WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/567

Metallurgical Examination of Twelve 1 Inch
Cast Homogeneous Armor Plates of Varying Hardnesses
Manufactured by Lebanon Steel Foundry

BY

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DATE 10 December 1943

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Watertown Arsenal Laboratory

Memorandum Report WAL 710/567

Final Report on Problem B-4.5

10 December 1943

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homogeneous

1. As requested by The Proving Center, Aberdeen (APG 470.5/749, Wtn 470.5/6820), metallurgical examination has been completed on twelve (12) 1 inch cast armor ~~test~~ plates manufactured by Lebanon Steel Foundry. The plates were heat treated similarly except for the final tempering temperatures which were varied to give the hardnesses desired. Two plates were tested in each hardness range and all plates were from heat HE 3498. Ballistic test results are reported in Armor Test Report AD-381. The plates were tested as a part of the large program at The Proving Center on the effect of hardness on ballistic properties. The plates behaved in a manner coincident with the respective hardnesses under the applied ballistic tests. Plates were Q113 to Q124 inclusive.

2. The metallurgical tests conducted indicate the plates to be of satisfactory quality with respect to soundness and heat treated condition. All samples developed the fibrous fracture, even at hardnesses of 341 Brinell. This characteristic is associated with a microstructure of essentially tempered martensite with traces of high temperature transformation products. Charpy V-notch impact tests were conducted on all plates at four temperatures, from room temperature to -70°C. (-94°F.). These values are considered to be representative of essentially the best impact properties that may be expected of cast armor, especially at the low temperatures and are recorded herein for future reference. (See Figures 4 and 5.)

3. Metallurgical examination consisted of the following tests:

   a. Fibre fracture tests.

   b. Macroetch tests.

   c. Brinell hardness determinations.

   d. Chemistry and Jominy hardenability.

   e. Microscopic examination.

   f. Charpy V-notch impact tests at 20°C., -10°C., -40°C., and -70°C.

4. The results of the above tests in detail are presented below.

a. Fibre fracture tests. Samples approximately 8" x 3" in size were notched transversely to the long dimension to a depth of approximately 3/4" on both sides and broken rapidly by the impact of a forge hammer. All plates were completely fibrous with small amounts of lustrous porosity visible in the fractures.

b. Macroetch tests. Results of these tests are shown as Figure 1. The plates are considered to be satisfactory with respect to soundness and segregation for material of this thickness. Considerable variation in solidification pattern is noticeable among the several plates. The dendritic pattern seems to be well diffused in the majority of the plates, particularly Q119, Q122 and Q123.

c. Brinell hardnesses. Brinell hardness determinations were made across the section on samples from each plate. The values reported are the average of three readings equidistantly spaced. The readings reported by the manufacturer are also recorded for purposes of comparison.

Brinell Hardnesses

Plate No.	Reported by Manufacturer	Cross Sectional Values Range	Cross Sectional Values Average
Q113	255-262	248-255	253
Q114	255-262	241-248	246
Q115	269-277	262-262	262
Q116	269-277	262-269	267
Q117	293	285-293	291
Q118	293	277-285	282
Q119	302-311	311-321	314
Q120	302-311	321-321	321
Q121	321-332	321-321	321
Q122	321-332	321-321	321
Q123	340	331-341	334
Q124	340	331-341	338

Hardnesses across the section were uniform in all cases. The values obtained at this arsenal using the tungsten carbide Brinell ball are, in general, somewhat lower than those reported by the manufacturer.

d. Chemistry and Jominy hardenability. Chemical analyses were obtained on plates Q113 and Q117. These results, together with the heat ladle analysis reported by the manufacturer, are given below.

Sample	C	Mn	Si	S	P	Ni	Cr	Mo	V
Q113	.32	.82	.45	.029	.029	.52	.70	.31	.01
Q117	.33	.78	.45	.035	.029	.51	.74	.32	.015
Ladle	.29	.76	.40	.029	.025	.53	.68	.33	--

The results obtained at this arsenal check the ladle analysis reported by the manufacturer as closely as would be expected. This is the typical low alloy nickel-chromium-molybdenum analysis which has been successfully used by Lebanon Steel Foundry during the past year.

