NBSIR 76-1121 (R

# Examination of Failed Six Inch Cast Iron Pipe Natural Gas Main, Brooklyn Union Gas Company, Queens County, New York

Bruce W. Christ and T. Robert Shives

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

Failure Analysis Report

July 1976

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Prepared for

**Office of Pipeline Safety Operations**
**Department of Transportation**
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*
Edward O. Vetter, *Under Secretary*
Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

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FIGURES (continued)

## SUMMARY

The Office of Pipeline Safety Operations, Department of Transportation, submitted a length of six inch diameter cast iron natural gas pipeline to the NBS Mechanical Properties Section for examination. The OPSO indicated that the pipe length was taken from Kew Gardens, Queens County, New York. The pipe length contained a transverse crack that had penetrated the entire wall thickness for about 90% of the pipe circumference. The nature of the corrosion product on the fracture surface indicated that the crack was not "fresh." The fracture was brittle --- typical for gray cast iron. Failure apparently occurred due to the application of a bending load from an external source. The material appeared to be normal for gray cast iron in regard to microstructure and hardness. Chemical composition also appeared normal, with the possible exception of a slightly high phosphorus content. In the sections examined, there was one area of high porosity. There were localized regions of graphitization, but the discontinuous nature of the graphitization around the circumference of the pipe suggests that graphitization did not play a significant role in the propagation of the crack. Measured variation in wall thickness was within specified tolerances.

# Examination of Failed Six Inch Cast Iron Pipe Natural Gas Main, Brooklyn Union Gas Company, Queens County, New York

## 1. INTRODUCTION

### 1.1 Reference

Office of Pipeline Safety Operations, Department of Transportation, Washington, D.C. 20590. This investigation was conducted at the request of Mr. Cesar DeLeon, Acting Director of the Office of Pipeline Safety Operations, under Agreement Number DOT-AS-60053. The request was dated April 14, 1976 and was received at NBS on April 28, 1976.

### 1.2 Background Information

The information in this section was furnished by Mr. Walter Dennis, Jr., of the Office of Pipeline Safety Operations, Mr. Robert L. Swartwout of the New York State Public Service Commission, Mr. Kurt M. Richter of the Brooklyn Union Gas Company, and Mr. John T. Wynne, Jr., Assistant District Attorney for Queens County, New York.

On January 30, 1976, there was an explosion followed by a fire involving four houses on 86th Road between 134th and 135th Streets in Kew Gardens, Queens County, New York. The houses were identified as follows: 134-14, 134-16, 134-18, and 134-20 86th Road. The explosion and subsequent fire were attributed to an accumulation of natural gas that had escaped from a cracked six inch diameter cast iron pipe gas main located under 86th Road about two feet from and running parallel to the south curb line of 86th Road.

The gas main had been installed in January 1927. The main was under three feet of cover at the location of the crack.

Within the last five years, there had apparently been no excavations within 9 feet east and 14 feet west of the location of the crack in the gas main pipe. In October 1971, however, excavations were made over the gas main about 10 feet east and 15 feet west of the location of the crack in order to put plastic inserts in the service lines to the houses located at 134-15 and 134-16 86th Road.

It was reported that no unusually heavy traffic had been using the street. The heaviest vehicles to use the street, at least on a regular basis, were garbage collecting trucks and fuel oil delivery trucks. The crack in the gas main pipe occurred in what was described as a quiet residential area.

The closest pipeline in 86th Road to the gas main in the vicinity of the fracture was a 12 inch diameter storm sewer. The sewer, which was installed in 1946, lay essentially parallel to the gas line and about 7 feet north of it.

It was reported by the Brooklyn Union Gas Company that there had been unusually large settlement of the north curb and a 4 inch settlement of the south curb line of 86th Road. The west wall of the house located at 134-14 86th Road had abnormal settlement in the front of the building. The greatest settlement of the south curb was about 17 feet west of the location of the crack in the pipe. All points of maximum settlement were west of the crack in the pipe. The settlement values are based on a comparison between a 1956 survey and a survey made on February 19, 1976.

According to Mr. Richter, the specification to which this cast iron pipe was manufactured was probably the 1925 edition of the American Gas Association Standard Specifications For Cast Iron Pipe and Special Castings. A copy of this specification was provided to NBS by Mr. Swartwout.

### 1.3 Part Submitted

A piece of the six inch diameter cast iron pipe about 5 feet-8 inches (1.7 meters) long containing the crack was delivered in a wooden crate to the NBS Mechanical Properties Section on February 9, 1976 by Detective Robert D. Gabriel of the New York City Police Department, Mr. Mario Martello of the New York State Public Service Commission, and Mr. Willie Merriweather of the Brooklyn Union Gas Company. The pipe length was cushioned in foam rubber.

## 2. PURPOSE

The Office of Pipeline Safety Operations requested that the NBS Mechanical Properties Section perform the following tasks in conjunction with an examination of the cracked pipe.

1. Provide photo documentation and maintain a custodial record.
2. Prepare a test specimen in such a manner so as to preserve the extremities of the fracture.
3. Examine for possible graphitization.
4. Determine mechanical properties, make a chemical analysis, and compare results with appropriate standards.
5. Provide fractographic analysis of the fracture surfaces.
6. Make additional tests or analyses that may be necessary to determine, if possible, the failure cause.

