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REPORT

NO. WAL 710/863

O.O. Project No. TB4-150F

HEAVY WROUGHT ARMOR

Metallurgical Evaluation of Commercially Produced Heavy Wrought Armor to Improve the Specification Requirements

AD-A954 885

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BY

P. V. Riffin
Metallurgist

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DATE 2 February 1946

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TITLE

HEAVY WROUGHT ARMOR

Metallurgical Evaluation of Commercially Produced Heavy Wrought Armor to Improve the Specification Requirements

Report Number: WAL 710/863

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WATERTOWN ARSENAL LABORATORY

Authorized by: ORDTB

2 February 1948

O.O. Project Number: TB4-150F
Report Number: WAL 710/863
Priority: 2C
Title of O.O. Project: Armor, Steel, Wrought, Over 4"
WAL Project No.: 8.11-G

TITLE

HEAVY WROUGHT ARMOR

Metallurgical Evaluation of Commercially Produced
Heavy Wrought Armor to Improve the Specification Requirements

OBJECT

1. To obtain metallurgical information on heavy wrought homogeneous armor (4" to 12" thick) to justify and improve Army specification requirements for this class of armor.

2. To determine the metallurgical properties of twelve samples of commercially produced heavy wrought (Navy Class B) armor.

SUMMARY

Metallurgical examination of twelve samples of Navy Class B armor (wrought homogeneous) ranging in thickness from 6 to 13-1/2" indicate that armor can be produced commercially which will comply with the requirements of U. S. Army Tentative Specification AXS-1803 Armor Plate: Steel, Wrought, Homogeneous (4" to 12" inclusive). The results of the investigation indicated the necessity for revising slightly downward the notched bar impact requirements of the 1 November 1946 draft of the above specification. It was found that one 7" plate, one 10-1/2" plate, and two 13-1/2" plates failed to meet the revised impact requirements of the Tentative Specification. The plates were not made for acceptance under the above specification. Therefore it is expected that much greater success will be attained in meeting the requirements under the more favorable conditions of procurement for compliance with the subject specification.

CONCLUSIONS

1. Heavy wrought homogeneous armor of the type manufactured for the Navy (Class B armor) is capable of meeting the requirements of the 1 December 1947 draft of the specification for "Armor Plate: Steel, Wrought, Homogeneous (4" to 12" inclusive)".

2. As a result of this study, it was necessary to modify the notched bar impact requirements of the specification, compare the requirements of the 1 November 1946 draft to those of the 1 December 1947 draft, Table IV.

3. The high carbon content (0.40%) and the excessive laminations observed in a few of the plates decrease their desirability from a welding standpoint.

4. The macroetch test was found to be inadequate for evaluating steel soundness when used alone although it is useful in supplementing the results of the fracture test.

P. V. Riffin
Metallurgist

APPROVED:

P. N. GILLON
Lt. Col., Ord. Dept.
Director of Laboratory

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INTRODUCTION

In the latter stages of World War II, the Ordnance Department expressed the need for specifications covering heavy gage homogeneous armor (over 4" thick) and the Office, Chief of Ordnance - Detroit requested[1] that Watertown Arsenal recommend metallurgical requirements for this class of armor. Initially, emphasis was placed on requirements for heavy cast armor and this has resulted in the formulation of Specification AXS-1013, Rev. 1, dated 26 November 1945 covering cast homogeneous armor 4" to 12" in thickness. A proposed specification for heavy wrought armor was written at this arsenal in April 1945, but lack of procurement of this type of armor at that time mitigated the need for a specification to cover this class of armor.

Late in 1946, the project was revived when the Office, Chief of Ordnance considered procurement of heavy wrought armor for experimental purposes. At that time very little information was available regarding the ballistic performance against Army type projectile attack or pertinent metallurgical characteristics of this class of armor. Consequently, the specification was quite similar to the one written in 1945 with some revision in the tables based on the results obtained in the studies of heavy cast armor[2] and a few heavy wrought armor plates.[3]

In view of the lack of adequate test projectiles and the paucity of information regarding the ballistic performance of heavy wrought armor against Army type projectiles, it was considered undesirable to include ballistic tests in the specification until such time as their evaluation has been made and necessity demonstrated. In other thicknesses of armor, it has been demonstrated consistently that the ballistic performance is closely related to the results obtained in metallurgical control tests. Therefore the specification contained significant mechanical tests including hardness or tensile tests, fracture tests for steel soundness, and V-notch Charpy impact tests. Minimum cross-sectional Brinell hardness values were required as a function

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[1]Letter file No. OO 400.114/Wtn. Ars. (20 Oct. 1944)

[2]A. Hurlich, "Development of Notched Bar Impact Requirements for Heavy Cast Armor 4" to 12" in Thickness". Watertown Arsenal Laboratory Report No. WAL 710/792, dated 19 November 1945

[3]P. V. Riffin, "Correlation of Metallurgical and Ballistic Properties of 8" Thick Forged and Cast Homogeneous Armor Plates Ballistically Tested with the 90 mm HVAP T44 Projectile". Watertown Arsenal Laboratory Report No. WAL 710/840, dated 9 January 1947.

of the thickness. Minimum V-notch Charpy impact values as a function of the hardness were required in tests conducted at one inch below the surface and at the center of the cross section at a temperature of -40°F.

At a meeting between representatives of the Ordnance Department and several heavy wrought armor producers which was held on 14 November 1946,[1] the proposed specification was discussed. The main objection to the specification centered around the impact test requirement, and the manufacturers were reluctant to accept this requirement without having a significant amount of data. This investigation is a result of the recommendation at the subject meeting in which it was decided that Watertown Arsenal obtain some commercially produced heavy wrought armor samples made by several manufacturers to insure that the values required in the mechanical tests can be obtained. The following report contains information obtained on Class B armor, obtained from the Naval Proving Ground, which has been produced by three manufacturers in four thickness ranges. The complete list of plates studied is as follows:

Plate No.	Wtn. No.	Thickness	Manufacturer
53E421-A3	1	6"	A
TT896	2	6"	B
10650-1	3	6"	C
55G435-A1	4	7-1/4"	A
DD661	5	7-1/8"	B
12762	6	7-1/8"	C
31E624-A1	7	10-1/4"	A
TT315	8	10-1/2"	B
10882	9	10-3/4"	C
34E556-A1	10	13-1/8"	A
TT613	11	13-3/8"	B
12102	12	13-3/4"	C

TEST PROCEDURE

In order to evaluate the metallurgical properties of the twelve (12) armor samples, the following tests were made:

1. Fracture tests for steel soundness and fibre. The fracture test specimens and set-up for breaking them is shown in Figure 1. The fractures were made by dropping a 5000 lb. skull crusher a distance of 50 ft. The fractures were rated for both soundness and fibre.

2. Macroetch tests. Longitudinal and transverse slices were cut in planes perpendicular to the plate surface and examined after etching one hour in hot hydrochloric acid (at 160°F.)

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1. Minutes of the meeting are inclosed in Appendix A.

3. Hardness tests. Brinell hardness tests were taken every 1" along the cross section of each plate.

4. Tensile tests. The tests were made with 0.357" diameter test bars. Tensile test specimens were taken 1" below the surface and at the center of the cross-section of the plates in both longitudinal and transverse directions.

5. V-notch Charpy impact tests. Tests were made on standard bars notched with a carbide tipped milling cutter.[1] This technique forms a very accurate and consistent radius at the root of the notch without polishing. All bars were broken at -40°F after being held at temperature at least 15 minutes. It has been found[2] that the time between removal from the cooling and breaking the bar must be less than 5 seconds to prevent a significant heating of the impact test specimen.

6. Microscopic examination. The structure at 1" below the surface and at the center of the plates was examined. The presence of non-metallic inclusions causing the severe laminations in some of the plates was investigated at 100X with a light picral etch. The grain size was determined at 100X with the temper brittleness etchant[3] and with Vilella's reagent.

The microstructure and presence of the temper brittleness constituent were investigated at 1000X using picral and the Zephiran chloride etch respectively.

DATA AND DISCUSSION

Summary of Results in Tables and Figures

Table I - Chemical Analyses of the Heavy Wrought Armor Plates

Table II - Hardness, Tensile, and Fracture Results in the Heavy Wrought Armor Plates

Table III - V-notch Charpy Impact Properties

Tables IV & V - Revised Specification Requirements of V-notch Charpy Impact Values

Table VI - Microscopic Grain Size Values

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[1] S. E. Siemen, "Method of Notching Impact Test Specimens", ASTM Bulletin, March 1946, page 45.

[2] D. E. Driscoll, Unpublished investigation in which the effect of variations in the procedure for making V-notch Charpy impact tests were studied.

[3] J. B. Cohen, A. Hurlich, and M. Jacobson: "A Metallographic Etchant to Reveal Temper Brittleness in Steel", Transactions, American Society for Metals, Vol. 39, 1947, p. 109-136.

Figure 1 - Sketch Showing Location of Samples and Fracture Test Set Up

Figures 2, 4, 6, 9, 11, 15, 22 - Photographs of Selected Fractures

Figures 3, 5, 7, 8, 10, 12-14, 16-21, 23-26 - Macroetched Cross-Section of the Plates in the Longitudinal and Transverse Directions

Figure 27 - Graphical Evaluation of the Impact Data

Figure 28 - Typical Non-metallic Segregations in Selected Plates

Figure 29 - Comparison of Grain Size in Plate #9

Figures 30-33 - Microstructure at 1" Below Surface and at the Center of All the Plates

Chemical Composition

The compositions employed by the three companies were essentially similar, being basically low manganese, 4% nickel, 2% chromium steels. The molybdenum varied from residual to .50%. Four plates contained vanadium.

The carbon content of three plates was on the high side but all except plate #3 satisfied the requirements that a government check analysis be not over .40%. The high carbon however makes these plates more difficult to weld.

Steel Soundness

Fracture tests for steel soundness (See Table II and Photographs) show that plate #1 (6" - Company A) and plate #8 (10-1/2" - Company B) were subject to rejection because of excessive laminations.

Macroetch tests for evaluating steel soundness have been considered in view of the testing difficulties encountered in making fracture tests. Tests were obtained in both the longitudinal and transverse directions (See Photographs), and the results were compared with those of the fracture test for steel soundness. (See Table II). The plates which did not exhibit any severe etched out segregations in the macrostructure were also of acceptable quality in the fracture test. The presence of severe segregations as revealed by macroetch tests, however, was not always accompanied by severe laminations in the fracture test. An examination of the non-metallic inclusions in the microstructure helps explain this inconsistency. The segregations of non-metallics in plates #8 and #9 (See Figure 28) were quite different. Plate #8 contained a narrow band of inclusions which were sufficiently continuous to cause a separation in the fracture test whereas plate #9 contained a wide band of short discontinuous inclusions which were etched out in the form of a dark segregation but were not sufficiently continuous to form a lamination in the fracture test.

The extent and continuity of non-metallic inclusions cannot be determined by studying a single plane in the macroetch test. It is considered desirable to supplement the results in the fracture test by examining the macroetched structure, but not employ the macroetch test as an independent control test for steel soundness in the final gage.

Impact Properties

The results of the V-notch Charpy impact test are shown in Table III, the revised specification requirements are shown in Tables IV and V, and a graphical comparison of the two are shown in Figure 27. The results of individual tests are listed in Table II of Appendix B.

Eight out of the twelve plates exhibited impact values satisfying the specification requirements at both 1" below the surface and at the center. Of the remaining four plates, three exhibited satisfactory values at 1" below the surface.

In the case of the four plates subject to rejection, six additional tests were made in accordance with the specification allowing a retest based on the average of 8 values. The results did not change the ratings on these two plates although two of the plates came within one ft.lb. of passing the requirement for the average of 8 tests.

These results may be summarized as follows:

		Tests at 1" below the Surface No. Failed		Tests at Center No. Failed	
Thickness Range-In.	No. of Plates Tested	Ave. of 2 tests	Ave. of 8 tests	Ave. of 2 tests	Ave. of 8 tests
6-9	6	0	--	1	1
9-13	6	1	1	3	3

Under the specification, the manufacturer would have additional opportunities of meeting this requirement by reheat-treating the plates subject to rejection. No reheat-treating studies were attempted at this arsenal because the precise conditions prevailing during the commercial heat treatment of this armor were unknown.

At first glance, the impact requirements appear to be very severe especially for the thicker sections. It must be considered, however, that two of the four failed plates came within one ft.lbs. of passing. Yet the plates were not made under the subject specification. It is expected that manufacturers will be able to pass the proposed specification requirements much more readily when they make armor specifically to meet the requirements set up for this material.

The impact values obtained in steel heat treated to a tempered martensitic microstructure are shown in Figure 27. The specification requirements were made considerably lower than these values because of the metallurgical limitations which prevent the securing of optimum toughness in steel heat treated in heavy sections. Improving the toughness in heavy armor to these optimum values will have to await the solution of the problem of obtaining tempered martensite in heavy sections free from temper embrittlement. At present, difficulties are encountered because, when the alloy content is increased to obtain martensite in heavy sections, the material becomes temper brittle at the cooling rates encountered during water quenching these sections from the tempering temperature. Consequently it has been necessary to compromise by lowering the hardness to a point at which the minimum degree of toughness needed for ballistic performance is reached.

The fibre fracture test was not used in the proposed specification because of the inability to make heavy armor of sufficient toughness that it would exhibit fractures which are completely fibrous when heat treated in large plates. The ratings were obtained on the steel soundness fracture bars for information. The results as listed in Table II show that only plates #2 (6" - Company B) and #3 (6" - Company C) were fibrous or close to it, indicating the difficulty of employing this test in the specification for heavy armor at the present time. Acceptance based on a partially crystalline fracture is unsatisfactory because of the wide variation possible in a specific material and the attendant difficulties of rating a fracture which is partially cyrstalline.

Hardness and Tensile Tests

The specification requires either the cross-sectional hardness or tensile strength (choice of test is at the discretion of the manufacturer) to be above a specified value depending upon the thickness. The results listed in Table II show that all plates were above the hardness specified. A comparison of the results of the tensile and hardness tests indicates fairly good agreement. It appears, however, that the hardness test yields more consistent results, and in view of the ease with which it is made it is considered a preferable test to use. The complete results are listed in Table I of Appendix B.

Microscopic Examination

The microstructure was examined in order to determine the cause of the deficiencies brought out by the other tests. The grain size, non-metallic inclusions, microconstituents, and presence of temper embrittlement were studied. Typical segregations of non-metallic inclusions responsible for the laminations in plates #8 and #9 are shown in Figure 28. The friable alumina type inclusions of plate #8 resulted in severe laminations whereas the cloud of sulfide and silicate inclusions of plate #9 showed up in the macroetched structure but did not open up to any extent in the fracture test.

The grain size was measured after etching in the Zephiran chloride reagent of Cohen et al[1] and in Vilella's reagent. In this group of samples the grain size was revealed more accurately by the Zephiran chloride reagent than by Vilella's reagent. The grain size of the twelve (12) plates varied considerably, many of them being very coarse grained (See Table IV). It was not possible, however, to correlate the results with toughness as determined by impact tests. Examination of the microconstituents (Figures 30-33) reveals acicular constituents indicative of tempered bainites in most of the plates as well as the uniformly spheroidized structure of tempered martensite. These non-martensite constituents are considered to be responsible, at least in part, for the low impact energy observed in several of the plates. The effect of temper embrittlement in lowering the toughness was not determined in view of the extensive additional testing which would be required, but its presence was ascertained qualitatively in all except plate #1 by the temper brittleness etchant referred to above.

GENERAL CONSIDERATIONS

The tests employed in the proposed heavy wrought armor specification are considered to be very effective in evaluating this class of armor. Hardness is considered to be of prime importance since this factor correlates very well with resistance to penetration by undermatching projectiles. Some degree of toughness is required in the above type of attack as well as in attack by larger caliber projectiles in order to prevent excessive cracking and back spalling in the armor. The present trend of increasing muzzle velocity of projectiles which is sometimes accompanied by a decrease in the caliber of the penetrating element (in the HVAP projectiles) emphasizes the importance of increasing the hardness of armor. In the future it may be necessary to sacrifice the toughness still further in order to obtain the increase in hardness.

Although ballistic tests have been conducted on the subject plates by the Navy Department they were not discussed because the tests were made with matching or overmatching projectiles which are not considered to be pertinent to Army service conditions. It is expected that these or similar plates will be subjected to ballistic tests by undermatching projectiles in the near future.

The fact that the impact values in most of the plates greatly exceeded the specified values indicates that the inferior values obtained in a few of the plates can be improved considerably. It is felt that proper selection of the composition and heat treating cycles with emphasis on an efficient quench following both the austenitizing and tempering cycles will lead to a marked improvement in the impact values.

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[1]See reference 3, page 5.

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Manufacturer	Code
Bethlehem Steel Co.	A
Carnegie-Illinois Steel Corp.	B
The Midvale Co.	C

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TABLE I

Chemical Analyses of the Heavy Wrought Armor Plates

Plate No.	Mfgr.	Thickness Inches	Tested By	C	Mn	Si	S	P	Ni	Cr	Mo	V	Al	Cu
1	A	6	Mfgr.	.34	.31	.07	.018	.018	3.85	2.04	.47	.19	--	--
			Wtn.	33	.29	.07	.018	.019	3.88	2.12	.47	.21	.05	.115
2	B	6	Mfgr.	.30	.62	.23	.023	.016	3.68	1.30	.42	.17	--	--
			Wtn.	.29	.68	.22	.018	.017	3.78	1.37	.47	.18	.01	.07
3	C	6	Mfgr.	.47	.22	.07	.025	.017	3.18	1.28	.25			
			Wtn.	.41	.20	.03	.024	.018	3.21	1.24	.29	--	.01	.19
4	A	7-1/4	Mfgr.	.28	.30	.11	.012	.017	3 66	1.98	.35			
			Wtn.	.33	.30	.06	.018	.016	3.80	2.06	.34	--	.01	.17
5	B	7-1/8	Mfgr.	No	Data	Available								
			Wtn.	.40	.23	.06	.025	.018	3.45	1.70	.02		.03	.04
6	C	7-1/8	Mfgr.	.29	.34	.07	.022	.030	3.04	1.85	.27	--	.03	.04
			Wtn.	.33	.37	.08	.019	.029	3.01	1.89	.23	--	.035	.14
7	A	10-1/4	Mfgr.	.32	.28	.09	.018	.016	3.96	2.00	.38	.16		
			Wtn.	.31	.29	.09	.021	.017	4.03	2.10	.46	.15	.02	.14
8	B	10-1/2	Mfgr.	.31	.24	.07	.020	.013	3.86	2.14				
			Wtn.	.34	.23	.03	.019	.014	3.80	2.17	.08	--	.01	.08
9	C	10-3/4	Mfgr.	.34	.35	.09	.023	.022	3.37	1.98	.24			
			Wtn.	.33	.37	.08	.026	.019	3.31	1.97	.25	--	.03	.185
10	A	13-1/8	Mfgr.	.38	.30	.07	.022	.017	3.91	2.19	.50	.20		
			Wtn.	.35	.30	.06	.021	.019	3.88	2.30	.50	.18	.01	.24
11	B	13-3/8	Mfgr.	.31	.21	.08	.020	.014	3.71	2.07				
			Wtn.	.32	.20	.08	.019	.013	3.78	2.10	.09	--	.01	.09
12	C	13-3/4	Mfgr.	.30	.28	.06	.025	.024	3.61	1.87	.29			
			Wtn.	.33	.31	.07	.046	.025	3.56	1.87	.26	--	.02	.13

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Hardness.