Jominy hardenability results were obtained on a standard end-quenched bar from plate Q113. The results are shown in Figure 2. The analysis retains a hardness of Rc 43 at a distance of approximately 12/16 inches from the quenched end. This is equivalent to a plate thickness of 2 inches which will quench out to 400 Brinell hardness at the center in a still water quench. Hardenability, therefore, is adequate for the plate thicknesses involved in this series.

e. Microscopic examination. A specimen from each plate was examined for grain size, extent of decarburization, nonmetallic inclusion distribution and microstructure. All plates except Q115, Q121 and Q123 were of clean steel with small globular nonmetallic inclusions randomly distributed throughout the outer portions of the plate and at the center concentrations of nonmetallic material with a tendency to form a network. (See Figure 3.) These effects are not considered to be serious, however, and apparently resulted from a mold condition rather than a characteristic of the heat of steel.

Decarburization of the plates was not serious, averaging .01" on each face. The grain size of all plates was a uniform A.S.T.M. 5-6.

The microstructures of all plates except Q118 and Q124 were a uniformed tempered martensite with slight traces of high temperature transformation product. (See Figure 3.) Acicularity increased with hardness as expected. Plate Q118, also essentially tempered martensite, showed evidence of the formation of small amounts of bainite on quenching. Plate Q124 shows occasional patches of ferrite and carbide. The microstructures of all plates are considered satisfactory. The small amounts of high temperature transformation products in two of the plates did not either influence the fracture characteristics even at rather high hardnesses or impair the impact properties at low temperatures.

f. Impact tests. Charpy V-notch impact tests were conducted on each plate at four temperatures: +20°C. (+68°F.), -10°C. (+18°F.), -40°C. (-40°F.) and -70°C. (-94°F.). The impact bars were cut from the plate midway between surface and center to avoid unsoundness as much as possible. The results in detail are tabulated as Table I. Plots of impact properties versus hardness and as influenced by temperature are shown as Figure 4. Similarly curves are shown for the individual plates as a function of temperature in Figure 5. The superior performance of this material in the impact test is indicated by the small drop in absorbed energy with temperature down to -40°C. (-40°F.). Such performance is not only a function of heat treated condition but is also affected by steel making practice. It will be observed that at hardnesses above 320 Brinell the impact energy falls off more rapidly with a lowering of temperature. This effect correlates with the inferior shock resistance of this material at higher hardnesses. It has previously been shown in data obtained at this arsenal[1] that steels which retain 25 ft.lbs. impact at -40°F. have satisfactory low temperature ballistic shock properties. This statement has been applied, generally, to the heavier thicknesses of armor at hardnesses up to 260 Brinell. However, it will be seen that this steel retains 25 ft.lbs. impact at -40°F. at hardnesses up to and including 290 Brinell. It will further be observed that all plates above 255 Brinell lose considerably more impact resistance as the temperature is further lowered to -70°C. (-94°F.). This means that no cast armor can be expected to consistently absorb the specified shock test at temperatures in the range -50 to -80°F. This is important to be considered in future cold test programs; low temperature ballistic tests must be conducted at reasonably low temperatures such as may be encountered in combat, within the range -20° to -40°F.

1. W.A. Report 710/534, "Correlation of Metallurgical Properties with the Low Temperature Ballistic Shock Characteristics of 1" to 2" Low Alloy Cast Armor Tested at Camp Shilo" P. V. Riffin.

5. Metallurgical examination indicated satisfactory heat treated conditions in all cases. The material is considered to be of superior quality. Ballistic results, therefore, may be expected to be representative of essentially the best that can be obtained in cast armor at the respective hardnesses.

