

Analysis of Gas Pipeline Failure

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SUMMARY

Failure of an operating gas pipeline is a rare event. However, when it does occur, it must be properly analyzed to prevent recurrence. What follows are analytical procedures for analyzing pipelines along with examples and characteristics of some typical failures.

INTRODUCTION

Failure of a natural gas transmission or gathering line during service is extremely serious because of the potential for loss of life. Yet statistics show that failures occur only once a year per thousand miles of pipeline. Part of the reason for this excellent record is the pipeline industry research over the past thirty years into failures and means of prevention. Figure 1. This work, sponsored by such organizations as The American Gas Association, The American Iron and Steel Institute, and The British Gas Corporation, has resulted in improved pipeline steels, manufacturing and inspection procedures, and improved pipeline designs.

ANALYTICAL TECHNIQUES

While pipeline configuration simplifies the geometrical aspects of analysis, the trauma accompanying the failure often obscures or destroys characteristics important to identifying the causes. The sudden release of large amounts of stored elastic strain energy can badly deform the pipe, while gas fires, if they occur, can alter pipe properties. In addition, post-failure corrosion and handling away from laboratory facilities may obliterate fine-scale fracture features. To overcome inherent difficulties and accurately determine causes, a variety of analytical techniques must be applied in a careful and well-prescribed fashion.

• *Overall Macroscopic Visual Inspection*-To identify the failure origin, it is imperative that a careful macroexamination of the entire available fracture surface be done. In-service pipeline ruptures generally develop from a region of stable crack growth or from a defect caused by an outside force or corrosion. Certain macrofeatures on the fracture surface can aid in locating the failure origin. The most common of these is the chevron pattern on plane strain fracture areas pointing back to the origin. The acute angle edge of a full shear propagation ductile failure often contains secondary cracks which form saw tooth-like ridges pointing back to the origin. Running a finger back and forth along this edge will often indicate by roughness differences, which way the crack was propagating. Since crack branching will show propagation directions, putting a fragmented pipeline together (usually done by matching paper patterns of the various pieces) will help identify the origin area.

• *Sectioning and Cleaning*-Often, the critical areas identified by the visual analysis will have to be sectioned from the rest of the pipe allowing detailed fractography and microstructural analysis¹. Care must be exercised to prevent damage to the fracture area when cutting small pieces for laboratory analysis. In particular, torch cutting of samples requires caution to avoid thermal damage to the metal in the fracture area. The orientation of small pieces relative to the macro-crack propagation direction and the pipe outside and inside surfaces should be marked for identification during the microanalysis.

The techniques for cleaning debris and corrosion products from pipeline fractures include washing with a mild detergent and bristle brush, solvent cleaning and degreasing in an ultrasonic cleaner, replica stripping, and chemical or electrochemical etching in mild or inhibited alkaline or acid solutions. The techniques should be applied in a serial fashion employing only the minimum necessary for cleaning the specific fracture region analyzed. Prior to cleaning, potentially significant corrosion products should be carefully removed and saved for analysis.

• *Microfractography*-The aim of high magnification fractography, using transmission or scanning electron microscopy, is to relate the fracture appearance to the cause or mechanism of fracture. This procedure involves comparing the service failure resulting

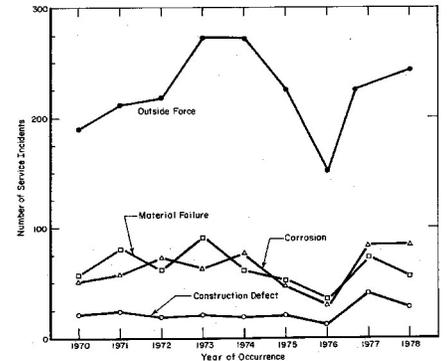


Figure 1. Number of gas pipeline service incidents versus year of occurrence by cause. (From Giedon, D.N. and R.B. Smith, "An Analysis of Reportable Incidents for Natural Gas Transmission and Gathering Lines 1970 through 1978," NG-18 Report No. 121, Sept. 1980.)

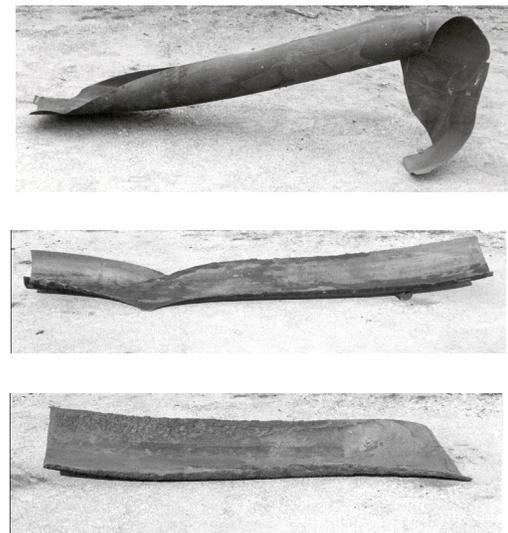


Figure 2. Rupture sections of 8-5/8 inch gas pipeline that failed due to external mechanical damage.



