WATERTOWN ARSENAL LABORATORY

Final

MEMORANDUM REPORT

NO. WAL 710/714

Metallurgical Examination of a Cast Armor Gun Shield Manufactured by General Steel Castings Corp.

BY
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Phys. Sci. Aide

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WATERTOWN ARSENAL
WATERTOWN, MASS.

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Final Report on Problem B-4.63

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ABSTRACT

Metallurgical examination was conducted on samples from the heaviest section (5.5"-6.3") of a cast armor gun shield, Serial No. 88, Heat No. 9035 produced from Pattern D7041960 at the Eddystone Plant of the General Steel Casting Corp. Coarse crystallinity throughout the section was observed in the samples fractured and the results obtained from V-notch Charpy impact tests were exceedingly low. Moreover, in view of the fact that the microstructure consisted of large bainite and martensite grains (ASTM grain size Nos. 4-6), it was apparent that this casting was improperly quenched and tempered. This fact was confirmed by the manufacturer who stated that this casting was one of two castings which was heat treated with regular production castings of thinner sections and, therefore, the quenching and tempering time was entirely too short for a heavy casting of this type.

1. As requested by the Ordnance Research Center, Aberdeen[1], metallurgical examination has been completed on samples designated as Nos. 88, 5.5" thick and 88-1, 6.3" thick from the heaviest section of a cast armor gun shield, Serial No. 88, Heat No. 9035, Pattern No. D7041960 which is used in conjunction with the 76mm. gun with concentric recoil on Medium Tank M4 and which was manufactured at the Eddystone plant of the General Steel Castings Corp.

1. APG 472/553-185 - Wtn. 472.3/579 dated 16 October 1944.

2. Apparently, this casting was incorrectly heat treated by the manufacturer, the exact details of which were stated in recent correspondence[2] and are reproduced below.

"Our Eddystone Plant produced two experimental pieces from this pattern which were numbered serial 38 and 39. At the time that these pieces were produced they contained the heaviest metal thickness of any armor casting in production in our shop. These pieces were heat treated with regular production castings of thinner sections, and our records indicate that in the light of present knowledge they were under quenched. The fracture specimens contained in this load which represented the production castings were satisfactory and test pieces attached to the shields themselves produced satisfactory results."

"The heat treatment which these castings received is as follows:

1 - heated to 1675°F - held six hours
2 - water quenched five minutes
3 - heated to 1200°-1225°F - held six hours."

"You will note that the quenching time is only five minutes. It is our current practice to quench T-26 turrets with a maximum metal section of 4" for ten minutes and to quench sections of 6" in thickness for fifteen minutes. As the maximum section of the shield casting is approximately 6", it is evident that the quenching time used for the experimental shield casting is entirely too short. In addition, the tempering time of six hours is also shorter than that which we are now using for sections of this thickness."

3. Metallurgical examination on representative samples included the following tests:

a. Hardness tests (cross-sectional Brinell, Rc and Knoop hardness surveys).

b. Fillo fracture test for revealing response to heat treatment.

c. Reheat treatment of samples resulting in an essentially fibrous fracture.

d. V-notch Charpy impact tests.

e. Chemical analysis.

f. Microscopic examination.

4. The results of the metallurgical examination are as follows:

2. General Steel Castings Corporation letter dated 20 December 1944.

a. Hardness test surveys.

(1) Cross-sectional Brinell hardness survey.

On properly ground cross sections, five, equidistantly spaced Brinell hardness readings were made through the sections. The results are as follows:

Sample No.	Brinell Hardness Readings	
	Range	Average
88	255-262	261
88-1	285-341	305

As noted above, considerable variation in hardness was evident along the cross section of sample No. 88-1.

(2) Rc hardness survey.

Rc hardness readings were made on Charpy bars taken from the surface and the center. The readings, as noted below, reveal the surface to be about 23 BHN harder than the center.

Sample No. 88	Rc Hardness Readings	Converted to BHN Average
Surface	31-30-29	283
Center	25-27-26	260

(3) Knoop hardness survey.

Knoop hardness impressions were made upon martensitic and bainitic areas of polished and etched metallographic samples. The impressions are produced by a diamond indenter under a load of 100 grams and then measured on the ground glass of a microscope camera at a magnification of X1000. The Knoop hardness numbers are roughly equivalent to Vickers Pyramid hardness numbers in the range 100-400 Knoop. Results of the readings, as evaluated below, indicate that the surface is harder than the center. This may be accounted for by the porous condition of the center detected under the microscope at a magnification of X100 on unetched metallographic samples.

Knoop Hardness Values

Near Surface of Sample		At Center of Sample	
Martensitic Area	Bainitic Area	Martensitic Area	Bainitic Area
454	267	382	234
409	246	370	234
438	234	395	222

b. Fibre fracture test for revealing response to heat treatment.

(1) Sample of shield "as-received".

Fibre fracture tests were made on properly notched specimens and were rated with respect to the fibre fracture test for revealing response to heat treatment. A coarse crystalline fracture resulted. However, as described below in paragraph 3c. when reheat treated an essentially fibrous fracture was obtained.

c. Sample heat treated at Watertown Arsenal. A section cut from one half of the fracture 88 was given the following reheat treatment and which when fractured revealed an essentially fibrous fracture. The following is the heat treatment:

Temperature	Time	Coolant
1675°F.	3 hrs.	water
1175°F.	3 hrs.	water

d. V-notch Charpy impact tests. V-notch Charpy tests were made on samples "as-received" and after reheat treatment. Listed below are the results of the impact tests and the fracture ratings of the bars with respect to the fibre fracture test.