## 3. RESULTS OF EXAMINATIONS, TESTS, AND ANALYSES

### 3.1 Visual and Macroscopic Examination

The submitted pipe length is shown as received at NBS in figure 1, except that the top of the wooden crate in which it was delivered had been removed. As soon as the pipe length was removed from the crate, three 2 1/2 cm wide steel straps were placed across the crack to keep it from propagating further as the pipe was handled. The straps were held in place with machine screws that were attached to the pipe in drilled and tapped holes on either side of the crack. One such strap can be seen in figure 2 which shows what was reported by the Brooklyn Union Gas Company to be the top of the pipe as it was oriented in service.

The transverse crack that can be seen in figure 2 had penetrated the entire wall thickness of the pipe around nearly 90% of the pipe circumference. With the pipe oriented as shown in figure 2, the "hinged" portion is near the bottom.

Prior to being delivered to NBS, "top" had been written with chalk on what was reported to be the top of the pipe as it had been oriented in service. In addition, the pipe length had been marked on the reported top with an "E" on one side of the crack and with a "W" on the other side. The "E" and "W" can be seen in figure 2. For convenience in referring to the pipe lengths on either side of the crack, one side will be referred to as the "E-length" and the other side as the "W-length." The crack was about 96 cm from the end of the "E-length."

When received at NBS, the pipe length (except for an area near the crack) was covered with what appeared to be a mixture of ashes and soil. Some of the pipe surface near the crack had been cleaned of the ash-soil mixture before the pipe had been submitted for examination. The cleaning was especially evident at the top of the pipe. Some of the ash-soil mixture on the pipe can be seen in figure 2, and more can be seen in figure 3 which shows the bottom of the pipe in the region of the crack. Where the ash-soil mixture had been removed, the pipe surface exhibited some general corrosion, but this corrosion did not appear to be severe enough to significantly affect the integrity of the pipe. Corrosion of the inside wall surface of the pipe was negligible.

There were two depressions near the top of the pipe adjacent to the crack. It appeared as though material had either been chipped out or had fallen out. These depressions can be seen in figure 4. No other significant mechanical damage to the pipe was observed.

In order to expose the fracture surface for examination, while preserving the crack extremities, the pipe length was cut as follows. A through transverse saw cut was made in the E-length about 33 cm from the fracture. A similar saw cut was made in the W-length about 6 cm from the fracture. Then on an approximate pipe diameter, a longitudinal saw cut was made from the W-length transverse saw cut into the crack. Both the E-length and the W-length fracture surfaces were then exposed over about 180° of the pipe circumference. Only the W-length fracture surface was used in the NBS examination. The E-length side of the fracture was retained in the as-received condition at NBS.

The entire exposed fracture surface was covered with what appeared to be a superficial, light reddish-orange corrosion product as shown in figure 5. Approximately one-half of the exposed W-length fracture surface was cleaned ultrasonically. The light colored corrosion product was removed by this cleaning operation. Beneath the light colored product, the entire portion of the fracture surface that had been cleaned was covered with a more adherent, darker colored corrosion product that was not removed by the ultrasonic cleaning. Much of this material was removed from approximately a 2 1/2 cm length of the fracture by repetitive replication with cellulose acetate, but some of it remained. This 2 1/2 cm length was about 180° circumferentially from the hinged portion and was in the vicinity of the probable fracture origin near the top of the pipe.

### 3.2 Fractographic Examination with the Scanning Electron Microscope

The 2 1/2 cm length of the W-length fracture that had been cleaned both ultrasonically and by repetitive replication was examined with the scanning electron microscope. Figure 6 shows features typical of those exhibited by the fracture about halfway between the inside and outside surfaces of the pipe. Two examples of the fracture surface features near the outside surface of the pipe are shown in figures 7 and 8. Note, the magnifications of figures 6, 7, and 8 are different.

Some evidence of cleavage appears in figures 6 and 7. The smooth appearing regions in figure 8 are cavities that may have been porosity or gas pockets. In figure 6, the narrow dark particles are graphite flakes. Such flakes are a normal constituent in gray cast iron. The graphite flakes are not as easily seen in figures 7 and 8. Fracture features near the inside surface of the pipe appeared similar to those shown in figure 8.

### 3.3 Chemical Analysis

A chemical analysis was performed on a sample of the pipe material by a commercial laboratory with the following results:

| Element | Percent by Weight |
|---|---|
| Total carbon | 3.61 |
| Combined carbon | 2.84 |
| Manganese | 0.35 |
| Phosphorus | 0.596 |
| Sulfur | 0.088 |
| Silicon | 1.80 |
| Nickel | 0.03 |
| Chromium | 0.04 |
| Molybdenum | <0.01 |
| Copper | 0.07 |

The 1925 edition of the American Gas Association Standard Specifications for Cast Iron and Special Castings does not specify a chemical composition for the pipe material. However, the chemical composition of the Queens County pipe appears to be normal for a gray cast iron, with the possible exception of a slightly high phosphorus content. A phosphorus content greater than 0.50% is considered undesirable since it may lead to the formation of excessive steadite, a brittle phase consisting of iron-iron phosphide eutectic.[1]

## 3.4 Wall Thickness Measurements

It was reported by the Brooklyn Union Gas Company that the pipe had been pit cast, a process that generally resulted in a nonuniform wall thickness around the pipe circumference. There was, indeed, some variation in the wall thickness of the submitted pipe length. As measured on a cross section about 6 cm from the fracture, the minimum wall thickness was 0.35 inch near the top of the pipe (as the pipe was reportedly oriented in service) and the maximum was 0.48 inch near the bottom of the pipe. This variation in wall thickness is within the tolerances given in the 1925 edition of the American Gas Association Standard Specifications for Cast Iron Pipe and Special Castings.

