WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/549

Completes Problem B-4.18

2 November 1943

Jones and Laughlin 1" Rolled Homogeneous Armor

1. A metallurgical examination has been completed on nine samples of 1" rolled homogeneous armor made by the Jones and Laughlin Steel Corp. and the results are included in this report. The samples received for examination were selected from a group of 16 plates tested at The Proving Center, Aberdeen as a part of the program correlating the effect of hardness on the ballistic properties of armor. Eight of the samples were from plates which had been subjected to penetration tests using 37 MM, 20 MM, and Cal. .50 AP M2 projectiles. The remaining sample was from the cracked area of Plate 12 whose brittle behavior was inconsistent with the results obtained on the other plates in this group subjected to the shock test of 57 MM T1 proof projectiles. The ballistic results were reported in A.P.G. Report AD-508.

2. The results of the metallurgical examination may be summarized as follows:

a. The sections examined were properly heat treated (absence of high temperature transformation products) and the steel quality was acceptable except for plate 8, heat 359 which exhibited a "D" fracture.

b. The hardness values observed at The Proving Center were somewhat higher, for the most part, than those obtained at this arsenal, although, for most plates, the agreement was within the experimental error of the test. As was indicated in the ballistic report (AD-508), the values reported by the manufacturer are unreliable probably because the plates were improperly numbered.

c. Plate 12 was made of good quality steel, properly hardened upon quenching and its inferior shock resistance could not be associated with any metallurgical defects. It is believed that the poor performance of this plate against 57 MM T1 proof projectiles is a function of its hardness. Furthermore, additional testing of high hardness plates is advisable in order to evaluate more completely 1" armor impacted with the 57 MM T1 proof projectile.

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3. Results of the metallurgical tests conducted on the samples are as follows:

a. Hardness Tests

Brinell hardness tests were obtained at three points along the cross-section of the plates as well as on the face and back. In Table I, the results are compared with those reported.

TABLE I

Brinell Hardness Tests

Plate No.	Heat No.	W.A. BHN Values Cross-Section	Face	Back	A.P.G. BHN Values	J&L BHN Values
2	359	302/311	285	285	311	352
3	359	302/311	293	293	311	302/311
4	589	277/277	262	262	293	286/297
5	359	302/302	302	302	316	388/388
6	359	311/321	302	302	321	331/341
7	359	363/363	352	352	358	363/401
8	359	341/352	352	341	370	341/341
12	359	331/331	331	331	310/331	321/331
13	359	285/293	277	293	286	302/302

In some plates, there was a difference in the results obtained by this arsenal and The Proving Center, Aberdeen. The difference, however, is minor except for plate 4, heat 589 and plate 8, heat 359. That the results taken by this arsenal are more accurate is indicated by their effect in producing a smoother curve of ballistic limit versus hardness for caliber .50 AP M2 projectiles.

As was noted by The Proving Center, the values reported by the manufacturer are to be discounted, since it is believed the plates were probably mixed up with respect to numbers and corresponding reported hardnesses.

The hardnesses of the plates tested for shock resistance appear to be those reported by the manufacturer and, therefore, cannot be considered reliable in correlating the shock properties against hardness. In good quality armor, the hardness generally correlates with the amount of deformation a plate will withstand without cracking when subjected to an overmatching proof projectile. Lowering the hardness increases the ductility and permits a greater amount of deformation at a given proof projectile velocity. This trend does not show up to any extent in the shock tests performed using the hardnesses reported. Consequently these ballistic data should be substantiated with supplementary tests in order to discover whether the 57 MM T1 proof projectile possesses idiosyncracies or whether tests performed are not truly representative of the shock performance that is generally observed.

b. Fracture Test for Steel Quality

The fracture ratings of the plates sampled in the longitudinal and transverse directions are as follows:

Plate No.	Heat No.	*Longitudinal Fracture	Transverse Fracture
2	359	B	B
3	359	C	C
4	589	C	C
5	359	C	C
6	359	C	C
7	359	C	C
8	359	D	D
12	359	C	C
13	359	C	C

*Longitudinal fracture - section is transverse to major rolling direction or fracture surface parallel to direction of greatest reduction.