V-Notch Charpy Impact Tests
"As-Received"

Sample No.	Location	Temp.	Ft.Lbs.	*Description of Fracture
88	Near Surface	+70°F.	18.1	Cb
		-40°F.	11.2	
88	At Center	+70°F.	22.5	Cb
		-40°F.	6.6	
88-1	At Center	+70°F.	6.9	Cb
		-40°F.	8.6	

After Watertown Arsenal Reheat Treatment

1675°F. - 3 hrs. - water quench
1175°F. - 3 hrs. - water quench

88	At Center	+70°F.	77.6	F (some shrinkage)
		-40°F.	30.3	Cbf(some shrinkage)

*Cb = Bright crystalline (complete)
F = Fibrous
Cbf = Bright crystalline patch surrounded by fibrous border.

The very low values of the V-notch Charpy bars in the "as-received" condition, noted above, are indicative of poorly heat treated cast armor. Reheat treatment resulted in the improvement of the V-notch Charpy impact values. The low value obtained at -40°F. at the center of the section may have been due to the presence of shrinkage in this area.

e. Chemical analysis. The result of the chemical analysis obtained was as follows:

Chemical Composition

C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu	Al	Ti	B
.26	.84	.35	.016	.019	tr	2.56	.49	nil	.11	.04	.03	tr

f. Microscopic examination. Microscopic examination was made on samples, "as-received" and after the Watertown Arsenal reheat treatment. These samples were cut from the surface and center of the gun shield. The microstructure of samples located near the surface and at the center of the section in the "as-received" condition consisted of large grains of martensite and bainite with an occasional boundary of fine pearlite. Evidence of dendritic segregation was noted in the microstructure which indicated that the casting may not have been thoroughly homogenized (ASTM grain size Nos. 4-6). A tempered martensite microstructure was obtained after the reheat treatment mentioned in the previous discussion. In regard to the nonmetallic inclusion content, the casting was fairly clean with occasional sulphide inclusions scattered throughout the section. However, the center section showed evidence of porosity. Typical microstructures of the material "as-received" and after reheat treatment are shown in Figure 1.

4. The results of these tests indicate that the cast gun shield was improperly quenched and tempered, resulting in a coarse crystalline fracture throughout the section at a Brinell hardness varying from 261 to 305, and an exceedingly low V-notch Charpy impact value. Although it is reported that the casting investigated was tempered at 1200°F.-1225°F. for 6 hours, it is believed that the casting was actually tempered at a considerably lower temperature and at a much shorter time since a considerable amount of martensite was evident in the microstructure. Furthermore, the presence of pronounced dendritic segregation detected in the microstructure indicated that this casting may not have been properly homogenized. It was noted, however, after proper heat treatment an essentially fibrous fracture and a tempered martensite microstructure were obtained.

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APPROVED:

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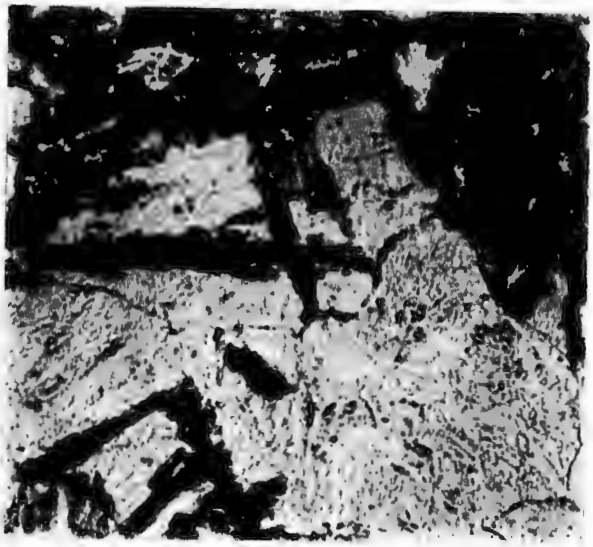
Microstructure of Cast Armor Gun Shield
Manufactured by General Steel Castings Corp.

"As-Received" Condition

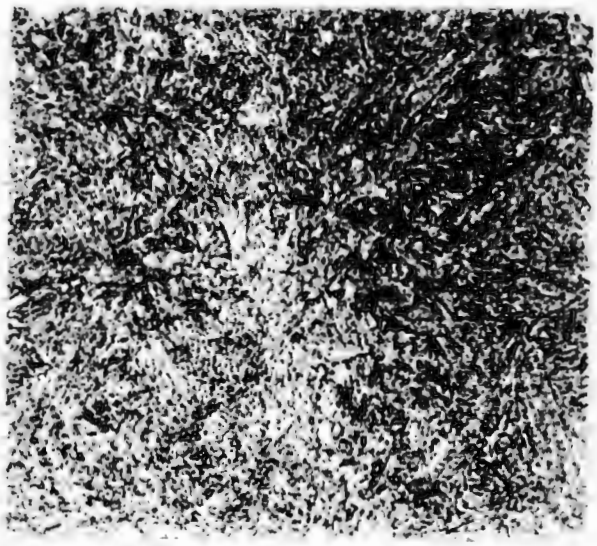


Martensite and Bainite

Martensite, bainite and fine pearlite at the grain boundaries.

These two microstructures were found in samples cut from near the surface and center of section. ASTM grain size Nos. 4-6.

After Reheat Treatment



Tempered Martensite

All Photomicrographs X1000 - Picral Etch

FIGURE 1.