Wtn. Plate No.	Mfgr.	Plate No.	Thickness	Average Cross-Sec. BHN	Tensile Properties Longitudinal - 1" Below Surface: Y.S. psi 0.1% Offset	T.S. psi	Elong. %	R.A. %	Long… Y.S… 0.1…
1	A	53E421-A3	6	250	82,500	116,000	22.9	72.3	9
2	B	TT896	6	285	110,000	132,000	20.7	67.3	11
3	C	10650-1	6	266	93,100	12[illegible],400	19.3	59.8	9
4	A	55G435-A1	7-1/4	260	99,500	127,500	20.7	66.7	9
5	B	DD661	7-1/8	217	72,000	102,000	23.6	73.2	7
6	C	12762	7-1/8	240	55,500	113,500	22.9	63.7	6
7	A	31E624-A1	10-1/4	260	69,000	119,100	21.4	68.3	9
8	B	TT615	10-1/2	223	83,000	108,300	23.6	72.0	7
9	C	10882	10-3/4	199	53,000	94,500	24.3	69.2	4
10	A	34E556-A1	13-1/8	244	84,300	112,950	22.9	68.6	8
11	B	TT613	13-3/8	217	62,500	102,200	25.7	72.5	6
12	C	12102	13-3/4	211	65,000	97,500	26.4	69.5	6

*Subject to rejection

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TABLE II

Hardness, Tensile, and Fracture Properties of Heavy Wrought Armor Plates

urface		Tensile Properties Longitudinal-Center of Cross-Section				Tensile Properties Transverse - 1" Below Surface				Transve
	R.A. %	Y.S. psi 0.1% Offset	T.S. psi	Elong. %	R.A. %	Y.S. psi 0.1% Offset	T.S. psi	Elong. %	R.A. %	Y.S. psi 0.1% Off
	[illegible]	[illegible]	115,800	20.7	65.0	95,500	117,600	20.7	61.0	88,50
	57.3	111,500	134,500	19.3	61.3	110,500	132,000	17.1	49.4	109,50
	[illegible]	94,000	122,500	21.4	64.7	79,000	130,000	17.9	49.8	98,00
	[illegible]	[illegible]	120,000	21.4	66.7	82,500	124,500	19.3	54.1	89,00
	[illegible]	[illegible]	[illegible]	22.9	58.9	76,000	100,400	22.9	66.0	67,00
	[illegible]	[illegible]	111,500	20.0	57.8	56,000	117,400	21.4	59.9	79,00
4	[illegible]	[illegible]	[illegible]	20.0	64.7	84,500	127,500	18.5	54.4	95,00
	[illegible]	[illegible]	[illegible]	22.9	68.3	75,000	107,700	22.9	63.7	70,00
	[illegible]	40,000	[illegible]	25.0	59.9	54,500	93,700	25.0	62.0	62,50
	[illegible]	[illegible]	115,500	20.7	60.3	81,000	112,700	25.0	61.3	88,50
7	72.5	65,000	93,800	24.5	69.8	70,000	101,000	25.0	63.0	65,50
4	69.5	69,000	98,600	22.9	65.4	73,500	98,800	23.6	60.3	67,0

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ce	Tensile Properties Transverse - Center of Cross-Section				Steel Soundness Fracture Rating	Fibre Fracture Rating	
R.A. %	Y.S. psi 0.1% Offset	T.S. psi.	Elong. %	R. A. %		Depth of Fibrous Edge	Cryst. at Center
61.0	88,500	114,200	20.7	57.4	D2*	2"	50%
49.4	109,500	134,000	17.9	42.8	D1	3"	None
49.6	98,000	125,000	20.7	60.3	B	3"	Trace
54.1	89,000	121,000	20.7	56.3	C	2"	50%
53.0	67,000	102,700	22.9	63.4	D1	1-3/4"	100%
59.9	79,000	111,000	22.9	60.6	D2	2-1/2"	25%
54.4	[illegible]	121,000	18.6	53.3	Indeterminate	1-1/2"	100%
53.7	70,000	105,000	22.1	59.6	E*	3-1/2"	50%
62.0	62,500	97,600	24.3	61.3	C	1-1/2"	100%
61.3	88,500	114,400	14.3	29.4	D1	4"	90%
53.0	65,500	93,600	21.4	56.7	C	4"	50%
60.3	67,000	97,600	22.9	59.2	Indeterminate	2"	100%

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TABLE III

V-Notch Charpy Impact Properties of the Heavy Wrought Armor Plates

Wtn. Plate No.	Mfgr.	Mfgr. Plate No.	Plate Thick-ness	Cross-Sectional Hardness Range	Average Cross-Sectional BHN	V-Notch Charpy at -40°F (Average of two tests) Longitudinal-Ft. Lbs.		Transverse Ft. Lbs.		V-Notch Charpy at -40°F *(Average of 8 Tests) Transverse-Ft. Lbs.	
						1" Below Surface	Center of Cross-Section	1" Below Surface	Center of Cross-Section	1" Below Surface	Center of Cross-Section
1	A	53E421-A3	6	241-255	250	101.1	61.1	61.0	50.4		
2	B	TT896	6	285	285	82.4	70.2	39.5	33.5		
3	C	10650-1	6	255-277	266	43.8	62.6	47.5	55.0		
4	A	55G435-A1	7-1/4	255-262	260	72.0	68.6	45.0	44.6		
5	B	DD661	7-1/8	217	217	100.3	41.6	63.8	33.1**		33.9
6	C	12762	7-1/8	229-255	240	54.4	45.9	57.0	45.8		
7	A	31E624-A1	10-1/4	255-277	260	62.9	48.7	32.4	28.4	34.6	25.9
8	B	TT315	10-1/2	217-229	223	89.0	74.4	68.7	47.1		46.0
9	C	10882	10-3/4	197-201	199	74.5	40.7	52.5	30.1	54.7	30.0
10	A	34E556-A1	13-1/8	241-248	244	74.9	36.8	50.1	23.2		24.3
11	B	TT613	13-5/8	207-229	217	99.3	112.7	71.8	55.3		
12	C	12102	13-3/4	207-217	211	71.6	38.7	55.8	26.5	56.7	30.0

*Six additional tests made when average of two tests were borderline or failed to meet proposed specification requirements

**Underlined values are lower than revised requirements of the specification.

REPRODUCED AT GOVERNMENT EXPENSE

TABLE IV*

Minimum V-Notch Charpy Impact Requirements, Ft.Lbs.
(Average of Two Tests)

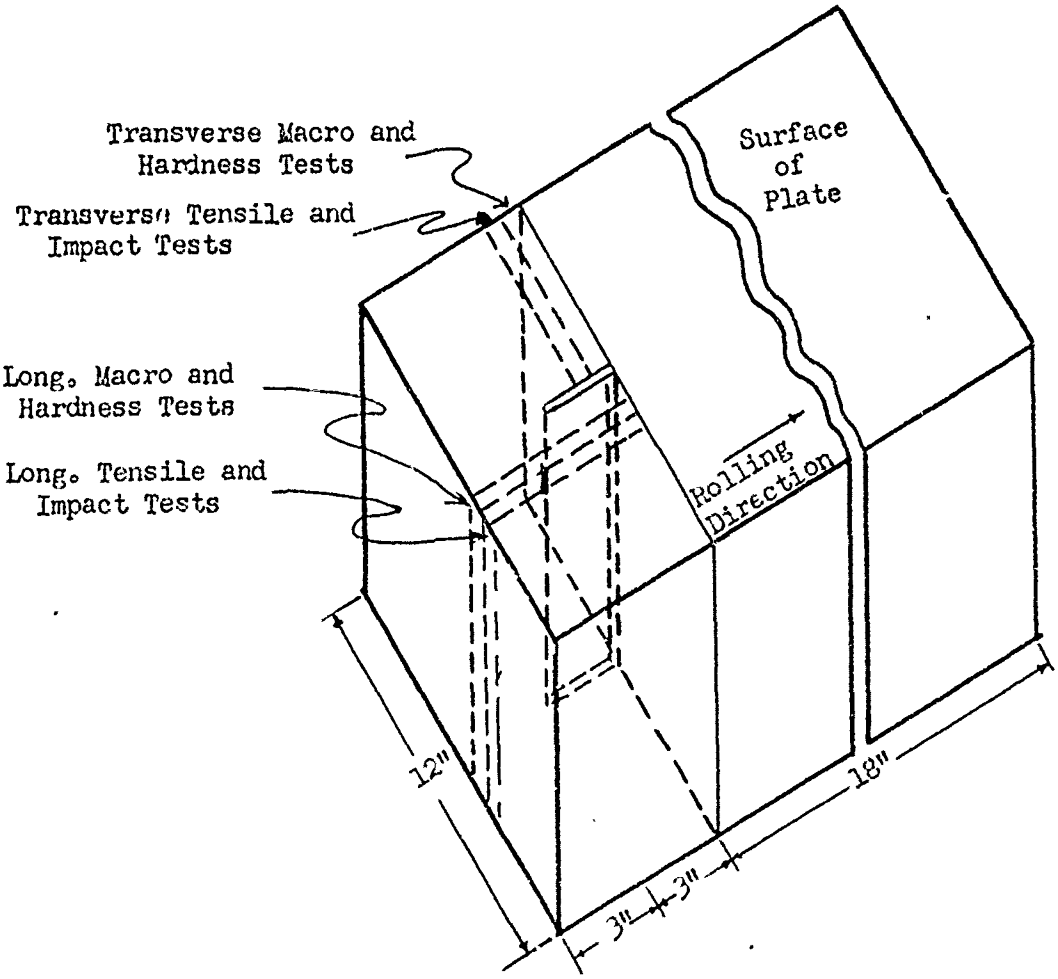
Brinell Hardness	1" Below Surface of Plate, Temp. -40°F: Values of 1 Nov 1946	1" Below Surface of Plate, Temp. -40°F: Revised Values of 1 Dec 1947	Center of Plate, Temp. -40°F: Values of 1 Nov 1946	Center of Plate, Temp. -40°F: Revised Values of 1 Dec 1947
180-199	65	60	55	45
200-219	60	55	50	40
220-239	50	50	50	35
240-259	40	40	40	30
260-279	30	30	30	25
280-299	25	25	25	20
300-329		20		15
330-359		15		10

*Table II of the Specification

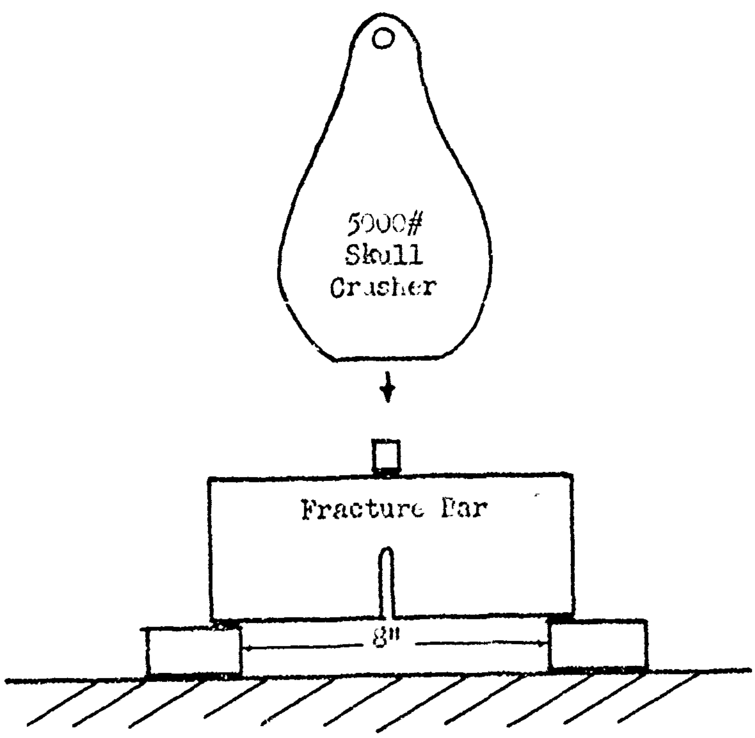
TABLE VI

Grain Size (ASTM)

Wtn. Plate No.	Mfgr.	Thickness	Grain Size	
			Zephiran Etch	Vilella's Etch
1	A	6	1, -1, -1+	1, -1, -1+
2	B	6	1, -1	1, -1
3	C	6	6, 4	6, 4
4	A	7-1/4	3, 2, 1	3, 2, 1
5	B	7-1/8	6, 5	6, 5
6	C	7-1/8	4, 3	5, 4, 3
7	A	10-1/4	3, 1, -1	3, 1, -1
8	B	10-1/2	6, 5, 3, 1	5, 4, 1
9	C	10-3/4	-1+	1, -1, -1+
10	A	13-1/8	3, 1, -1, -1+	3, 1, -1, -1+
11	B	13-3/8	4, 2	5, 3, 2
12	C	13-3/4	2, 1, 0, -1	2, 1, 0, -1



Location of Fracture Bar and Test Specimens



Fracture Test Set Up

Figure 1

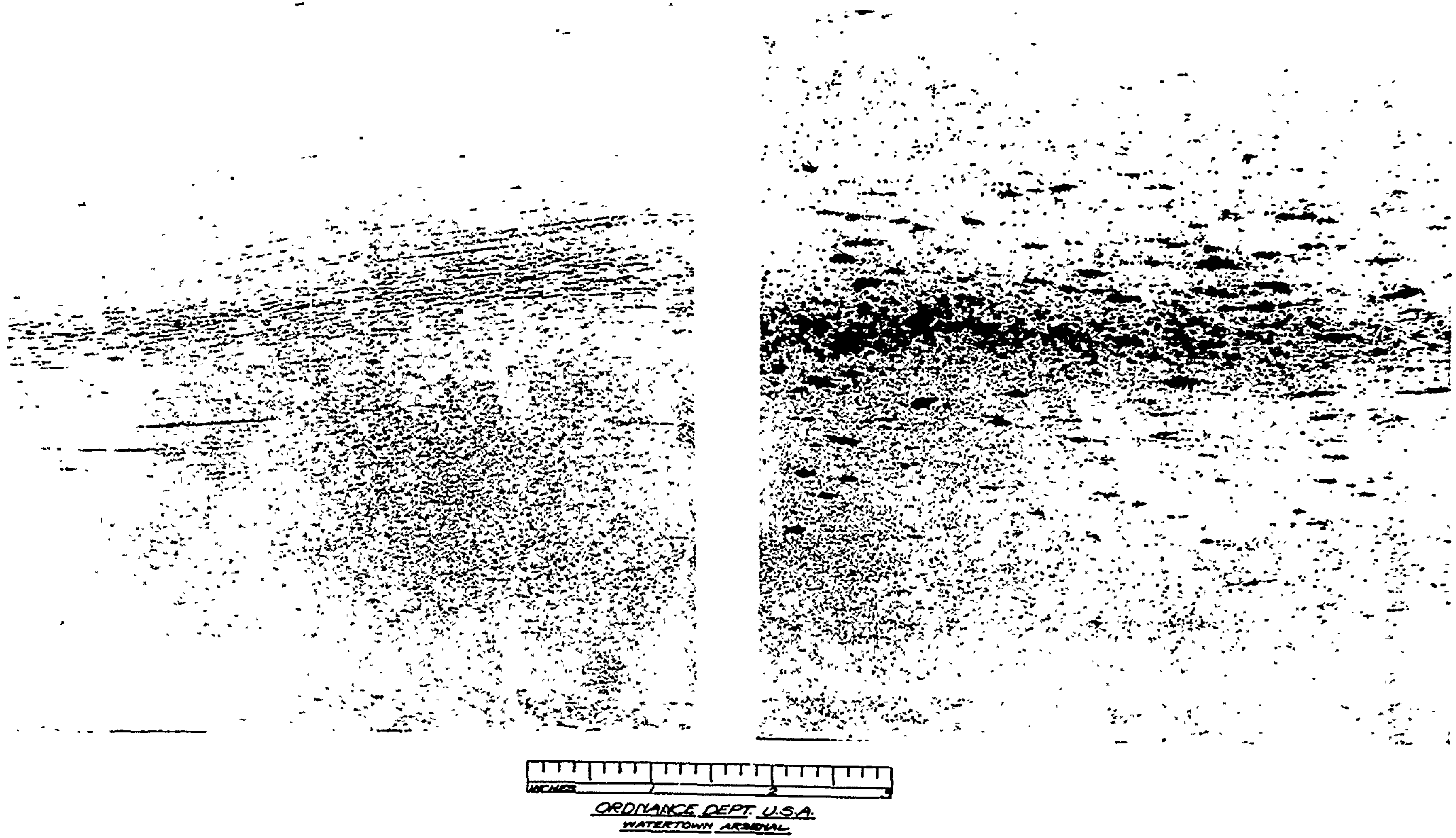
REPRODUCED AT GOVERNMENT EXPENSE

LONGITUDINAL FRACTURE TEST OF 6" THICK PLATE #1 (MFG. #53E 421A3) MADE BY . Co.A
FRACTURE RATINGS: FC 1/4, SOUNDNESS, D2. WTN.710-2404

FIGURE 2

FIGURE 2

REPRODUCED AT GOVERNMENT EXPENSE



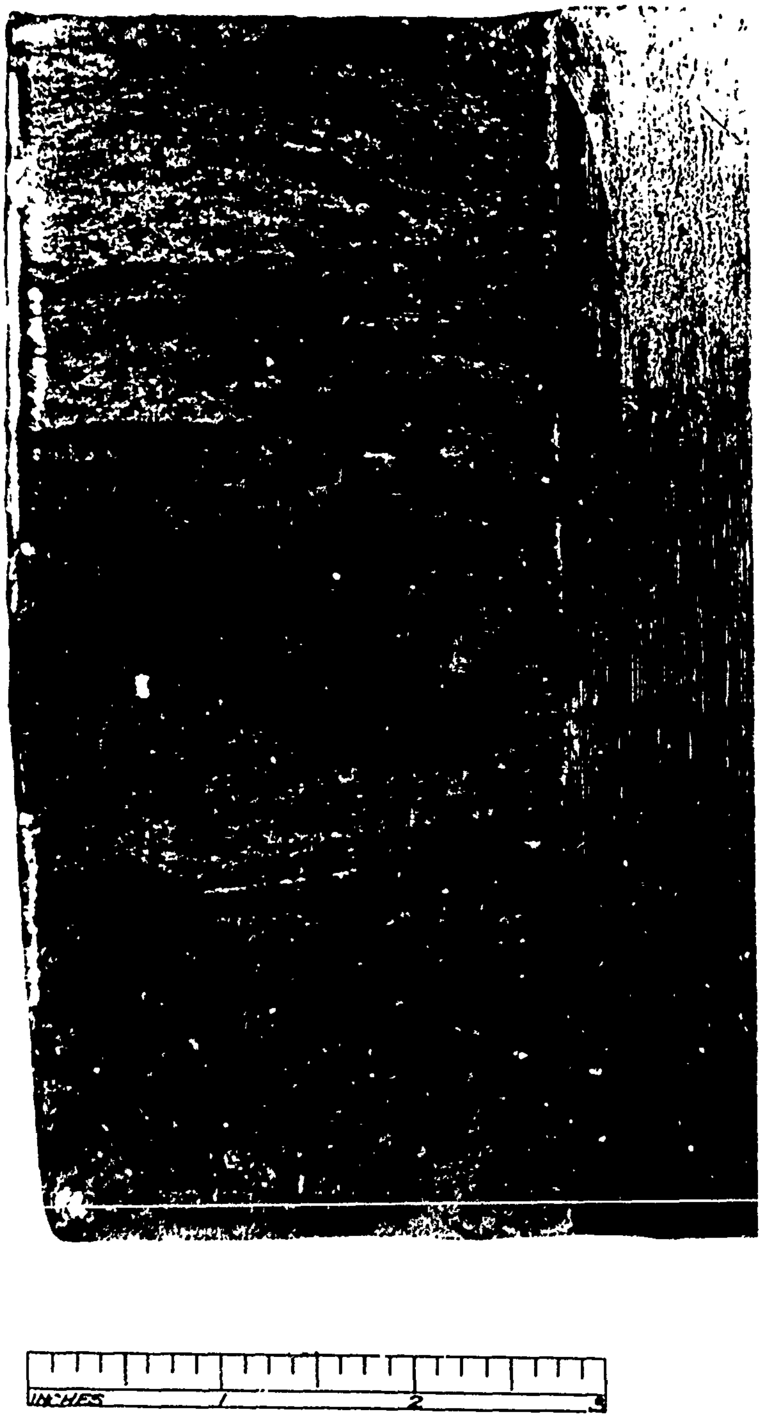
LONGITUDINAL TRANSVERSE

MACROETCHED STRUCTURES OF 6" THICK PLATE #1 (MFG. # 53E421-A3) MADE BY . Co. A NOTE MARKED DIRECTIONALITY BUT ABSENCE OF LAMINATIONS.

