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REPORT NO. 710/375

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METALLURGICAL EXAMINATION OF  
TWO HEAVE CAST ARMOR PLATES

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By *H. L. Reed*  
Research Metallurgist

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June 12, 1941

WATERTOWN ARSENAL  
WATERTOWN, MASS.

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Report No. 710/375  
Watertown Arsenal

June 12, 1941

Metallurgical Examination of  
Two Heavy Cast Armor Plates

Purpose

↳ The purpose of this investigation was to study the metallurgical characteristics of samples cut from the centers of a 3-inch cast plate and a 15 inch grate casting manufactured by the Continental Roll and Steel Foundry Company. --

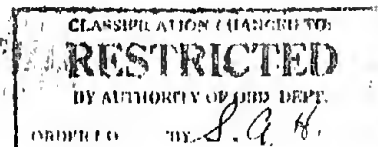
Introduction

It was reported that the 3" plate was generally sound, but that due to a few local casting defects it failed under the impact of a 75 mm. shell. The 15" grate casting also failed under the impact of a 6" shell presumably also because of foundry defects. Two samples from each of the two plates were submitted with a letter dated December 14, 1940 written by Mr. R. O. Henslett, General Metallurgist, Continental Roll and Steel Foundry Company.

Conclusions

The results of this investigation indicate that the failure of the material is due to the following factors:

1. Unsound metal due to casting defects, see Figure #1.
2. Extremely large grain size, see Figure #5.



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Unannounced		<input type="checkbox"/>
Justification		

- 3. Short prominent cracks, see Figure #1.
- 4. Carbon content on the high side. See Table below.

Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

Results

1. Chemical Analyses

The chemical analyses of the two castings are:

<u>Casting</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>	<u>Cu</u>
3" Plate	.32	.62	.018	.024	.480	1.44	1.13	.51	.16	.056
15" Grating	.40	.63	.022	.032	.505	1.44	1.13	.49	.16	.058

UNANNOUNCED

2. Macrostructure

A. Deep Etching

Interior of 3" Cast Armor Plate

Area "A" - The metal shows a quite coarse dendritic structure throughout with prominent interdendritic segregates and occasional small cracks.

Area "B" - The macrostructure and the dendrites in this section are as coarse as those described for Area "A", but the interdendritic segregates are not as extensive.

Interior of 15" Grate Casting

Area "1." - A reasonably fine dendritic structure is seen throughout this section. The segregations noted are similar to sulphide-rich impurities.

Area "2" - This metal shows very heavy segregations in the mid-wall portion, and short quite prominent cracks.

### B. Oberhoffer's Etch

#### Interior of 3" Plate

Area "A" - The metal shows a coarse dendritic structure.

Area "B" - The metal shows a mixture of fine and coarse dendritic structure.

#### Interior of 15" Grating

Area "A" - A medium coarse dendritic structure is present.

Area "B" - A fairly coarse dendritic structure is evident.

### 3. Microscopic Examination

Microscopic examination of samples cut from the 3 inch plate and the 15 inch grate casting showed in each case fairly well distributed nonmetallic inclusions. The amount of nonmetallics evident was considerable; and although no information is available to indicate a detrimental effect, it is believed desirable to reduce the amount of nonmetallics as much as possible.

The general structure was sorbitic and the materials possessed a very coarse grain size of Number 1 rated on the A.S.F.M. grain size scale. Only traces of net work grain boundary carbides were evident.

### 4. Heat Treatment

The heat treatment of the two heavy cast armor plates is as follows:

Heated to 1600°F	in 22 hrs.,	held 12 hrs.	- slow cooled with furnace.
" " 1650°F	" 17 "	" " "	- normalized.
" " 1600°F	" 10 "	" 20 "	- water quenched.
" " 1575°F	" 9 "	" " "	- " "
" " 1225°F	" 6 "	" " "	- slow cooled with furnace.
" " 1250°F	" 10 "	" " "	- " " " "

### 5. Physical Tests

The results of physical tests made on the 3 inch and 15 inch castings are as follows:

<u>Casting</u>	<u>Y.S.P. Lbs./Sq.In.</u>	<u>T.S. Lbs./Sq.In.</u>	<u>Elong. %</u>	<u>Cont. of Area %</u>	<u>Appearance of Fracture</u>
3" Plate Area "A"	79,500	103,000	17.0	27.4	45° break, coarse pitted structure, lustrous cavities.
Area "B"	79,000	101,500	10.0	16.2	45° break, coarse pitted structure, large lustrous cavities, large crack on stem.
15" Grating Area "A"	82,500	110,000	17.5	35.4	Partially cupped coarse pitted structure, check on stem.
Area "B"	84,000	84,000	3.0	11.0	90° break, spongy and dendritic structure.

