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6 DEVELOPMENT OF QUALITY ASSURANCE TRAINING MANUAL TO ASSIST IN ESTABLISHING SOUNDNESS REQUIREMENTS FOR ALUMINUM AND STEEL CASTINGS.

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TECHNICAL REPORT NUMBER 12256

DEVELOPMENT OF QUALITY ASSURANCE TRAINING MANUAL TO ASSIST IN ESTABLISHING SOUNDNESS REQUIREMENTS FOR ALUMINUM AND STEEL CASTINGS

BY

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ARMOR, MATERIAL APPLICATION AND TECHNOLOGY FUNCTION

ABSTRACT

Samples of aluminum and steel casting flaws most commonly experienced in production were selected to be radiographed in order to develop quantitative and descriptive picture images of various radiographic reference standards. Graphic illustrations of flaw size and flaw distribution for various radiographic reference standards were depicted by using radiographs and associated cross-sectional photo-macrographs. These graphic illustrations of radiographic levels of acceptance will provide meaningful design criteria for establishing realistic standards of acceptance for new material applications. This report also furnishes operational guidance to quality assurance and radiographic personnel in their normal on-the-job duties.

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INTRODUCTION

Present soundness requirements for many military castings are being specified according to severity levels listed in various specifications. Standards are selected on the basis of their numerical rating, or as specified in a related specification without serious consideration of the type and degree of flaw permitted for each grade level. It was originally intended that reference radiographs be used to categorize designated standards according to the stress requirements of the casting. With this procedure many castings are produced to a greater soundness requirement than necessary; conversely, this procedure is too lenient for other highly critical castings and ultimately creates service problems.

In accordance with project authorization from U.S. Army Materials and Mechanics Research Center, the task of compiling a flaw correlation document was established under the Materials Testing Technology Program. The effort was determined necessary to greatly assist the human judgement presently involved in designating casting soundness requirements.

OBJECT

The object of this task is to provide a document which illustrates flaw correlation with radiographic images to assist design engineers in the proper selection of casting soundness requirements.

SUMMARY

Typical flaw specimens of varying severity levels, presently encountered in aluminum and steel castings, were selected from representative components obtained from government and commercial sources. Flaw severity levels were graded radiographically to existing military and ASTM reference standards and categorized according to casting size and thickness. Photo-macrographs of flaw cross-sections were correlated with radiographic images to illustrate the actual relationship of flaw size to the casting area under evaluation.

CONCLUSIONS

The completion of this document provides design engineers with flaw correlation data which will assist in more accurately selecting radiographic soundness requirements on future castings. This document will also furnish operational guidance to quality assurance and radiographic personnel in their normal on-the-job duties.

TEST MATERIALS

1. Scrapped steel armor castings.
2. Scrapped aluminum castings of 355, 356 and special hi-strength Kaiser K01 alloy.
3. Industrial x-ray film of various sizes, medium grain, fine grain, and extra-fine grain.
4. Commercial photographic copy film, size 4 x 5 inches.
5. Photographic projection print paper.

TEST EQUIPMENT

1. Industrial x-ray machine, 1000KVP, 3MA capacity
2. Industrial x-ray machine, 250KVP, 10MA capacity
3. Industrial x-ray machine, 140KVP, 2MA capacity
4. Industrial x-ray machine, 25KVP, 5MA capacity
5. Commercial 4 x 5 inch View camera
6. Commercial 4 x 5 condenser type photographic enlarger
7. Photographic reproduction printing equipment
8. Lithographic printing equipment

TEST PROCEDURE

1. The procedure followed during the program was as follows:
   a. Radiographic evaluation
   b. Metallographic evaluation
   c. Selection of standards for flaw correlation
   d. Reproduction of selected standards

2. Following is a brief description of each procedure:

   a. Radiographic evaluation:

      Radiography of approximately 20 each aluminum and steel armor castings was performed in accordance with MIL-STD-453(1), dated 4 September 1963 (Radiographic Inspection). A minimum quality level of 2-1T, representing 1.4 percent sensitivity was maintained for all exposures. Several x-ray machines and a variety of radiographic exposure techniques were employed.

   b. Metallographic evaluation:

      Cross-sections were extracted from the selected specimens of most flaw types for verification of radiographic evaluation. Photo-macrographs were made of typical flaw conditions for correlation with reference standards.

   c. Selection of standards for flaw correlation:

      Grading of standards for flaw correlation were based on existing military and ASTM reference standards. Two levels of severity and in some flaws special gross conditions were selected to correlate the radiographic image with the flaw cross-sectional area.

   d. Reproduction of selected standards:

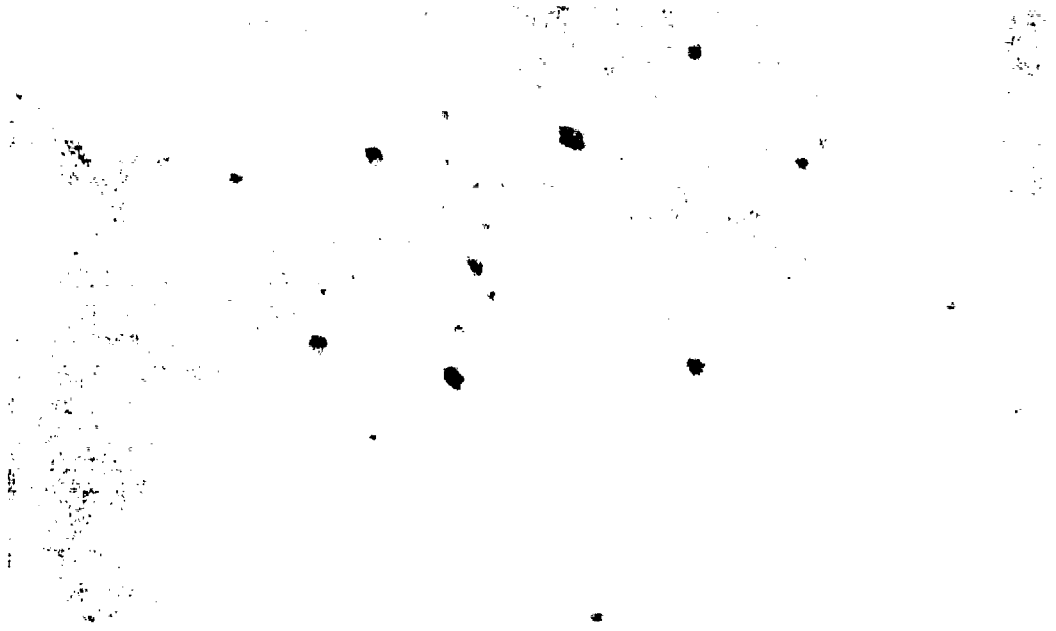
      The original radiographs were photographically reproduced utilizing a conventional 4 x 5 inch view camera to copy the radiographic image as viewed with an eleven-tube flourescent illuminator. Since photographic printing papers do not have the latitude of x-ray film, projection prints were made to allow the control necessary to obtain an authentic reproduction. Two methods of final reproduction were used in this document. The aluminum standards were reproduced by the photographic method; however, due to the exceptionally high cost of photographic reproduction, the steel standards were reproduced by the lithographic method.

RESULTS AND DISCUSSIONS

The lack of flaw correlation data has led to a questionable procedure of specifying radiographic soundness requirements according to severity levels listed in specification without adequate radiographic and pictorial illustrations. The illustrated correlation data contained in

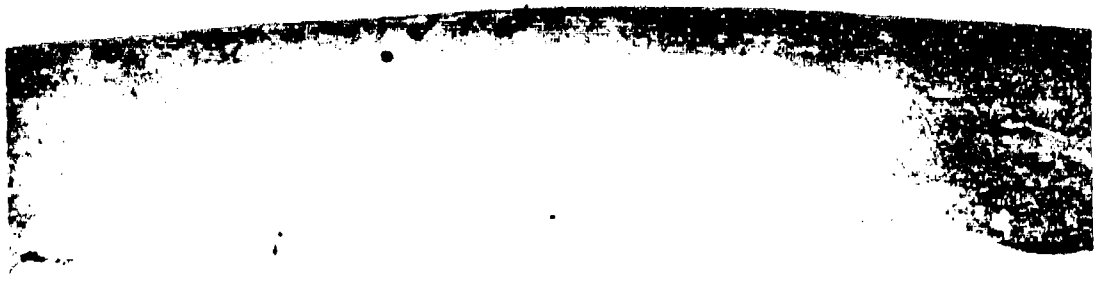
Figures 1 through 13 will enable recognition of flaw sizes and distribution as compared to casting cross-sectional appearance and assist in establishing more realistic standards of acceptance by design engineers and quality assurance personnel. This should ultimately result in greater reliability of aluminum and steel armor castings.

STEEL CASTING FLAWS



Radiographic image of gas porosity. Severity level shown compares with the following:

ASTM—E—446 — Grade 2
ASTM—E—186 — Grade 2
MIL—R—11469 — Acceptance is based on pore size and casting thickness. Amount shown meets Std. 2 for 1", and Std. 1 for 2" thickness.



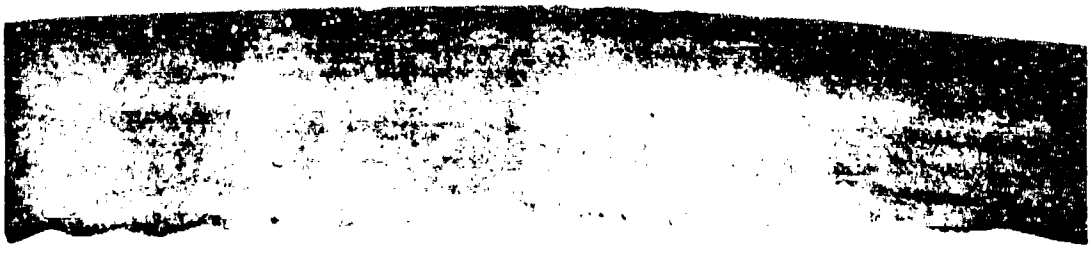
Macrograph of partial casting cross section showing normal location of porosity near the surface. (unetched, actual size)

EVALUATION OF GAS POROSITY IN CAST STEEL

Fig 1

Radiographic image of gas porosity. Severity level shown compares with the following:

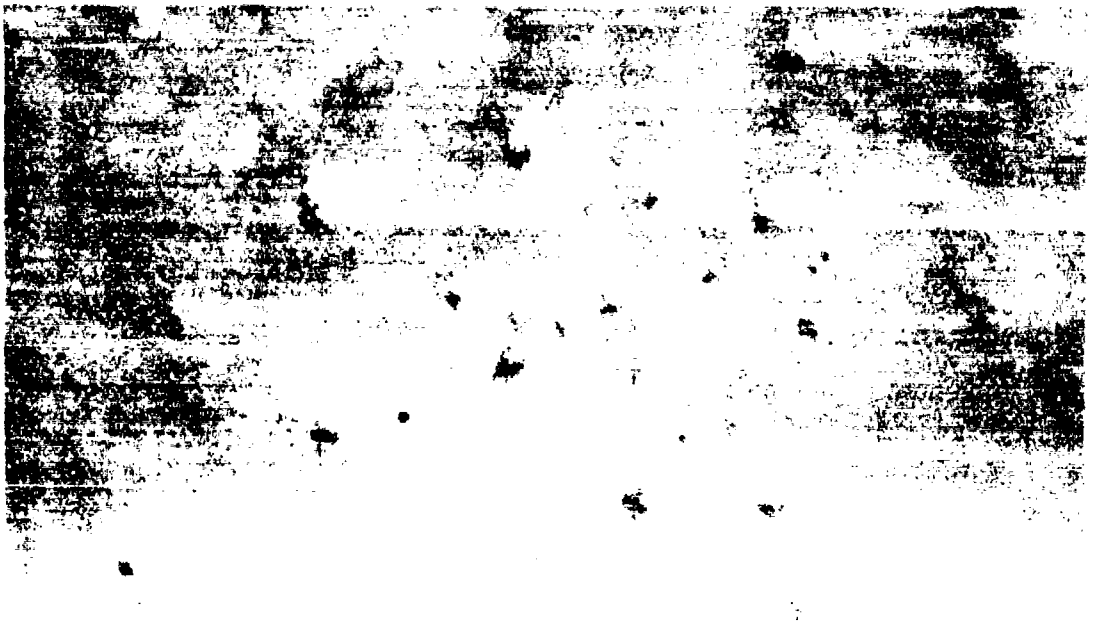
ASTM—E-446 — Grade 4
ASTM—E—186 — Grade 4
MIL—R—11469 — Acceptance is based on pore size and casting thickness. Amount shown meets Std. 3 for 1", and Std. 2 for 2" thickness.



