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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/775

Metallurgical Examination of 4 Inch and 5 Inch Thick Cast Armor Manufactured by the Pittsburgh Steel Foundry

BY

A. Hurlich
Metallurgist

DATE 27 August 1945

WATERTOWN ARSENAL
WATERTOWN, MASS.

Form No. SPOBE-38
L 18 July 1944

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/775

Final Report on Problem B-4-99

27 August 1945

Metallurgical Examination of 4 Inch and 5 Inch Thick Cast Armor Manufactured by the Pittsburgh Steel Foundry

ABSTRACT

Four 4" thick and four 5" thick cast armor plates of the 2.5% Cr, 0.5% Mo type composition were subjected to metallurgical tests including fracture tests, hardness surveys, notched bar impact tests, and microscopic examination. Good correlation was established between the ballistic and metallurgical properties of the armor. The optimum hardness of both thicknesses of armor as demonstrated by the ballistic and metallurgical tests is approximately 240 BHN. The plates possessed reduced resistance to penetration at lower hardnesses and exhibited excessive brittleness at higher hardnesses. This behavior is consistent with the bainitic microstructure characteristic of the Cr-Mo steel at thicknesses in excess of approximately 3".

1. Sections of four 4" thick and four 5" thick cast armor plates manufactured by the Pittsburgh Steel Foundry were submitted by the Ordnance Research Center, Aberdeen Proving Ground, Maryland for metallurgical examination. The subject plates were made in connection with the development of heavy cast armor. The Watertown Arsenal Laboratory had been requested by the Office, Chief of Ordnance - Detroit[1] to recommend a heat treatment procedure for these plates which would produce optimum properties. The CAS-2 forms covering a 4" and a 5" thick plate from heat No. 9258 were submitted to the Watertown Arsenal Laboratory where it was concluded that the alloy content of the plates was insufficient to permit full hardening of the sections[2]. A heat treatment was, however, recommended with the stipulation that the plates be tempered to not harder than 240 Brinell in view of the poor shock resistance of nonmartensitic structures at higher hardnesses.

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1. Letter File OOM 470.5/APG (4 Aug. 44)R, APG 470.5/427, Wtn 470.5/8378, 1st Ind., see Appendix.

2. 2nd Ind. to above letter, see Appendix.

2. The cast armor plates consisted of the following:

Thickness Inches	Plate No.	Heat No.	Chemical Analysis(Reported by Company) C	Mn	Si	S	P	Cr	Mo
4	5	9258	.25	.78	.50	.015	.019	2.20	.52
4	6	9258	.25	.78	.50	.015	.019	2.20	.52
4	9	2446	.31	.96	.48	.015	.023	2.56	.52
4	10	2446	.31	.96	.48	.015	.023	2.56	.52
5	5	9258	.25	.78	.50	.015	.019	2.20	.52
5	9	2446	.31	.96	.48	.015	.023	2.56	.52
5	10	2446	.31	.96	.48	.015	.023	2.56	.52
5	11	10430	.27	.84	.46	.026	.022	2.63	.54

Details of the ballistic tests conducted upon these plates are contained in Armor Test Report No. AD-990, prepared by the Ordnance Research Center, Aberdeen Proving Ground, Maryland in May 1945. It is reported that 5" plate No. 10 broke upon the fourth impact during the ballistic test and that the harder plates of both thicknesses exhibited a tendency toward crystalline fracture during ballistic testing.

3. The metallurgical tests performed upon the plates at this arsenal lead to the following conclusions and observations:

a. The ballistic properties of the subject 4" and 5" thick plates correlate well with the results of the hardness, fracture, and impact tests.

b. The optimum hardness of both the 4" and 5" thick plates is approximately 240 BHN. At lower hardnesses the resistance to impact is reduced and at higher hardnesses the plates exhibit brittle behavior.

c. The behavior of the subject plates is consistent with their microstructure obtained upon heat treatment. Bainite has been found to possess adequate shock resistance at hardnesses below approximately 240-260 Brinell and to exhibit brittleness at higher hardnesses.

