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Examination of Failed 3/4 Inch Steel Pipe Natural Gas Service Line, Sierra Pacific Power Company, Reno, Nevada

T. Robert Shives

Mechanical Properties Section
Metallurgy Division
Institute for Materials Research
National Bureau of Standards
Washington, D. C. 20234

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Failure Analysis Report

Prepared for
Office of Pipeline Safety
Department of Transportation
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U.S. DEPARTMENT OF COMMERCE, Rogers C.B. Morton, Secretary
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Acting Director

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FIGURES (continued)

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SUMMARY

At the request of the Office of Pipeline Safety, the NBS Mechanical Properties Section examined a fractured 3/4 inch diameter steel pipe gas service line from Reno, Nevada. The pipe was reportedly fabricated according to American Petroleum Institute specification 5L.

The gas line had failed about two feet from the house it was serving, apparently by overload. The fracture surfaces exhibited essentially no corrosion product and there was no evidence to indicate a pre-existing crack. Quasi-cleavage was the fracture mode over a significant portion of the fracture. Comparison of the fracture with laboratory produced uniaxial tensile fractures indicated that failure was likely caused by the single application of an essentially axial tensile load at a relatively rapid loading rate.

The ultimate tensile strength of the material conformed to that required by API specification 5L. There was some banding in the microstructure.

Examination of Failed 3/4 Inch Steel Pipe Natural Gas Service Line, Sierra Pacific Power Company, Reno, Nevada

1. INTRODUCTION

1.1 Reference

Office of Pipeline Safety, Department of Transportation, Washington, D.C. 20590. This investigation was conducted at the request of Mr. Lance F. Heverly of the Office of Pipeline Safety under order number DOT-AS-10041. The request was made on October 1, 1974.

1.2 Background Information

The information in this section was furnished by Messrs. Lance F. Heverly and Paul J. Cory of the Office of Pipeline Safety, and by Mr. Charles Lefeber of the Public Service Commission of Nevada.

On September 8, 1974, there was an explosion at the residence at 701 Thoma Street in Reno, Nevada, which was attributed to the ignition of escaping natural gas. A break was found in the 3/4 inch diameter steel gas service line to the residence at a point about two feet from the house and 75 feet from the gas main at the street. Fracture had occurred in a threaded portion near the end of a pipe length where it was joined to another length with a coupling. At the location of the failure, the pipe was under 26 to 30 inches of cover.

The pipe was reported to have been manufactured in accordance with American Petroleum Institute specification API 5L. The gas line had been installed in 1956. From 1956 to 1963, it had carried a mixture of propane and air. Since 1963, it had carried natural gas. At the time of failure, pressure in the line was about 25 psig.

The gas main was cathodically protected, the nearest anode to the failure being about 40 feet from the junction of the main and the service line. There were no anodes attached to the service line itself.

The sewer service line to the same residence was located under the gas service line at the point of failure. The sewer service line pipe was cast iron where it left the house; from there to the main it was clay. The sewer service line was under about eight feet of cover, and it was reported that the backfill was "very poor." There had been some settling of the soil. The sewer service line was thought to have been installed at about the same time as the gas service line.

The break in the gas line occurred under an area of the yard where there were extensive plantings of shrubbery. The shrubbery was frequently watered and fertilized. The ground in the vicinity of the fracture was described as being "water saturated."

The soil in this part of Reno was reported to be "corrosive" in nature. An odor of "swamp gas" was detected in the vicinity of the pipeline.

1.3 Parts Submitted

Two pieces of 3/4 inch diameter carbon steel gas service pipe, each about 1 1/2 feet in length, were submitted to the NBS Mechanical Properties Section for examination. The pipe pieces were tagged "PSSC - S. P. P. Co., 701 Thoma Street, Reno, Nev," "A" and "B." A coupling which had joined the two pieces of pipe was attached to the piece tagged "A." The piece tagged "B" had fractured in the coupling, and a small part of the threaded end of this piece was still in the coupling. The two pieces of pipe are shown as received at NBS in figure 1.

2. PURPOSE

The Office of Pipeline Safety requested that the NBS Mechanical Properties Section examine the fractured pipe in order to characterize the fracture and, insofar as possible, to determine the cause of failure.

