321/10

[redacted] LABORATORY

Watertown Arsenal, Watertown, Massachusetts - April 14, 1941

INDEXED

For purposes of record, the attached Metallurgical Report on Bullet Core Steel, Experiment #240, Bethlehem Steel Company, is distributed as:

REPORT #8 - Subcommittee for Armor Piercing Projectile and Bullet Core Steel.

COPY # _____

R. C. LEECH
2nd Lt., Ord. Dept.
Secretary

(6) # METALLURGICAL REPORT

ON

BULLET CORE STEEL.

(1)

(14) WA-321/10

(12) 26

PREPARED FOR

EXPERIMENT #240

(11) 25 Aug 38

[redacted]

BETHLEHEM STEEL COMPANY

BETHLEHEM, PA.

370900

81 9 11 087

FOR INTER-OFFICE CORRESPONDENCE

SUBSIDIARY COMPANIES OF BETHLEHEM STEEL CORPORATION

BETHLEHEM, PA. 8/25/38

FILE REFERENCE

FROM T G Foulkes — Experiment #240

TO A D Shankland

SUBJECT BULLET CORE STEEL

OBJECT:

To determine the internal condition of billets of bullet core steel cast in larger ingots than specified in U. S. Army Spec. 57-107-8A.

CONCLUSION:

The indications from the data shown in this investigation, wherein comparisons of 7-1/2" Sq., 16" x 19", 18" x 21", 20" corrugated and 21-1/2" corrugated ingots were made, are that there would be a decided advantage both to customers and ourselves by the use of larger ingots than those now specified in U. S. Army Spec. 57-107-8A. The benefits which would be derived from their use would be:

(1) Greater uniformity of material
(2) Less segregation of important elements.
(3) Equally clean steel as judged by hot acid etch tests.
(4) Improved deliveries and more economical manufacturing due to hot working larger ingots under usual rolling equipment and practice instead of hammer cogging and rolling smaller ingots.

DISCUSSION:

It has been considered objectionable to produce armor piercing bullet core steel to U. S. Army Specification 57-107-8A due to the fact that the specification requires that the ingots "shall be not less than 4-1/2" square nor more than 10" square." The use of small ingots such as the customary 7-1/2" square when producing steel to this specification increases production costs and this experiment was undertaken to determine whether the use of the small ingots is justified from a segregation and cleanliness standpoint.

PROCEDURE AND RESULTS:

Data on three 6-ton electric furnace heats as well as data on three open hearth heats is shown on table I. The three E.F. heats HX4100, HX-4099, and GX-4880 were made primarily to fill orders for Frankford Arsenal to U. S. Army Spec. 57-107-8A. Therefore, about half of each

heat was cast in 7-1/2" square ingots to meet the requirements of the specification while the balance of the heats were cast into 16" x 19" and 18" x 21". Comparable data between the 7-1/2" square ingots and the larger ingots is available only on one heat GX4880. Data is shown for the larger ingots only on the other two electric furnace heats; while table II shows the data for the 7-1/2" square ingots on GX4880.

Data for three acid open hearth heats 28H654, 26H553 and 28H641 are also shown on Table II. These heats were all cast in large ingots (20" and 21-1/2" corrugated). The data on these larger ingots of acid steel are included since the results on segregation, etc. are comparable with the larger ingots of electric furnace steel.

In studying table I and II, the following subjects will be considered in order. (1) Segregation by Chemical analysis, (2) Yields, ingot to billet and (3) Etch tests results.

SEGREGATION:

This feature may best be studied by considering plates III to VI inclusive where data on chemical analysis of drillings taken from various locations through the heats is plotted.

Plate III shows data on carbon segregation. In the larger size ingots cast of electric furnace steel, the segregation of carbon appears slightly worse than in the smaller 7-1/2" square ingots. Carbon segregation is not excessive however, in the larger ingots after the discards are made. The extreme carbon segregation shown for the midway location on the 7-1/2" square billets is about equivalent to the extreme variation shown near the top of the 18" x 21" ingot, heat GX-4880.

The open hearth ingots show data for the midway locations throughout the heat. Carbon segregation as judged from this data is not excessive, in fact, it is excellent.

It should be noted from the curves shown on plates III, IV, V and VI that the segregation data for heats HX4100, HX4099 and GX4880 (16" x 19" and 18" x 21") are for one ingot only; while the data for GX4880 (7-1/2 x 7-1/2") are for all ingots and the data for 28H654, 26H553 and 28H641 (20" corrugated) are for entire heats (between six and eight ingots to a heat).

Plates IV and V show the segregation in Tungsten obtained on the same heats. A glance at plate IV reveals excessive Tungsten segregation for the 7-1/2" square ingots from heat GX4880 which is unequaled in the larger size ingots. Thus, a decided improvement in Tungsten segregation for the large ingots is apparent.

Plate VI shows chromium segregation for two 16" x 19" ingots from two electric furnace heats. No comparable data is available on other heats. Chromium segregation appears excessive for HX4099.

Segregation data for Manganese is not plotted due to the fact that practically no segregation was exhibited on any heat.

NOTE: Drillings for chemical analysis were taken from either four or four and one-half inch billets in the case of all large ingots. In the case of the 7-1/2" square ingots, the drillings were taken from 2" x 2" billets.

YIELDS:

As a good indication of the amount of pipe and segregation encountered, a comparison of yields, ingot to billets has been made. The available data made it impossible to make strictly accurate comparisons in all cases. For instance, yields were figured down to 4" and 4-1/2" billets in the case of the large ingots because the discards for pipe were taken at this size and complete records were available at this point while the 7-1/2" square ingots did not have the discards for pipe taken until the billet had reached 2" square section.

By studying the yield column of table I, it is apparent that yields between 60 and 85% (approximately) were obtained on the larger ingots while a yield of 79%(approximately) (table II) was obtained from the 7-1/2" square ingots. The average yield on the larger ingots was 71.4%.

This data would point to the desirability of the use of 7-1/2" square ingots but this conclusion should not be made since the comparison between the same heat GX4880 where a yield of 84.2% is shown for an 18" x 21" ingot as compared with a yield of 78.8% for the 7-1/2" square ingots shows superiority for the larger size ingot for the same heat. As a matter of fact, the difference in cost for processing the two ingot sizes would overbalance the difference in average yields of 7.4% anyway.

ETCH TEST RESULTS:

A series of macrographs are shown of etched discs on some of the heats. In order to understand what is represented by these macrographs, it is necessary to understand the identification system. This will be explained as the macrographs are considered.

