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WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL-311/5

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CAST STEEL

Lustrous Cavities in Steel Cast in Stationary Molds

10 23

BY
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Watertown Arsenal Laboratory
Report No. WAL 311/5
Problem No. G-2.1

29 May 1944

CAST STEEL

Lustrous Cavities in Steel Cast in Stationary Molds

OBJECT

To correlate the occurrence of lustrous cavities as revealed by tensile test bar fractures with ingot pipe and segregation pattern as observed by macroetch.

CONCLUSIONS

1. There is an excellent correlation between the occurrence of lustrous cavities as revealed by tensile test bar fractures with the ingot segregation pattern as observed by macroetch - the greater the segregation the more pronounced is the lustrous cavity condition.

2. The reduction of area value appears to be a good index of lustrous cavities and substantiates the above conclusion. It is believed, however, that other factors affect the reduction of area to such an extent that its value as an over-all index of lustrous cavities is questionable.

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Associate Metallurgist

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APPROVED:

H. K. Lornig
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Director of Laboratory.

INTRODUCTION

The term "lustrous cavities" seems to be peculiar to Watertown Arsenal. The term is used to describe lustrous areas that commonly appear on the fracture of tensile test bars from heat treated centrifugally cast gun tubes. The nature and cause of lustrous cavities have been a topic of controversy for many years. Lustrous cavities affect adversely the ductility of the metal as measured by reduction in area.

Since lustrous cavities are observed in both static and centrifugal castings made from the same melt¹, it was deemed advisable to attempt to correlate the occurrence of lustrous cavities as revealed by tensile test bar fractures with ingot pipe and segregation pattern as observed by macroetch.

TEST PROCEDURE

A 350 pound melt of Watertown Arsenal Gun composition, made in the acid induction furnace according to standard production practice, was poured into an ingot 8" x 8" x 27". The melt had the following analysis:

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>P</u>	<u>S</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>
.23	.71	.29	.011	.020	.84	.51	.07

No hot top was used on the big-end-up ingot so that the unsoundness due to pipe would extend far down into the ingot. The ingot was slow cooled in ashes from casting to prevent flaking.

The ingot was split longitudinally along the centerline and macro-etched. Transverse discs 3/4" thick taken from various locations were

¹
Pappas and Bender. Lustrous Cavities in Stationary and Centrifugally Cast Steel. WAL 314/69, 1943.

macroetched and heat treated. The heat treatment was as follows:

1650°F	-	6 hours	-	water quench
1300°F	-	6 hours	-	air cool.

From the heat treated discs, transverse tensile test bars were taken $3/8"$, $1-1/4"$, $2-1/8"$, and $3"$ from the center-line of the ingot.

DATA AND DISCUSSION

Figure 1 shows typical tensile bar fractures found in the heat-treated test bars. They are classified visually as having (1) large lustrous cavities, (2) lustrous cavities, (3) small lustrous cavities, and (4) no lustrous cavities.

Figure 2 shows an unetched longitudinal view of the top and middle sections (top 18" of total 27" length) of the ingot split along the center-line. This figure shows the extent of the shrinkage cavity.

Figure 3 shows a macroetched longitudinal view of the top and middle sections of the ingot. Superimposed on this photograph at the proper locations are the code numbers for the type of fractures obtained in the tensile test bars from the several locations. Figures 4 to 8 show the macroetched views of the transverse discs with the type of tensile test bar fractures again superimposed at their various locations. It is apparent from these figures that the greater the segregation as revealed by macroetch, the more pronounced the lustrous cavity condition in the tensile test bar fractures. Any exceptions to this correlation can be explained by the fact that the centers of the physical test bars were of necessity a small distance, probably $3/8"$, away from the macroetched faces photographed. It would appear that the lustrous cavity condition is associated with segregation, either metallic or nonmetallic, or minute voids which impart a spongy appearance to the macroetched surfaces.

The reduction of area figure has been sometimes used as an index of lustrous cavities. Figures 9 to 14 are the same as Figures 3 to 8, respectively, except that the reduction in area values are substituted for the type of fracture code numbers. In this case the average reduction of area for each type fracture is as follows:

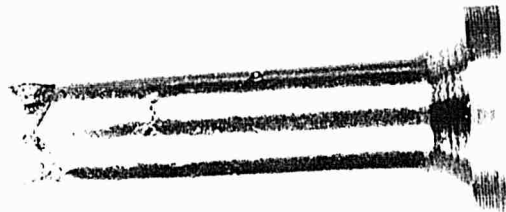
<u>Type of Fracture</u>	<u>Ave. Red. of Area</u>
Large Lustrous Cavities	32.2%
Lustrous Cavities	46.4
Small Lustrous Cavities	52.4
No Lustrous Cavities	58.1

The reduction of area value, however, is influenced by other factors, such as yield strength level and microstructure, and when several heats are considered it may be very insensitive as an index of severity of lustrous cavities. Within the particular heat studied, the reduction of area values substantiate the observation that the greater the segregation, the more pronounced the lustrous cavity condition.

For record purposes included in Appendix A are the complete physical properties of each tensile test bar.

GENERAL CONSIDERATIONS

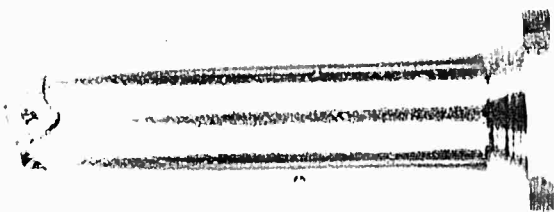
From this study it appears that lustrous cavities can be reduced in number and severity by reducing the amount of segregation. Freezing rates, chemical compositions, metal cleanliness, metal distribution, and physical size and shape affect segregation materially. In centrifugal castings and in stationary castings many factors limit considerably the variations obtainable in these factors to reduce segregation and lustrous cavities.



