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REPORT NO. 710/387

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WAT-710/387

RESTRICTED

METALLURGICAL EXAMINATION

OF EXPERIMENTAL CAST ARMOR TURRET NO. 2

MANUFACTURED BY THE GENERAL STEEL CASTINGS CORPORATION

By

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Research Metallurgist

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1st Lt., Ord. Dept.

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2. This investigation indicates that if x-ray inspection is adopted for acceptance or rejection of heavy armor castings, liberal inspection standards will be required to prevent the rejection of castings which would be satisfactory for the service intended.

Introduction

The left half of the cast steel turret, No. 2, manufactured by the General Steel Castings Corporation, was sent to Watertown Arsenal for metallurgical examination as directed in A.P.G. letter 451.21/303, October 1, 1940. This turret was ballistically tested at Aberdeen with 37 mm. and 75 mm. A.P. projectiles and found to possess satisfactory ballistic properties. (Reference A.P.G. Firing Record No. 16562.)

The thickness of the turret wall varied from approximately 2.3" at the bottom of the side wall to about 1" at the top of the turret.

Test Procedure and Materials

Metallurgical examination included chemical analysis, macro and microscopic examination, physical tests and x-ray examination. The areas on the turret which were investigated are as shown in Figure 1.

Results

1. Chemical Analysis

Chemical analysis of the material as determined at this arsenal is given below:

C	Mn	P	S	Si	Cr	Mo	V
.47	.90	.022	.022	.38	2.24	.48	trace



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Check carbons were run on other samples cut from the turret and the values were .48, .44, and .51% carbon. This chemistry, especially the carbon, differs from that reported in the A.P.G. Firing Record which was as follows:

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Cr</u>	<u>Mo</u>
.31	.57	.014	.013	.26	2.14	.58

2. Macrostructure

a. Deep Etch

The macrostructure as revealed by the deep etch shows that the structure throughout the section is dendritic and exhibits a columnar pattern near the surface of the plate. The central portion has a coarse, nearly equiaxed structure, and contains a great many prominent, partially etched-out nonmetallics, see Figure 4.

b. Oberhoffer Etch

The central portion contains some porosity but shows a refined dendritic structure. Sections near the front and rear surface of the section had a pronounced dendritic structure.

c. Deep Nital Etch

Porosity was present only in the center of the cross section of the casting, see Figure 4c.

3. Microstructure

The central portions of the cross section of the casting contained the greatest percentage of nonmetallic inclusions and porosity, (Figure 5) while the areas near the outer surfaces of the cross section showed the presence of some large nonmetallics present in conjunction with a uniform distribution of fine nonmetallics. (Figure 5c).

The casting was heat treated to a uniform sorbitic structure. The grain size of the casting was determined as A.S.T.M. No. 5, see Figure 6c.

Some dendritic segregation was revealed by the Murakami etch and evidence of decarburization was observed on the outer surface, see Figures 7 and 4c.

4. X-Ray Examination

X-ray examination of the sections shown in Figure 1 indicates the presence of scattered gas cavities in area 2-1, fairly clear metal in area 2-2, and piping or centerline porosity in areas 2-3 and 2-4. An x-ray study made at area 3 containing the 37 mm. A.P. impact showed the presence of considerable centerline porosity (Figure 2) in the metal surrounding the penetration. No spalling occurred in this area of impact. An x-ray examination of the metal at area 4 containing the 75 mm. A.P. impact indicated the presence of considerable centerline porosity, see Figure 3. No spalling occurred in this area of impact.

5. Hardness

The hardness on a cross section of the casting was determined to be 255, 269 and 255 Brinell.

6. Physical Properties

Physical properties of the material are:

<u>Yield Point Divider Lbs./Sq.In.</u>	<u>Ultimate Strength Lbs./Sq.In.</u>	<u>Elong. % in 1.4"</u>	<u>Red. of Area %</u>	<u>Remarks</u>
109,000	130,200	10.0	17.6	Irregular break, coarse pitted struc- ture, lustrous cavi- ties, checks & cracks on stem.
111,000	132,200	10.7	21.6	" " " "

7. Heat Treatment

The heat treatment of the turret as furnished by the manufacturing company is given below:

- a. Homogenized at 1950 - 2000°F for 10 hours.
- b. Tempered at 1150°F for 4 hours.
- c. Reheated to 1650°F for 4 hours.
- d. Quenched in oil.
- e. Tempered at 1200°F for 4 hours.

