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REPORT NO. [illegible]

CONFIDENTIAL

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METALLURGICAL EXAMINATION

CAST [illegible] OF BRITISH [illegible]

[illegible]
Research Metallurgist

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1st Lt., Ord. [illegible]

October 29, [illegible]

WATERTOWN ARSENAL
WATERTOWN, MASS

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Report No. 710/393
Watertown Arsenal
Restricted

October 29, 1941

Metallurgical Examination of Punchings from Cast Turret of British A-12 Infantry Tank

Purpose

The purpose of this investigation was to determine the metallurgical characteristics of these punchings blown from the cast turret of the British A-12 Infantry Tank by 75 mm. M61 A.P. shell.

Conclusions

1. The carbon content (0.44%) is considered too high for the thickness of armor employed in the construction of this turret (namely, 3-3/16" thick).

2. There was no evidence of homogenization as indicated by the presence of segregations of massive carbides in the interdendritic fillings. (See Figure 10a.)

3. The turret was heat treated to a relatively high hardness (302-340 Brinell).

4. The cast armor is considered inferior quality material showing evidence of poor deoxidation practice and occasional hairline cracks in the metal. (See Figures 5, 6, 8a, 8b, and 9a.)

5. The microstructure of the samples revealed a fairly uniform acicular structure with an occasional segregation of massive carbides

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and nonmetallics in the dendritic fillings. (See Figures 9b and 9c.)

6. Unsoundness, lack of homogenizing treatment, and relatively high hardness are the probable causes of failure.

Introduction

In accordance with instructions in A.P.G. letter 470.5/1654 dated August 15, 1941, the metallurgical characteristics of three punchings from the British A.12 Infantry Tank were determined. Confidential A.P.G. Report 10-52, 2nd Report on Ordnance Program 5493, dated August 28, 1941, covers the ballistic tests on this tank.

Procedure and Test Materials

The three punchings were sent to Watertown Arsenal from Aberdeen with no identification and were numbered at this Arsenal, namely, No. 1, No. 2, and No. 3 respectively. These numbers have no relation to the round numbers in the firing data.

Metallurgical examination included chemical analysis, macro and microscopic examination, and hardness surveys. The average thickness of area subjected to ballistic test was 3-3/16". Ballistic tests were made at Aberdeen Proving Ground as noted above. Figures 1 and 2 are copies of Aberdeen Proving Ground photographs of the turret after ballistic test (reference, A.P.G. photograph Nos. 48979 and 48980 respectively.) Figure 3 illustrates the type of punchings examined. Figure 4 is a drawing indicating the areas on the punchings subjected

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to microscopic examination. Figures 5 to 9 inclusive illustrate the macro and microstructure of the samples.

Section No. 3 which originally showed occasional segregations of massive carbides in the dendritic filling was homogenized and given a ballistic heat treatment, noted below, in order to determine if such a heat treatment would eliminate these segregations.

Homogenized at 2000°F - 10 hours, air cooled.

Reheated to 1650°F - 3 hours, air cooled.

Drawn at 1150°F - 4 hours, air cooled.

The resulting hardness after this heat treatment was the same as determined on the samples as received.

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Results

1. Chemical Analysis

Chemical analysis of the samples is given below:

C	Mn	S	P	Si	Ni	Cr	Mo	Cu	Al
.44	.71	.018	.016	.39	3.39	.72	.44	.07	.06

2. Macroscopic Examination

The deep hot acid etch shows a dendritic structure with interdendritic segregation in the central portions. (See Figures 5 and 6.) The macro etch reveals the presence of interdendritic shrinkage throughout the central portion of the cross section.

Figure 7 illustrates the typical dendritic structure revealed by the Oberhoffer etch. A crack is visible extending into the cross section from the surface. It was noted that the path of rupture

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followed the dendritic pattern. (See Figure 11a.) Figure 11b shows macrostructure of same punching after Watertown Arsenal heat treatment.