Except for plate 8, the plates possessed acceptable steel quality according to the fracture standards of Proposed Specification AXS-488, Revision 2, Appendix 1. Plate 8 possessed undesirably large laminations in the center of the plate which would probably affect the penetration and back spalling characteristics of the armor if it were subjected to impacts of overmatching projectiles at high obliquities.

c. Fibre Fracture Test

Specimens from all the plates broke in a fibrous manner when fractured under a forge hammer, thus indicating that the plates were properly heat treated and would satisfactorily withstand a severe ballistic shock test compatible with the respective hardnesses and thickness.

d. Hardenability and Chemical Compositions

Jominy and quench hardenability tests were conducted on plates 3 and 6 from heat 359 and plate 4 from heat 589. See Figure 1. The hardenability observed in both heats is adequate to completely harden 1" plates using a mild water quench.

The chemical compositions of three plates sampled are as follows:

Plate No.	Heat No.	C	Mn	Si	S	P	Ni	Cr	Mo	B	V
3	359	.26	1.48	.23	.017	.012	Tr	.01	.40	nil	nil
6	359	.26	1.50	.26	.016	.013	Tr	.02	.40	nil	nil
4	589	.26	1.53	.22	.017	.011	Tr	.02	.25	nil	nil

The heats were of the manganese-molybdenum type steel with boron added. The effect of the boron is reflected in the increased hardenability of both heats, but the analysis did not reveal the presence of boron which was reported to have been added. This condition has been observed in previous work on boron, for it is a difficult element to detect in the small amounts used and its effect is more readily correlated with the amount added than the amount found by analysis.

The lower hardenability of Heat 589 is undoubtedly attributed to the lower molybdenum content of this heat.

e. Impact Tests

Charpy impact tests were conducted on bars cut in the transverse rolling direction of several of the plates to compare the notched bar strength of Plate 12 with plates of different hardness. The results are listed in Table II.

TABLE II

V-Notched Charpy Impact Strength of
1" Rolled Homogeneous Plates Made by
Jones & Laughlin Steel Corp.

Plate No.	BHN	68°F. Ft.Lbs.	68°F. Fract.	-40°F. Ft.Lbs.	-40°F. Fract.	-94°F. Ft.Lbs.	-94°F. Fract.
4	277	49.0	F	41.5	F	31.5	FC
				47.0	F	42.5	Fc
6	311/321	57	F	49.0	F	31.0	FC
		55	F	51.0	F	35.0	FC
12	331	27.5	F	26.0	Cfe	17.0	C
		46.0	F	27.0	Cfe	15.0	C
7	363	25.5	FH	15.5	Cfe	12.0	C
		28.0	FH	19.5	Cfe	16.5	C

F - Fibrous C - Crystalline Fc - Large F small c FC - Mixed F and C
Cfe - C with F edge FH - F at high hardness

The low temperature impact strength is markedly affected by hardness, the plates of higher hardness being more brittle. Lowering the temperature is considered to be proportioned to increasing the speed of impact. Consequently, plates of lower hardness should be less susceptible to cracking under the proof projectile test.

f. Macro Examination

Macro-etched sections were photographed as shown in Figure 2. No excessive laminations were apparent in the areas examined, but the macro-etch is not as selective as the fracture test in revealing steel quality. The plates were cross-rolled as indicated by the similarity of etching characteristics in the transverse and longitudinal sections. The variations in the degree of attack by the etchant is associated for the most part with the hardness variations of the plates.

g. Microscopic Examination

The plates contained some segregations of nonmetallics which were most prevalent in Plate 8. Typical segregations are shown in Figures 3A and 3B.

The microstructure of the plates consisted of a tempered martensite in which no high temperature transformation products were observed. Typical structures are shown in Figure 3. The structure at a hardness of 363 BHN was a tempered martensite as shown in Figure 3E. This specimen was etched rather deeply to bring out the acicularity. This etching accentuated the presence of carbides to a greater extent than in the softer plates as shown in Figure 3F and G.

The steel in the plates examined possessed a fine grained structure.

The surfaces of all the plates examined were decarburized approximately the same amount; about .002" complete decarburization to ferrite and .010" partial decarburization.

h. General Considerations

The plates examined were properly heat treated to various hardness levels, whose values were found to be somewhat different from those reported. Except for Plate 8, the plates were relatively free from undesirable laminations. This plate, however, would, probably, exhibit a brittle exit condition under the perforation of overmatching projectiles especially when tested at high obliquities.

The variation in the ballistic limits of the plates is believed to be a function of the hardness.