Macrograph of partial casting cross section showing normal location of porosity near the surface. (unetched, actual size)

EVALUATION OF GAS POROSITY IN CAST STEEL

Fig. 2



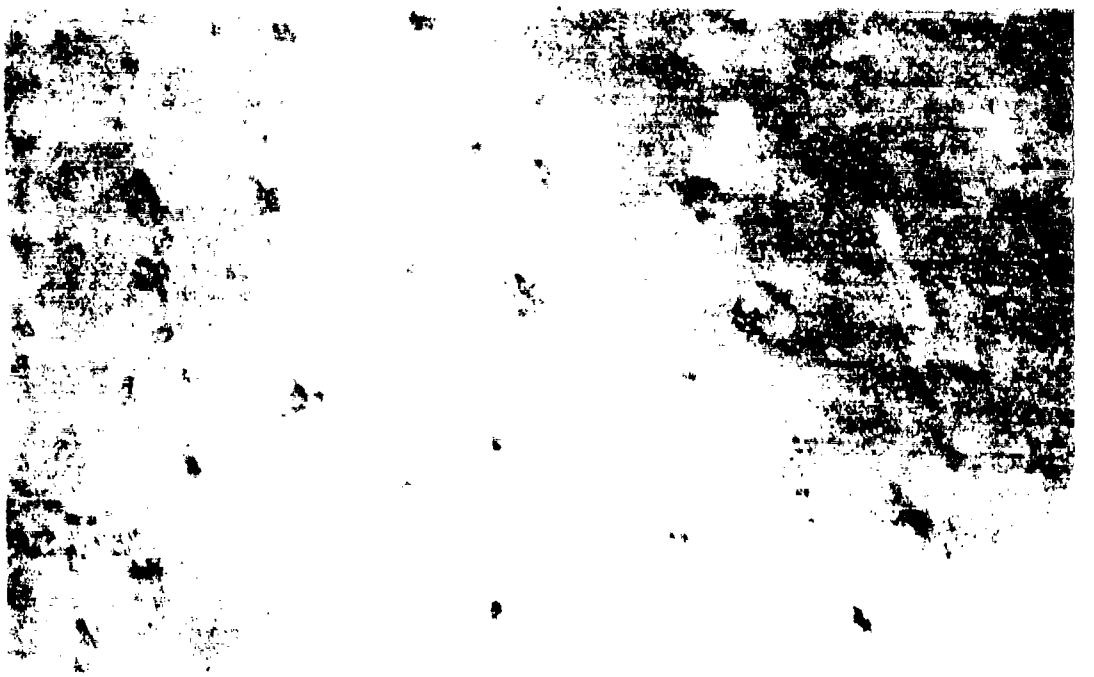
Radiographic image of inclusions. Severity level shown compares with the following:

ASTM—E—446 — Grade 2
ASTM—E—186 — Grade 2
MIL—R—11469 — Acceptance based on inclusion size and casting thickness. Amount shown meets Std. 2 for 1", and Std. 1 for 2" thickness.

Macrograph of partial casting cross section showing normal location of inclusions near the surface. (unetched, actual size)

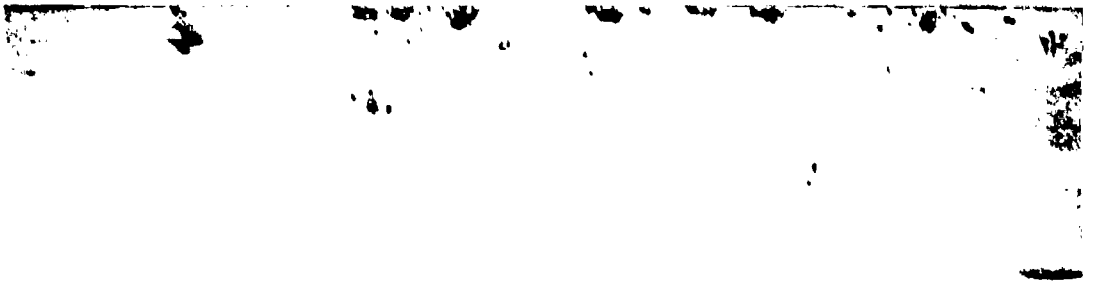
EVALUATION OF SAND AND SLAG INCLUSIONS IN CAST STEEL

Fig. 3



Radiographic image of inclusions. Severity level shown compares with the following:

ASTM—E446 — Grade 5
ASTM—E186 — Grade 4
MIL—R—11469 — Acceptance based on inclusion size and casting thickness. Amount shown meets Std. 4 for 1" and Std. 3 for 2" thickness.

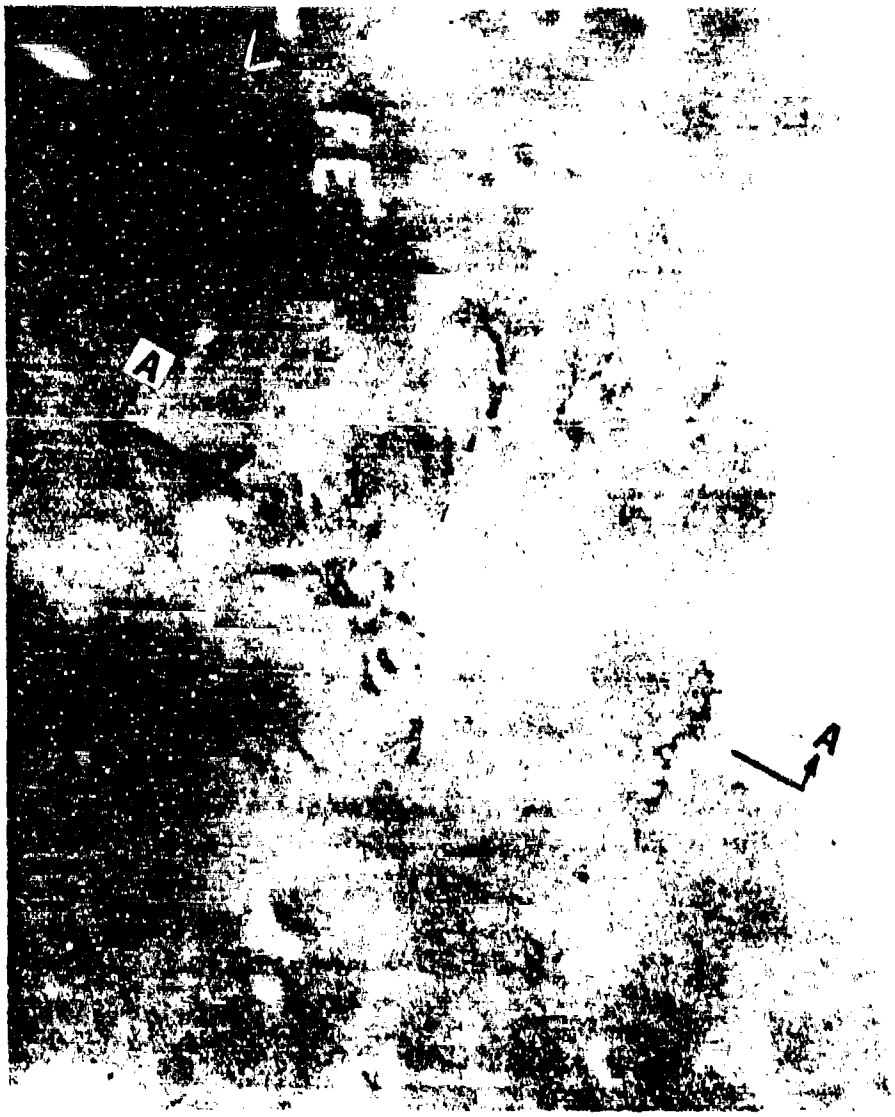


Macrograph of partial casting cross section showing normal location of inclusion near the surface. (unetched, actual size)

EVALUATION OF SAND AND SLAG INCLUSIONS IN CAST STEEL

FIG. 4

SHRINKAGE — (DENDRITIC)



RADIOGRAPHIC IMAGE OF DENDRITIC SHRINKAGE IN CAST STEEL 2 INCHES THICK.

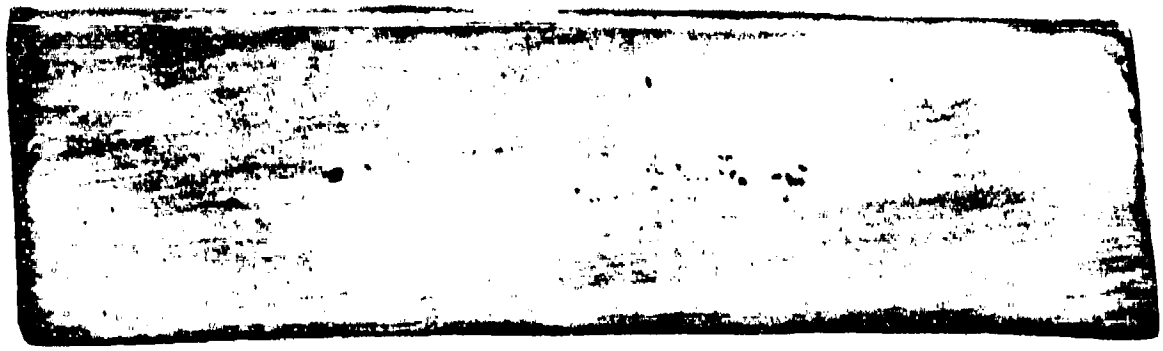
EVALUATION INCLUDED IN FIG. 5B.

Fig. 5A

EVALUATION OF FIG. 5A

Severity level of the shrinkage shown in Fig. 5A compares with the following:

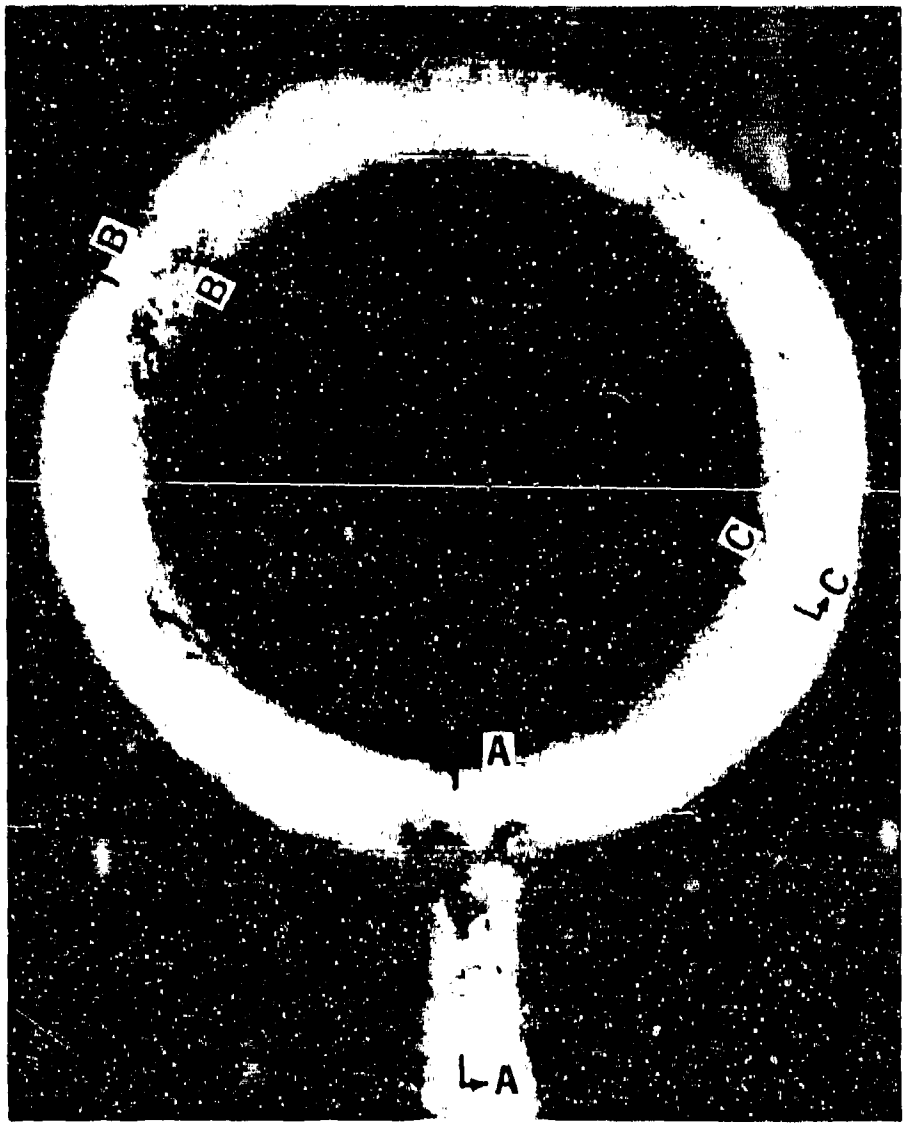
ASTM—E—446 — Type CA — Grade 3
ASTM—E—186 — Type I — Grade 3
MIL—R—11469 — Type B — Std 2



Macrograph of casting cross section AA, shown in Fig 5A, revealing severity and location of the shrinkage condition. (unetched, actual size)

EVALUATION OF DENDRITIC SHRINKAGE IN CAST STEEL 2 INCHES THICK

Fig. 5B



RADIOGRAPHIC IMAGE OF INTERNAL SHRINKAGE IN CAST STEEL.