## 3.5 Metallographic Examination

An unetched longitudinal section through the approximate top of the W-length of the pipe showing the fracture profile appears in figure 9. The fracture profile is at the left, the outside surface of the pipe is at the bottom, and the inside surface of the pipe is at the top as the section is oriented in the figure. Part of the fracture profile is shown at higher magnification in figure 10. The apparent lack of deformation adjacent to the fracture is characteristic of a low ductility or brittle fracture. The thin dark particles appearing in figure 10 and in several subsequent figures are graphite flakes.

The mottled region that can be seen in figure 9 in about the center one-third of the section length, and away from the outside wall surface of the pipe, is in an area of porosity or gas pockets. Some of this porosity is shown at higher magnification in figure 11. Of the sections of the pipe examined, the area shown in figures 9 and 11 contains the greatest concentration of porosity.

The dark region along the outer wall surface in figure 9 is graphitized. Two areas from the section appearing in figure 9 showing partial graphitization and nearly complete graphitization appear in figures 12 and 13, respectively.

Two transverse rings were taken through the W-length of pipe at 6 cm and 15 cm from the fracture. Both of these rings exhibited some evidence of graphitization. One of the rings is shown in figure 14.

A longitudinal section intersecting the fracture at one of the depressions mentioned earlier where material was missing (arrows A, figure 4) is shown in figure 15. Material adjacent to the depression (upper left, figure 15) is graphitized.

The region of severest graphitization in the sections examined can be seen in figure 9 near the right side of the photomacrograph. Graphitization has penetrated about 3/4 of the wall thickness of the pipe in this region.

The typical microstructure of the pipe material away from the graphitized regions is shown in figure 16. The microstructure consists primarily of graphite flakes (long, thin, dark particles) and pearlite (fingerprint pattern) with small amounts of ferrite (light color) and steadite (small rounded particles).

### 3.6 Hardness Measurements

Brinell hardness measurements (HB) were made on a cross section through the pipe. The results of four measurements averaged HB 153. The 1925 edition of the American Gas Association Standard Specifications For Cast Iron Pipe and Special Castings does not specify hardness, but the measured hardness is reasonable for gray cast iron.[1]

## 4. DISCUSSION

This six inch diameter cast iron natural gas pipe failed as a result of the initiation and propagation of a transverse crack that penetrated the entire wall thickness of the pipe for about 90% of its circumference. The hinged portion of the cracked pipe was reportedly at the bottom as the pipe had been oriented in service. Cracks of this nature can be caused by the application of an external bending load.

Perhaps the most significant feature of the fracture surfaces was the corrosion products found on them. The entire portions of the fracture surfaces that were exposed during the examination were covered with a light colored superficial corrosion product that was rather easily removed by ultrasonic cleaning. Beneath the light colored product, however, was a darker, more adherent corrosion product. Attempts to remove this darker material by ultrasonic cleaning were unsuccessful. Much of it was removed from a 2 1/2 cm length of the fracture by repetitive replication with cellulose acetate, but some remained. The amount, color, and adherence of the darker corrosion product on the fracture surface indicates that the crack was not "fresh."

No significant mechanical damage to the pipe was observed, with the possible exception of two depressions adjacent to the crack near the top of the pipe where material appeared to be missing. A metallographic examination of a section through one of the depressions revealed graphitized material adjacent to the depressions. It is likely that the missing material was also graphitized. This graphitized region would have been rather easily knocked off during handling, which could explain the forming of the depression. A similar explanation might account for the second depression.

The fracture appeared to be brittle in nature, as expected for a cast iron. The fracture features and the lack of deformation adjacent to the fracture are both indicative of a brittle fracture.

General corrosion of the inside wall surface of the pipe length was negligible, and the general corrosion of the outside wall surface of the pipe length was not considered to be severe enough to significantly affect the integrity of the pipe.

Graphitization was discontinuous around the two complete circumferential sections examined. Graphitized regions penetrated the wall from the outside to depths ranging from essentially zero to 75% of the wall thickness. Because there is less resistance to crack formation in graphitized regions, as compared to non-graphitized regions, the presence of graphitization probably assisted in the development of the crack. However, the discontinuous nature of graphitization around the circumference suggests that graphitization did not play a significant role in the propagation of the crack.

There was a high concentration of porosity in one region of one of the sections examined. In general, however, the porosity in the pipe appeared to be low. The porosity did not seem to have had a significant effect on the fracture.

Except for the regions of porosity and graphitization, the microstructure of the pipe material appeared to be as expected for gray cast iron. The microstructure consisted primarily of graphite flakes and pearlite with some ferrite and steadite. The amount of steadite does not appear to be excessive.