Figure 3. A 3-1/2 inch long gouge found near the midpoint of the rupture shown in Figure 2.

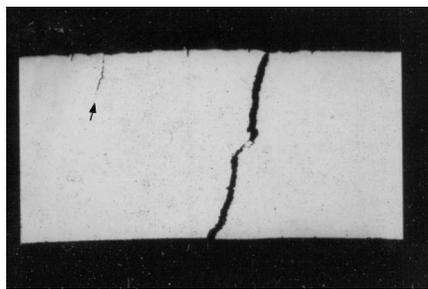


Figure 4. A cross section through the gouge Shows a dark etching area near the outside Surface with a small secondary crack (arrow) Near the fracture.

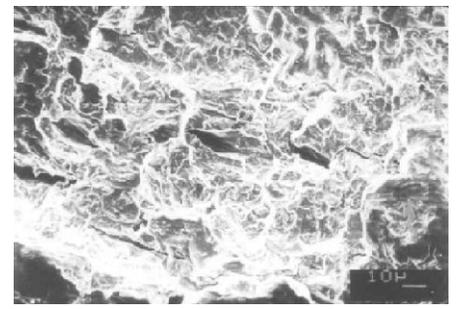


Figure 5. SEM fractograph of fatigue damage associated with the longitudinal weld seam of a 34-inch O.D. pipeline.



Figure 6. Inside surface at the failure origin of a 20-inch pipeline.

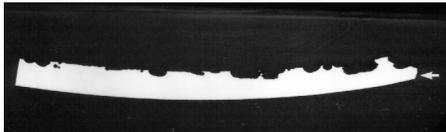


Figure 7. Cross section taken adjacent to the fracture shown in Figure 6. The arrow identifies the fracture surface in the pipeline.



Figure 8. Outside surface of pipeline section removed because of a leak. The arrows indicate two clusters of crack indications visible after magnetic particle inspection.

from unknown conditions to "pedigreed" fractures generated in the laboratory under known conditions of stress, strain, strain-rate, and environment. Fractographic examinations can also reveal changes in fracture mode, local crack propagation directions, and the progress or history of cracking.

- *Metallographic Analysis*-The fracture path relative to grain boundaries, inclusions, transformed and second phases, and external defects can be determined by metallographic analysis using standard techniques. The mounting and polishing of a cross section of matching fracture surfaces at the failure origin often provides evidence to positively identify the failure mode.

- *Chemical Composition and Mechanical Properties*-Chemical analyses and mechanical tests are generally run to determine: if the pipe is of the proper type and grade, whether it meets appropriate standards, and whether any deviation contributed to the failure. The most common mechanical tests are tensile, bend, and flattening tests. Other tests, such as Charpy impact tests or crack tip opening displacement (CTOD) tests may be useful in determining fracture behavior.

CAUSES OF PIPELINE FAILURES

Over half of all in-service pipeline failures result from some externally applied mechanical force as shown in Figure 1. The following are examples of five typical failures.

Figure 2 shows the rupture that developed in a section of 8-5/8 inch O.D. electric-resistance line pipe. Visual and metallographic examination revealed the failure was caused by mechanical damage, in the form of a gouge and dent, often associated with heavy equipment such as a back-hoe. Figure 3 shows a detail of a gouge that was near the midpoint of the rupture. The profile of the gouge, shown in Figure 4, is a polished and etched cross section of matching fracture surfaces at the failure origin. The combination of a gouge and dent is particularly damaging. The gouge cold works the steel and reduces its resistance to crack initiation. The dent, by changing the geometry, creates an area of high stress and stress concentration.

A second form of external damage can be introduced by fatigue cracking during pipe shipment, particularly in rail and sea shipment. The damage, sometimes called transit fatigue, results from flexing the pipe during load movement. Transit fatigue in seamless pipe and the base metal of welded pipe results from concentrated stresses where the pipe contacts a protrusion, such as a rivet or bolt, the weld of an adjacent pipe, or bearing strips of insufficient size. In submerged-arc welded pipe, transit fatigue cracks can develop at the toe of the weld even in the absence point contact. Figure 5 shows the fine ductile fatigue striations and secondary cracking that characterize transit fatigue damage.