It is believed that the nonmetallic substance visible around the grains in the unetched section has been opened up by the hot acid etch, which also reveals that this condition is more general than expected from the examination of the unetched surfaces.

3. Microscopic Examination

The general inclusion rating of the turret is about average for cast armor plate, with some nonmetallics segregated in the interdendritic fillings. Throughout the sample, however, are small areas in which nonmetallic material surrounds the grain boundaries. There are also segregations of nonmetallics in some areas that are more pronounced than in the average case. Areas containing porosity are found which have grain boundary cracks adjacent to the porosity.

The grain size is not revealed by etching, and if the nonmetallic substance in the grain boundary and intergranular voids is taken as an indication of the grain size, the grain size thus determined is coarser than ASTM No. 1. The nital etch shows a fairly uniform acicular structure that on high magnification is revealed as sorbite.

Massive carbides are occasionally found in all of the micro specimens which is indicative of the lack of a proper homogenizing treatment. These carbides are usually found associated with numerous nonmetallics in the interdendritic filling. Figures 5 - 9 inclusive

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illustrate the macro and microstructure of the samples.

Figures 10a, b, and c illustrate typical segregations of carbides in the interdendritic fillings and also the absence of these segregations after the Watertown Arsenal homogenizing and ballistic heat treatments. Figure 11a shows one of the samples whose fracture follows the dendritic pattern.

4. Hardness Surveys

The results of hardness surveys made on the samples are given below.

Maximum - 340 Brinell

Minimum - 302 Brinell

Average - 321 Brinell

5. Ballistic Tests

The ballistic tests reported below were made at Aberdeen Proving Ground and reported in Confidential A.P.G. Report 10-52, "Report on Ballistic Test on British A-12 Infantry Tank and Second Report on Ordnance Program 5459", dated August 26, 1941.

a. The British A-12 Infantry Tank was tested on August 13, 1941, in accordance with the change of the original firing program recommended by Mr. Ferguson of the B.M.C. to prevent excessive damage of the tank. It was requested by Mr. Ferguson that the tank be conserved for testing tracks, and hence that only the turret be tested. Therefore, the tests outlined in paragraph "h" and "i" of the firing program in the basic letter were carried out.

b. The first round of 75 mm. A.P. M61 (45° yaw) caused a partial penetration with no damage to the rotating mechanism. Three more rounds were fired to obtain a ballistic

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limit. The first of these rounds knocked out a punching (1597 f.s. s.v.) and passed through the wall of the turret. The third and fourth shots also removed punchings, one of which fell out; the other was almost pushed through (s.v. 1511 f.s. and 1435 f.s. respectively). After this firing 13 bolts in the base ring of the turret were missing and 4 of the 6 remaining were loose. All bolted fixtures near the impacts were loosened during the firing. In that the fourth round caused a complete penetration with a small crack of light, it was concluded that the ballistic limit with the above four rounds was about 1410 f.s. The average thickness of area tested was 3-3/16".

e. One round of 105 mm. H.E. shell with delayed fuze (zone loaded to 1020 f.s. m.v.) was then fired at the turret well about a foot above the deck plate on the left front side of the tank. The heads of three bolts in the edge of the deck plate were sheared off. The deck plate close to the turret at the front left corner was bent downward causing the angle inside the tank below this deck plate to bend and allowing a 1/8" crack to open between the deck plate and adjacent side plate. Two bolts holding the turret ring to the deck plate were blown down into the sponson. A bracket mounted on the turret near the front of the impact was blown off. The rotating mechanism of the turret was still in operating condition after all firing had been completed.

Discussion

The punchings blown from the cast turret (Figures 1 and 2) which are shown in Figure 3 indicate a coarse crystalline fracture on the exit face. (See arrows.) Macro and microscopic examination made on sections of the punchings (Figures 4 - 9 inclusive) clearly showed the presence of occasional unsoundness such as voids, dendritic segregation, and nonmetallic grain boundary segregates. The defects noted are the result of a combination of poor deoxidation practice and incomplete diffusion treatments. A homogenization study was

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made at Watertown Arsenal on one of the samples showing carbide segregations and it was shown that the homogenization cycle employed, described on page 3, completely eliminated this type of segregation. Furthermore, this turret was heat treated to a relatively high hardness. The high hardness, 302-340 Brinell, associated with the casting defects present was responsible for failure.