8. Ballistic Properties

The ballistic properties of this turret were determined at Aberdeen. The results of these tests which are recorded in A.P.G. Firing Record No. 16562, dated August 29 and 30, 1940 are given below:

- a. Four rounds of 37 mm. A.P. M51 were fired normal to the rear surface of the turret, obtaining a ballistic limit of 2129 f.s.
- b. One round of 75 mm. M48 H.E. with M48 fuse "super-quick" was fired, at a striking velocity of 1786 f.s., normal to the rear surface, hitting just to the left of the two closely grouped rounds of 37 mm. This round did not appreciably damage the turret.
- c. One round of 75 mm. M48 H.E. with M48 fuse set "delay" was fired, at a striking velocity of 1785 f.s., normal to the rear surface, hitting below the two closely grouped rounds of 37 mm. This round opened up a crack which had been started by the third round of 37 mm. hitting near the base ring.

d. One round of 75 mm. M48 inert with sand load (hex-plug) was fired at a striking velocity of 1741 f.s., normal to the rear surface, hitting above the two closely-grouped rounds of 37 mm. This round did not appreciably damage the turret.

e. Two rounds of 37 mm. A.P. M51 were fired normal to the left side of the turret obtaining a ballistic limit of 2104 f.s.

f. One round of 75 mm. A.P. (modified Navy 3", wt. 13.75#) was fired at 30° from normal with a striking velocity of 1425 f.s. on the left side of the turret. A 3" button was punched into the turret, but the projectile did not enter the turret. The base ring was cracked. Thickness - 2.321".

g. One round of 105 mm. M1 H.E. with M48 Pd fuse set "delay" was fired at a striking velocity of 1407 f.s., normal to the rear surface of the turret. Other than splash marks, the round had no appreciable effect on the turret.

h. A ballistic limit of 2321 f.s. was obtained on the top of the turret with .50 cal. A.P. M1 projectiles fired normal to the surface, average thickness 1.08".

i. A ballistic limit of 1816 f.s. was obtained on the right side of the turret with the British 40 mm. gun mounted in the British Tank Mk. 2.

Discussion

The cast armor material of the turret successfully passed the ballistic tests prescribed notwithstanding the presence of pronounced piping and porosity as revealed by x-ray examination. This fact indicates that at the comparatively low Brinell hardness ranges employed in heavy cast armor as produced today the presence of discontinuities in the section in the form of piping and porosity to the extent present in this casting is not conducive to spalling and cracking. If x-ray inspection is to be used as a tool for the inspection of cast armor, liberal standards must be set up to avoid the rejection of castings which would be satisfactory in service or when subjected to ballistic tests.

The piping and porosity were most prevalent on the side wall of the turret and decreased in intensity towards the top of the turret, see Figure 1.

Recent evidence obtained on two 2-3/4" test plates furnished by the same manufacturer indicates that the hardness range and not soundness as revealed by x-ray examination is the most important factor affecting spalling tendencies of heavy cast armor. Two plates of the same chemistry and thickness were fired for penetration resistance with 37 mm. M51 A.P. projectiles. The two plates gave practically the same ballistic limit, approximately 2270 f.s, but the plate having a Brinell hardness of 321 spalled badly on the face and rear whereas the second plate at 285 Brinell gave clean penetrations with no evidence of spalling. Both plates showed serious porosity under x-ray examination. The complete investigation of these two plates will be reported in the near future.

Macroscopic and microscopic examination revealed that the porosity in the section was confined to the middle third. The dendritic pattern was columnar at the surfaces of the section and more pronounced than in the center. The microstructure was a satisfactorily uniform sorbite and the grain size was uniform at No. 5 A.S.T.M. The physical properties of the turret material are considered normal for production cast armor of this thickness and hardness.

The turret appears normal and satisfactory for the service intended for castings of this type in spite of the fact that the internal soundness could be improved.

Respectfully submitted,

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APPROVED:

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Figure 1

Showing sections on the Cast Turret subjected to metallurgical examination.

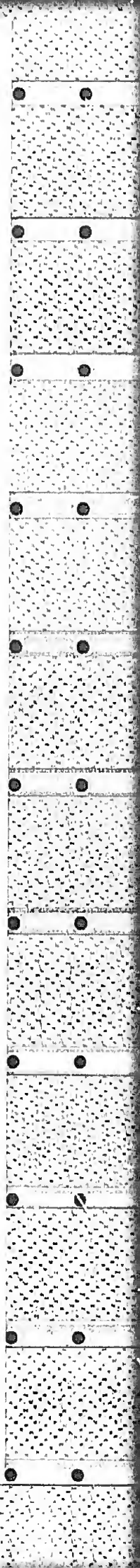


Figure 2

Radiograph of Area 3

Area adjacent to impact of 37 mm. A.P. projectile shows presence of centerline porosity. No spalling occurred under impact of armor piercing projectile.

