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WAL 710/690

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/690

Metallurgical Examination of 2" Cast Armor Manufactured by Continental Foundry and Machine Company

BY

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WATERTOWN, MASS.

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Final Report on Problem B-4.41

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ABSTRACT

This report covers the investigation of 2" cast armor (24 plates) of varying hardnesses from 217 to 315 Brinell submitted under Office, Chief of Ordnance - Detroit Project 1113. The plates were reasonably sound, but those above 240 Brinell in hardness exhibited low impact strength and crystallinity in the fibre fracture test. Tests indicated that temper embrittlement was involved to a small degree. Experiments on small specimens, however, indicated that the steel would not respond to an ideal heat treatment to yield satisfactory impact properties because of some undetermined steel deficiency.

1. As requested in a letter from the Ordnance Research Center, Aberdeen dated 3 June 1944 (APG 470.5/6533, Wtn 470.5/9171(r)), a metallurgical examination has been completed on twenty-four (24) samples of 2 inch thick cast armor manufactured by Continental Foundry and Machine Company. The plates were cast from three heats of steel and were similarly heat treated except for the final tempering temperature, which was varied to produce Brinell hardnesses over the range 220 to 315 Brinell. The plates were tested ballistically to determine the optimum hardness level for cast armor of this thickness.

2. The samples had been essentially completely quench hardened and developed essentially fibrous fractures at hardnesses up to 240 Brinell. Above 240 Brinell considerable crystallinity was seen which to a small degree has been shown to be due to temper embrittlement. However, experiments on small specimens indicated that the steel has some inherent deficiency which prevents a normal response to heat treatment and the development of satisfactory impact properties.

3. The metallurgical examination consisted of the following tests:

a. Brinell hardness surveys.

b. Fibre fracture tests on all samples as received.

c. Fracture tests of selected plates after retempering and reheat treating.

d. V-notch Charpy impact tests of selected plates in the as-received condition, after retempering followed by water quenching, and after reheat treating.

e. Microscopic examination of selected plates.

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

a. Chemical analyses. The chemical compositions of the three heats, as reported on the CAS-2 forms, are as follows:

CHEMISTRY

Heat	C	Mn	Si	S	P	Ni	Cr	Mo
6787	.31	1.33	.41	.036	.043	.65	.79	.41
6777	.33	1.31	.44	.034	.042	.66	.69	.38
6571	.30	1.39	.39	.039	.038	.56	.67	.41

b. Brinell hardness. Five equally spaced Brinell readings were taken across the thickness of each plate. The hardnesses through the sections were uniform in all plates and, therefore, only the range and average hardness are recorded. (See Table I.)

c. Fibre fracture tests. The samples were notched such that the unnotched area was 2"xT (thickness) and broken under the impact of the head of a forge hammer. The results are shown in Table I. At 240 Brinell hardness and below, the fractures show only traces of crystallinity which are probably associated with segregation effects. Above 240 Brinell the percentage of crystallinity increases with hardness to such an extent that all fractures of plates above 250 Brinell are considered unsatisfactory.

It was considered that temper brittleness might be a contributing cause of the poor fractures observed above 240 Brinell. Samples from heat 6777 were retempered for 2 hours at temperatures designed to cause no change in hardness and yet reasonably close to the original tempering temperatures. All samples were water quenched from the tempering temperature. Some improvement in fractures was observed in the samples at the higher hardnesses, but fibrous fractures were not obtained. (See Table I.)

Three samples from heat 6571 were reheat treated to 280 Brinell hardness to determine whether the steel of this type analysis is susceptible to temper brittleness and whether it could be heat treated to fracture in a fibrous manner at this hardness level. The following results were obtained.

Sample Number	Heat Treatment		Fracture	Brinell Hardness
6571-9	1675°F - 3 hrs. - W.Q.	1165°F - 4 hrs. - W.Q.	Fc 1/8	285
6571-10	1675°F - 3 hrs. - W.Q.	1165°F - 4 hrs. - A.C.	Fc 1/3	293
6571-11	1675°F - 3 hrs. - W.Q.	1165°F - 4 hrs. - F.C.	Fc 3/4	277

W.Q. - Water quenched cold. A.C. - Air cool to room temperature
F.C. - Furnace cool to below 300°F.