A chemical analysis of the pipe material indicated that there was a slightly greater than desirable phosphorus content. Otherwise, the chemical composition appeared to be as expected for gray cast iron.

The hardness of the material as measured on a transverse section was normal for gray cast iron.

There was some variation in wall thickness of the submitted pipe length which was attributable to the manufacturing process used to make the pipe, namely, pit casting. This variation in wall thickness is, however, within specified tolerances.

## 5. CONCLUSIONS

1. The length of six inch diameter cast iron pipe natural gas main that was submitted to NBS for examination failed as a result of the formation of a transverse crack that had penetrated the entire wall thickness of the pipe for about 90% of the pipe circumference.

2. The crack was probably initiated by an externally applied bending load.

3. The nature of the corrosion product on the fracture surfaces indicates that the fracture was not "fresh."

4. The fracture mode appeared to be brittle.

5. General corrosion of the pipe wall surfaces was slight and was not considered to have had a significant effect on the integrity of the pipe.

6. There were localized regions of graphitization, but the discontinuous nature of the graphitization around the circumference of the pipe suggests that graphitization did not play a significant role in the propagation of the crack.

7. In the sections examined, there was one region where the porosity was quite high; in all other regions, the porosity was low. Porosity did not appear to have played a significant role in the fracture.

8. The microstructure of the pipe material away from the regions of porosity and graphitization appeared to be as expected for gray cast iron.

9. The chemical composition of the pipe material was normal for gray cast iron with the possible exception of a slightly high phosphorus content.

10. Variations in wall thickness were within the specified tolerances set forth in the 1925 edition of the American Gas Association Standard Specifications For Cast Iron Pipe and Special Castings.

11. Hardness measurements gave results which are as expected for gray cast iron.

## 6. ACKNOWLEDGEMENT

Mr. Leonard C. Smith of the NBS Mechanical Properties Section performed the photographic work, prepared the metallographic specimens, and assisted in other aspects of this investigation.

## REFERENCES

1. Gray and Ductile Iron Castings Handbook, Charles F. Walton, Editor, Gray and Ductile Iron Founders' Society, 1971.

Figure 1. Length of six inch diameter cast iron pipe natural gas main reported to be from Queens County, New York as received at NBS except that the top of the wooden shipping crate has been removed. The arrow near the center indicates the location of the crack. X 1/8


Figure 2. View of what was reported to be the top of the pipe as oriented in service. This photograph was taken after the pipe had been removed from the wooden shipping crate and steel straps had been placed across the crack. One of the steel straps can be seen in the figure. The "E" and "W" were written on the pipe with chalk before it was submitted to NBS. X 1/2

Figure 3. Bottom view of the pipe length in the vicinity of the crack (arrow). The two white, horizontal chalk marks indicate the approximate ends of the hinged portion. X 1/2