HEAT HX4100:

Plate VII represents a 50-50 HCl hot etch of a disc cut from the third billet sheared from the top of the ingot. It is identified as T3. The first billet sheared from the top end of the ingot would be T1, the second T2, etc. Ingots are rolled bottom first on the 35" mill. It will be noticed that pipe is in evidence at the center of this 9" square billet T3. This billet was rejected and a disc cut from the next billet T4. It was necessary to cut back on this same billet to obtain sound metal. The etch of the second disc from T4 is shown as plate VIII and sound metal was found.

Plates IX and X show discs cut from billets 8 and 1 counting from the bottom. Since fourteen billets were produced from the ingot, B8 represents an etch from the center of the ingot and B1 represents the bottom of the ingot. Both B8 and B1 show sound metal.

HEAT HX4099:

Plate XI represents a cut from the third billet from the top (T3). Pipe is shown at the center. A disc from the bottom of T3 showed the pipe to clear up at the bottom so T3 was rejected and T4 was the first billet used. Plates XII and XIII show sound steel obtained at the center and bottom of the ingot as exhibited by discs from B8 and B1.

HEAT GX4880 - (18" x 21")

In discussing the etches on this heat, it will be necessary to again explain identification as a different system was used for this type of steel at the time the rollings took place. The system has been changed since that time to conform with present etch identification on the 35" mill.

Eight billets were rolled from the ingot. Plate XIV identified as T is the extreme top cut showing pipe, plates XV (TA), XVI (T1), XVII (T4) show cuts made progressively in order from the top of the first 825# billet. Segregation is shown to decrease successively to T4 and all material up to and including this point was rejected (about 400# or half the billet). Sound metal was found throughout the balance of the ingot.

HEAT GX4880 (7-1/2" SQUARES)

Plate XVIII represents discs cut from the tops and bottoms of the first ingot cast (1) and sixth ingot cast (6) and the eleventh ingot cast (11): "A" designates the top and "B" designates the bottom. Eleven ingots of this size were cast so the discs represent top, middle and bottom of the series. The discs were cut from 2" x 2" billets. BA6 and BA11 show slight cracks while there are slight signs of segregation apparent on A11. These billets were cut back for additional discard where segregation and cracks were noted as in BA6, A11 and BA11. However, the discs BA6, A11 and BA11 showing these conditions were included in plate XVIII because all the discs were taken at identical locations to enable a fair comparison. Disc A6 on plate XVIII was by error drilled for chemical analysis before photographing, thus accounting for the holes shown in this disc.

Etched discs were not photographed on the open hearth heats.

In comparing etched discs of sound material from the large ingots with those obtained from the small ingots, equally clean material is exhibited, that is, the presence of non-metallics are no more numerous in discs shown on plates 8, 9, 10, 12 and 13 than on A1, A6, BA1, BA6 and BA11 of plate XVIII.

ppk/rd

T. G. Foulkes
Metallurgical Supervisor.

Per:

CC: JHS HW PEM SDG HCB
JES RRS MWD File

Heat Number	Melting Process	Number and Type of Ingots Cast from Heat	Type of Ingot Rolled Experimentally	Processing of Expe Ingots at Mill
HX 4100	Elec.Fce.-6 Ton	18 - 7-1/2" Square 1 - 16" x 19"	16 x 19" Wt.-5,060	35" Mill-Rolled to 13" x Pits-rerolled to 4" x 4"
HX 4099	Elec.Fce.-6 Ton	17 - 7-1/2"Square 1 - 16" x 19"	16" x 19" Wt.-5,000	35" Mill-Rolled to 13" x Pits - rerolled to 4" x
GX 4880	Elec.Fce.-6 Ton	11 - 7-1/2"Square 1 - 18" x 21"	18" x 21" Wt.-6,860	Pits - rolled to 4-1/2"
28H654	Acid Open Hearth Fce.	5 - 20" Corrugated 3 - 21-1/2" "	20" Corr. 21-1/2"Corr. 39,700 Total Wt.	35" Mill-Rolled to 16" x Pits-rerolled to 14" x 9 " " " 4-1/2"
26H553	Acid Open Hearth Fce.	6-20" Corrugated	20" Corr. 30,400 Total Wt.	35" Mill-Rolled to 16"x1 Pits-rerolled to 4 1/2 x
28H641	Acid Open Hearth Fce.	6-20" Corrugated 1 - 21-1/2" Corr.	20" Corr. 21-1/2" Corr. 35,200 Total Wt.	35" Mill-Roll to 16" x 1 Pits-rerolled to 4-1/2"

fe

Processing of Experimental Ingots at Mill	No. of Billets Rolled from Ingot	Total Weight of Billets Rolled	Etch Test Results on Billets	No. of Billets Rejected due to Pipe and Segregation	Weight of Billets Rejected	% Yield to Billets (4" to 4-1/2"
Mill-Rolled to 13" x 13" x 4800 rerolled to 4" x 4" x 300#	14	4,220	T1,T2,T3, & T4 piped rejected due to pipe T4 - cut back-piped (Bottom O.K.(B1 & M1 O.K.	4	1,225	59.1
Mill-Rolled to 13" x 13" x 4,500 - rerolled to 4" x 4" x 300	14	4,200	T1, T2 - piped T3 cut back-piped-Bott. O.K. B1 and M1-O.K. T1, T2 & T3 rejected (Pipe)	3#	900	66.8
- rolled to 4 1/2"x4-1/2"x825	8	6,190	T - cut back piped T4 - cut back piped T4 - O.K. B1 - cut back-dirty T1 - " " pipe	Part of one	400	84
Mill-Rolled to 16" x 13"-30,000 rerolled to 14" x 9" " " 4-1/2" x 4-1/2"	71	29,885	8 tops showed light segregated centers 2B - O.K.	Part of one	215	75.
Mill-Rolled to 16"x13"-22,800 rerolled to 4 1/2 x 4-1/2	64	23,200	6 tops showed scattered segregation 6 bottoms O.K.	1	595	74.
Mill-Roll to 16" x 15"-27,300 rerolled to 4-1/2" x 4-1/2"	63	26,415	6 tops showed cracked centers and 6 bottoms scattered segregation All rejected 1 top scattered segregation (cut back) 7 bottoms O.K.	6 probably about 350# each	Not Recorded	69. Est mat