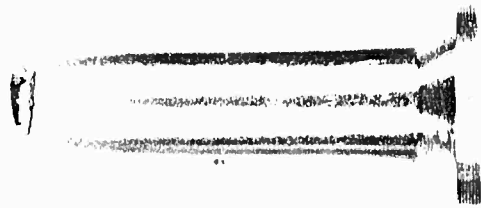
NO. 1



NO. 2



NO. 3

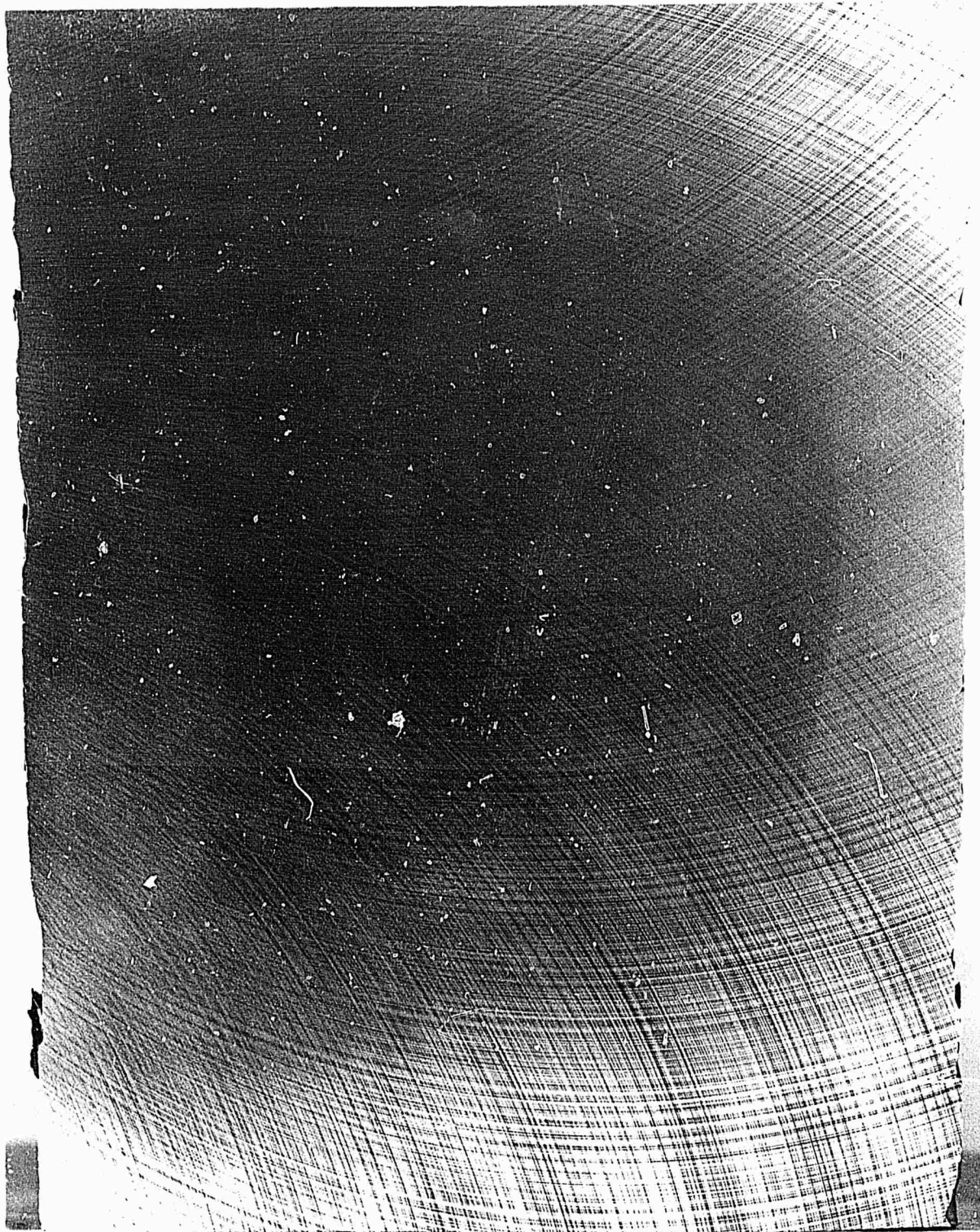


NO. 4

WATERTOWN ARSENAL

TYPE OF TENSILE BAR FRACTURES

#1 - LARGE LUSTROUS CAVITIES. #2 - LUSTROUS CAVITIES. #3 SMALL LUSTROUS CAVITIES.
#4 - NO LUSTROUS CAVITIES. MAG. X 2 19 MAY 1944 WTN.223-4741

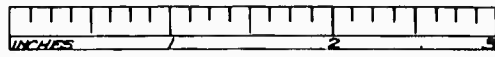
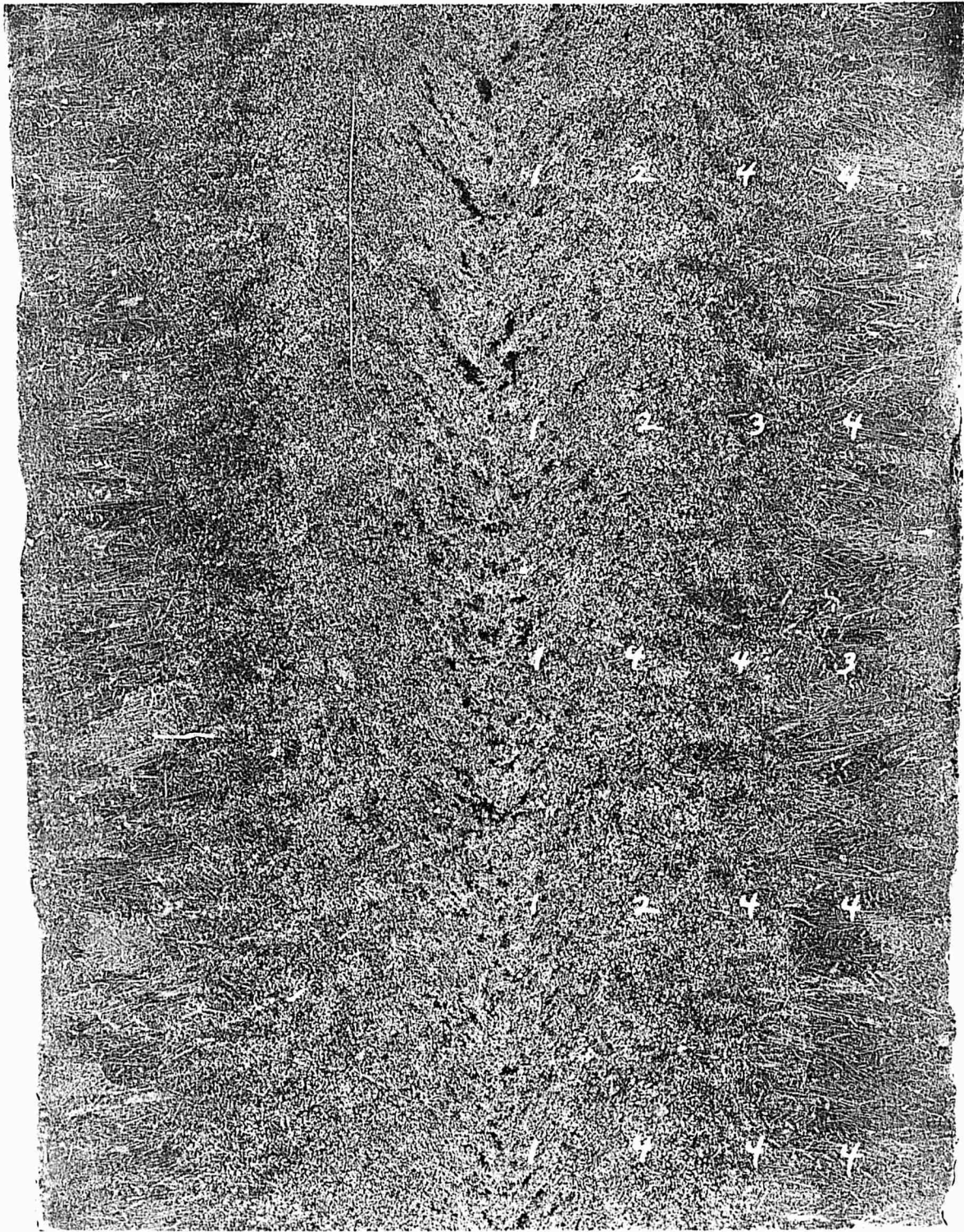


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WATERTOWN ARSENAL.

UNETCHED LONGITUDINAL VIEW OF TOP AND MIDDLE SECTIONS HEAT X-1345
8"X8"X27" INGOT SPLIT ALONG CENTER LINE. W.A. GUN COMPOSITION.
"AS CAST" 19 MAY 1944 WTN.223-4740