### 6. Brinell Hardness

Brinell hardness determinations made on samples taken from both castings are given below:

<u>Casting</u>	<u>Brinell Hardness</u>
3" Plate - Area "A"	217, 217
" " Area "B"	217, 217
15" Grating - Area "A"	228, 228
" " Area "B"	228, 228

### Test Procedure and Materials

Two bars about 1"x1"x6" marked 50-P and two bars of the same size marked 50-B were submitted for examination. The 50-P bars which were cut from the center of the 3 inch plate were designated as 3" plate Area "A" and Area "B" respectively. The 50-B bars which were cut from



the 15 inch grate casting were designated as 15 inch grating, Area "A" and Area "B".

Metallurgical examination of these samples included chemical analysis, macroscopic examination, microscopic examination, physical tests and hardness curves.

#### Discussion

A survey of the chemical analysis indicates that the carbon in the two castings, especially that of the 15 inch grate casting is relatively high. It is believed that a carbon range of .25/.30 would be more desirable for this type of material.

Generally speaking the 3 inch cast plate had quite a coarse dendritic structure with prominent interdendritic segregates and occasional cracks. In the case of the 15 inch grate casting rather heavy segregations associated with quite prominent cracks were present in the mid-wall portion, see Figure #1. The size and distribution of the dendritic segregation in both plates is shown in Figure #2.

Figures #3 to #7 illustrate the microstructure of the 3" plate and the 15" grate casting. Both castings had an A.S.T.M. grain size No. 1. Recent investigations made at Rock Island Arsenal and this Arsenal indicate that a very large grain size such as reported in this material is correlated with poor ballistic properties. It has been determined to date that good quality cast armor should possess a grain size not larger than No. 6 A.S.T.M. grain size. The variation in the ductility values of the two castings, especially that of the 15 inch grate casting

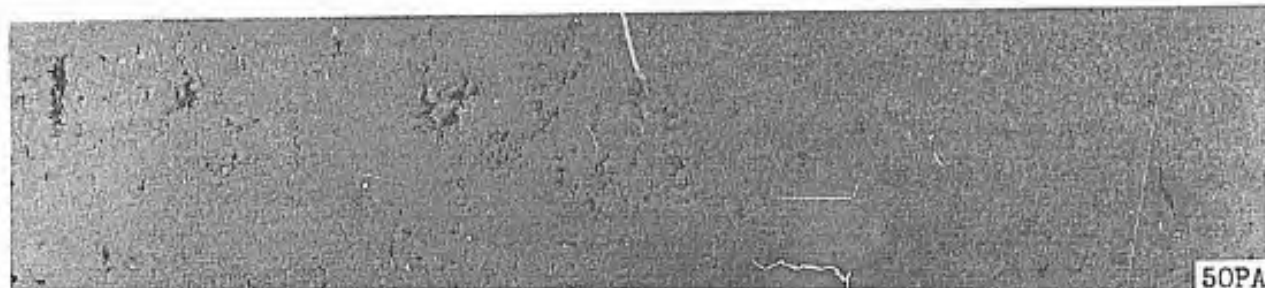
indicated the presence of heterogeneity in the material.

Respectfully submitted,

E. L. Reed,  
Research Metallurgist.

APPROVED:

S. B. Ritchie,  
Lt. Col., Ord. Dept.,  
Director of Laboratory.



INCHES 1 2 3  
ORDNANCE DEPT. U.S.A.  
WATERTOWN ARSENAL  
ARMOR PLATE  
January 9, 1941. W.A. 710-872

FIG. I



Figure 2

Etched in Oberhoffer's Reagent

Dendritic Structure of 3" Plate

Area "A" - Specimen 50-P-A

A coarse dendritic structure.

X2

MA-2740

Area "B" - Specimen 50-P-B

A mixture of fine and coarse dendrites.

