NBSIR 73-273

Examination of Failed Six Inch Cast Iron Pipe Natural Gas Main; Illinois Power Company, East Saint Louis, Illinois

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National Bureau of Standards
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October 15, 1973

Failure Analysis Report

Prepared for
Office of Pipeline Safety
Department of Transportation
Washington, D. C. 20590

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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SUMMARY

Examination revealed that the subject pipe had a microstructure not normally present in material meeting the usual specifications for the application. Graphitization probably aided crack initiation and crack propagation and fracture probably resulted from an externally applied load.

From the freshness of the fracture surface, it was concluded that the fracture was of recent origin when its presence was detected.

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1. INTRODUCTION

1.1 History

The following information relative to the failure has been excerpted from the Leak Report [1] obtained from the Office of Pipeline Safety, Department of Transportation.

"A gas leak was detected in an alley north of Illinois Avenue near 14th Street in East St. Louis, Illinois at 5:57 P.M. on November 11, 1971. The source of the gas was traced to a break in the 3/8 inch thick wall of the 6 inch I.D. pit-cast iron pipe gas main, approximately six feet from an adjacent 5 story residential building. The gas ignited and an explosion occurred as a result of the escape of the gas."

When the break was uncovered a continuous circumferential crack was observed. Only a narrow section of the pipe remained uncracked. The leak report [1] contained no information with regard to the location of the uncracked section relative to the position of the pipe as it was placed in service.

1.2 Purpose

A 38 inch long section of the pipe containing the undisturbed crack was packed in a supporting box and delivered by the Power Company to NBS for examination on December 13, 1971 at the request of the Office of Pipeline Safety (OPS), Department of Transportation. OPS requested a metallurgical examination to determine, if possible, the cause of the crack and to obtain any other available information that might be useful in the investigation of the incident. Figure 1 is a view of the section as-received.

2. EXAMINATION PLAN

(a) Make record photographs of selected positions around the surface of the pipe section at the fracture showing the location of gap and deflection measurements.

(b) Cut the pipe section near mid-length, obtaining a 20 inch-long segment containing the fracture, for examination. Saw-cut the segment obtaining a sub-section approximately 3 inch x 11 inch, containing 11 inches of the circumferential fracture surface. From this sub-section prepare one longitudinal metallographic specimen whose examination face is parallel to the fracture surface and also shows the depth of graphitization. Prepare a second specimen (transverse) whose examination face is parallel to the fracture surface and also shows the depth of graphitization. Examine both specimens for micro-structural features adjacent to the graphitization. The boxed area adjacent to H in Figure 2b shows the location at which the metallographic specimens were obtained.

(c) Conduct a chemical analysis of a sample from the pipe.

(d) Check the hardness of the pipe material.

3. EXAMINATION RESULTS

3.1 Visual Examination

Large areas covered by a black oxide scale were observed on the outside surface of the pipe section. Pits ranging from match-head to thumb-nail in size were found scattered around the outside surface. Some of the larger pits were quite deep. Shallow lace-like pitting covered by a film of red rust was observed throughout the interior of the pipe section. A reddish band of rust varying from approximately 1 to 2 inches in width was observed to extend longitudinally from one end to the other of the interior of the pipe section.

3.2 Deflection and Gap Measurements

A six-foot, flexible steel tape was wrapped around the circumference of the pipe at a distance of about 6 inches from the crack, with the zero point of the tape located approximately at the center of the uncracked region, arrow C, Figure 2a. The tape and a steel scale were used to allow measurements of deflection and gap at various positions on the pipe. The maximum deflection occurred at C and measured between 0.045 and 0.050 inches in 6 inches. The maximum gap appeared to be at G, approximately 150 degrees from C (see Figure 2b). An accurate gap measurement could not be made at G because the scale used in measurement did not fit flatly on the pipe surface on either side of the fracture.

3.3 Chemical Analysis

The composition of the pipe sample is given in Table 1.

Table 1. Chemical Composition of Pipe Sample

	Percent
Combined Carbon	0.35
Graphitic Carbon	3.07
Total Carbon	3.42
Silicon	2.06
Phosphorus	0.604
Sulfur	0.079
Manganese	0.35

3.4 Hardness Tests

The hardnesses of the pipe material are given in Table 2.