1. METALLURGICAL SAMPLES

2-1, 2-2, 2-3, 2-4 - X-RAY

3. X-RAY AND EXHIBIT

4. X-RAY AND EXHIBIT

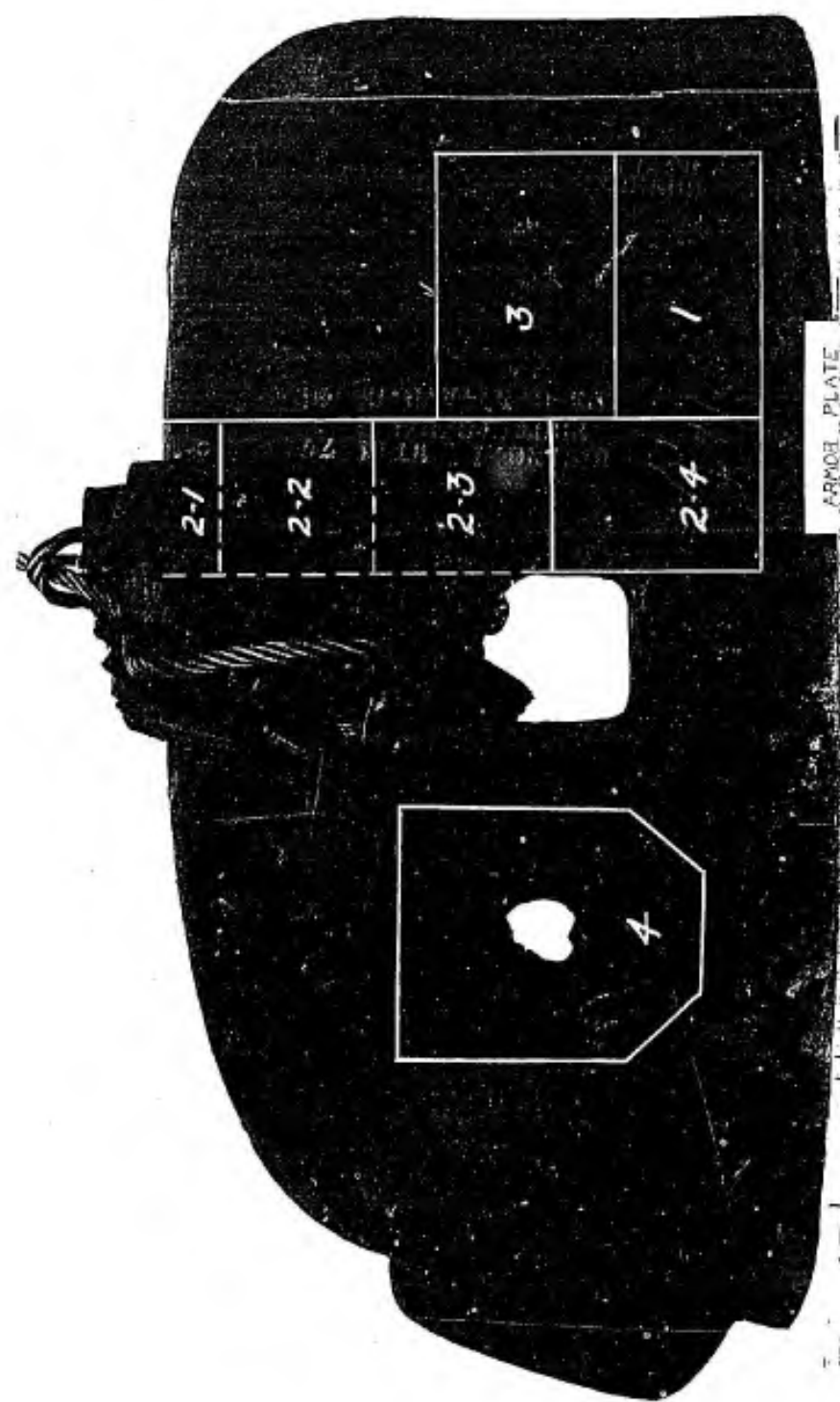


FIG. 1

EXPERIMENTAL CAST A.P. FOR TANKS
Oct. 29, 1940 W.A. 710-697

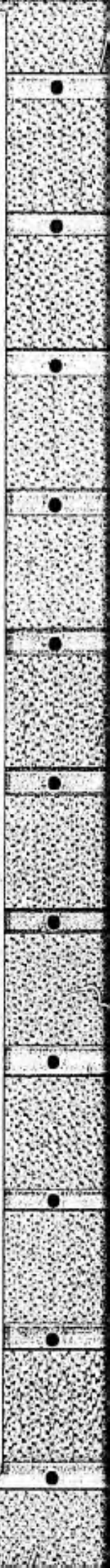
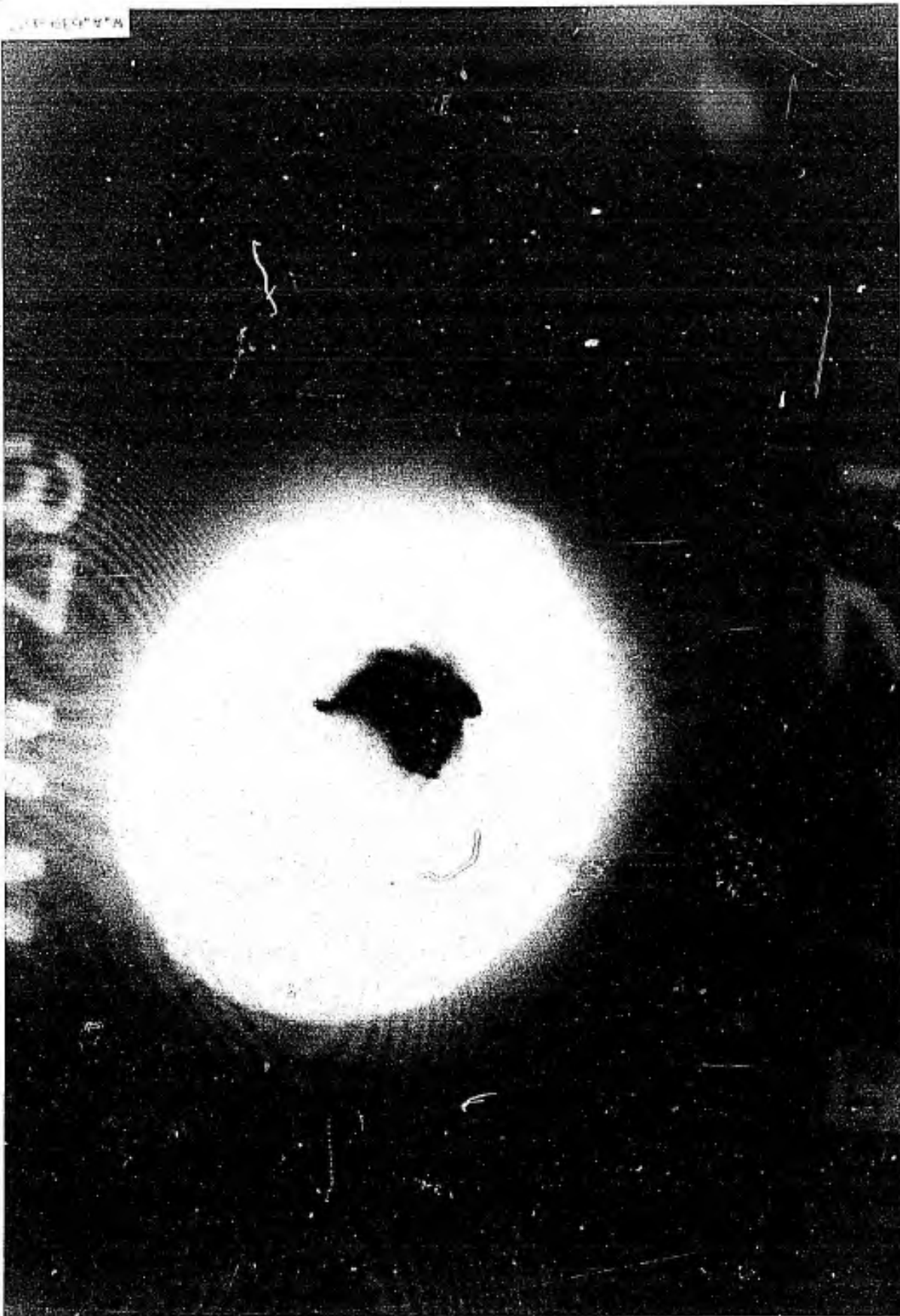


Figure 3

Radiograph of Area 4

Radiograph adjacent to 75 mm. A.P. impact resulting in a complete penetration. Presence of pronounced centerline porosity is visible.