3. RESULTS OF EXAMINATIONS, TESTS, AND MEASUREMENTS

3.1 Visual and Macroscopic Examination

Piece "B" of the pipe had fractured transversely in a threaded region about 7/16 inch from one end at a coupling joining pieces "A" and "B." The 7/16 inch piece was still in the coupling when the parts were received. This coupling had "recessed" threads; i.e., the last 3/16 inch at either end of the coupling was not threaded. The inside diameter of the coupling in the unthreaded region was about 0.07 inch greater than the greatest outside diameter of the pipe in a threaded region. The pipe had fractured at the outermost thread of the coupling.

The two opposing fracture surfaces are shown in figure 2 as received at NBS. There was essentially no corrosion product on either of them, although some parts of the surface of the fracture still attached to the coupling were covered with a tarry appearing substance. This substance, which could be rather easily removed mechanically, was not found on the other fracture surface. Both fracture surfaces had suffered an insignificant amount of mechanical damage. Except for about a 6 1/2 inch length surrounding (and including) the coupling, the outside surfaces of the two pieces of pipe were coated with a black, tarry substance. The region around the coupling was wrapped with what appeared to be black electrical tape. When the pipe was received at NBS, this tape had been removed from piece "B" for a short distance beyond the threads adjacent to the fracture. The exposed area which had been covered with the tape was essentially free of corrosion product.

The remainder of the tape and the heavier tarry coating were removed at NBS from the piece of pipe labeled "B." There was essentially no evidence of corrosive attack on the whole length of pipe.

The tape was removed from the unfractured piece of pipe (piece "A") where it entered the coupling. There was some corrosion product on this piece of pipe, but the corrosive attack appeared to be insignificant.

There was no evidence of any significant mechanical damage to either piece of pipe or to the coupling.

Some deformation could be seen in the vicinity of the step on the fracture surface. This region would have probably been the last part of the fracture to form. The step can be seen in figure 2 (arrow) on the part of the fracture still attached to the coupling.

3.2 Fractographic Examination

The fracture surface of pipe piece "B" (not attached to the coupling) was examined with the scanning electron microscope after it was cleaned with petroleum ether. Some areas of the fracture surface exhibited dimpled rupture as the primary fracture mode, some areas exhibited quasi-cleavage as the dominant mode, and some areas exhibited a mixed mode. The fracture surface examined is shown in figure 3. The mode exhibited by the fracture at each of the areas numbered in figure 3 is as follows:

Area	Fracture Mode
1	Predominantly dimpled rupture
2	Mixed - about 75% quasi-cleavage, 25% dimpled rupture
3	Predominantly quasi-cleavage, some dimpled rupture
4	Essentially all dimpled rupture
5	Mixed - mostly dimpled rupture near the inside and outside walls, quasi-cleavage in the center
6	At outside, nearly all quasi-cleavage
7	At inside, mostly quasi-cleavage with some dimpled rupture adjacent to the inside wall
8	Essentially all quasi-cleavage
9	Essentially all quasi-cleavage
10	Essentially all quasi-cleavage
11	About half quasi-cleavage and half dimpled rupture
12	Nearly all dimpled rupture

Representative fractographs from areas 1, 5, 7, and 9, figure 3, are shown in figures 4, 5, 6, and 7, respectively.

3.3 Tensile Tests

It was decided to conduct uniaxial tensile tests on specimens of the submitted pipe in order to produce fractures under known conditions of loading rate for comparison with that of the submitted failure. The decision to run the tests was based on several criteria as follows. (1) There was a considerable amount of quasi-cleavage on the fracture surface of this reasonably ductile material. Quasi-cleavage is normally associated with a lack of ductility. (2) There was no evidence of a pre-existing crack which might suggest stress corrosion cracking as a possible crack mechanism. (3) The fracture did not appear to have been produced by the application of a bending load.

Consequently, two specimens, each about three inches long, were made from the piece of the submitted pipe labeled "B." To simulate the configuration of the field fracture, each specimen was threaded at one end. For the test, the threaded end of the specimen was fitted into a fixture on the tensile testing machine and the other end was secured with a pin through a drilled hole.