Mr. A. Hurlich made the metallographic examinations.

Respectfully submitted,

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Research Metallurgist.

H. A. Matthews,
1st Lt., Ord. Dept.

APPROVED:

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

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Figure 1

Photograph of turret after ballistic test showing effect of 75 mm. A.P. shell M61. Ballistic limit approximately 1410 f/s. (Photograph by Aberdeen Proving Ground.)

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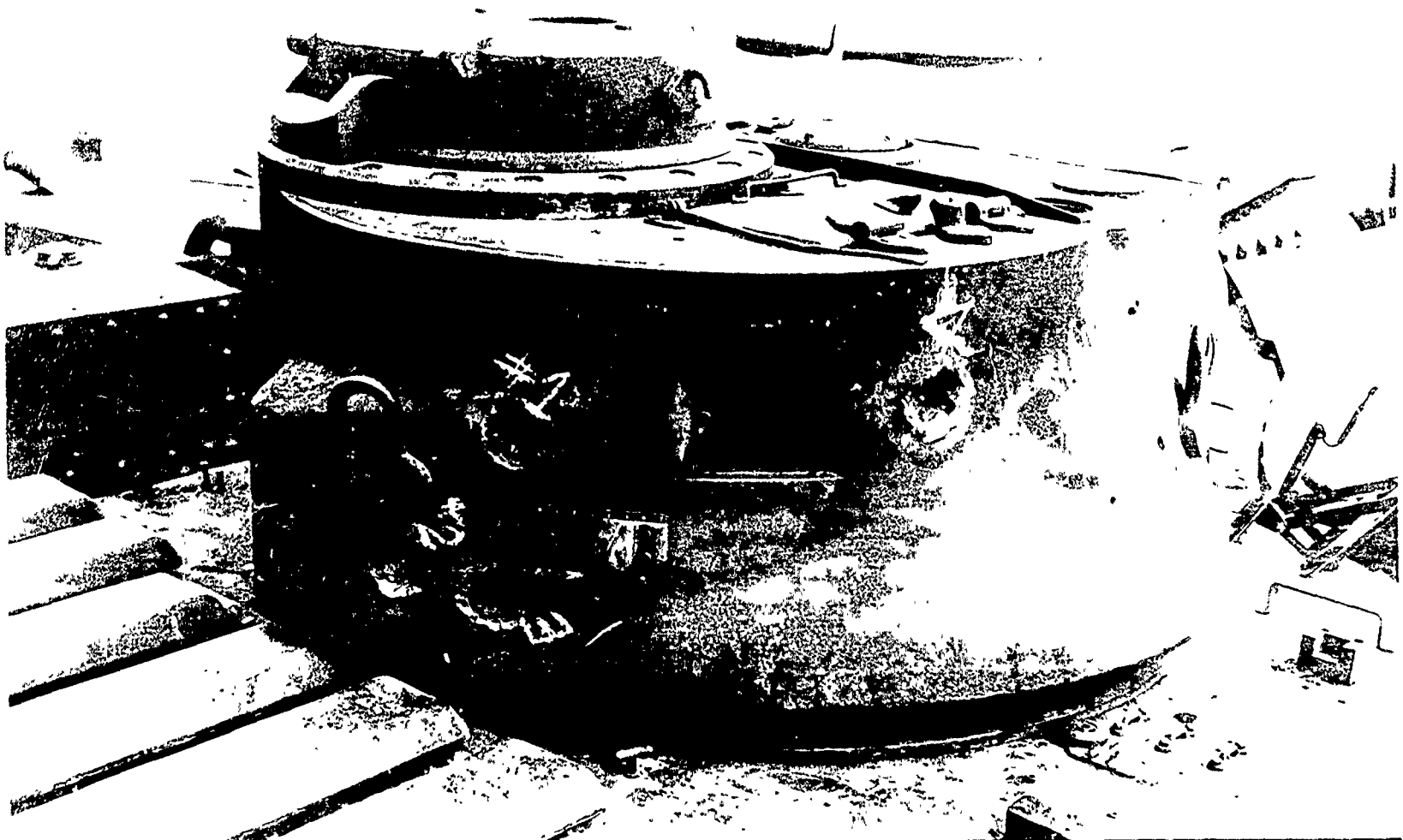