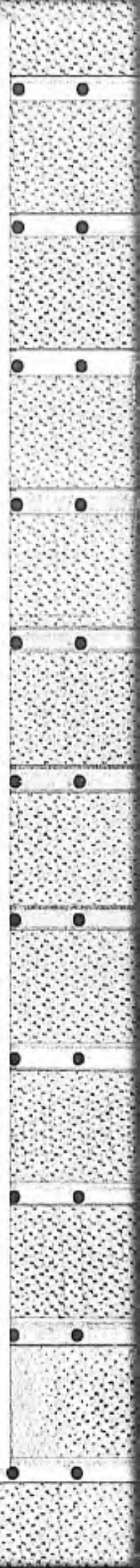


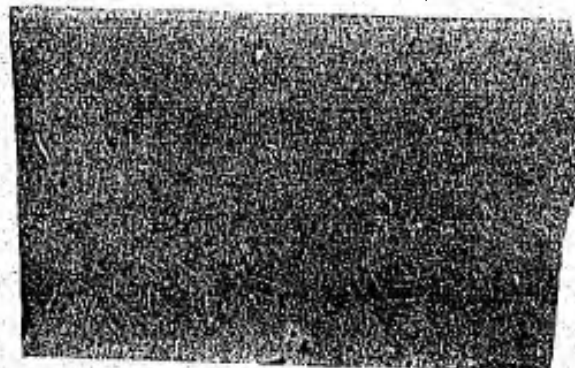
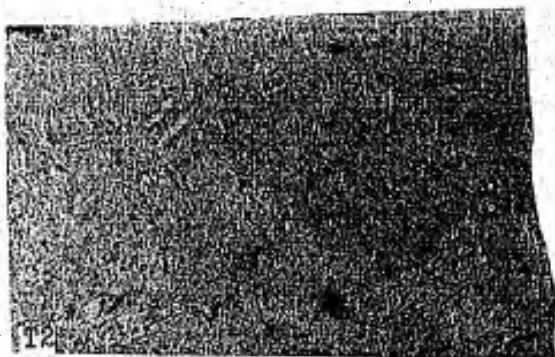
K.A.420-121

Figure 4
Macrostructure

Deep Etch

(a) The structure throughout the plate is dendritic and shows a columnar pattern near the surface of the plate. The central portion has a coarse nearly equiaxed structure, and contains a great many prominent, partially etched-out nonmetallics.