X2

MA-2741

Dendritic Structure of 15" Grate Casting

Area "A" - Specimen 50-G-A

A medium coarse dendritic structure.

X2

MA-2742

Area "B" - Specimen 50-G-B

A fairly coarse structure.

X2

MA-2743

Figure 2

Etched in Oberhoffer's Reagent



Area "A" - Specimen 50-P-A



Area "B" - Specimen 50-P-B

Dendritic Structure of 3" Plate



Area "A" - Specimen 50-G-A



Area "B" - Specimen 50-G-B

Dendritic Structure of 15" Grate Casting

All Magnified 2 Diameters

Figure 3

Condition of Non-Metallics in Castings

Non-Metallics in 3" Plate

Area "A" - Specimen 50-P-A

Large, round inclusions in a background of numerous fine non-metallics.

X25

MA-2696

Area "B" - Specimen 50-P-B

Same type and distribution of the non-metallics as in Area "A", but slightly dirtier.

X25

MA-2697

Non-Metallics in 15" Grate Casting

Area "A" - Specimen 50-O-A

A great many large, round inclusions, with a small amount of fine non-metallics present.

X25

MA-2698

Area "B" - Specimen 50-O-B

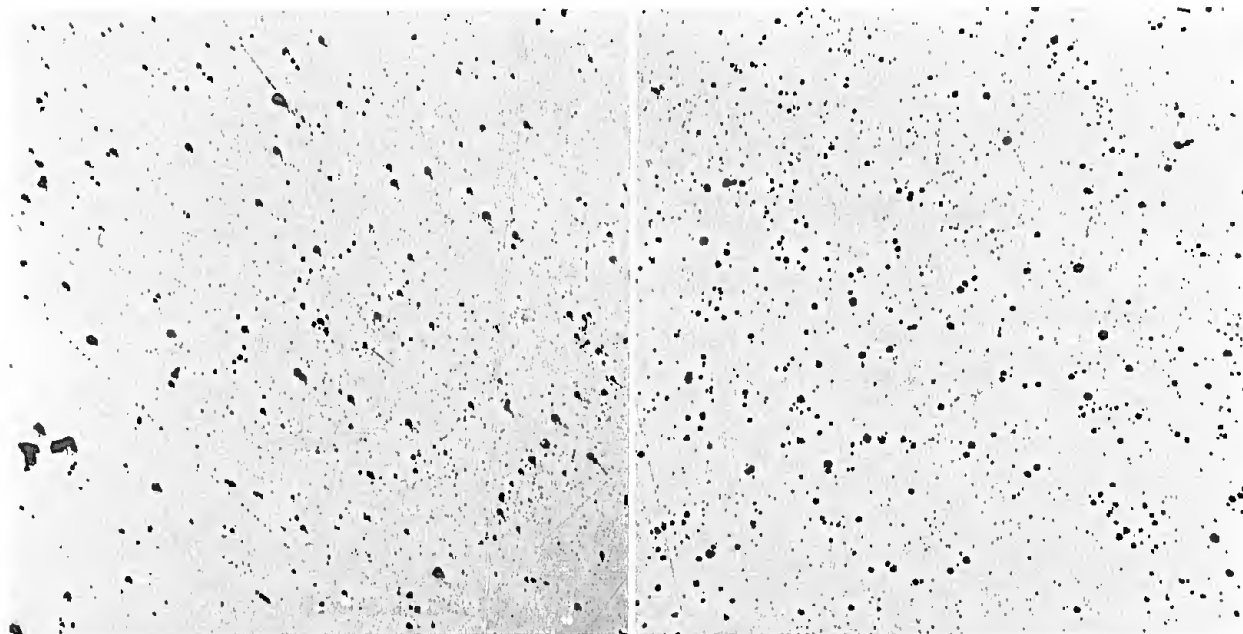
Large, round inclusions in an extremely dirty background of fine non-metallics.

