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WATERTOWN ARSENAL LABORATORY
MEMORANDUM REPORT NO. WAL 710/547

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Partial Report on Problem No. B4.6

20 October 1943

Metallurgical Examination of Sections from Two Cast Armor Final Drive Housings

1. With reference to the request contained in letter APG 470.5/543 - Wtn 470.5/6795(r), a metallurgical examination has been completed on a final drive housing, Pattern 53579, Serial 1, made by the General Steel Castings Corporation and Pattern E4186, Serial 2B, made by the American Steel Foundries. The ballistic results were reported in APG Reports AD-497 and AD-502 respectively.

2. The effects observed in the ballistic test of the General casting are believed to be representative of good quality cast armor. A low temperature shock test, however, would probably show up a brittle tendency in this casting, since the steel was not completely fibrous in the fracture test. The cause of this condition is incomplete hardening upon quenching because the steel has insufficient hardenability for the section size heat treated.

3. Results of the ballistic tests conducted on the casting made by the American Steel Foundries were not available, but the metallurgical tests indicate that the casting would not exhibit optimum ballistic performance. The steel was heat treated to a rather low hardness (200 to 210 Brinell) at which the ballistic efficiency at high obliquities is believed to be lower than when heat treated to higher hardnesses probably 260 to 300 Brinell for the thicknesses involved. Poor performance is to be expected against the slug test, especially if conducted at a low temperature, for the steel was incompletely hardened upon quenching. This condition is attributed to the exceedingly low hardenability and low alloy content which must be greater in order to properly heat treat steel of the given thickness irrespective of the quenching practice used.

4. Results of the metallurgical examination are as follows:

a. Chemical Composition

An analysis of the two castings was made at this arsenal, and results are compared with that reported on the CAS-2 forms. (See Table I.)

TABLE I

Chemical Composition

Casting	Analyzed by	C	Mn	Si	S	P	Cr	Mo	Ni
General, Serial 1	General Steel	.33	1.60	.42	.015	.012	.45	.36	-
General, Serial 1	Watertown Arsenal	.30	1.57	.44	.018	.011	.53	.26	.09
A.S.F., Serial 2B	Watertown Arsenal	.25	1.50	.47	.020	.014	.30	.12	trace

The alloy content of the American Steel Foundries casting, Serial 2B, is extremely low for this thickness of armor. The analysis of the General Steel Foundries casting, Serial 1, is a typical Mn-Cr-Mo steel of much higher alloy content.

b. Hardness Surveys

Cross-sectional Brinell hardness tests were conducted on both castings with the following results:

Casting	Brinell Hardness Values						
General, Serial 1	269	269	262	255	262	269	269
A.S.F., Serial 2B	207	212	201	197	201	212	207

The American Steel Foundries casting possessed an extremely low hardness which is probably associated with incomplete hardening upon quenching.

c. Hardenability

Jominy end-quench hardenability tests were conducted on the two castings, and the results are shown in Figures 1 and 2. Using a conversion table,[1] distances on a Jominy bar can be correlated with thicknesses of plate quenched in water. On this basis, the hardenability of the General casting is sufficient to harden plate 2½" thick to a core hardness of Rockwell "C" 43 (400 Brinell) whereas the hardenability of the American Steel Foundries casting is only sufficient to harden plate 7/8" thick. The hardenability of the General casting is slightly less than that necessary for full hardening in the 2½" thick section of this casting. The American casting possesses very low hardenability which is reflected in the low hardness of this casting.

1. "Hardenability Conversions" - Publication of the Great Lakes Steel Corporation - 1942.

d. Fracture Test

Sections of the two castings were fractured under the forge hammer for the fibre test. Both castings possessed a mixed fracture, half fibrous - half crystalline. This condition is grounds for rejection under the present cast armor specification.[2] A specimen from the General casting fractured under a slow press was completely fibrous. That the steel is fibrous under a slow press and mixed (fibrous crystalline) under a forge hammer reveals the importance of an impact blow in fracturing the specimens. The impact blow of the forge hammer is believed to more nearly simulate the conditions of projectile impact at high velocities and has been found necessary to prevent acceptance of armor at low hardnesses which was not satisfactorily quench hardened.

e. Impact Tests

V-notched Charpy impact tests were conducted on the two castings and the results are listed in Table II.