177





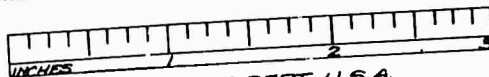
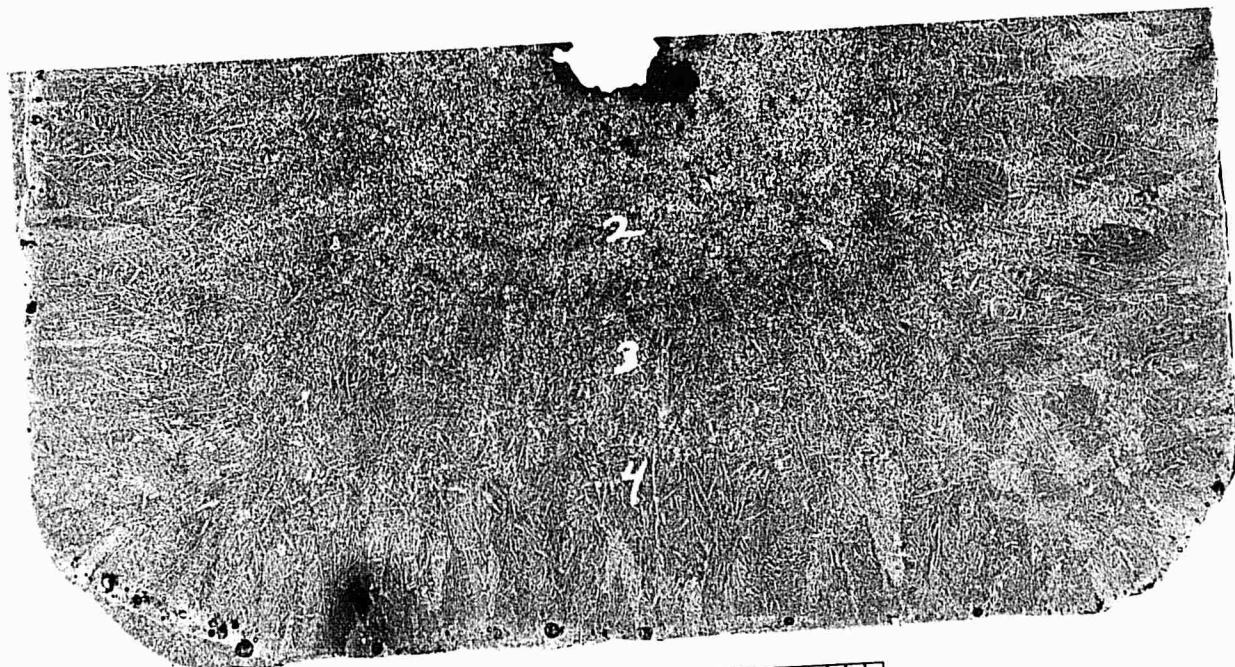
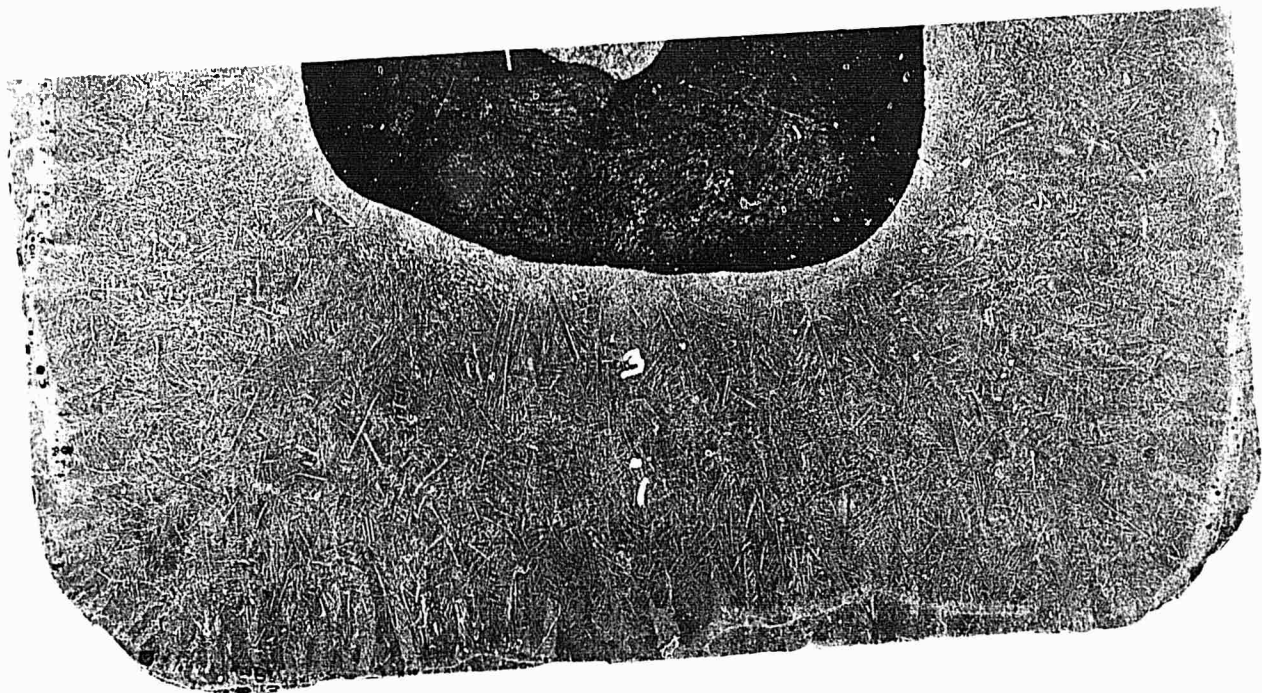
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WATERTOWN ARSENAL

MACROETCHED LONGITUDINAL VIEW OF TOP AND MIDDLE SECTIONS HEAT X-1345, 8" x 8" x 27" INGOT SPLIT ALONG CENTER LINE. W.A. GUN COMPOSITION. "AS CAST". FIGURES SHOW LOCATION AND TYPE OF TENSILE BAR FRACTURES AS FOLLOWS; (1) LARGE LUSTROUS CAVITY (2) LUSTROUS CAVITIES. (3) SMALL LUSTROUS CAVITIES. (4) NO LUSTROUS CAVITIES.
5 MAY 1944 WTN.223-4676&7

