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710/583

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/583

Metallurgical Examination of 2½" Rolled Homogeneous Armor Plate

Manufactured by H. Disston and Sons, Inc.

Which Backspalled under the PTP Test

BY

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DATE 26 January 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

Watertown Arsenal Laboratory

Memorandum Report No. WAL 710/583

Final Report on Problem B-4.26

26 January 1944

Metallurgical Examination of 2½" Rolled Homogeneous Armor Plate Manufactured by H. Disston and Sons, Inc. Which Backspalled under the PTP Test

1. Reference basic communication A.P.G. 470.5/3532(r) - Wtn 470.5/7743(r), 22 December 1943, a metallurgical examination has been completed on a sample of the 2½" thick rolled homogeneous armor forwarded from the Ordnance Research Center, Aberdeen Proving Ground. The plate, number 4529-1, was one of two produced by Henry Disston and Sons, Inc. under Contract W-670-ORD-4707. Both plates failed to meet the resistance to penetration and PTP requirements under Specification AXS-488-2(tentative). The subject plate backspalled upon impact of a 90 mm. A.P.C. M82 projectile at an obliquity of 45°, and backspalled on the PTP test with a 90 mm. A.P. M77 at 0° obliquity. The details of the ballistic tests are contained in Aberdeen Proving Ground Report No. A-11233, 2-11 December 1943.

2. The following observations result from the metallurgical examination of the submitted section of the plate:

a. The steel quality, as judged from two fractures, one in a direction perpendicular to the other, is excellent. The steel is free from harmful laminations and evidences no directional properties.

b. The impact properties over the temperature range of +20°C. to -40°C. (+68°F. to -40°F.) are excellent for the hardness level of the subject armor. Heat treating experiments show that the steel has no susceptibility whatsoever to temper brittleness. The ductility of the steel as measured by the tensile test is satisfactory.

c. Macroetch tests in both rolling directions indicate satisfactory cross-rolling and reveal the same freedom from laminations shown by the fracture test.

d. The Jominy hardenability determination showed the steel to possess somewhat insufficient hardenability for the section thickness.

e. The photograph of the back of the plate shows a condition in the backspalled area of round No. 2 which looks similar to the "fish-eyes" caused by hydrogen embrittlement. The examination of the sample forwarded to this arsenal, which was located approximately 6" away from round No. 2 failed to show any signs of brittleness upon tensile, V-notch Charpy impact, and fracture testing. The appearance of the photograph is, of course, insufficient evidence of hydrogen embrittlement. It is recommended that the areas of the plate immediately adjacent to the backspalled regions be subjected to fracture tests to disclose the existence of possible local variations in steel quality.

f. The possibility exists that the small corner sample of the plate examined at this arsenal is not representative of the general quality of the rest of the plate. The tests conducted upon the submitted sample indicate it to be of superior quality with respect to cleanliness, lack of directional properties, ductility, and tensile and impact strength.

g. The questions contained in the basic communication are answered in the discussion at the end of this report.

3. One half of a fracture test sample cut from the corner of the plate nearest the PTP failure was forwarded from the Ordnance Research Center, Aberdeen. The fracture block was broken at the Ordnance Research Center and was rated there as a "B" fracture with respect to steel quality under the standards set forth in AXS-488-2 (Tentative). The portion of the plate forwarded to this arsenal was 5" x 5-1/4" x 2½" in size, and its location on the plate is shown in Figure 1. Impact No. 2 resulted from a 90 mm. A.P. M72 at 0° obliquity and a velocity of 1530 ft/sec., impact No. 10 from a 90 mm. A.P.C. M82 at 45° obliquity and a velocity of 2031 ft/sec., and impact No. 12 from a 90 mm. A.P.C. M82 at 45° obliquity and a velocity of 1956 ft/sec.