Table 2. Hardnesses of Pipe Material

Location	Hardness Rockwell "B"
Adjacent to outside surface	85
Mid-thickness	83
Adjacent to inside surface	75

3.5 Metallography

3.5.1 Macro-examination

Figures 3a and 3b show the fracture surface and the unfractured section, respectively. Features observed are described in the legends for these two figures. Figures 4a and 4b are views of longitudinal and transverse sub-sections, respectively, adjacent to the probable fracture origin. The plane viewed in Figure 4a is at a right angle to the fracture plane while in Figure 4b, the plane viewed is parallel to the fracture plane. The arrows point to patches of graphitization present on the outside surface of the pipe. Graphitization is a phenomenon whereby the iron in the cast iron is progressively corroded leaving a porous mass of carbon and iron oxide.

3.5.2 Microstructural examination

Figures 5a through 5c show the microstructure of the cast iron pipe adjacent to the fracture surface in a traverse made from the outside surface to the inside surface of a longitudinal cross-section specimen. The area shown in Figure 5a is adjacent to the probable fracture origin at the outside surface of the pipe. Both complete and partial graphitization were observed at the outside surface. Below the graphitized zone the structure is essentially a ferrite matrix containing type B graphite in a rosette grouping. Graphitization was observed adjacent to the fracture surface at the center of the section. The core of the pipe wall consisted essentially of a ferrite matrix containing both type A and type B graphite (see Figure 5b). Figure 5c shows the inside surface of the pipe. An oxide layer (dark) is present on the inside surface of the pipe wall. A narrow band of pearlite was observed adjacent to the inside wall. The remainder of the structure is essentially a ferrite matrix containing coarse type A graphite. Figure 6 shows the structure adjacent to the narrow band of pearlite shown in Figure 5c at a higher magnification. Areas of the iron-iron phosphide eutectic (small rounded particles in light-colored ferrite), coarse type A graphite flakes in a ferrite matrix, and lamellar pearlite are present.

The microstructure of the pipe wall was found to be largely ferritic. A narrow band of pearlite was observed adjacent to the inside wall surface. The iron-iron phosphide eutectic was observed, quite heavily concentrated, adjacent to the inside surface. Graphite flake sizes ranged from moderate adjacent to the outside of the pipe wall to quite coarse adjacent to the inside surface.

4. DISCUSSION

The hardness, greatest adjacent to the outside of the wall and least adjacent to the inside of the wall is apparently related to the difference in the size and shape of the graphite flakes [2]. The presence of a large amount of ferrite in the structure may have contributed some ductility and may account for the incomplete fracture around the pipe circumference.

The chemical analysis of a sample of the subject pipe indicated a low ratio of combined carbon to total carbon and a high ratio of graphitic to total carbon. The phosphorus content, 0.604 percent, is quite high and may have contributed to localized embrittlement at the fracture origin. The ratio of manganese to sulfur content, about 4 to 1, is low. A ratio of 5 to 1 is usually aimed at in good casting practice, to minimize deleterious effects from the presence of sulfur in the composition of gray cast iron [3].

Type A and type B graphite in a ferrite matrix such as that observed in the microstructure produce a relatively weak cast iron [2]. The iron-iron phosphide eutectic, also observed is known to contribute to brittleness [4]. Material having these structural features does not meet the requirements of the specifications [5] usually required for cast iron pipe to be used in natural gas service.

The outer surface of the pipe between G and H (area K) was deeply pitted. It was found that pitting resulting from graphitization reduced the wall thickness at H, where the examination specimens were obtained, as much as 56 percent. A notch was produced within area K that acted as a severe stress concentrator. For this reason it is believed that initiation of the pipe fracture was localized at this spot of graphitization.

As was previously indicated, no information was supplied with regard to the location of the uncracked section relative to the position of the pipe as it was placed in service. If this information had been supplied it could have been useful in determining positively the location of the crack origin with respect to the position of the pipe as it was placed in service. If the band of rust described in paragraph 3.1, and which may have formed in the pipe bottom, is accepted as a criterion of orientation, then the probable fracture origin, K, is located approximately 120 degrees from the position of the pipe bottom as it was placed in service.

Severe graphitization at K in the pipe section produced a notch that acted as a stress-concentrator and aided crack initiation in that area. Crack propagation, from the appearance of the fresh fracture surface, appears to have been rapid thereafter and probably occurred in a single event. An externally applied load produced by settlement could have been of sufficient magnitude to cause the break.