4. The tests performed upon the armor samples include the following:

a. Fracture test.

b. Hardness surveys.

c. V-notch Charpy impact tests.

d. Microscopic examination.

5. Details of the tests follow:

a. Fracture Test

The approximately 12" x 12" sections were notched by flame cutting in from two parallel sides and were broken under the impact of a steam forge hammer. The fracture ratings are listed in Table I.

The fracture ratings correlate well with the ballistic performance of the armor. Of the two plates exhibiting completely crystalline fractures, 5" thick plate No. 10 broke apart under the fourth impact during ballistic testing and 4" thick plate No. 9 was broken into five pieces at the completion of the ballistic tests. 4" thick plate No. 10, with a 75% crystalline fracture, was severely cracked and broke into two pieces during the ballistic test. The remaining plates with 20 - 50% crystalline fractures exhibited little or no cracking during the ballistic tests.

b. Hardness Surveys

One-half inch thick slices were cut from the fractured sections and the cross-sectional surfaces were prepared for hardness surveys. Brinell hardness readings were made at 3/4" intervals upon a cross-sectional surface. The results are contained in Table I.

According to the CAS-2 forms submitted by the manufacturer, 4" and 5" plates No. 5 were tempered at 1200°F. and the remainder of the plates at 1125°F. The higher hardness of 4" thick plates No. 9 and 10 is attributable to the higher carbon content of heat No. 2446 as compared to heat No. 9258. The great disparity in hardness between 5" thick plates No. 9 (233 BHN) and No. 10 (298 BHN) which are from the same heat and which are reported to have been identically heat treated is inexplicable.

It is noteworthy that the predominately crystalline fractures are associated with the harder plates, which range from 271 to 298 BHN. This is completely in accord with the Watertown Arsenal Laboratory's analysis of the subject plates which is contained in the 2nd Indorsement to letter File No. APG 470.5/427, OOM 470.5/APG(4 Aug. 44)R, Wtn 470.5/8378, see Appendix.

c. V-Notch Charpy Impact Tests

Four V-notch Charpy impact test specimens were prepared from each plate. The specimens were taken perpendicular to the plate surfaces and were notched at a distance of approximately one inch from the surface. Duplicate specimens were broken at temperatures of +70°F. and -40°F. The impact data contained in Table I are the averages of the two tests.

The impact energies at both +70°F. and -40°F. correlate well with the fracture ratings and the shock resistance exhibited under ballistic attack.

d. Microscopic Examination

Fractured impact test specimens were polished and examined under the microscope. The microstructures of all eight plates are distinctly bainitic, ranging from a tempered bainite having relatively uniformly distributed carbides as in 4" plate No. 5 to a heterogeneous bainite with some segregation of carbides at grain boundaries and rejected ferrite as in 5" plate No. 10. The variations in microstucture are indicative of possible variations in hardenability and in quenching efficiency during heat treatment of the individual plates.

The results obtained with the subject series of plates is a further verification of the reduced shock resisting properties of bainitic structures at hardnesses in excess of approximately 240 BHN.

6. General Considerations

The subject plates were made from the 2.5% Cr, 0.5% Mo type composition which produces predominately bainitic microstructures when quenched in thicknesses greater than approximately 3". When tempered to hardnesses below approximately 240 BHN bainite has reasonably satisfactory shock resisting properties. These properties fall off rapidly, however, with increasing hardness and are generally quite low at approximately 300 BHN.

Examination of the ballistic data contained in Armor Test Report No. AD-990 indicates that the best ballistic properties were obtained in the 4" thick plates at 247 BHN and in the 5" thick plates at 244 BHN, with reduced resistance to penetration occurring at lower hardnesses and excessive brittleness at higher hardnesses.