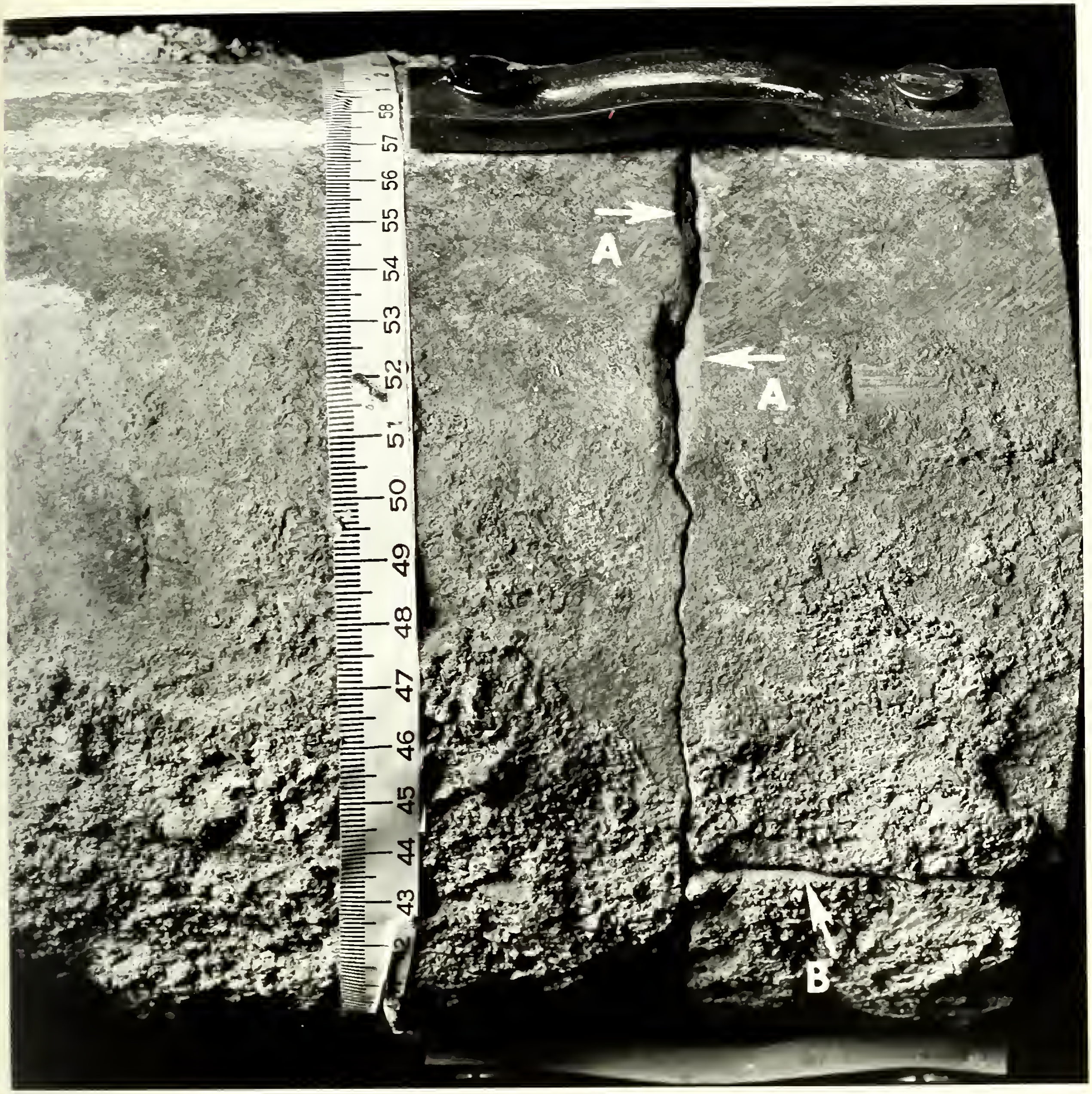


Figure 4. View of the pipe near the top showing depressions at the crack. The depressions are indicated by arrows "A." Arrow "B" indicates a sawcut made in the laboratory. This sawcut is not related to the failure. The W-length of the pipe is to the right of the crack and the E-length is to the left. X 1

Figure 5. Partially exposed fracture surfaces of the pipe showing corrosion product before any cleaning was done. The E-length fracture surface is intact and the W-length has been cut into two pieces. The white arrows indicate the approximate extremeties of the crack. X 1/2

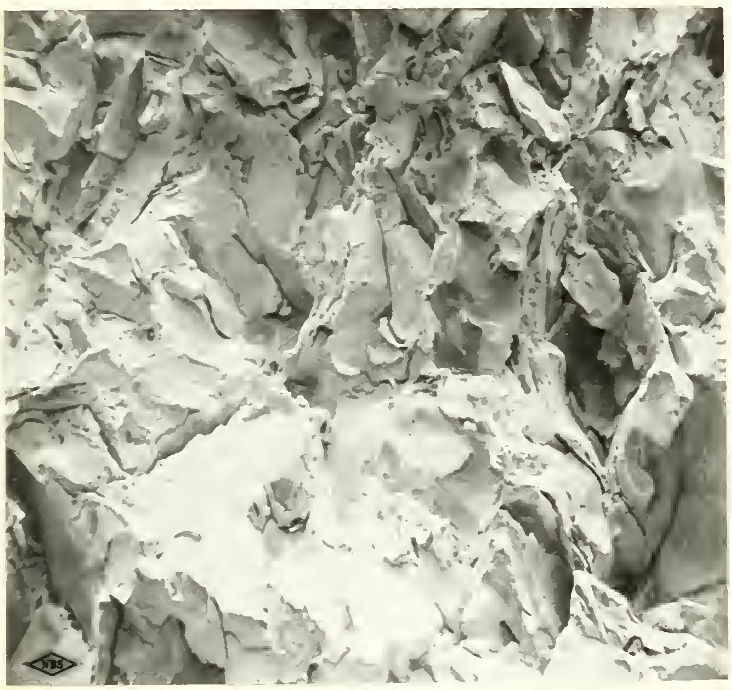

Figure 6. Scanning electron fractograph showing features typical for the region of the fracture about midway through the wall thickness. Cleavage is evident. X 110

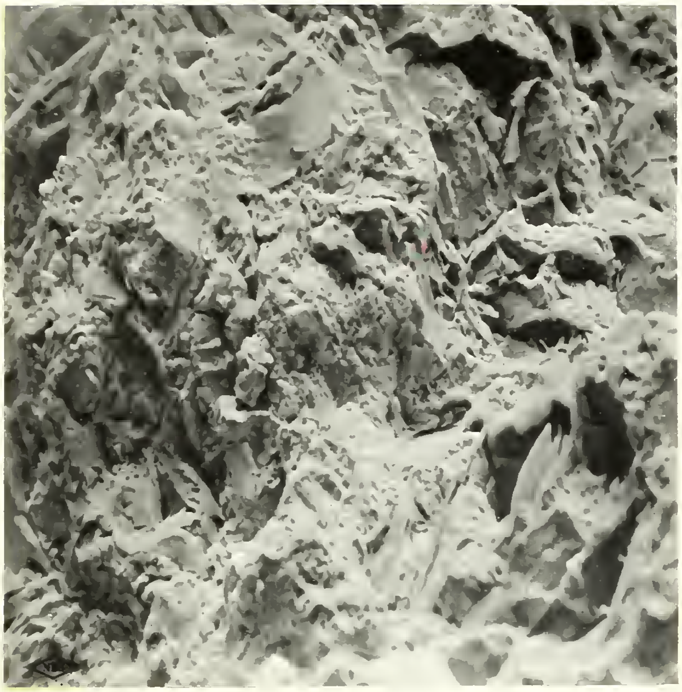

Figure 7. Scanning electron fractograph near the outside wall surface of the pipe. There is some evidence of cleavage. X 210