These results indicate that the steel is definitely susceptible to temper brittleness. The results also indicate that it is not possible to heat treat this steel in such a manner as to obtain a completely fibrous fracture at 280 Brinell hardness in the 2 inch thick section. Factors other than temper embrittlement are involved in the poor fractures on this material as-received and after reheat treatment.

d. V-notch Charpy Impact Tests. The results of Charpy impact tests conducted on selected samples are shown in Table II. There was an apparent improvement in the impact strength of plate 6777-7 achieved by retempering and water quenching to eliminate temper brittleness. However, the effect was negligible on the impact properties at the -40°F testing temperature, and it, is concluded therefore, that the degree of temper embrittlement in the plates as-received was small. At the lower hardness levels (230 Brinell) there was no improvement affected by water quenching from the temper, and the impact properties, in all cases, are not satisfactory both with respect to the energy level as a function of hardness and the change in energy absorption with testing temperature.

It has been observed in the past that some of the higher a alloy armor steels tend to retain austenite upon quenching which subsequently may transform upon tempering to impair the impact properties. Consequently, one of the samples (6777-9) was heat treated in small sections, using a cold temperature treatment after the quench to complete the transformation of any retained austenite. The heat treatment applied and the resulting impact properties are as follows:

	Temperature	Time	Quench
Austenitize	1675°F	3 hrs.	Water to room temperature, dry ice - alcohol to -110°F.
Temper	1225°F	4 hrs.	Water

Charpy Impact Results

68°F			-40°F		
Ft. Lbs.	Fracture	Rockwell C	Ft. Lbs.	Fracture	Rockwell C
48.5	F*	24.0	43.0	Cbf 1/4*	24.5
43.0	F	24.0	31.5	Cbf 1/2	24.0

*F - fibrous, Cbf - bright crystalline patch surrounded by a fibrous border. Fraction refers to fractional area that is crystalline.

These results indicate that, even in small sections, this steel cannot be heat treated to yield satisfactory impact properties. The energies absorbed at -40°F are low, and the change in energy absorbed with the reduction in testing temperature is excessive. The fractures of the bars broken at -40°F are poor. In this experiment complete quench hardening was obtained; a treatment was applied to transform any austenite retained upon quenching and the small specimens were water quenched from a tempering temperature sufficiently high that it is certain that temper brittleness is not involved. It is, therefore, concluded that the steel exhibits an inherent brittleness which prevents the development of the desired impact properties.

e. Microscopic examination. Samples 6777-2, 5, 7, 9, 6571-10, and 6787-10 were selected for examination. No undesirably poor distributions of nonmetallic inclusions were observed in any of the specimens. The inclusions were randomly distributed globular oxides and sulphides. The microstructures at the center of four plates are shown in Figure 1. A small amount of ferrite was observed in plate 5. The presence of high temperature transformation products was not extensive in any of the specimens.

5. These plate fractures showed considerable crystallinity at hardnesses above 240 Brinell. Tests have indicated that temper embrittlement may have been involved to a small degree. However, experiments on small specimens indicated that the steel is inherently poor and does not respond to an ideal heat treatment to yield satisfactory impact properties.

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TABLE I

Cross Section Hardnesses and Fracture Test Results

Sample No.	Range BHN	Ave. BHN	Fractures*	
			As Received	Retempered and Water Quenched from Temper
6787-3	248-255	253	Fc 1/8	
-4	248-255	252	Fc 1/4	
-5	293-302	298	Fc 3/4	
-7	285	285	Fc 3/4	
-8	285	285	Fc 3/4	
-9	229	229	Fc trace	
-10	229	229	Fc 1/8	
-11	293-302	294	Fc 1/2	
6777-2	235-241	240	Fc 1/8	Fc trace
-4	241	241	Fc trace	Fc trace
-5	302-311	307	Fc 1/2	Fc 1/8
-6	293-302	298	Fc 1/2	Fc 1/3
-7	302	302	Fc 1/2	Fc 1/4
-8	311-321	315	Fc 1/2	Fc 1/8
-9	212-217	216	Fc trace	Fc trace
-10	229	229	Fc trace	Fc trace
6571-3	277	285	Fc 3/4	
-5	269	269	Fc 1/2	
6571-6	269-277	272	Fc 1/2	
-7	235-241	239	Fc trace	
-8	302-311	307	Fc 1/2	
-9	235	235	Fc trace	
-10	217-223	222	Fc trace	
-11	217	217	Fc 1/8	

*Fc - Mixed - fibrous matrix with spots of crystallinity. Fraction refers to the amount of crystallinity.

Fc trace - essentially fibrous. Trace of crystallinity probably caused by segregation effects.