Fig 3

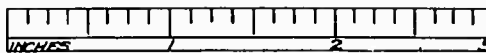
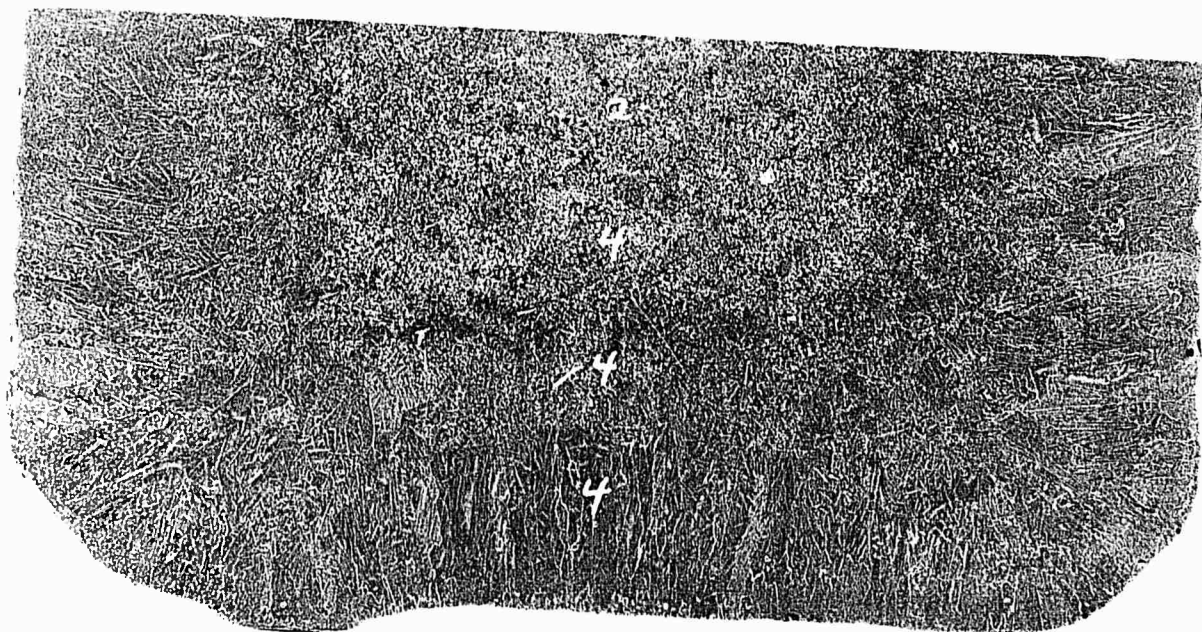
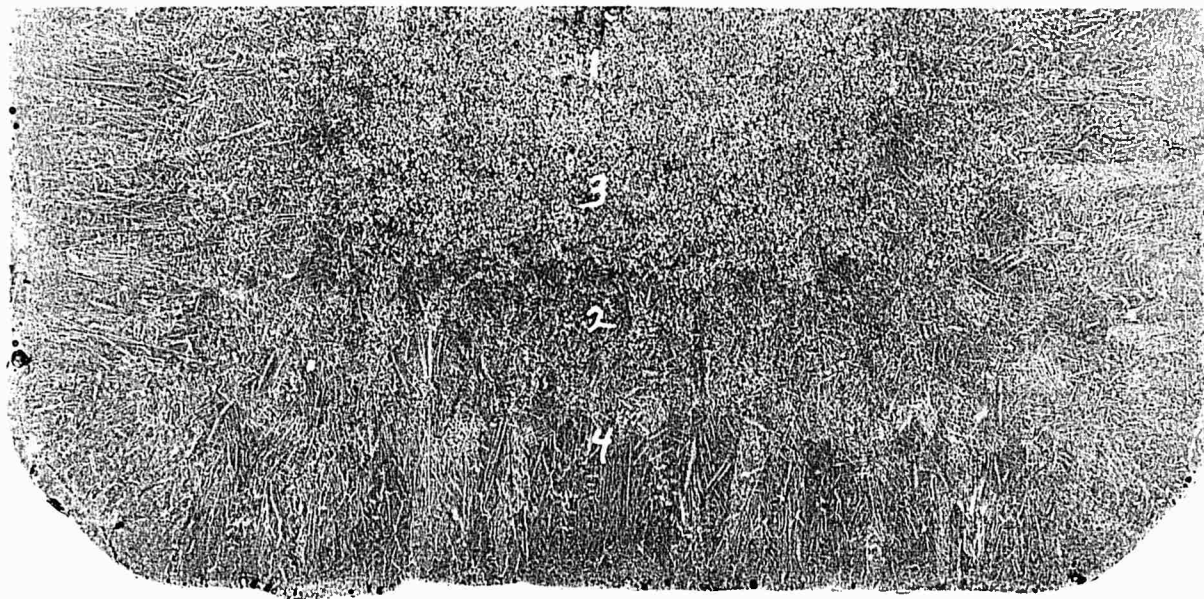
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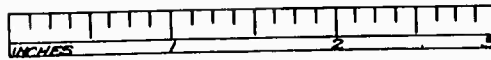
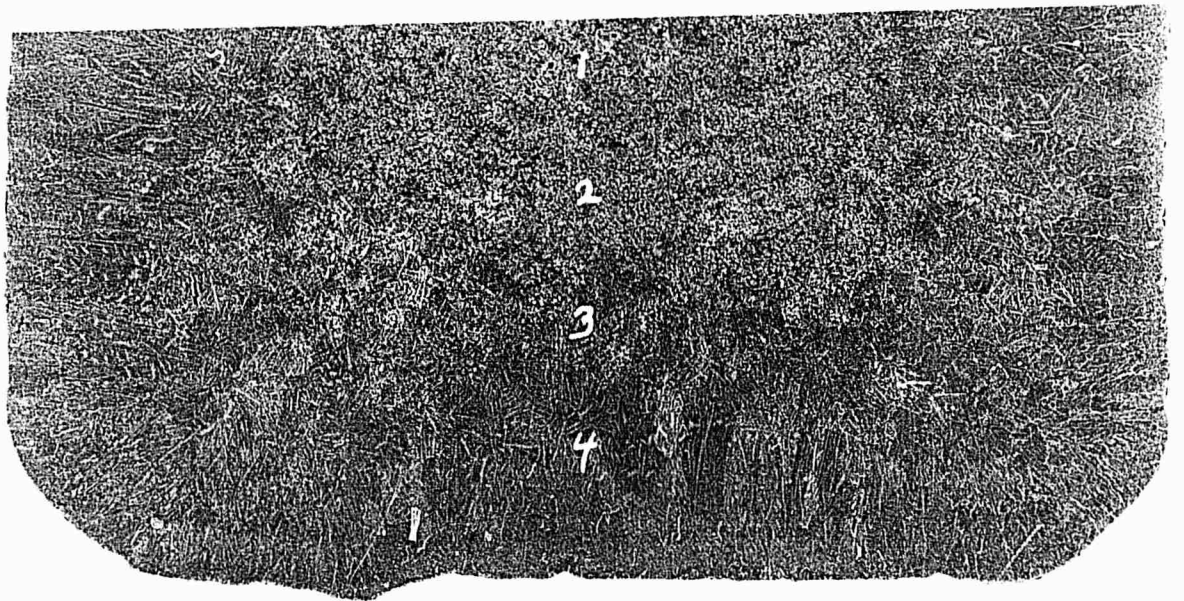
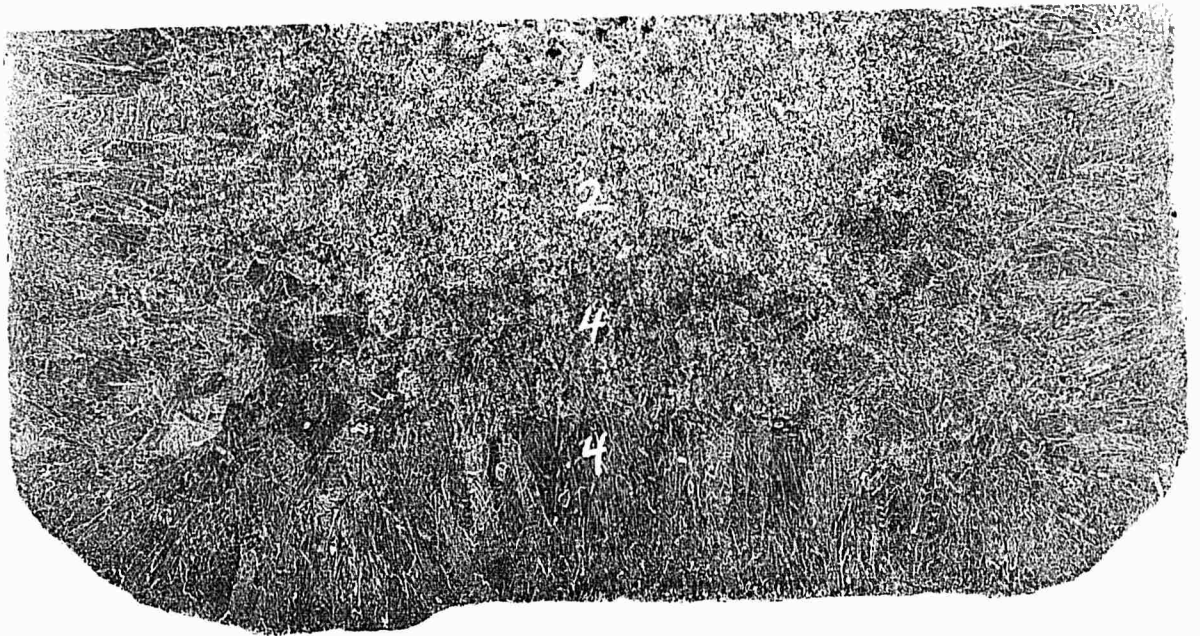
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MACROETCHED VIEW OF HALF CROSS SECTIONS 2" (UPPER) AND 5" (LOWER) BELOW TOP OF 6"x8"x27" INGOT. HEAT X-1345. W.A. GUN COMPOSITION. "AS CAST". FIGURES SHOW LOCATION AND TYPE OF TENSILE BAR FRACTURES AS FOLLOWS: (1) LARGE LUSTROUS CAVITIES. (2) LUSTROUS CAVITIES (3) SMALL LUSTROUS CAVITIES. (4) NO LUSTROUS CAVITIES. 5 MAY 1944 WTN.223-4678&9



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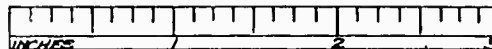
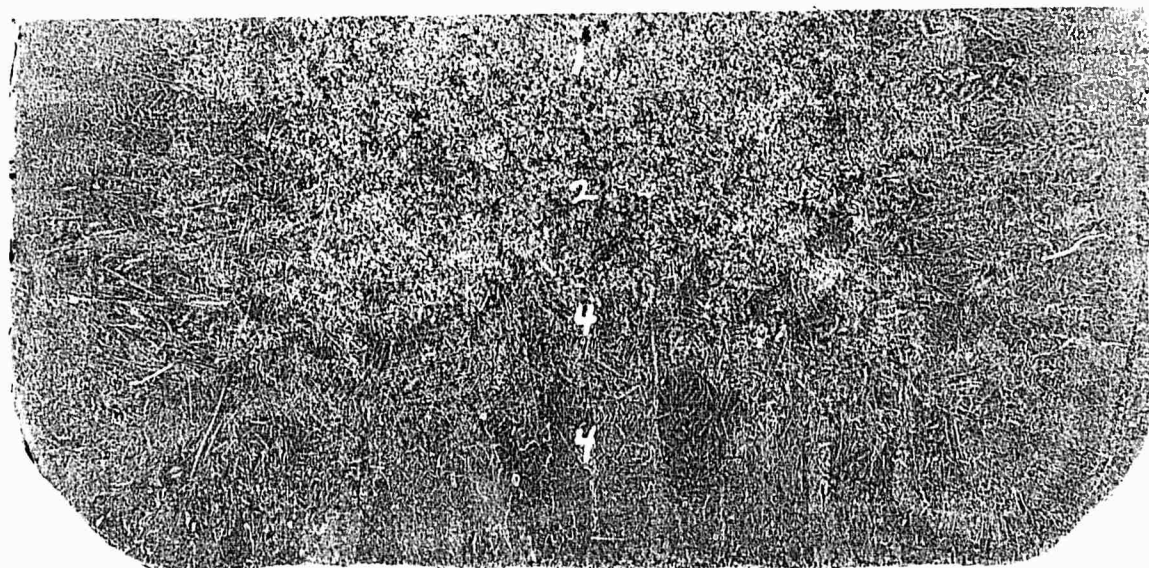
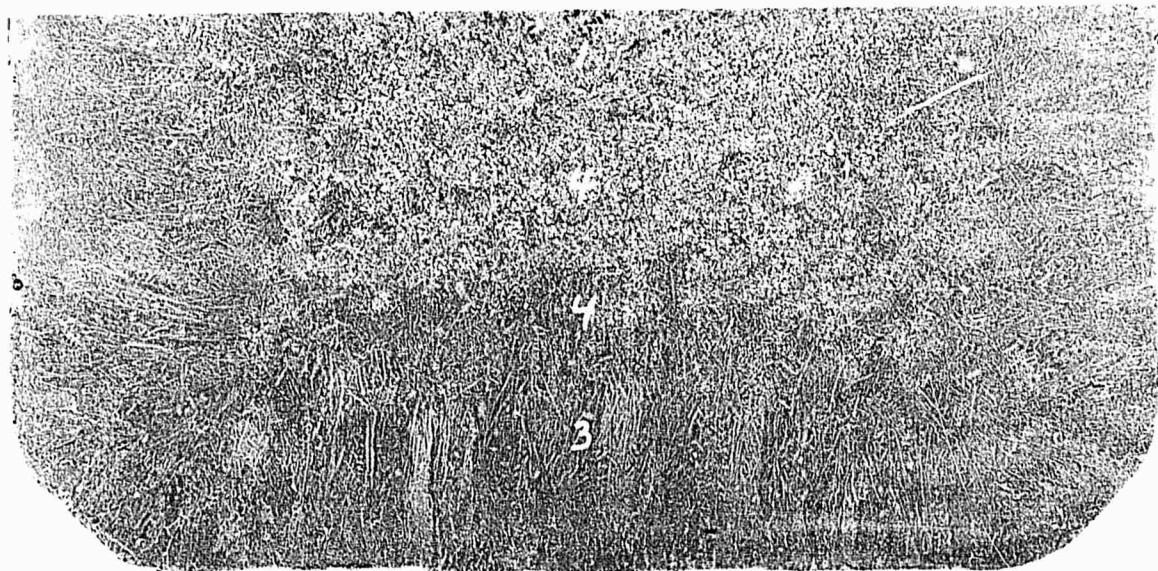
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WATERTOWN ARSENAL