5. CONCLUSIONS

The following conclusions are drawn from this examination:

1. The microstructure of the material does not meet the minimum requirements of the specifications usually used for cast iron pipe for natural gas service [5], since it consists of a matrix of ferrite with coarse flakes of types A and B graphite and a region near the inner surface rich in iron-iron phosphide eutectic.

2. It is likely that graphitization aided crack initiation.

3. Initiation and propagation of the fracture probably resulted from the imposition of an overloading external force that may have been derived from settlement of the ground.

4. The crack was apparently of recent origin when its presence was detected.

ACKNOWLEDGEMENTS

The metallographic specimens were prepared by Mr. C. H. Brady, Mechanical Properties Section, Metallurgy Division. The photographic prints were also made by Mr. Brady.

REFERENCES

[1] Department of Transportation Leak Report-Distribution System No. 210843, Operator Information(Illinois Power Co.) No. 08012; dated December 1, 1971.

[2] "Gray and Ductile Iron Castings Handbook" (1971), edited by Charles F. Walton, published by the Gray and Ductile Iron Founders' Society, Inc., Cleveland, Ohio; page 201 section 3.

[3] ibid, page 196 b. Alloy Additions.

[4] ibid, page 104 and page 112, lines 6-21 inclusive.

[5] American Standard Specification for Cast Iron Pit Cast Pipe for Gas, ASA A21.3-1953, Section 3-3, Quality of Iron.