24 SEP 1947 WTN.710-2411

FIGURE 3

REPRODUCED AT GOVERNMENT EXPENSE



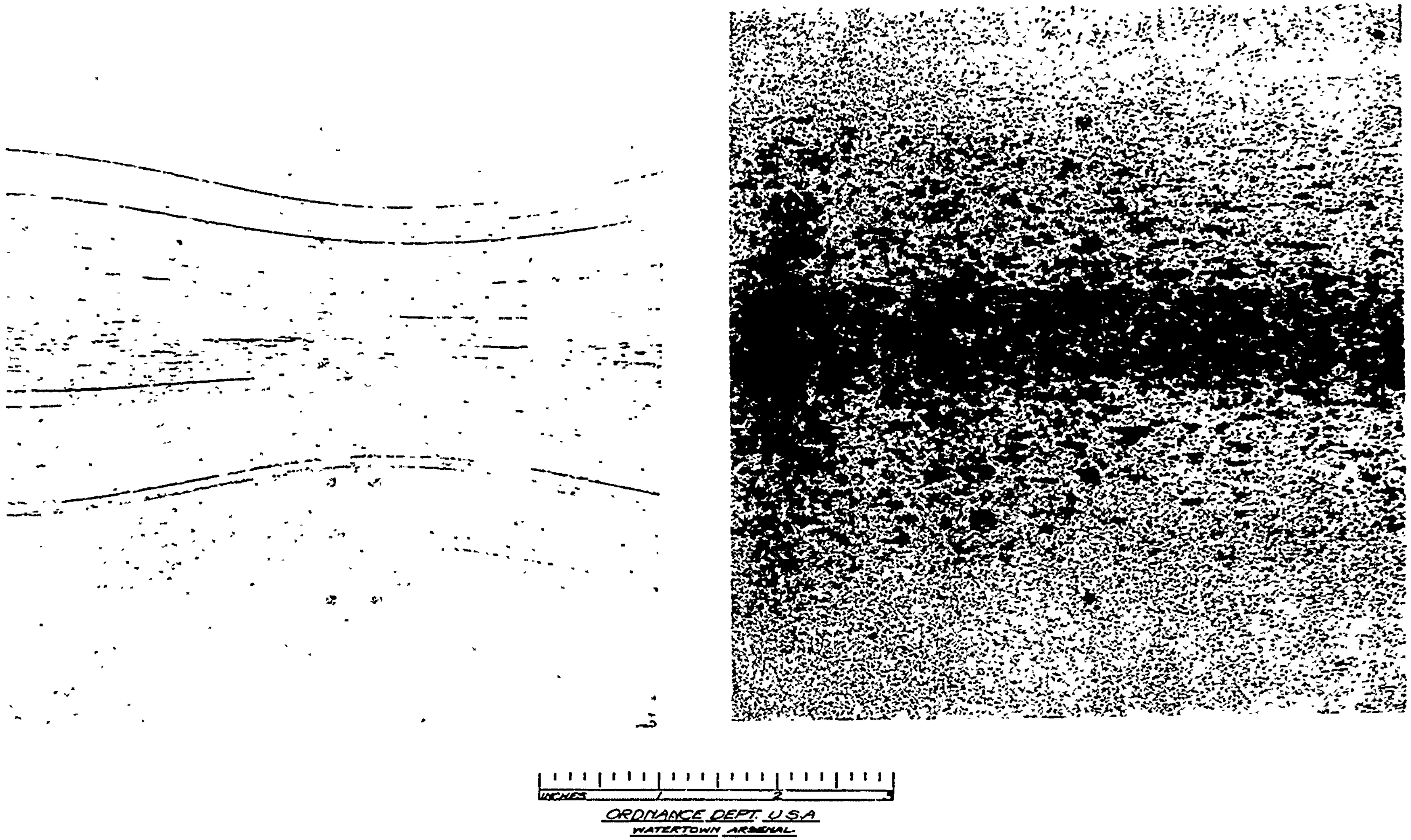
ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL.

LONGITUDINAL FRACTURE TEST OF 6" THICK PLATE #2 (MFG. #TT896) MADE BY Co. B
FRACTURE RATINGS: F, SOUNDNESS, DI. WTN.710-2405

FIGURE 4

FIGURE 4

REPRODUCED AT GOVERNMENT EXPENSE



LONGITUDINAL

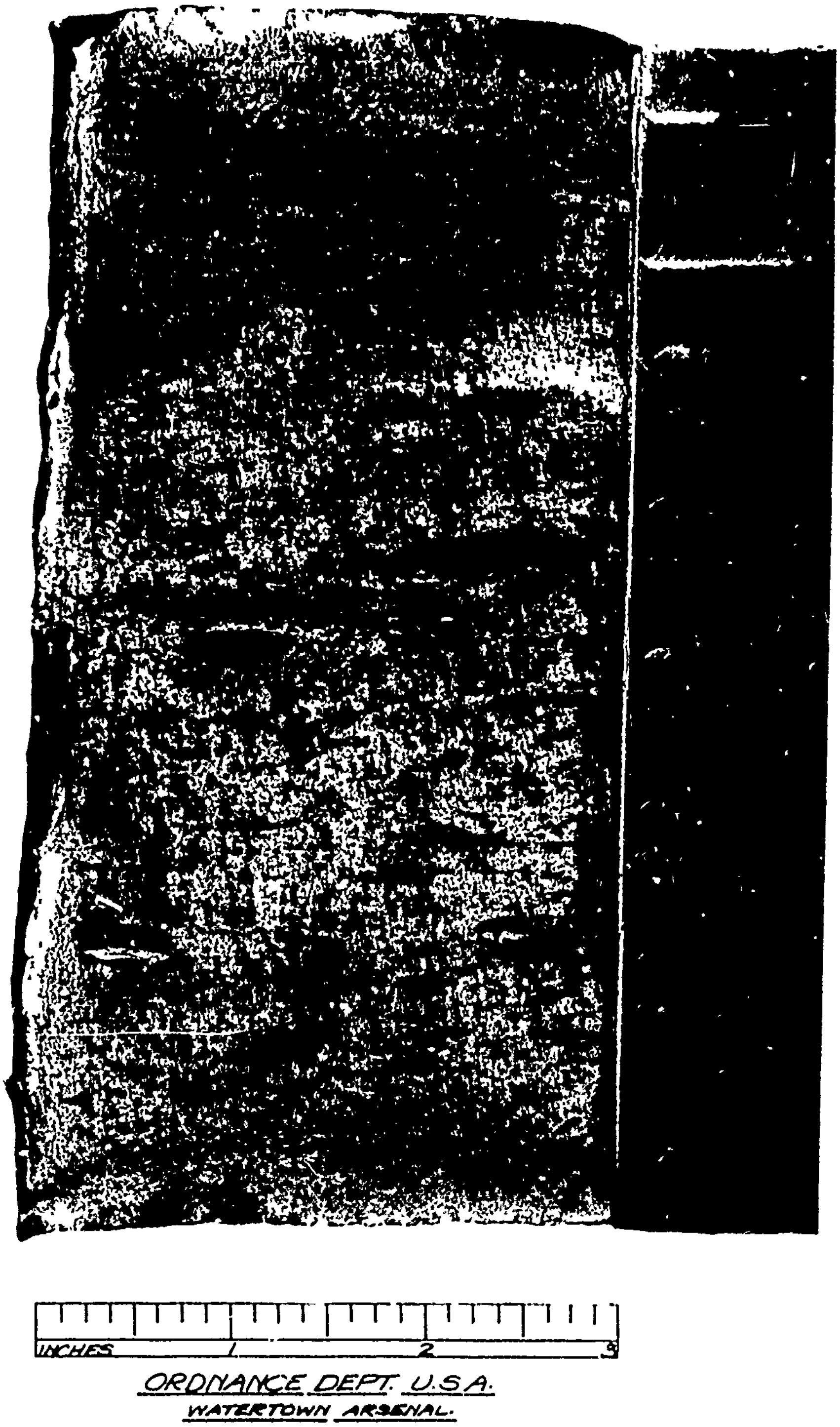
TRANSVERSE

MACROETCHED STRUCTURES OF 6" THICK PLATE #2 (MFG. # TT896) MADE BY Co B
NOTE MARKED DIRECTIONALITY AND LAMINATIONS.
24 SEP 1947

WTN.710-2412

FIGURE 5

REPRODUCED AT GOVERNMENT EXPENSE

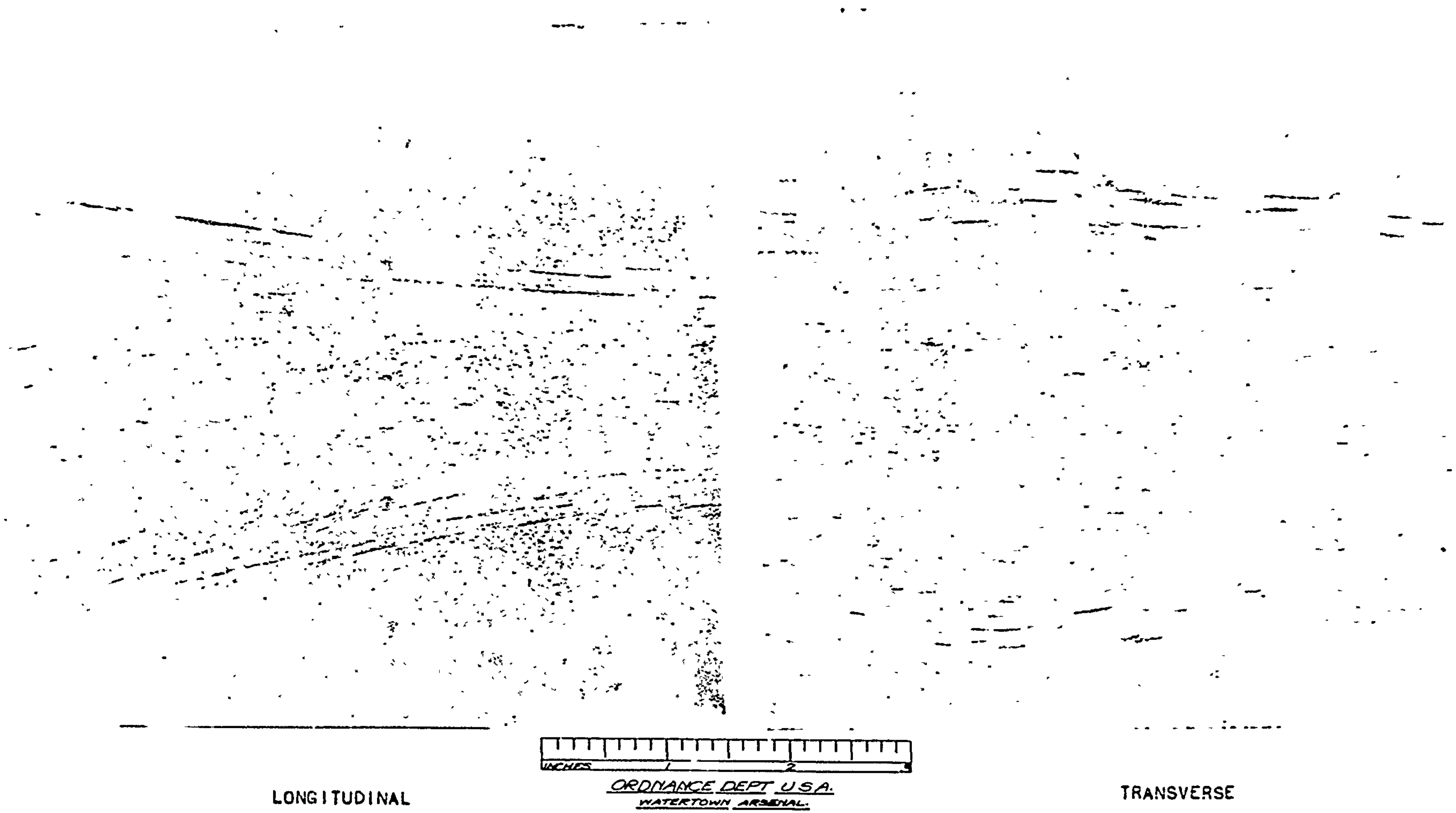


TRANSVERSE FRACTURE TEST OF 6" THICK PLATE #3 (MFG. #10650-1) MADE BY Co. C
FRACTURE RATINGS: FIBRE - FC TRACE, SOUNDNESS, B. WTN.710-2406

FIGURE 6

FIGURE 6

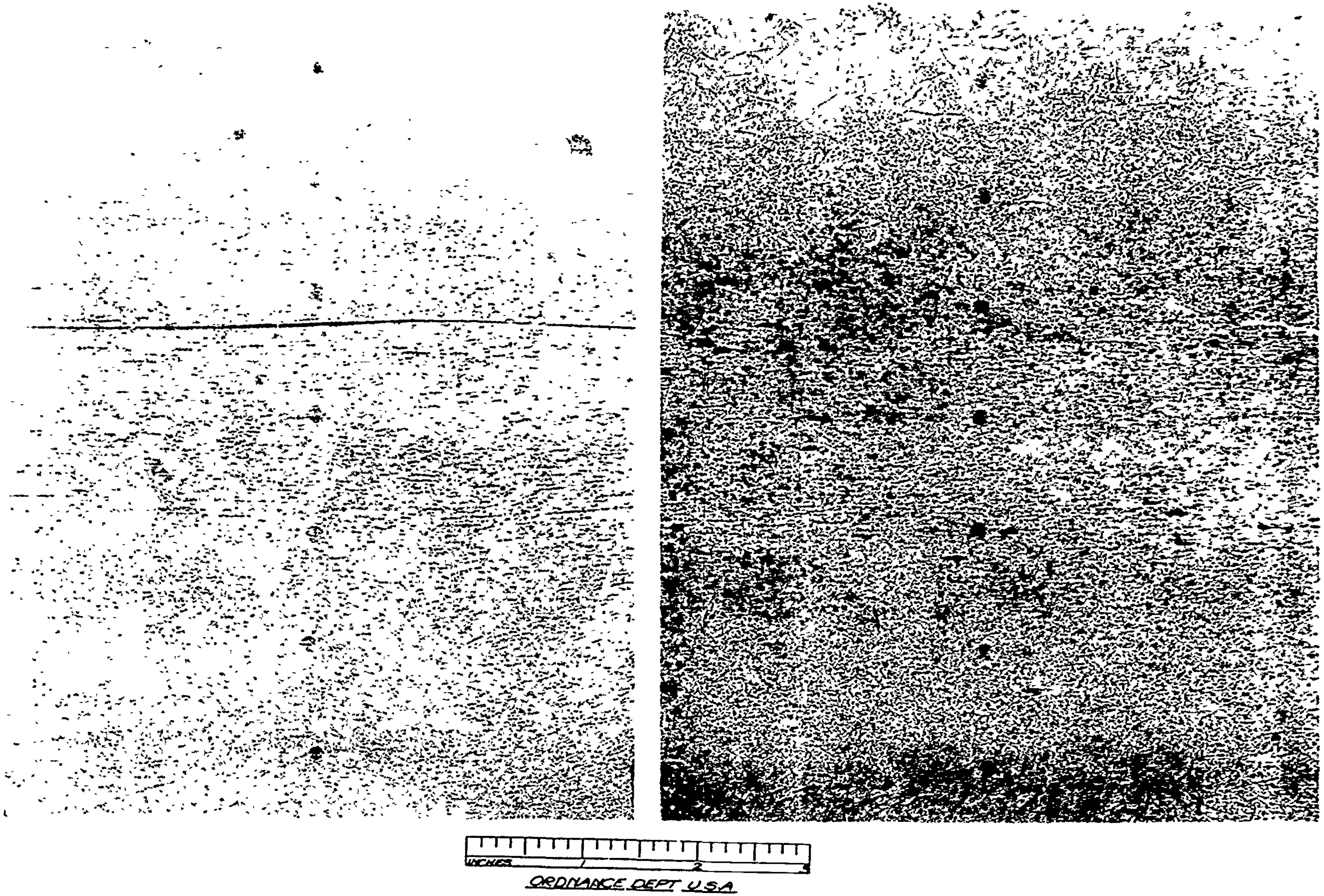
REPRODUCED AT GOVERNMENT EXPENSE



MACROETCHED STRUCTURES OF 6" THICK PLATE #3 (MFG. #10650 - 1) MADE BY Co. C NOTE MINOR DIFFERENCES IN DIRECTIONALITY AND ABENCE OF SEVERE LAMINATIONS. 24 SEP 1947 WTN.710-2413

FIGURE 7

REPRODUCED AT GOVERNMENT EXPENSE



LONGITUDINAL
MACROETCHED STRUCTURES OF 7¼" THICK PLATE #4 (MFG. #55G435-A1) MADE BY
THE PRESENCE OF ONE SEVERE LAMINATION.