TABLE II

V-Notched Charpy Impact Values

Casting	68°F. (20°C.)		+14°F. (-10°C.)		-40°F. (-40°F.)	
	Ft.-Lbs.	Fract.*	Ft.-Lbs.	Fract.	Ft.-Lbs.	Fract.
General, Serial 1	56.0	F	56.0	F	29.0	Fc
	54.5	F	43.5	Fc	41.0	Fc
A.S.F., Serial 2B	45.0	F	50.0	Fc	21.5	Cf
	58.0	F	45.0	FC	26.0	Cf

*F - Fibrous C - Crystalline Fc - Mostly F some C.
FC - Mixed F and C. Cf - Mostly C some F.

The room temperature notched bar impact strength of the American Steel Foundries casting was considerably lower than that generally attained in good quality steel, properly heat treated to a hardness of 200 to 210 Brinell, the hardness of this casting. The impact properties dropped off at -40°F. with a definite change to a brittle type of failure. The energy absorption of the General casting did not drop off as rapidly and its fracture possessed considerable ductility at -40°F.

f. Macroexamination

The macroetched sections examined contained scattered segregations of nonmetallics and shrinkage porosity as shown in Figure 3.

2. Specification AXS-492, Rev. 3., Amend. 1.

The soundness of the section of the General casting was considerably superior to that of the American casting.

g. Microscopic Examination

Scattered nonmetallics were observed in the unetched specimens of both castings.

The microstructure of the castings is shown in Figure 3. A small amount of ferrite was present in the center of the casting made by the General Steel Castings Corp. This condition confirms the impact and fracture test results which predicted that a small amount of high temperature transformation products were present. The American casting possessed a relatively poor microstructure containing a considerable quantity of free ferrite as evidence of its incomplete hardening upon quenching.

h. General Considerations

The ballistic properties observed in the General casting are representative of those that may be expected from good quality armor heat treated to 260 Brinell. A severe shock test such as a low temperature slug test would probably reveal the brittleness in the thicker sections of this casting which had not been completely quenched out. The ballistic results reported in APG report AD-497 are considered to be indicative of those that would be expected of good quality cast armor tempered to 260 Brinell.

The merit of a double wall section in the design of this casting is to be questioned. The limited ballistic tests imply that the composite has a lower ballistic efficiency than a solid section of equivalent thickness at the obliquities used.[3] This composite type section might be advantageous against AP projectiles wherein the outer wall would break up the projectile or when the obliquity of fire is increased with respect to the second wall by positioning the second wall or by deflecting the projectile with the first wall. Against H.E. projectiles the outer wall would be an aid in exploding the charge in a zone where it would do a minimum of harm. On the other hand, the ballistic efficiency of a second wall which is relatively thin (E/D cos θ ratio of less than .4) is much less than a similar thickness incorporated in a single thick wall, and this latter effect would probably outweigh the previous considerations.

The American Steel Foundries casting exhibited poor metallurgical properties. The fracture was not fibrous, the notched bar strength at -40°F was poor, the hardness was low, and a considerable quantity of high temperature transformation products was observed in the microstructure. The poor quality is attributed to incomplete hardening

3. Aberdeen Proving Ground Report AD-498.

during the quench as a consequence of the steel possessing too low a hardenability for the section size. The hardenability should be increased considerably by increasing the alloy content in order to attain complete transformation to martensite during the quench.