SEGREGATION DETERMINATION BY A

Yield to Billets (4" to 4-1/2" Sq.)		Ladle	Center T2	Midway T2	Outside T2	Center T3	Midway T3	Outside T3	Center T4	Midway T4	Outside T4
59.1%	C	.98	.80	.99	.99	1.00	.99	.98	.98	.98	.9
	Mn	.30	.30	.32	.32	.31	.33	.32	.31	.32	.3
	P	.021									
	S	.013									
	Si	.31									
	Ni	.06									
	Cr	.58	.58	.63	.65	.47	.54	.47	.54	.51	.5
	W	3.95	3.76	3.95	3.98	3.97	3.90	3.95	3.97	3.96	3.9
66.8%	C	.98				.85	.98	.99			
	Mn	.31				.34	.31	.30			
	P	.017									
	S	.013									
	Si	.15									
	Ni	.04									
	Cr	.51				.43	.44	.48			
	W	4.06				3.85	3.92	3.97			
84.2%	C	1.03	.96	.97	1.01				1.14	.96	1.
	Mn	.35	.28	.35	.34				.33	.34	.
	P	.016									
	S	.011									
	Si	.31		T						T4	
	Ni	.06									
	Cr	.54									
	W	3.95	4.12	4.18	4.25				4.37	4.17	4.2
75.0%	C	.91		.93			.92				
	Mn	.30									
	P	.023									
	S	.028		1T			3T				
	Si	.22									
	Ni	.13									
	Cr	.53									
	W	3.55		3.67			3.71				
74.4%	C	1.02		1.04			1.03				
	Mn	.31									
	P	.024									
	S	.026		1T			3T				
	Si	.22									
	Ni	.12									
	Cr	.54									
	W	3.55		3.55			3.53				
69.0% Esti-mated	C	1.02		1.07			1.05				
	Mn	.31									
	P	.022									
	S	.028									
	Si	.29		1T			3T				
	Ni	.11									
	Cr	.53									
	W	4.13		4.16			4.17				

INATION BY ANALYSIS

dway	Outside	Center	Midway	Outside	Center	Midway	Outside	Center	Midway	Outside
T4	T4	B8	B8	B8	B4	B4	B4	B1	B1	B1
.98	.92	1.04	1.02	1.00	.98	1.00	.99			
.32	.33	.31	.32	.31	.32	.32	.32			
.51	.53	.50	.48	.53	.56	.55	.50			
3.96	3.91	3.93	3.94	3.92	3.91	3.94	3.92			
		1.00	1.03	.89				.98	.98	.98
		.31	.31	.31				.31	.31	.30
		.48	.35	.44				.50	.30	.45
		3.86	3.94	3.98				3.91	4.00	3.95
.96	1.03							1.02	1.03	1.04
.34	.33							.32	.32	.32
T4									B1	
.17	4.26							4.37	4.30	4.34
						.87			.89	
						3B			1B	
						3.68			3.63	
						1.00			1.02	
			2B			3B			1B	
			3.49			3.48			3.52	
						1.02			1.03	
			2B			3B			1B	
			4.14			4.12			4.12	

7-1/2" SQUARE INGOTS

Heat GX 4880

No. of 7-1/2" square ingots cast - 11

Total weight of ingots " - 5,020#

" " " 4" x 4" produced - 4,520#

" " " 2" x 2" " - 4,300#

" " " 2" x 2" " - 3,960# after discard for pipe segregation and grinding

Yield - Ingot to 2" x 2" Billet - 78.9%

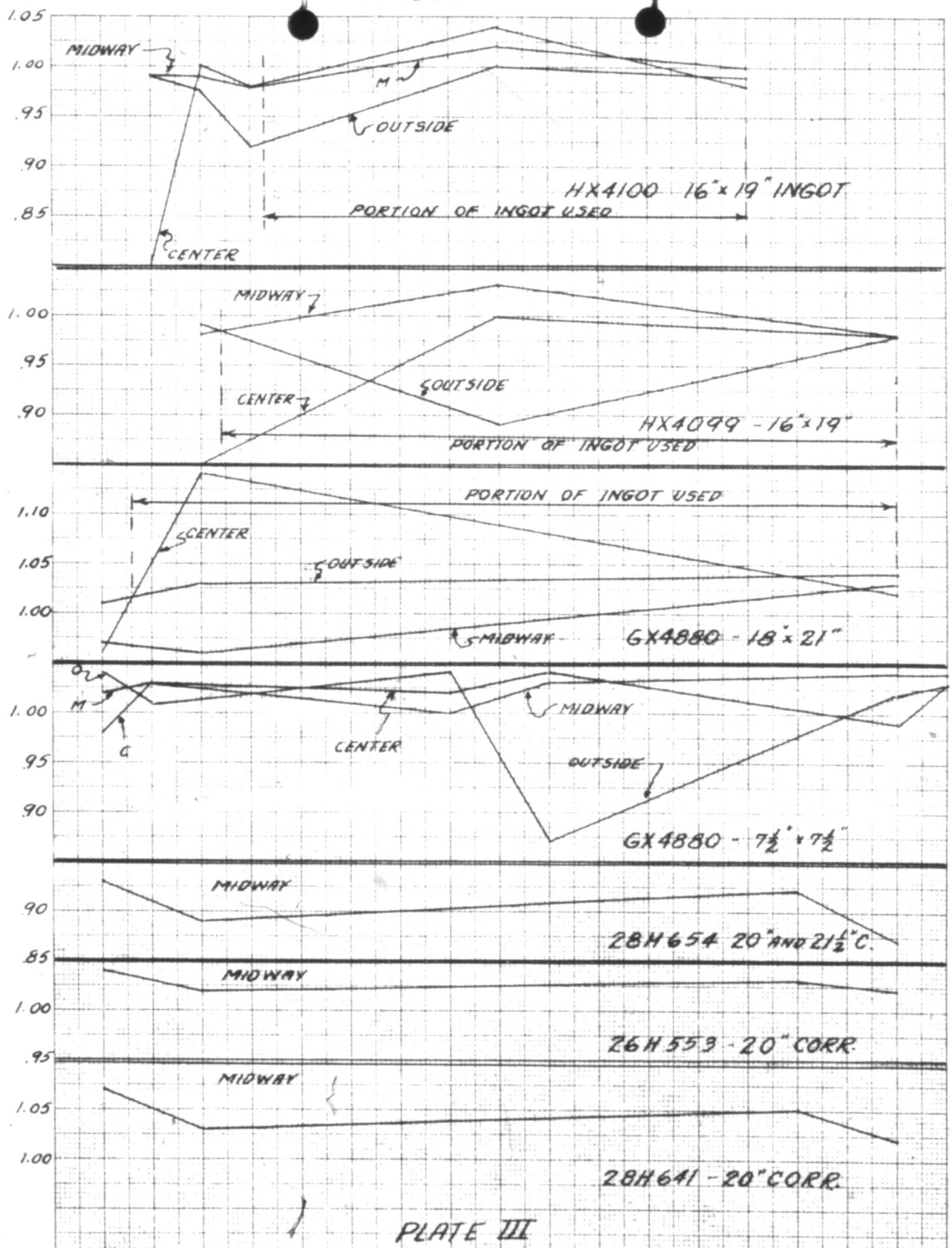
SEGREGATION - 11 - 7-1/2" Square ingots cast