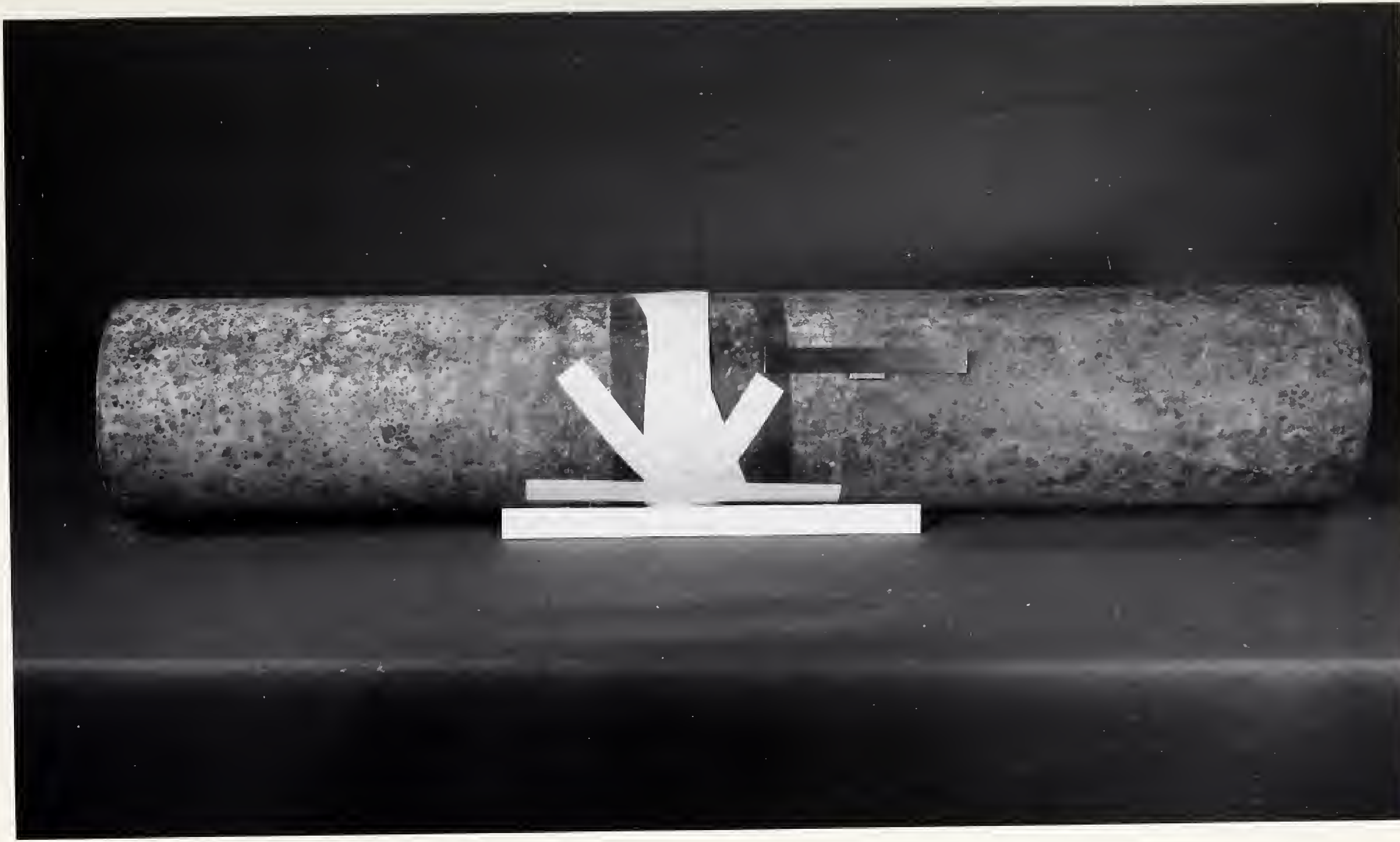


Figure 1. Length of Fractured Cast Iron Pipe As-received by NBS for Examination. Tape had been applied to prevent damage to fracture surfaces during shipping. Approx. 1/5 X

Figure 2. Maximum Deflection and Gap in Section of Fractured Pipe. Approx. 1/3 X

a. Maximum deflection, 0.04-0.05 inch in 6 inches, occurred at C.

b. Maximum gap produced in fracturing occurred adjacent to G. An accurate gap measurement could not be made because of surface conditions. Specimens for metallographic examination were obtained from the boxed area.

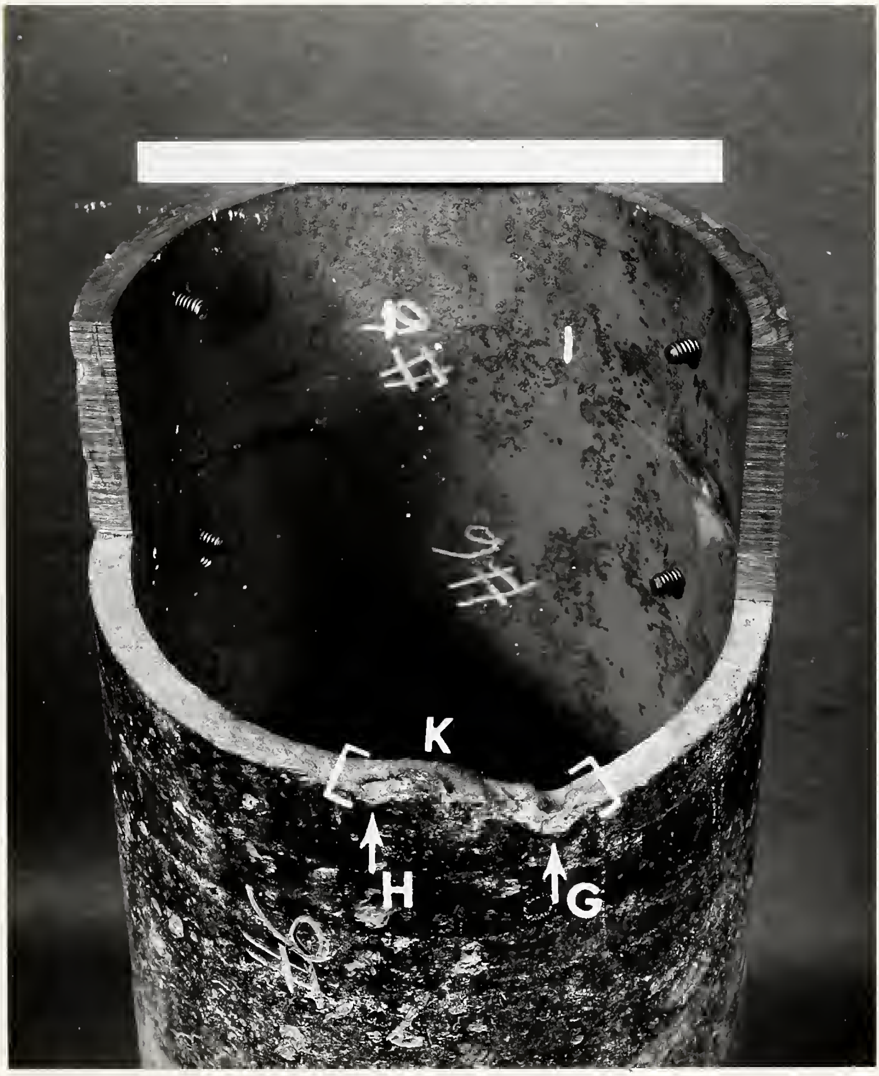
a

b

Figure 3. Fractures Adjacent to Fracture of Cast Iron Pipe, As-received.

