seam-weld anomalies that are potential integrity threats. In a recent program, though, 99 of 100 anomalies removed from service survived a subsequent hydrostatic test to 100% of SMYS.[*] Clearly, guidance is needed to identify when anomalies threaten integrity and when they do not.

---

[*] Proprietary data.

The goals of this program were to provide (1) an improved understanding of the quality and mechanical properties of early generation seam welds for use in engineering critical assessments, (2) a comprehensive database of anomalies, typically found in these welds, and (3) guidance on assessing the severity of anomalies. Based on the results of this project, pipeline operators should be able to use engineering critical assessments to develop excavation criteria in response to in-line inspection programs, repair criteria based upon field measurements, options for repair, and re-inspection intervals.

This report primarily focuses on anomalies and material properties of lap-welded pipe, low frequency ERW seam pipe, and flash weld pipe. Limited data are available for single submerged arc welds, double submerged arc welds, and high-frequency ERW.

Report Organization

Three sections comprise the main body of this report:

- The first section summarizes the development of the material-property database. Appendix A provides measured material-property data. Where known, the pipe manufacturer and type of service (gas or liquid) are provided.
- The second section describes and summarizes the types of seam-weld anomalies identified in this program. Appendix B provides detailed descriptions and measurements of the anomalies. Where known, the pipe manufacturer and type of service (gas or liquid) are provided.
- The third section provides guidance on analyzing seam-weld anomalies.

The first task was funded by the PRCI, while the second and third tasks were funded by the Office of Pipeline Safety. Work on the first task is continuing under separate PRCI sponsorship. This follow-on work will be reported at a later date.

Following the above sections, recommendations are given.

TASK 1. MATERIAL PROPERTIES

This section summarizes the first task of this project, under which a database of material properties related to early generation seam welds was assembled.

Prior to the project, CC Technologies collected a large amount of seam property data in programs conducted for other clients. CC Technologies sought and obtained permission to include much of these data in the database for this project. In addition, CC Technologies solicited and obtained pipeline samples containing seam-weld anomalies from pipeline operators, which included additional mechanical testing and material property data. Our clients for whom this information was collected have supplied written or verbal approval for their anonymous inclusion in this report. Individual company names were not included in the report.

The data cover a wide range of seam weld types, ages, grades, wall thicknesses, and manufacturers. The data contain anomaly types and material property measurements on pre-1970 pipe made by the ERW, flash weld, lap weld, single-sided arc weld, and double sided arc weld processes. In addition to the data from CC Technologies' files, test data include compositional analysis, tensile testing, Charpy V-notch impact testing, ring compression testing, metallurgical analyses, and hardness testing. Test methods are described below. The completeness of the data included in this report depends on the availability of prior data and/or the amount of pipe available for testing.

Extensive background and historical research was conducted for every pipe section in the database. This included efforts to identify the pipe mill, date of manufacture, and manufacturing process, as well as locating mill test reports, contacting owner/operators for other historical data, and reviewing any paperwork associated with the operation of the line. The mechanical property data were also related to the manufacturer information summarized in a 1996 ASME research report.[1.] The data are reported in Appendix A. When available, the data include:

- Pipe background information, including diameter, wall thickness, manufacturer, year of manufacture, seam weld type, and reported pipe grade.
- Base metal tensile test results, including tensile and yield strengths, elongation, reduction of area, mode of failure.
- Chemical analysis results for the weld and/or bondline and/or heat affected zone.
- Bondline Charpy V-notch results for –40^{o}F to 212^{o}F, transition temperature, and upper shelf energy.

- Metallographic photographs, hardness measurements, and ring-flattening results.
- General notes and observations.

Tensile Testing

Base metal tensile tests were performed to establish the tensile properties of the pipe. These tests were performed using flattened samples taken directly across from the seam weld. In addition, cross weld tensile tests were performed using flattened samples. In both cases, careful control of the flattening process was used to prevent over-flattening of the specimens. Tensile testing of “all weld metal” samples was not performed. The configuration of most seam welds precludes this type of testing.

Yield and tensile strength are reported for the base metal, and the results are compared to the applicable API specifications (if the grade of pipe and the year of manufacture was known or reported). Tensile strengths are reported for the cross-weld samples.

Compositional (Chemical) Analyses

Wet chemical analyses were performed to determine chemical compositions. For ERW and flash weld pipe, a sample that included the seam and the heat-affected zone was used to provide enough material for the analysis. When testing lap-welded pipe, the sample removed included the lap, but the majority of the sample consists of base metal. For single submerged arc welds, the sample included only weld metal.

Chemical analysis results were compared to applicable API specifications for a base metal ladle analysis (if the year of manufacture and manufacturing process i.e., open hearth, electric furnace, Bessemer, killed deoxidized, etc., was available).

Charpy Impact Testing

Charpy impact testing was performed to ASTM Standard E-23. For ERW and flash welds, the notch was placed directly on the bondline, which was located after etching with Nital. For lap-welded pipe, the notch was placed at the mid-point of the lap. The notch was placed directly on the centerline of the seam for single submerged arc welds.

When additional material was available after testing, Charpy testing was conducted in the heat-affected zone as well.

Metallurgical Analyses

Metallurgical samples were taken across the seam when material was available. The cross-section was etched with Nital, examined for anomalies, and digitally photographed.

Hardness Testing

Vickers hardness testing was conducted on selected pipe samples. Typically, the testing consisted of hardness indents along the centerline or bondline of the seam, along both HAZ's, and in the base metal, on both sides of the seam.

Ring Flattening Tests

Ring flattening tests were conducted to API 5LX code specifications and consisted of flattening full pipe ring specimens in a hydraulic press and examining the seam for delamination. Separate ring specimens were used, one with the seam at 0° to the horizontal and one with the seam at 90° to the horizontal.

Each ring was compressed to three different degrees: Two-thirds the original diameter of the pipe; one-third the original diameter, then completely flattened. The seam was inspected for delamination at each stage. If delamination occurred, the test was stopped.

TASK 2. SEAM-WELD ANOMALIES

This section summarizes the second task of this project, under which seam-weld anomalies were collected and characterized. A catalog of anomaly types and characteristics was assembled and contains 145 seam-weld anomalies. Tables 1 and 2 show which anomalies occurred in which weld type and compare the observed anomaly characteristics. Table 3 presents a list of seam welds and a count of the anomaly types that were found in each. Table 4 provides a listing of the pipe manufacturers (when known) associated with material in which the anomalies were found.

Five types of seam welds were included in the catalog, as follows:

ERW	Electric Resistance Weld
FW	Flash Weld
SSAW	Single Submerged Arc Weld
DSAW	Double Submerged Arc Weld
LW	Lap Weld

Each anomaly in the catalog is identified with a unique catalog number, a report number and an anomaly number. (The last two numbers are for anomaly identification by CC Technologies.) The catalog contains background information on the pipe material and the analysis results for each anomaly in addition to photo(micro)graphs of cross-sections and fracture surfaces. The following information is reported in the catalog:

- Pipe: Vintage, Manufacturer, Seam Type, Grade, Nominal Diameter, Nominal Pipe Wall Thickness, Measured Pipe Wall Thickness, Failure Conditions, MAOP/MOP, Coating Type, and Cathodic Protection.
- Anomalies: Non-Destructive Examination (NDE) Type, NDE Result, Visual Inspection Result, Anomaly Length, Anomaly Width, Anomaly Depth, Weld Thickness at Anomaly, and Anomaly Depth - Weld Thickness Ratio.

Anomaly Types

This section defines the types of seam-weld anomalies included in this report. For reference, published industry consensus standards and other sources were consulted. The list below aims to clarify the definitions, considering that in some cases more than one definition was available and that different documents may use different names for a particular type of anomaly. When no definition was available, a new definition was formulated for use in this document.

This list is not all-inclusive to cover every possible anomaly type. It specifically defines only those anomaly types identified in the current project. The origin of each definition in the list is clarified in end or footnotes.

Alloy Segregation	Alloy segregation(*) is a distinctive partition of the metallographic phases, as compared with the surrounding microstructure. Alloy segregation may be visible metallographically in transverse weld samples as bands of ferrite that follow the weld metal flow pattern within the ferrite/pearlite microstructure.
Contact Mark(s)	A contact mark, also called "Arc Burn"(2)(3), is a localized point of surface melting caused by arcing between electrode or ground and pipe surface. For electric resistance welds, contact marks(2), are intermittent and adjacent to the weld line resulting from the electrical contact between the electrodes supplying the welding current and the pipe surface.
Crack (Other than Hook)	A crack or "Weld Area Crack"(2) is a stress-induced separation of the metal which, without any other influence, is insufficient in extent to cause complete rupture of the material. A weld area crack is located in the weld line, immediately adjacent to the weld line, or in the weld upset zone.
Dent	A dent(2) is a local change in surface contour caused by mechanical impact but not accompanied by loss of metal. A dent(3) is measured as the gap between the lowest point of the dent and a prolongation of the original contour of the pipe.
Hook Crack (ID or OD)	Hook cracks, also called "Upturned Fiber Imperfections"(2) are metal separations, resulting from imperfections at the edge of the plate or skelp, parallel to the surface, which turn toward the ID or OD pipe surface when the edges are upset during welding.
Inclusion	An inclusion(2) or "Slag Inclusion"(2) is foreign material or non-metallic particles, entrapped in the weld deposit or between weld metal and base metal during solidification.