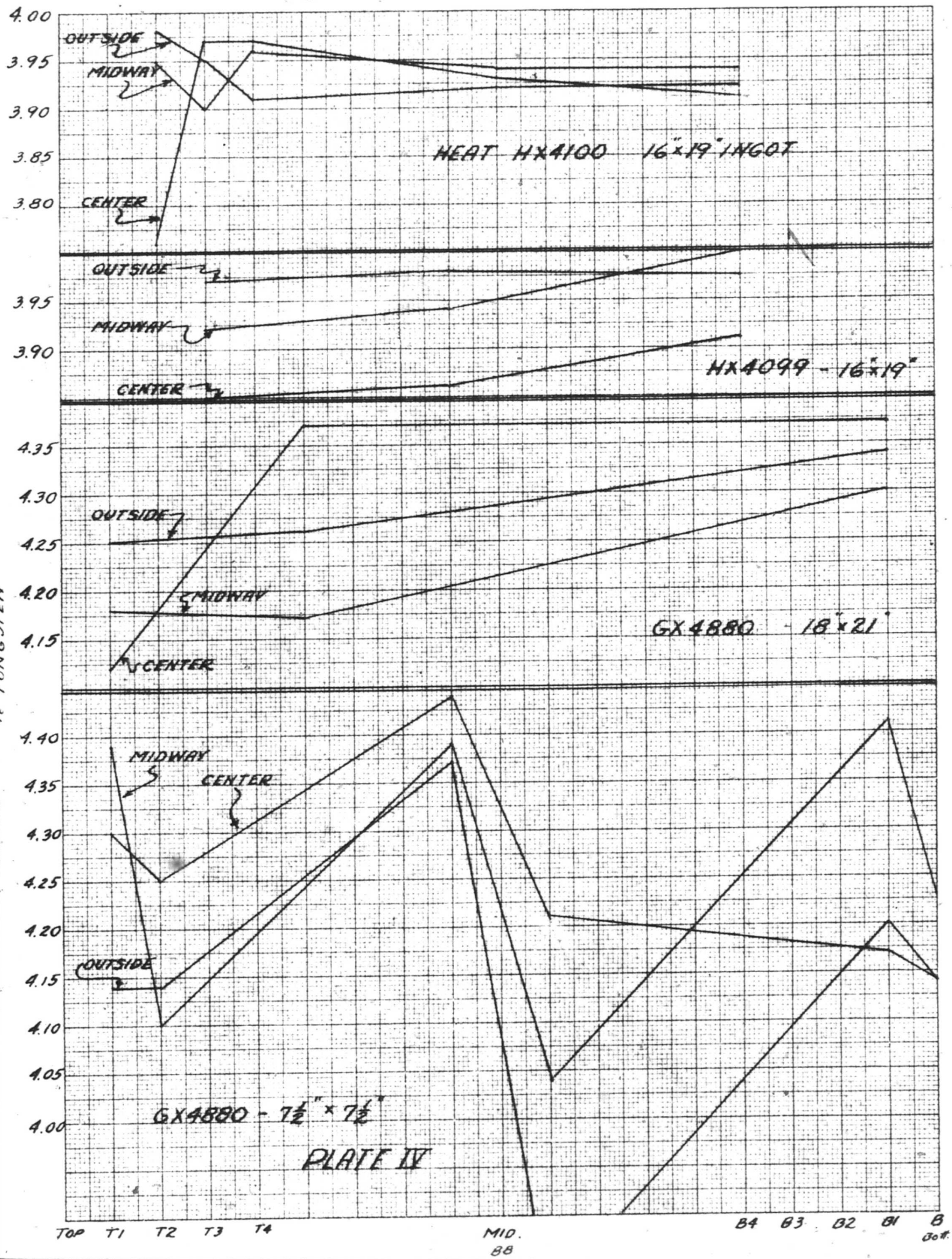
(Analysis on 2" x 2" Billets)

		C	Mn	W		C	Mn	W
Top 1st Ingot	(Outside	1.04	.35	4.14	Bottom 1st Ingot	(1.01	.34	4.14
	(Middle	1.02	.35	4.39		(1.03	.34	4.10
	(Center	.96	.35	4.30		(1.03	.34	4.25
Top 6th or middle Ingot	(Outside	1.04	.34	4.27	Bottom of 6th or Middle Ingot	(.87	.35	3.68
	(Middle	1.00	.34	4.39		(1.03	.35	4.04
	(Center	1.02	.36	4.44		(1.04	.35	4.21
	(					(		
Top 11th or last ingot	(Outside	1.02	.35	4.20	Bottom of 11th or last Ingot	(1.03	.35	4.14
	(Middle	1.04	.34	4.41		(1.04	.34	4.23
	(Center	.99	.34	4.17		(1.03	.36	4.14

TABLE II

CARBON


% CARBON
1.05
1.00
.95
.90
.85
MIDWAY
M
OUTSIDE
CENTER
HX4100 16" x 19" INGOT
PORTION OF INGOT USED
MIDWAY
OUTSIDE
CENTER
HX4099 - 16" x 19"
PORTION OF INGOT USED
1.10
1.05
1.00
PORTION OF INGOT USED
CENTER
OUTSIDE
MIDWAY
GX4880 - 18" x 21"
M
C
CENTER
MIDWAY
OUTSIDE
GX4880 - 7½" x 7½"
MIDWAY
28H654 20" AND 21½" C.
MIDWAY
26H553 - 20" CORR.
MIDWAY
28H641 - 20" CORR.
PLATE III
TOP T1 T2 T3 T4 MID B4 B3 B2 B1 B
1T 1B
B8
3T 3B Bott


TUNGSTEN
4.00
3.95
3.90
3.85
3.80
OUTSIDE
MIDWAY
CENTER
HEAT HX4100 16"×19" INGOT
OUTSIDE
MIDWAY
CENTER
HX4099 - 16"×19"
4.35
4.30
4.25
4.20
4.15
OUTSIDE
MIDWAY
CENTER
GX4880 - 18"×21"
% TUNGSTEN
4.40
4.35
4.30
4.25
4.20
4.15
4.10
4.05
4.00
MIDWAY
CENTER
OUTSIDE
GX4880 - 7½" × 7½"
PLATE IV
TOP T1 T2 T3 T4 MID. B8 B4 B3 B2 B1 B
Bott.