One of the specimens was tested at a relatively low loading rate and the other at a relatively high loading rate. The specimen tested at the low loading rate was tested to failure in tension at a cross head speed of 0.02 inch per minute. As would be expected, failure occurred in the threads. The fracture that was produced exhibited dimpled rupture as the primary factor mode over the entire fracture surface except for one small region which was close to the apparent crack origin. In this region, the mode was mixed, consisting partly of dimpled rupture and partly of quasi-cleavage. The quasi-cleavage was near the center of the fracture surface; i.e., not near the inside or outside wall surfaces of the pipe. A representative fractograph from an area not close to the apparent crack origin is shown in figure 8. Part of the area showing a mixed mode is shown in figure 9.

The specimen that was tested at the higher loading rate was tested to failure in the same way as the first specimen, but the cross head speed was about 16 inches per minute. The fracture surface was quite different from that produced at a cross head speed of 0.02 inch per minute. Approximately one-third of the area of the fracture surface exhibited quasi-cleavage as the primary fracture mode. A representative fractograph showing quasi-cleavage as the primary mode appears in figure 10. About an additional third of the fracture surface exhibited a mixed mode; i.e., both dimpled rupture and quasi-cleavage. An example of the mixed mode is shown in figure 11. The remainder of the fracture surface exhibited dimpled rupture as the primary fracture mode. This part of the fracture included the apparent last part of the fracture to form. A representative fractograph from this region is shown in figure 12.

The increase in testing speed from 0.02 inch per minute to 16 inches per minute significantly increased the percentage of the fracture surface exhibiting quasi-cleavage as the fracture mode, and correspondingly decreased the percentage of dimpled rupture.

3.4 Metallographic Examination

Four longitudinal sections adjacent to the fracture were examined metallographically. These sections intersected the fracture at approximately locations 1, 5, 6, and 12, figure 3. As-polished regions showing average and estimated worst inclusion areas from these four sections are shown in figures 13 and 14, respectively.

Etched fields from two of these sections are shown in figures 15 and 16. The fracture profile in each case is horizontal at the top in the figure. In figure 15, where the section intersects the fracture at location 6 in figure 3, the lack of distorted grains indicates that there is essentially no mechanical deformation except possibly adjacent to the fracture on the inside of the pipe (upper right in the figure). This lack of deformation is consistent with the fracture mode in this region of the fracture which is primarily quasi-cleavage. The microstructure consists primarily of ferrite with small amounts of pearlite. There is considerable evidence of banding (straight vertical features). In the narrow bands, there appears to be only ferrite and no pearlite. Sometimes manganese segregates to the narrow ferrite bands.

Figure 16 shows part of an etched specimen intersecting the fracture surface at location 12, figure 3. The fracture exhibited dimpled rupture as the primary fracture mode in this region. Consistent with this ductile mode of fracture, there is considerable mechanical deformation adjacent to the fracture as evidenced by the necking down and bending of the material. In this particular section, no banding is evident. The microstructure again consists primarily of ferrite with small amounts of pearlite.

The two other sections examined showed some evidence of banding, but to a lesser extent than that exhibited in figure 15.

3.5 Hardness Measurements

A Knoop hardness traverse at a load of 500 grams (KHN_{500}) was made on the longitudinal section that intersected the fracture at location 12, figure 3. The traverse was made on a plane perpendicular to the longitudinal axis of the pipe. The results are as follows:

Distance from the outside wall surface of the pipe	KHN_{500}	Approx. R_B equivalent
0.004	186	87
0.008	195	89
0.016	186	87
0.024	206	91
0.032	211	92
0.040	238	97
0.048	182	86
0.056	194	89
0.064	158	78
0.072	174	83
0.080	174	83
0.088	179	85

The hardness was highest (R_B 97) in one of the narrow banded areas shown in figure 15. This is consistent with the way in which the specimens responded to metallographic polishing. It may be that the increased hardness is due to manganese segregation to the narrow ferrite bands.

The ultimate tensile strength approximately equivalent to the lowest of the above hardness values is well above the 60,000 psi minimum required by API specification 5L.

4. DISCUSSION

This API specification 5L steel pipe gas service line failed after about 18 years use at a location about two feet from the house it was serving. Failure occurred in a threaded region of the pipe where it was attached to a coupling. The threading operation had reduced the wall thickness, and consequently the cross sectional area of the pipe, especially in the thread roots, in the region of the failure. The thread roots also acted as stress concentrators. These are the likely reasons that the fracture occurred in the threads.