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* Definition formulated for the current report.

	In ERW pipe(4), inclusions are precursors to hook cracks if they exist in large quantities at the edges of the skelp used to form the pipe.
Lack of Fusion	Lack of fusion, also called "Incomplete Fusion"(2) for submerged arc welds or a "Penetrator"(2) for electric flash welds, is a condition of lack of complete coalescence of some portion of the metal in a weld joint or a localized spot of incomplete fusion. A condition similar to lack of fusion is "Stitching"(2), which is a variation in the properties of the weld occurring at short regular intervals among the weld line due to repetitive variation in welding heat. The variation in properties gives rise to a regular pattern of light and dark areas visible only when the weld is broken in the weld line.
Mid-Wall Void	Mid-wall voids(1) are relatively large, rounded or triangularly shaped holes that are located at the weld bondline, and have no opening to the ID or OD surface. Mid-wall voids typically occur at the weld bondline, and are presumably formed during the upset-stage of electric resistance or flash welding when a skelp edge may have separated parallel to the pipe surface. A mid-wall void should not be confused with "Porosity"(2), which refers to relatively small voids in a metal, usually resulting from shrinkage or gas entrapment occurring using solidification of a weldment.
Misalignment	Misalignment(3), also called "Offset of Plate Edges"(2) is a radial offset of plate edges in the weld seams. The bondline of the weld may be deflected(4) on an angle because of the offset edges.
Notch	A notch or gouge(2) is an elongated groove or cavity caused by mechanical removal of material.
Outbent Fiber	An outbent fiber(1) is an imperfection at the edge of the plate or skelp, parallel to the surface, which turns toward the ID or OD pipe surface when the edges are upset during welding.
Over-trim / Under-trim	Over-trim(3) is a condition where the outside or inside flash of electric welded pipe after trimming exceeds the limits set in API Specification 5L to which the pipe was manufactured. Under-trim(3), also called "Inadequate Flash Trim"(2) is a condition where the depth of groove resulting from removal

	of the internal flash of electric welded pipe exceeds the limits set in API Specification 5L to which the pipe was manufactured.
	Depth of groove(3) is defined as the difference between the wall thickness measured approximately 1 inch (25.4 mm) from the weld line and the remaining wall under the groove.
Pit	A pit(1) is defined as a surface cavity confined to a small area resulting from the removal of metal, either by corrosion or by dislodging of a portion of metal or particle that was embedded during manufacturing.
Repair Weld	Repair welds(1) are usually submerged arc welds that are applied to an existing pipe seam, to reinforce or replace a seam weld area with one or more suspected weld anomalies.
Roll-In Anomaly	A roll-in anomaly, also called "Roll-in Slug"(2), is a foreign body rolled into the metal surface, usually not fused.
Scab	A scab(2) is an imperfection in the form of a shell or veneer, generally attached to the surface by sound metal. It usually has its origin in an ingot anomaly.
Selective Seam Corrosion	Selective seam corrosion, also called "Grooving"(4) is the preferential corrosion of the bondline or the heat affected zone of a seam weld at a faster rate than the surrounding material.
Split	A pipeline split(1) failure is a catastrophic rupture from internal pressure in the pipe, caused either during operation or during a burst test.

TASK 3. ASSESSING SEAM-WELD ANOMALIES

This section presents guidelines for assessing seam-weld anomalies. The guidelines reference data from the material property database developed under Task 1 and the anomaly type catalog developed under Task 2.

This section contains guidelines, rather than rigid rules, for pipeline operators to use in assessing seam-weld anomalies. The guidelines allow individual companies to choose assessment methods that are best suited for specific anomalies and conditions under which they are found.

Background on Seam-Weld Anomalies

Seam-weld anomalies differ from most other pipeline anomalies in four important respects.

1. Seam-weld anomalies exist in or near an area where the geometry, material properties, and loading can differ significantly from those away from the weld. Sources of these differences can include:
    - Misalignment between the edges of the plate, skelp, or coil across the weld;
    - Geometric discontinuities resulting from weld reinforcement, flash, and flash trimming;
    - Higher or lower yield and ultimate strengths, toughness values, and transition temperatures as a result of the heating cycles;
    - Residual stresses due to the welding process.
2. Seam-weld anomalies are typically not volumetric, which affects the ability to nondestructively detect and size them.[*] With axial magnetic flux leakage (MFL) in-line inspection tools, they are hard to find and nearly impossible to size. Circumferential MFL tools fare better, especially with regard to detection but sizing is still problematic. Angle-beam ultrasonics is more reliable than MFL at

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[*] A discussion of detection reliabilities and sizing accuracies of in-line inspection technologies is beyond the scope of this document. (See NACE TR 35100 In-Line Nondestructive Inspection of Pipelines, December, 2000, for additional information on inspection capabilities.) In general, while a number of inspection systems have been developed, data on true capabilities are lacking, and some anomalies are difficult to detect and size with any inspection technology. This is especially true when the geometry of the weld is irregular or complex. It is also true when some types of metallurgical anomalies (such as inclusions and laminations) are present and near the weld anomaly to be detected and sized.

detecting non-volumetric and crack-like indications, but many inspection systems do not detect anomalies shorter than 1 to 1.5 inches. Many types of seam-weld defects, such as lack of fusion, are often shorter than one inch. In addition, while ultrasonics is often used to estimate crack depths, many seam-weld anomalies cannot be reliably sized with the technique.[*]

3. The characteristics of different types of seam-weld anomalies significantly differ from other types. For example, hook cracks are nearly perpendicular at the pipe surface but curve to become nearly parallel at their terminus. In ERW or flash weld pipe, lack of fusion is usually planar and perpendicular to the weld surface, but the anomalies are often not continuous. Optimizing inspection tools for one type of anomaly can make the tool less sensitive to other types.

4. Certain crack-like seam-weld anomalies are not true cracks. So-called “cold welds” are welds with some fusion between the edges of the plate, skelp, or coil used to make the pipe. Rather than being a true crack, the anomaly is attached at some places but not others. Nearly all analysis techniques were developed for true crack-like anomalies.

Anomaly Types and Characteristics

For this report, the anomalies identified and measured in Task 2 are grouped as follows:

Longitudinal Crack-Like Anomalies

- Hook Crack (ID or OD): A metal separation, resulting from imperfections at the edge of the plate or skelp, parallel to the surface, which turn toward the ID or OD pipe surface when the edges are upset during welding.
- Crack (Other than Hook): A stress-induced separation of the metal which, without any other influence, is insufficient in extent to cause complete rupture of the material.

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[*] Ultrasonic sizing of weld anomalies is not yet fully mature. Some anomalies, such as hook cracks, produce ultrasonic signals that are different from those of cracks that are truly planar and perpendicular to the pipe surface. Ultrasonic sizing works best for the latter. More experience and correlations between in-line inspection results and the true geometries of weld anomalies is needed to improve sizing accuracies.

- Lack Of Fusion: A condition of lack of complete coalescence of some portion of the metal in a weld joint or a localized spot of incomplete fusion.

- Stitching: A variation in the properties of the weld occurring at short regular intervals among the weld line due to repetitive variation in welding heat.

- Seam Corrosion: Preferential corrosion of the bondline or the heat affected zone of a seam weld at a faster rate than the surrounding material.

Others

- Alloy Segregation: A distinctive partition of the metallographic phases, as compared with the surrounding microstructure.

- Contact Mark(s): A localized point of surface melting caused by arcing between electrode or ground and pipe surface.

- Dent: A local change in surface contour caused by mechanical impact but not accompanied by loss of metal.

- Inclusion: A foreign material or non-metallic particles, entrapped in the weld deposit or between weld metal and base metal during solidification.

- Mid-Wall Void: A relatively large, rounded or triangularly shaped hole that are located at the weld bondline, and have no opening to the ID or OD surface.

- Misalignment: A radial offset of plate edges in the weld seams.

- Notch: An elongated groove or cavity caused by mechanical removal of material.

- Outbent Fiber: An imperfection at the edge of the plate or skelp, parallel to the surface, which turns toward the ID or OD pipe surface when the edges are upset during welding.

- Over-Trim / Under-Trim: A condition where the outside or inside flash of electric welded pipe after trimming exceeds the limits set in API Specification 5L to which the pipe was manufactured.

- Pit: A surface cavity confined to a small area resulting from the removal of metal, either by corrosion or by dislodging of a portion of metal or particle that was embedded during manufacturing.

- Roll-In Defect: A foreign body rolled into the metal surface, usually not fused.
- Scab: An imperfection in the form of a shell or veneer, generally attached to the surface by sound metal.

Most of the anomalies listed under "Others" can be analyzed using conventional analysis methods. Conventional analyses are not covered in this report. This report covers analysis of anomalies in the first category (longitudinal crack-like anomalies).