48979 8-14-41 ABERDEEN PROVING GROUND ORDNANCE DEPT.

British Tank A-12, showing effect of 75 mm A. P. Shell M61. BL approximately 1410 f. s.

W.A.639-3609

Fig. 1

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Figure 2

Photograph of portion of interior of turret showing complete penetrations under attack of 75 mm. A.P. shell M61. Ballistic limit approximately 1410 f/s. (Photograph by Aberdeen Proving Ground.)

Fig. 2.

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Figure 3

Photograph of punchings - Nos. 1, 2, and 3.

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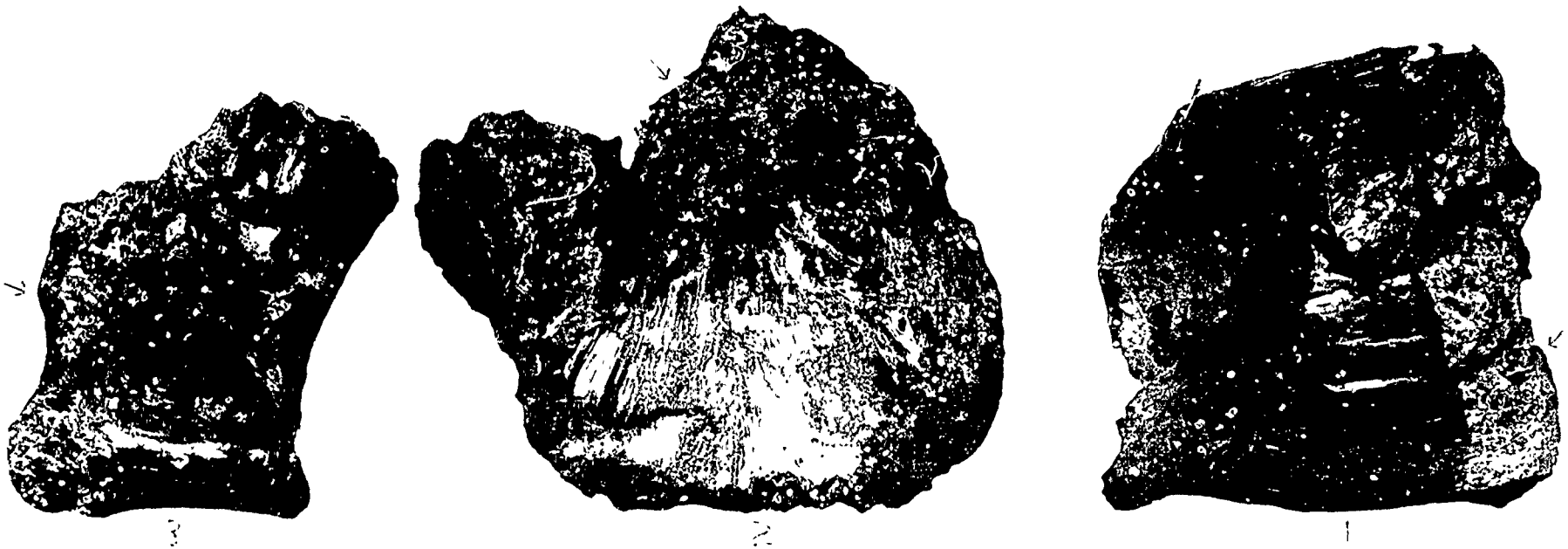

FIG. 3

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Figure 5

Macrostructure of Punching No. 1

(Deep Etch)

The deep hot acid etch shows a dendritic structure with interdendritic segregation in the central portions. The macro etch reveals a coarse dendritic structure with small hair-line cracks throughout the central portion of the cross section.