The fact that the fracture surfaces exhibited little or no evidence of corrosive attack suggests that the fracture had occurred only a short time before the pipe was removed from the ground, and further, that there was no pre-existing crack.

Quasi-cleavage was the dominant fracture mode over a significant percentage of the fracture surface. This indicates a lack of ductility. A relatively low-speed bending or tensile overload failure at room temperature in a relatively low strength steel such as API 5L would normally be expected to result in a ductile fracture with dimpled rupture as the primary fracture mode. The low strain rate tensile test performed at NBS resulted in such a fracture. The high strain rate tensile test performed at NBS resulted in a fracture in which quasi-cleavage was the primary fracture mode over about two-thirds of the fracture surface. The fracture surface of the specimen tested at 16 inches per minute was similar to that of the submitted failure.

Based on the appearance of the fracture and the results of the NBS tensile tests, a reasonable premise is that the fracture of the submitted pipe was caused by the single application of a predominantly axial tensile load at a relatively rapid rate. This premise leads to the possibility that the pipe failed as a result of the explosion at the house, rather than that the break occurred before the explosion.

In the sections examined, the inclusion content did not appear to be abnormal. The microstructure, which consisted of ferrite and a small amount of pearlite, appeared to be satisfactory. Some banding, which apparently had no significant influence on the failure, appeared in places.

The results of hardness measurements which were converted to tensile strengths indicated that the ultimate tensile strength requirement of API specification 5L was satisfied.

The lack of corrosion product on the pipe suggests that the heavy watering and fertilizing of the lawn and shrubbery did not have any significant effect on the condition of the pipe.

5. CONCLUSIONS

1. Failure occurred in this 3/4 inch diameter steel pipe gas service line due to the apparent single application of an essentially axial tensile load, resulting in an overload fracture.

2. Quasi-cleavage was the primary fracture mode over a significant portion of the fracture surface, indicating less ductility than would normally be expected in a low loading rate overload fracture in a steel of this type.

3. The fracture surfaces were essentially free of corrosion product. There was no evidence of a pre-existing crack.

4. The outside wall surface of the pipe had suffered no significant corrosive attack.

5. The ultimate tensile strength of the pipe material (based on a conversion from hardness measurements) met the requirement of API specification 5L.

6. The microstructure of the pipe material appeared to be satisfactory, although there was some banding.

6. ACKNOWLEDGEMENT

Mr. L. C. Smith of the NBS Mechanical Properties Section carried out the metallographic specimen preparation, the photographic work, and the hardness measurements. Mr. W. A. Willard of the NBS Mechanical Properties Section and Mr. Smith conducted the tensile tests.

Figure 1. The two pieces of pipe as received at NBS. The smallest division of the scale equals 1/16 inch.

Figure 2. The two opposing fracture surfaces of the pipe as received at NBS. Piece "B" is at the left and piece "A" is at the right. Arrow indicates step in the fracture. The smallest division of the scale equals 1/16 inch.

Figure 3. The fracture surface from the part of piece "B" which was not attached to the coupling. The step in the fracture (where the fracture path jumped a thread) is at the bottom. The numbers 1 through 12 represent areas referred to in the Section on the Fractographic Examination. X 4

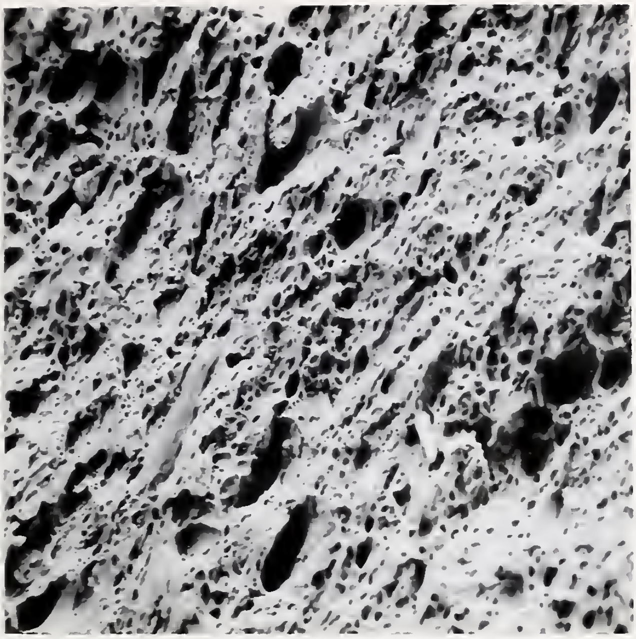

Figure 4. SEM fractograph from area 1, figure 3. The primary fracture mode is dimpled rupture. X 235