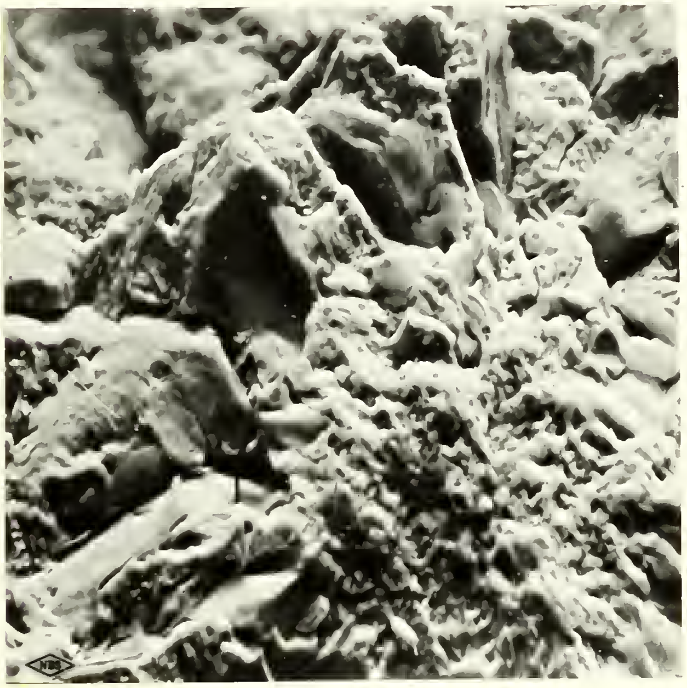

Figure 8. Scanning electron fractograph near the outside wall surface of the pipe. The smooth areas may have been regions of porosity or gas pockets. X 490

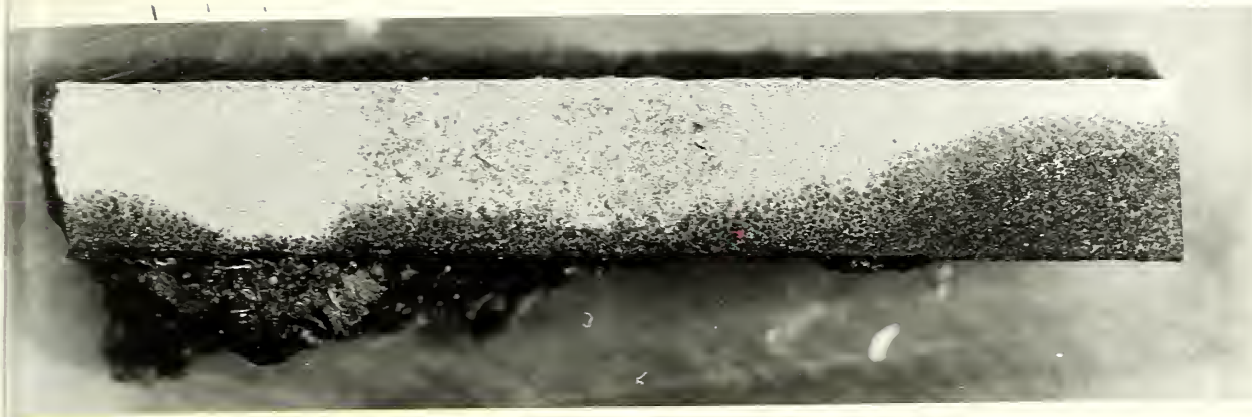

Figure 9. Etched longitudinal section intersecting the W-length fracture at a point 5 cm beyond the 9 cm point on the circumferential metric scale that can be seen in figure 2. The fracture is vertical at the left. The outside surface of the pipe is at the bottom, and the inside of the pipe is at the top. Some adherent soil and ash appear on the outside surface.
Etchant: 1% nital X 2 1/2

Figure 10. Part of the longitudinal section shown in figure 9 in the unetched condition. The fracture profile is at the left. There is no evidence of deformation.
As-polished X 100