Material Properties

As expected, material properties are a necessary input parameter for analyzing the effects of anomalies on pipeline behavior. For volumetric anomalies, such as metal loss, the most important properties are related to strength (yield, flow, and tensile strengths). For longitudinal seam-weld anomalies, the situation is more complex. Here, behavior is strongly affected by toughness and other properties.

The data from the material property database developed in Task 1 that most strongly affect the assessment of anomalies are:

- Pipe diameter, wall thickness, and pipe grade;
- Base metal tensile test results, including tensile and yield strengths;
- Charpy V-notch results at and near the bond and in the base pipe material;
- Hardness measurements – (provides insight into the variability of material properties around the weld).

Approach

Figure 1 shows a flow chart for assessments of pipeline anomalies.[5] The diagram is similar to one developed as part of a joint industry project conducted in Europe, which also developed a *Pipeline Defect Assessment Manual*. The flow chart outlines a series of analysis stages for pipeline anomalies. It also shows the types of data required to perform the assessment.

As shown in Figure 1, analyses can range from relatively simple and qualitative to complex and probabilistic. As the analysis becomes more complex, a higher level of expertise is required.

- Stage 1: Qualitative Assessment (Workmanship Levels)
- Stage 2: Quantitative Assessment (Basic)
- Stage 3: Quantitative Assessment (Fracture Mechanics)
- Stage 4a and b: (Experimental Testing and Numerical Analyses)
- Stage 5: Probabilistic Analyses

When an anomaly "fails" a stage of the assessment or analysis, the next stage is required (or a decision can be made to repair or remove the anomaly).

For the seam-weld anomalies covered in this report, qualitative or workmanship assessments (Stage 1) no longer apply. So, the assessments start at Stage 2 and increase in complexity from there, as needed. For the assessments, expertise in fracture mechanics, numerical analysis methods, and probabilistic methods are needed.

Table 5 shows recommended assessment methods for assessing the burst strength of anomalies in pipe under pressure from Reference 5. For seam-weld anomalies (shaded for emphasis), two standards are referenced: British Standard 7910: "Guide on methods for assessing the acceptability of flaws in fusion welded structures"[6] and API Recommended Practice 579 "Fitness-for-Service."[7]

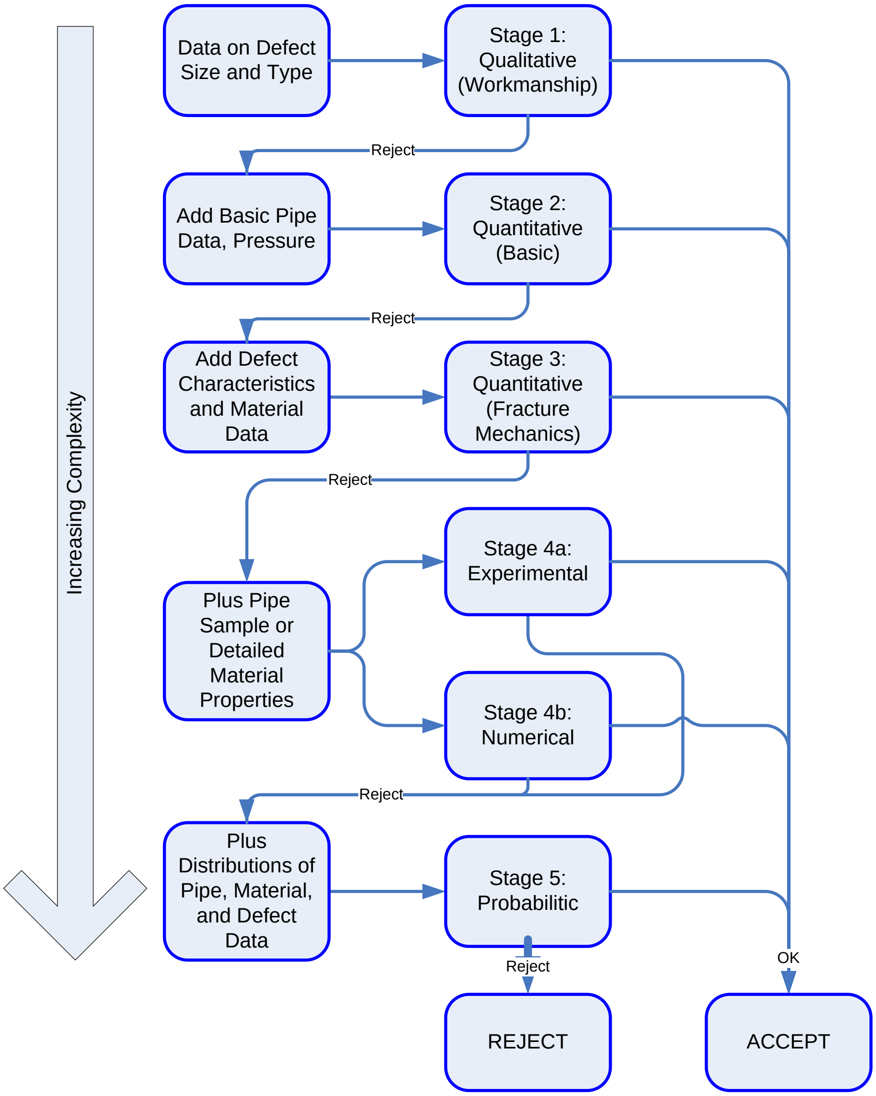

Figure 1. Pipeline Defect Assessment: The Five Stages

Both BS 7910 and API 579 address crack-like flaws in steel structures. API 579 also covers other anomalies, such as metal loss, blisters, laminations, and misalignment. For crack-like flaws, each addresses brittle and ductile fracture as well as failure by yielding or plastic distortion and fatigue crack growth. In terms of likely failure modes, seam-weld anomalies in early pipelines are most likely to fail by either brittle or ductile fracture (so-called “toughness dependent” failures) at overload or after some fatigue crack growth.

Stage 2 Quantitative Analysis

BS 7910 and API 579 provide a “Level 1” analysis method that is comparable to the “Stage 2” assessment shown in Table 5. In the analyses, an applied stress intensity factor is calculated and compared to the material toughness to determine whether an anomaly is acceptable. The applied stress intensity factor is a function of the anomaly and pipe dimensions as well as the maximum stress, and the material toughness is derived from the Charpy V-notch energy at the service temperature.

Conservative values of toughness, anomaly depth, anomaly length, and stress are used in the calculations. If the applied stress intensity factor is larger than the material toughness, the anomaly is rejected. This type of analysis generally leads to very small acceptable flaw sizes. In practical terms, Stage 2 / Level 1 analyses are rarely used for assessing seam-weld anomalies.

Stage 3 Quantitative Analysis

BS 7910 and API 579 provide “Level 2” and “Level 3” analysis methods that are comparable to the “Stage 3” assessment shown in Table 5. In this type of analysis, partial safety factors are sometimes used to account for uncertainties in measurements of anomaly dimensions, toughness, and stress. Alternatively, more accurate calculations are made of critical flaw sizes.

Input parameters include toughness, anomaly dimensions, and pipe dimensions, as before, and more realistic estimates of maximum stresses. As before, conservative estimates are generally used for toughness and anomaly dimensions. A failure assessment diagram is constructed and used for assessing individual anomalies. Figure 2 shows a typical failure assessment diagram, along with the steps used a typical analysis. Both overload (x-axis) and fracture (y-axis) are considered.

Stage 3 analyses are less conservative than Stage 2 / Level 1 analyses, but they are not widely used for assessing anomalies in early generation seam welds for two reasons. First, when lower bound estimates are used for toughness and upper bound estimates for anomaly dimensions, the analyses lead to excessive conservatism. Second, they do not explicitly account for the potential for growth by fatigue or other mechanisms.