A. Hurlich

A. Hurlich
Metallurgist

APPROVED:

E. L. Reed

E. L. REED
Research Metallurgist
Chief, Armor Section

TABLE I

Pittsburgh Steel Foundry 4" and 5" Thick Cast Armor

Thickness Inches	Plate No.	Hardness Reported by Company - BHN	Cross-Sectional Hardness Determination at Watertown - BHN		Fracture Rating	V-Notch Charpy Impact Specimens Notched 1" Below Surface	
			Range	Average		Ft.Lbs. at +70°F.	Ft.Lbs. at -40°F.
4	5	199	229-241	237	Fibrous Matrix 50% Crystalline	55.1	44.1
4	6	241	235-255	247	1½" fibre at surfaces 20% Crystalline	64.5	33.1
4	9	253	269-277	273	100% Crystalline	28.5	16.0
4	10	252	269-277	271	½" fibre at surfaces 75% Crystalline	33.5	17.3
5	5	207	217	217	1½" fibre at surfaces 30% Crystalline	59.1	32.5
5	9	231	229-235	233	3/4" fibre at surfaces 50% Crystalline	53.0	29.2
5	10	255	293-302	298	100% Crystalline	22.7	8.6
5	11	245	235-255	244	3/4" fibre at surfaces 50% Crystalline	59.3	27.3

APPENDIX

CORRESPONDENCE

Wtn 470.5/8378
OOM 470.5/APG (4 Aug 44)-R
Attn: SPOME-EE
APG 470.5/427

1st Ind.

Boucher/dw
2994/24th Fl.

Army Service Forces, Office, Chief of Ordnance-Detroit, Detroit 32, Michigan
16 August 1944.

To: Commanding Officer, Watertown Arsenal, Watertown 72, Massachusetts
ATTN: Laboratory

1. In accordance with the conversation between Captain A. F. Boucher, this office, and Major Matthews, your office, CAS-2 forms of material presently at Aberdeen Proving Ground manufactured by Pittsburgh Steel Foundry are inclosed herewith.

2. It is requested that your station furnish this office with the heat treatment procedure to be used by Pittsburgh Steel for the balance of the material at their plant.

3. It is believed that a specification of heat treatment will provide the Ordnance Department with material which can be more adequately used for heavy armor specification development. It is further believed that the hardness level on these plates should be at a maximum which you believe can be used and still produce a fibrous fracture.

By order of the Chief of Ordnance:

(s) John F. Randall

for D. C. PIPPEL
Major, Ord. Dept.
Assistant

2 Incls: n/c

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Wtn 470.5/8378
OOM 470.5/APG (4 Aug 44)-R
Attn: SPOTE-EE
APG 470.5/427

2nd Ind. Matthews/avk

C.O., ASF, Ord. Dept., Watertown Arsenal, Watertown 72, Massachusetts, 21 August 1944.

To: The Commanding General, ASF, Office, Chief of Ordnance-Detroit, Detroit 32, Michigan. Attn: SPOTE-EE

1. Reference preceding correspondence, the subject heat analysis is borderline hardenability for 4 and 5 inch thick cast armor. Both the carbon and chromium contents are below that considered necessary to avoid partial transformation to pearlite in the center of 4-6 inch sections. Even assuming that transformation to pearlite is avoided, the major transformation product will then be bainite in this type of steel; and studies at this arsenal have indicated that the impact properties of such steels after tempering are poor at hardnesses above approximately 240 Brinell.

2. There is, therefore, no assurance that a fibrous fracture will be obtained on these plates. The heat treatment recommended is as follows:

(a) Homogenize and soften as shown on CAS-2 form.

(b) Austenitize - 1700°F. for 8 hrs.

(c) Water quench cold (below 100°F.).

(d) Temper to obtain approximately 240 Brinell.

(e) Water quench from temper to 300°F. maximum on surface.

For the Commanding Officer:

H. H. ZORNIG
Colonel, Ord. Dept.
Assistant

2 Incls: n/c

UNCLASSIFIED