1

ORDNANCE DEPT. U.S.A.

WATERTOWN ARSENAL.

[illegible] FROM CAST [illegible] TURNET,
[illegible] TANK [illegible] SETP. [illegible]

FIG 5

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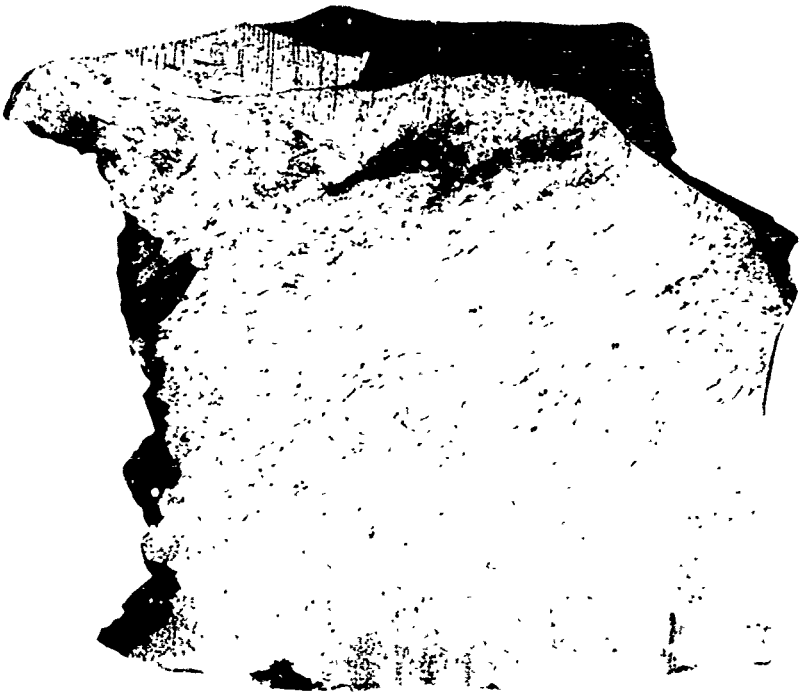
Figure 6

Macrostructure of Punching No. 3

(Deep Etch)

Description same as that noted in Figure 5.



ORDNANCE DEPT. U.S.A.

WATERTOWN ARSENAL.

75 MM PUNCHINGS FROM CAST STEEL TURRET, BRITISH INFANTRY TANK T12. SEPT. 25, 1941 WA710-143

FIG. 6

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Figure 7

Typical Macrostructure of Casting (Oberhoffer Etch) and Microscopic Study of Dendritic Segregation

(a) No. 2 - Dendritic nature of casting. Crack extending down from the casting surface.

