WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/347

Metallurgical Examination of Two T23 Cast Turrets

Produced by the Continental Foundry and Machine Company

BY

A. HURLICH
Assoc. Metallurgist

DATE 28 November 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Final Report on Problem B-4.56

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ABSTRACT

Metallurgical examination of two T23 cast turrets indicates both were temper embrittled to approximately the same degree. In addition, turret No. 5 was further embrittled as a result of incomplete quench hardening, which, in conjunction with the temper embrittlement, was sufficient to cause rejection of the casting because of the displacement of fragments from the back during partial penetration of 3" APC M62 projectiles. Turret No. B6, despite its temper embrittlement, still possessed sufficient ductility to meet the requirement of Specification AXS-492-4. Impact tests show that turret No. B6 possesses approximately twice the impact energy of turret No. 5, both at room and reduced temperatures. Water quenching from the tempering temperature should prevent the temper embrittlement of castings of the composition and section thicknesses of the subject turrets.

1. Reference basic communication - APG 470.5/608(r), Wtn 470.5/8433(r), 16 September 1944, a metallurgical examination has been completed upon samples from two T23 cast turrets produced by the Continental Foundry and Machine Co.; turret No. 5, heat No. 1136, supplied by the East Chicago Plant, and turret No. B6, heat No. 2250, supplied by the Wheeling Plant.

2. Ballistic tests were performed upon the subject turrets to obtain engineering information on the Medium Tank T-23 Cast Turret, Drawing No. D7054366. The firing tests were conducted in accordance with Specification AXS-492-4 and are reported in Armor Test Report AD-699 by the Ordnance Research Center. It was concluded that turret No. B6 is acceptable under Specification AXS-492-4 and turret No. 5 is unacceptable due to fragments being displaced

from the back upon partial penetration (Army criterion) of 3" APC M62 projectiles in the right side of the turret. Turret No. 3 also displayed more cracking and more fragments displaced from the back during the course of the ballistic tests than did turret No. B6.

3. Metallurgical examination of the submitted samples leads to the following observations and conclusions:

a. Both turrets exhibit a 15-20 ft.lb. decrease in impact energy (when tested at -40°F.) resulting from temper embrittlement.

b. In addition to the above, turret No. 5 has been incompletely quench hardened. The loss in impact energy resulting from the combination of poor quench hardening and temper embrittlement was sufficient to cause brittle behavior during ballistic testing.

c. Water quenching after tempering should be capable of preventing temper embrittlement of castings of the composition and section thickness of the subject turrets.

d. Adequate heat treatment to prevent embrittling due either to incomplete hardening or slow cooling after tempering should permit the attainment of higher hardnesses combined with sufficient ductility to possess adequate shock resistance and increased resistance to penetration.

4. The samples submitted for examination consisted of one section from each turret, approximately 10" x 15" x 2½" in size presumably cut from the side walls after ballistic testing. The following tests were conducted upon the sections:

a. Chemical analysis.

b. Fracture test.

c. Brinell hardness across the section.

d. Macroetch test.

e. V-notch Charpy impact tests.

f. Reheat treatment to improve impact properties.

g. Jominy hardenability.

h. Microscopic examination.

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

a. Chemical analysis. The analyses of the two turrets are as follows:

	C	Mn	Si	S	P	Ni	Cr	Mo	Al
Turret No. 5									
Reported by Company	.32	1.45	.42	.036	.040	.55	.63	.40	-
Watertown Arsenal	.32	1.48	.47	.025	.045	.64	.60	.39	.03
Turret No. B6									
Reported by Company	.30	1.26	.27	.028	.040	.60	.57	.40	-
Watertown Arsenal	.32	1.36	.34	.029	.038	.72	.60	.41	.02

Both steels were also checked for boron and vanadium, but neither element was found in sufficient quantity to indicate deliberate addition as alloying or deoxidizing agents. The steel for both turrets was produced in acid open hearth furnaces, and contain the high sulfur and phosphorus contents associated with the acid practice.