(a) DEEP ETCH



FIG. 4



Figure 4 (Cont'd)

Macrostructure

Oberhoffer and Deep Nital Etch

(b) Photomicrograph of cross section of casting showing dendritic structure. The two outer thirds of the cross section are relatively sound, while the middle third contains porosity. Cross section cut into thirds for polishing and photographing.

Oberhoffer Etch

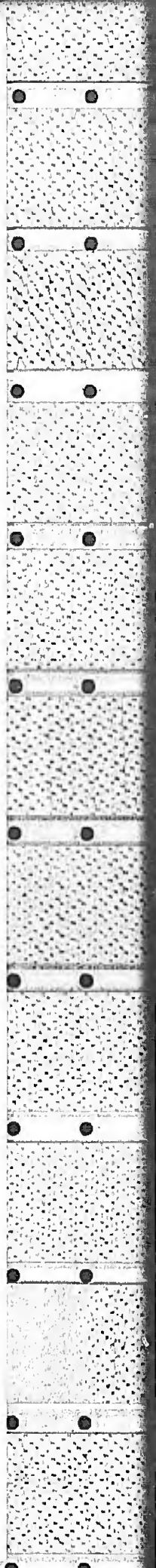
X3

MA3361, 3362, 3363

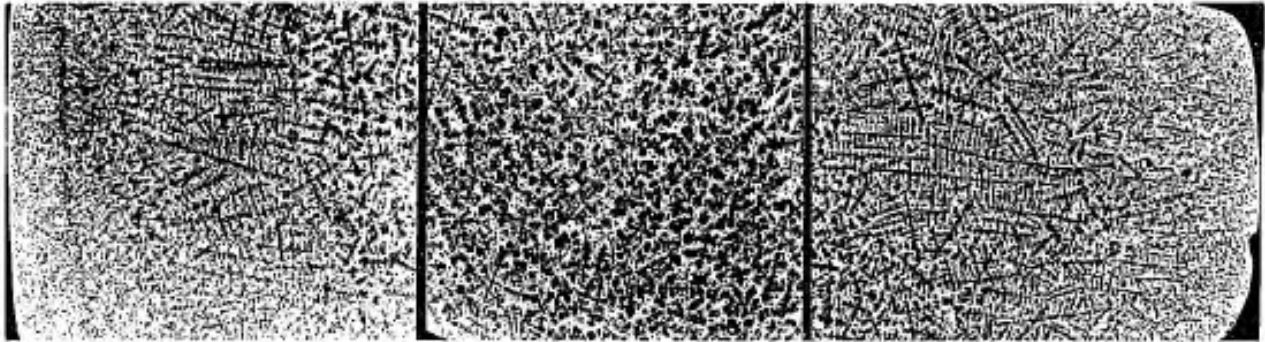
(c) Same as above but deep etched with 1% Nital, showing surface decarburization. Maximum depth of decarburization is 0.035", with 0.010" severely decarburized. The two outer thirds have a uniform structure, while the middle third contains segregation and porosity.

X3

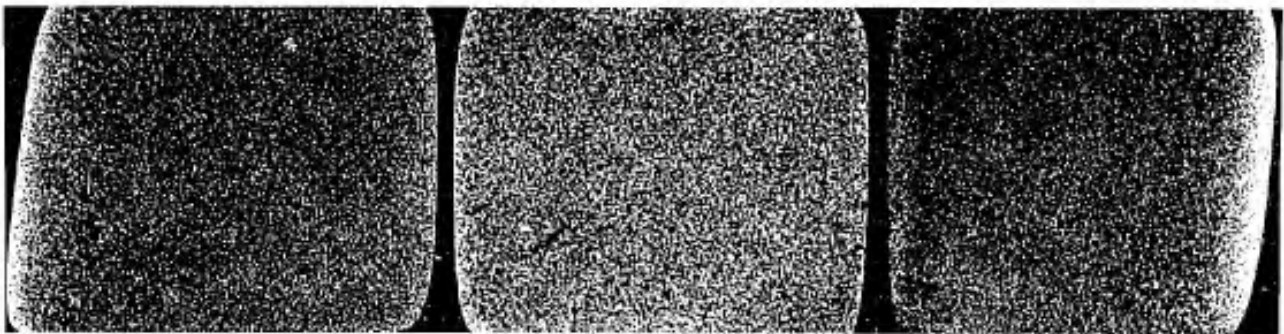
MA2949, 2950, 2951



Macrostructure



b. Oberhoffer Etch - Magnified 3 Diameters



c. Deep Nital Etch - Magnified 3 Diameters

W.A.639-3463

Figure 5

Distribution of Nonmetallic Inclusions in Turret T2

- A. Average distribution of nonmetallics in outer layers of cross section of casting. Coarse particles distributed among many fine nonmetallics. There is no tendency towards network formation.

X25

MA-2910

- B. Most prominent segregation of nonmetallics found in the central portion of the cross section of the casting. Some fine porosity exists in this section.