Oberhoffer's Etch X2 MA-3527a, b

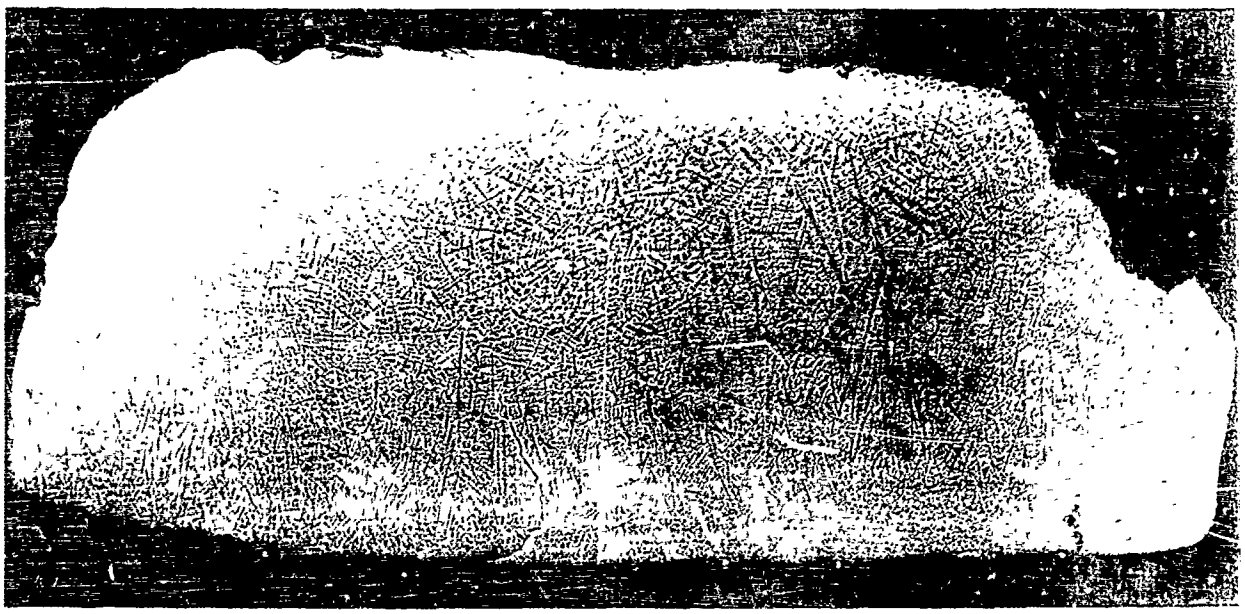
(b) No. 2-4 - Dendritic segregation typical of the casting.

Nital Etch X25 MA-3541

(c) No. 1-2 - Average nonmetallic inclusion condition in the punchings. Inclusions segregated largely in the interdendritic fillings.

Unetched X25 MA-3531

Figure 7



a. Magnified 2 Diameters

b. Magnified 25 Diameters

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Figure 8

Microstructure

Unetched

(a) No. 1-1 - Films around grain boundaries found in isolated region in microspecimen. The hot acid etch shows this condition to be more widespread than expected from an examination of the polished unetched surfaces.

Unetched X100 MA-3533

(b) No. 1-2 - Oxides and oxide films around grains found in a porous region about 1/8"x1/4" in area on specimen.

Unetched X100 MA-3515

(c) No. 1-2 - Porosity and grain boundary cracks found in a porous area about 1/8"x1/4" in extent.

Unetched X100 MA-3530

It is believed that the coarse fracture found on the punchings is due to failure extending along defective regions like the above. Although only isolated regions of this type were found in the polished specimens, the hot acid etch revealed a more general occurrence of hairline cracks, and a coarse, open dendritic structure, associated with shrinkage porosity.

Figure 8

a. Magnified 100 Diameters

b. Magnified 100 Diameters

c. Magnified 100 Diameters

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Figure 9

Microstructure

Unetched and Etched in 1% Nital

(a) No. 2-3 - Slag-filled shrinkage porosity found at surface of casting. The surface of the casting is marked with many lines and cracks, some of which are found to extend more than 1/2" into the metal. (See MA-3527.) These cracks seem to be hot tears. Some porosity also extends to the casting surface.

Unetched X25 MA-3532

(b) No. 3-2 - There is a band about 1/8" wide extending across this specimen and roughly parallel to the casting surface and 1-1/4" away from the surface that contains heavy segregations of nonmetallics and massive carbides are found associated with the nonmetallic inclusions just as in MA-3529. This region has, in addition, a more segregated microstructure, with the nonmetallics and the carbides usually found in the interdendritic fillings. (This band also extends across specimen No. 3-1.)

Nital Etch X100 MA-3536

(c) No. 3-2 - Average microstructure of punchings. Spheroidized sorbite arranged in acicular fashion. This microstructure is fairly uniform.