The following tests were conducted upon the submitted sample:

a. Chemical analysis.

b. Fracture test for steel quality in a direction perpendicular to the original fracture.

c. Jominy hardenability.

d. Macro-etch tests in both rolling directions.

e. Brinell hardness across the section.

f. Tensile tests.

g. V-notch Charpy impact tests in the as-received condition and reheat-treated conditions.

h. Microscopic examination.

The locations of the various test specimens are indicated in Figure 2.

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

a. Chemical Analysis. The analysis of the steel is the following:

C	Mn	Si	S	P	Ni	Cr	Mo	Cu	V	B	Al
.21	.48	.23	.021	.015	4.53	.12	.26	.17	nil	.0009	.01

This analysis agrees with that reported by the manufacturer on the CAS-2 form contained in Aberdeen Proving Ground Report No. A-11233 except for the element boron. The manufacturer's report contains no reference to boron.

b. Fracture Test. The fractured surface produced at the Ordnance Research Center is shown in Figure 3A. The steel quality is rated as "B"; in agreement with the rating assigned at the Ordnance Research Center. Some short disconnected stringers are visible in the upper portion of the photograph. The fracture is fibrous, indicative of ductile material.

The sample was notched in a direction perpendicular to the original fracture and broken. The small span necessitated notching in at both the top and bottom of the sample as well as the sides, and the application of repeated impact blows to produce fracture of the specimen. The steel quality in the direction perpendicular to the original fracture surface is also rated as "B". The fracture is fibrous and jagged, with a residual dendritic pattern visible, Figure 3B.

The results of the fracture test indicate that the submitted sample is of excellent steel quality with respect to freedom from laminations.

c. Jominy Hardenability. The hardenability test specimen was end-quenched after heating for 1½ hours at 1500°F, the same temperature used by the manufacturer in heat treating the subject armor plate. The Jominy bar retained a hardness in excess of Rc 43 up to 12/16ths of an inch from the water quenched end, see Figure 4, indicating sufficient hardenability to harden plate to 400 BHN in the center up to a thickness of 1.9" in still water and to 2.3" in thickness upon spray quenching. Since the thickness of the subject plate is 2.5", the steel has insufficient hardenability to completely quench harden to martensite using the most drastic quench available. A slight increase in the carbon content would undoubtedly raise the hardenability to a satisfactory level.

d. Macro-etch Tests. Sections parallel to the two fractured surfaces were prepared for hot acid macroetching. Photographs of the etched specimens are shown in Figure 5. The steel is unusually clean and free from segregations. The macrostructure indicates extremely good cross-rolling practice.

Cracks occur at the edge of the specimen taken parallel to the original fracture. This position corresponds to the left edge of the sketch shown in Figure 2, which is one of the plate edges which had been flame cut prior to the final heat treatment. It is believed that these cracks resulted from thermal stresses engendered by flame cutting. These cracks are confined to the plate edges and are not related to the ballistic failures.

Both the fracture and the macroetch tests testify to the high quality of the submitted sample.

e. Brinell Hardness. The Brinell hardness across the section was determined on the specimen cut for microscopic examination. The

consecutive readings from surface to surface were 262, 262, 248, 262, and 255 Brinell. The reading of 248 BHN was in the middle of the cross section. The Brinell hardness of the subject plate is considered satisfactory for the gage. The manufacturer reported the hardness as 269-296 BHN.

f. Tensile Tests. The tensile properties determined from the two .357" tensile bars illustrated in Figure 2 are as follows:

Specimen	Yield Strength 0.1% set p.s.i.	Tensile Strength p.s.i.	% Elongation	% Red. of Area	Fracture
1	116,250	129,500	17.1	61.7	cup and cone
2	115,000	127,500	14.3	62.7	incomplete cup and cone

The above values are indicative of good quality steel at the hardness level involved. Referring back to Figure 1, which is the photograph of the back of the plate after ballistic testing, it is noted that the fractured surface of the back spalled area of round No. 2 contains bright patches very similar in appearance to those resulting from hydrogen flakes. This region is located only six inches away from the sample forwarded to this arsenal for examination. The tensile tests were conducted to detect any possible adverse effect of hydrogen upon the ductility and the appearance of the fracture of the tensile bars. The results of the tensile test indicate that the submitted sample is free from hydrogen flakes.