Stage 4 Experimental Testing and Numerical Analyses

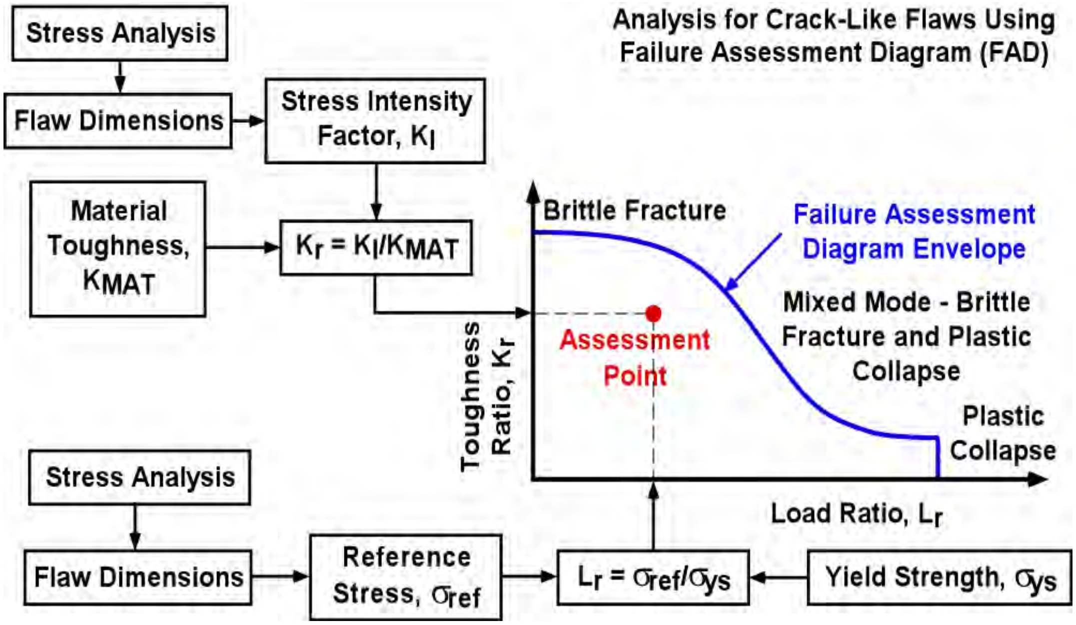

Figure 2. Failure Assessment Diagram and Analysis Flowchart

Stage 4 assessments include experimental testing and/or detailed numerical analyses. Testing is often problematic for seam-weld anomalies as pipe samples with similar defects are not generally available. In addition, because flaw characteristics and material properties vary significantly, the results of a small set of tests must be used with a suitable factor of safety to account for variabilities.

Numerical analyses can provide insight into the mode of failure and the relative importance of defect characteristics (e.g., dimensions), material properties, and cyclic loading. Again, because the actual defect characteristics and material properties can vary significantly, caution must be exercised when using the results.

A third alternative, an Engineering Critical Assessment, combines the results of detailed fracture-mechanics analyses with information on the variability of loading and material properties to assess whether a given defect threatens integrity. This approach approximates the results of probabilistic analyses, discussed below.

Stage 5 Probabilistic Analyses

Given the inherent variability of material properties in early generation seam welds, as well as uncertainties in estimating the true size of seam-weld anomalies, probabilistic assessments can provide meaningful insights. Probabilistic analyses can account for variations in material properties as well as sizing uncertainties. This type of analysis, when combined with fatigue analyses (as a result of variations in pressures), provide an estimate of the remaining life of a weld anomaly.

To conduct probabilistic assessments, distributions of material properties and anomaly dimensions are needed. The data collected in Tasks 1 and 2 can be used as input in estimating material property and anomaly dimension distributions. Loading data can be taken from pressure records.

Analysis Flow Chart

Figure 3 shows a flow diagram for assessing seam-weld anomalies, based on a similar chart in Reference 5. The diagram includes the basic steps used in any analyses as well as additions that cover (1) consideration of inspection type and limitations, (2) comparison of anomaly type with the Anomaly Type Catalog, (3) use of the Material Property Database as background information, and (4) a time-dependent assessment reflecting the possibility of anomaly growth.

Inspection Type and Limitations

The methods used to obtain inspection results determine the type of data collected and the inherent quality that may be expected of that data. At a minimum, the inspection technique and the measured inspection data should satisfy the following criteria:

1. The inspection technique should be selected based on the probable damage mechanism to be identified. See NACE TR 35100 (In-Line Nondestructive Inspection of Pipelines, December, 2000) for additional information on selecting inspection techniques as a function of anomaly type.
2. The inspection technique should be applicable to and calibrated for the pipeline dimensions (diameter, wall thickness), weld type to be inspected, and anomaly sizing requirements.
3. A quality assurance plan should be in place for the inspection.
4. The inspection technique should pass the quality control check.
5. The inspection data should be sufficiently detailed to permit re-inspection at a later date, typically 5 or more years in the future.

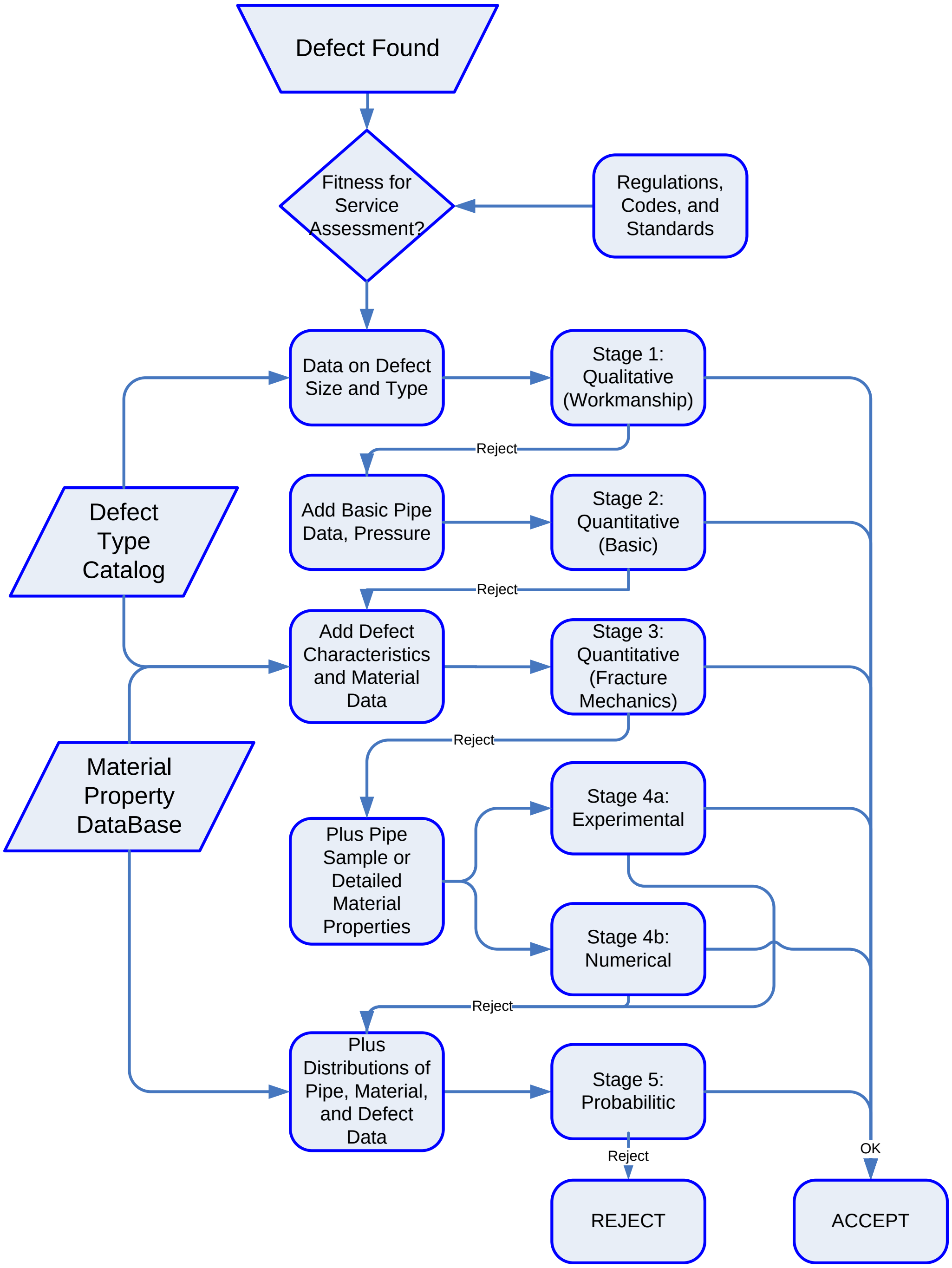

Figure 3. Seam-Weld Anomaly Assessment Procedure

6. The limitations of the inspection technique should be stated in writing, and that document should be maintained with the inspection data for future reference.

7. The inspection data should be stored in a permanent from so that it may be re-used in a future assessment.

Anomaly Type

The assessment of the severity of pipeline anomalies can only be accurate when the correct damage mechanism is identified first. Often, this is done from experience and comparison of the detected anomalies with results obtained from previous work. The Anomaly Type Catalog (Appendix B) can be used as a tool to identify and assess anomalies found in seam welds.

At a minimum, the assessment of anomaly to determine their anomaly type by comparison to previously obtained results, should satisfy the following criteria:

1. To positively identify a pipeline anomaly, its features should be determined consistent with those from previously documented anomalies.
2. The anomaly dimensions should be identified and compared with previously measured anomalies of the same anomaly type.
3. The orientation (o'clock, and transverse or longitudinal), location (seam weld, heat-affected zone [HAZ], or base metal) and relation to nearby features (e.g. girth weld) should be evaluated and found consistent with the identified anomaly type.
4. An anomaly that has features non-consistent with a certain anomaly type should not be evaluated as that anomaly-type but evaluated further to determine the correct anomaly type classification.
5. The information used to identify a given anomaly as being of a certain anomaly type should be recorded and stored in a permanent form so that it may be used or re-evaluated in a future assessment.