TABLE II

V-notch Charpy Impact Results

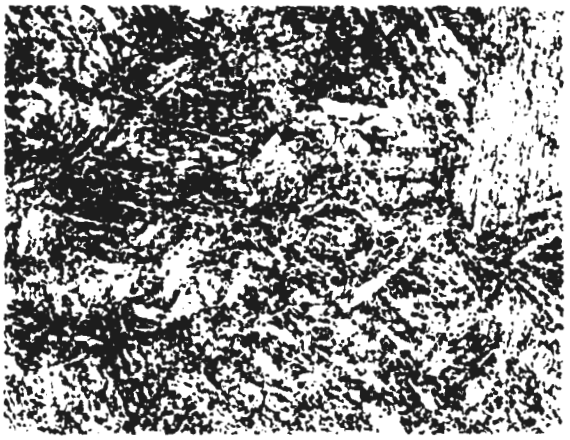
Plate No.	Condition	Results at 68°F			Results at -40°F		
		Ft. Lbs.	Fracture	Rc	Ft. Lbs.	Fracture	Rc
6777-2	As received	53.0	F	21	34.0	Fc 1/8**	20
"	"	44.0	F	20	50.5	Fc trace	21
"	Retempered*	50.0	F	22	39.5	Fc 1/8	20
"	"	49.0	F	22	40.0	Fc 1/8	21
6777-10	As received	32.0	Fc trace	21	39.0	Fc 1/4	19
"	"	41.5	Fc trace	17	35.5	Fc 1/4	19
"	Retempered	48.0	F	21	44.0	Fc 1/4	20
"	"	52.5	F	20	34.5	Fc 1/3	20
6777-7	As received	20.0	Fc 1/3	31	21.5	Fc 1/2	31
"	"	25.5	Fc 1/4	31	17.0	Fc 3/4	31
"	Retempered	36.0	Fc trace	30	22.5	Fc 1/2	30
"	"	37.5	Fc trace	30	18.0	Fc 1/2	30

*The retempered specimens were reheated for 2 hours at temperatures of 1200°F, 1220°F, and 1165°F, for plates 2, 10, and 7 respectively and all were water quenched from the tempering temperature.

**Fc - Mixed - fibrous matrix with spots of crystallinity. Fraction refers to the amount of crystallinity.

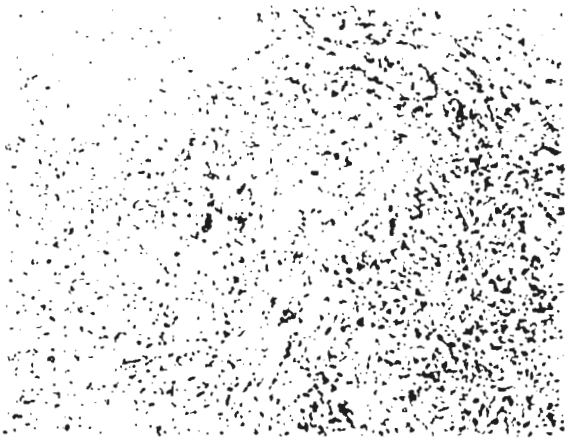
Microstructure of 2" Plates Manufactured by

Continental Foundry and Machine Company

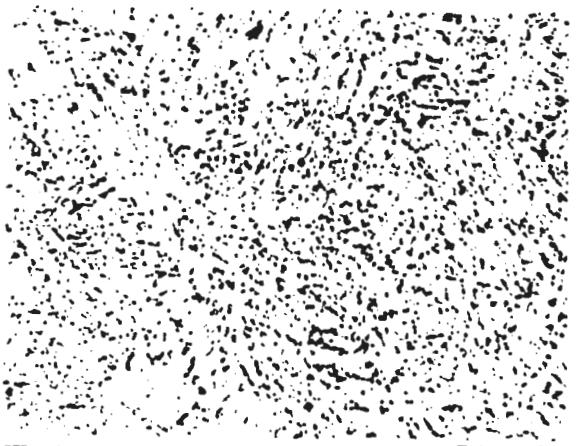


X1000 -A- Picral
Plate 6777-7. Tempered martensite at 302 BHN.

X1000 -B- Picral
Plate 6777-5. Tempered martensite at 307 BHN. A small amount of proeutectoid ferrite is present.



X1000 -C- Picral
Plate 6777-2. Tempered martensite at 240 BHN.



X1000 -D- Picral
Plate 6777-9. Tempered martensite at 216 BHN.

FIGURE 1