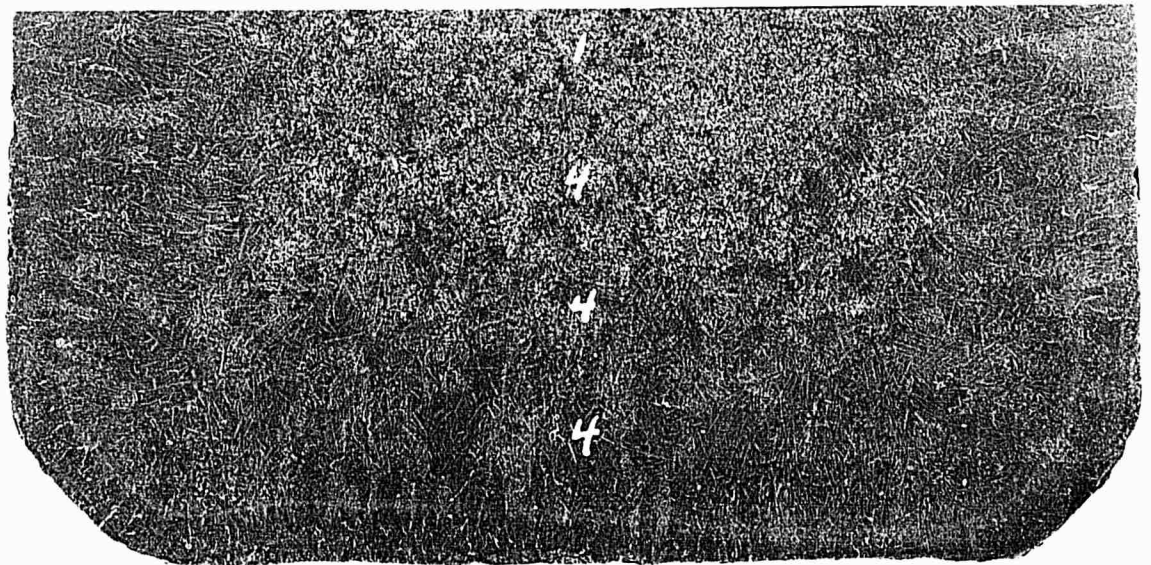
MACROETCHED VIEW OF HALF CROSS SECTIONS 10" (UPPER) AND 12" (LOWER) BELOW TOP 8"x8"x27" INGOT. HEAT X-1345, W.A. GUN COMPOSITION, "AS CAST". FIGURES SHOW LOCATION AND TYPE OF TENSILE BAR FRACTURES AS FOLLOWS: (1) LARGE LUSTROUS CAVITIES. (2) LUSTROUS CAVITIES (3) SMALL LUSTROUS CAVITIES. (4) NO LUSTROUS CAVITIES. 5 MAY 1944 WTN.223-4682&3

Fig 6



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MACROETCHED VIEW OF HALF CROSS SECTIONS 13 $\frac{1}{4}$ " (UPPER) AND 15" (LOWER) BELOW TOP 8"x8"x27" INGOT. HEAT X-1345. W.A. GUN COMPOSITION. "AS CAST". FIGURES SHOW LOCATION AND TYPE OF TENSILE BAR FRACTURES AS FOLLOWS: (1) LARGE LUSTROUS CAVITIES. (2) LUSTROUS CAVITIES (3) SMALL LUSTROUS CAVITIES. (4) NO LUSTROUS CAVITIES. 5 MAY 1944 WTN.223-4684&5



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MACROETCHED VIEW OF HALF CROSS SECTION 17" BELOW TOP 8"x8"x27" INGOT, HEAT X-1345, W.A. GUN COMPOSITION, "AS CAST". FIGURES SHOW LOCATION AND TYPE OF TENSILE BAR FRACTURES AS FOLLOWS: (1) LARGE LUSTROUS CAVITIES. (2) LUSTROUS CAVITIES. (3) SMALL LUSTROUS CAVITIES (4) NO LUSTROUS CAVITIES.