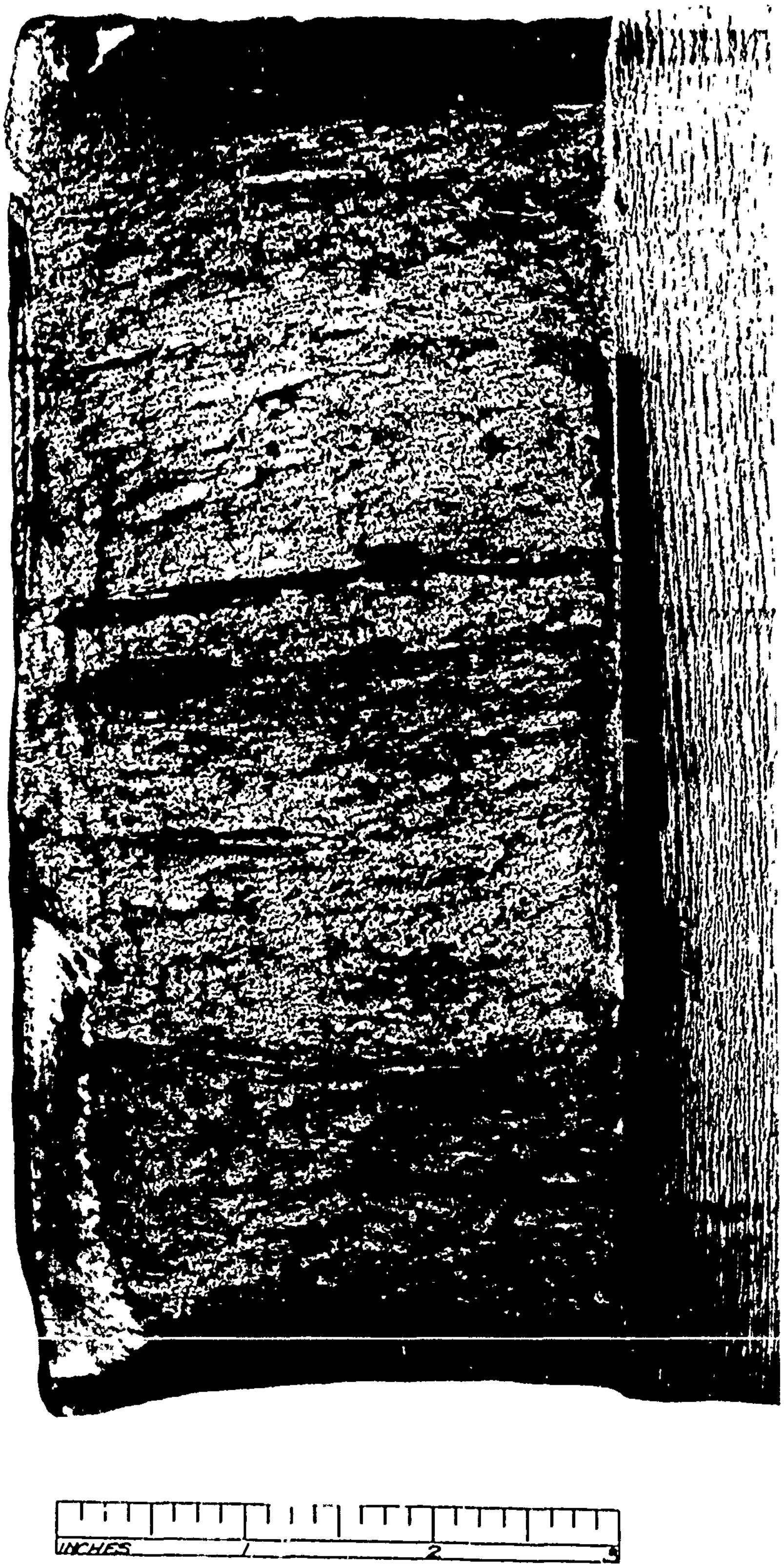
24 SEP 1947

Co. A

TRANSVERSE
NOTE MARKED DIRECTIONALITY AND
WTN.710-2414

FIGURE 8

REPRODUCED AT GOVERNMENT EXPENSE

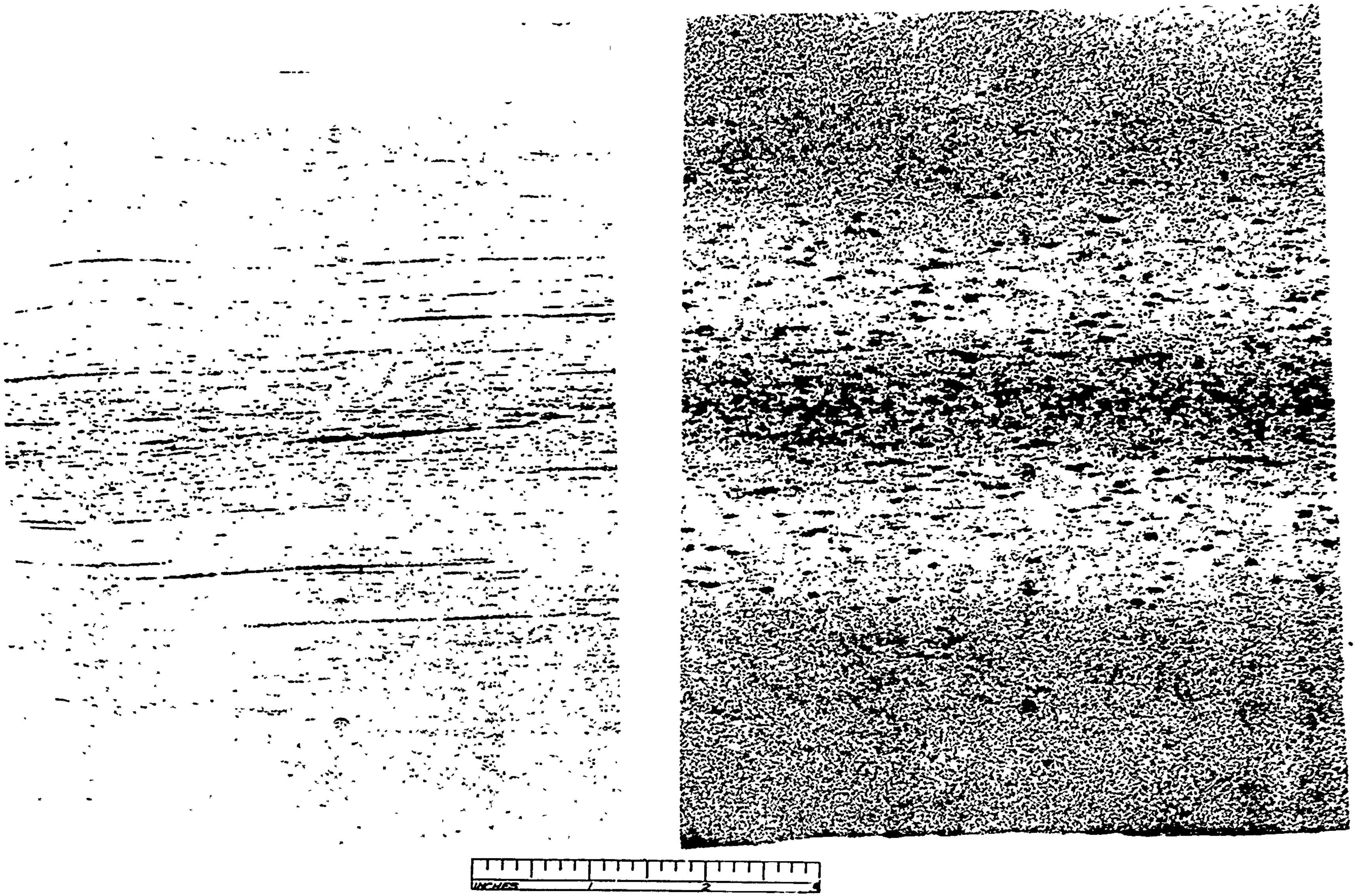


ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL.

LONGITUDINAL FRACTURE TEST OF 7 1/8" THICK PLATE #5 (MFG. # DD661) MADE BY : Co. B
FRACTURE RATINGS: FIBRE CF 3/4, SOUNDNESS, DI. WTN,710-2407

FIGURE 9 FIGURE 9

REPRODUCED AT GOVERNMENT EXPENSE



LONGITUDINAL

TRANSVERSE

Co. B

MACROETCHED STRUCTURES OF 7 1/8" THICK PLATE #5 (MFG. #00661) MADE BY 24 SEP 1947
NOTE MARKED DIRECTIONALITY
AND SEVERE LAMINATIONS.

WTN.710-2415

FIGURE 10

REPRODUCED AT GOVERNMENT EXPENSE

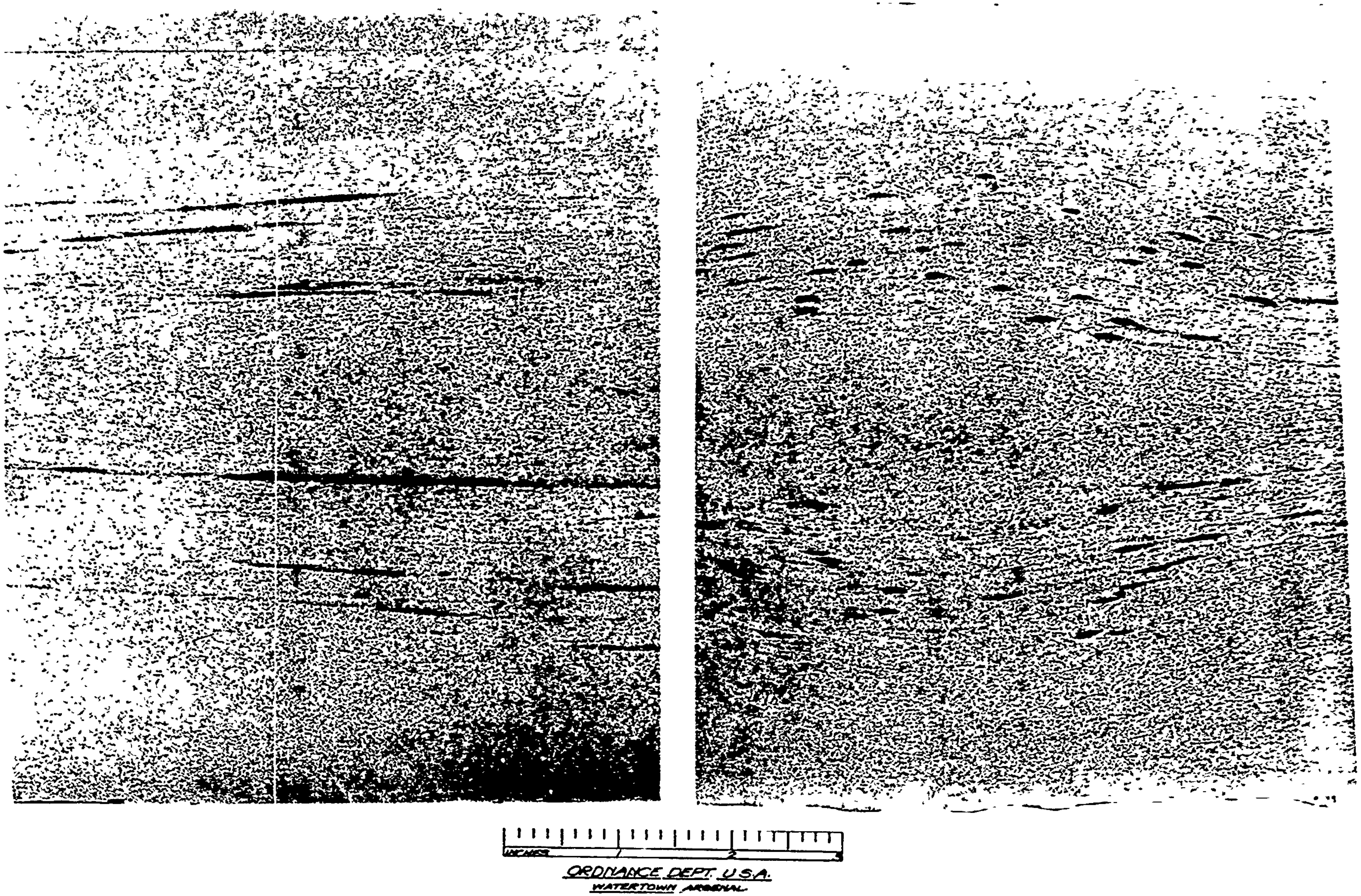
Co. C

TRANSVERSE FRACTURE TEST OF 7 1/8" THICK PLATE #6 (MFG. #12762) MADE BY
FRACTURE RATINGS: FIBRE, FC 1/8, SOUNDNESS, D2. WTN.710-2408

FIGURE 11

FIGURE 11

REPRODUCED AT GOVERNMENT EXPENSE



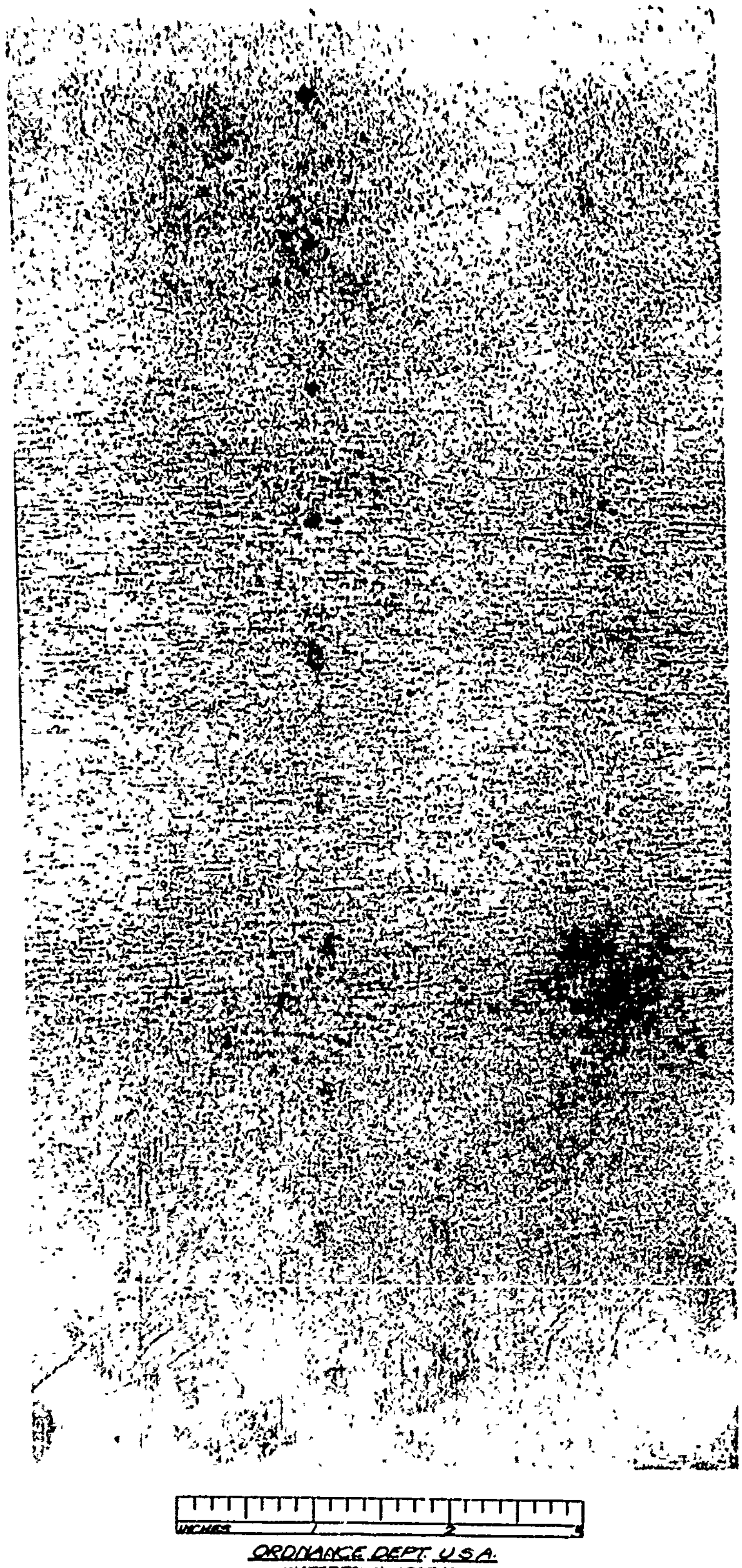
LONGITUDINAL Co. C TRANSVERSE

MACROETCHED STRUCTURES OF 7 1/8" THICK PLATE #6 (MFG. #12762) MADE BY - NOTE MARKED DIRECTIONALITY AND SEVERE LAMINATIONS.

24 SEP 1947 WTN.710-2416

FIGURE 12

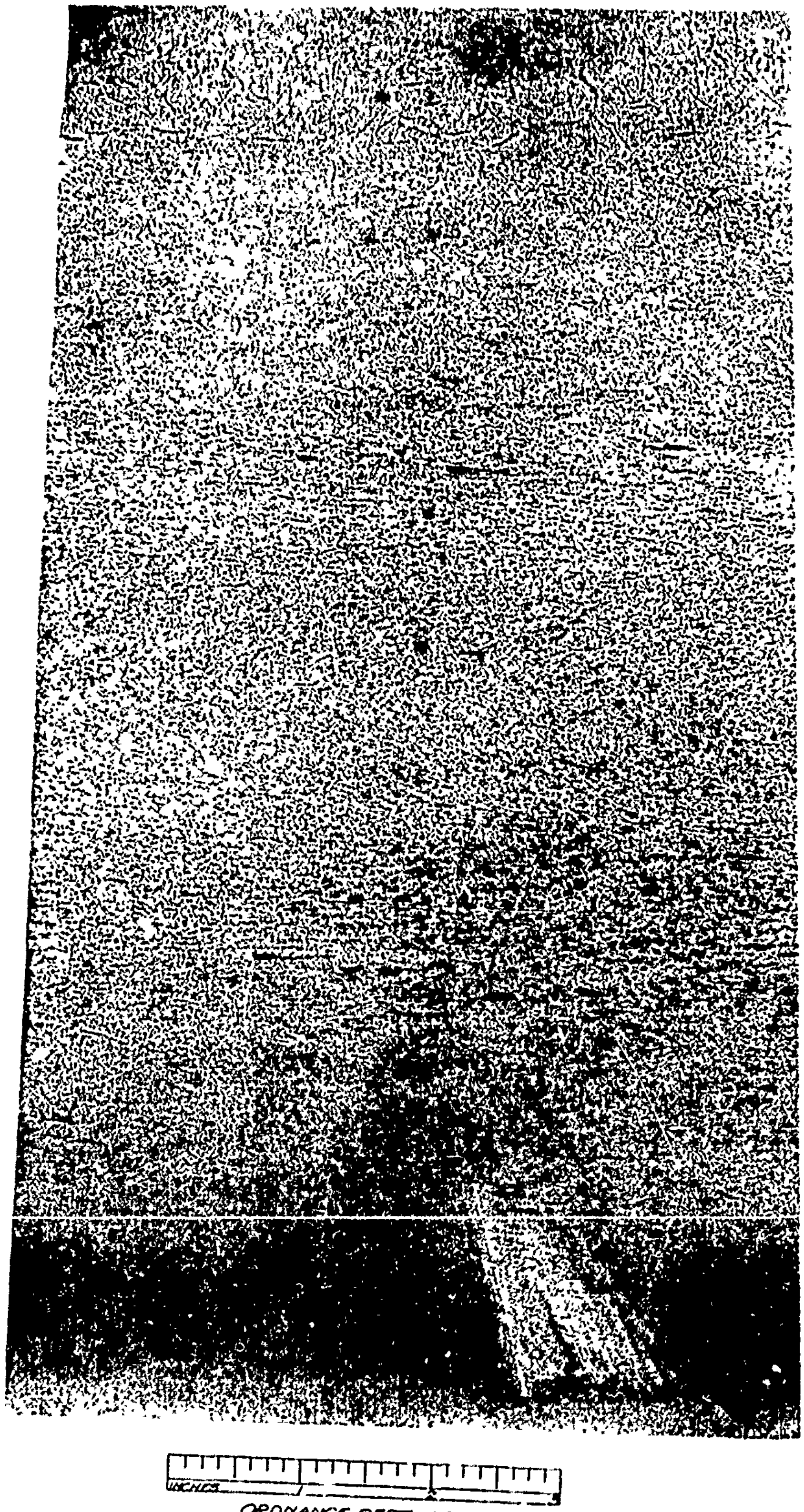
REPRODUCED AT GOVERNMENT EXPENSE



LONGITUDINAL MACROETCHED STRUCTURE OF 10½" THICK PLATE #7 (MFG. #31E624-A1) MADE BY Co. A
BY COMPARISON WITH TRANSVERSE STRUCTURE NOTE THE MINOR DIFFERENCE IN DIRECTIONALITY AND ABENCE OF LAMINATIONS. 24 SEP 1957 WTN.710-2417