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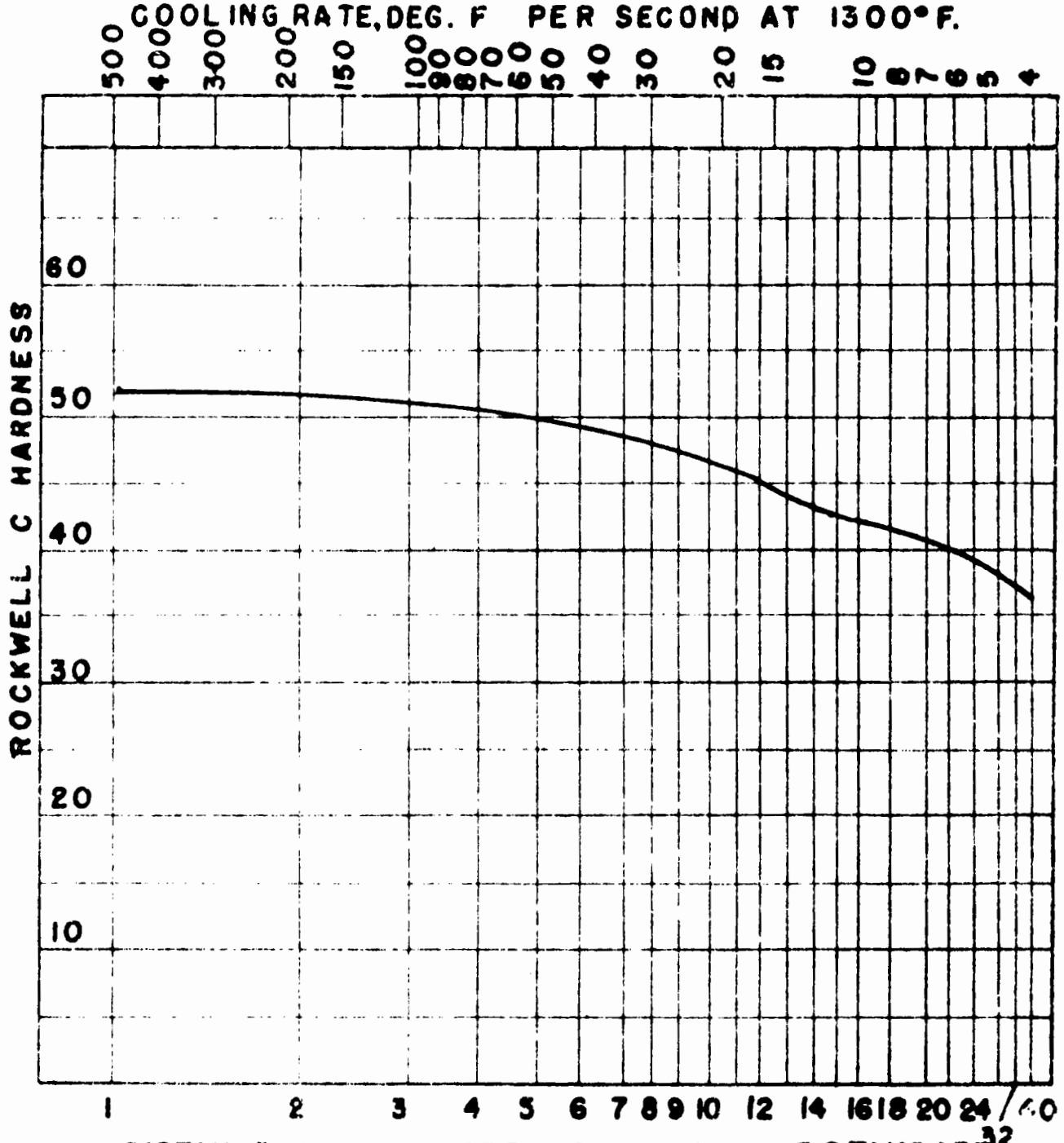


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	Al	V_n	QUENCH TEMP	QUENCH TIME	G.S.
Serial 1		.30	1.57	.44	.018	.011	.09	.55	.26	.04	Tr	1625	2 hrs	