g. V-notch Charpy Impact Tests. To check the impact strength of the steel and the susceptibility to temper brittleness, four V-notch Charpy impact bars were machined from the steel in the as-received condition, and from each of two 2½x2½x1" pieces which were reheat-treated. Both pieces were heated to 1500°F., held at temperature for 1½ hours and water quenched. The section size was sufficiently small to insure complete transformation to martensite upon quenching. Both were tempered for 2 hours at 1150°F., one being water quenched from the tempering temperature, and the other furnace cooled. The furnace cooling was accomplished by shutting down the tempering furnace and allowing the specimen to cool down with the furnace overnight.

The hardness in the as-received condition was 248-262 Brinell, and after reheat-treatment it was 269-277 BHN.

The impact data are as follows:

Specimen No.	Heat Treatment	Temperature of Impact Test °C.	Temperature of Impact Test °F.	Impact Strength Ft.Lbs.	Fracture
1	As Received	+20	+68	54.7	Fibrous
2	" "	+20	+68	60.0	"
3	" "	-40	-40	58.4	"
4	" "	-40	-40	57.8	"
A1	Water Quenched from Draw	+20	+68	54.2	Fibrous
A2	"	+20	+68	57.1	"
A3	"	-40	-40	57.1	"
A4	"	-40	-40	54.7	"
B1	Furnace Cooled from Draw	+20	+68	56.2	Fibrous
B2	"	+20	+68	58.2	"
B3	"	-40	-40	58.2	"
B4	"	-40	-40	57.3	"

An impact strength of approximately 60 ft.lbs. over the temperature range of +20°C. to -40°C. (+68°F. to -40°F.) represents excellent properties for rolled armor at a hardness of 260-270 Brinell. The high impact strength of the furnace cooled sample demonstrates that the subject steel has no susceptibility towards temper brittleness.

4. Microscopic Examination. Microscopic examination of the cross section of the plate in the unetched condition reveals only small scattered nonmetallic inclusions and no laminations, Figure 3C. The microstructure consists of tempered martensite with some ferrite and pearlite which had formed at high temperature due to the hardenability being insufficient to quench out a 2½" thick section, Figure 3D.

5. The results of the metallurgical examination outlined in paragraph 3 indicate the submitted sample to be of superior quality. Upon the basis of these tests, no explanation can be offered for the occurrence of backspalling upon ballistic testing except that the quality of the small specimen examined at this arsenal may not be representative of that of the ballistically impacted areas. Plates of heavy gage are made from large portions of the original ingots, and thus may contain wide variations in steel quality depending upon segregations within the ingots. Fracture tests made in the regions immediately adjacent to the backspalled regions may disclose local variations in steel quality.

From the appearance of the photograph of the back of the plate, it was suspected that hydrogen embrittlement might have been a factor responsible for back spalling, but the tests conducted upon the submitted sample revealed no traces of embrittlement of any type.

6 The basic letter contained two questions regarding the Fracture Test for Steel Quality. These questions are:

a. "Is the fracture test, as set forth in AXS 488-2 (Tentative), a measure of steel quality, or solely one for the determination of insufficient discard from the top and bottom of the ingot?"

b. "Can the fracture test on the heat, treated product be used as a measure of overall steel quality, besides the features of fiber or crystallinity, using only the present standards as shown for determining steel quality on the "as-rolled" plate?"

The answer to question "a." is that the fracture test is both a measure of steel quality and the determination of insufficient discard from the top and bottom of the ingot. If the ingot contained large amounts of nonmetallics distributed throughout, the fracture test is capable of disclosing this condition and rejecting all plates made from that ingot if the steel quality is sufficiently poor.