a. Area K (within brackets) contains the probable fracture origin. Deep pits were observed adjacent to the fracture surface of the pipe at arrows G and H. Note that the fracture surface both to the left and to the right of the bracketed area is quite flat. X 1/2

b. Area C (within brackets) contains the unfractured section and the converging crack tips. Shallow lace-like pitting shown in this view was present throughout the interior surface of the pipe length submitted. X 1/2



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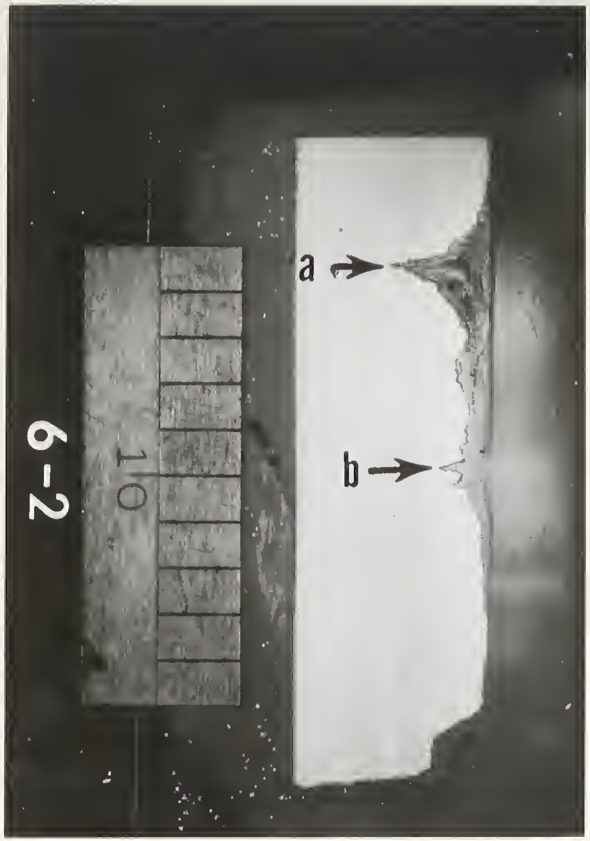

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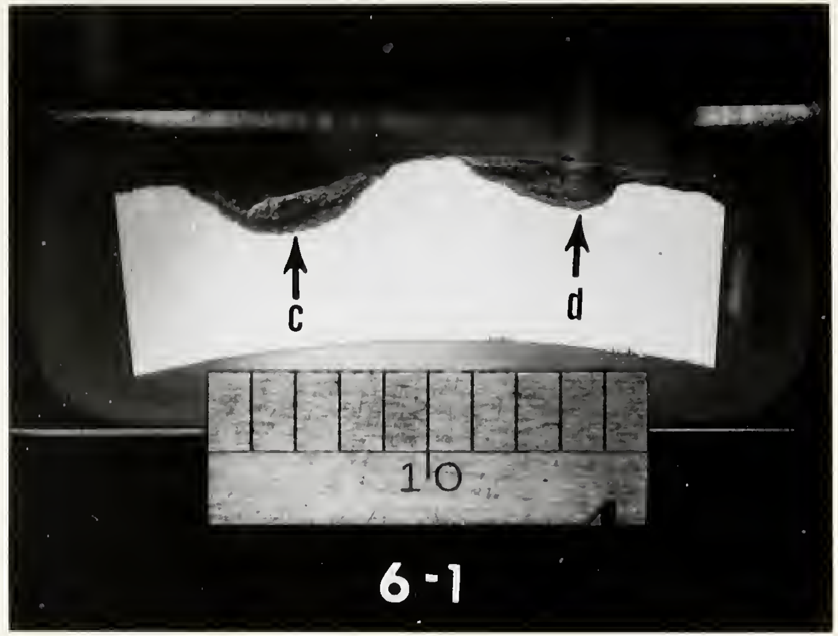


b

Figure 4. Views of Cross Sections Adjacent to Point H, Fig. 2b. Arrows point to patches of graphitization penetrating from outside surface. Approximate depths of graphitization are: at arrow a, 0.21 inch; b, 0.11 inch; c, 0.14 inch; d, 0.10 inch. The original pipe wall thickness was approximately 0.375 inch. Magnification X 2

a. Longitudinal section.

b. Transverse section.