TUNGSTEN

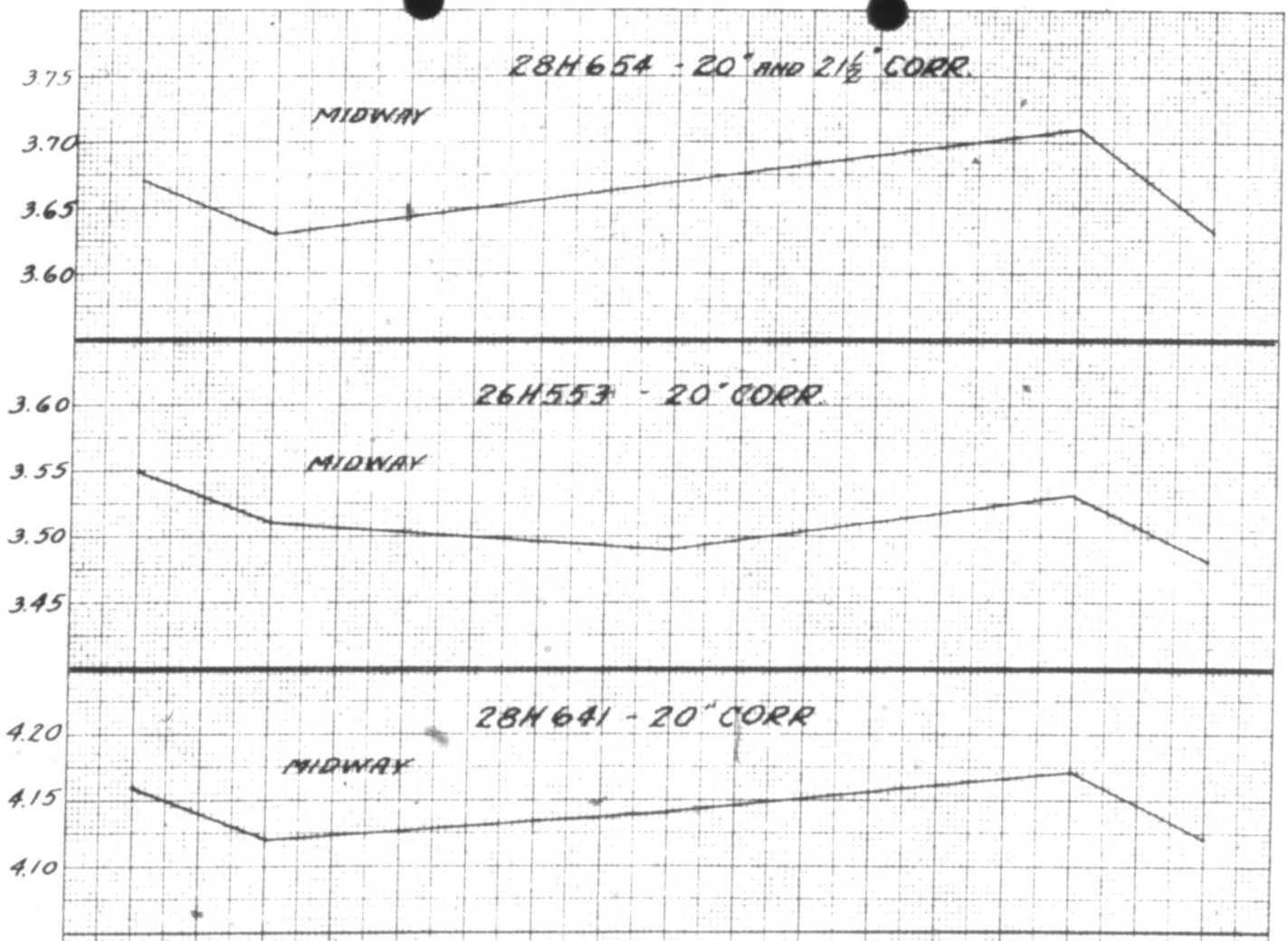


PLATE V

TOP 1T 1B MID 3T 3B BOTT.