Corrosion can cause failures by thinning the wall over a large area or localized pitting. Both external and internal corrosion can lead to failures, but the widespread use of cathodic protection has greatly reduced external corrosion. Figure 6 shows the inside surface at the failure origin of a 20-inch gas line that failed shortly after the operating pressure was increased. The failure resulted from internal pitting corrosion on the bottom of the pipeline that significantly reduced its wall thickness. Figure 7 shows the depth of the pitting on a polished cross-section cut transverse to the fraction (arrow).

Another form of corrosion, stress-corrosion cracking, can also lead to failures.

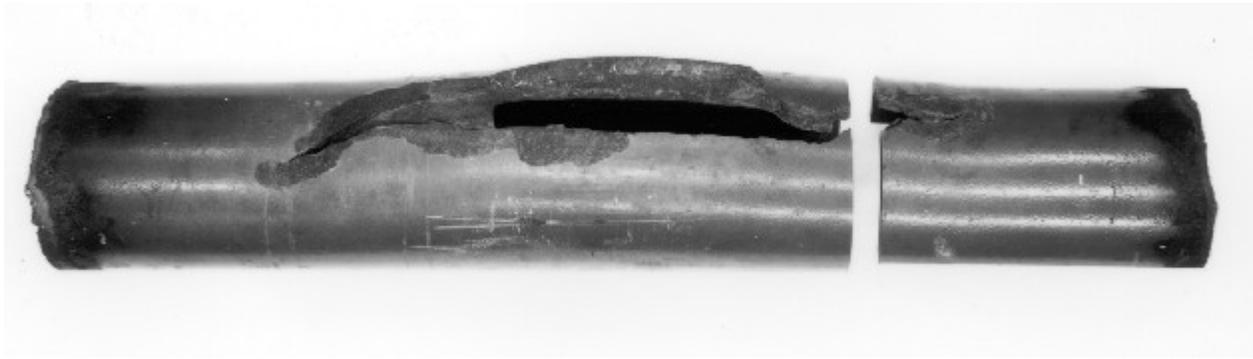


Figure 11. Hydrostatic test rupture of seamless 6-5/8 inch O.D. pipeline showing thin tongue of metal protruding from around a pipe lamination.

External stress-corrosion cracking results from the accumulation of moisture on the pipe surface at imperfections in the pipe coating. Certain corrosives in the moisture in conjunction with normal operating stresses cause cracking. Stress corrosion cracking in pipelines is identified by the distinctive intergranular nature of the cracks. Figure 8 shows cracks in a section of pipe removed for examination because of a leak. The cracks resulted from stress-corrosion cracking. The surface of a crack, extending across the wall, was broken open in the laboratory and is shown in Figure 9. A metallographic cross-section, Figure 10, showed the cracks to be intergranular.

Material defects are not common causes of service failures because they are usually found before the pipe is placed in service, either during inspection of the pipe or during hydrostatic testing. The few failures that do result typically originate at longitudinal weld seams or at laminations in seamless pipe. Figure 11 shows the rupture of a 6-5/8 inch O.D. seamless pipeline that resulted from a pipe lamination. In this instance, failure occurred during hydrostatic testing.

CONCLUSIONS

Despite advances in manufacturing, testing, and inspection of gas pipelines, failures do occur. Research and experience have helped characterize the different types of failures so that their cause can be determined and appropriate preventive measures applied. By using careful analytical techniques, and with a thorough understanding of the pipeline operating conditions, the cause of failure can almost always be determined.



Figure 9. Surface of crack (see Figure 8) that was broken open in the laboratory. The inside surface is at the top.

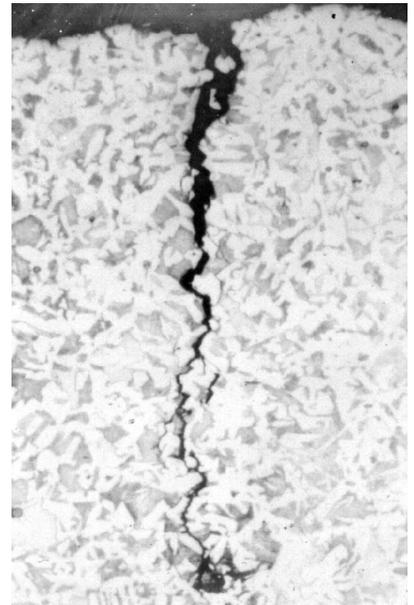


Figure 10. Microstructure in area of secondary crack showing an intergranular cracking mode.