Acid furnace steels generally contain between two and three times as much sulfur and phosphorus as basic furnace steels, and have frequently been found to possess poorer soundness characteristics, lower impact energy levels, and greater susceptibility to temper embrittlement as compared to basic furnace steels of similar composition.[1]

b. Fracture test. Both samples were notched in at the middle of the longer sides and were fractured under the impact blow of a steam hammer. The fractured surface of the sample from turret No. 5 contained small, uniformly distributed patches of crystallinity covering approximately one half of the entire surface, with the remainder being fibrous; while that of turret No. B6 contained similar crystalline patches over approximately one quarter of its area.

c. Hardness surveys. After the fracture test blocks were broken, a 1½" thick section, parallel to and approximately 2" from the fractured surface, was cut from one half of each block. The surfaces were ground, and Brinell hardness impressions were made every half inch apart from one surface to the other. The results follow:

1. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/695(c) - "Metallurgical Examination of 10" Cast Homogeneous Armor Manufactured by General Steel Castings Corp. and 6" Cast Homogeneous Armor Manufactured by Union Steel Castings Co.", 31 August 1944, A. Hurlich. Discussion on pages 7-9.

Brinell Hardness Surveys across the Section

Turret No. 5	Turret No. 36
248	241
241	229
241	223
241	229
241	241
Average - 242 BHN	Average - 233 BHN
Reported by Mfgr. - 235/255 BHN	Reported by Mfgr. - 241/248 BHN

The hardnesses of both turrets are considered average for production cast armor in the section thicknesses involved.

d. Macroetch test. The hot acid etched structures of both turrets are similar, showing fairly extensive V-type solidification shrinkage generally confined to the middle third of the sections. The steel quality as evidenced by macroetching is considered average for the subject castings.

e. Charpy impact tests. V-notch Charpy impact specimens were machined from the sections prepared for hardness surveys, being taken from regions halfway between the centers and the surfaces of the castings. Duplicate specimens were tested at temperatures of +70°F. and -40°F. with the results recorded in the following table.

V-Notch Charpy Impact Tests

	As Rec'd. Tested at +70°F, Ft. Lbs.	Fracture Rating*	As Rec'd. Tested at -40°F, Ft. Lbs.	Fracture Rating	Retempered 1 Hr. at 1175 F. Water Quenched Tested at -40°F, Ft. Lbs.	Fracture Rating
Turret #5	30.3	Fc	10.9	Cb (Dendritic)	31.1	Fc
	20.8	Fc	18.1	Cbf (Dendritic)	23.6	Fc
Average -	25.6		14.5		27.4	
Turret #B6	49.2	Fc	26.9	Fc	45.8	Fc
	40.7	Fc	24.7	Cbf	45.3	Fc
Average -	45.0		25.8		45.6	

*Fc - Fibrous matrix with spots of crystallinity.

Cb - Bright crystalline.

Cbf - Bright crystalline patch surrounded by fibrous border.

Well heat treated cast armor, of the same hardness as the subject material, produced in acid open hearth furnaces generally develops an impact energy lying between 45 and 60 ft.lbs. when tested at +70°F., which decreases possibly 5 to 10 ft.lbs. when tested at -40°F. The impact properties of turret #B6 are somewhat low both at room temperature and at -40°F., while those of turret #5 are decidedly inferior.

The reduction in the impact energy levels of turret #5 at room temperature and of both turrets at -40°F. is due to incomplete transformation to martensite or a low temperature bainite upon quenching, to temper embrittlement, or to a combination of the two.