General Steel Castings Corporation

FIGURE 1

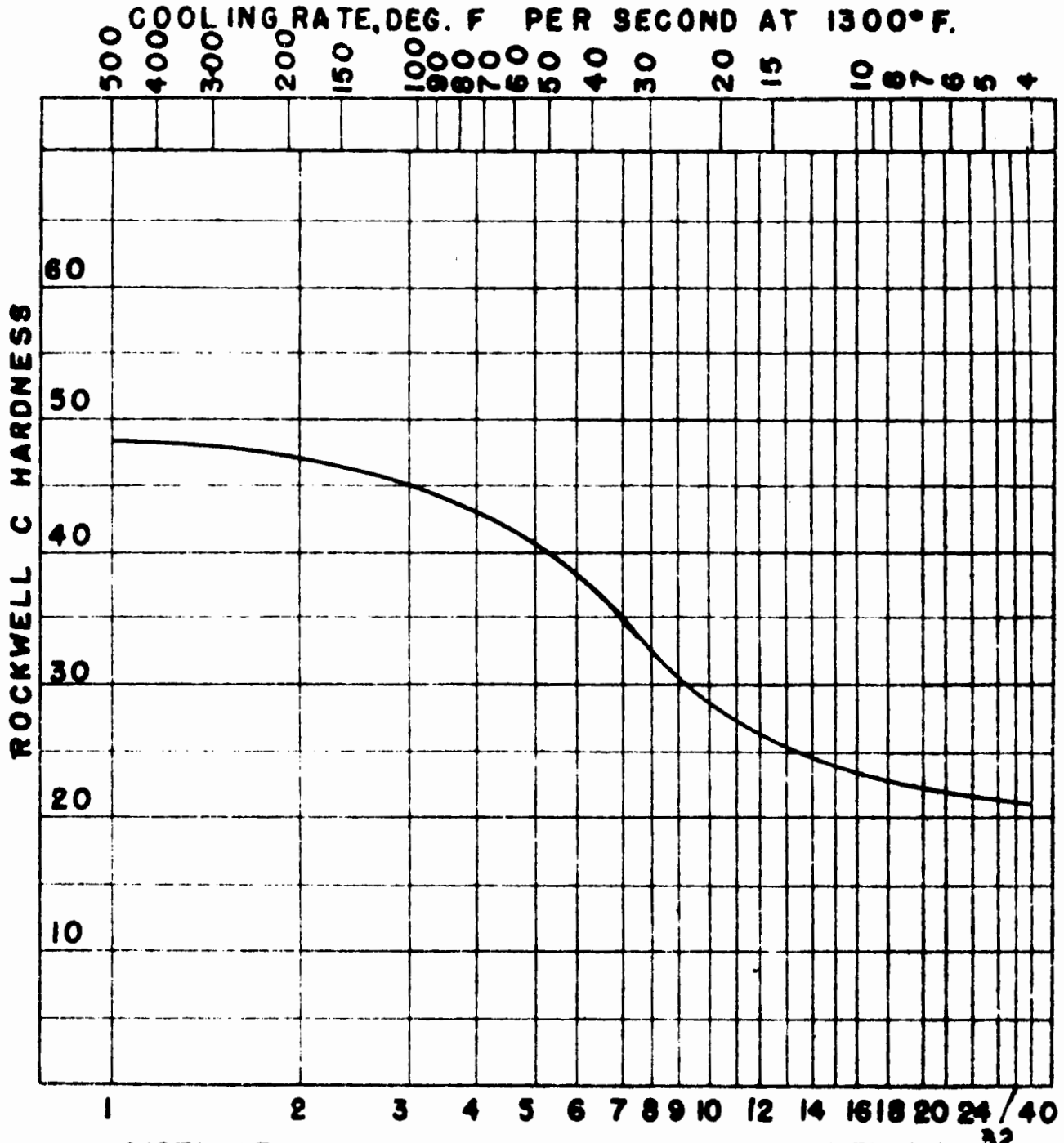


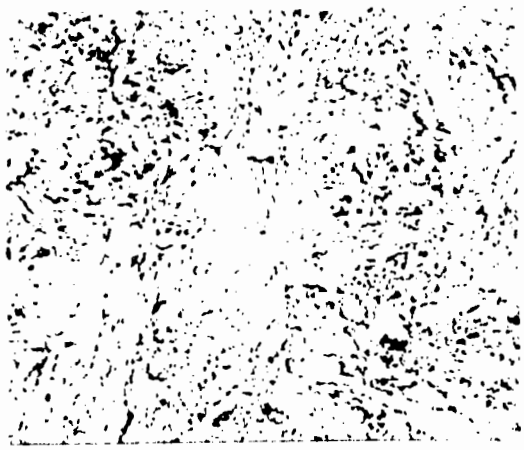
PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	Al	Va	QUENCH TEMP	QUENCH TIME	G.S.
Serial23		.25	1.50	.47	.020	.014	[illegible]	.32	.12	.03	tr	1625	2hrs.	
						American Steel Foundries								

FIGURE 2

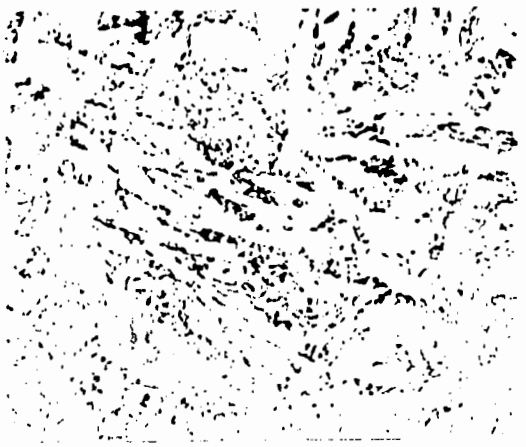
Structure of Final Drive Housing Castings

Macroetched Section of Casting Serial 1 Made by the General Steel Castings Corporation. X1

Macroetched Section of Casting Serial 2B Made by the American Steel Foundries. X1



Serial 1 X1000



Serial 2B X1000

Microstructure at center of castings, etched in picral, showing the extent of free ferrite.