X25

MA-2699

Figure 3

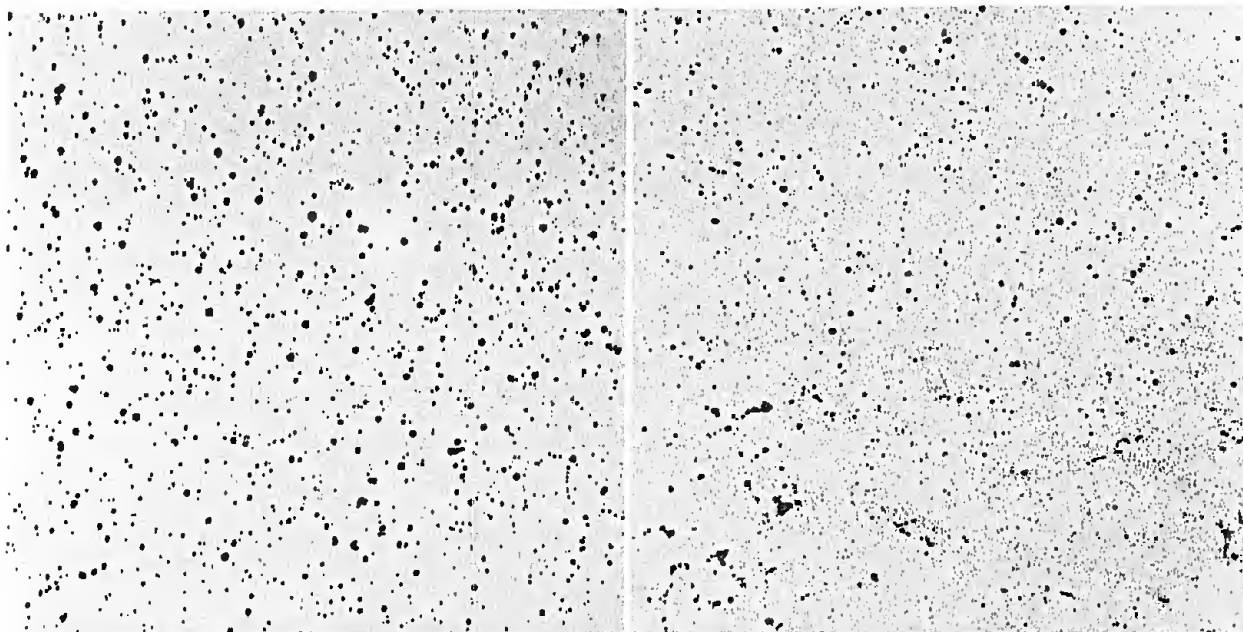
Condition of Non-Metallics in Castings



Area "A" - Specimen 50-P-A

Area "B" - Specimen 50-P-B

Non-Metallics in 3" Plate



Area "A" - Specimen 50-G-A

Area "B" - Specimen 50-G-B

Non-Metallics in 15" Grate Casting

All Unetched

Magnified 25 Diameters

W.A.639-3198

Figure 4

Evidence of Porosity in Castings

Porosity in 3" Plate

Area "A" - Specimen 50-P-A

Porosity in Specimen 50-P-A. The large black irregular areas are gas holes. This is the worst field found. There are in addition a few scattered gas holes in the specimen. Specimen 50-P-B has no field comparable to this, there being only a few gas holes in the specimen.

X25

MA-2731

Porosity in 15" Orate Casting

Area "B" - Specimen 50-G-B

Porosity in Specimen 50-G-B. The large black irregular areas are gas holes. There are only a few fields as bad as this. In addition there are several scattered gas holes in the specimen and also in Specimen 50-G-A.