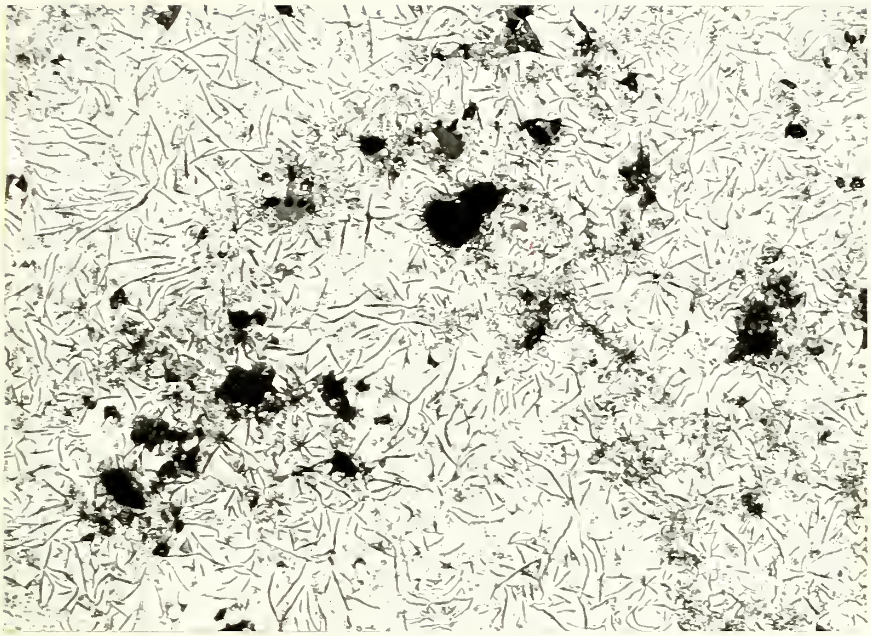

Figure 11. Center area of the section shown in figure 9 where there is a concentration of porosity or gas pockets.
As-polished X 50

Figure 12. An area from the section shown in figure 9 where there is partial graphitization.
Etchant: 1% nital X 200

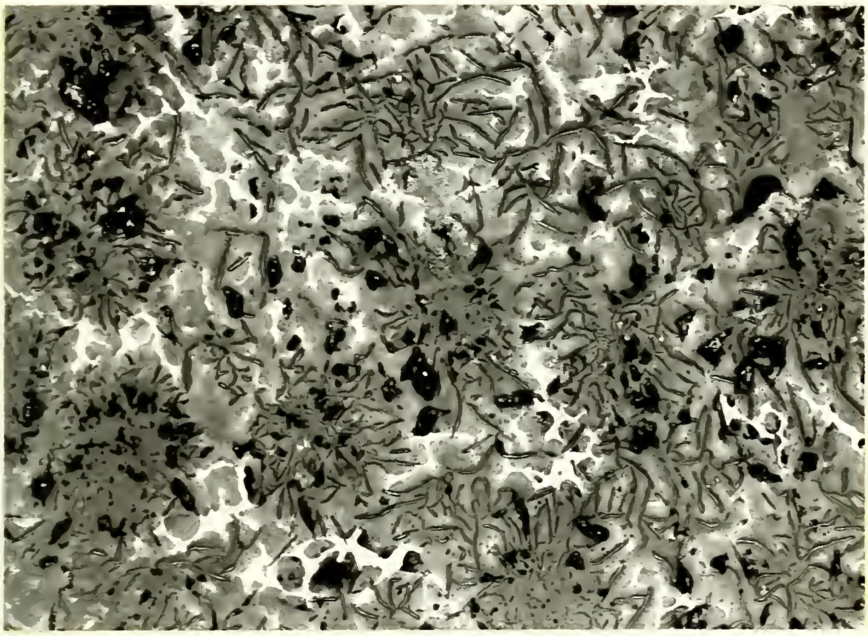

Figure 13. An area from the section shown in figure 9 where graphitization is nearly complete.
As-polished X 100