The answer to question "b." is partly answered by paragraph F-4b(3) of Specification AXS 488 (Rev. 2) of 15 November 1943, page 7, which reads as follows:

"Preparation and fracturing of specimens. The specimens shall be hardened and tempered to a hardness not exceeding 300 Brinell. After this heat-treatment, the specimens shall be nicked perpendicularly to and at the center of the longitudinal axis (leaving a maximum area to be fractured), and broken slowly in a press."

The fracture test must be conducted upon the heat treated plate and not upon the "as-rolled" plate mentioned in question "b.". The term "as-rolled" is understood to mean the condition resulting from hot rolling and air cooling without subsequent heat treatment. In the "as-rolled" condition the steel will fracture in a brittle manner giving a crystalline fracture. When this occurs, the shelving opened up when laminated, heat treated steel is fractured, does not develop. The path of the fracture of a brittle material will not be greatly influenced by nonmetallic laminations while in a heat treated, ductile material the path of the fracture will be deviated by the laminations, resulting in the revelation of the distribution and amount of nonmetallics in the plate.

The fracture test, if properly applied to the heat treated product, is a measure of overall steel quality.

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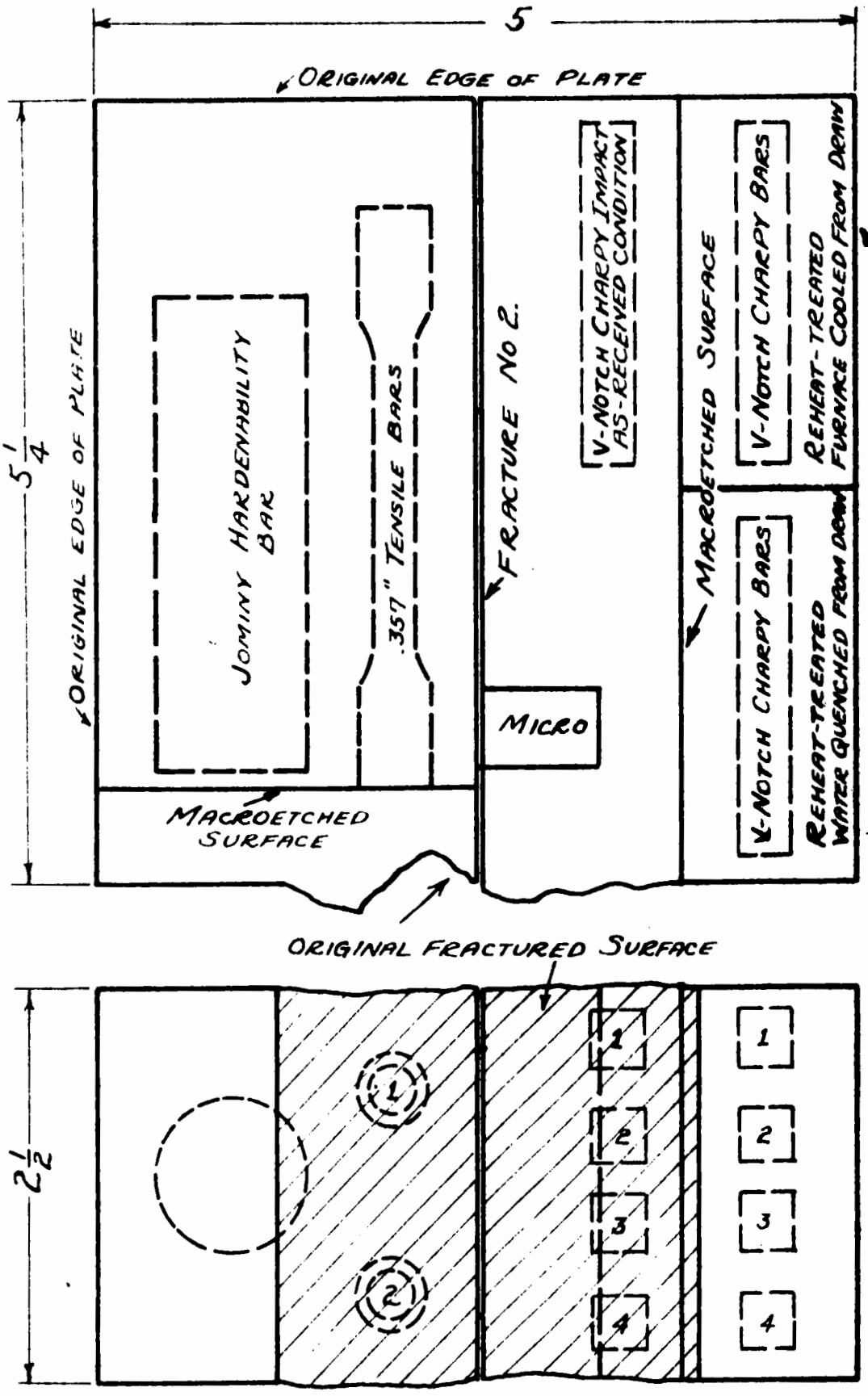
APPROVED:

N. A. MATTHEWS
Major, Ord. Dept.

96465 12-9-43 | ABERDEEN PROVING GROUND | ORDNANCE DEPT.

Development of 2½" Rolled Homogeneous Armor, submitted by Henry Disston & Sons, Heat #4529, Plate #1. Rear view.

FIGURE 1



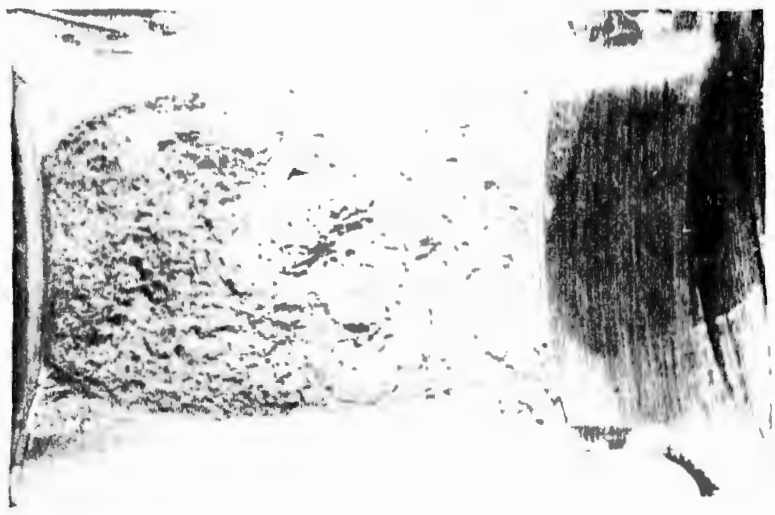
LAYOUT OF SPECIMENS CUT FROM SAMPLE OF DISSTON PLATE NO. 4529-1.

FIGURE 2

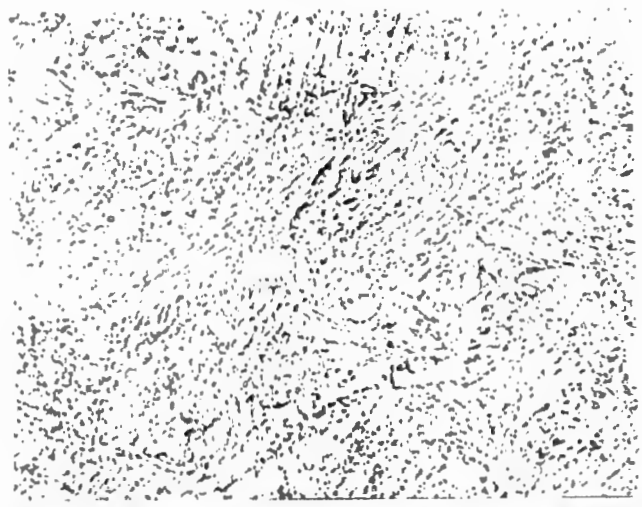
A.H. 1-12-44

Diston Plate No. 1529-1

Original fractured surface. -A- X1
Fibrous fracture. Steel quality - B.