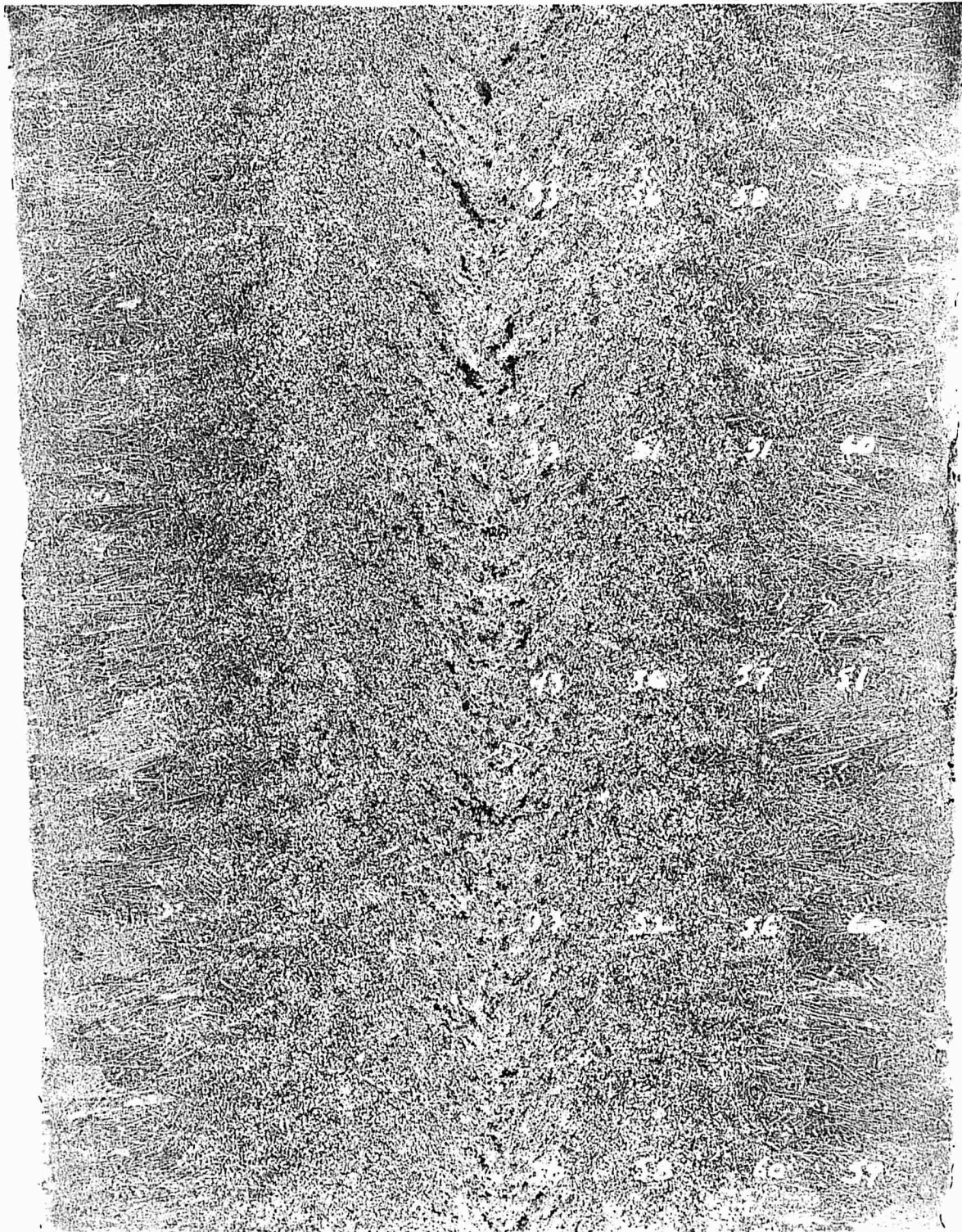
5 MAY 1944

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WTN. 223-4676

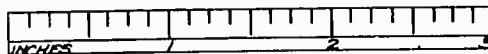
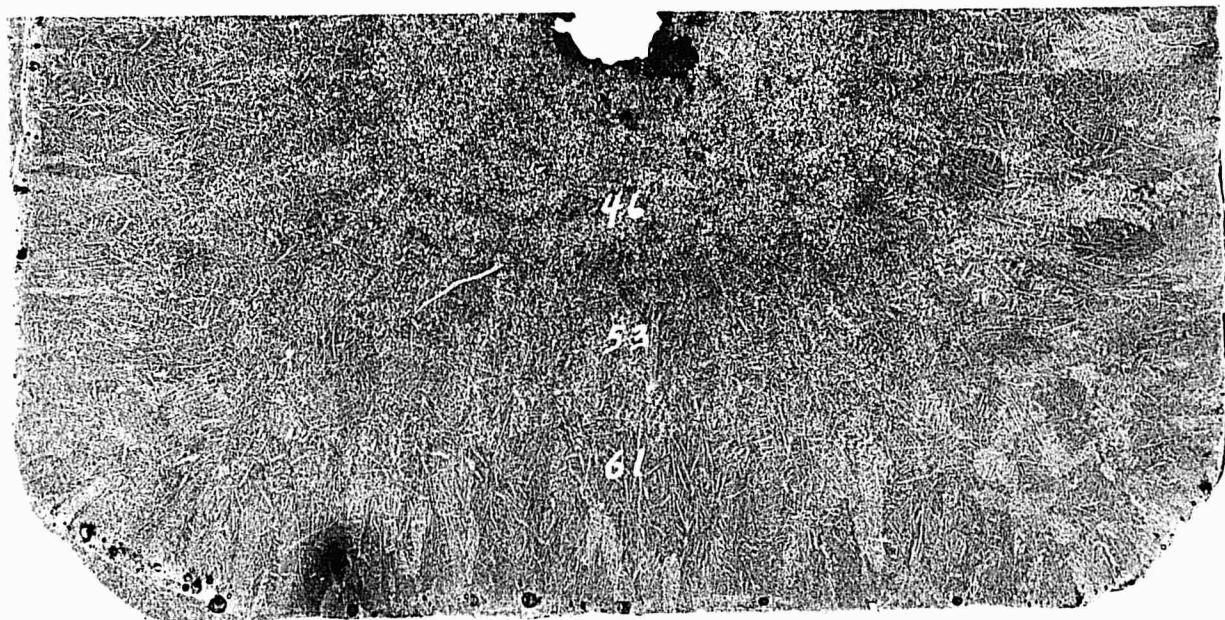
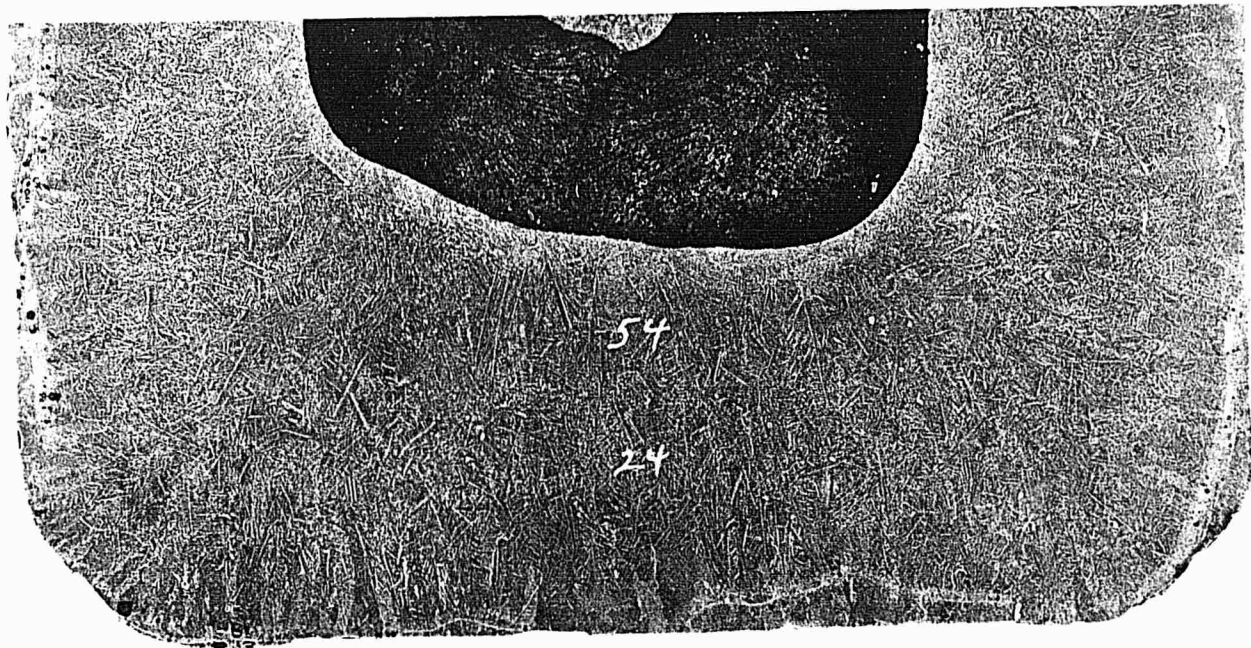




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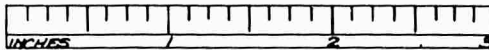
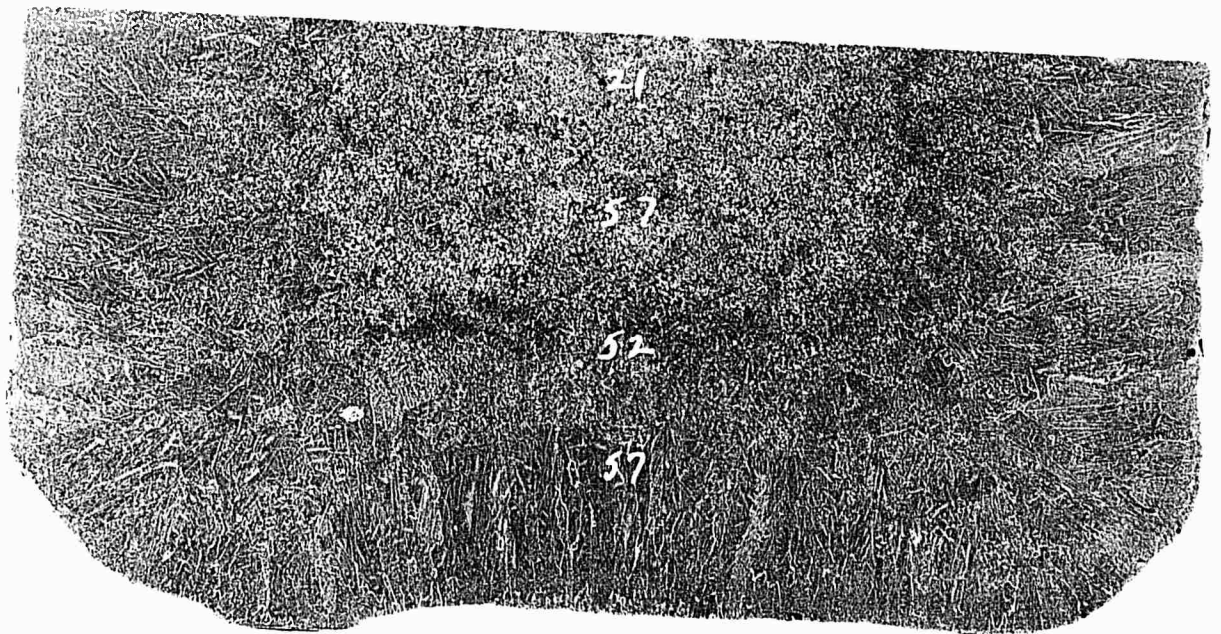
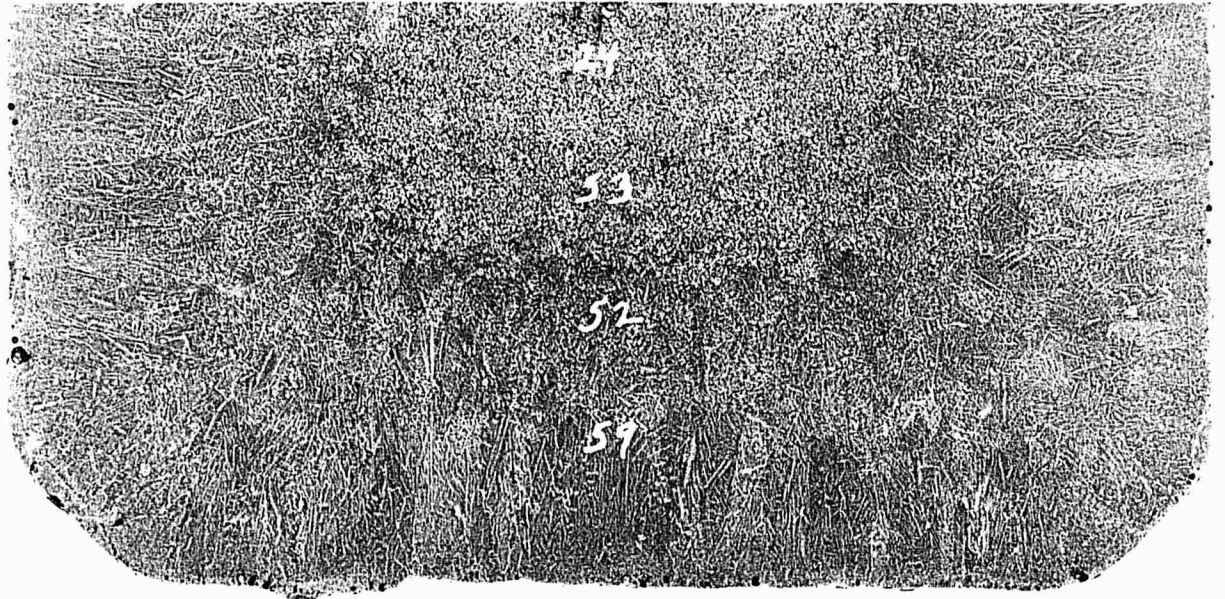
MACROETCHED LONGITUDINAL VIEW OF TOP AND MIDDLE SECTIONS HEAT X-1345, 8" X 8" X 27"
INGOT SPLIT ALONG CENTER LINE. W.A. GUN COMPOSITION. "AS CAST". FIGURES SHOW
LOCATION OF TENSILE BAR TESTS AND THEIR PERCENT REDUCTION IN AREA. WTN.223-4676&7