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TABLE I

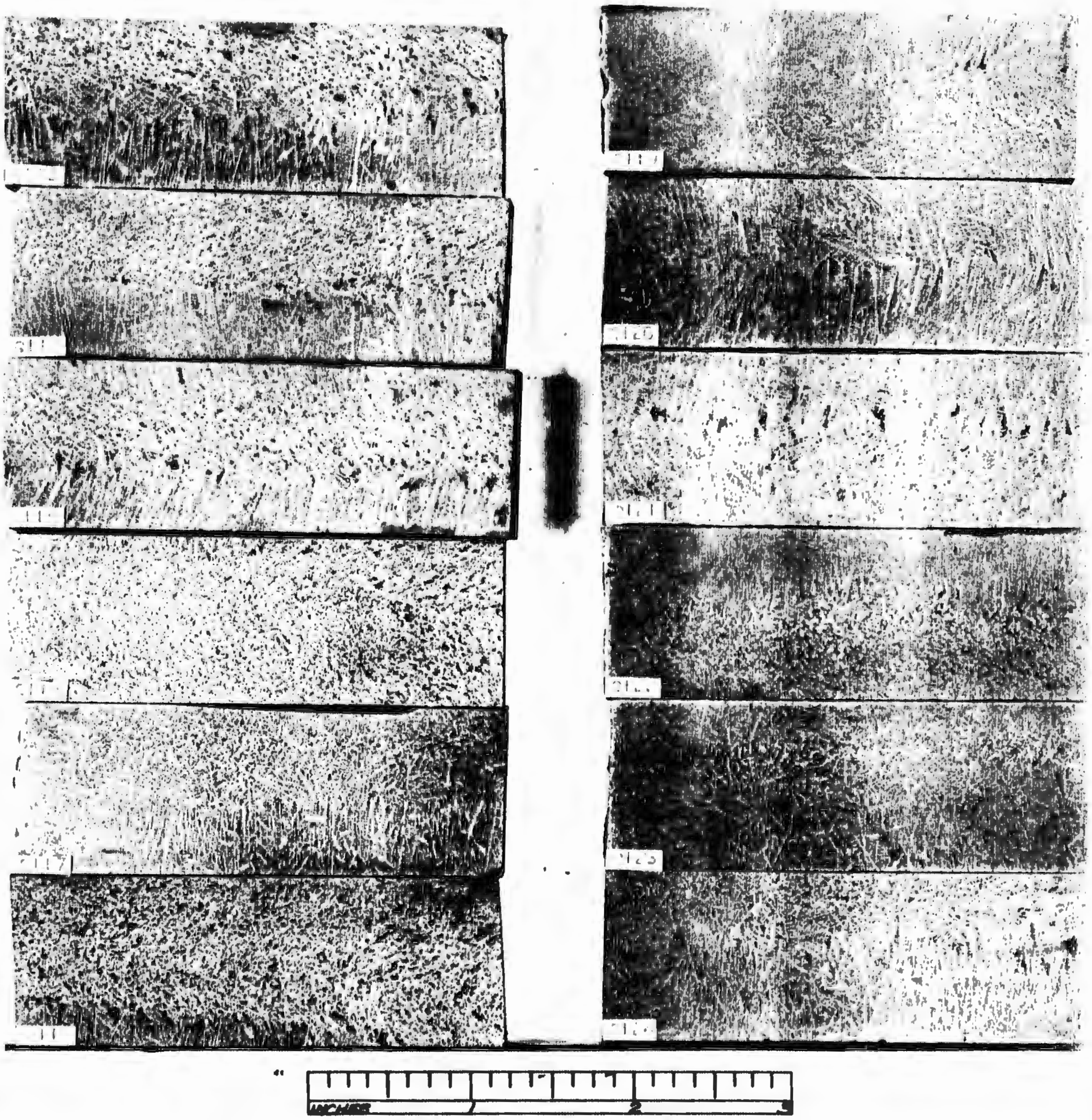
Lebanon Steel Foundry 1 Inch Cast Plates