Figure 5. SEM fractograph from area 5, figure 3. The fracture mode is mixed with dimpled rupture adjacent to the inside and outside wall surfaces at the left and all the way across at the right. Quasi-cleavage appears in the center at the left. The inside wall surface is at the bottom. X 78

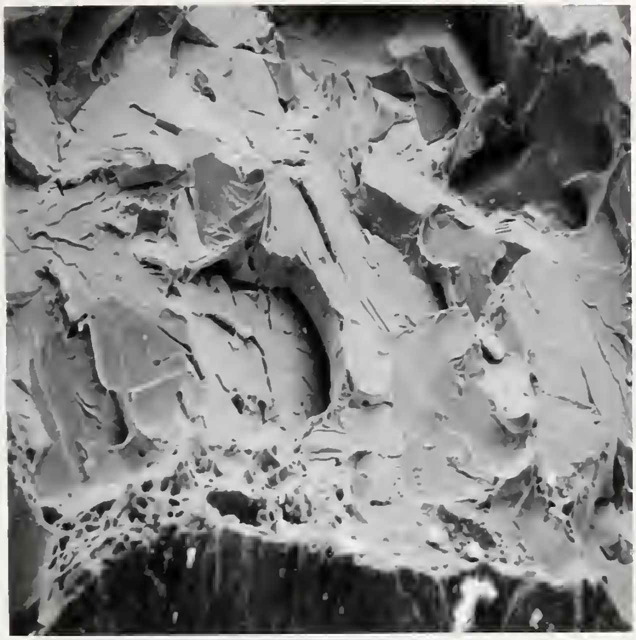

Figure 6. SEM fractograph from area 7, figure 3. The primary fracture mode is quasi-cleavage. There is some dimpled rupture near the inside wall. X 420

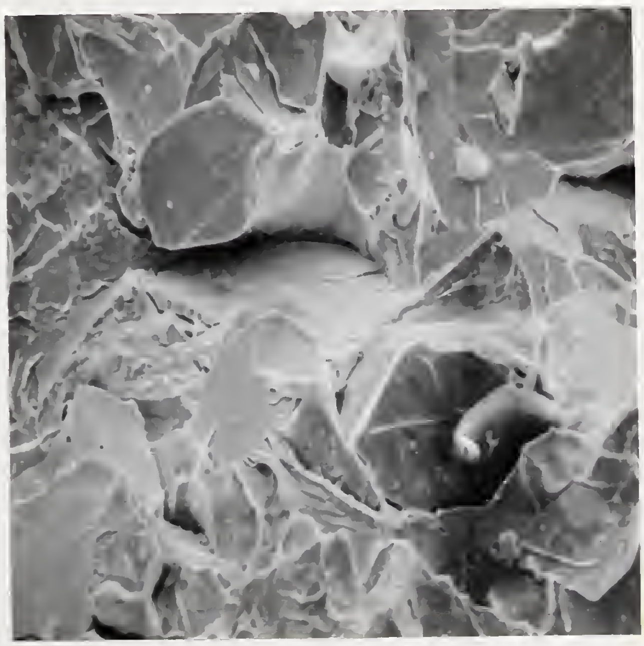

Figure 7. SEM fractograph from area 9, figure 3. The fracture mode is essentially all quasi-cleavage. X 475