CHROMIUM

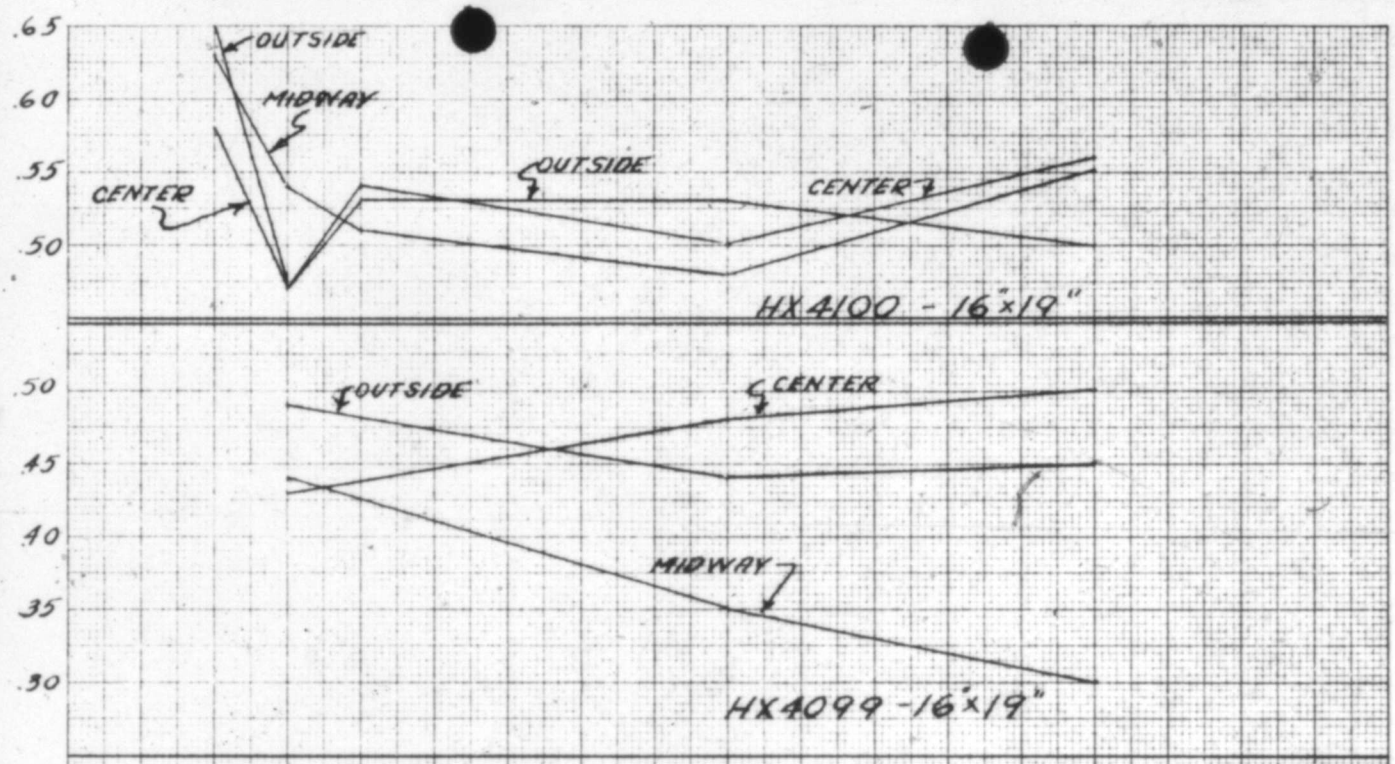


PLATE VI

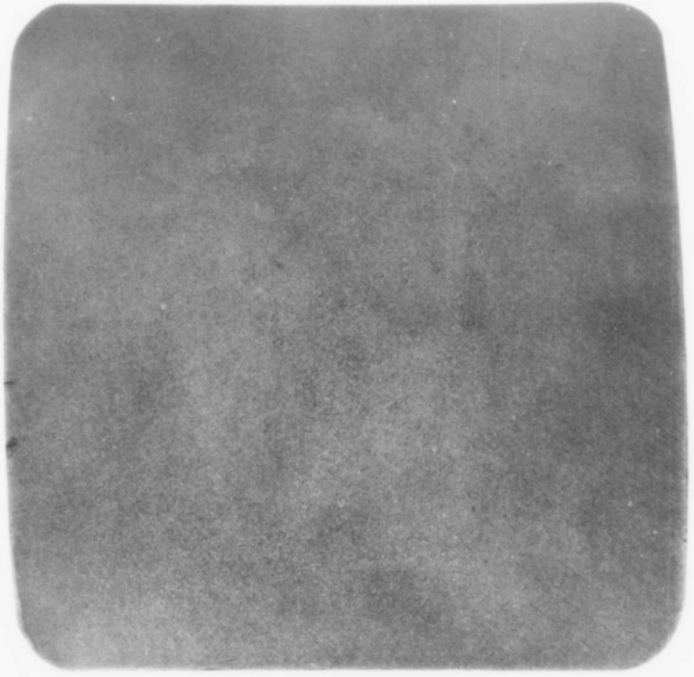
Top T1 T2 T3 T4 Mid. B4 B3 B2 B1 Butt.