In order to ascertain to what extent temper embrittlement was a factor in lowering the impact properties, 4"x3"x3/4" thick sections from both turrets were retempered at 1175°F. for one hour and water quenched. This temperature was selected because it is above the solution temperature of the precipitate responsible for temper embrittlement, but below the actual tempering temperature employed by the manufacturer, hence no reduction in hardness should result from this treatment. V-notch Charpy impact specimens were machined from positions comparable to the original test locations and broken at a temperature of 40°F. Rockwell C hardness surveys made of the broken impact bars indicated no change in hardness from the original values. From the data contained in the foregoing table, it is apparent that the water quenching after retempering approximately doubles the impact energy of both turrets when tested at -40°F. In both cases, water quenching after retempering returned the impact energy to the same level at -40°F. which the steel originally displayed at room temperature.

Although the CAS-2 forms indicate that the manufacturer had water quenched both turrets after the tempering treatment, the results of the retempering experiments conducted at this arsenal indicate that the manufacturer's treatment was ineffective in preventing temper embrittlement. An impact energy of 45 ft.lbs. at -40°F. after retempering and water quenching indicates that turret No. B6 has been adequately quench hardened, whereas turret No. 5, which has an impact energy at -40°F. of only 27 ft.lbs. after the elimination of temper brittleness, has evidently been incompletely quench hardened. Thus, the entire reduction of approximately 20 ft.lbs. in impact energy of turret No. B6 when tested at -40°F. in the as-received condition is traceable to temper embrittlement, while turret No. 5 lost approximately 15 ft.lbs. through temper embrittlement and an equal amount as a result of inadequate quench hardening.

The inferior shock properties of turret No. 5 as reflected in the Charpy impact tests correlate with the results of the ballistic tests. The displacement of fragments from the backs of partial penetrations indicates excessive brittleness and is very justly considered sufficient reason for rejection of armor.

f. Hardenability determination. Standard Jominy hardenability bars were end-quenched after austenitization at 1575°F. for 3 hours. The resultant hardness curves are plotted in Figure 1. The hardenability of both heats is considered adequate to fully quench out the heaviest section occurring in the T-23 turret. Water quenching for a sufficient length of time to bring the temperature of the casting below 300-400°F., air cooling, then tempering to attain the desired hardness, followed by a water quench to reduce the temperature below 400°F. should develop the optimum properties without difficulty.

g. Microscopic examination. The microstructure of both turrets consists of relatively uniformly distributed spheroidal carbides in ferrite. No gross ferrite areas are present in either steel. It is impossible to ascertain from the microstructure of the tempered material whether the quenching had resulted in the formation of martensite or martensite and bainite aggregates. The impact properties are, however, satisfactory criteria of the degree of quench hardening. On the basis of the impact tests, turret No. B6 appears to have been fully hardened and turret No. 5 incompletely hardened.

6. General Considerations. The results of the metallurgical examination of the subject castings indicate that both turrets have been temper embrittled by insufficiently rapid cooling from the tempering temperature. In addition, turret No. 5 has also been inadequately quench hardened. The loss in impact energy resulting from the combination of poor quench hardening and temper brittleness reduced the shock resistance of turret No. 5 to a degree that the casting was rejectable on the basis of brittleness exhibited during ballistic testing.

Temper embrittlement was responsible for a decrease in impact energy at -40°F. of 15-20 ft.lbs. in both turrets. This embrittlement could have been avoided by drastic water quenching from the tempering temperature.

Proper heat treatment to prevent embrittlement due either to incomplete quench hardening or to slow cooling after tempering should permit the attainment of higher hardnesses, which would result in increased resistance to penetration combined with adequate shock resistance.

A. Hurlich
A. Hurlich
Assoc. Metallurgist

APPROVED:

E. L. Reed
E. L. REED
Research Metallurgist
Acting Chief of Armor Section

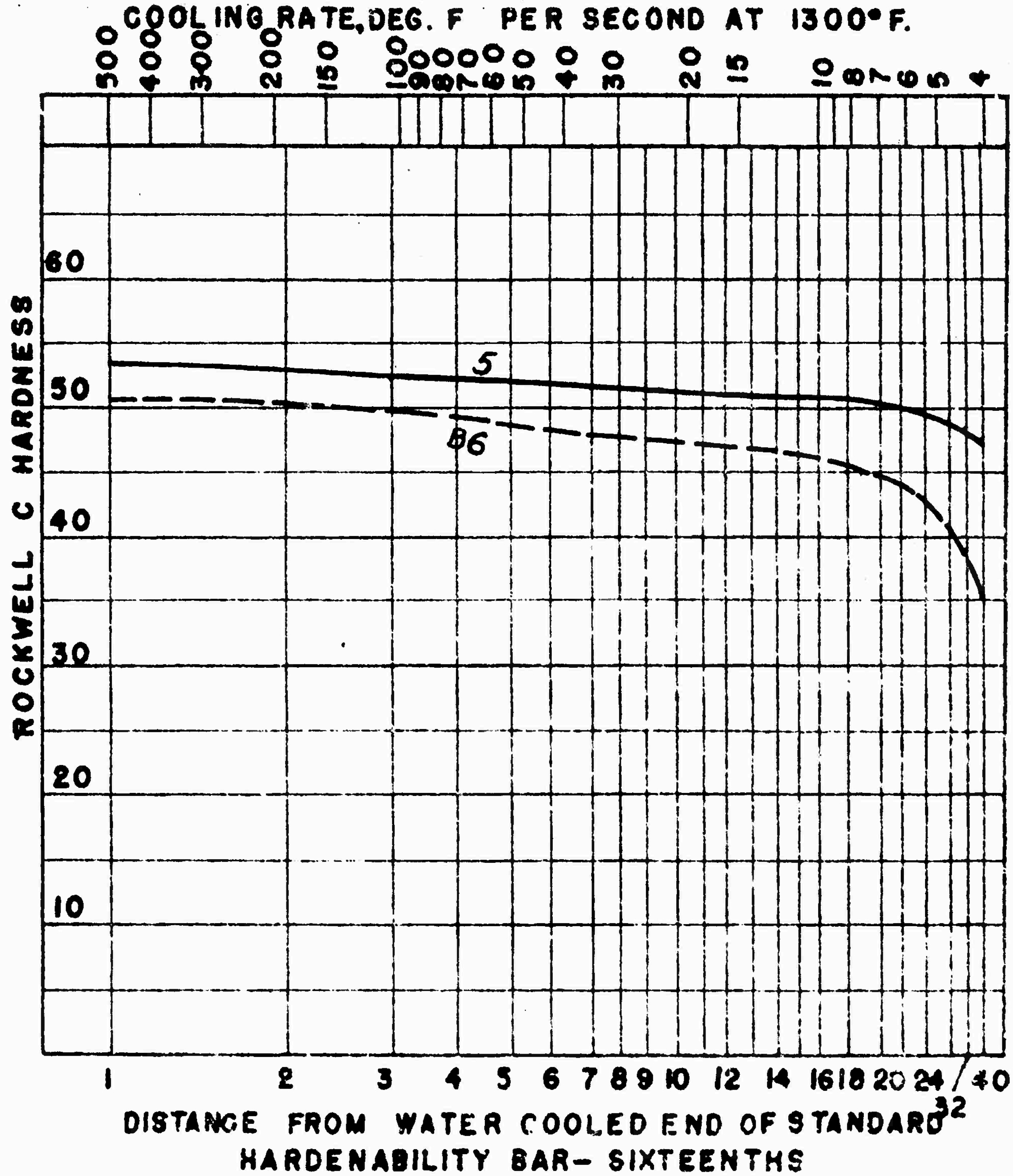

PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	AL		QUENCH TEMP	TIME	G.S.
5	1136	.32	1.48	.47	.025	.045	.64	.60	.39	.03		1575	3 HRS	
B6	2250	.32	1.36	.34	.029	.038	.72	.60	.41	.02		1575	3 HRS	

T23 CAST TURRETS

CONTINENTAL FOUNDRY AND MACHINE COMPANY

FIGURE 1.