Fracture No. 2. Perpendicular to original fractured surface. -B- X1
Fibrous fracture. Steel quality - B.



Unetched -C- X100
Clean steel. Small nonmetallic inclusions. No laminations.

Picral Etch -D- X1000
Incompletely quench hardened structure. Martite tempered pearlite and

FIGURE 3

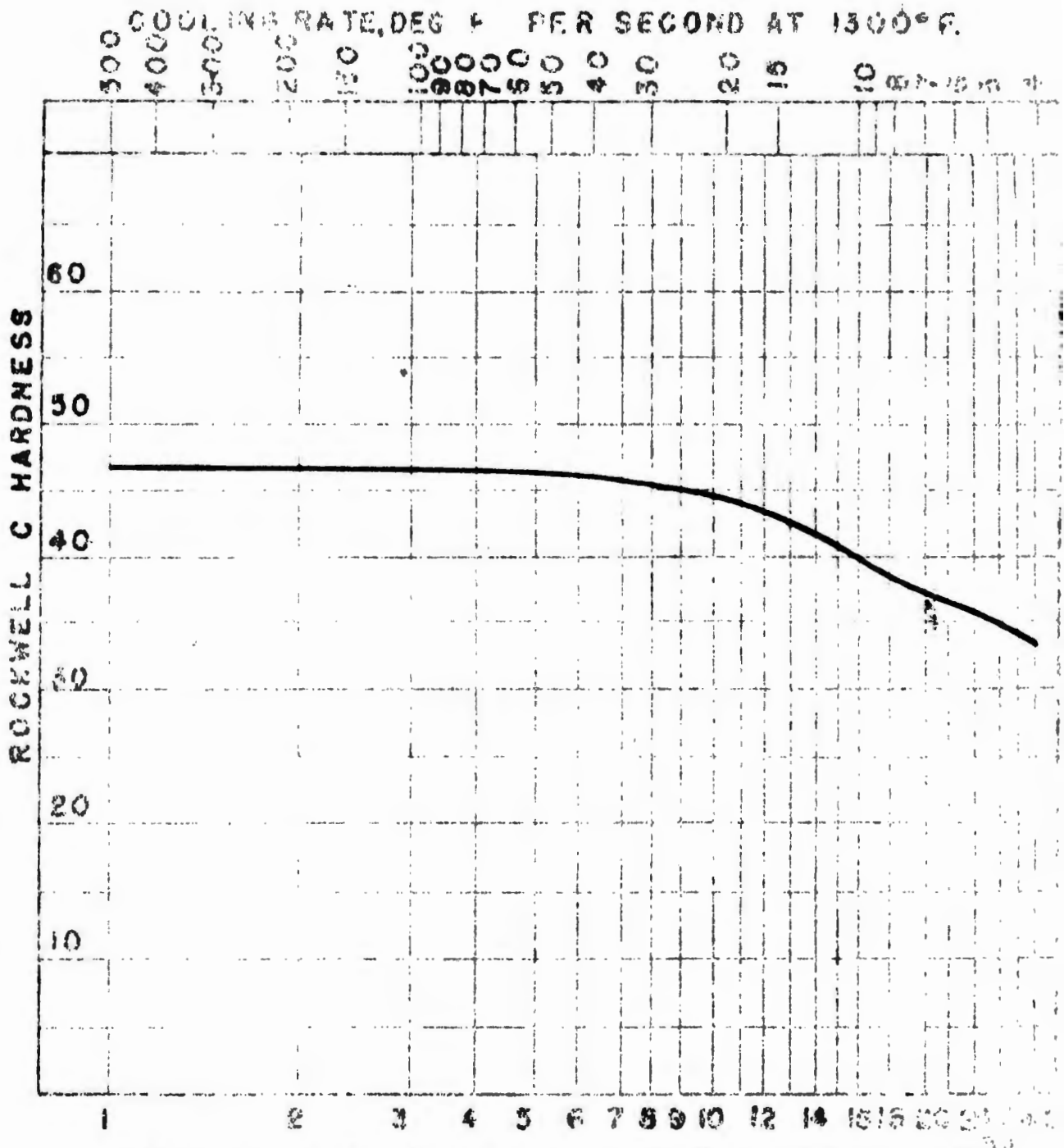
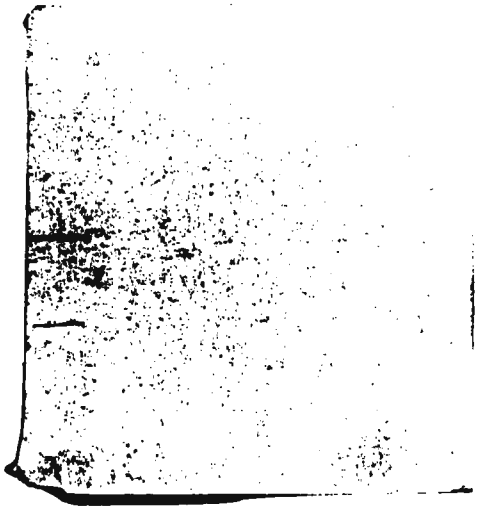