X25

MA-2732



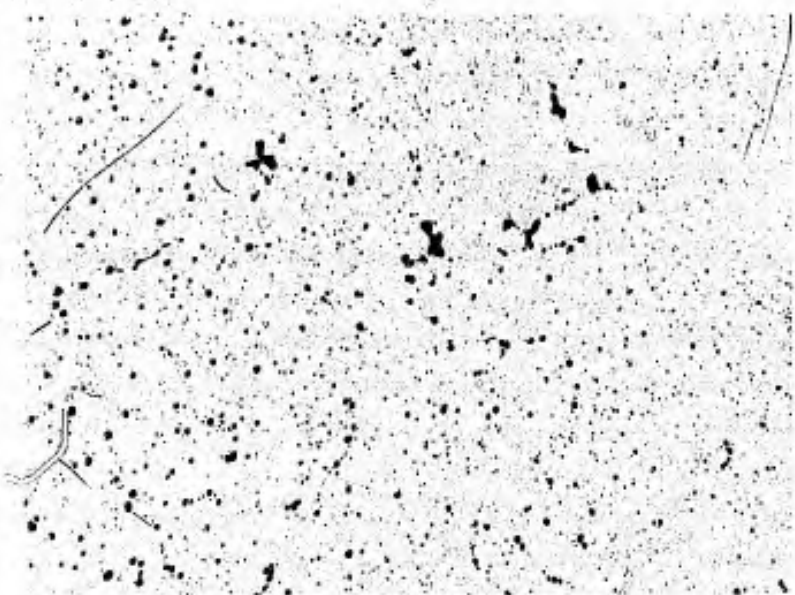
Figure 4

Evidence of Porosity in Castings



Area "A" - Specimen 50-P-A

Porosity in 3" Plate



Area "B" - Specimen 50-G-B

Porosity in 15" Grate Castings

All Unetched - Magnified 25 Diameters

W.A.639-3199

Figure 5

Grain Size of Castings

Grain Size of 3" Plate

Area "A" - Specimen 50-P-A

Grain size index number 1.

X25

MA-2708

Area "B" - Specimen 50-P-B

Grain size index number 1-2.

X25

MA-2709

Grain Size of 15" Grate Casting

Area "A" - Specimen 50-G-A

Grain size index number 1.

X25

MA-2710

Area "B" - Specimen 50-G-B

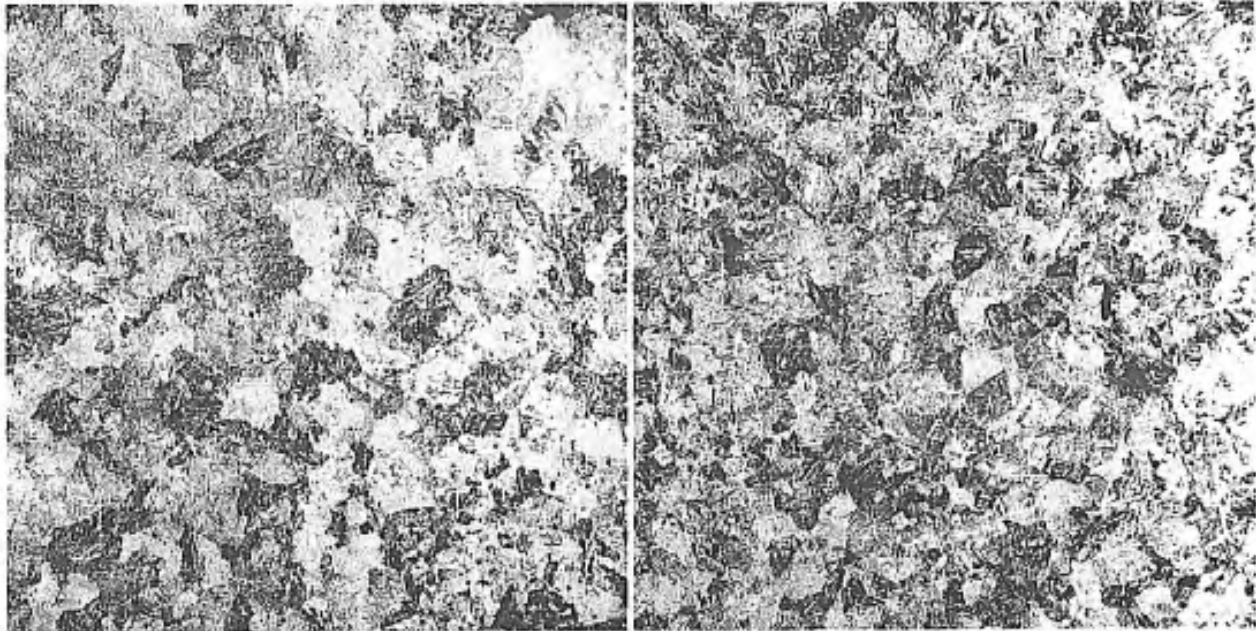
Grain size index number 1.