Sufficient data were not obtained to accurately evaluate the characteristics of 1" homogeneous armor when subjected to the shock test of 57 MM T1 projectiles. Since only plate No. 12 of the plates tested for shock was impacted at a velocity high enough to cause cracking, it is difficult to make an accurate comparison of the shock properties of the plates. Plate 12 was the only plate subjected to the 57 MM T1 slug test which was investigated at this arsenal, and so no conclusions regarding its failure are possible. It is felt, however, that the steel in this plate was of acceptable quality properly heat treated, and that the hardness and severity of the test were responsible for the cracking observed.

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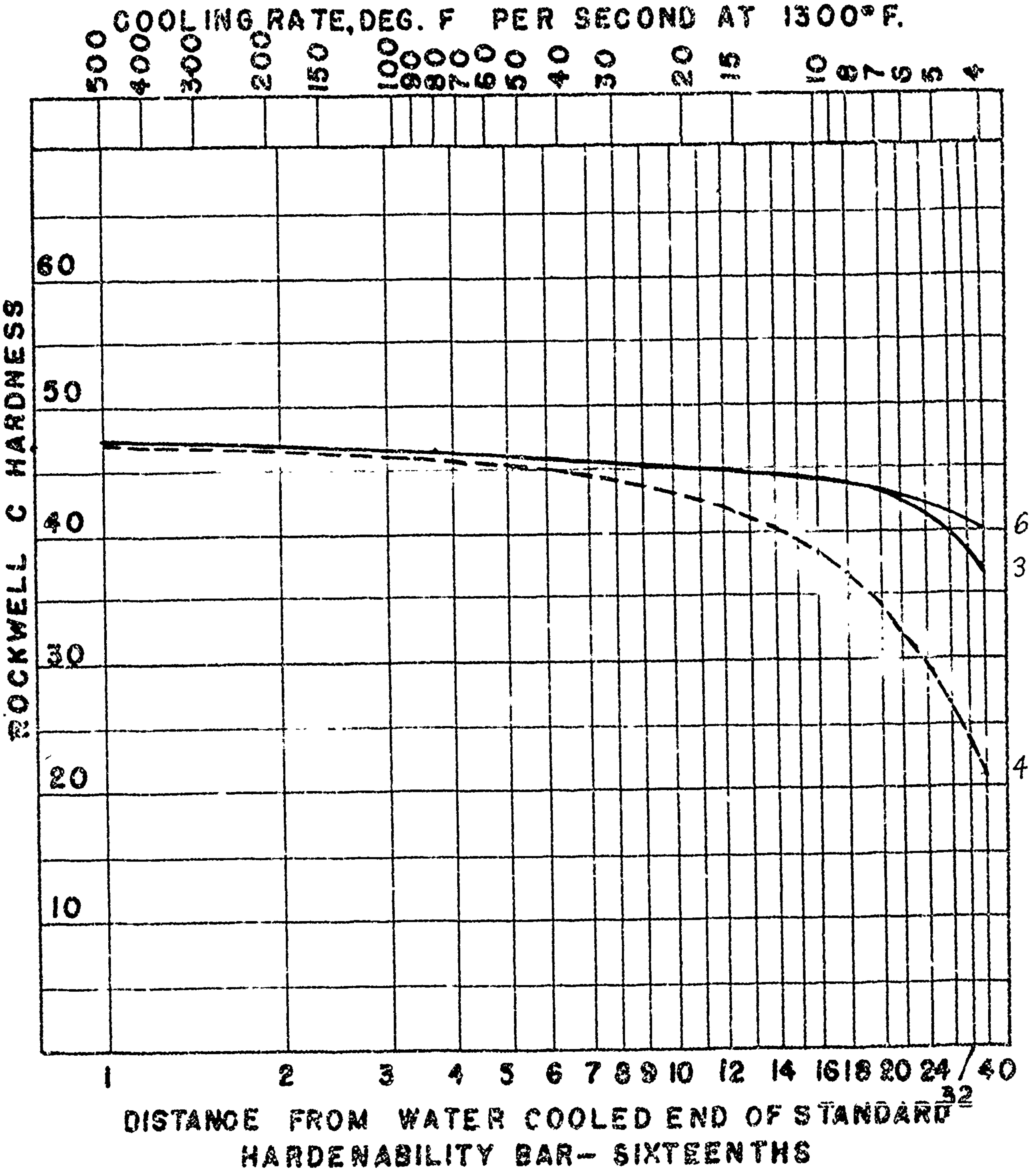
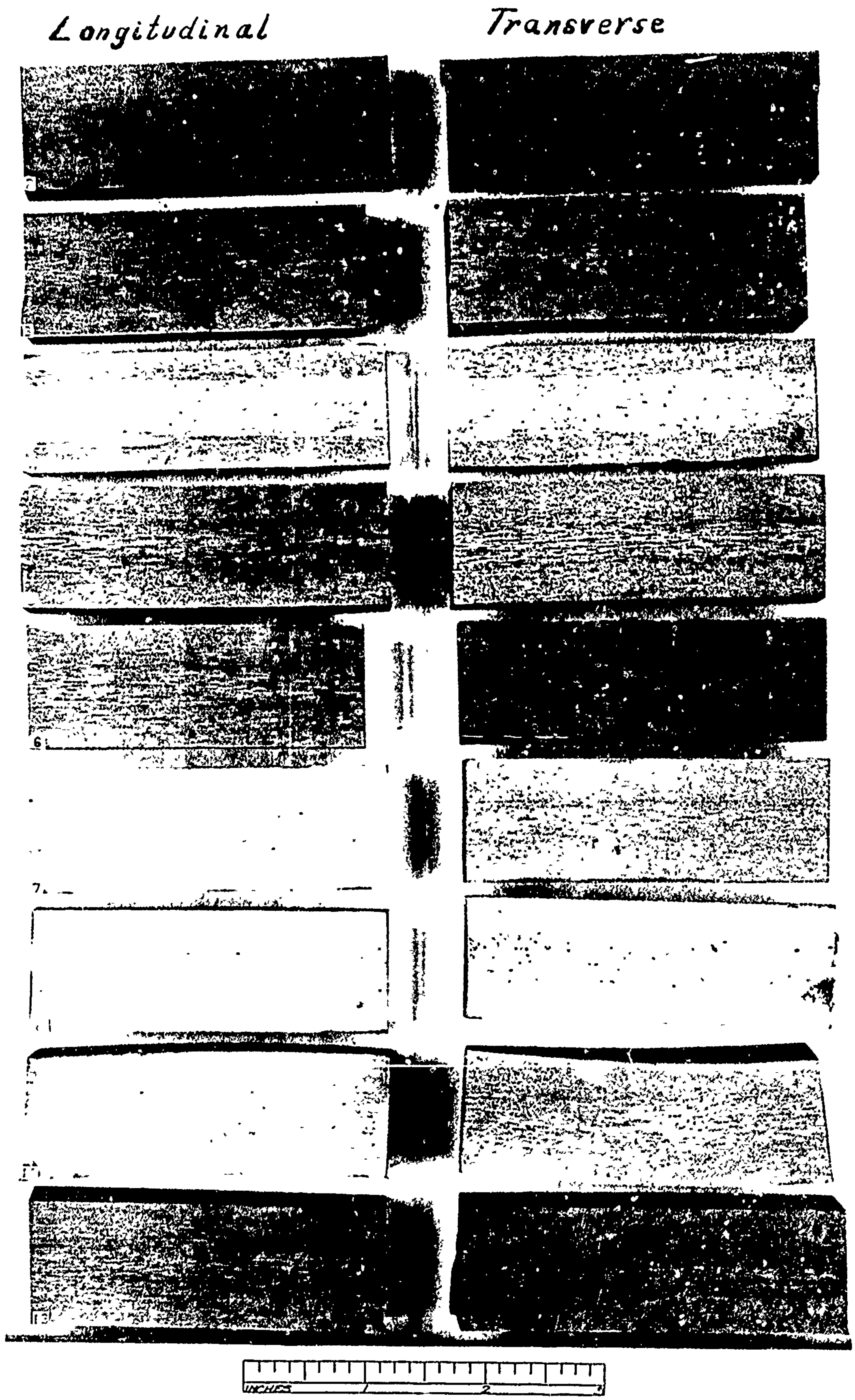