EVALUATION INCLUDED IN FIG. 6B.

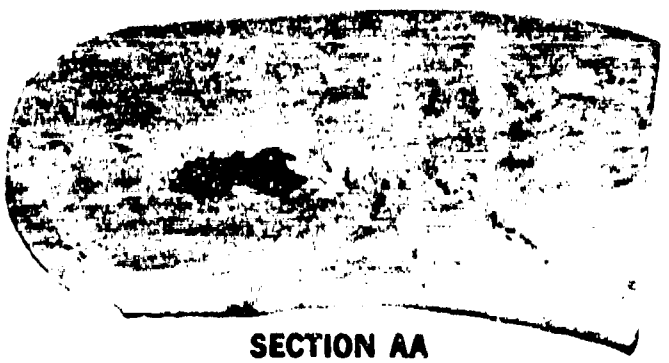
Fig. 6A

EVALUATION OF FIG. 6A

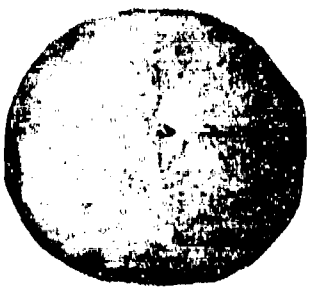
Severity level of shrinkage shown in Fig. 6A compares with the following:

SECT AA CAVITY
- **ASTM—E—446 — Fails to meet any grade**
- **ASTM—E—186 — Not applicable, too thin**
- **MIL—R—11469 — Std. 5 (judged as gas)**

SECT BB & CC DENDRITIC
- **ASTM—E—446 — Type CA — grade 3**
- **ASTM—E—186 Not applicable, too thin**
- **MIL—R—11469 — Type C — Std. 2**



SECTION AA



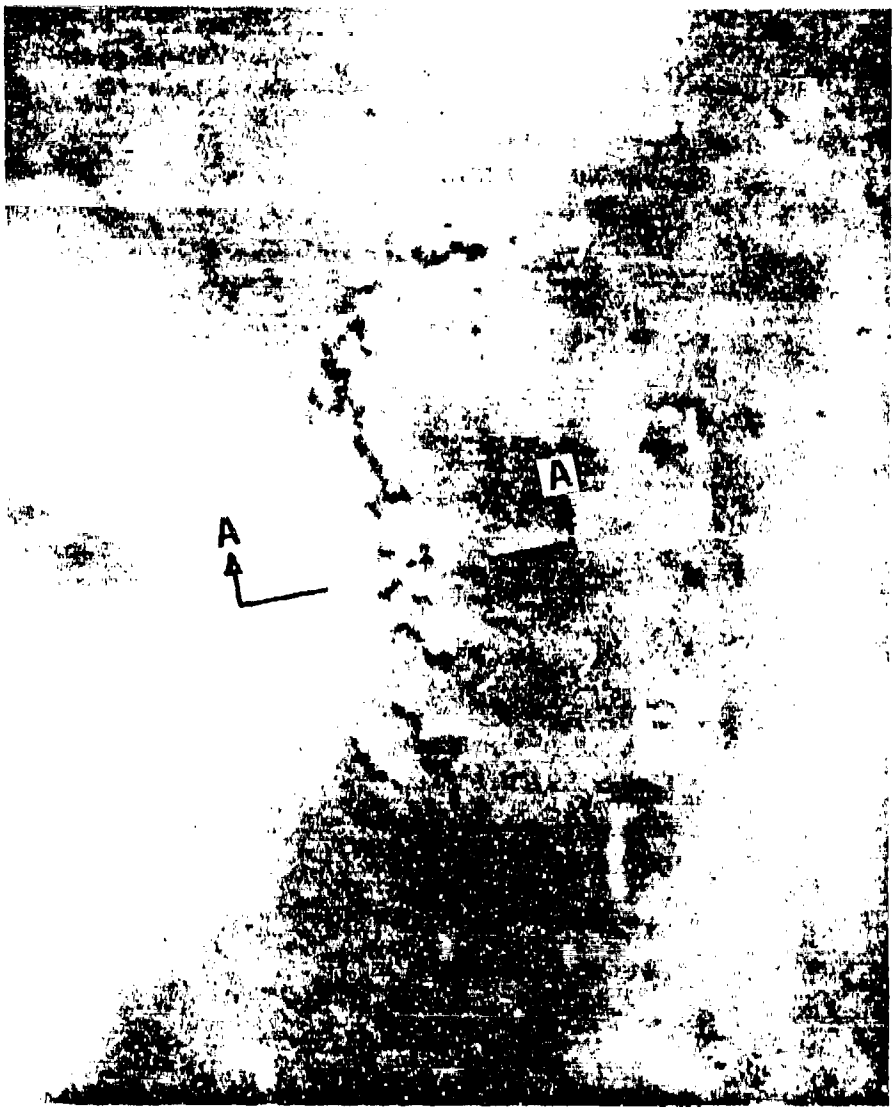
SECTION BB

SECTION—CC

Marcographs of casting cross sections, shown in Fig 6A, revealing severity and and location of shrinkage condition. (unetched, actual size)

EVALUATION OF INTERNAL SHRINKAGE IN CAST STEEL

Fig. 6B



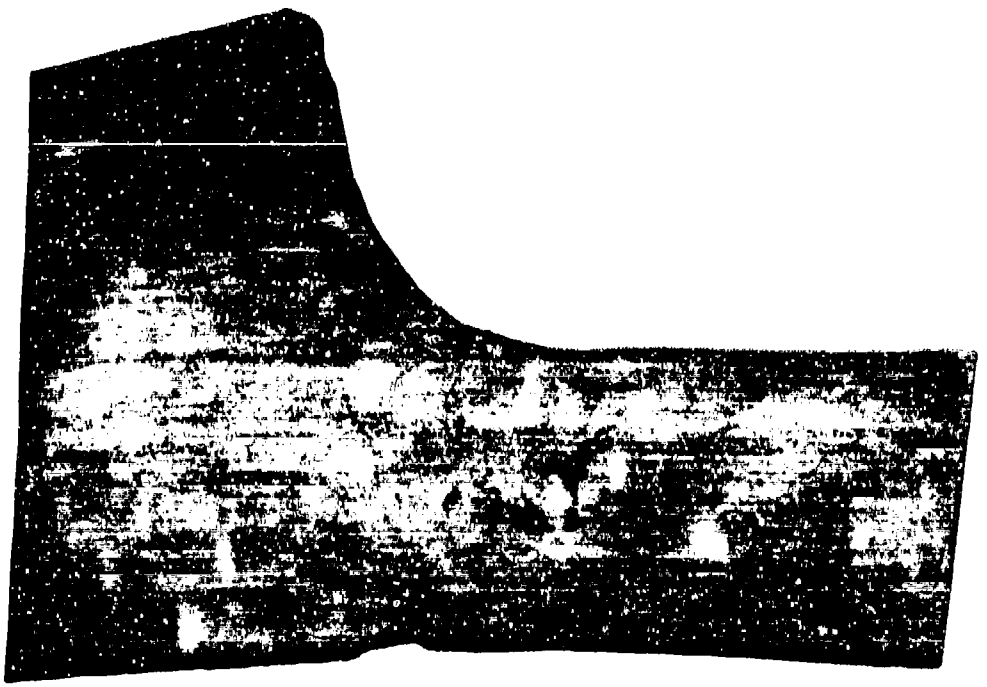
RADIOGRAPHIC IMAGE OF DENDRITIC SHRINKAGE IN CAST STEEL 1¾ INCHES THICK. EVALUATION IS SHOWN IN FIG. 7B.

Fig. 7A

EVALUATION OF FIG. 7A

Severity level of shrinkage shown in Fig. 7A compares with the following:

ASTM—E—446 — Type CB — Grade 5
ASTM—E—186 — Not applicable, too thin
MIL—R—11469 — Type C — Std. 3



Macrograph of casting cross section — AA, shown in Fig 7A, revealing severity and location of the shrinkage condition. (unetched, actual size)

EVALUATION OF DENDRITIC SHRINKAGE IN CAST STEEL 1¾ INCHES THICK.

Fig. 7B

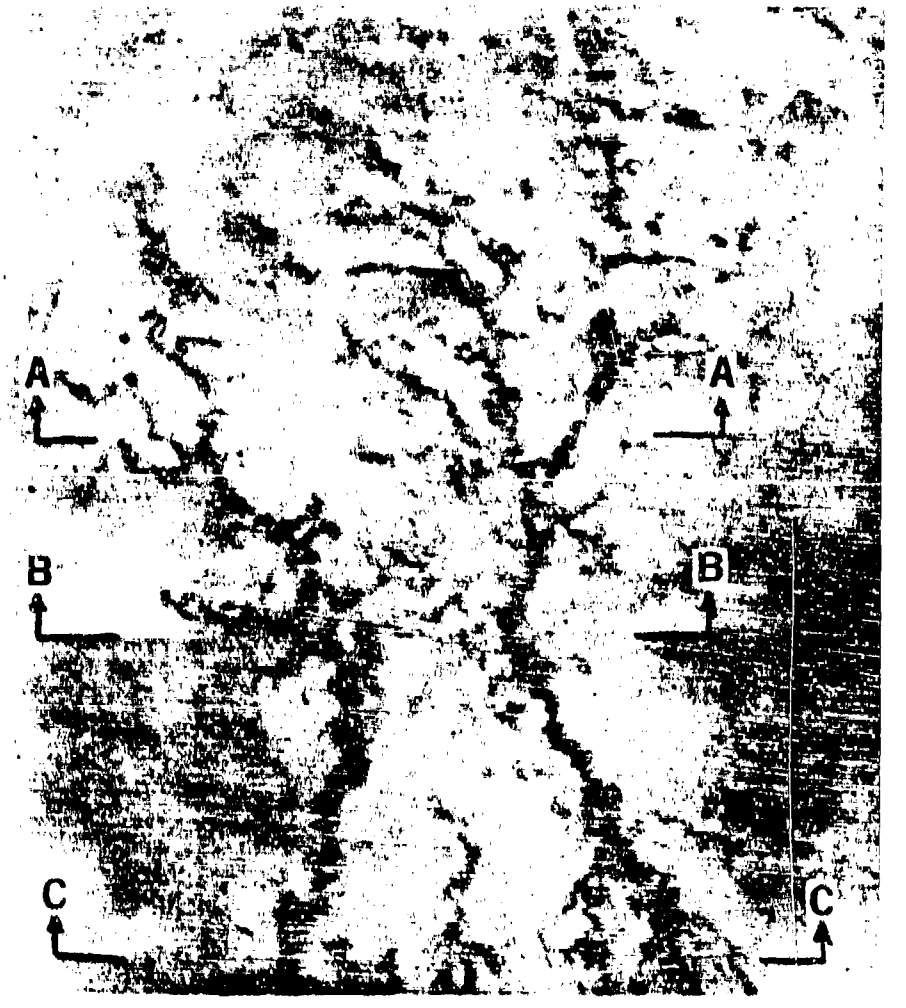
Radiographic image of dendritic shrinkage in 2½" thickness of steel. Severity level shown compares with the following:

ASTM—E—446 — Not applicable, too thick
ASTM—E—186 — Type C — Std. 4
MIL—R—11469 — Type C — Std. 3

Fig. 8A

Macrograph of casting cross section, shown in Fig. 8A, revealing severity and location of shrinkage condition. (unetched, actual size)

Fig. 8B



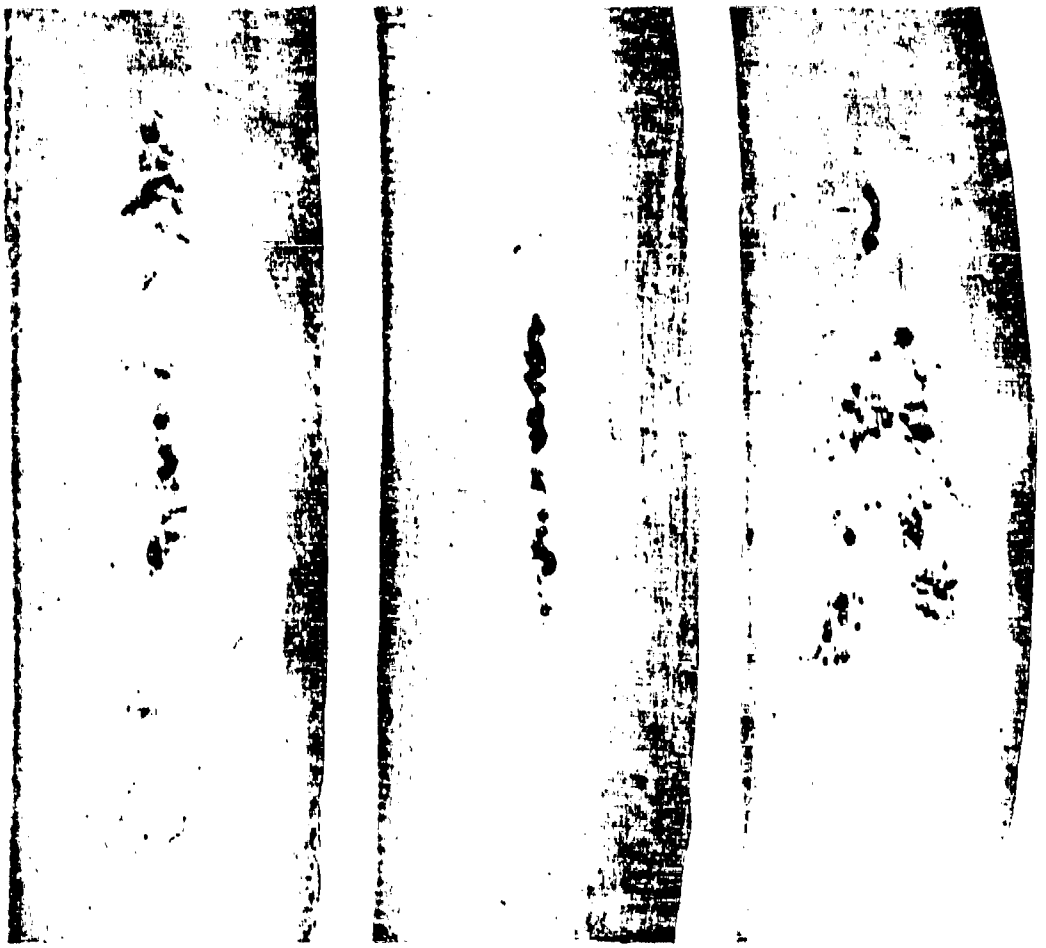
RADIOGRAPHIC IMAGE OF DENDRITIC SHRINKAGE IN CAST STEEL 2 INCHES THICK. EVALUATION SHOWN IN FIG. 9B.

Fig. 9A

EVALUATION OF FIG. 9A

Severity level of shrinkage shown in Fig. 9A compares with the following:

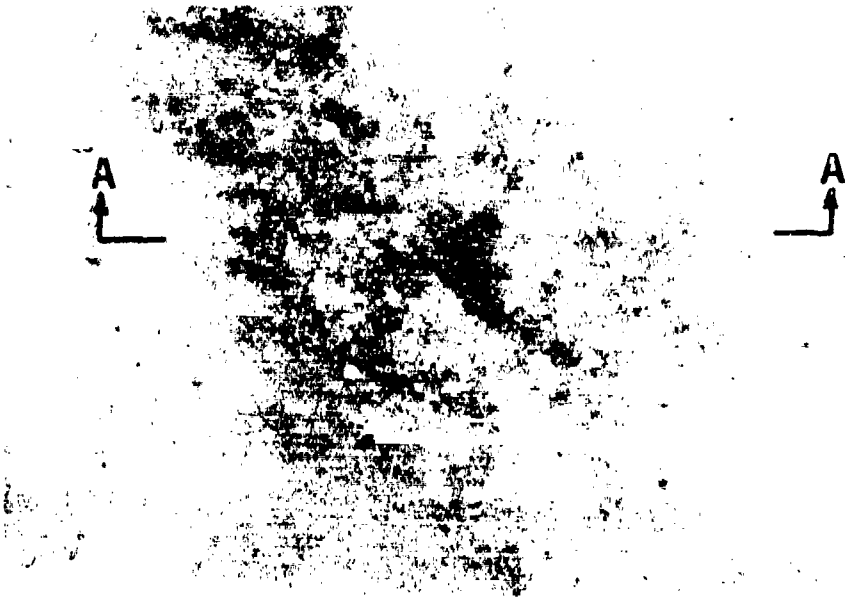
ASTM—E—446 — Exceeds Grade CB-5
ASTM—E—186 — Type 2 — Grade 5
MIL—R—11469 — Type C — Std. 4



SECTION AA SECTION BB SECTION CC

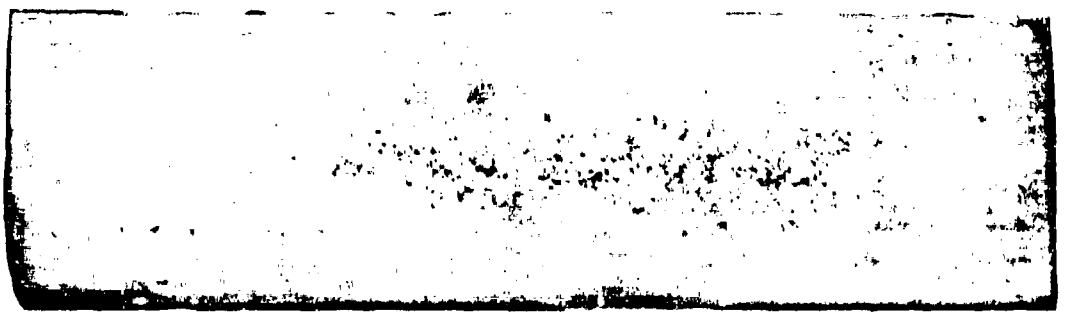
Macrographs of casting cross sections, shown in Fig. 9A, revealing severity and location of shrinkage condition. (unetched, actual size)

Fig. 9B



Radiographic image of sponge shrinkage in 1½" steel. Severity level shown compares with the following:

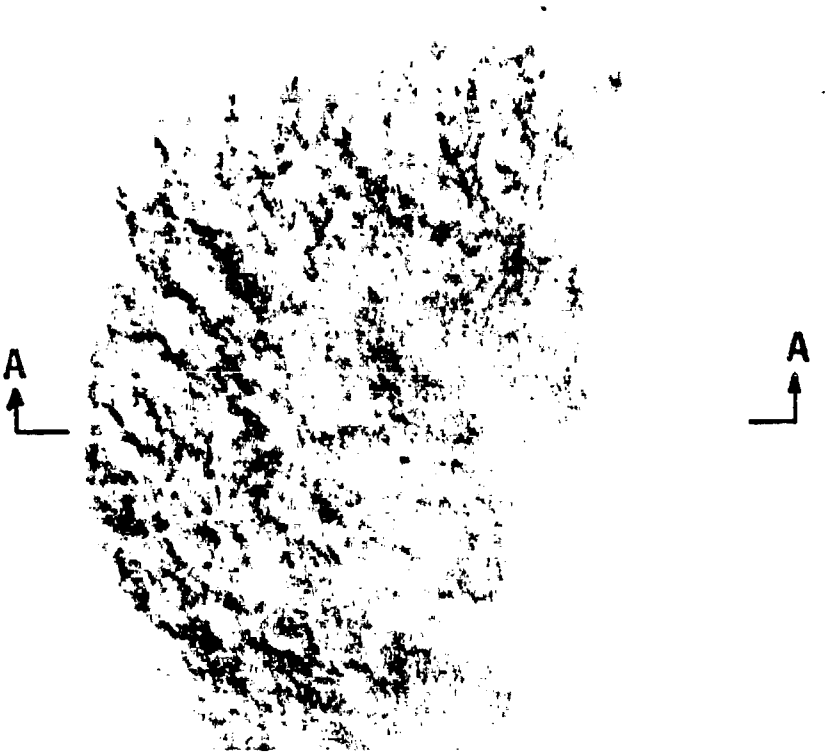
ASTM—E—446 — Type CC, Grade 4
ASTM—E—186 — Not applicable, too thin
MIL—R—11469 — Type D — Std. 3



Macrograph of casting cross section-AA showing severity and location of shrinkage condition. (unetched, actual size)

EVALUATION OF SPONGE SHRINKAGE IN CAST STEEL 1½ INCHES THICK.

Fig. 10



RADIOGRAPHIC IMAGE OF SPONGE SHRINKAGE IN CAST STEEL 1½ INCHES THICK. EVALUATION INCLUDED IN FIG. 11B.

Fig. 11A

EVALUATION OF FIG. 11A

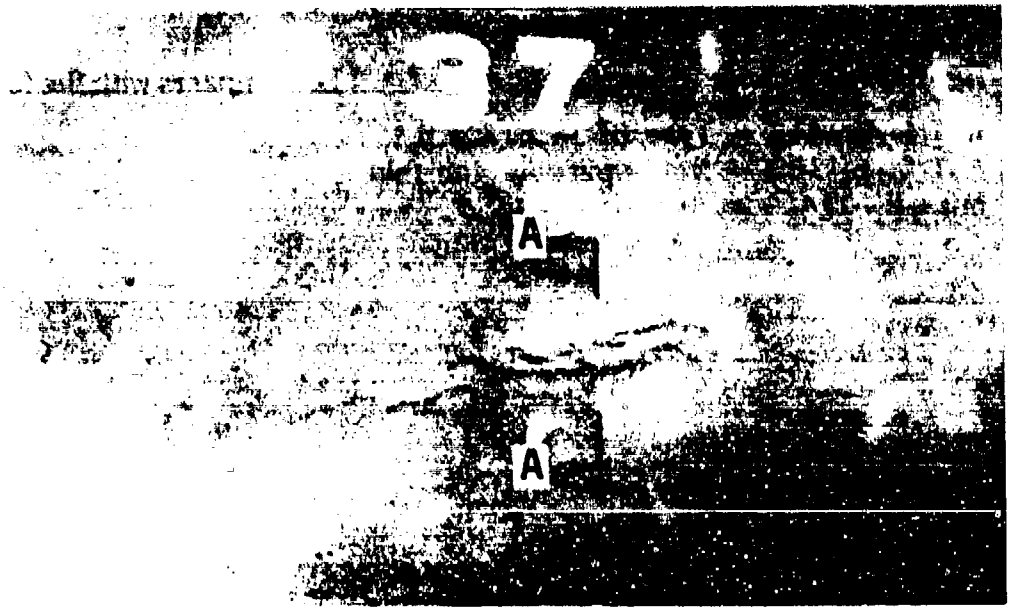
Severity level of the shrinkage shown in Fig. 11A compares with the following:

ASTM—E—446 — Type CC — Grade 5
ASTM—E—186 — Not applicable, too thin
MIL—R—11469 — Type D — Std. 3