X25

MA-2711

Figure 5

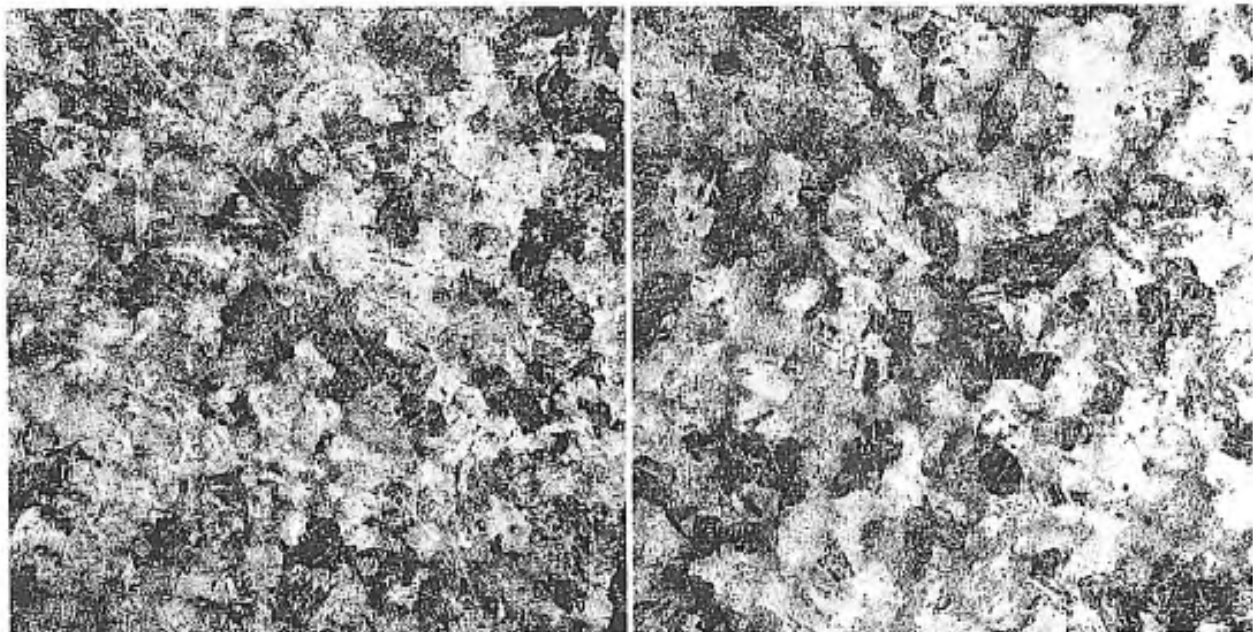
Grain Size of Castings



Area "A" - Specimen 50-F-A

Area "B" - Specimen 50-F-B

Grain Size of 3" Plate



Area "A" - Specimen 50-G-A

Area "B" - Specimen 50-G-B

Grain Size of 15" Grate Casting

All Etched in 1% Nital

Magnified 25 Diameters

W.A.639-3200

## Figure 6

### Microstructure of Castings

#### Microstructure of 3" Plate

Area "A" - Specimen 50-P-A Brinell 217

A coarse pseudo-martensitic sorbite having pronounced but fairly uniformly distributed micro-segregation. The triangular formation is most prominent in the dark grains (see Figure 5) which are of different chemical composition than the light grains.

X500 MA-2701

Area "B" - Specimen 50-P-B Brinell 217

Exactly the same as above.

X500 MA-2703

#### Microstructure of 15" Grate Casting

Area "A" - Specimen 50-G-A Brinell 228

The same as 50-P-A and 50-P-B.