FIGURE 13

REPRODUCED AT GOVERNMENT EXPENSE

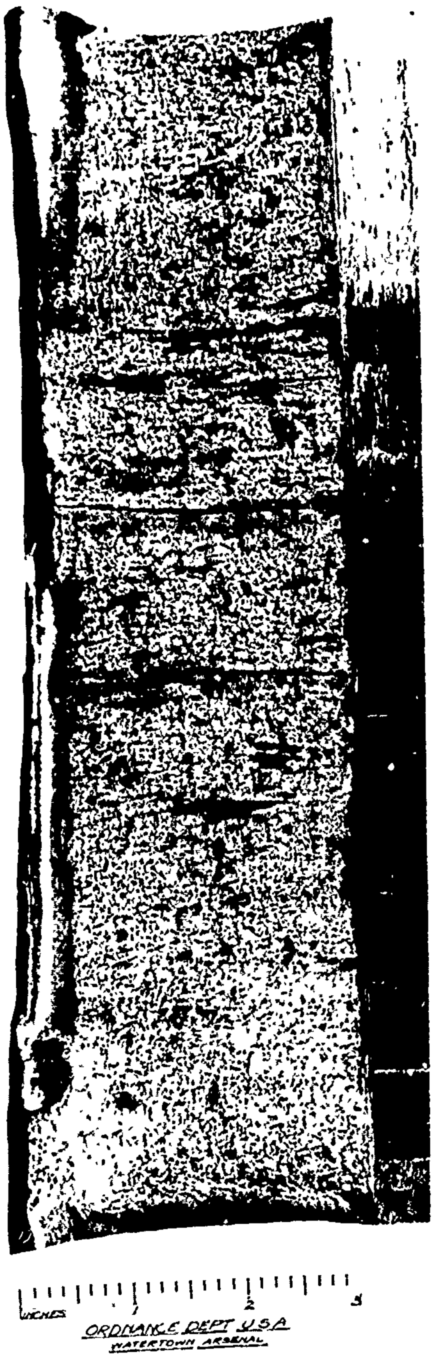


TRANSVERSE MACROETCHED STRUCTURE OF 10¼" THICK PLATE #7 (MFG. #31E624–A1) MADE BY
COMPARE WITH LONGITUDINAL STRUCTURE. 24 SEP 1947 WTN.710–2418

Co. A

FIGURE 14

REPRODUCED AT GOVERNMENT EXPENSE

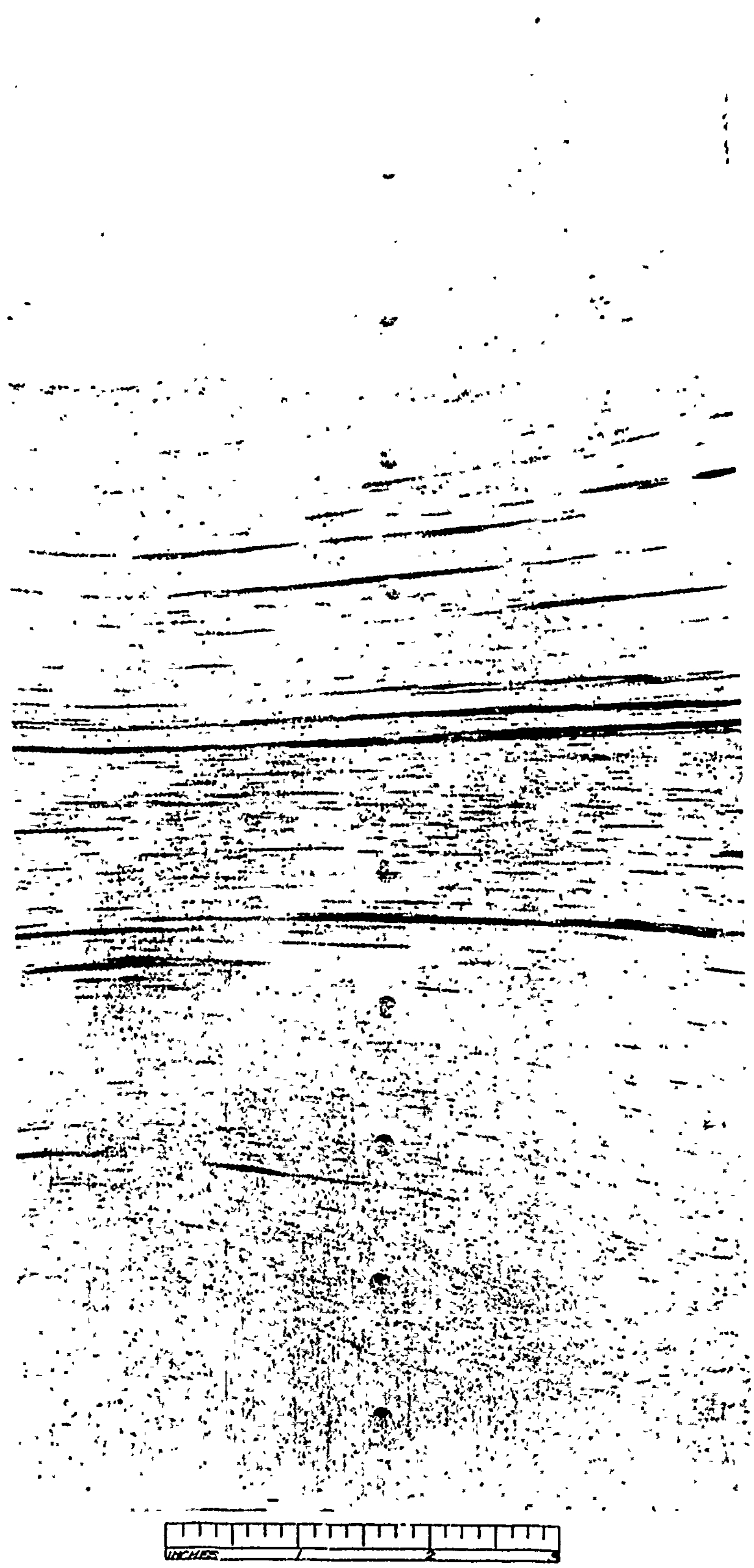


LONGITUDINAL FRACTURE TEST OF 10 1/2" THICK PLATE #8 (MFG. #TT315) MADE BY Co. B
FRACTURE RATINGS: FIBRE - FC 1/8, SOUNDNESS, E) WTN.710-2409

FIGURE 15

FIGURE 15

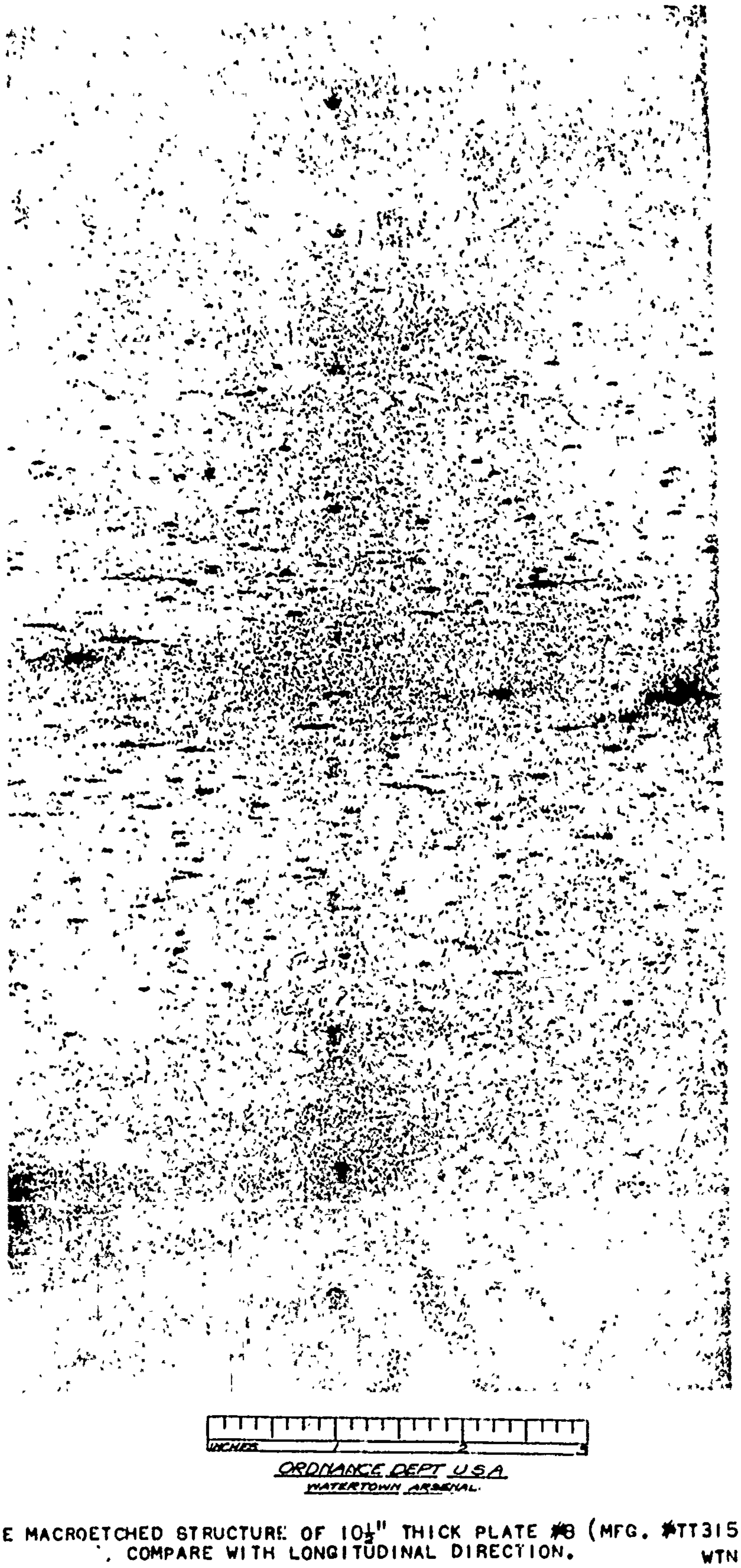
REPRODUCED AT GOVERNMENT EXPENSE



Co. B LONGITUDINAL MACROETCHED STRUCTURE OF $10\frac{1}{2}$" THICK PLATE #8 (M.G. #TT315) MADE BY . . BY COMPARISON WITH THE TRANSVERSE STRUCTURE NOTE THE MARKED DIRECTIONALITY AND SEVER LAMINATIONS. 24 SEP 1947 WTN.710-2419

FIGURE 16

REPRODUCED AT GOVERNMENT EXPENSE



TRANSVERSE MACROETCHED STRUCTURE OF 10½" THICK PLATE #8 (MFG. #TT315) MADE BY ', COMPARE WITH LONGITUDINAL DIRECTION. WTN.710-2420

Co. B

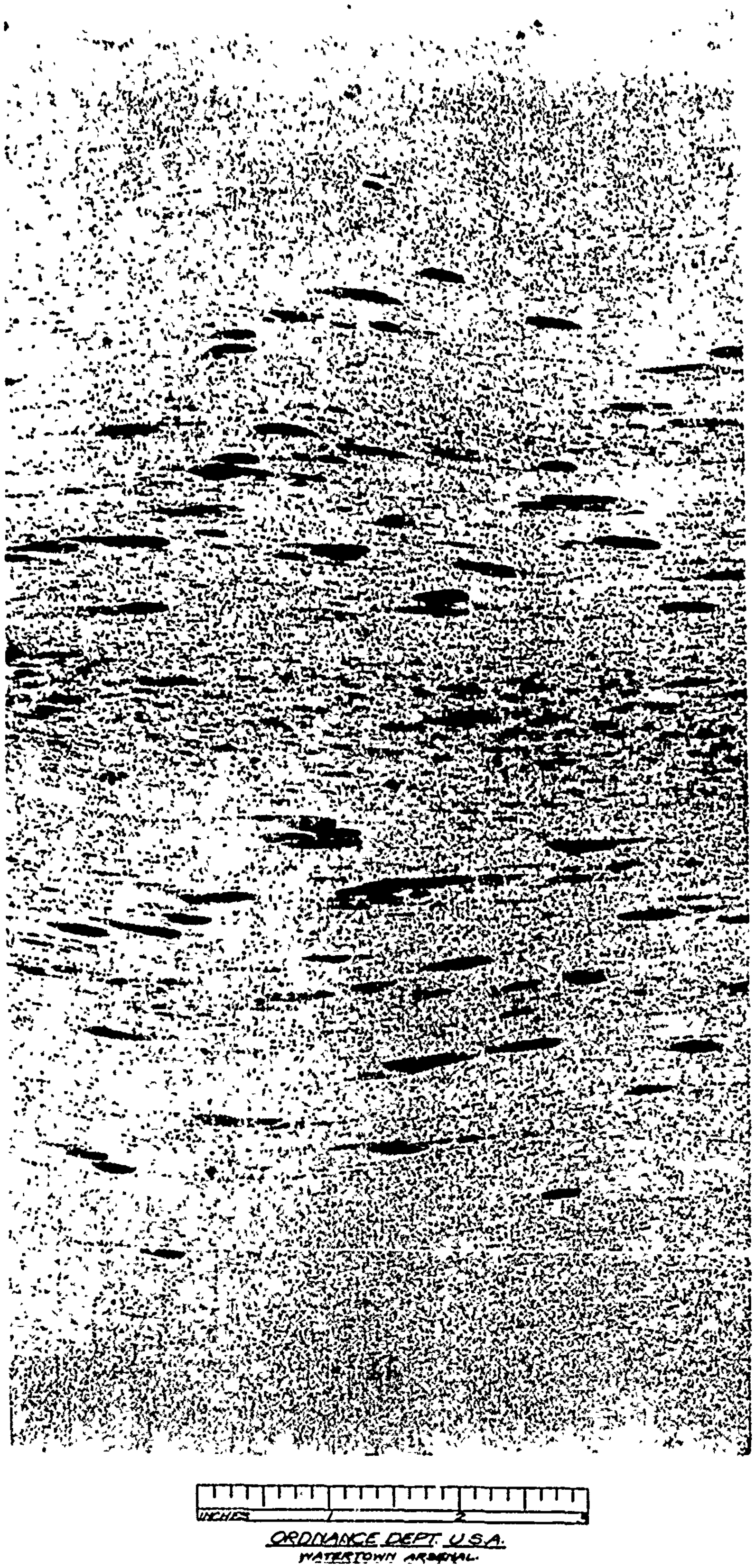
FIGURE 17

REPRODUCED AT GOVERNMENT EXPENSE

Co. C LONGITUDINAL MACROETCHED STRUCTURE OF 10 3/4" THICH PLATE #9 (MFG. #10882) MADE BY NOTE MARKED DIRECTIONALITY BY COMPARISON WITH THE TRANSVERSE STRUCTURE AND THE SEVERE LAMINATIONS. 24 SEP 1947 WTN.710-2421

FIGURE 18

REPRODUCED AT GOVERNMENT EXPENSE



TRANSVERSE MACROECTHED STRUCTURE OF 10 3/4" THICK PLATE #9 (MFG. #10882) MADE BY
COMPARE WITH LONGITUDINAL DIRECTION. 24 SEP 1947 WTN.710-2422

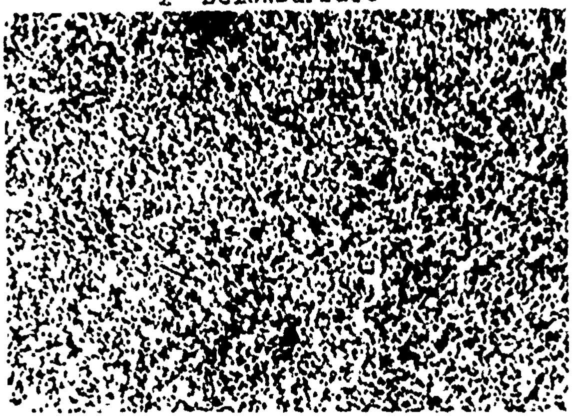
Co.e

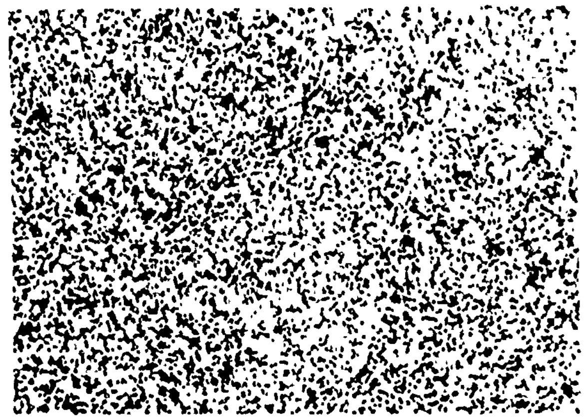
FIGURE 19

REPRODUCED AT GOVERNMENT EXPENSE

Microstructure of 13½" Thick Wrought Armor

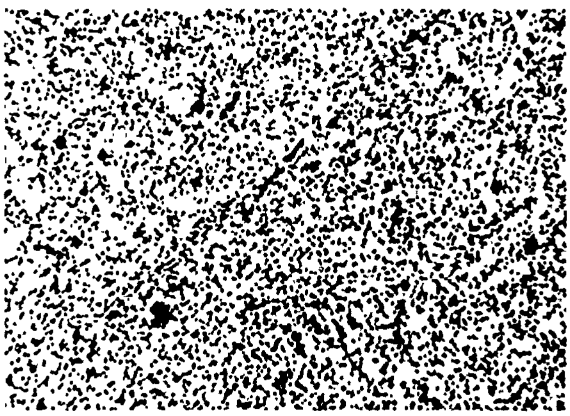
1" Below Surface	Center of Cross-Section





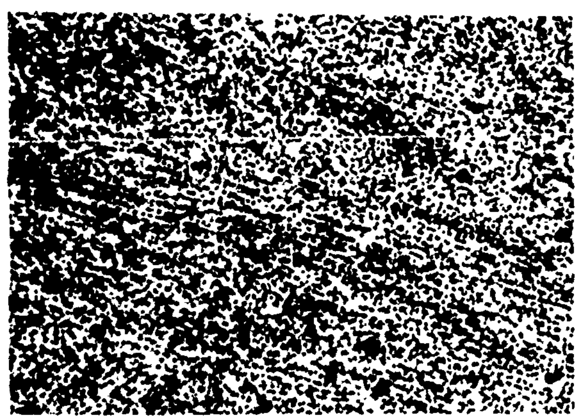
Impact Energy - 50.1 ft.lbs. Impact Energy - 23.2 ft.lbs.

Plate #10 made by Co. A possessing a hardness of 244 BHN



Impact Energy - 71.8 ft.lbs. Impact Energy - 55.3 ft.lbs.

Plate #11 made by Co. B possessing a hardness of 217 BHN



Impact Energy - 55.8 ft.lbs. Impact Energy - 26.5 ft.lbs.