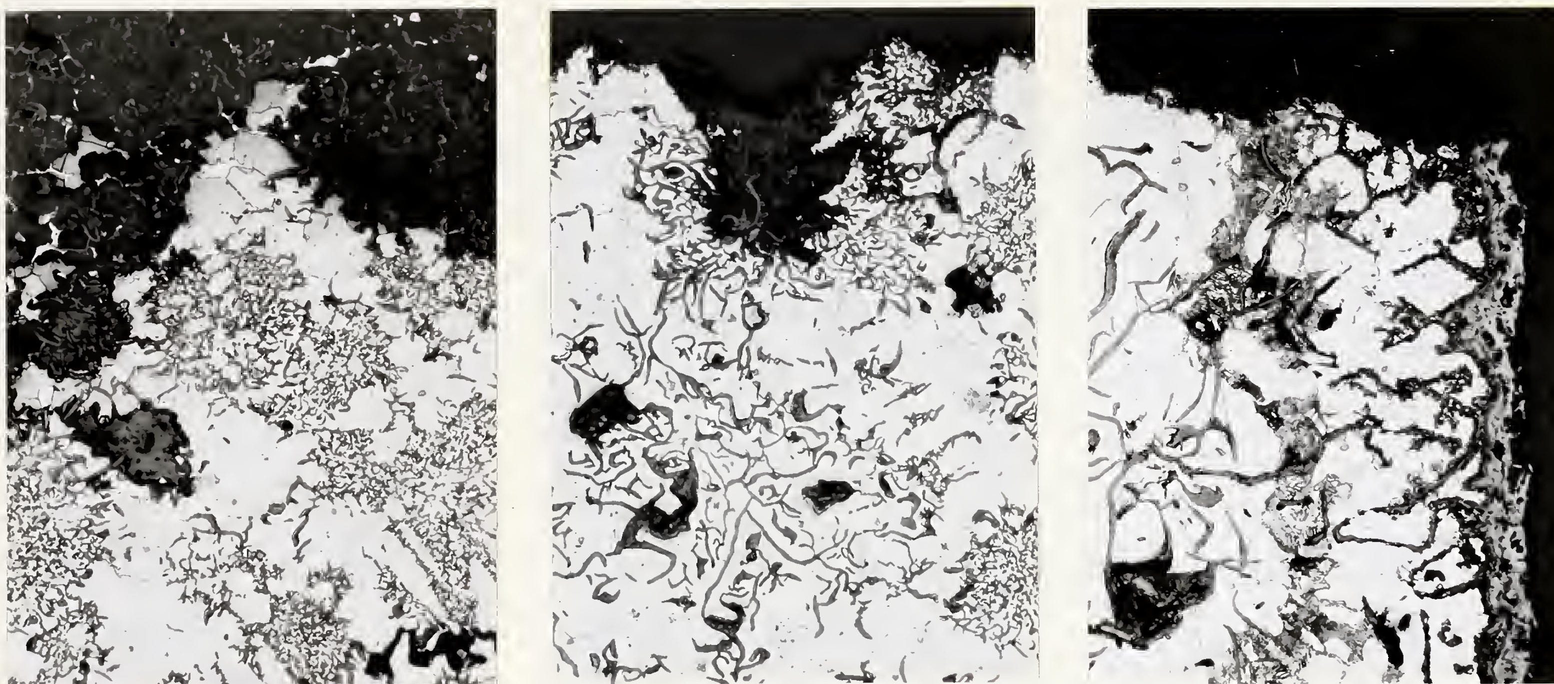
Figure 5. Microstructures at Point H Adjacent to Probable Fracture Origin Longitudinal Cross-section. Etched with nital. X 250

a. Adjacent to outside of pipe wall. At top is a zone of graphitized and partially graphitized material (dark). Below the graphitized zone the structure is essentially a ferrite matrix containing type B graphite in a rosette grouping.

b. Center of pipe wall. Graphitization (dark) at fracture surface. Core of pipe wall is essentially a ferrite matrix containing both types A and B graphite.

c. Inside edge of pipe wall. At right is an oxide layer on inside surface of pipe wall; adjacent to this is a narrow band of pearlite. Remainder of structure is essentially a ferrite matrix containing coarse type A graphite.