X500 MA-2705

Area "B" - Specimen 50-G-B Brinell 228

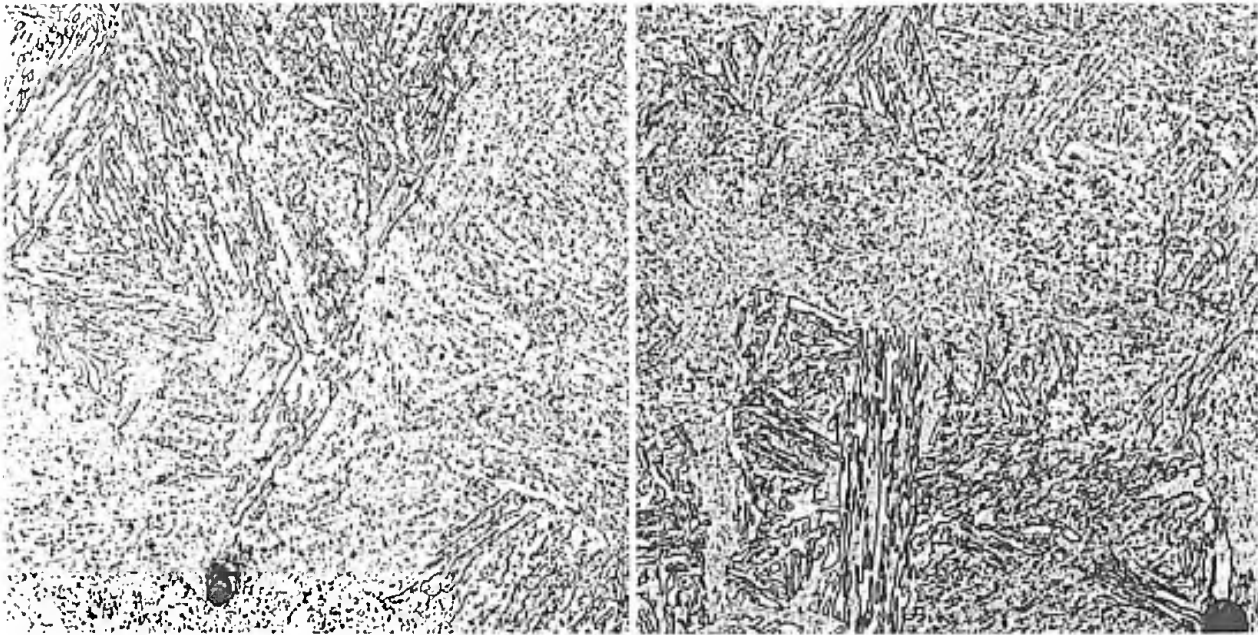
The same.