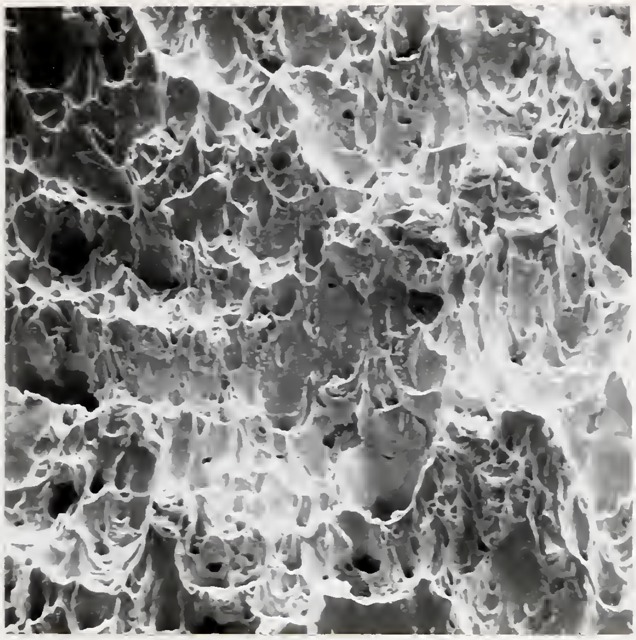

Figure 8. SEM fractograph from the tensile fracture produced in the laboratory at a machine cross head rate of 0.02 inch per minute. The mode of fracture is essentially all dimpled rupture. X 280

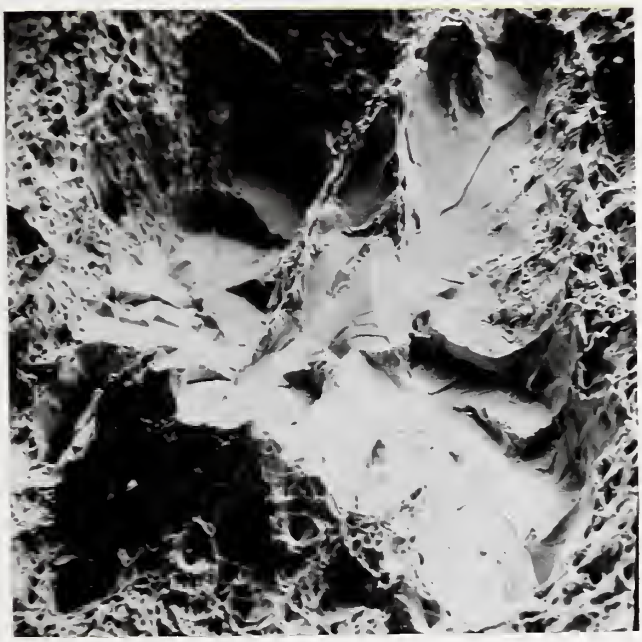

Figure 9. SEM fractograph from the tensile fracture produced in the laboratory at a machine cross head rate of 0.02 inch per minute. The mode of fracture in the center is quasi-cleavage. Around the periphery, the mode is primarily dimpled rupture. X 215

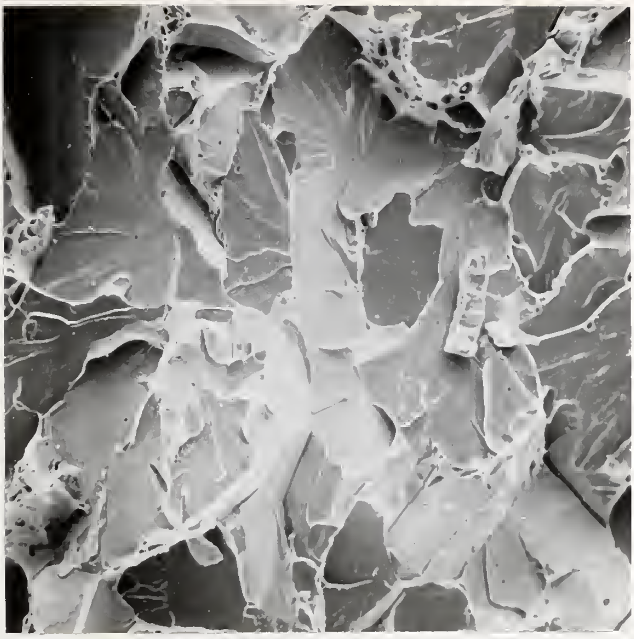

Figure 10. SEM fractograph from the tensile fracture produced in the laboratory at a machine cross head rate of 16 inches per minute. The mode of fracture in this region is primarily quasi-cleavage. There is a small amount of dimpled rupture. X 260