V-Notch Charpy Impact Results

Plate No.	Brinell Hardness	20° C	Impact Values and Type Fracture -10° C	-40° C	-70° C
Q113	253	45.8 F	39.9 F 37.1 F Ave. 38.5	32.9 Fc 40.5 Fc Ave. 36.7	24.9 Cf
Q114	246	46.0 F	38.9 F 37.3 F Ave. 38.1	40.9 Fc 44.1 F Ave. 42.9	25.2 Cf
Q115	262	39.4 F	31.5 F 32.5 F Ave. 32.0	36.9 Fc 32.9 Fc Ave. 34.9	15.7 Cf
Q116	267	37.2 F	37.4 F 40.4 F Ave. 38.9	27.6 Fc 32.5 Fc Ave. 30.0	15.2 Cf
Q117	291	30.6 F	29.8 F 28.2 F Ave. 29.0	23.4 FC 28.2 Fc Ave. 25.8	14.2 Cfe
Q118	282	35.3 F	34.5 F 35.6 F Ave. 35.0	29.7 Fc 31.4 Fc Ave. 30.5	15.5 Cfe
Q119	314	26.7 F	29.5 F *22.9 F Ave. 26.2	18.7 Cf 19.5 Cf Ave. 19.1	14.5 Cfe
Q120	321	27.9 F	23.2 Fc 24.7 Fc Ave. 23.9	15.5 Cfe 15.6 Cfe Ave. 15.5	13.0 Cfe
Q121	321	28.2 F	24.9 Fc 25.2 Fc Ave. 25.0	19.6 Cf 18.7 Cf Ave. 19.2	11.7 Cfe
Q122	321	25.8 F	20.5 Fc 23.4 Fc Ave. 22.0	16.1 Cfe 18.1 Cfe Ave. 17.1	11.8 Cfe
Q123	334	22.0 F	18.3 Fc 19.4 FC Ave. 18.8	12.9 Cfe 15.0 Cfe Ave. 14.0	7.1 Cfe
Q124	338	20.8 F	17.0 FC 17.4 FC Ave. 17.2	15.5 Cfe 9.8 Cfe Ave. 12.6	7.3 Cfe

*Porosity

F - Fibrous
C - Crystalline
FC - Mixed - fibrous and crystalline
Fc - mixed, predominantly fibrous
Cf - mixed, predominantly crystalline
Cfe - crystalline with fibrous edge.



ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL.

MACROETCHED SECTIONS OF 1" CAST ARMOR OF VARYING HARDNESSES
MANUFACTURED BY LEBANON STEEL FOUNDRY.
6 OCTOBER 1943 WTN.710-2156