X500 MA-2707



Figure 6

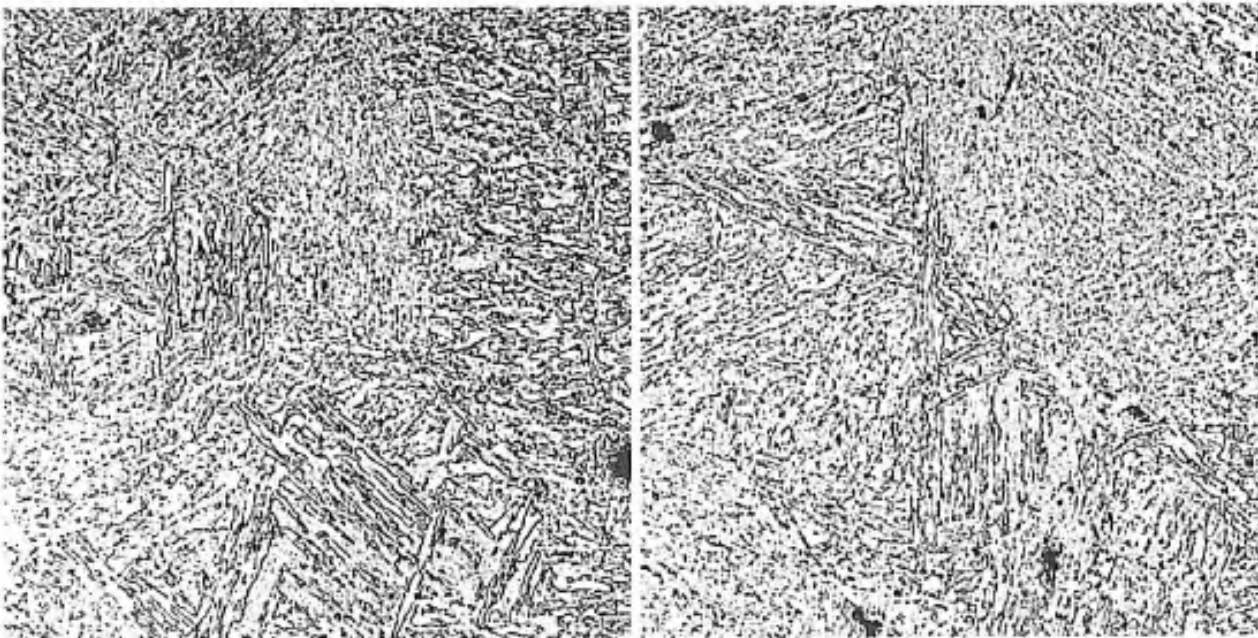
Microstructure of Castings



Area "A" - Specimen 50-P-A

Area "B" - Specimen 50-P-B

Microstructure of 3" Plate



Area "A" - Specimen 50-G-A

Area "B" - Specimen 50-G-B

Microstructure of 15" Grate Casting

All Etched in 1% Nital

Magnified 500 Diameters

W.A.639-3201



Figure 7

Condition of Carbides in Castings

General Carbide Condition in Both Castings

Uniformly distributed carbides. The carbides were revealed by a ten minute etch in Kurakami's Reagent, which stains carbides black.

X500

MA-2718

Evidence of Grain Boundary Carbides in Both Castings

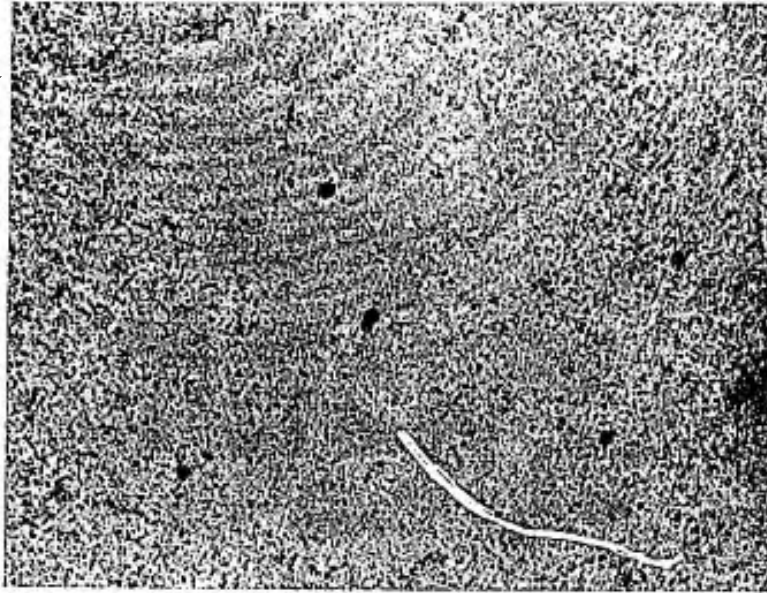
Grain boundary carbide chains. Chains exist in only about 5% of each specimen.

X500

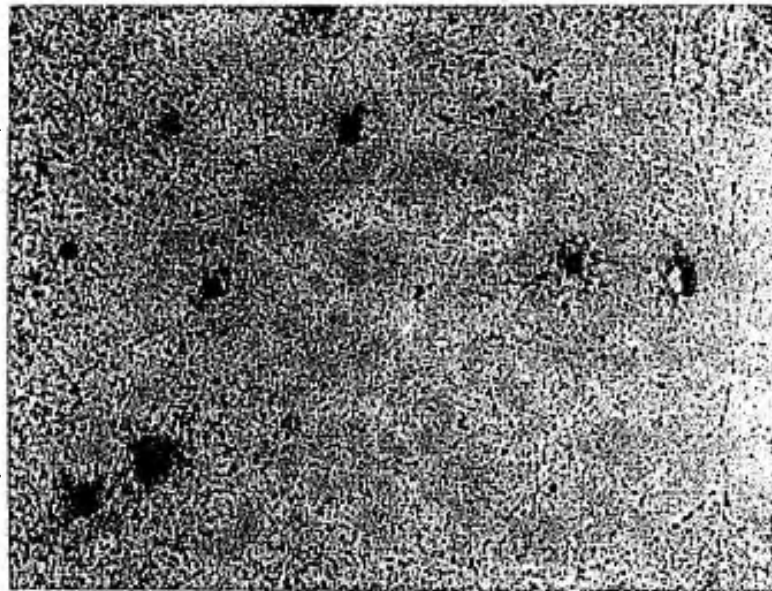
MA-2716

Figure 7

Condition of Carbides in Castings



General Carbide Condition in Both Castings



Evidence of Grain Boundary Carbides in Both Castings

All Etched in Murakami's Reagent - Magnified 500 Diameters