Figure 11. SEM fractograph from the tensile fracture produced in the laboratory at a machine cross head rate of 16 inches per minute. The fracture mode is mixed; there is about half dimpled rupture and half quasi-cleavage in this field. X 105

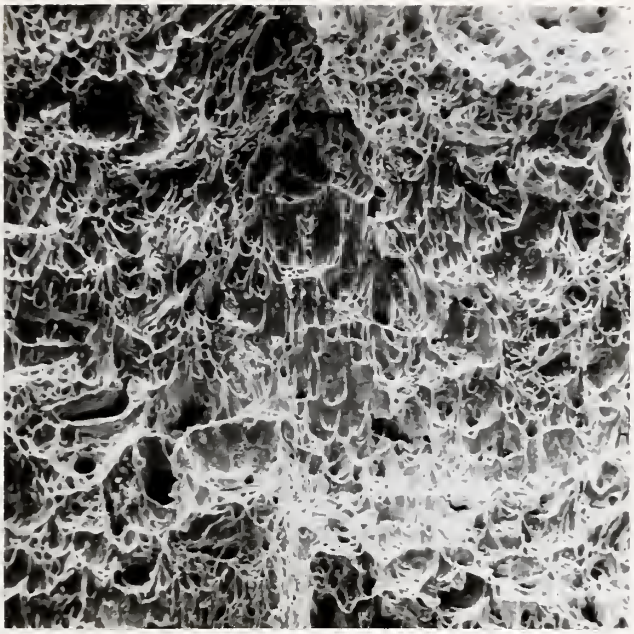

Figure 12. SEM fractograph from the tensile fracture produced in the laboratory at a machine cross head rate of 16 inches per minute. The fracture mode is primarily dimpled rupture. X 290

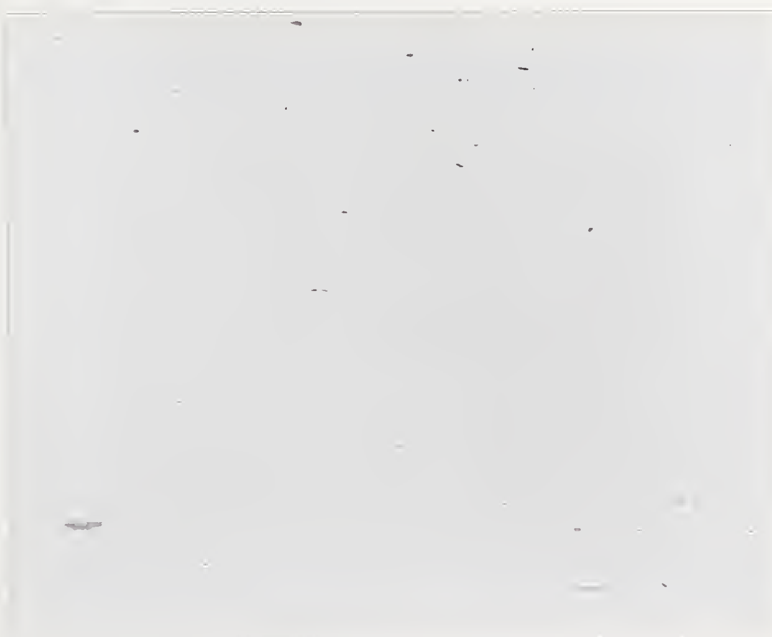

Figure 13. As-polished longitudinal section that intersected the fracture at location 5, figure 3. This field exhibits the average inclusion content for the material examined. X 100

Figure 14. As-polished longitudinal section that intersected the fracture at location 6, figure 3. This field is estimated to have the greatest inclusion content of any of the sections examined. X 100