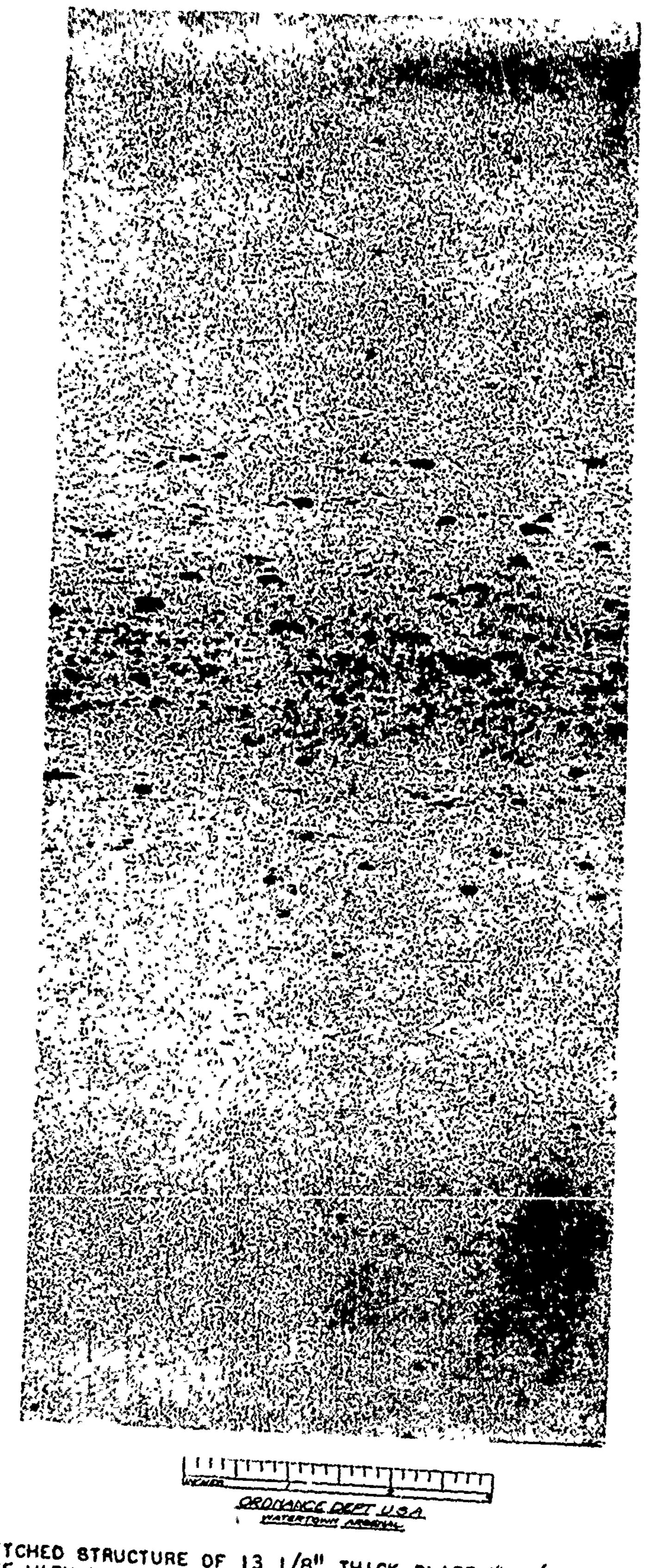
Plate #12 made by Co. C possessing a hardness of 211 BHN

All Structures Etched in 4% Picral, Mag. -1000X

Figure 33

WTN.639-9208

REPRODUCED AT GOVERNMENT EXPENSE

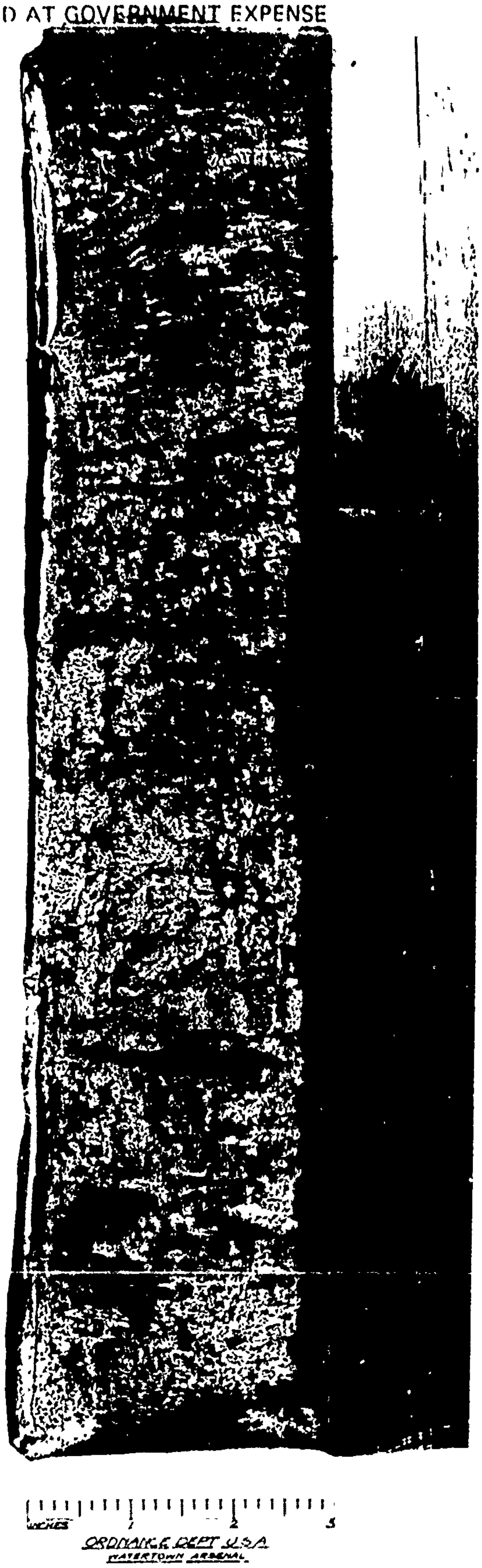


TRANSVERSE MACROETCHED STRUCTURE OF 13 1/8" THICK PLATE #10 (MFG. #34E556-A1) MADE BY Co. A. COMPARE WITH LONGITUDINAL DIRECTION. 24 SEP 1947

WTN.710-2424

FIGURE 21

REPRODUCED AT GOVERNMENT EXPENSE



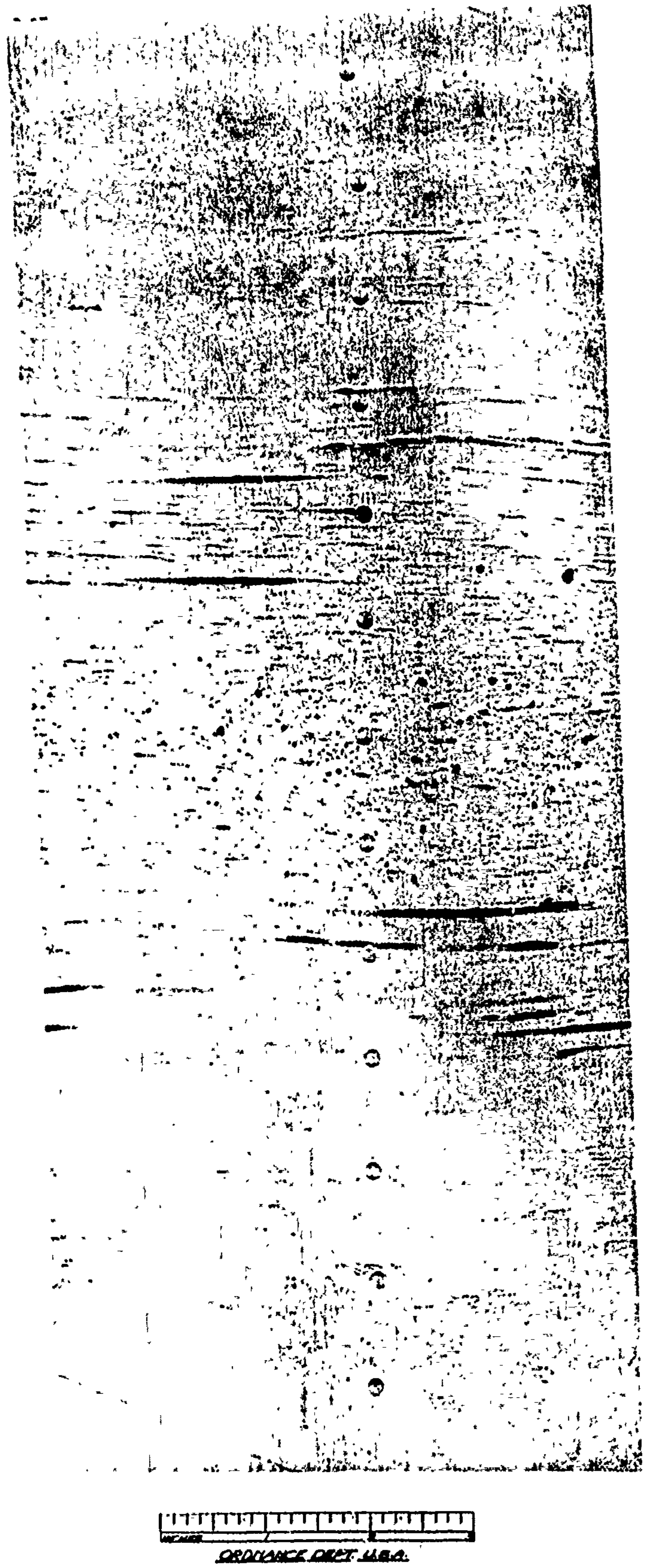
Ca B

LONGITUDINAL FRACTURE TEST OF 13 3/8" THICK PLATE #11 (MFG.#TT613) MADE BY
FRACTURE RATINGS: FIBRE – FC 1/4, SOUNDNESS, C. WTN.710-2410

FIGURE 22

FIGURE 22

REPRODUCED AT GOVERNMENT EXPENSE

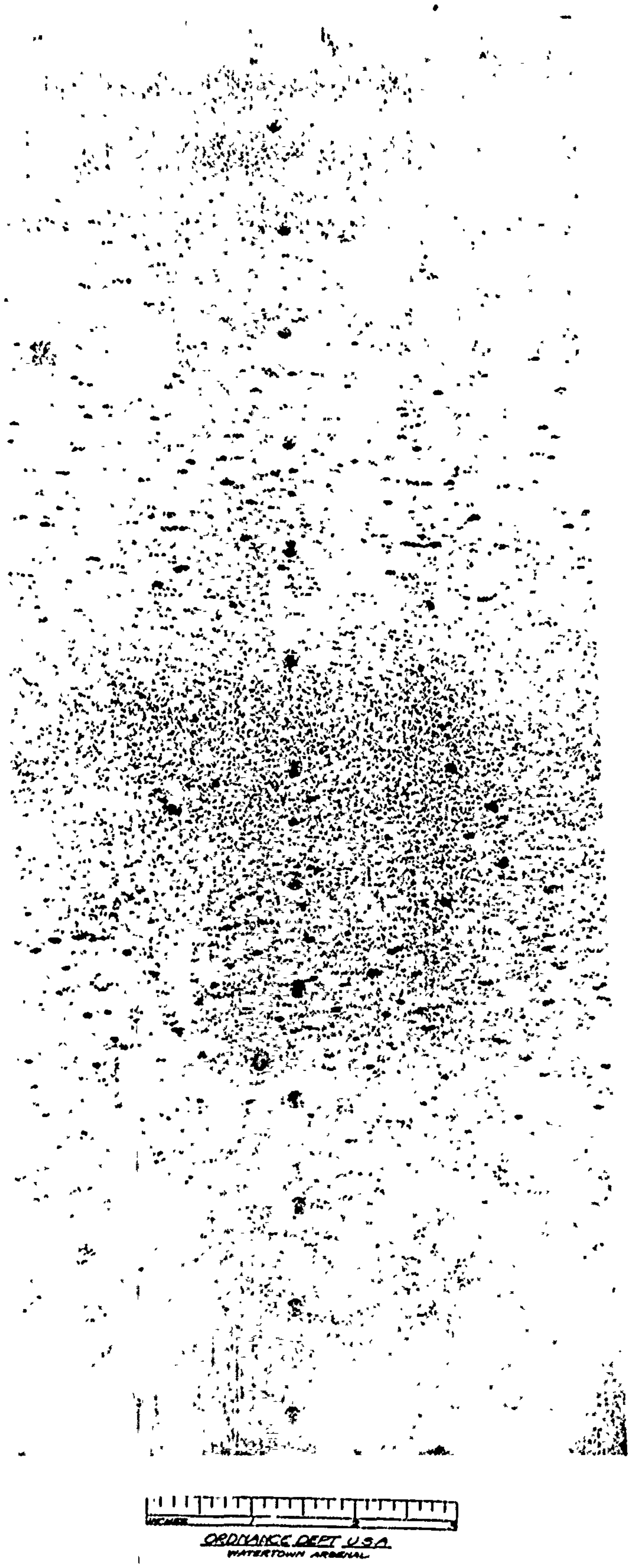


LONGITUDINAL MACROETCHED STRUCTURE OF 13 3/8" THICK PLATE #11 (MFG. #TT613) MADE BY
NOTE THE FAIRLY PRONOUNCED SEGREGATIONS. WTN.710-2425

Co. B

FIGURE 23

REPRODUCED AT GOVERNMENT EXPENSE

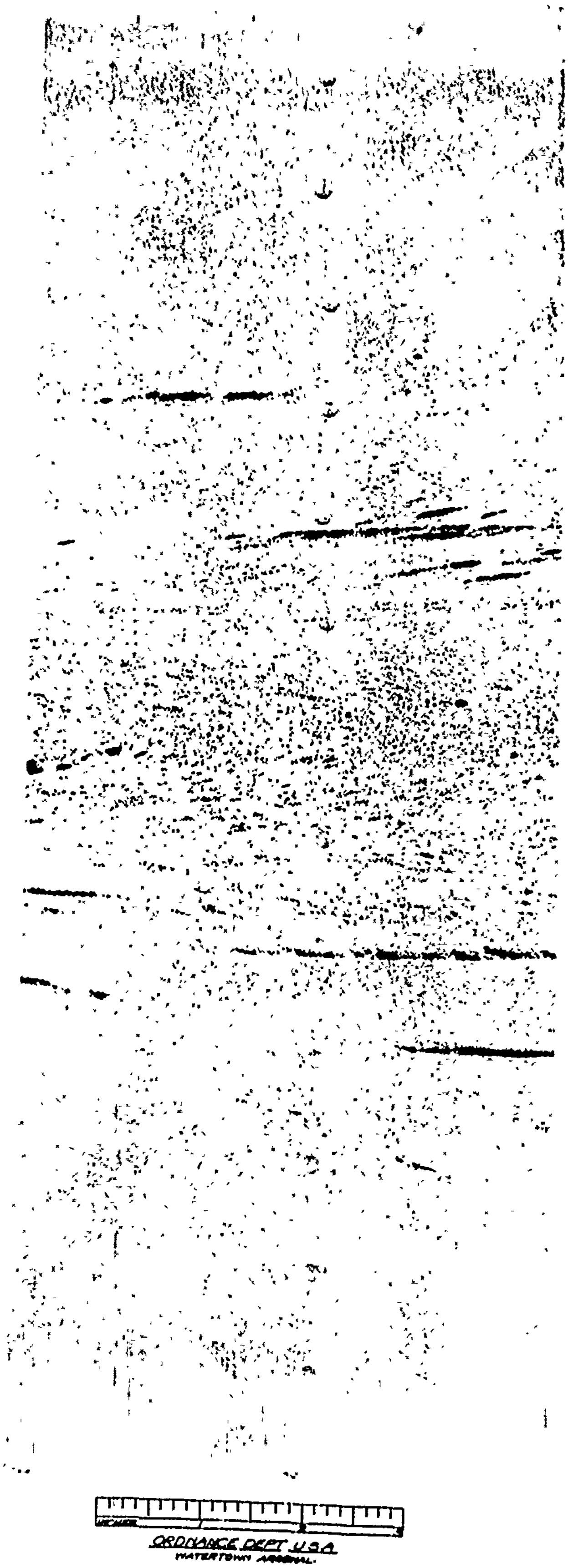


TRANSVERSE MACROETCHED STRUCTURE OF 13 3/8" THICK PLATE #11 (MFG. #TT613) MADE BY
COMPARE WITH THE LONGITUDINAL DIRECTION. WTN.710-2426

Co. B

FIGURE 24

REPRODUCED AT GOVERNMENT EXPENSE

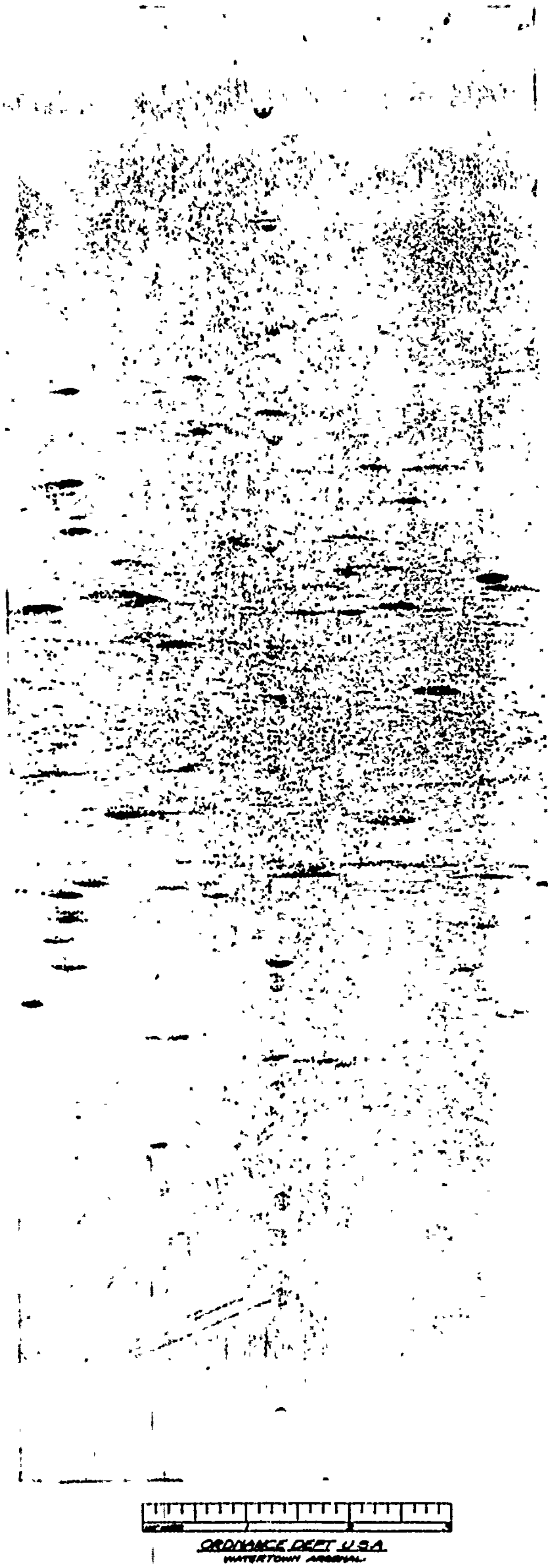


LONGITUDINAL MACROETCHED STRUCTURE OF 13 3/4" THICK PLATE #12 (MFG. #12102) MADE BY . . . , Co. C NOTE MAMINATIONS AND BY COMPARISON WITH THE TRANSVERSE DIRECTION THE DIRECTIONALITY. 24 SEP 1947

WTN.710-2427

FIGURE 25

REPRODUCED AT GOVERNMENT EXPENSE



TRANSVERSE MACROETCHED STRUCTURE OF 13 3/4" THICK PLATE #12 (MFG. #12102) MADE BY COMPARE WITH LONGITUDINAL DIRECTION. 24 SEP. 1947 WTN.710-2428

Co. C

FIGURE 26

REPRODUCED AT GOVERNMENT EXPENSE

Comparative Impact Values vs. Hardness in the Heavy Armor, the Specification, and Tempered Martensite