10.7



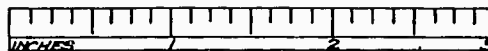
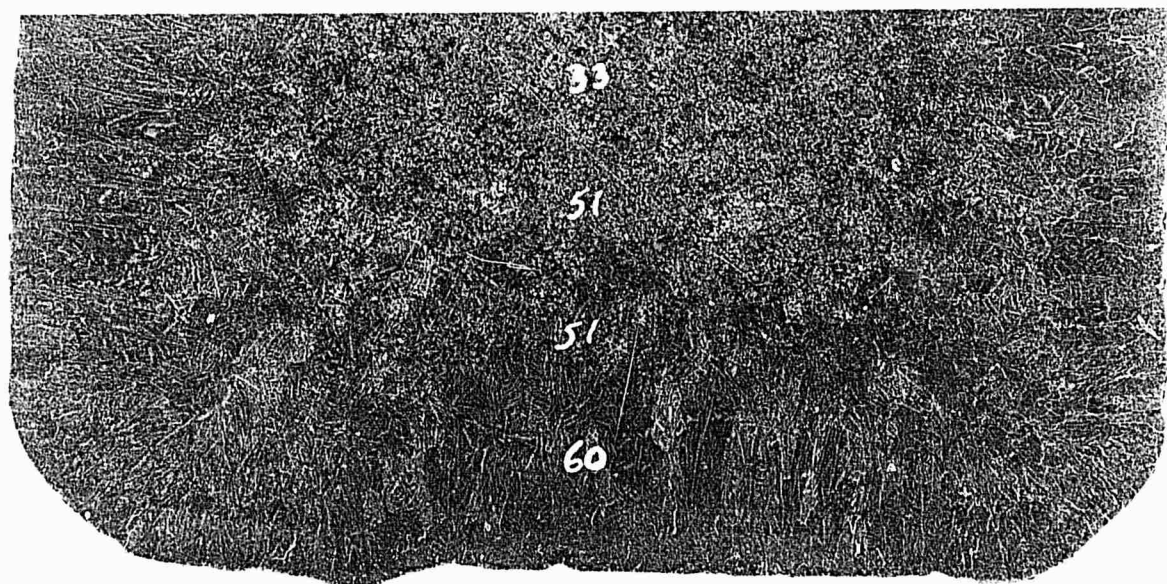
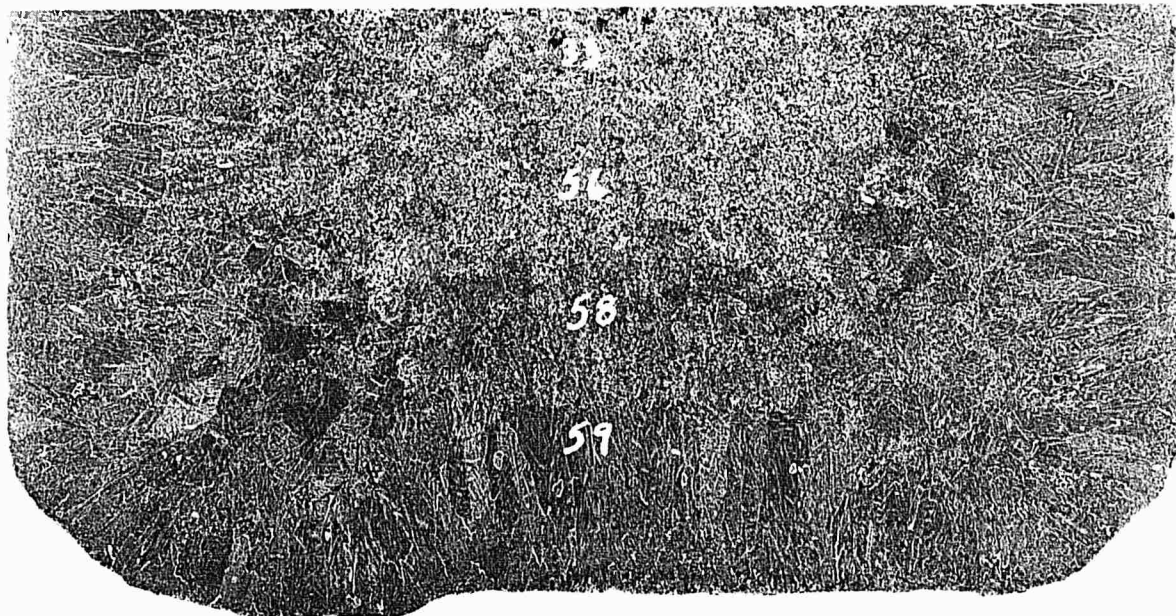
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MACROETCHED VIEW OF HALF CROSS SECTIONS 2" (UPPER) AND 5" (LOWER) BELOW TOP OF 8"x8"x27"
INGOT. HEAT X-1345. W.A. GUN COMPOSITION. "AS CAST". FIGURES SHOW LOCATION OF TENSILE
BAR TESTS AND THEIR PERCENT REDUCTION IN AREA VALUES. 5 MAY 1944 WTN.223-4678&9