X25

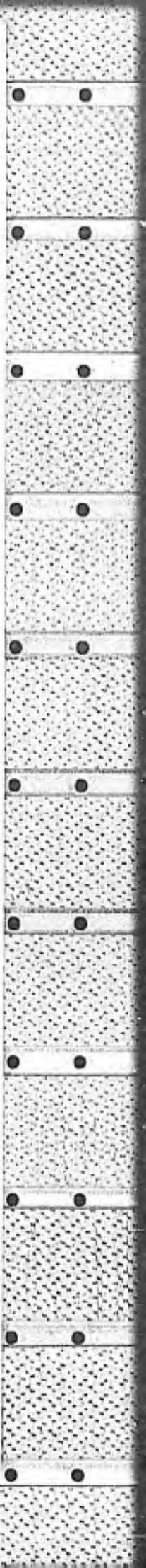
MA-2911

- C. Typical nonmetallic inclusions at a higher magnification. All inclusions have random distribution.

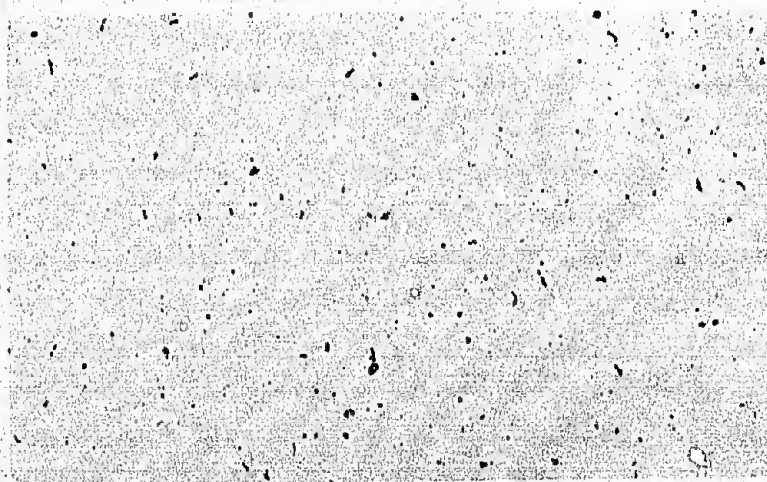
X100

Unetched

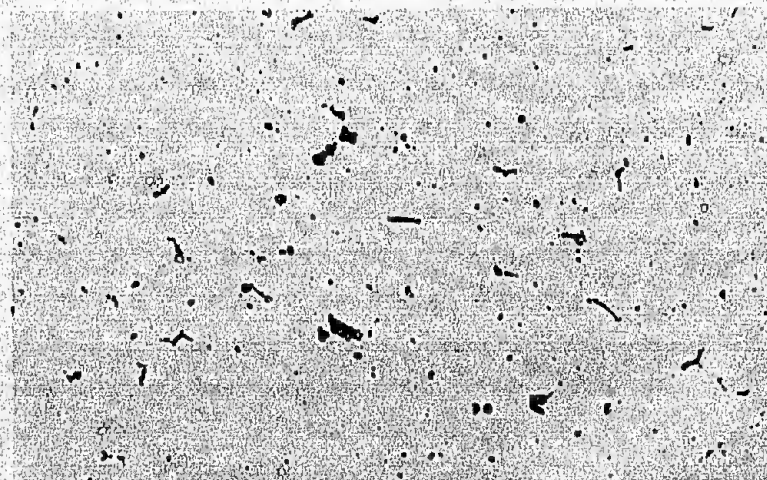
MA-2912



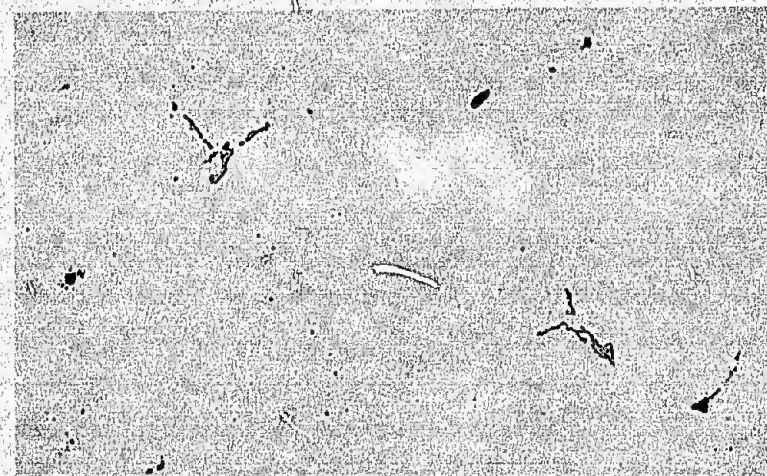
Distribution of Nonmetallic Inclusions



A. Magnified 25 Diameters



B. Magnified 25 Diameters



C. Magnified 100 Diameters

W.A.639-3462

Figure 6

Microstructure of Turret T2

- A. Typical structure found at the two outside surfaces and extending down to a depth of $1/3$ of the wall thickness. This region is quite uniform with very little segregation and porosity. The grain size is well revealed by the nital etch.

MA-2905

- B. Typical structure found in middle third of the cross section of the casting. Segregation and shrinkage porosity occur throughout this region.