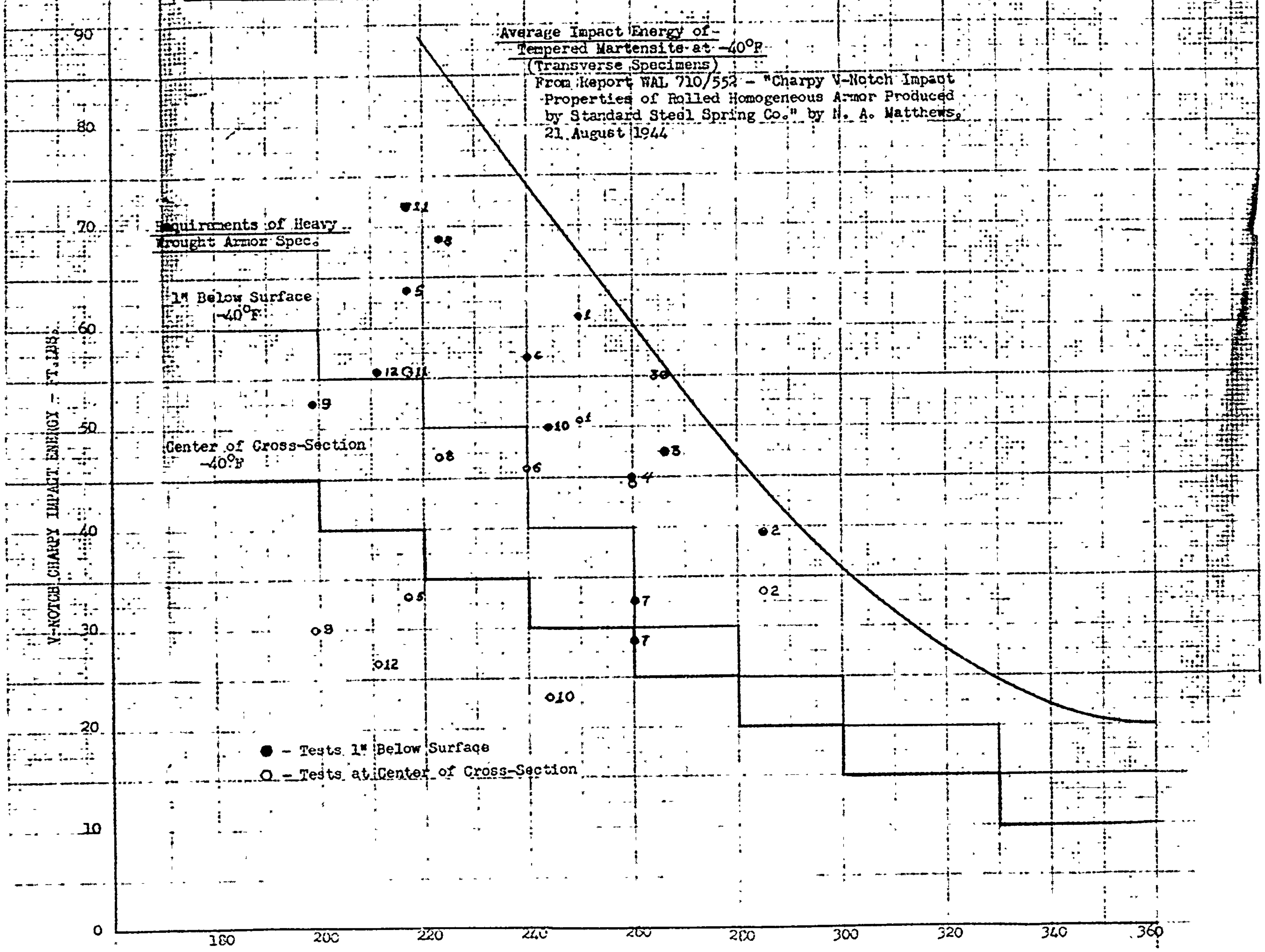


FIGURE 27

REPRODUCED AT GOVERNMENT EXPENSE

Typical Nonmetallics in Plates Having Laminations

X100 Light Picral Etch

Plate #9 - Segregations of sulfide and silicate type non-metallics revealed in macroetching

X100 Light Picral Etch

Plate #8 - A segregation of friable alumina type nonmetallics occasionally found in laminated areas.

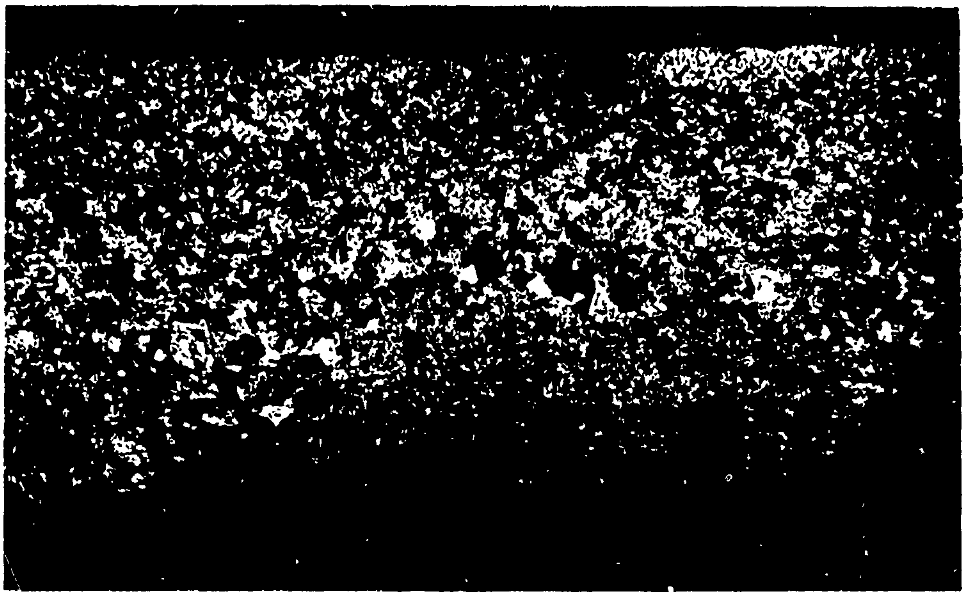
Figure 28

Reproduced from best available copy.

REPRODUCED AT GOVERNMENT EXPENSE

Structure of Coarse Grained Area of 10-3/4" Thick Plate #9

Surface of plate



WTN.639-9204

Macrostructure, actual size, etched in hot acid

X100 Zephiran Etch
Extremely coarse grain structure 1" below surface

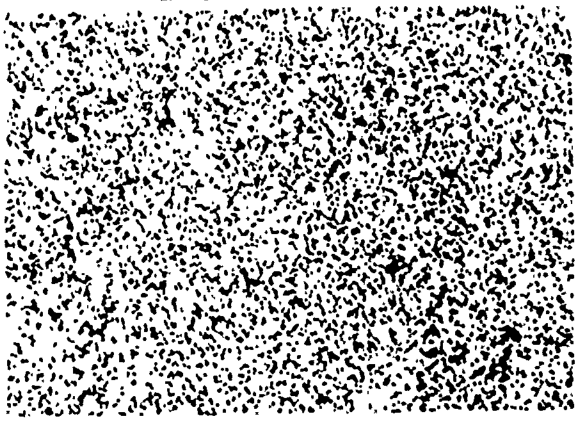
X100 Zephiran Etch
Moderately coarse grain structure (approx. ASTM #1) at center of plate

Figure 29

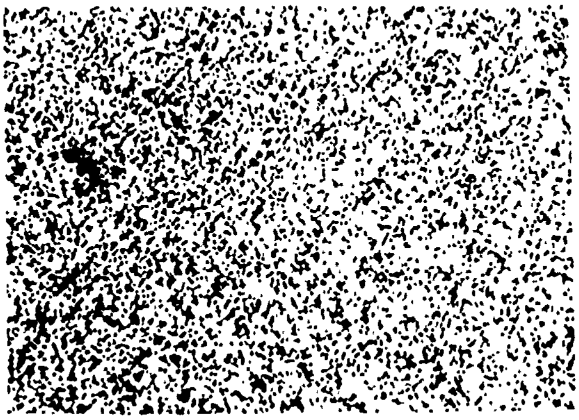
REPRODUCED AT GOVERNMENT EXPENSE

Microstructure of 6" Thick Wrought Armor

1" Below Surface | Center of Cross-Section

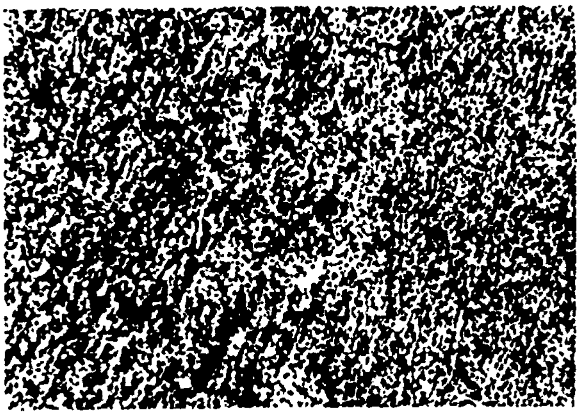


Impact Energy - 61.0 ft.lbs.

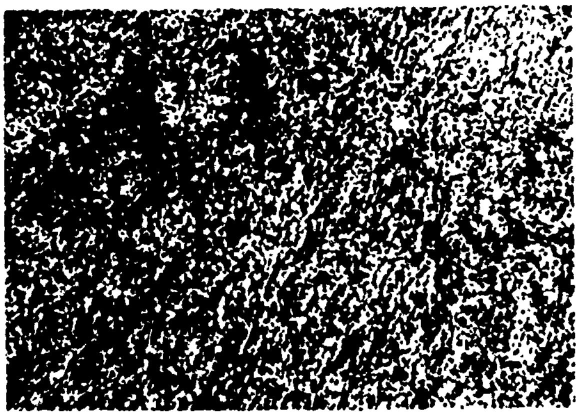


Impact Energy - 50.4 ft.lbs.

Plate #1 made by Co. A possessing a hardness of 250 BHN

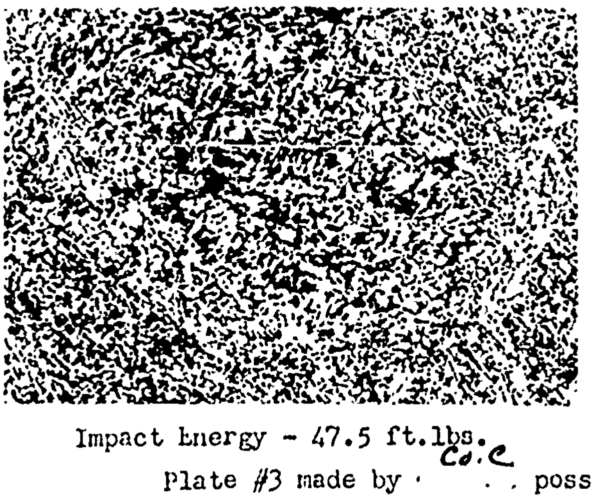


Impact Energy - 39.5 ft.lbs.

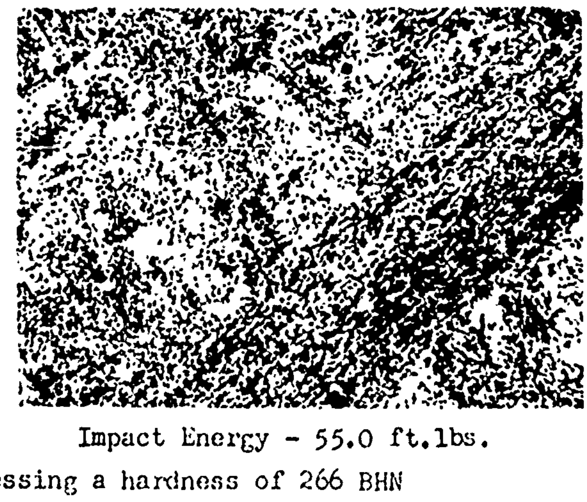


Impact Energy - 33.5 ft.lbs.

Plate #2 made by Co. B possessing a hardness of 285 BHN



Impact Energy - 47.5 ft.lbs.



Impact Energy - 55.0 ft.lbs.

Plate #3 made by Co. C possessing a hardness of 266 BHN

All Structures Etched in 4% Picral, Mag. -1000X.

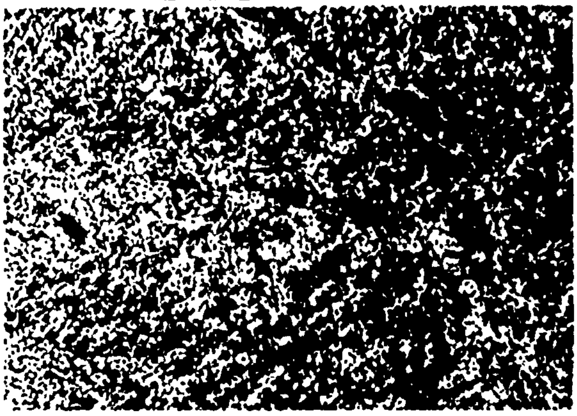
WTN.639-9205

Figure 30

REPRODUCED AT GOVERNMENT EXPENSE

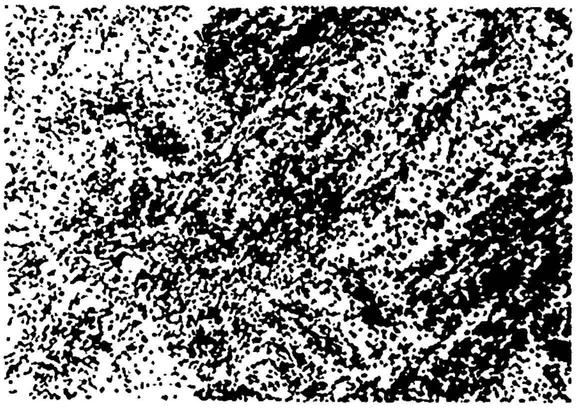
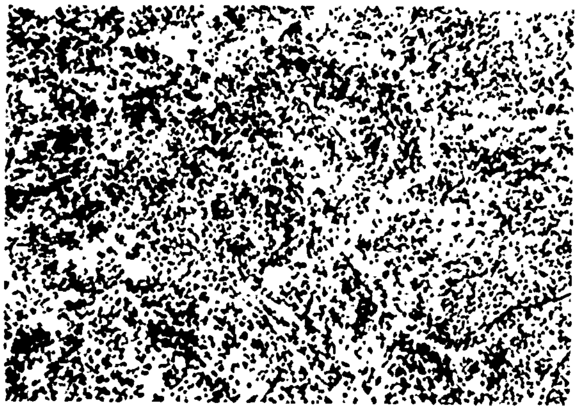
Microstructure of 7" Thick Wrought Armor

1" Below Surface | Center of Cross-Section



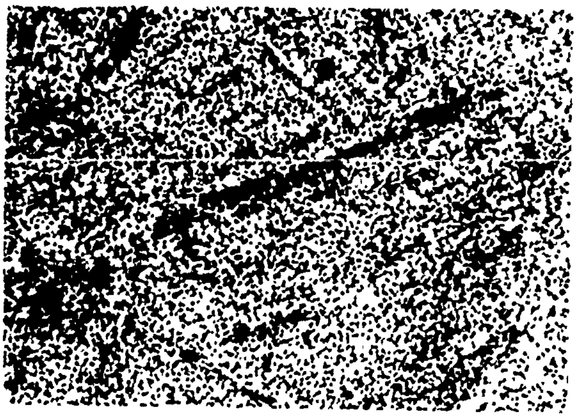

Impact Energy - 45.0 ft.lbs. Impact Energy - 44.6 ft.lbs.

Plate #4 made by Co. A possessing a hardness of 260 BHN

Impact Energy - 63.8 ft.lbs. Impact Energy - 33.1 ft.lbs.

Plate #5 made by Co. B possessing a hardness of 217 BHN

Impact Energy - 57.0 ft.lbs. Impact Energy - 45.8 ft.lbs.

Plate #6 made by Co. C possessing a hardness of 240 BHN

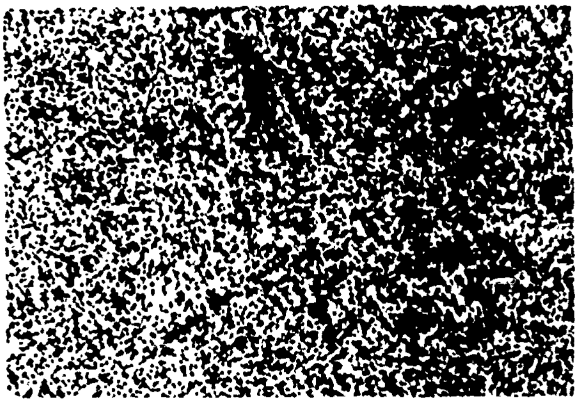
All Structures Etched in 4% Picral, Mag. -1000X

Figure 31

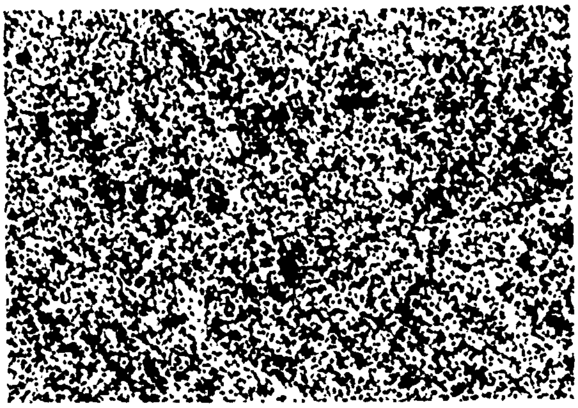
REPRODUCED AT GOVERNMENT EXPENSE

Microstructure of 10½" Thick Wrought Armor

1" Below Surface | Center of Cross-Section



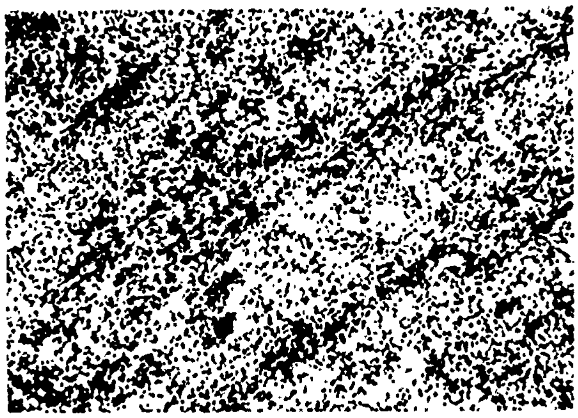
Impact Energy - 32.4 ft.lbs.



Impact Energy - 28.4 ft.lbs.

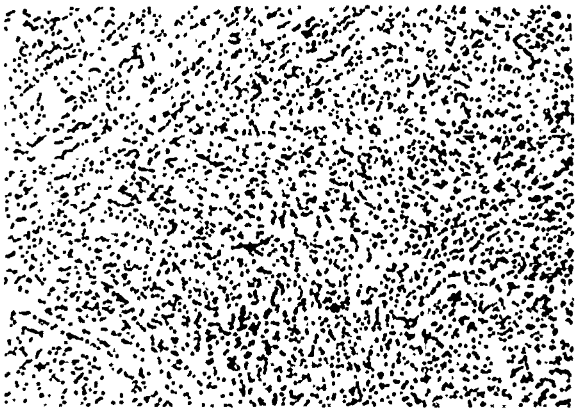
Plate #7 made by Co. A possessing a hardness of 260 BHN

Impact Energy - 68.7 ft.lbs.

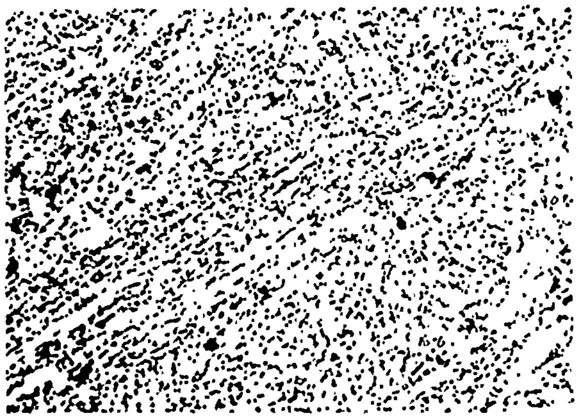


Impact Energy - 47.1 ft.lbs.