Material Property Database

The results of an anomaly assessment often depend heavily on the input data, including material properties of the pipe base and/or weld metal. A higher level of confidence in the results can be achieved with improved knowledge of the material properties of the pipe. If material property data on the actual pipe is not available, then data obtained from samples taken from similar pipeline can be used. The Material Property Database (Appendix A) can be used to obtain this information. At a minimum, the use of material properties for anomaly assessment, should satisfy the following criteria:

1. The material property data used in the assessment should be representative for the pipe joint in which the anomaly is located.
2. Any material property data used in an assessment, including data used from different but similar pipe, should be obtained from pipe of the same age (vintage), manufacturer, dimensions (diameter, wall thickness), and weld type.
3. The material property data used should be applicable for the temperature range to which the pipeline with an anomaly is operating. This is particularly important for fracture toughness data. Appendix A provides examples of Charpy toughness curves for various materials. When operating on the "lower shelf", the resistance to fracture is low.
4. The assessment should consistently use either minimum or average (actual) material properties, so that the end result of an assessment provides either conservative (minimum) or average (typical) values.*
5. The material property information used to assess a given anomaly should be recorded and stored in a permanent form so that it may be used or re-evaluated in a future assessment.

Time-Dependent And Probabilistic Assessments

Commonly occurring anomaly growth mechanisms for pipelines include corrosion and fatigue. Loss of wall thickness due to corrosion may compromise the pressure carrying capacity of pipelines. Various methods are available to calculate the strength of pipelines with areas of localized metal loss. In many cases, though, the initial anomaly is, or results in, a crack or crack-like surface anomaly prone to growth due to pressure fluctuations. As a result, analysis methods for metal-loss are generally not appropriate for assessing seam anomalies.

A fracture mechanics analysis is more appropriate for weld anomalies. Time-dependent growth by fatigue depends on a number of factors, including the stress field surrounding a given anomaly. The stresses at a given anomaly can be higher than normal pipeline stresses and the magnitudes of stress may vary within anomalies.

Stable crack growth caused by pressure fluctuations depends upon the pipe toughness, the pipe wall stress, crack size, and a fixed relation between the crack growth rate per each pressure cycle and the stress intensity factor related to a high stress field near the crack tip. Estimating pipeline life under normal operating conditions

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* Different factors of safety are required when using average versus minimum or lower-bound material properties.

consists of determining the number of pressure cycles for an initial crack to grow to a critical size resulting in eventual pipeline failure.

At a minimum, statistical and anomaly growth assessments should satisfy the following criteria:

1. The Anomaly Growth Model used in the assessment should be appropriate for the anomaly type.*
2. The assessment should use realistic distributions of growth rates, so that the assessment provides meaningful estimates of remaining life.
3. The assessment should use realistic distributions of material properties and anomaly dimensions, so that the analyses provide results that match the conditions most likely found on the pipeline. Material property distributions are typically determined by testing a statistically relevant number of samples. Anomaly distributions are more difficult to generate and are often determined by appropriate subject matter experts.
4. The anomaly growth information used to assess remaining life of a given anomaly should be recorded and stored in a permanent form so that it may be used or re-evaluated in a future assessment.

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* In most cases, fatigue analyses are used for weld anomalies. Here, a Paris law approach is often used, where the resistance of a material to fatigue crack growth is expressed by two parameters.

RECOMMENDATIONS

The data included in this report provide valuable information on the properties of early generation pipe and seam welds. In general, though, the data are sparse and do not represent the full range of pipe manufactured and in use today. We recommend continuing efforts to obtain material property data for use by pipeline companies in their integrity management programs.

Appendix A provides information on the material properties of some early generation seam welds. While not extensive, this appendix provides a basis for estimating material properties and their variations. When possible, actual material properties should be used in analyses.

The catalog provided in Appendix B illustrates many of the anomalies present in early generation seam welds. This appendix can be used by subject matter experts to assess the validity of various inspection techniques and as an aid in selecting and using integrity analyses. Additional work is needed to characterize typical inspection signals as a function of anomaly type and dimensions.

Table 1. Summary of Visual and NDE Results to Characterize the Anomaly Types Found in 145 Samples.

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
30	ERW	ID Hook Crack	71%	60%, 3.5 inch ID Crack
134	ERW	OD Hook Crack	52%	99%, 2.25 inch OD-Connected Non-Fusion
135	ERW	Mid-Wall Void + Laminations + ID Hook Crack	48%	60%, 8.5 inch ID & Mid-Wall Non-Fusion
122	ERW	OD Hook Crack	46%	52%, 8 inch OD-Connected Non-Fusion
142	ERW	OD Hook Crack	44%	64%, 4.3 inch Intermittent Non-Fusion
22	ERW	ID Hook Crack	43%	50%, 7 inch Crack-like
126	ERW	OD Hook Crack	43%	80%, 6 inch ID-Connected Non-Fusion
124	ERW	OD Hook Crack	40%	84%, 7 inch OD-Connected Non-Fusion
104	ERW	ID Hook Crack + Mid-Wall Void	40%	40%, 3 inch ID Crack
140	ERW	OD Hook Crack	38%	48%, 6.5 inch OD-Connected Non-Fusion
23	ERW	ID Hook Crack	35%	20%, 2.5 inch ID Crack-like
24	ERW	ID Hook Crack	35%	80%, 5.5 inch ID Crack-like
108	ERW	OD Hook Crack + Mid-Wall Void + OD Weld Repair	34%	40%, 3.5 inch OD Crack
9	ERW	ID Hook Crack	29%	30% x 2.5 inch ID Crack
7	ERW	ID Hook Crack	28%	<10% x 2.4 inch grind area on seam
98	ERW	OD Hook Crack	28%	
106	ERW	ID Hook Crack + Mid-Wall Void	24%	30%, 2.5 inch ID Crack
103	ERW	ID Hook Crack + Mid-Wall Void	24%	25%, 4 inch ID Crack

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
32	ERW	ID Hook Crack	23%	40%, 4 inch ID Hook Crack
10	ERW	OD Hook Crack	23%	30% x 2.625 inch OD Crack
125	ERW	Misalignment + Hook Crack + Alloy Segregation	19%	16%, 8 inch Non-Fusion or Lamination
105	ERW	OD Hook Crack	17%	15%, 2 inch OD Crack
8	ERW	ID Hook Crack	4%	7% x 2.5 inch grind area on seam
114	ERW	Hook Crack		60%, 3.75 inch ID-Connected Non-Fusion
112	ERW	Hook Crack + Alloy Segregation		No Anomaly
143	ERW	Hook Crack + Alloy Segregation		No Anomaly
144	ERW	Hook Crack + Alloy Segregation		52%, 2.7 inch OD Non-Fusion
141	ERW	OD Hook Crack + Alloy Segregation		52%, 2.5 inch OD-Connected Non-Fusion
145	ERW	Weld Area Crack, Weld Crack + Misalignment + Alloy Segregation		92%, 4.8 inch Non-Fusion
100	ERW	OD Crack at Contact Mark + ID Under-trim	7%	
63	ERW	OD Crack + ID Outbent Fiber + Contact Marks	11%	No Anomaly Revealed
107	ERW	OD Crack	9%	50%, 5 inch OD Crack
93	ERW	OD Crack	9%	
29	ERW	ID Lack of Fusion & Small Crack	99%	12 x 7 inch OD seam grind area (UT) + 11 x 1.0 inch OD Weld Repair (UT) + 0.4 x 0.1 inch OD grind area (UT) + 0.25 inch OD Crack (MT) + 100%, 1.9 inch ID Hook Crack (Fast UT)
139	ERW	ID Extrusion Cracks + Alloy Segregation + Misalignment	16%	48%, 2 inch Non-Fusion

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
13	ERW	ID Crack + OD Repair Weld	42%	75% x 5.6 inch ID Crack
101	ERW	ID Crack + ID Under-trim	4%	
64	ERW	ID & OD Outbent Fibers + OD Crack + Contact Marks		No Anomaly Revealed
130	ERW	Misalignment + Alloy Segregation	8%	44%, 3.5 inch Mid-Wall Non-Fusion
129	ERW	Misalignment + Alloy Segregation		28%, 1 inch ID-Connected Non-Fusion
131	ERW	Misalignment + Alloy Segregation		20%, 1.1 inch Mid-Wall Non-Fusion
127	ERW	Mid-Wall Void + Laminations + Misalignment + Alloy Segregation		80%, 5.25 inch ID-Connected Non-Fusion
128	ERW	Mid-Wall Void + Laminations + Misalignment + Alloy Segregation		74%, 4 inch ID-Connected Non-Fusion
132	ERW	Mid-Wall Void + Laminations + Alloy Segregation + Misalignment		72%, 3 inch OD-Connected Non-Fusion
117	ERW	Mid-Wall Non-Fusion + Laminations, Misalignment, Alloy Segregation		48%, 7.25 inch + Non-Fusion (ID to Mid-Wall)
119	ERW	External Corrosion on Seam + Alloy Segregation + Misalignment	29%	30%, 2 inch Metal Loss
121	ERW	Alloy Segregation + Misalignment	14%	12%, 10 inch Gouge (Near Seam)
116	ERW	Alloy Segregation + Misalignment		8%, 9 inch OD & ID-connected Non-Fusion
133	ERW	Alloy Segregation + Misalignment		72%, 1.5 inch Non-Fusion
113	ERW	Alloy Segregation		No Anomaly
118	ERW	Alloy Segregation		No Anomaly
137	ERW	Alloy Segregation		20%, 4 inch ID-Connected Non-Fusion