Figure 1

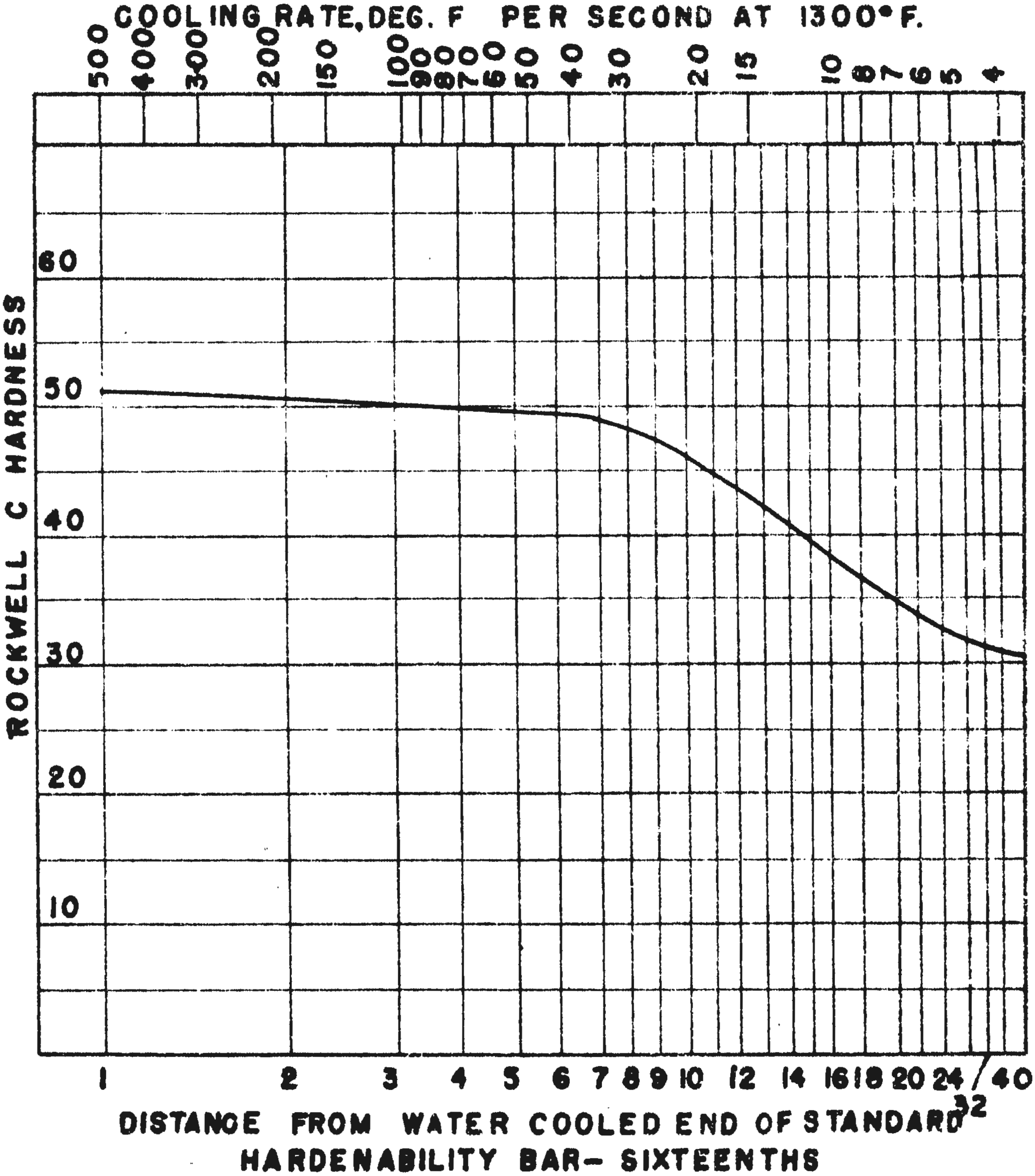


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	V		QUENCH TEMP	TIME	G.S.
Q 113	HE3498	.32	.82	.45	.029	.029	.52	.70	.31	.01		1640°F	2Hrs/	5-6

FIGURE 2

Lebanon Steel Foundry 1 Inch Cast Plates

Microstructures

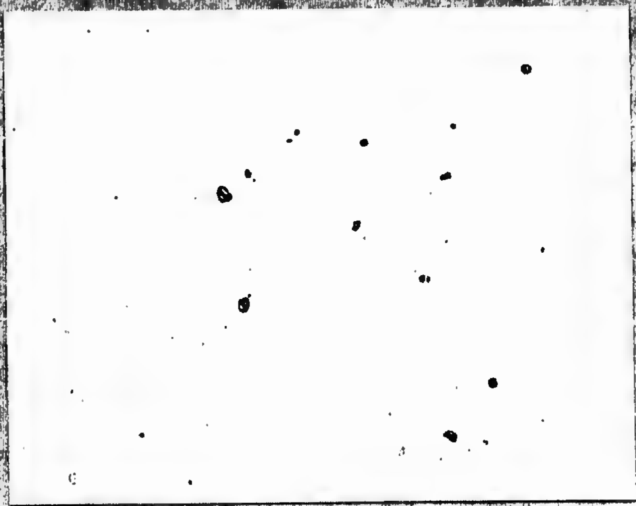
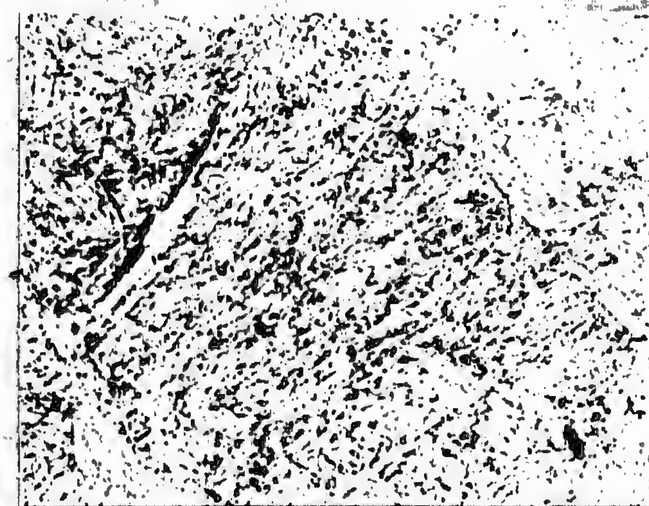


Plate 121. Unetched. Midwall. Typical also of plates Q115, Q123. Center. X10

Tempered martensite. Structure typical of majority of plates. Acicularity more pronounced in plates of higher hardnesses.

X1000 Plate 114 - Picral Etch

X1000 Plate 118 Picral Etch
Tempered martensite with small amounts of intermediate temperature transformation products.