Plate #8 made by Co. B possessing a hardness of 223 BHN



Impact Energy - 52.6 ft.lbs.



Impact Energy - 30.1 ft.lbs.

Plate #9 made by Co. C possessing a hardness of 199 BHN

All Structures Etched in 4% Picral, Mag. -1000X

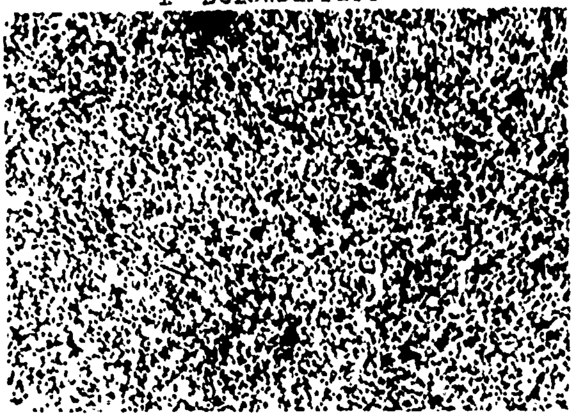
Figure 32

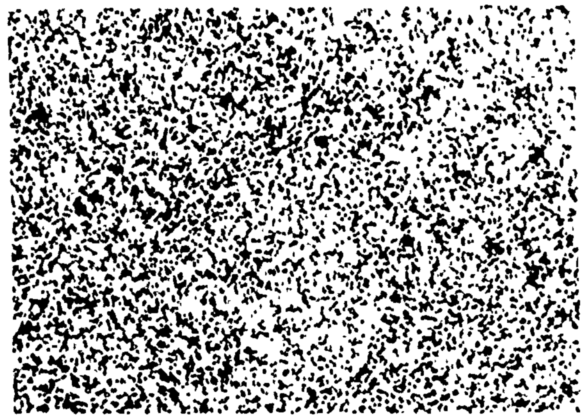
WTN.639-9207

REPRODUCED AT GOVERNMENT EXPENSE

Microstructure of 13½" Thick Wrought Armor

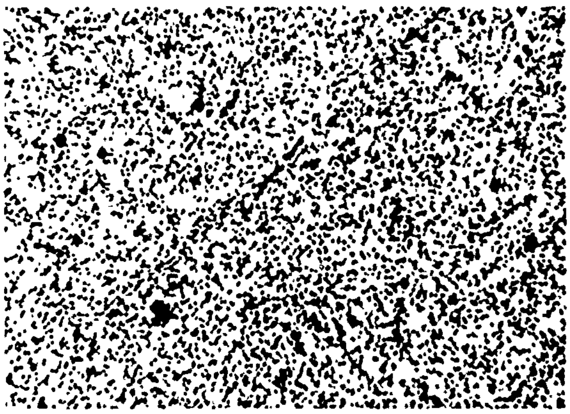
1" BelowSurface | Center of Cross-Section

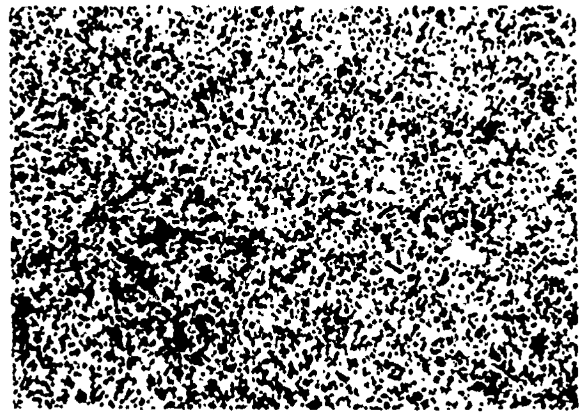




Impact Energy - 50.1 ft.lbs. | Impact Energy - 23.2 ft.lbs.

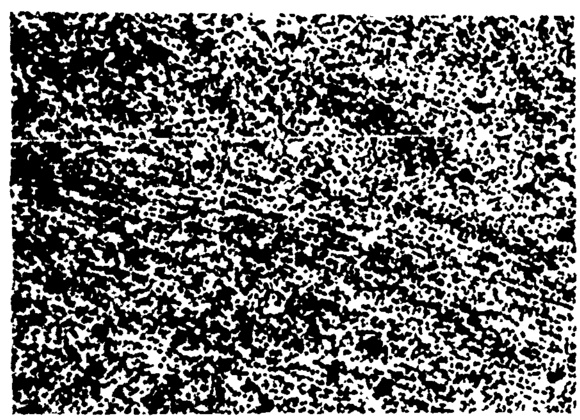
Plate #10 made by C.A possessing a hardness of 244 BHN





Impact Energy - 71.8 ft.lbs. | Impact Energy - 55.3 ft.lbs.

Plate #11 made by C.B possessing a hardness of 217 BHN



Impact Energy - 55.8 ft.lbs. | Impact Energy - 26.5 ft.lbs.

Plate #12 made by C.C possessing a hardness of 211 BHN

All Structures Etched in 4% Picral, Mag. -1000X

Figure 33

APPENDIX A

Minutes of Meeting on Heavy Wrought
Armor - 14 November 1946

MINUTES OF MEETING - 14 NOVEMBER 1946

THE ENGINEER'S CLUB, PHILADELPHIA, PENNA.

HEAVY WROUGHT ARMOR

Attendance:

Mr. C. W. Snadecki	Bethlehem Steel Co.
Mr. J. H. Stoll	" " "
Mr. G. W. Struble	" " "
Mr. H. V. Joyce	Carnegie-Illinois Steel Corp.
Mr. R. B. Cooney	" " " "
Mr. F. E. Goeckler	The Midvale Co.
Mr. J. C. Hawkins	Jones & Laughlin Steel Corp.
Mr. E. L. Hollady	Chief of Ordnance, Materials Branch
Mr. R. A. Webster	" " " " "
Mr. H. J. Rouse	Aberdeen Proving Ground, Md.
Mr. J. F. Sullivan	Watertown Arsenal
Mr. A. Hurlich	" "

1. Mr. Hollady opened the meeting by emphasizing the necessity for formulating a specification for heavy wrought armor. Vehicles now being designed are to be protected with considerably heavier armor than in the past and the procurement of this armor must be prepared for. In view of the lack of suitable armor piercing projectiles to adequately proof armor ranging from 4" to 12" in thickness and also in view of the considerable uncertainty which exists as to the type and caliber of projectiles such armor is intended to provide protection against, it was considered advisable to prepare a specification whose requirements would be non-ballistic in nature and would incorporate those metallurgical features which, from past experience, have been found to correlate best with ballistic performance.

2. The philosophy of the proposed metallurgical specification requirements for heavy wrought armor was described by Mr. Sullivan. During the war years the Watertown Arsenal Laboratory had accumulated a large amount of data on both the metallurgical and ballistic characteristics of armor which indicated a good correlation between such factors as hardness and resistance to penetration, and notched bar impact properties and resistance to brittle failure under shock loading conditions. Extrapolation of these data, buttressed by considerable supporting evidence accumulated in the case of heavy cast armor, provides the basis of the proposed non-ballistic specification requirements for heavy wrought armor.

3. Mr. Goeckler recounted some of the early experiences of the Navy Steering Committee and stated that it was found at Dahlgren that no satisfactory correlation exists between the metallurgical and ballistic characteristics of Class A armor and that both in this country and abroad the ballistic test

was the only generally accepted and recognized criterion for heavy armor. The Watertown Arsenal representatives emphasized that, for homogeneous armor, particularly when attacked by undermatching projectiles such as would most likely be the case with the armor under consideration, good correlation between metallurgical and ballistic properties exists. It was also pointed out that some of the lack of observed correlation, particularly in the case of Class A armor, may be traced to the variability of the ballistic test.

4. Mr. Stoll and Mr. Joyce stated that heavy armor producers traditionally manufactured armor to defeat specific projectiles. Representatives of the armor producers would prefer to have the Ordnance Department list specific ballistic requirements in terms of type, caliber, obliquity, and velocity of projectiles against which protection is desired and they would then try to produce armor to meet those requirements. This discussion crystallized about the point that, as yet, no clear statement has emerged from the designers as to the specific function of the heavy armor on the experimental vehicles being contemplated.

5. It cannot be too greatly emphasized that the optimum properties desired in armor are greatly dependent upon the type and caliber of the attacking projectile. A wide range of attacking projectiles must, of course, be anticipated in service, but definition of the most probable type of expected attack would aid immeasurably in choosing the desired armor properties. The Ordnance Department was urged to provide information on this subject.

6. The point was made that large caliber naval projectiles would not provide a satisfactory test for the heavy armor to be procured by the army since attack by these projectiles is considerably different from that of high velocity, smaller caliber artillery projectiles. The optimum hardness of armor to defeat the latter type of attack is significantly higher than in the former case. Mr. Goeckler offered the opinion that best protection against high velocity undermatching projectiles is provided by face hardened armor and stated that Class A armor should be considered for the subject application.

7. A general discussion of the specification requirements took place, of which the following is a brief digest:

a. Paragraphs E-1a and E-1b. The range of chemical composition listed in Table I was considered difficult to meet, particularly as regards carbon content. Segregation during solidification may alone account for a variation greater than permitted in Table I. A suggestion was made that plates having carbon above 0.40% be accepted and marked to assist fabricator in determining welding techniques.

b. Paragraph E-6a. The flatness tolerance was recommended. It was felt that vehicle designers and armor producers should decide some practicable tolerance.

c. Paragraph E-6b. Permissible thickness variation may have to be greater in the case of forged armor.

8. The main discussion centered about the notched bar impact test requirements of Table II. The heavy armor manufacturers are reluctant to accept these requirements without first having a significant amount of data accumulated to show that it is possible to meet the requirements. The Watertown Arsenal Laboratory has obtained data from 3 8" thick wrought plates produced by Carnegie-Illinois Steel Corp. which satisfactorily met the requirements. The Office, Chief of Ordnance, will arrange to procure samples of heavy wrought armor from the Naval Proving Ground to provide the Watertown Arsenal Laboratory with sufficient armor samples produced by a number of manufacturers to obtain the desired data.

9. Until the data described in the preceding paragraph is procured, representatives of the heavy armor manufacturers suggest that the armor be purchased on tensile strength requirements alone with all attempts made to meet the other requirements. Notched bar impact tests will be made for information only during this initial period. No definite decision was made relative to this suggestion.

10. The laboratory phase of the heavy armor research program was described by Mr. Hurlich. It was generally agreed that a research program of this type was necessary for the development of improved heavy armor.

A Hurlich
A. HURLICH
Armor & Ammunition Branch

APPENDIX B

Tabulated results of Hardness and Impact Tests

TABLE I

Results of Brinell Hardness Tests

Plate No.	Section	BHN Readings at 1" Intervals across Thickness	Ave. BHN
1	L*	255, 248, 241, 248, 255	
	T(X)	255, 248, 248, 248, 255	250
2	L	285, 285, 285, 285, 285	
	T	285, 285, 285, 285, 285	285
3	L	277, 255, 255, 269, 269	
	T	269, 269, 255, 269, 277	266
4	L	269, 262, 255, 255, 255, 262	
	T	262, 262, 255, 255, 255, 262	260
5	L	217, 217, 217, 217, 217, 217	
	T	217, 217, 217, 217, 217, 217	217
6	L	241, 229, 229, 235, 248, 248	
	T	255, 248, 241, 229, 241, 241	240
7	L	269, 269, 269, 255, 255, 255, 255, 255, 255, 255	
	T	277, 269, 269, 269, 255, 255, 255, 255, 255, 255	260
8	L	229, 229, 223, 217, 217, 217, 217, 223, 223, 223	
	T	229, 229, 229, 223, 217, 217, 223, 223, 223, 223	223
9	L	201, 201, 201, 201, 201, 201, 201, 197, 197, 197	
	T	197, 197, 197, 197, 201, 201, 201, 201, 197, 197	199
10	L	248, 248, 248, 248, 241, 241, 241, 241, 241, 241, 241, 241	
	T	248, 248, 248, 248, 248, 241, 241, 241, 241, 241, 241, 241	244
11	L	229, 229, 229, 229, 217, 212, 207, 207, 217, 217, 217, 217, 217	
	T	229, 229, 229, 217, 212, 207, 207, 212, 212, 212, 212, 212, 212	217
12	L	212, 212, 212, 212, 212, 207, 207, 207, 207, 207, 207, 207, 207	
	T	217, 217, 217, 217, 217, 217, 212, 212, 212, 207, 207, 212, 212	211

*L - Longitudinal cross section

(X)T - Transverse cross section

TABLE II

Results of V-Notch Charpy Impact Tests at -40°F (-40°C)

Wtn. Plate No.	Specimen Direction*	Tests 1" Below Surface of Plate Ft.Lbs.	Fracture**	Tests at Center of Plate Ft.Lbs.	Fracture**
1	L	102.6	F	73.7	Cf trace
	L	99.5	F	48.4	Cf 1/3
	L Ave. of 2 tests	101.1		61.1	
	T	61.9	F	44.9	Cf 1/3
	T	60.0	F	55.9	Cf 1/3
	T Ave. of 2 tests	61.0		50.4	
2	L	84.2	F	75.7	F
	L	80.6	F	64.7	F
	L Ave. of 2 tests	82.4		70.2	
	T	40.7	F woody	35.8	F woody
	T	38.2	F woody	31.1	F woody
	T Ave. of 2 tests	39.5		33.5	
3	L	48.4	F	59.6	F
	L	39.1	F	65.6	F
	L Ave. of 2 tests	43.8		62.6	
	T	45.8	F	46.2	Cf 1/4
	T	49.2	F	63.7	F
	T Ave. of 2 tests	47.5		55.0	
4	L	69.8	F	60.9	Cf 1/4
	L	74.2	F	76.2	Cf trace
	L Ave. of 2 tests	72.0		68.6	
	T	45.8	F	40.7	Cf 1/2
	T	44.1	F	48.4	Cf trace
	T Ave. of 2 tests	45.0		44.9	

(Continued)

TABLE II (cont.)

Wtn. Plate No.	Specimen Direction*	Tests 1" Below Surface of Plate Ft.Lbs.	Tests 1" Below Surface of Plate Fracture**	Tests at Center of Plate Ft.Lbs.	Tests at Center of Plate Fracture**
5	L	100.5	F	37.8	Cfe
	L	100.0	F	45.3	Cfe
	L Ave. of 2 tests	100.3		41.6	
	T	67.5	Cf trace	36.6	Cf 3/4
	T	60.0	F	29.5	Cf 3/4
	T Ave. of 2 tests	63.8		33.1	
	T			37.8	Cf 3/4
	T			37.4	Cf 3/4
	T			29.1	Cf 3/4
	T			29.9	Cf 3/4
	T			45.7	Cf 3/4
	T			37.0	Cf 3/4
	T Ave. of 8 tests			33.9	
6	L	56.4	F	41.1	Cf 1/2
	L	52.4	F	50.6	Cf 1/3
	L Ave. of 2 tests	54.4		45.9	
	T	56.4	F	47.5	Cf 1/4
	T	57.5	F	44.1	Cf 1/4
	T Ave. of 2 tests	57.0		45.8	
7	L	71.3	F	58.2	Cf 1/2
	L	54.6	Cf 1/3	39.1	Cf 3/4
	L Ave. of 2 tests	62.9		48.7	
	T	23.2	Cf 1/2	30.3	Cf 1/2
	T	41.5	Cf trace	26.5	Cf 1/2
	T Ave. of 2 tests	32.4		28.4	
	T	40.7	F	21.8	Cf 1/2
	T	44.1	F	24.7	Cf 1/2
	T	28.0	Cf 1/3	24.7	Cf 1/2
	T	26.9	Cf 1/3	26.9	Cf 1/2
	T	38.2	Cf trace	27.3	Cf 1/2
	T	34.2	Cf 1/4	24.7	Cf 1/2
	T Ave. of 8 tests	34.6		25.9	

(Continued)

TABLE II (cont.)

Wtn. Plate No.	Specimen Direction*	Tests 1" Below Surface of Plate		Tests at Center of Plate	
		Ft.Lbs.	Fracture**	Ft.Lbs.	Fracture**
8	L	92.3	F	83.1	Cf 1/4
	L	85.7	F	65.6	Cf 1/3
	L Ave. of 2 tests	89.0		74.4	
	T	68.0	F	47.5	Cf 1/2
	T	69.4	F	46.6	Cf 1/2
	T Ave. of 2 tests	68.7		47.1	
	T			52.8	Cf 1/8
	T			47.8	Cf 1/4
	T			40.7	Cf 1/4
	T			45.3	Cf 1/4
	T			45.8	Cf 1/4
	T			41.1	Cf 1/4
	T Ave. of 8 tests			46.0	
9	L	68.4	Cf trace	37.8	Cf 3/4
	L	80.6	Cf trace	43.6	Cf 3/4
	L Ave. of 2 tests	74.5		40.7	
	T	50.6	Cf 1/4	31.1	Cf 1/2
	T	54.6	Cf 1/8	29.1	Cf 1/2
	T Ave. of 2 tests	52.6		30.1	
	T	59.6	F	31.1	Cf 3/4
	T	54.6	Cf trace	30.3	Cf 3/4
	T	56.8	F	29.9	Cf 3/4
	T	55.5	Cf trace	25.8	Cf 3/4
	T	55.9	Cf trace	31.1	Cf 3/4
	T	50.1	Cf 1/4	31.4	Cf 3/4
	T Ave. of 8 tests	54.7		30.0	
10	L	76.6	F	35.4	Cf 1/2
	L	73.2	F	38.2	Cf 1/2
	L Ave. of 2 tests	74.9		36.8	
	T	48.8	F	16.8	Cf 7/8
	T	51.4	F	29.5	Cf 7/8
	T Ave. of 2 tests	50.1		23.2	
	T			26.9	Cf 1/2
	T			26.9	Cf 3/4
	T			28.4	Cf 3/4
	T			22.5	Cf 3/4
	T			19.4	Cf 3/4
	T			24.0	Cf 3/4
	T Ave. of 8 tests			24.3	

(Continued)

TABLE II (cont.)

Wtn. Plate No.	Specimen Direction*	Tests 1" Below Surface of Plate		Tests at Center of Plate	
		Ft.Lbs.	Fracture**	Ft.Lbs.	Fracture**
11	L	103.6	F	112.7	F
	L	94.9	F	112.7	F
	L Ave. of 2 tests	99.3		112.7	
	T	72.3	F	57.3	Cf 1/2
	T	71.3	F	53.2	Cf 1/2
	T Ave. of 2 tests	71.8		55.3	
12	L	75.2	F	39.1	Cf 3/4
	L	68.0	F	38.2	Cf 3/4
	L Ave. of 2 tests	71.6		38.7	
	T	62.3	F	28.0	Cf 3/4
	T	49.2	F	25.0	Cf 3/4
	T Ave. of 2 tests	55.8		26.5	
	T	58.6	F	31.1	Cf 3/4
	T	57.3	F	30.7	Cf 3/4
	T	56.8	F	27.6	Cf 3/4
	T	52.8	F	29.9	Cf 3/4
	T	59.1	F	34.2	Cf 3/4
	T	57.3	F	33.8	Cf 3/4
	T Ave. of 8 tests	56.7		30.0	

Legend:

*Specimen Direction
L - Longitudinal
T - Transverse

** Fracture Ratings
F - Fibrous
C - Crystalline
Cf - Mixed fracture containing a patch or patches of crystallinity surrounded by a fibrous zone.
Cfe - Crystalline with a fibrous edge

Fraction - represents approximate amount of crystallinity in the fractured surface.