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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/285

Metallurgical Examination of Twelve 4 Inch Rolled Homogeneous Armor Plates Manufactured by Gary Armor Plate Plant

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WATERTOWN ARSENAL
WATERTOWN, MASS.

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Final Report on Problem B-4.53

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ABSTRACT

Metallurgical examination, including Brinell hardness readings, fracture tests for steel soundness and response to heat treatment, was conducted on ~~each of the~~ twelve samples furnished by the Gary Armor Plate Plant. Microscopic and macroscopic examinations, chemical analyses, V-notch Charpy impact and tensile tests were made of selected samples. All the samples except two ("D" fractures) were satisfactory with respect to steel soundness. Fine crystallinity was observed in the fractures of samples 4-1A, 4-1B and 5-1A which spalled badly under the ballistic test. It is apparent that this material was satisfactorily quenched out and that the crystallinity noted in these particular plates is the result of tempering by the manufacturer in the temper brittle range (975-1000°F). Typical brittle samples which had an average Brinell hardness of about 356 were retempered at 1100°F, (no hold), immediately quenched in water, resulting in an entirely fibrous fracture at a Brinell hardness range of 302-315.

1. As requested by the Ordnance Research Center[1], metallurgical examination has been completed on sections from twelve (12), 4 inch rolled homogeneous armor plates manufactured by the Gary Armor Plate Plant and tested at Aberdeen as a part of the effect of hardness program.

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

1. APG 470.5/528 - Wtn 470.5/8398 dated 28 August 1944.

a. Cross sectional Brinell hardness surveys.

b. Fracture tests for steel soundness and fibre fracture tests for revealing response to heat treatment.

c. Reheat treatment of brittle plates resulting in fibre at about 300 Brinell.

d. V-notch Charpy impact tests.

e. Tensile tests.

f. Chemical analyses.

g. Macroscopic examination.

h. Microscopic examination.

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

a. Brinell hardness. On carefully ground cross section, Brinell hardness tests were made. The values reported are based upon the average of six equidistantly spaced readings on the section. The results are given in Table I. In all cases, the samples were heat treated to a fairly uniform hardness along their respective cross sections. The Brinell hardness of samples Nos. 4-1A, 4-1B and 5-1A varied from 341-375 which was some 20-44 points in excess of the range reported by the manufacturer. On the other hand the hardness values of the remainder of the samples were in close agreement with those values determined at Watertown Arsenal.

b. Fracture tests for steel soundness and fibre fracture tests for revealing response to heat treatment. On sections 4"x12"x14", fracture tests were made on the properly notched sections and then rated with respect to steel soundness and heat treated condition (See Table II for results of tests). With the exception of sample No. 8-1A and 12-2A the balance of the samples had satisfactory fractures with respect to steel soundness. Entirely fibrous fractures were noted in all samples except Nos. 4-1A, 4-1B, 5-1A and 8-1A. Samples Nos. 4-1A, 4-1B and 5-1A heat treated to an average Brinell hardness range of 354-360 exhibited completely crystalline fractures while sample No. 8-1A heat treated to a Brinell hardness of 282 showed a trace of crystallinity at the center of the section. As described below in paragraph 3c, a tempering cycle was determined which eliminated brittleness in the plates exhibiting crystallinity and thereby resulting in fibre at about 300 Brinell hardness.

c. Reheat treatment of brittle plates resulting in fibre at about 300 Brinell. In accordance with a request from Office, Chief of Ordnance - Detroit[2], representative samples of 4" thick rolled armor, Nos. 4-1A and 5-1A were subjected to tempering cycles which would result in a fibrous fracture at a Brinell hardness of about 300. These data will

2. Teletype 64111, Goud SPOKE-KE, 14 October 1944.

be sent to the manufacturer in order that these plates may be retempered at about 300 Brinell and subsequently returned to Aberdeen Proving Ground for test.