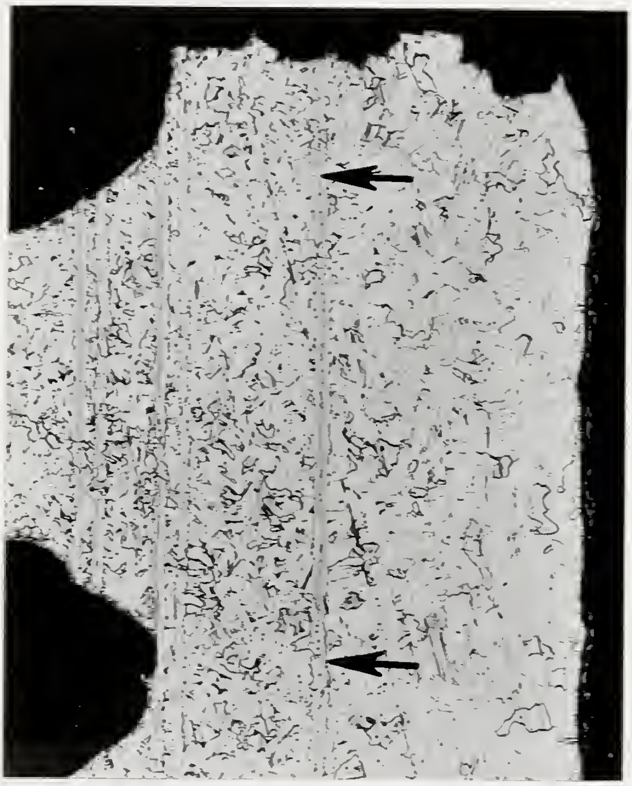

Figure 15. Etched longitudinal section intersecting the fracture at location 6, figure 3. The fracture profile is horizontal at the top. The microstructure consists of ferrite and pearlite except in the narrow bands which consist of ferrite. An example of one of the narrow bands is indicated by the arrows. The inside wall is vertical at the right and the threads are at the left. Etchant: 1% nital X 40

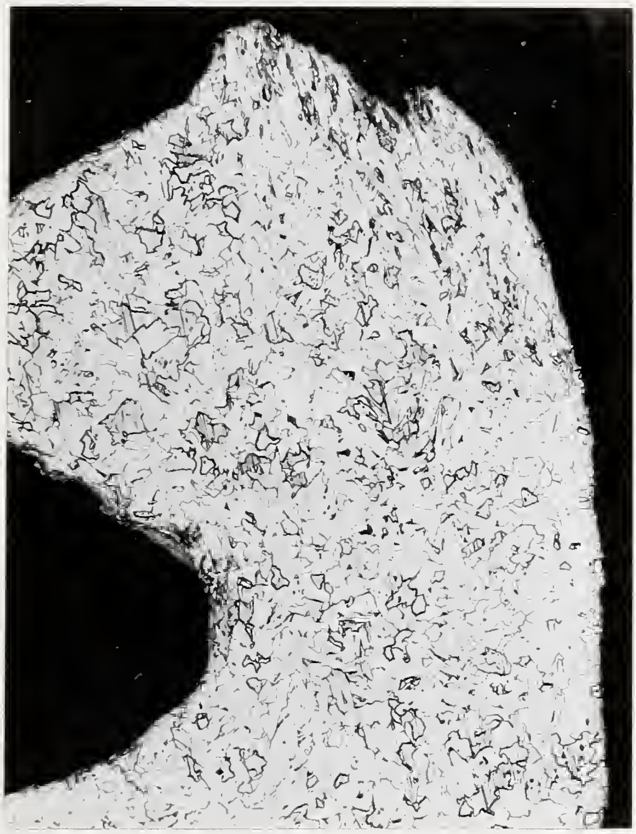

Figure 16. Etched longitudinal section intersecting the fracture at location 12, figure 3. The fracture profile is horizontal at the top. The microstructure consists of ferrite and pearlite. Distorted grains are evidence of deformation adjacent to the fracture. The inside wall is vertical at the right and the threads are at the left.
Etchant: 1% nital X 40

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

At the request of the Office of Pipeline Safety, the NBS Mechanical Properties Section examined a fractured 3/4 inch diameter steel pipe gas service line from Reno, Nevada. The pipe was reportedly fabricated according to American Petroleum Institute specification 5L.

The gas line had failed about two feet from the house it was serving, apparently by overload. The fracture surfaces exhibited essentially no corrosion product and there was no evidence to indicate a pre-existing crack. Quasi-cleavage was the fracture mode over a significant portion of the fracture. Comparison of the fracture with laboratory produced uniaxial tensile fractures indicated that failure was likely caused by the single application of an essentially axial tensile load at a relatively rapid loading rate.

The ultimate tensile strength of the material conformed to that required by API specification 5L. There was some banding in the microstructure.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Gas pipe; high strain rate fracture; overload fracture; pipe fracture

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