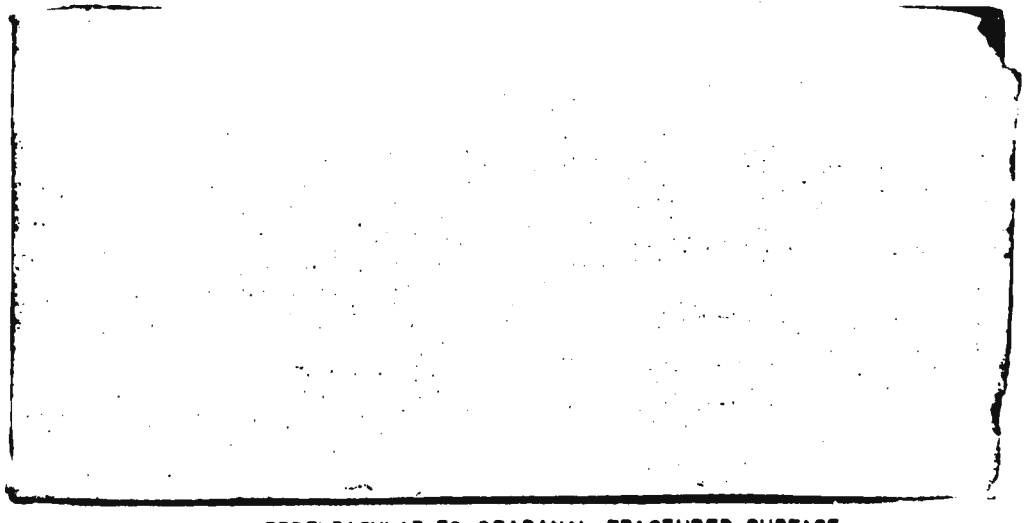
PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	B	CU	AL	QUENCH TEMP	QUENCH TIME
1	4529	.21	.48	.23	.021	.015	4.53	.12	.26	.0009	.17	.01	1500°	1½ HRS.

2½" ROLLED HOMOGENEOUS ARMOR.
HENRY DISSTON & SONS.

CRACKS IN FLAME CUT PLATE EDGE



SECTION PARALLEL TO ORIGINAL FRACTURED SURFACE



SECTION PERPENDICULAR TO ORIGINAL FRACTURED SURFACE

ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL

MACROETCHED SECTIONS OF 2½" HOMOGENEOUS ROLLED PLATE MFD. BY HENRY DISSTON & SONC, INC. HEAT 4529 MAG. X 1
7 JANUARY 1944 WTN.710-2242

FIGURE