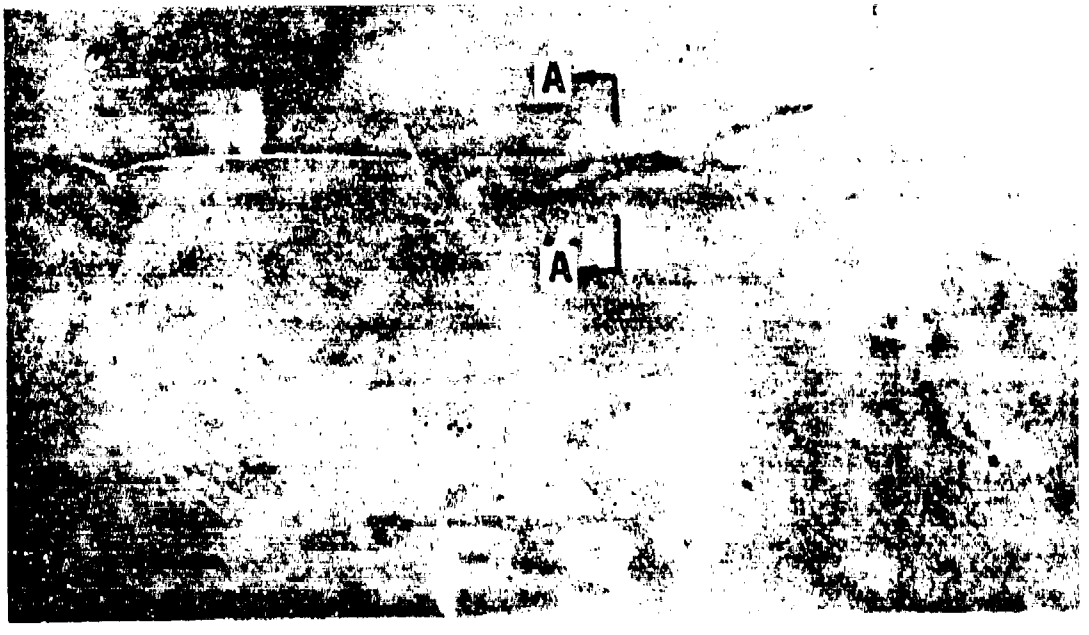
Macrograph of casting cross section AA, shown in Fig. 11A, revealing severity and location of the shrinkage condition. (unetched, actual size)

EVALUATION OF SPONGE SHRINKAGE IN CAST STEEL 1½ INCHES THICK.

Fig. 11B



Radiograph of a 3" hot tear in cast steel 2½ thick (Radiation angle 20°)



Same hot tears as above but radiation was more parallel with the tear. Severity evaluation shown in Fig. 12B.

Fig. 12A

EVALUATION OF FIG. 12A

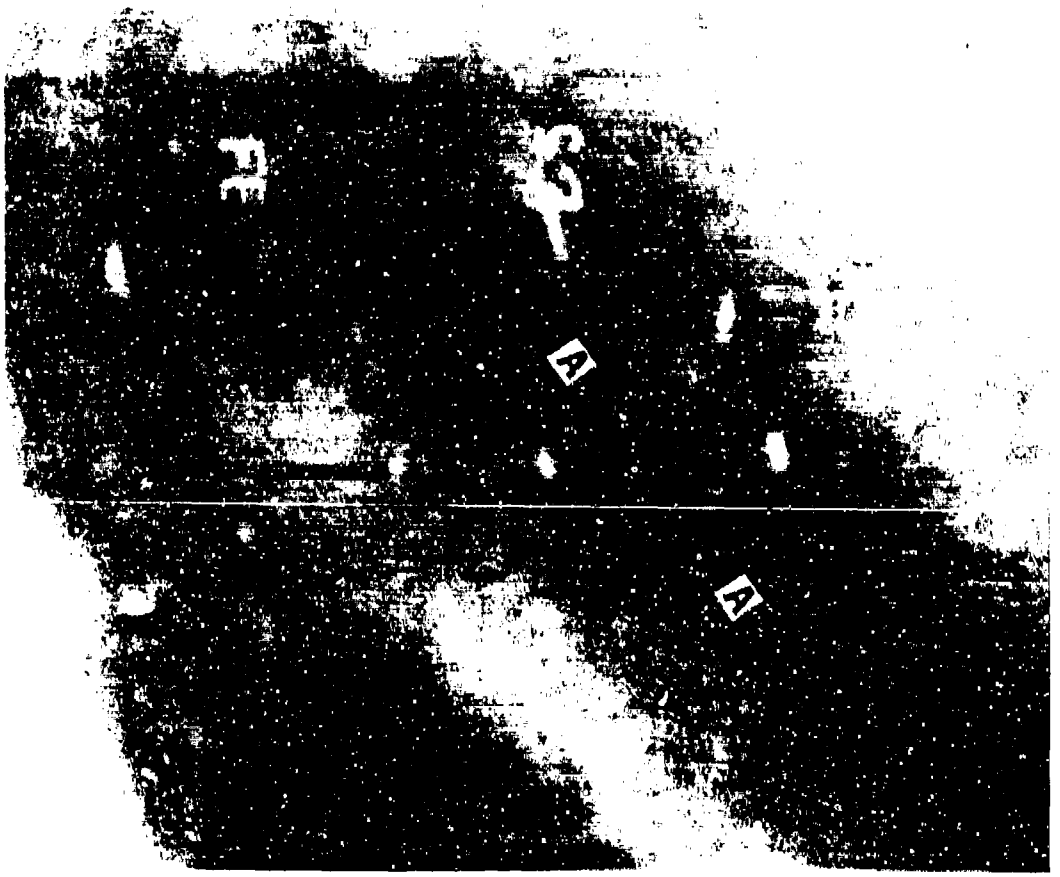
Severity level of the tear shown in Fig. 12A compares with the following:

ASTM—E—446 — Not applicable, too thick
ASTM—E—186 — Level 4
MIL—R—11469 — Std. 4

Macrograph of casting cross section AA, shown in Fig. 12A, revealing severity and location of the tear. (unetched, actual size)

EVALUATION OF HOT TEAR IN CAST STEEL 2½ INCHES THICK.

Fig. 12B



Radiograph of a 5" hot tear in cast steel 2½ inches thick. Severity level is as follows:

ASTM—E—446 — Not applicable, too thick
ASTM—E—186 — Level 5
MIL—R—11468 — Std. 5

EVALUATION OF HOT TEAR IN CAST STEEL 2½ INCHES THICK.

Fig. 13A

Macrograph of casting section AA shown in Fig. 13A, revealing cross sectional extent of the tear. (unetched, actual size)

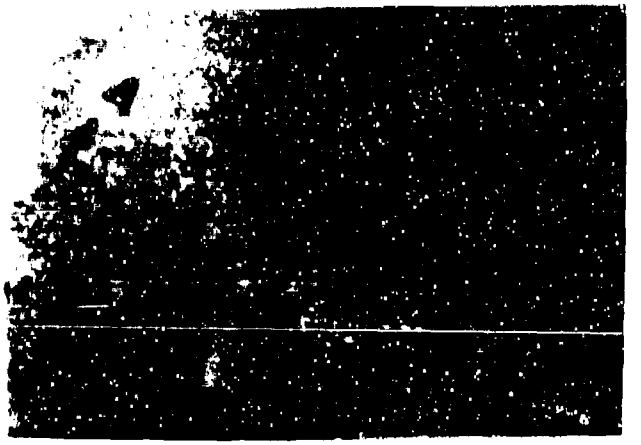
EVALUATION OF HOT TEAR IN CAST STEEL 2½ INCHES THICK.

Fig. 13B

ALUMINUM CASTING FLAWS

This edition of the report is updated to include 22 figures- actual photographs- of the various aluminum casting flaws under study. The pictures will permit engineers and technicians to get a realistic perception for material integrity and flaw classification in these thickness ranges of aluminum.

GAS HOLES



Actual Size Radiograph - Material Thickness 5/16"
Meets Std. 4 of ASTM E-155

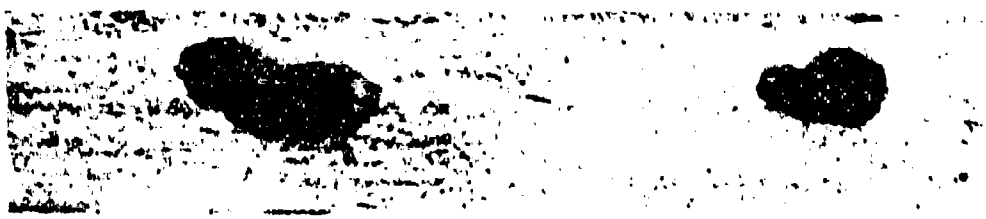
Macrograph of Cross Section AA Exposing the Flaw
4X Magnification- Unetched

EVALUATION OF GAS HOLES IN CAST ALUMINUM

Figure 1A

GAS HOLES

Actual Size Radiograph - Material Thickness 5/16"
Meets Std. 7 of ASTM E-155



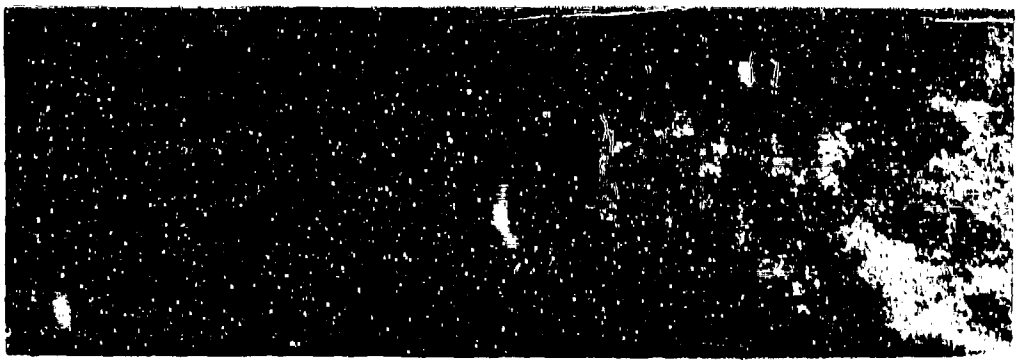
Macrograph of Cross Section AA Exposing the Flaw
4X Magnification- Unetched

EVALUATION OF GAS HOLES IN CAST ALUMINUM

Figure 1B

GAS POROSITY - ROUND

Actual Size Radiograph - Material Thickness 1/4"
Meets Std. 2 of ASTM E-155



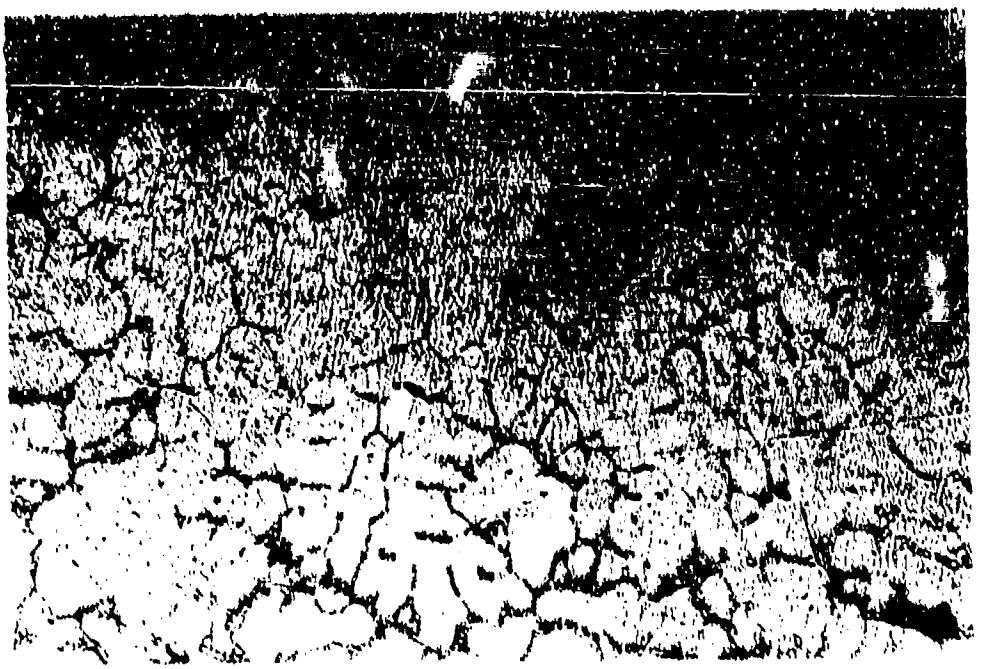
Micro-Radiograph of a .025" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Porous Condition at 10X Magnification.

EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 2A

GAS POROSITY - ROUND

Macrograph of Cross Section AA (Fig.2A) Showing Std. 2 Porosity at 4X Magnification. Unetched



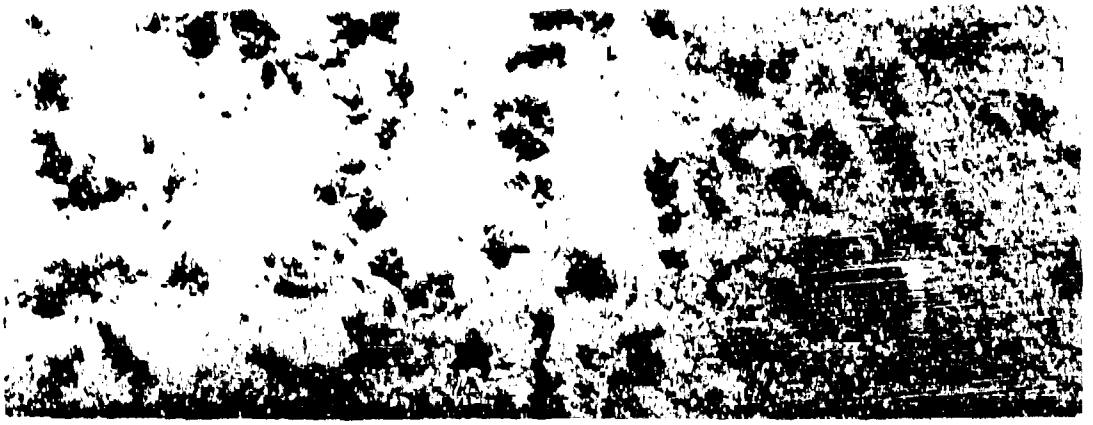
Micrograph of Cross Section AA (Fig.2A) Showing the Porous Condition at 100X Magnification - Kellers Etch.

EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 2B

GAS POROSITY - ROUND

Actual Size Radiograph - Material Thickness 3/8"
Meets Std. 4 of ASTM E-155



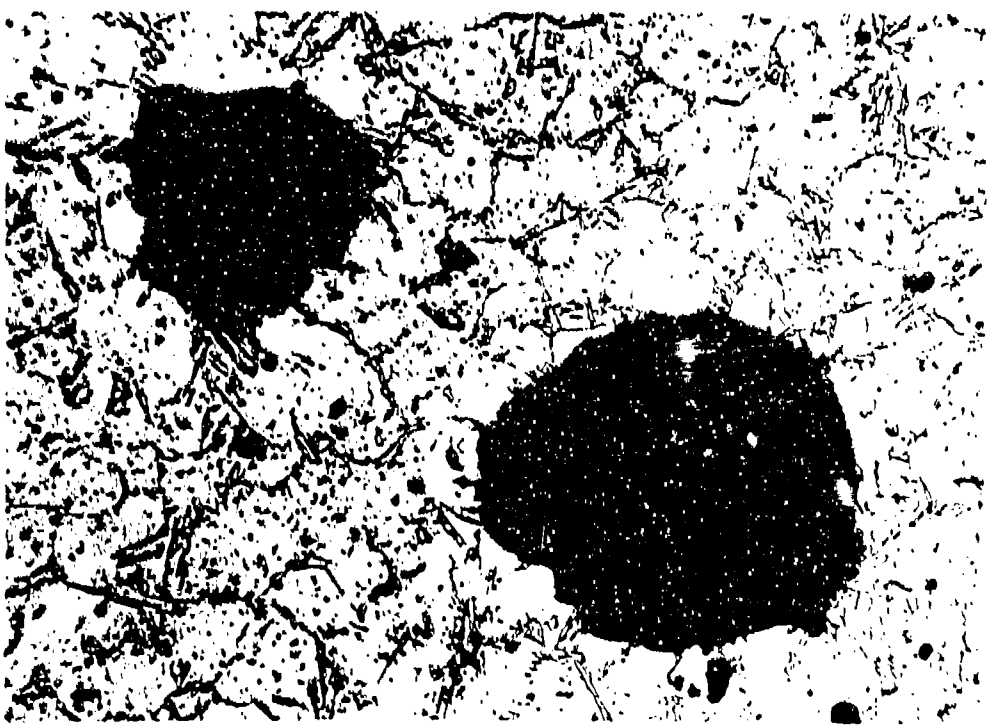
Micro-Radiograph of a .025" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Porous Condition at 10X Magnification.

EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 3A

GAS POROSITY - ROUND

Macrograph of Cross Section AA (Fig.3A) Showing Std.4 Porosity at 4X Magnification - Unetched.



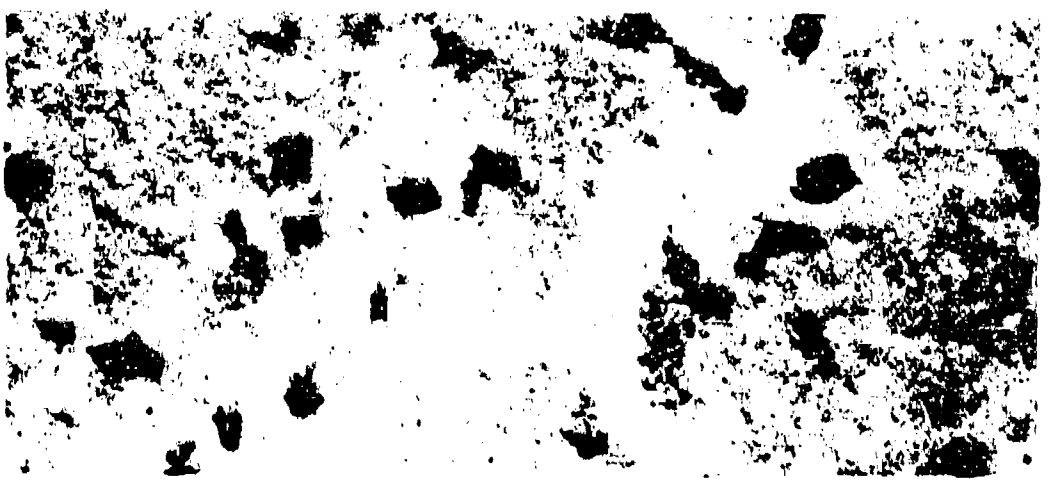
Micrograph of Cross Section AA (Fig.3A) Showing the Porous Condition at 100X Magnification - Kellers Etch.

EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 3B

GAS POROSITY - ROUND

Actual Size Radiograph - Material Thickness 1/4"
Meets Std.6 of ASTM E-155



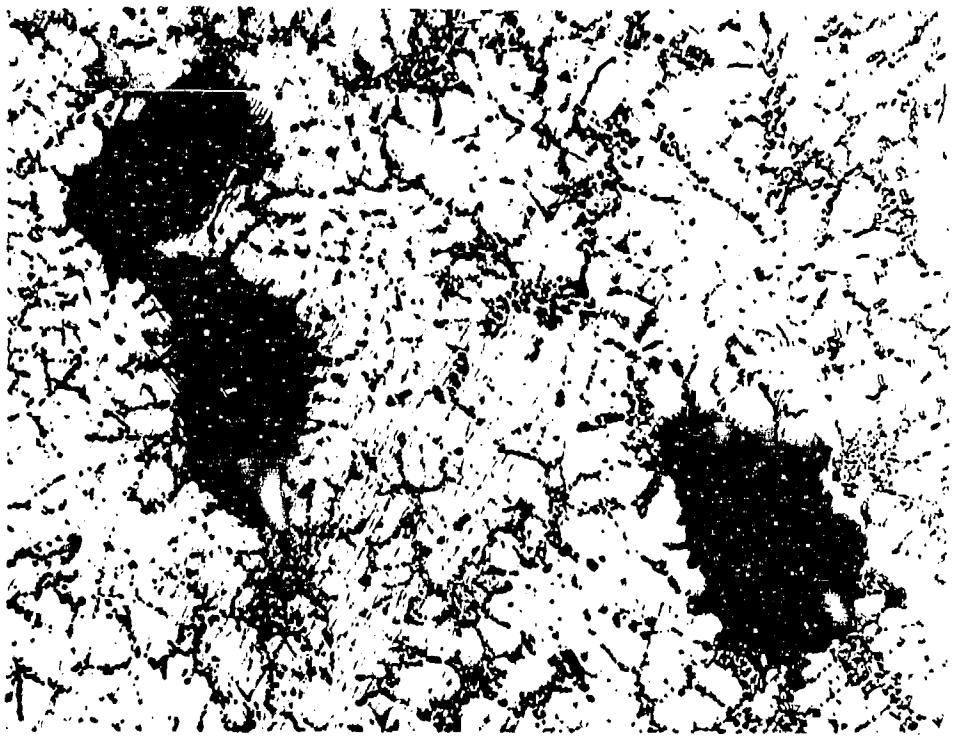
Micro-Radiograph of a .025" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Porous Condition at 10X Magnification.

EVALUTION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 4A

GAS POROSITY - ROUND

Macrograph of Cross Section AA (Fig.4A) Showing Std.6 Porosity at 4X Magnification - Unetched



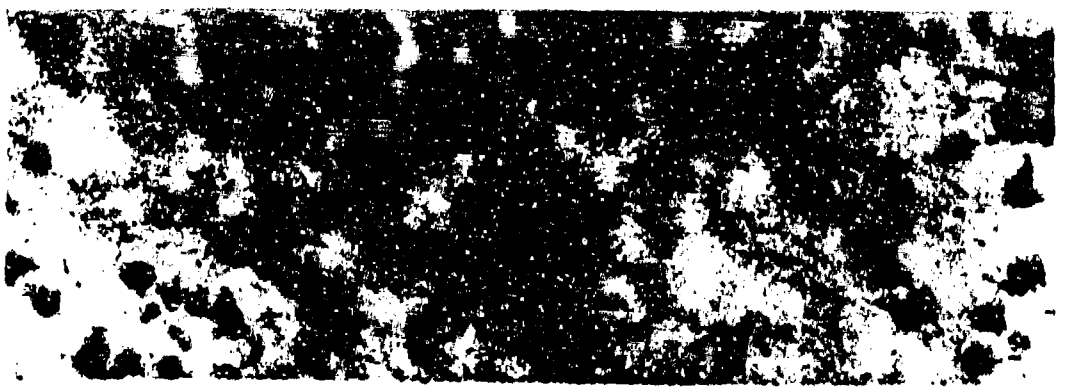
Micrograph of Cross Section AA (Fig.4A) Showing the Porous Condition at 100X Magnification-Kellers Etch.

EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 4B

GAS POROSITY - ELONGATED

Actual Size Radiograph - Material Thickness 1/4"& 3/8"
Meets Std. 3 of ASTM E-155



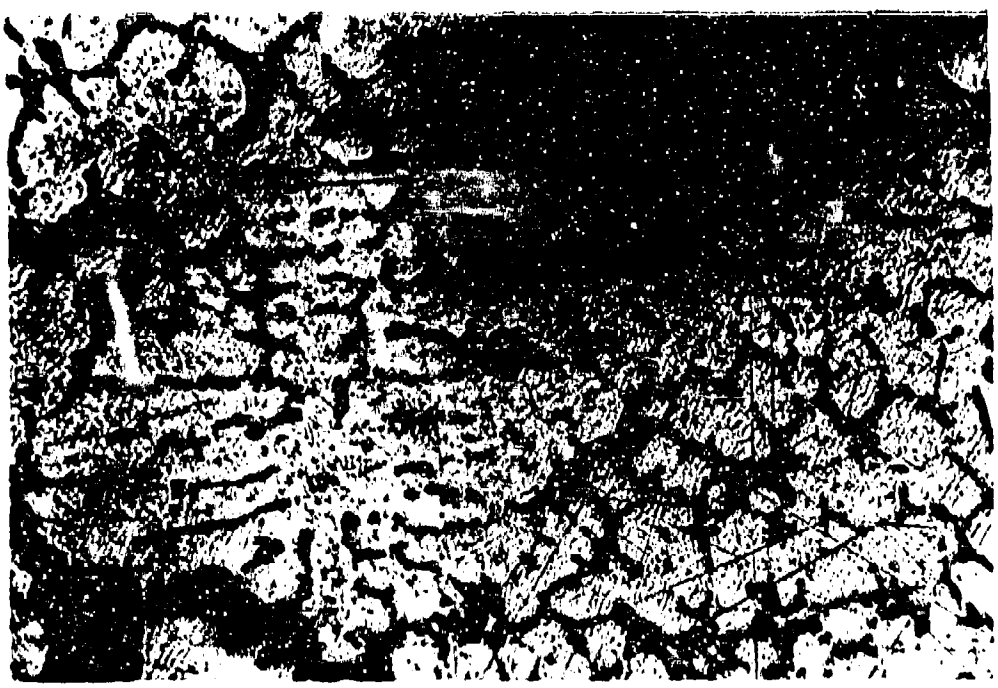
Micro-Radiograph of a .027" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Porous Condition at 10X Magnification.