(1) Sample No. 4-1A as received 6x7x4". This section was placed in a furnace, preheated to a temperature of 1100°F, and allowed to come to temperature in a period of 3-3/4 hours, at the end of which it was immediately quenched in water. The sample was not held at temperature before quenching. It was determined that there was no appreciable lag during the heating cycle between the temperature of the surface and that of the center of the section. Fibre fracture tests made on this sample indicated that the resulting fracture was entirely fibrous at an average Brinell hardness of 315. It is apparent that this material was originally satisfactorily quenched out and that brittleness in the samples as received is the result of tempering by the manufacturer in the temper brittle range (975-1000°F). Tempering at 1100°F is sufficient to restore ductility at a Brinell hardness of about 300.

(2) Sample No. 5-1A as received 6x7x4". An attempt was made to determine the hardness of this sample after placing it in a cold furnace and heating to 1150°F, during a period of 3-3/4 hours, holding at temperature for 10 minutes and quenching in water. Since the resulting hardness was only 260 Brinell, it was decided to re-quench the sample and retemper it by another method. The plate was then heated to 1650°F, held at temperature for 2½ hours, followed by quenching in water. The plate was placed in a cold furnace and heated to 1100°F in a period of 3-3/4 hours (no hold at temperature) and immediately quenched. In order to determine the true temperature of the piece during the heating cycle, a thermo-couple was placed under the sample. The sample showed complete fibre at a surface hardness of 302 Brinell. It is evident that satisfactory toughness at about 300 Brinell hardness may also be obtained by placing the sample in a cold furnace and heating to 1100°F, followed by immediately quenching into water.

d. V-notch Charpy impact tests. The results of the V-notch Charpy impact tests made on longitudinal and transverse sections at +70°F and at -40°F are given in Table III. Samples Nos. 4-1A, 4-1B and 5-1A, as received are brittle as noted by the results of the V-notch Charpy tests. According to the manufacturer's records, this particular series of plates were tempered in the range of 995-1000°F, which is within the temper brittle range. Heating to 1100°F, which is outside the temper brittle range, followed by quenching immediately into water, restores the ductility of the material resulting in a fibrous fracture and good V-notch impact properties at an average Brinell hardness of 315. Sample No. 7-2B which had a fibrous fracture as received has excellent V-notch impact properties both at room temperature and at -40°F. This sample also showed little evidence of directional properties.

e. Tensile tests. Tensile tests made in the longitudinal and transverse directions on samples are given in Table IV. Some directional properties were evident in sample No. 4-1A while no marked directional properties were noted in the other samples investigated.

f. Chemical analyses. The chemical analyses obtained of samples were as follows:

	Chemical Composition											
Sample No.	C	Mn	Si	S	P	Ni	Cr	Mo	Va	Cu	Al	B
4-1A	.27	1.42	.25	.014	.014	.66	.76	.41	Nil	.08	.025	.001
4-1B	.25	1.42	.24	.014	.014	.66	.82	.45	Nil	.08	.03	.0007
5-1A	.25	1.44	.23	.015	.014	.69	.82	.45	Nil	.08	.03	.0012
7-2B	.25	1.41	.24	.015	.014	.65	.76	.43	Nil	.07	.03	.0011

g. Macroscopic examination. In general, the macroetched sections examined were comparatively clean. However, samples 4-1A and 5-1A revealed slight centerline segregation and 7-2B showed evidence of occasional stringers.

h. Microscopic examination. Photomicrographs illustrating the distribution of the nonmetallic inclusions and also the typical microstructure of the samples are presented in Figure 1.

Metallographic samples were cut from the center of the samples and also the outer edge. Of those examined 4-1A and 4-1B revealed occasional segregated areas of sulphide nonmetallic inclusions in the outer edges with clean centers. Whereas, in 5-1A and 7-2B the condition is reversed, outside sections cleaner than the center. However, all samples were of comparatively clean steels.