X1000 Plate 124 Picral Etch
Tempered martensite with occasional patches of ferrite.

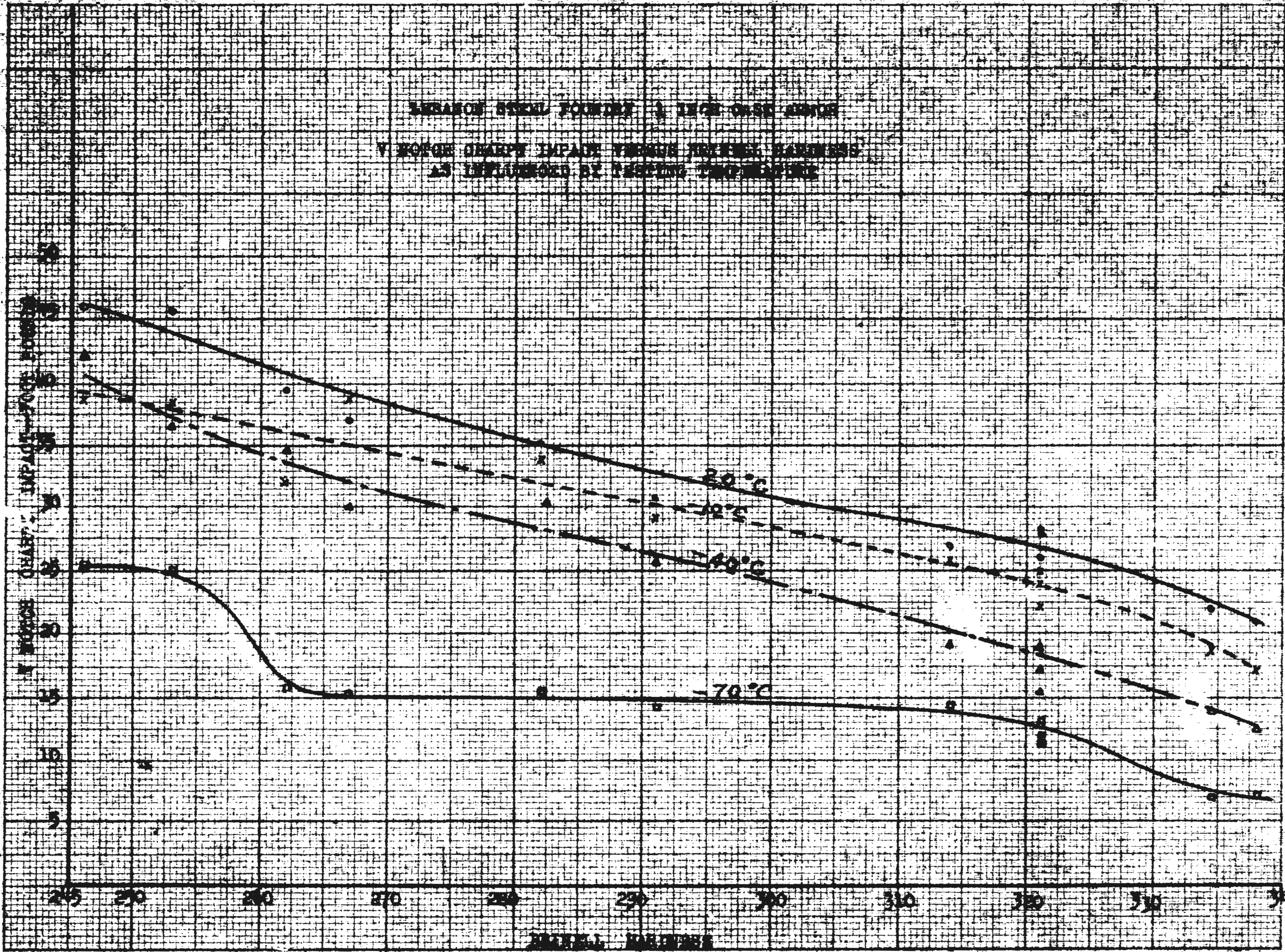

LEBANON STEEL FOUNDRY 1 INCH CAST ARMOR
V NOTCH CHARPY IMPACT VERSUS BRINELL HARDNESS
AS INFLUENCED BY TESTING TEMPERATURE
V NOTCH CHARPY IMPACT—FOOT POUNDS
BRINELL HARDNESS
20°C
-12°C
-40°C
-70°C
5
10
15
20
25
30
35
40
45
50
245
250
260
270
280
290
300
310
320
330
340