EVALUATION OF GAS POROSITY-ELONGATED IN CAST ALUMINUM

Figure 5A

GAS POROSITY - ELONGATED

Macrograph of Cross Section AA (Fig.5A) Showing Std. 3 Porosity at 4X Magnification-Unetched.



Micrograph of Cross Section AA (Fig.5A) Showing the Porous Condition at 100X Magnification-Kellers Etch.

EVALUATION OF GAS POROSITY-ELONGATED IN CAST ALUMINUM

Figure 5B

GAS POROSITY - ELONGATED

Actual Size Radiograph - Material Thickness 1/2"
Meets Std.6 of ASTM E-155

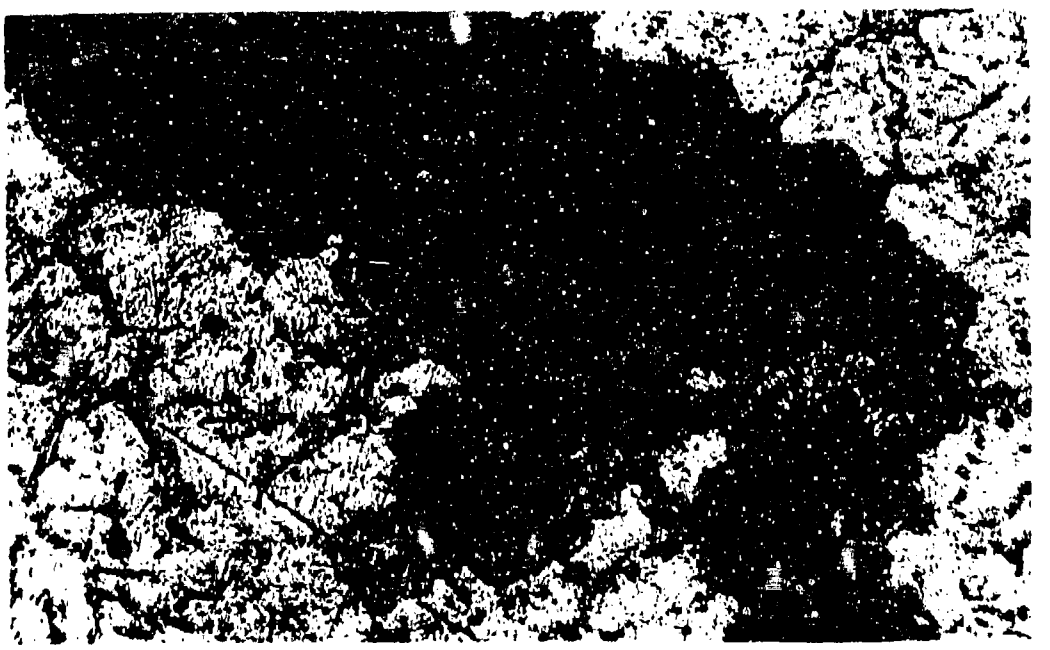
Micro-Radiograph of a .020" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Porous Condition at 10X Magnification.

EVALUATION OF GAS POROSITY-ELONGATED IN CAST ALUMINUM

Figure 6A

GAS POROSITY - ELONGATED

Macrograph of Cross Section AA (Fig.6A) Showing Std. 6 Porosity at 4X Magnification-Unetched.

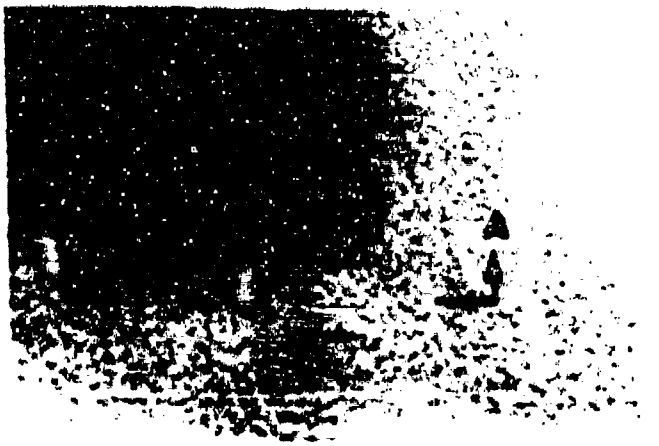


Micrograph of Cross Section AA (Fig.6A) Showing the Porous Condition at 100X Magnification-Kellers Etch.

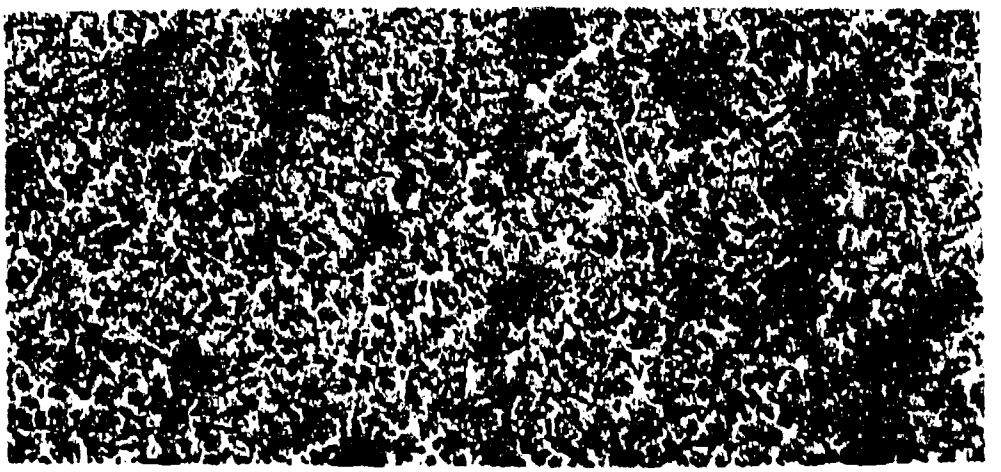
EVALUATION OF GAS POROSITY-ELONGATED IN CAST ALUMINUM

Figure 6B

GRAIN BOUNDARY SHRINKAGE



Actual Size Radiograph - Material Thickness 3/8"
This Condition is not included in ASTM E-155. It Appears Similar to, and Compares with Std.4 of Gas Porosity-Elongated.



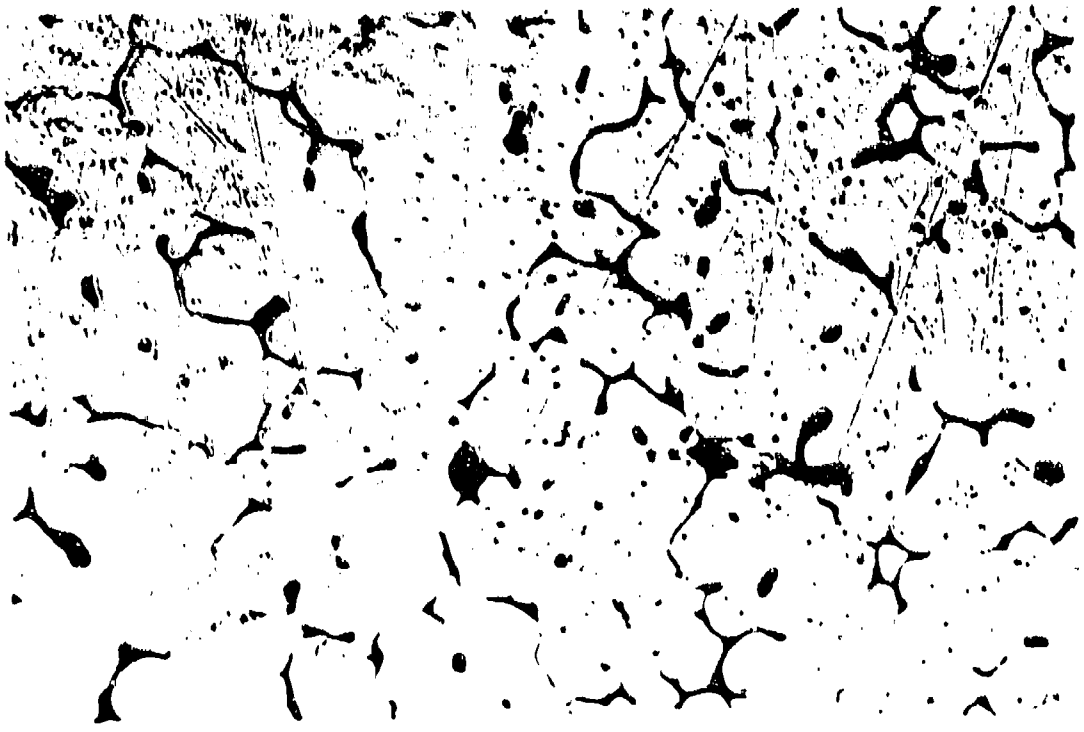
Micro-Radiograph of a .030" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Shrinkage Condition at 10X Magnification.

EVALUATION OF GRAIN BOUNDARY SHRINKAGE IN HIGH STRENGTH CAST ALUMINUM.

Figure 7A

GRAIN BOUNDARY SHRINKAGE

Macrograph of Cross Section AA (Fig.7A). No Evidence of the Shrink Condition is Visible at 4X Magnification - Unetched.



Micrograph of Cross Section AA (Fig.7A) Showing the Shrink Condition at 100X Magnification - Kellers Etch.

EVALUATION OF GRAIN BOUNDARY SHRINKAGE IN HIGH STRENGTH CAST ALUMINUM.

Figure 7 B

SHRINKAGE - CAVITY

Actual Size Radiograph - Material Thickness 1/4"
Meets Std.3 of ASTM E-155

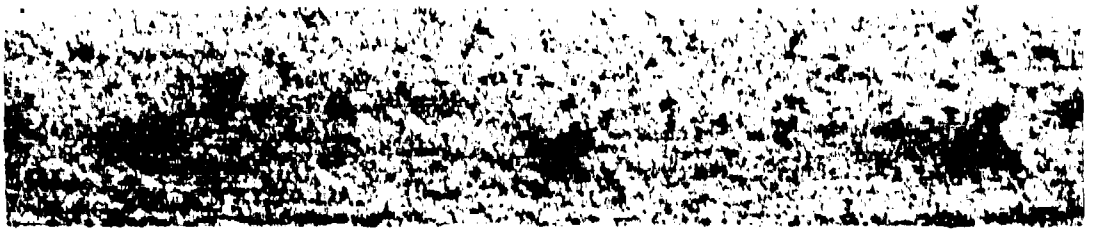
Macrograph of Cross Section AA Exposing the Flaw-
4X Magnification - Unetched. Small Pores are Gas Porosity.

EVALUATION OF CAVITY TYPE SHRINKAGE IN CAST ALUMINUM

Figure 8

SHRINKAGE - CAVITY

Actual Size Radiograph - Material Thickness 1/4"
Meets Std.7 of ASTM E-155



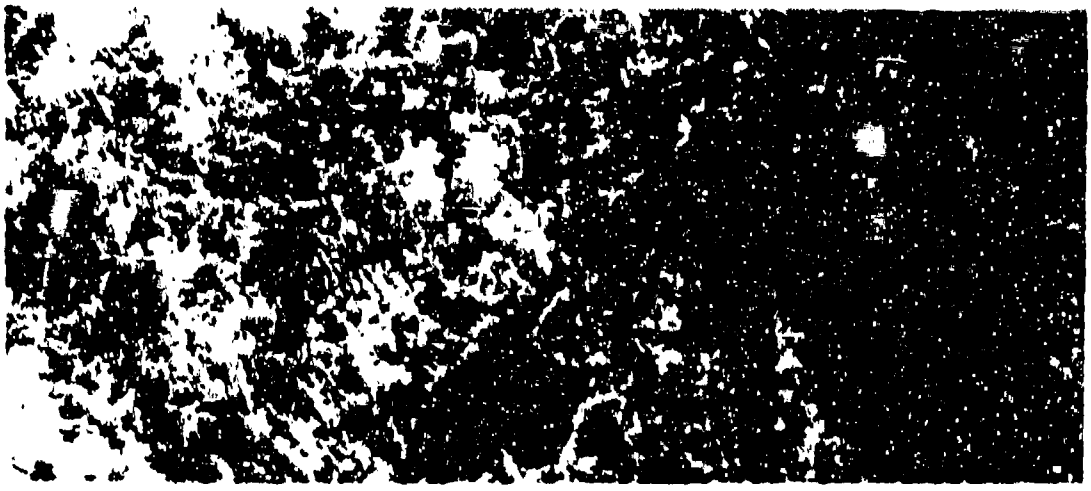
Macrograph of Cross Section AA Exposing the Flaw- 4X Magnification - Unetched. Small Pores are Gas Porosity.