Nital Etch X1000 MA-3538

Figure 3

a. Magnified 25 Diameters

c. Magnified 1000 Diameters

b. Magnified 100 Diameters

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Figure 10

Microstructure of Punchings

(a) Area 1/8" below impacted surface of specimen No. 1-1 showing massive carbides segregated in the interdendritic filling material containing a high concentration of non-metallic inclusions.

Unetched X250 MA-3529

(b) Microstructure of section of punching No. 3 after the following heat treatment:

2000°F - 10 hours - air cool
1650°F - 3 hours - air cool
1150°F - 4 hours - air cool

The massive carbides were put into solution by this heat treatment.

Nital Etch X100 MA-3691

(c) View at higher magnification of the above specimen. Acicular sorbitic structure with finely spheroidized carbides.

Nital Etch X1000 MA-3690

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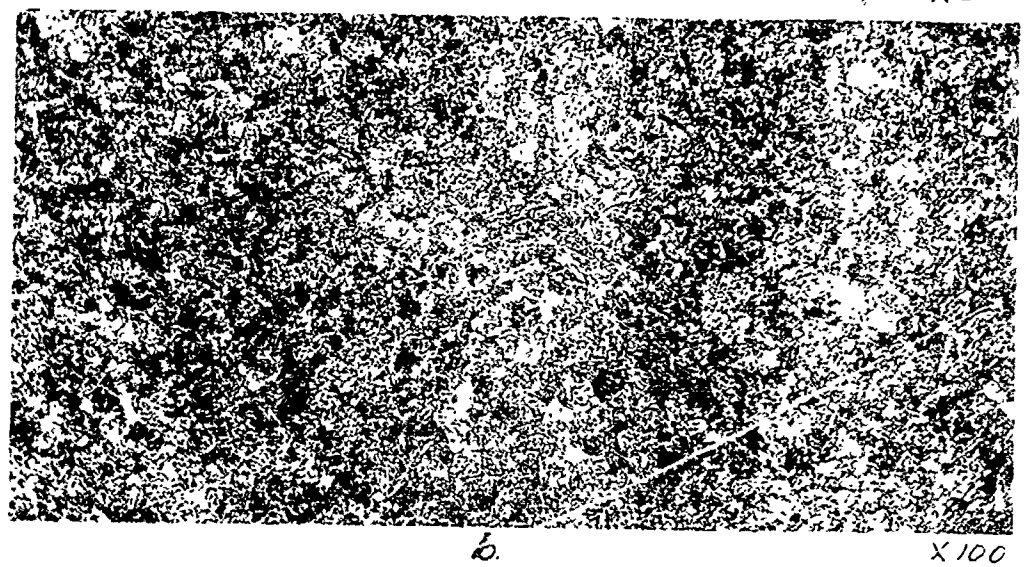
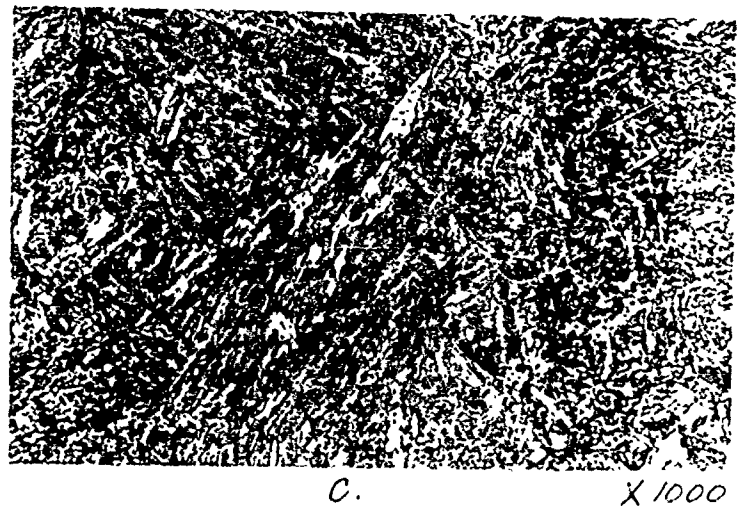
Figure 10
Microstructure of Punchings

a. X250



b. X100



c. X1000

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Figure 11

Macrostructure of Punchings

(a) Macrostructure of specimen No. 2-1 which had a coarse fracture. The fracture follows the outline of the interdendritic filling material in which the impurities and oxide films are segregated.