Fracture Surface



Outside Surface of Pipe

Inside Surface of Pipe

a b c

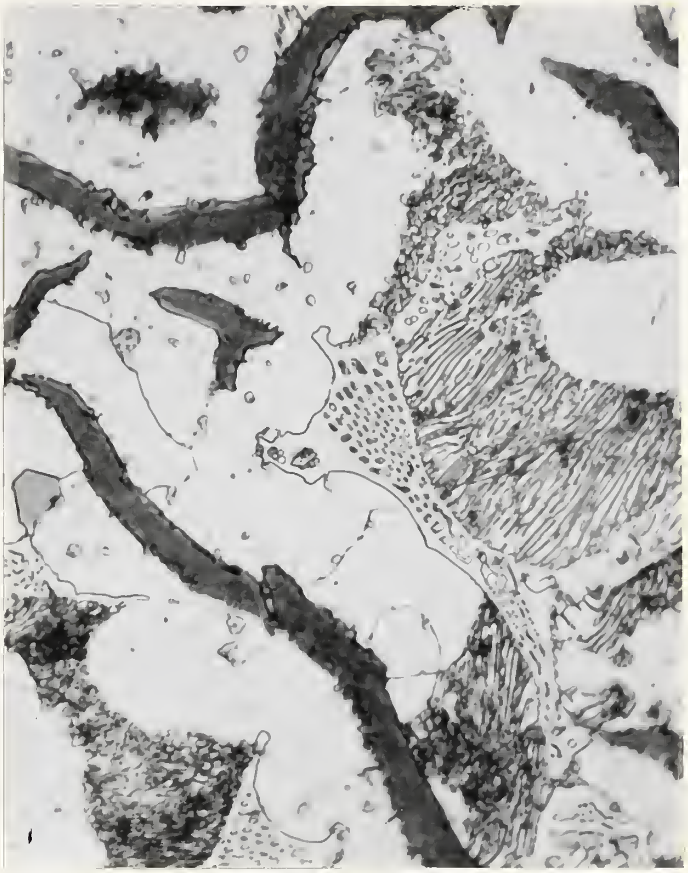


Figure 6. Microstructure Adjacent to Narrow Band of Pearlite Shown in Figure 5c at a Higher Magnification. Etched with nital. X 1000

Areas of the iron-iron phosphide eutectic (small rounded particles in light-colored ferrite), coarse type A graphite flakes in a ferrite matrix, and lamellar pearlite are present.

FORM NBS-114A (1-71)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 73-273	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE	5. Publication Date
EXAMINATION OF FAILED SIX INCH CAST IRON PIPE NATURAL GAS MAIN; ILLINOIS POWER COMPANY, EAST SAINT LOUIS, ILLINOIS	September, 1973
	6. Performing Organization Code
7. AUTHOR(S) I. J. Feinberg and M. L. Picklesimer	8. Performing Organization NBSIR 73-273
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234	10. Project/Task/Work Unit No. 3120418
	11. Contract/Grant No.
12. Sponsoring Organization Name and Address Office of Pipeline Safety Department of Transportation Washington, D. C. 20590	13. Type of Report & Period Covered Failure Analysis Report
	14. Sponsoring Agency Code

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.)

Examination revealed that the subject pipe had a microstructure not normally present in material meeting the usual specifications for the application. Graphitization probably aided crack initiation and crack propagation and fracture probably resulted from an externally applied load.

From the freshness of the fracture surface, it was concluded that the fracture was of recent origin.

17. KEY WORDS (Alphabetical order, separated by semicolons)
Cast iron; failure analysis; fracture; graphitization, microstructure; pipe.

18. AVAILABILITY STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
☐ UNLIMITED.	UNCLASSIFIED	21
☒ FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NTIS.	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price