EVALUATION OF CAVITY TYPE SHRINKAGE IN CAST ALUMINUM

Figure 9

SHRINKAGE - SPONGE

Actual Size Radiograph - Material Thickness 7/8"
Meets Std.4 of ASTM E-155



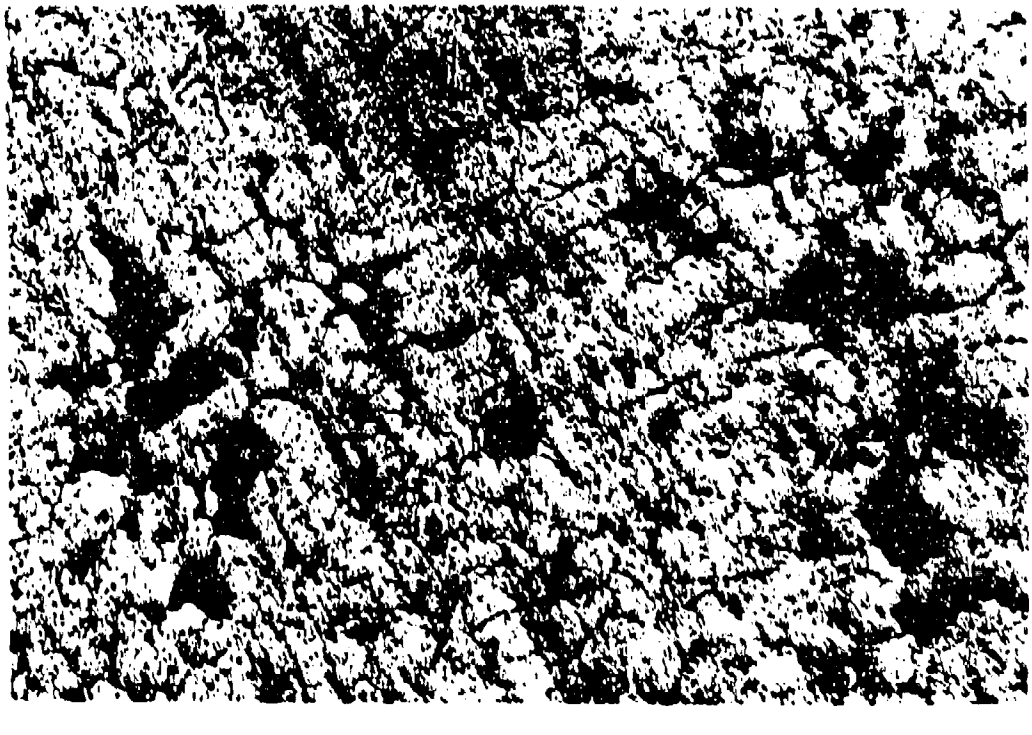
Micro-Radiograph of a .023" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Shrinkage Condition at 10X Magnification.

EVALUATION OF SPONGE SHRINKAGE IN CAST ALUMINUM

Figure 10A

SHRINKAGE - SPONGE

Macrograph of Cross Section AA (Fig.10A) Showing Std. 4 Shrinkage at 4X Magnification - Unetched.



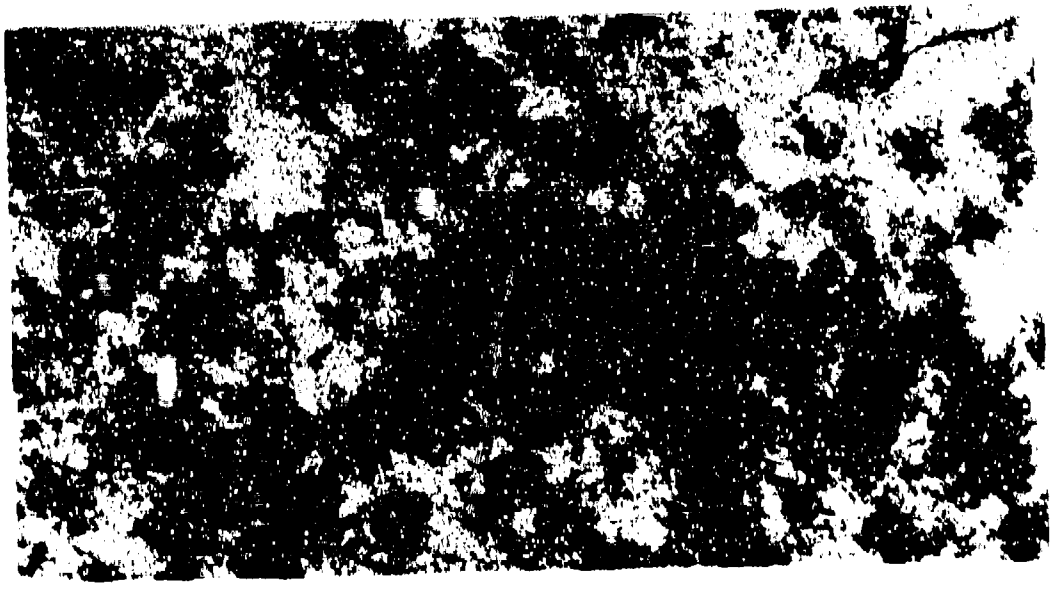
Micrograph of Cross Section AA (Fig.10A) Showing the Shrinkage Condition at 100X Magnification - Kellers Etch.

EVALUATION OF SPONGE SHRINKAGE IN CAST ALUMINUM

Figure 10B

SHRINKAGE - SPONGE

Actual Size Radiograph - Material Thickness 5/16"
Meets Std.7 of ASTM E-155



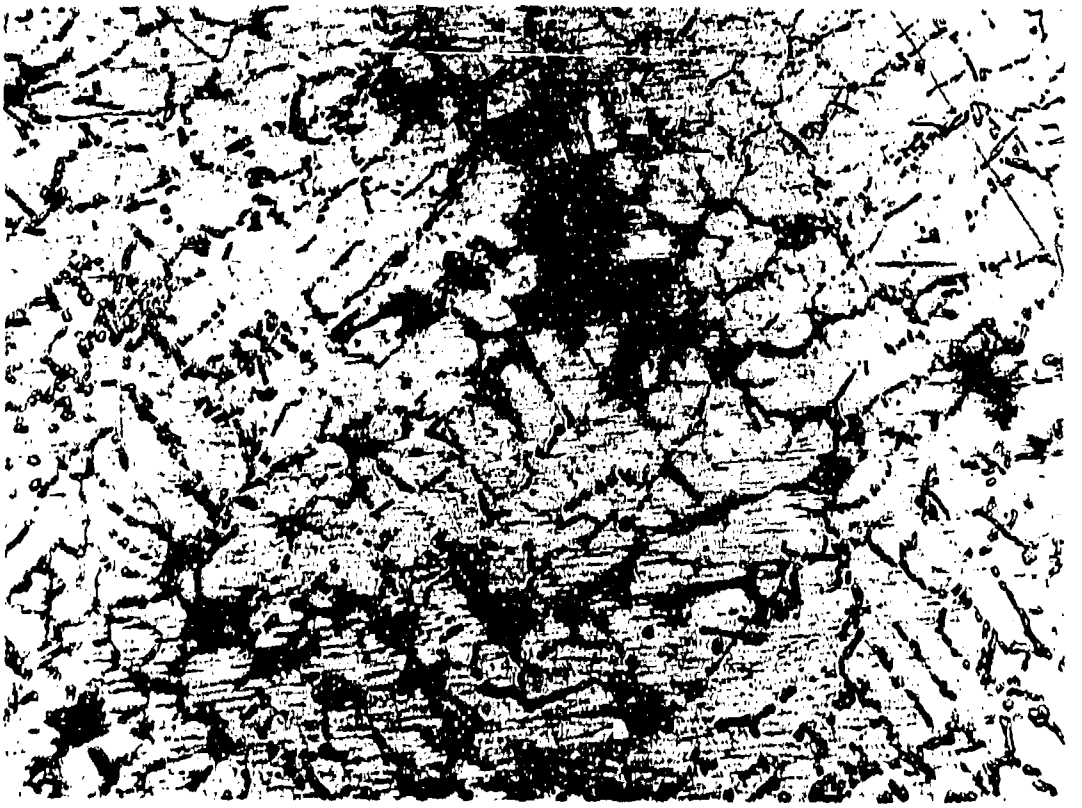
Micro-Radiograph of a .025" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Shrinkage Condition at 10X Magnification.

EVALUATION OF SPONGE SHRINKAGE IN CAST ALUMINUM

Figure 11A

SHRINKAGE – SPONGE

Macrograph of Cross Section AA (Fig.11A) Showing Std. 7 Shrinkage at 4X Magnification - Unetched.

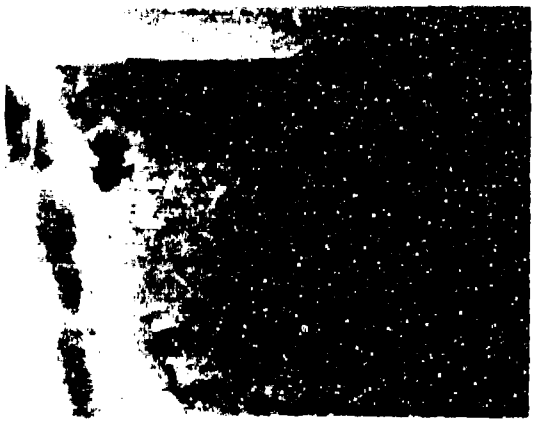


Micrograph of Cross Section AA (Fig.11A) Showing the Shrinkage Condition at 100X Magnification - Kellers Etch.

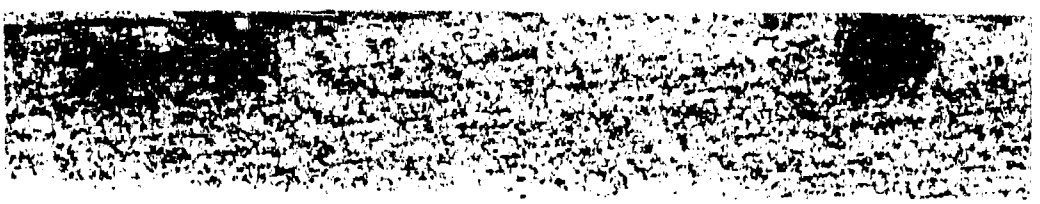
EVALUATION OF SPONGE SHRINKAGE IN CAST ALUMINUM

Figure 11B

FOREIGN MATERIAL - LESS DENSE



Actual Size Radiograph - Material Thickness 5/16"
Meets Std. 7 of ASTM E-155"



Macrograph of Cross Section AA Exposing the Flaw
4X Magnification - Unetched

Macrograph of Cross Section BB Exposing the Flaw
4X Magnification - Unetched

EVALUATION OF FOREIGN MATERIAL IN CAST ALUMINUM

Figure 12

FOREIGN MATERIAL - LESS DENSE

Actual Size Radiograph - Material Thickness 5/8"
Meets Std. 8 of ASTM E-155

Macrograph of Cross Section AA Exposing the Flaw
4X Magnification - Unetched

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Samples of aluminum and steel casting flaws most commonly experienced in production were selected to be radiographed in order to develop quantitative and descriptive picture images of various radiographic reference standards. Graphic illustrations of flaw size and flaw distribution for various radiographic reference standards were depicted by using radiographs and associated cross-sectional photo-macrographs. These graphic illustrations of radiographic levels of acceptance will provide meaningful design criteria for establishing

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20. ABSTRACT (continued)

realistic standards of acceptance for new material applications. This report also furnishes operational guidance to quality assurance and radiographic personnel in their normal on-the-job duties.