B8

MX 4100 T3

PLATE VII

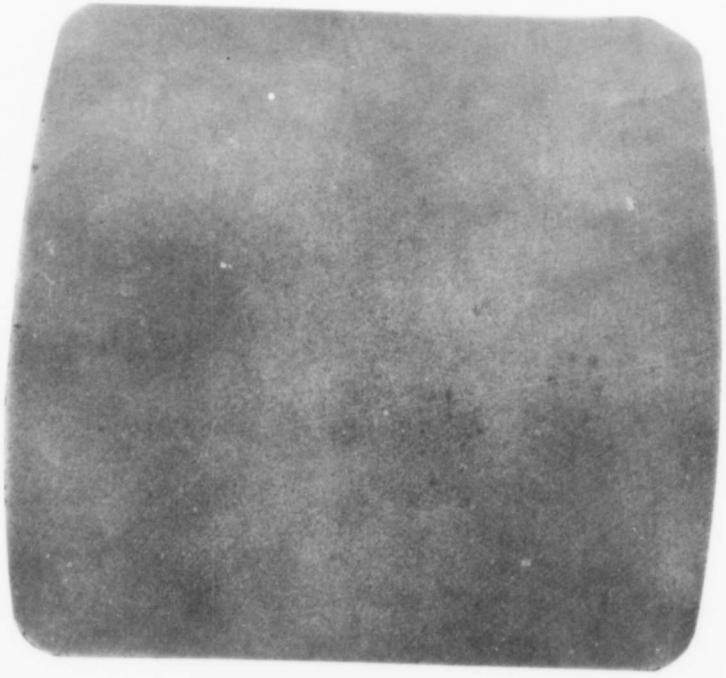
Plate VIII



HX 4100 T4

PLATE VIII

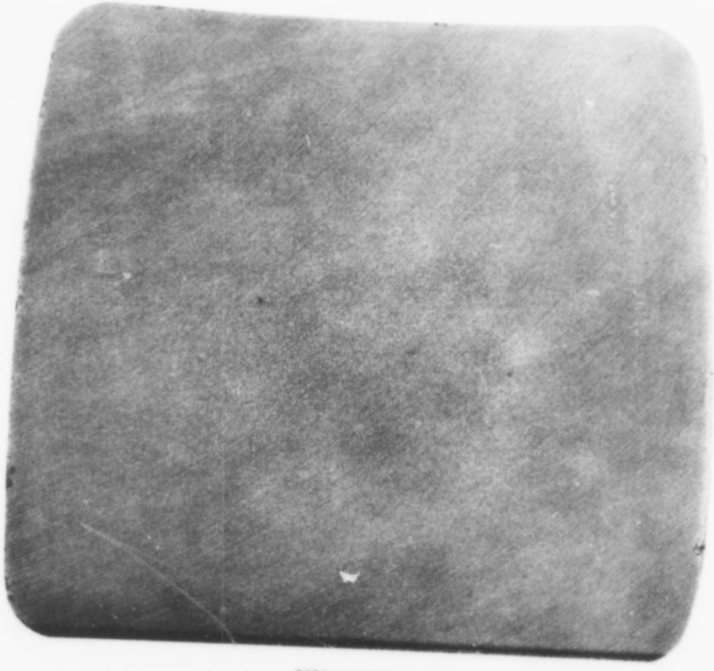
PLATE VIII



HX 4100 B8

Phot. IX

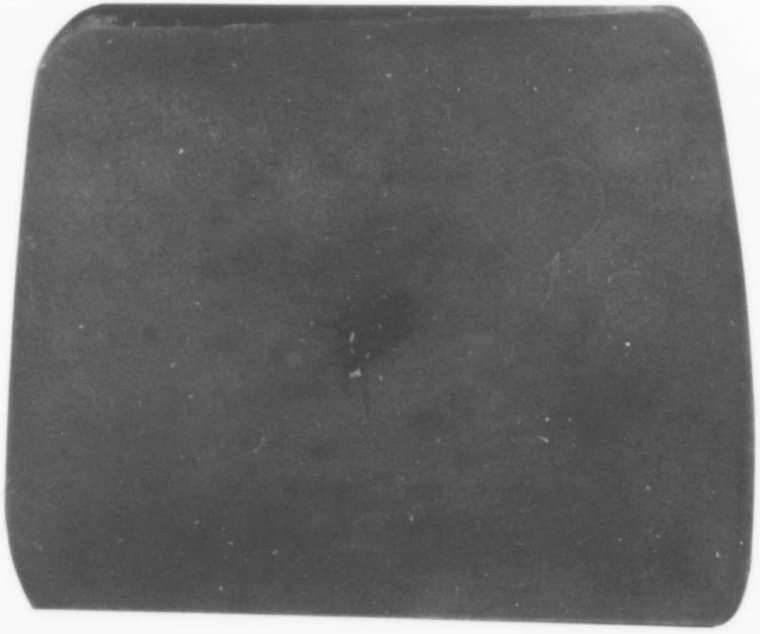
PLATE IX



HX 4100 B1

PLATE X

Plate X



HX 4099 T3

PLATE XI

PLATE XI

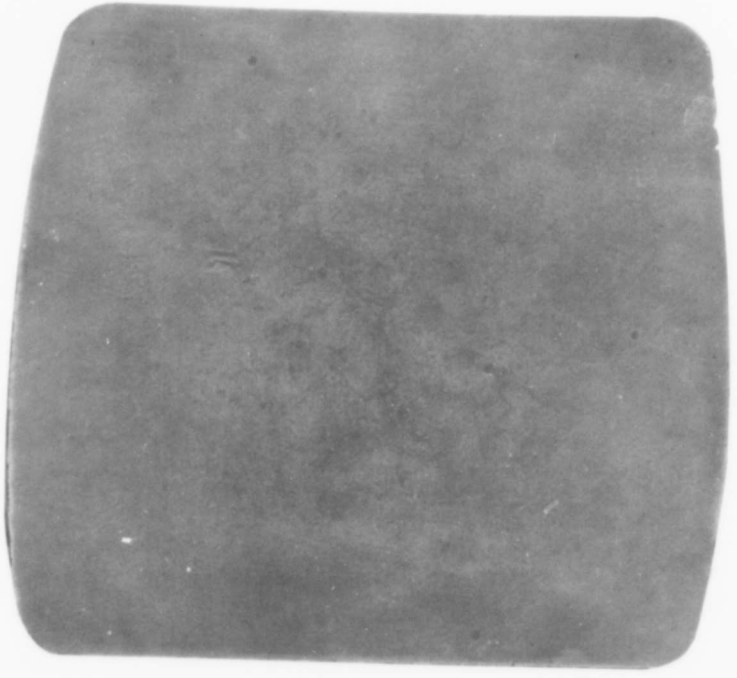


PLATE XII

HX 4099 B8

PLATE XII

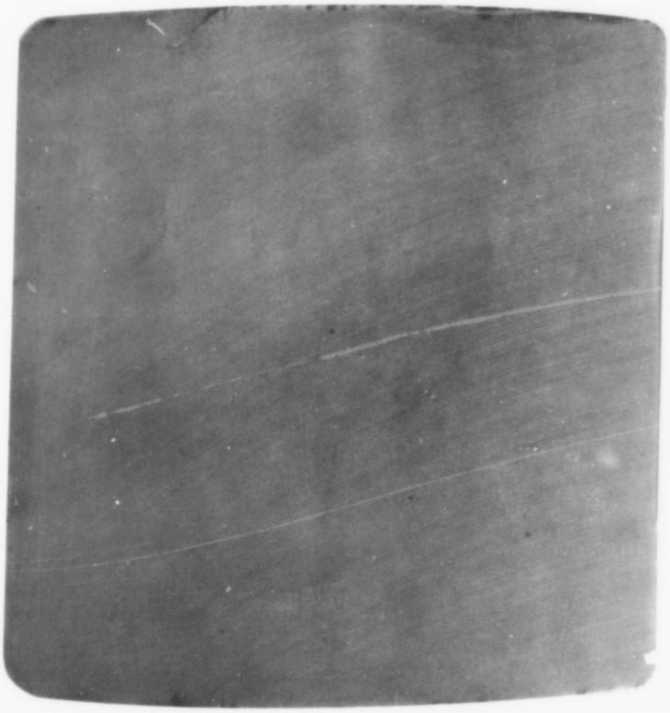
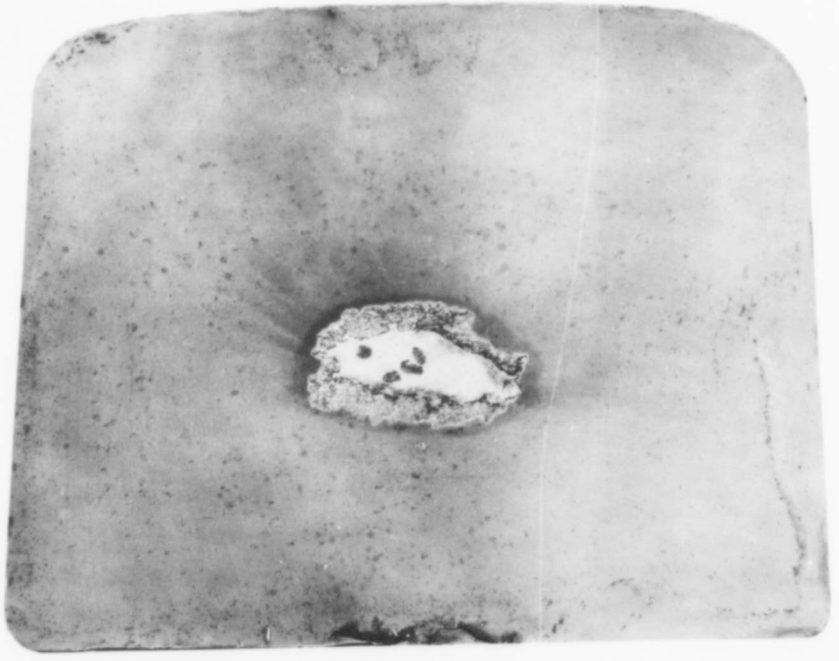