Oberhoffer's Etch X3 MA-3689

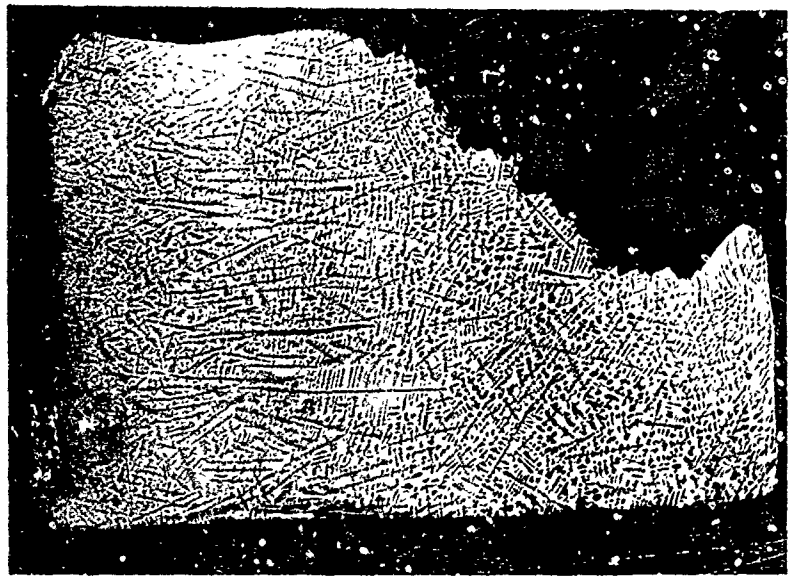
(b) Macrostructure of specimen No. 3 after the homogenizing heat treatment:

2000°F - 10 hours - air cool
1650°F - 3 hours - air cool
1150°F - 4 hours - air cool

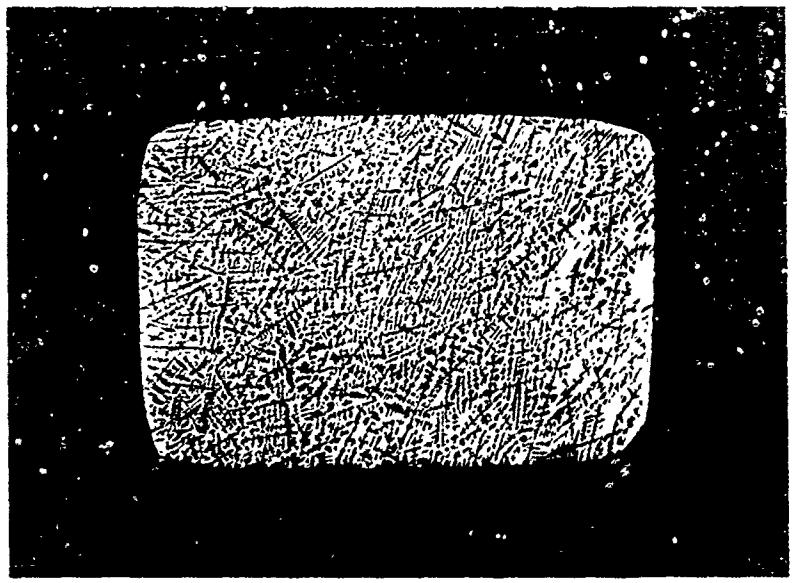
No appreciable change in the macrostructure was produced by the treatment.

Oberhoffer's Etch X3 MA-3692

Figure 11
Macrostructure of Punchings



a. X3



b. X3

Etched in Oberhoffer's Reagent.

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