MA-2904

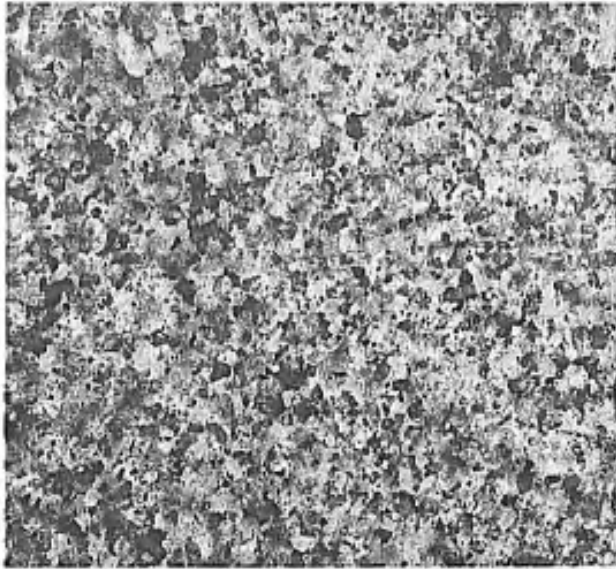
- C. Same region as "A" photographed at higher power. A.S.T.M. grain size rating No. 5.

MA-2906

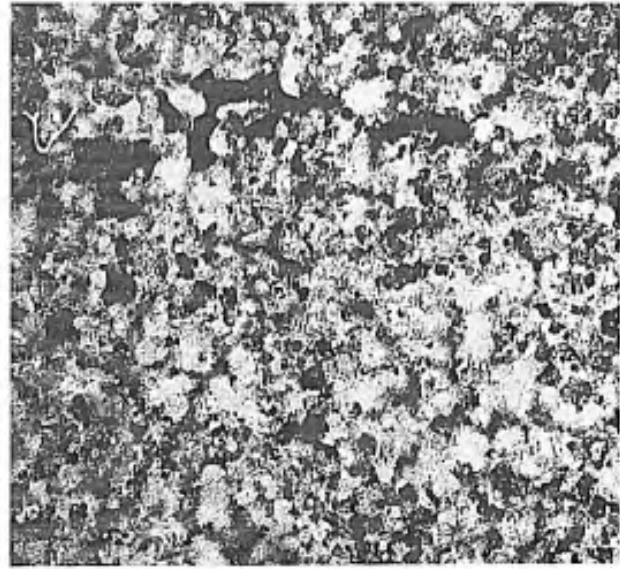
- D. Microstructure of casting is highly spheroidized sorbite. This structure is quite uniform throughout the section.

MA-2913

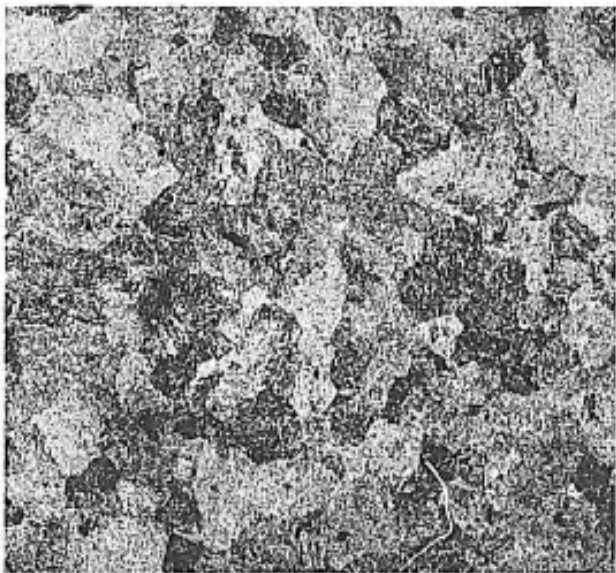
Microstructure of Turret T2



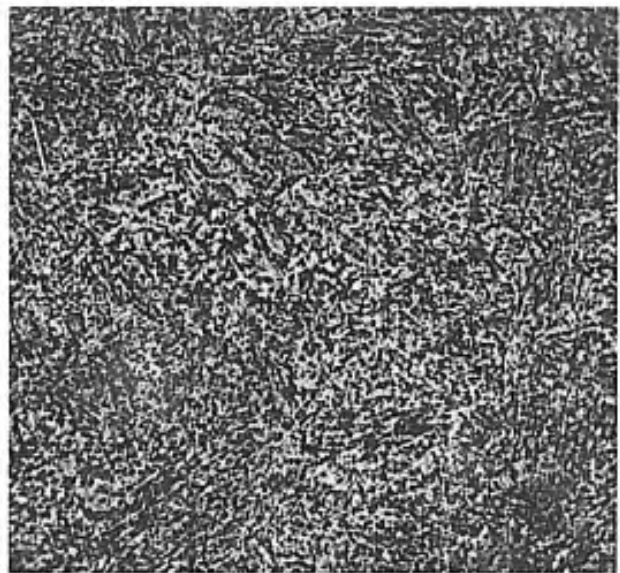
A. Magnified 25 Diameters



B. Magnified 25 Diameters



C. Magnified 100 Diameters



D. Magnified 1000 Diameters

All etched in 1% Nital

W.A.639-3461

Figure 7

Carbide Distribution in Turret T2

- A. Coarse carbides segregated in the interdendritic fillings of the casting. Uniformly fine carbides are distributed throughout the matrix.