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
95	ERW	Offset Plate Edges + OD Notch		
96	ERW	Offset Plate Edges + OD Notch		
102	ERW	Misalignment Contact Mark	9%	< 10%, 1.5 inch ID Gouge
138	ERW	Mid-Wall Void + Lamination		72%, 15 inch Mid-Wall Non-Fusion
109	ERW	ID Over-trim + OD Weld Repair	8.3% + 45%	15%, 4 inch ID Gouge
92	ERW	ID Under-trim + Weld Repair	55%	
99	ERW	ID Under-trim + OD Weld Repair	45%	
31	ERW	ID Gouge (Over-trim)	26%	5.5 x 0.5 inch ID Gouge from Over-trim (UT) + 12 inch OD (HiLo MT)
94	ERW	ID Under-trim + OD Notch at Contact Mark		
97	ERW	ID Under-trim + OD Notch		
12	ERW	OD Lack of Fusion + OD Repair Weld	37%	30% x 0.7 inch OD Crack
11	ERW	OD Repair Weld		10% x 2 inch grind area on seam
14	ERW	OD Repair Weld		<10% multiple minor Cracks at Weld toe
111	ERW	ID Pit	28%	24%, 1.25 inch ID Gouge (Metal Loss)
115	ERW	ID Pit	22%	24%, 0.6 inch ID Gouge (Metal Loss)
110	ERW	ID Pit	17%	88%, 3 inch ID & OD-Connected Non-Fusion
123	ERW	ID Pit	15%	44%, 2 inch ID-Connected Non-Fusion
73	ERW	ID Plate Edge Anomaly (Roll-in) + Contact Location Arc		ID Gouges
136	ERW	Roll-in	6%	48%, 1.25 inch OD Hook Crack

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
120	ERW	ID Scab		24%, 2 inch ID Gouge
65	ERW	Lack of Fusion	100%	100%, 0.25 inch (Seeper)
82	ERW	Not Determined		20% ID Non-Fusion + Irregular Weld root geometry along entire joint
83	ERW	Not Determined		25% ID Gouge
61	FW	3 ID + 1 OD Hook Cracks	43% + 31% + 31% + 11%	50% ID + 20% OD Crack
56	FW	Two OD Hook Cracks	40% + 28%	65% OD Crack
59	FW	Two ID Hook Cracks	24% + 40%	40% ID Crack
44	FW	ID & OD Hook Cracks	75%	2 overlapping Cracks 85%, 10.5 inch total length
62	FW	Dent and Hook Crack	70%	0.300 inch RDI Mechanical Damage + 70%, 1 inch OD Crack
26	FW	ID Hook Crack	63%	50% ID Crack-like
37	FW	ID Hook Crack (with Crack extension)	62%	ID-connected Crack-like (UT) + Intermittently dispersed minor Inclusions (UT) + Crack-like (UT) + OD Sub-surface Crack-like (MT) + NF with associated Crack-like (Fast UT)
35	FW	ID & OD Hook Cracks	57%	ID Connected, Crack-like (UT) + OD Crack-like (MT) + ID Connected, Crack-like + Some LOF (Fast UT)
51	FW	ID Hook Crack + Crack extension	54%	35%, 8 inch, ID-connected Crack-like + 2 inch Inclusions
58	FW	ID Hook Crack	50%	75% ID Crack
48	FW	ID Hook Crack (evidence of Crack extension)	48%	13.5 inch intermittent NF 2(1.6)5.3(.5)4.1 inch (gap)

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
55	FW	OD Hook Crack	47%	75% OD Crack
6	FW	ID Hook Crack	43%	60% x 6.0 inch ID Crack
45	FW	ID Hook Crack	40%	2.4 inch long, 50% Crack-like
84	FW	ID Over-trim + ID Hook Crack + Fatigue Crack	40%	
49	FW	OD Hook Crack	40%	65%, 14 inch Crack-like
76	FW	OD Hook Crack	39%	40% (0.158 inch) OD Crack
38	FW	ID Hook Crack (with Crack extension)	38%	Minor Inclusions (UT) + Minor Inclusions (Fast UT) + Crack-like (Fast UT)
67	FW	ID Hook Crack	37%	40% (0.170 inch) ID Crack
21	FW	OD Hook Crack	36%	30%, 8.5 inch OD Crack-like
60	FW	ID Hook Crack	34%	65% ID Crack
78	FW	OD Hook Crack	34%	30% (0.128 inch) OD Crack-Like
72	FW	ID Hook Crack	32%	30% ID Crack
57	FW	OD Hook Crack + Inclusions	32%	65% OD Crack
50	FW	ID Hook Crack	31%	4.8 inch Crack-like, ID connected
77	FW	OD Hook Crack	29%	30% (0.105 inch) OD Crack-like
5	FW	OD Hook Crack	28%	66% x 3.5 inch OD Crack
69	FW	ID Hook Crack	25%	20% ID Crack
4	FW	ID Hook Crack	24%	40% x 5.5 inch Crack
16	FW	ID Hook Crack	23%	50% x 5.0 inch ID Crack

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
17	FW	ID Hook Crack	23%	30% x 8.1 inch ID-connected Crack
40	FW	ID Hook Crack (surmised, anomaly not exposed)		2 interacting, ID-connected Crack-like indications combined L = 3.6 inch, 25% radial extent
41	FW	OD Hook Crack (surmised, anomaly not exposed)		50%, 3.7 inch Crack-like, OD-connected
36	FW	ID Shrinkage Crack	12%	No anomaly revealed (UT) + Minor Inclusions (Fast UT)
68	FW	OD Shrinkage Crack	10%	20% OD Crack-Like
33	FW	Shrinkage Crack (Weld trim anomaly)	10%	Minor indication from ID surface
39	FW	ID Shrinkage Crack (Under-trim)	7%	1.0 and 1.5 inch long, 30% radial extent NF at Mid-Wall
47	FW	OD Shrinkage Crack (inadequate trim)	5%	<10%, 3.75 inch Crack-like, OD-connected
15	FW	OD Crack	3%	<10% x 5.5 inch Crack
79	FW	OD Weld Repair + No Cracking visible from ID surface		OD Weld Repair
71	FW	3 ID Gouges + Weld Over-trim		< 10% ID Gouge + < 0.060 inch RDI Dent
52	FW	ID Over-trim (scrape)		9.2 inch linear indications + < 5% two small Cracks 0.1"(1.6")0.3"
53	FW	ID Over-trim (scrape)		< 5%, 3.1 inch OD Crack-like + 1.4 inch NF + 10%, 7.8 inch linear indications (over 9.5 inches)
46	FW	Plate roll-in	40%	50%, 1.25 inch ID-connected
43	FW	Plate roll-in	33%	5%, 2.4 inch NF
70	FW	ID Plate Edge Anomaly (Roll-in)		20% Mid-Wall Crack + < 10% ID Gouge
34	FW	Lack of Fusion	100%	ID connected Crack-like (UT) + NF with associated

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
				Crack-like (Fast UT) + Narrow band of NF (Fast UT)
66	FW	Lack of Fusion	100%	100% (Seeper)
80	FW	Lack of Fusion	100%	100% (Seeper)
81	FW	Lack of Fusion	100%	100% (Seeper)
19	FW	OD Lack of Fusion	91%	Through-wall, 1 inch long non-Fusion / Crack
20	FW	OD Lack of Fusion	91%	1 inch long ID Crack-like
42	FW	OD Lack of Fusion	84%	3 NF indications 10%, 1.5 inch + 10%, 2.0 inch + 30%, 0.75 inch
18	FW	OD Lack of Fusion	75%	>80%, 1 inch long Crack-like
54	FW	ID & Hook Cracks + Lack of Fusion	44%	70% (0.300 inch) ID Crack + 30% (0.128 inch) OD Crack
74	FW	OD Outbent Fiber	33%	30% OD Crack-like
75	FW	No Anomaly Revealed		<10% OD Crack-like
3	Lap Weld	OD & ID Lack of Fusion	22%	Crack visible
1	Lap Weld	OD, Mid-Wall & ID Lack of Fusion	31%	Crack visible
2	Lap Weld	OD, Mid-Wall & ID Lack of Fusion	37%	Crack visible
85	SSAW	Weld Penetration + Lack of Fusion + Hot Crack	50% + 30%	
27	SSAW	ID Lack of Fusion + ID Crack + OD Slag Inclusion	21% + 6% + 24%	1.5 inch Linear Inclusion at 0.235 to 0.291 inch depth
28	SSAW	ID Lack of Fusion + OD Slag Inclusion	29% + 29%	5 inch Linear Inclusion at 0.290 to 0.308 inch depth + suspected ID LOF
88	SSAW	Through-wall flaw + ID seam ground flush + Lack	100%	

Catalog #	Seam Type	Visual	Depth/tWeld	NDE Result(s)
		of Fusion		
89	SSAW	Lack of Fusion + Void	85%	
25	SSAW	Intermittent ID Lack of Fusion	45%	20%, 9.4 feet long ID Crack-like
86	SSAW	Weld Penetration + Lack of Fusion	44%	
90	SSAW	Seam Split		
91	SSAW	Seam Split		
87	DSAW	Initiation at toe of OD Weld bead + Small OD Cracks parallel to main fracture	100%	

Table 2. Summary of Anomaly Types Found in 145 Samples.