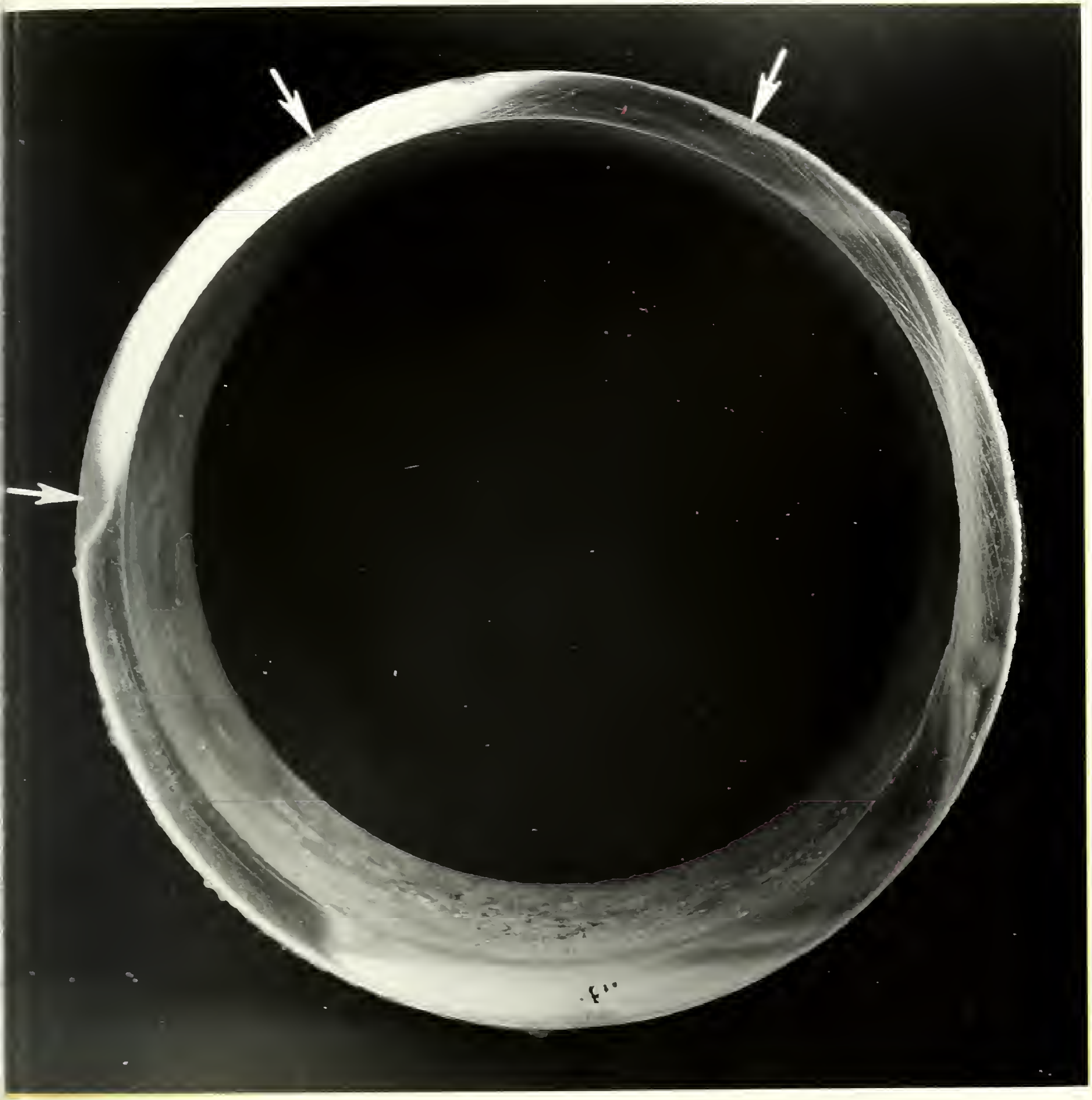

Figure 14. Transverse section through the W-length of the pipe about 6 cm from the fracture exhibiting some graphitization adjacent to the outside wall surface. Arrows indicate some of the regions of graphitization.
As-polished X 1

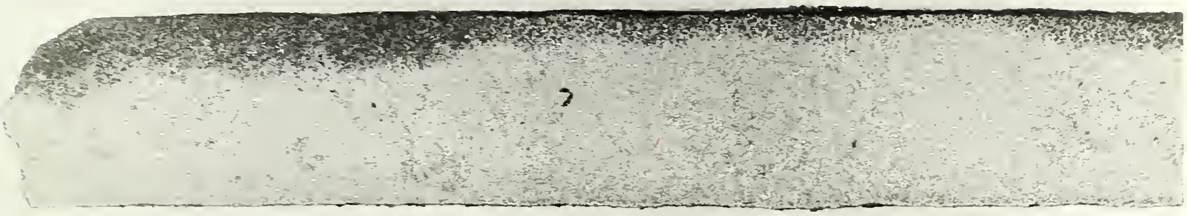

Figure 15. Longitudinal section intersecting the fracture at one of the depressions shown in figure 4. The section was taken at about 52 1/2 cm on the circumferential scale shown in figure 4. The fracture is vertical at the left; the outside surface of the pipe is at the top. The dark region adjacent to the outside surface is graphitized. The depression is at the upper left of the section.
Etchant: 1% nital X 2 1/2

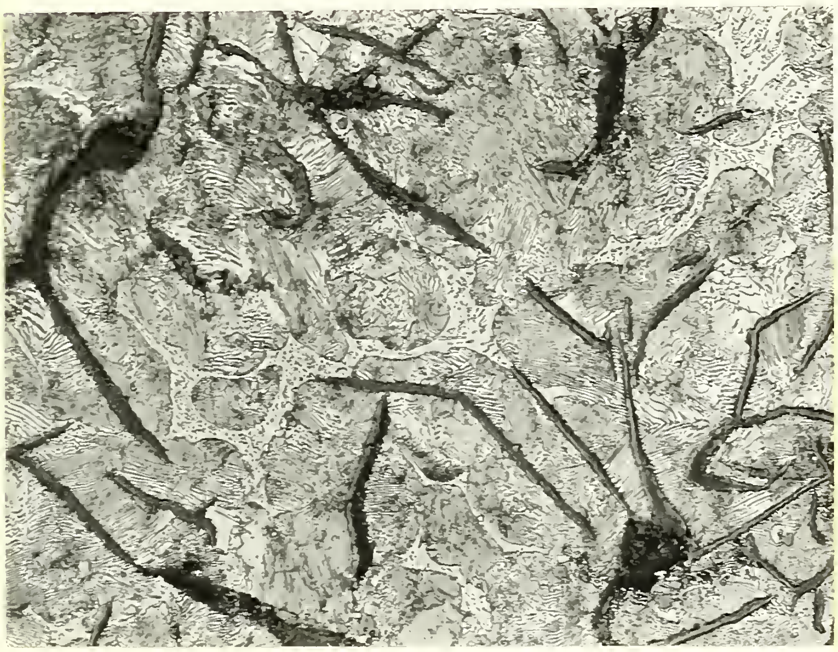

Figure 16. Typical microstructure of the submitted pipe material in an area away from graphitization and porosity. The microstructure consists primarily of graphite flakes (long, thin, dark particles) and pearlite (fingerprint pattern) with small amounts of ferrite (light color) and steadite (small rounded particles).
Etchant: 1% nital X 400

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SUPPLEMENTARY NOTES

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

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. 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)*

rittle fracture; cast iron; cast iron pipe; natural gas pipe; natural gas pipe racture

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