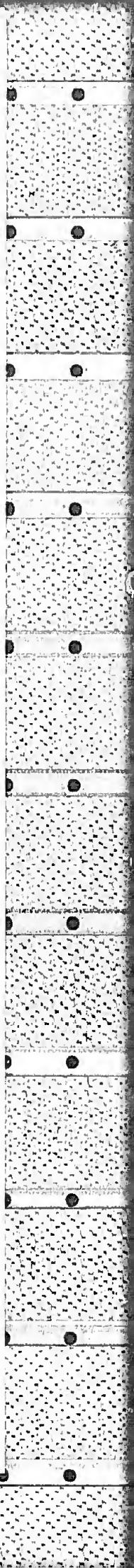
MA-2909

- B. Magnification at X1000 showing fine carbides in the matrix. There is a very faint tendency for the carbides to outline grain boundaries.

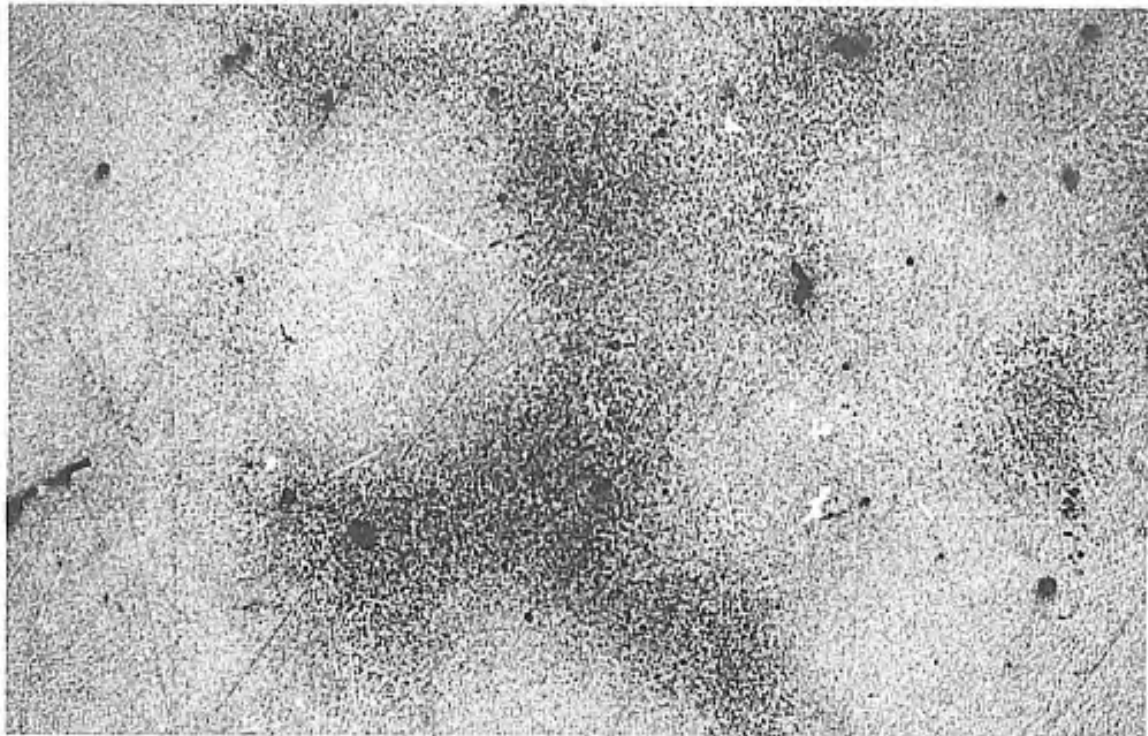
MA-2908

- C. Magnification at X1000 showing coarse carbides in the interdendritic fillings.

MA-2907



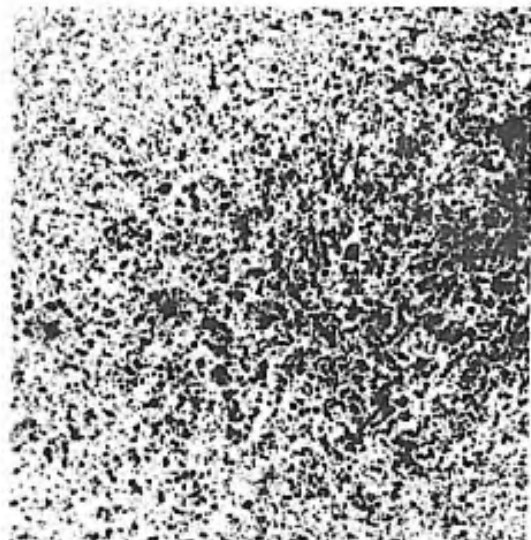
Carbide Distribution in Turret T2



A. Magnified 250 Diameters



B. Magnified 1000 Diameters



C. Magnified 1000 Diameters

Etched in Murakami's Reagent

W.A.639-3460