With the exception of 7-2B, the microstructure was a tempered martensite. Sample 7-2B revealed fine carbides in tempered martensite in the center section and traces of ferrite and carbides in tempered martensite in the outer section.

4. The results of these tests indicate that all the samples except two ("D" fractures) were satisfactory with respect to steel soundness. Fine crystallinity was observed in the fractures of samples Nos. 4-1A, 4-1B and 5-1A which exhibited spalls as a result of both normal and oblique attack with under matching AP and APC projectiles. Brinell hardness of these particular plates varied 341-375, some 20-44 points Brinell in excess of the range reported by the manufacturer. The lack of ductility noted in plates Nos. 4-1A 4-1B and 5-1A is the result of heating the plates by the manufacturer in the temper brittle range. These plates were made ductile by retempering at 1100°F (no hold) following by immediately quenching in water.

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TABLE I

Brinell Hardness Survey

Sample No.	Cross Section Reported by Watertown Arsenal		Manufacturer's Reported BHN
	Range	Average	
4-1A	341-375	358	321-331
4-1B	352-375	360	321-331
5-1A	341-363	354	321-321
6-2A	229-255	243	241-248
6-2B	241-255	250	241-248
7-2A	207-212	210	201-207
7-2B	207-212	211	201-207
8-1A	277-285	282	269-277
8-1B	277-293	285	269-277
8-2A	201-207	205	197-207
10-1A	285-293	288	269-277
12-2A	241-255	252	241-248

TABLE II

Fracture Test Results

Sample No.	Steel Soundness	Fibre Fracture Test
4-1A	B	Essentially fine crystalline
4-1B	B	" " "
5-1A	B	" " "
6-2A	C	Fibrous
6-2B	C	Fibrous
7-2A	B	Fibrous
7-2B	B	Fibrous
8-1A	D	Fibrous(trace crystallinity in center)
8-1B	B	Fibrous
8-2A	B	Fibrous
10-1A	B	Fibrous
12-2A	D	Fibrous

TABLE III

V-Notch Charpy Impact Values Determined on 4" Thick Plate

Sample No.	Specimen Direction	BHN	Temp. of Test	Foot Pounds	Description of Fracture
As-Received					
4-1A	Long.	358	+70°F	32.6	Fc
4-1A	Long.	358	-40°F	10.6	Cd
4-1A	Trans.	358	+70°F	28.0	Fc
4-1A	Trans.	358	-40°F	26.5	Cd
4-1B	Long.	360	+70°F	34.2	Fc
4-1B	Long.	360	-40°F	14.2	Cd
4-1B	Trans.	360	+70°F	31.4	F
4-1B	Trans.	360	-40°F	12.1	Cd
5-1A	Long.	354	+70°F	40.7	F
5-1A	Long.	354	-40°F	14.2	Cd
5-1A	Trans.	354	+70°F	36.2	F
5-1A	Trans.	354	-40°F	14.8	Cd
7-2B	Long.	211	+70°F	85.7	F
7-2B	Long.	211	-40°F	81.6	F
7-2B	Trans.	211	+70°F	74.2	F
7-2B	Trans.	211	-40°F	73.2	F
After Retempering at 1100°F.					
4-1A	Long.	315	+70°F	57.3	F
4-1A	Long.	315	-40°F	58.2	F

NOTE: F = Fibrous.
Fc = Fibrous matrix with spots of crystallinity.
Cd = Dull crystalline (complete).