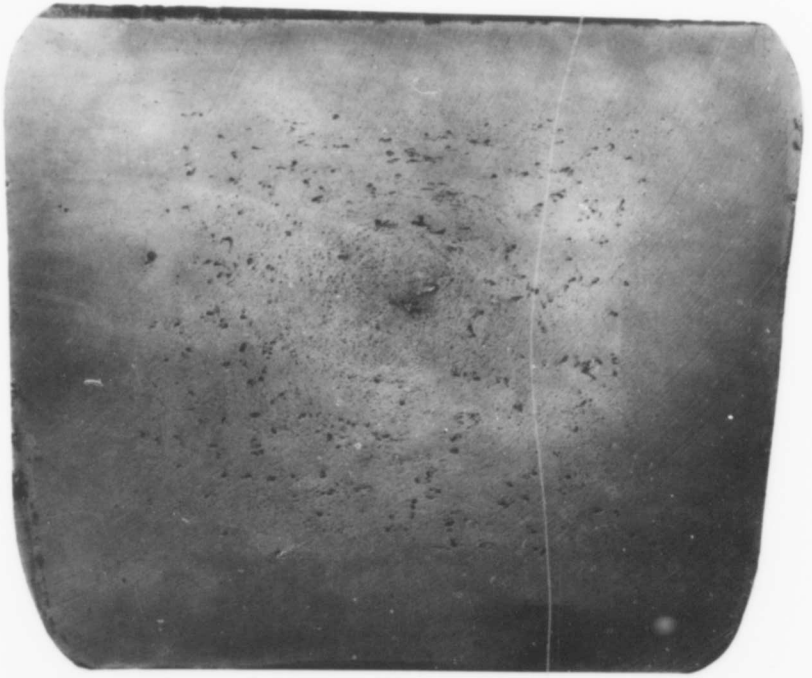
PLATE XIII



GX4880 T

PLATE XIV

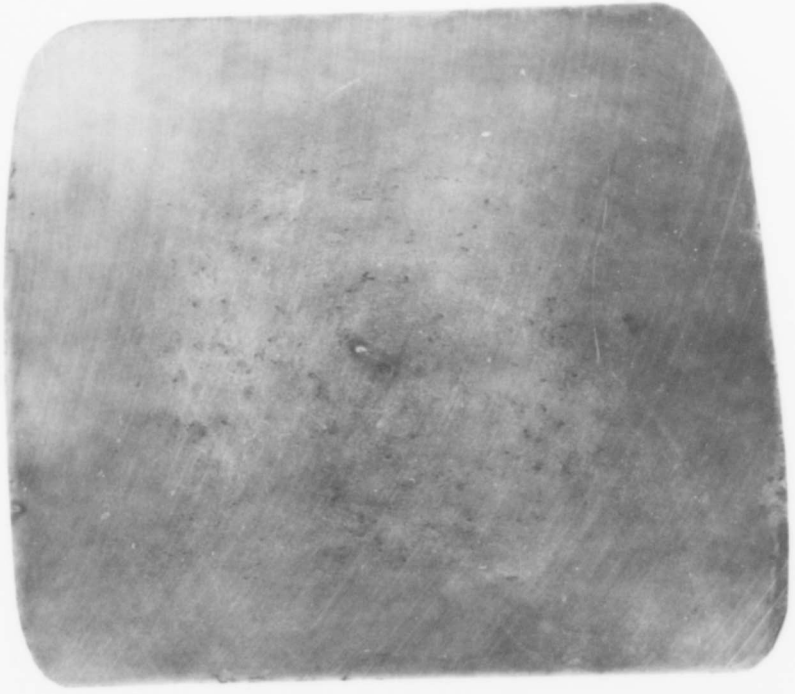
Plate XIV



GX4880 TA

PLATE XV

PLATE XV



GX4880 T1

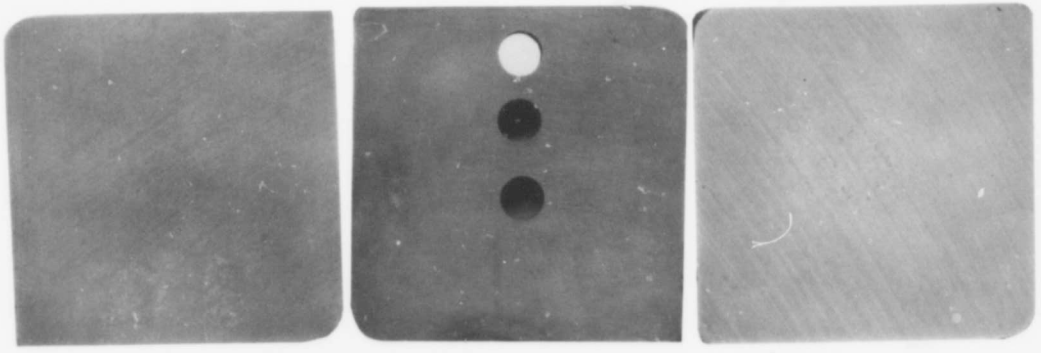
PLATE XVI

PLATE XVI

GX4880 T4

PLATE XVII

PLATE XVII



A 1 A6 A 11

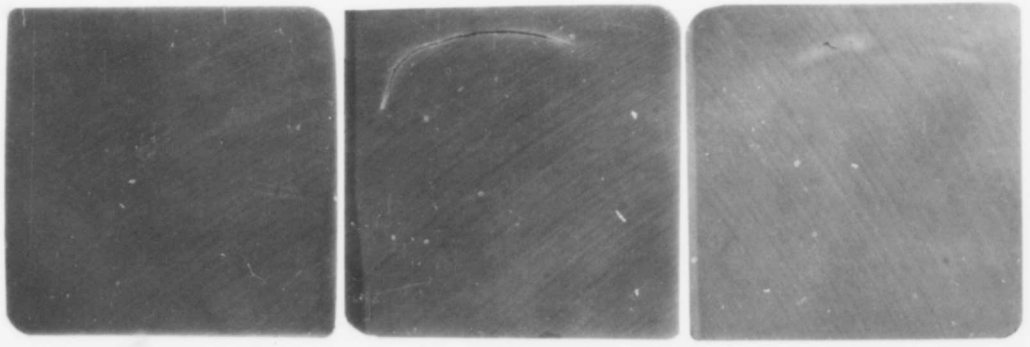


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PLATE XVIII