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
30	ERW	X															
134	ERW	X															
135	ERW	X				X											
122	ERW	X															
142	ERW	X															
22	ERW	X															
126	ERW	X															
124	ERW	X															
104	ERW	X				X											
140	ERW	X															
23	ERW	X															
24	ERW	X															
108	ERW	X				X		X									
9	ERW	X															
7	ERW	X															

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
98	ERW	X															
106	ERW	X				X											
103	ERW	X				X											
32	ERW	X															
10	ERW	X															
125	ERW	X		X	X												
105	ERW	X															
8	ERW	X															
114	ERW	X															
112	ERW	X		X													
143	ERW	X		X													
144	ERW	X		X													
141	ERW	X		X													
145	ERW		X	X	X												
100	ERW		X				X							X			
63	ERW		X											X			X
107	ERW		X														

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
93	ERW		X														
29	ERW		X								X						
139	ERW		X	X	X												
13	ERW		X					X									
101	ERW		X				X										
64	ERW		X											X			X
130	ERW			X	X												
129	ERW			X	X												
131	ERW			X	X												
127	ERW			X	X	X											
128	ERW			X	X	X											
132	ERW			X	X	X											
117	ERW			X	X												
119	ERW			X	X								X				
121	ERW			X	X												
116	ERW			X	X												
133	ERW			X	X												

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
113	ERW			X													
118	ERW			X													
137	ERW			X													
95	ERW				X							X					
96	ERW				X							X					
102	ERW				X									X			
138	ERW					X											
109	ERW						X	X									
92	ERW						X	X									
99	ERW						X	X									
31	ERW						X										
94	ERW						X					X		X			
97	ERW						X					X					
12	ERW							X			X						
11	ERW							X									
14	ERW							X									
111	ERW								X								

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
115	ERW								X								
110	ERW								X								
123	ERW								X								
73	ERW									X							
136	ERW									X							
120	ERW											X					
65	ERW										X						
82	ERW																
83	ERW																
61	FW	X															
56	FW	X															
59	FW	X															
44	FW	X															
62	FW	X										X					
26	FW	X															
37	FW	X															
35	FW	X															

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
51	FW	X															
58	FW	X															
48	FW	X															
55	FW	X															
6	FW	X															
45	FW	X															
84	FW	X					X										
49	FW	X															
76	FW	X															
38	FW	X															
67	FW	X															
21	FW	X															
60	FW	X															
78	FW	X															
72	FW	X															
57	FW	X													X		
50	FW	X															

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
77	FW	X															
5	FW	X															
69	FW	X															
4	FW	X															
16	FW	X															
17	FW	X															
40	FW	X															
41	FW	X															
36	FW		X														
68	FW		X														
33	FW		X				X										
39	FW		X				X										
47	FW		X				X										
15	FW		X														
79	FW		X					X									
71	FW						X										
52	FW						X										

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
53	FW						X										
46	FW									X							
43	FW									X							
70	FW									X							
34	FW										X						
66	FW										X						
80	FW										X						
81	FW										X						
19	FW										X						
20	FW										X						
42	FW										X						
18	FW										X						
54	FW										X						
74	FW																X
75	FW																
3	Lap Weld										X						

Catalog #	Seam Type	ID or OD Hook Crack	Other Crack	Alloy Segregation	Misalignment	Mid-Wall Void	Over-trim / Under-trim	Repair Weld	Pit	Roll-In Anomaly	Lack Of Fusion	Notch / Dent / Scab	Seam Corrosion	Contact Mark(s)	Inclusion	Split	Outbent Fiber
1	Lap Weld										X						
2	Lap Weld										X						
85	SSAW		X								X						
27	SSAW		X								X				X		
28	SSAW										X				X		
88	SSAW										X						
89	SSAW					X					X						
25	SSAW										X						
86	SSAW										X						
90	SSAW															X	
91	SSAW															X	
87	DSAW		X														

Table 3. List of Seam Welds and Number of Anomalies of Certain Type Found.

	ERW	FW	Lap Weld	SSAW	DSAW	TOTAL
ID or OD Hook Crack	28	33				61
Alloy Segregation	21					21
Misalignment	17					17
Other Crack	10	7		2	1	20
Mid-Wall Void	9			1		10
Over-Trim / Under-Trim	8	7				15
Repair Weld	8	1				9
Notch / Dent / Scab	5	1				6
Contact Mark(s)	5					5
Pit	4					4
Lack of Fusion	3	9	3	7		22
Roll-In Anomaly	2	3				5
Outbent Fiber	2	1				3
Seam Corrosion	1					1
Inclusion		1		2		3
Split				2		2

Table 4. Listing of Early Generation Seam-Weld Pipe

Seam Weld Type	Year	Manufacturer	Pipe Grade	Nominal Diameter		Nominal Wall Thickness	
				(in)	(mm)	(in)	(mm)
LF ERW, Post Tempered Seam	1963	Bethlehem Steel Co., Yoder Mill	API 5LX-46, non-expanded	8	203	0.250	6.4
LF ERW	1957	Unknown	Assumed API 5LX-42, non-expanded	Unknown		0.250	6.4
LF ERW	1926	Unknown	Unknown	8	203	0.233	5.9
LF ERW	1967	Unknown	API 5LX-42, non-expanded	18	457	0.312	7.9
Flash Weld	1962	A. O. Smith Corp., Houston facility	API 5LX-42, cold-expanded	34	864	0.312	7.9
SSAW	1955	Republic Steel Corp., Gasden, AL	API 5LX-56, cold-expanded	20	508	0.375	9.5
Lap Weld	1930	National Tube Co., McKeesport, PA	API 5L Gr. B, non-expanded	22	559	0.375	9.5
Flash Weld	1959	A. O. Smith Corp., Houston facility?	Not reported. Probably API 5LX-46	20	508	0.312	7.9

Seam Weld Type	Year	Manufacturer	Pipe Grade	Nominal Diameter		Nominal Wall Thickness	
				(in)	(mm)	(in)	(mm)
Flash Weld	1957	A. O. Smith Corp.	Not reported. Probably API 5LX-42	26	660	0.281	7.1
1955	LF ERW	Lone Star	API 5LX-42, non-expanded	16	406	250	6.4
LF ERW	1930	Unknown. Possibly Republic Steel	Not reported. Probably API 5L Gr. B, non-expanded	16	406	0.266	6.8
HFC ERW	1963	Cal-metal Pipe Corporation	API 5LX-46, non-expanded	8	0.203	0.188	4.8
Lap Weld	1932	Unknown	Probably API 5L Gr. B, non-expanded	8	0.203	0.322	8.2
HFC ERW	Unknown	US Steel, bought by Camp Hill Corp.	API 5LX-52, possibly cold-expanded	16	406	0.312	7.9
HFC ERW	Unknown	US Steel, bought by Camp Hill Corp.	API 5LX-52, possibly cold-expanded	16	406	0.312	7.9

Seam Weld Type	Year	Manufacturer	Pipe Grade	Nominal Diameter		Nominal Wall Thickness	
				(in)	(mm)	(in)	(mm)
HFC ERW	Unknown	US Steel, bought by Camp Hill Corp.	API 5LX-52, possibly cold-expanded	16	406	0.312	7.9
HFC ERW	Unknown	US Steel, bought by Camp Hill Corp.	API 5LX-52, possibly cold-expanded	16	406	0.312	7.9
HFC ERW	Unknown	US Steel, bought by Camp Hill Corp.	API 5LX-52, possibly cold-expanded	16	406	0.312	7.9
LF ERW	Unknown	Lone Star, Yoder Mill	API 5LX-52, non-expanded	16	406	0.312	7.9
LF ERW	Unknown	Lone Star, Yoder Mill	API 5LX-52, non-expanded	16	406	0.312	7.9
LF ERW	Unknown	Lone Star, Yoder Mill	API 5LX-52, non-expanded	16	406	0.312	7.9
Flash Weld	1951-1952	A. O. Smith Corp.	API 5LX-52, cold-expanded	20	508	0.312	7.9
SSAW	Early 1960’s	Kaiser Steel Corporation	API 5LX-52, non-expanded	20	508	0.312	7.9