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	B	V	QUENCH TEMP	TIME	G.S.
3	J-359	.26	1.48	.23	017	.012	Tr	.01	.40	NIL	NIL	1600	2 Hrs.	
6	J-359	26	1.50	.26	016	013	Tr	.02	.40	NIL	NIL	1600	2 Hrs.	
4	J-589	.26	1.53	22	017	011	Tr	.02	.25	NIL	NIL	1600	2 Hrs	

FIGURE 1

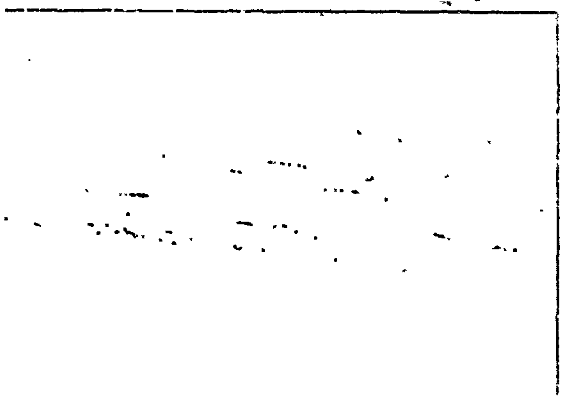


ORDNANCE DEPT U.S.A.
WATERTOWN ARSENAL

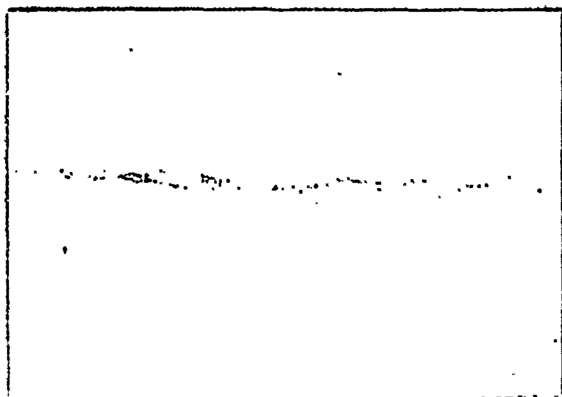
MACROETCHED SECTIONS OF 1" ROLLED HOMOGENEOUS ARMOR
MADE BY JONES AND LAUGHLIN STEEL CORPORATION.
31 AUGUST 1943 WTN.710-2142

Figure 2

MICROSTRUCTURE OF PLATES

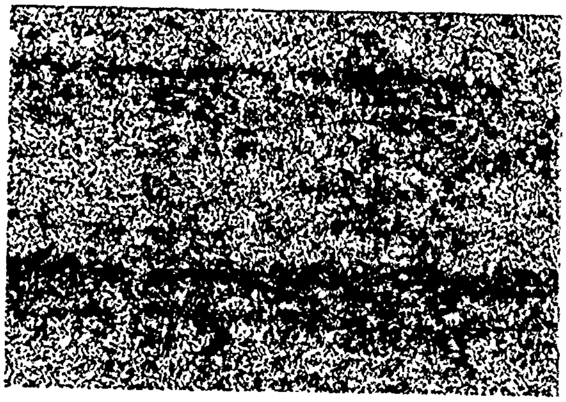


X100 -A- Unetched.



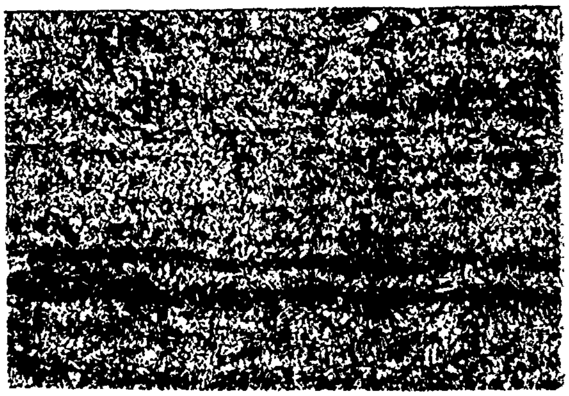
X100 -B- Unetched

Plate 8: Two types of non-metallic segregations observed in the plates.



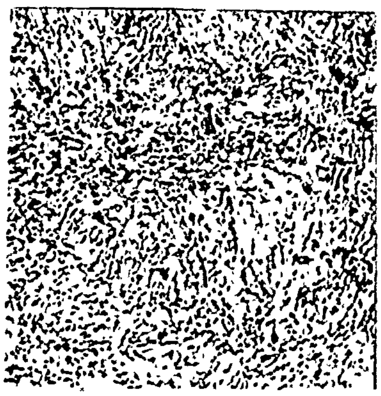
X100 -C- Picral-Nital

Plate 8: Slight degree of banding at 345 BHN.



X100 -D- Picral Nital

Plate 4: Greater degree of banding at a lower hardness of 277 BHN.



X1000 -E- Picral-Nital

Plate 7: Tempered martensite at 363 BHN

X1000 -F- Picral-Nital

Plate 13: Tempered martensite at 289 BHN

X1000 -G- Picral-Nital

Plate 4: Tempered martensite at 277 BHN

Figure 3