FIGURE 4

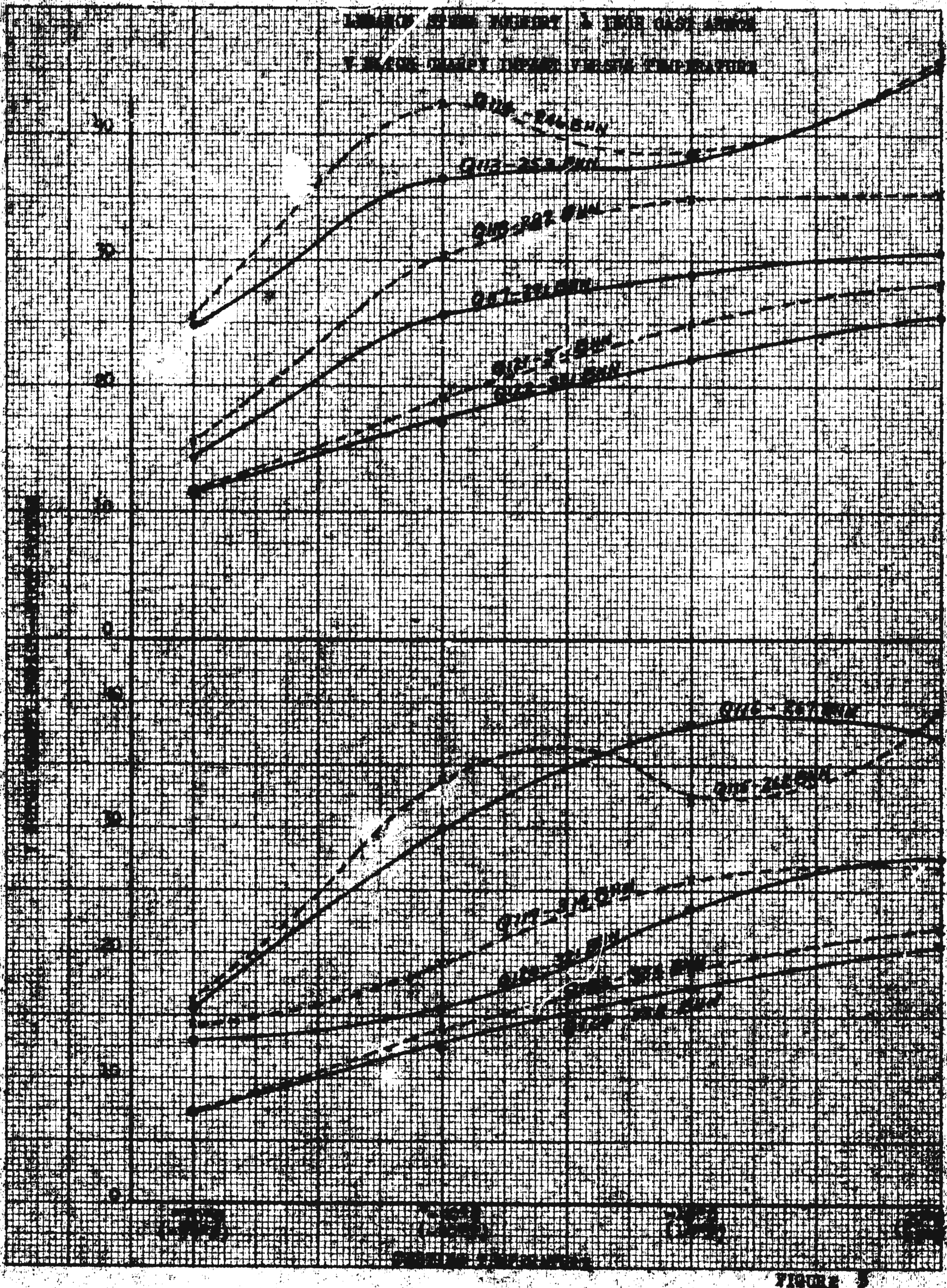


FIGURE 5