TABLE IV

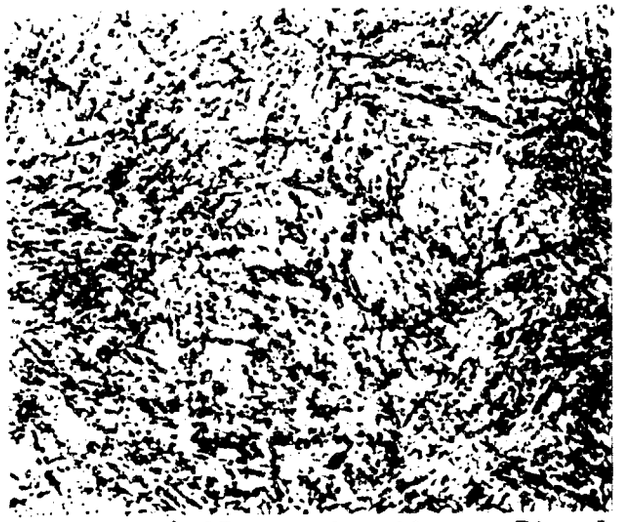
Results of Tensile Tests Made on 4" Thick Plate

Sample No.	Direction	Y.S. .1% Set Lb./Sq. In.	T.S. Lb./Sq. In.	% El.	% R.A.	BHN
4-1A	Long.	149,000	164,400	14.0	51.5	358
4-1A	Trans.	155,000	171,000	12.9	33.5	
4-1B	Long.	155,000	169,500	15.7	52.1	360
4-1B	Trans.	155,000	170,000	15.0	49.8	
5-1A	Long.	150,000	165,000	15.7	52.5	354
5-1A	Trans.	147,500	167,500	13.6	49.8	
7-2B	Long.	80,000	103,600	26.4	67.9	211
7-2B	Trans.	73,750	103,600	25.0	62.7	

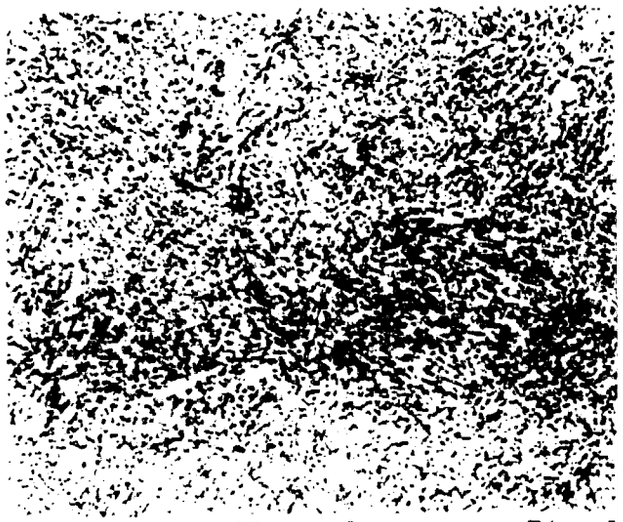
Gary Armor Plate Plant - 4 Inch Rolled Armor Plate

Typical Microstructures

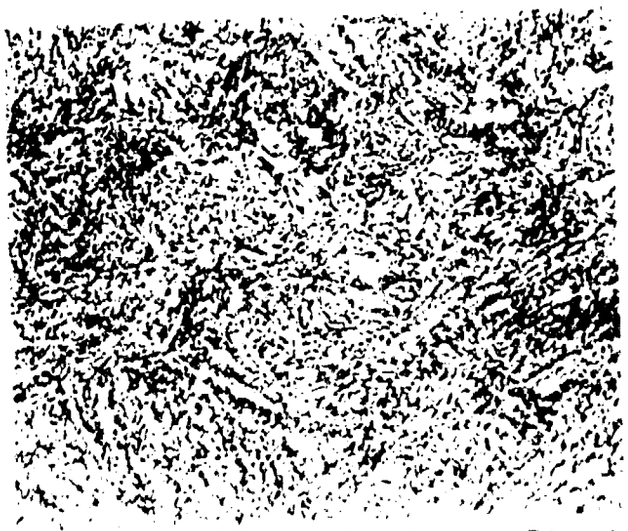
X100 7-2B Unetched
Occasional segregation of sulphides.



X1000 4-1B Outside Picral
Carbides in tempered martensite.



X1000 7-2B Center Picral
Fine carbides in tempered martensite.



X1000 7-2B Outside Picral
Traces of ferrite and carbides in tempered martensite.

FIGURE 1