Seam Weld Type	Year	Manufacturer	Pipe Grade	Nominal Diameter		Nominal Wall Thickness	
				(in)	(mm)	(in)	(mm)
DC ERW	1951-1952	Youngstown Steel & Tube, Final mill	API 5LX-52, probably cold-expanded	20	508	0.312	7.9
Lap Weld	Reported as early 1940's	Youngstown Sheet & Tube	API 5L Gr. B, non-expanded	8	203	0.250	6.4
Lap Weld	1925 – 1928	Unknown	Probably API 5L Gr. B	12	305	0.233	5.9
Lap Weld	1925	Unknown	Probably API 5L Gr. B	10	254	0.250	6.4
Electric Fusion Weld	1957	Cal-Metal Pipe Corporation	Reported as API 5L Gr. B	6	152	0.219	5.6
LF ERW	1948	Republic Steel Corporation	API 5L Gr. B, non-expanded	10	254	0.250	6.4
LF ERW	1966	Lone Star Steel, Yoder Mill?	API 5LX-52, non-expanded	14	356	0.219	5.6
LF ERW	1951	Consolidated Western Steel	API 5LX-42, non-expanded	8	203	0.250	6.4
LF ERW	1954	Kaiser, Fontana, CA mill	API 5L X-46, non-expanded	8	203	0.250	6.4

Table 5. Recommended Assessment Methods for Pipeline Anomalies

	Internal Pressure (Static) Longitudinally Oriented	**Internal Pressure (Static) Circumferentially Oriented**
Corrosion	DnV-RP-F01 *Modified B31G* RSTRENG	Kastner Local Collapse Solution
Gouges	DnV-RP-F01 *PAFFC* *BS 7910 (or API 579)*	Kastner Local Collapse Solution *BS 7910 (or API 579)*
Plain Dents	Empirical Limits	
Kinked Dents	No Method	
Smooth Dents on Welds	No Method	
Smooth Dents and Gouges	Dent-Gouge Fracture Model	No Method
Smooth Dents and Other Types of Defect	Dent-Gouge Fracture Model	No Method
Manufacturing Defects in the Pipe Body	NG-18 Equations *BS 7910 (or API 579)*	Kastner Local Collapse Solution *BS 7910 (or API 579)*
Girth Weld Defects	-	Workmanship, EPRG *BS 7910 (or API 579)*
Seam weld defects	Workmanship *BS 7910 (or API 579)*	-
Cracking	*BS 7910 (or API 579)* *PAFFC*	
Environmental Cracking	*BS 7910 (or API 579)* *PAFFC*	
Leak and Rupture	NG-18 Equations *PAFFC*	

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1. Kiefner, J. F., and Clark, E. B., History of Linepipe Manufacturing in North America, Report for the Gas Pipeline Safety Research Committee, ASME, New York, 1996.

2. API Standard 5T1, Standard on Imperfection Terminology, 10th Edition, American Petroleum Institute, Washington, D.C., November 1996.

3. API Specification 5L, "Specification for Line Pipe, 42nd Edition, January 2000, Effective Date: July 1, 2000.

4. Kiefner, J. F., and Clark, E. B., "History of Line Pipe Manufacturing in North America".

5 “The Pipeline Defect Assessment Manual,” Andrew Cosham and Phil Hopkins, Paper Number IPC02-27067 in the Proceedings of IPC 2002, International Pipeline Conference, 29 September – 3 October 2002, Calgary, Alberta, Canada.

6 British Standard 7910:1999 “Guide on methods for assessing the acceptability of flaws in fusion welded structures, ”British Standards Institution, London, UK, 1999.

7. API Recommended Practice 579 “Fitness-for-Service,” American Petroleum Institute, January 2000.

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-005

REQUEST:

Refer to the Weisker Testimony, page 5, lines 17-21. Explain how replacing the pipe results in the need to also replace any associated regulator stations.

RESPONSE:

No Duke Energy Kentucky regulating facilities are being replaced as part of the Phase One scope of work. A new regulating facility is being added due to the need for pressure cut between AM07 and the piping north that will be downrated to distribution pressure.

PERSON RESPONSIBLE: Bradley A. Seiter

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-006

REQUEST:

Refer to the Weisker Testimony, page 6, the table at line 8. Given the recent surge in inflation and supply chain issues, explain whether Duke Kentucky anticipates a change to the proposed budget.

RESPONSE:

Duke Energy Kentucky stays in constant communication with preferred material vendors to help forecast material costs and minimize potential supply chain issues. Risk associated with increase in cost is built into contingency in the event unpredictable rises in cost occur. Duke Energy Kentucky currently expects to stay within the projects proposed budget.

PERSON RESPONSIBLE: Bradley A. Seiter

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-007

REQUEST:

Refer to the Weisker Testimony, page 7, lines 3-4. For the current pipeline that will be abandoned, provide the following:

a. Explain why Duke Kentucky is proposing to abandon a portion of the pipeline.

b. Provide the total amount Duke Kentucky is proposing to abandon.

c. Explain the environmental impact of the abandonment.

d. Explain whether there is a cost-benefit analysis for removal of the portion of the abandoned pipeline.

RESPONSE:

a. As noted in the application, several segments of the AM07 pipeline do not have traceable, verifiable, and complete pressure test records and is incapable of ILI. As part of the replacement of these segments, the existing pipeline will be abandoned after new pipeline is installed.

b. Duke Energy Kentucky is proposing to abandon approximately 9,600 feet of the AM07 pipeline on Phase One of the project.

c. After the line has been taken out of service, environmental testing for contaminants such as PCB and condensate will be done. In the event that presence of contaminants is found, the pipeline will be grouted to 50% of the volume of the pipeline. If no environmental issues are found, the line will be abandoned in place.

d. The cost-benefit to abandon the line in place is much more cost effective than removal of pipe. The typical cost to remove abandoned pipe is anywhere from $1000-2000/linear foot depending on the surface it's removed from. This includes the additional spending associated with pipe abatement, special hauling, and disposal. As a result, pipe abandonment is much more cost effective.

PERSON RESPONSIBLE: Bradley A. Seiter

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-008

REQUEST:

Refer to the Weisker Testimony, page 8, line 14-18. Regarding the pressure testing, explain why Duke Kentucky is not proposing to by-pass the current pipe to pressure test and instead replace the pipeline. Provide a cost-benefit analysis supporting Duke Kentucky's decision.

RESPONSE:

Pressure testing AM07 is not technically or logistically feasible and could create customer interruptions. The number of by-passes required to continue service to the multiple regulator stations and lateral pipelines served off AM07 would be extensive along the approximate 18-mile route. There also is inadequate availability of temporary natural gas supply volumes necessary to support the customer load supplied off sections of AM07 removed from service in order to perform pressure testing. Finally, there is a high probability to perform PHMSA code-required pressure reductions and numerous pipe segment replacements to address deficiencies found during the in-line inspection of the aged AM07 pipeline. Permitting and implementing work to correct these deficiencies in order to return pressure to normal would be time consuming and would likely not allow the pipeline to be at full pressure in time for the winter heating season, resulting in customer interruptions.

The Company has not performed a cost-benefit analysis.

PERSON RESPONSIBLE: Brian Weisker

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-009

REQUEST:

Refer to the Weisker Testimony, page 9, lines 7. Provide a list of all Duke Kentucky pipelines that are currently using In Line Inspection tools for integrity reassessment.

RESPONSE:

Line C340 currently uses in-line inspections tools. Line AM00b is presently undergoing retrofits to allow an in-line inspection to be performed during the summer of 2022.

PERSON RESPONSIBLE: Brian Weisker

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-010

REQUEST:

Refer to the Direct Testimony of Bradley A. Seiter (Seiter Testimony), page 4, lines 1-2. Explain whether or not the new pressure regulating station is included in the Phase One budget.

RESPONSE:

Yes, the installation of a new regulating station is included in the Phase One budget.

PERSON RESPONSIBLE: Bradley A. Seiter

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-011

REQUEST:

Refer to the Seiter Testimony, page 4, lines 11-23 and page 5, lines 1-5. Provide an update to all the applied for permits.

RESPONSE:

There has been no change in status of necessary permits for construction. Duke Energy Kentucky is waiting on approval from KYTC District 6 for a highway crossing approval to a permit request submitted on February 8, 2022. For the Kentucky Division of Water and Sanitation District 1 Stormwater permits, Duke Energy Kentucky will follow typical process for submitting permit requests after 90% Design drawings have been completed and approve. All other permits have been approved and provided as exhibits to the initial filing.

PERSON RESPONSIBLE: Bradley A. Seiter

Duke Energy Kentucky
Case No. 2022-00084
STAFF First Set Data Requests
Date Received: May 19, 2022

STAFF-DR-01-012

REQUEST:

Refer to the Seiter Testimony, page 6, lines 2-6. Provide the amount for which Duke Kentucky has budgeted for these anticipated deviations from the workplan and if these costs are included in the contingency budget amount.

RESPONSE:

As part of the project budget development, contingency funding is considered for potential unforeseen or forecasted deviations to the workplan. For construction and land acquisition activities noted on page 6, lines 2-6, approximately $2,700,000 has been budgeted to account for unforeseen circumstances. This is included in the project contingency budget amount.

PERSON RESPONSIBLE: Bradley A. Seiter