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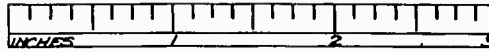
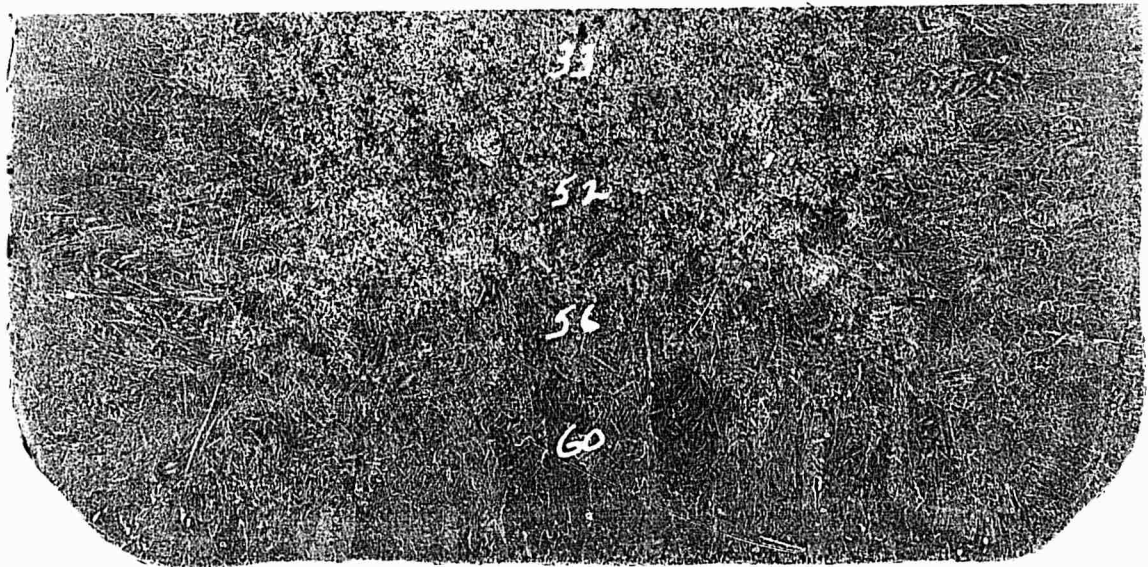
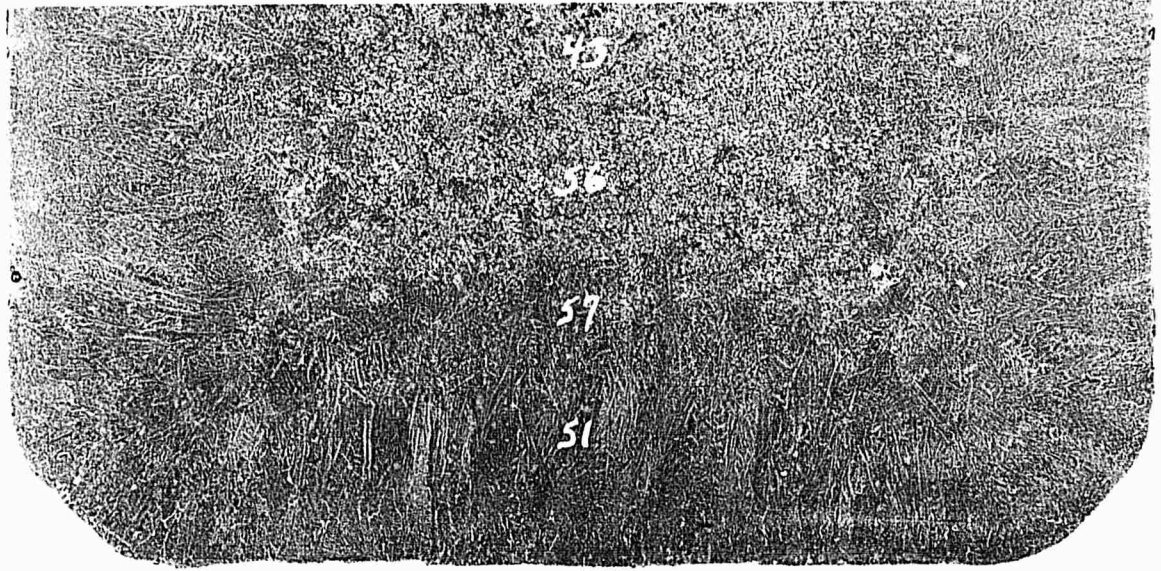
MACROETCHED VIEW OF HALF CROSS SECTIONS $6\frac{1}{2}$ " (TOP) AND 8" (LOWER) BELOW TOP OF 8"X8"X27" INGOT. HEAT X-1345. W.A. GUN COMPOSITION. "AS CAST". FIGURES SHOW LOCATION OF TENSILE BAR TESTS AND THEIR PERCENT REDUCTION IN AREA VALUES. 5 MAY 1944 WTN.223-4680&1



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MACROETCHED VIEW OF HALF CROSS SECTIONS 10" (UPPER) AND 12" (LOWER) BELOW TOP 8"x8"x27" INGOT. HEAT X-1345. W.A. GUN COMPOSITION, "AS CAST". FIGURES SHOW LOCATION OF TENSILE BAR TESTS AND THEIR PERCENT REDUCTION IN AREA VALUES. 5 MAY 1944 WTN.223-4682&2

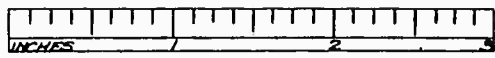
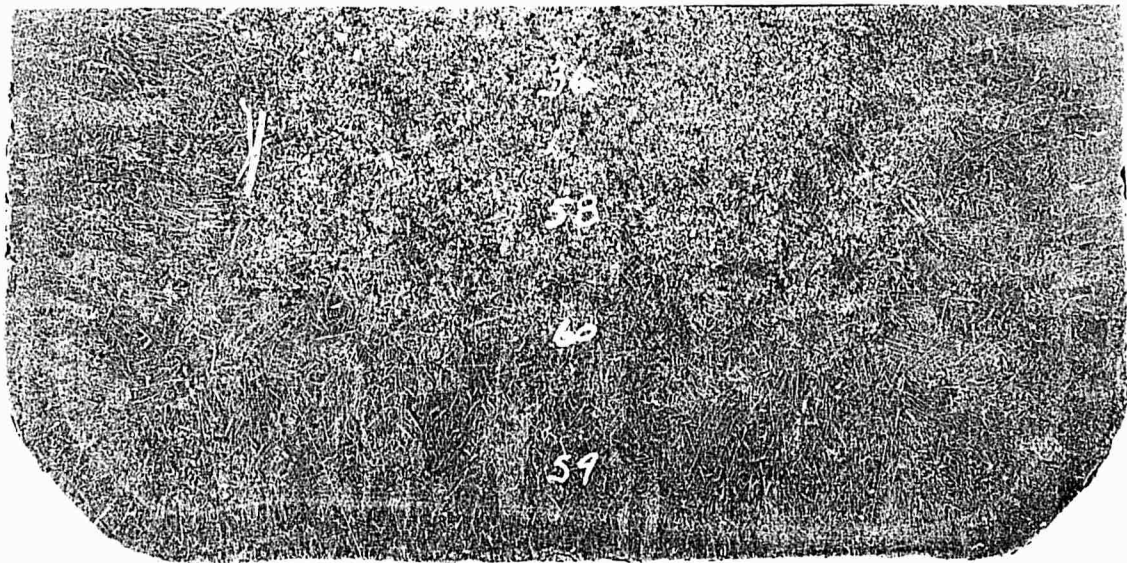
Fig 12



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MACROETCHED VIEW OF HALF CROSS SECTIONS 13½" (UPPER) AND 15" (LOWER) BELOW TOP 8"x8"x27" INGOT. HEAT X-1345. W.A. GUN COMPOSITION, "AS CAST". FIGURES SHOW LOCATION OF TENSILE BAR TESTS AND THEIR PERCENT REDUCTION IN AREA VALUES. 5 MAY 1944 WTN.223-4684&5

779 12



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MACROETCHED VIEW OF HALF CROSS SECTION 17" BELOW TOP 8"x8"x27" INGOT. HEAT X-1345. W.A. GUN COMPOSITION. "AS CAST". FIGURES SHOW LOCATION OF TENSILE BAR TESTS AND THEIR PERCENT REDUCTION IN AREA VALUES. 5 MAY 1944 WTN.223-4686

Fig 14

APPENDIX A

APPENDIX A

Physical Properties of Tensile Test Bars Taken

From 8" x 8" x 27" Ingot - Heat X-1345

<u>Approximate Location</u>		<u>Yield Strength</u> P.S.I. (.01% Offset)	<u>Tensile Strength</u> P.S.I.	<u>Elong.</u> %	<u>R. A.</u> %	<u>Fracture</u>
<u>Vertical Distance</u> Below Top	<u>Horizontal Distance</u> From Center-line					
2-1/2"	2-1/8"	90,500	112,200	20.0	53.7	SLC
2-1/2	3	92,500	112,000	11.4	23.6	LLC
5	1-1/4	94,000	116,600	17.1	46.1	LC
5	2-1/8	93,000	116,000	19.3	52.9	SLC
5	3	95,000	116,600	20.7	60.6	C
7	3/8	85,000	104,600	10.7	23.6	LLC
7	1-1/4	88,500	109,600	19.3	52.5	SLC
7	2-1/8	92,000	113,400	18.6	52.1	LC
7	3	94,500	114,000	20.7	59.2	C
8-1/2	3/8	86,500	106,600	10.7	20.6	LC
8-1/2	1-1/4	87,500	108,600	20.0	57.4	C
8-1/2	2-1/8	91,500	112,000	19.3	52.5	C
8-1/2	3	91,500	111,600	20.0	57.0	C
10-1/2	3/8	83,500	104,600	14.3	33.5	LLC
10-1/2	1-1/4	83,500	106,200	20.0	56.3	LC
10-1/2	2-1/8	84,000	109,800	20.7	58.1	C
10-1/2	3	85,500	108,600	20.0	59.2	C
12	3/8	84,000	104,100	11.4	32.6	LLC
12	1-1/4	90,000	110,000	19.3	51.4	LC
12	2-1/8	90,500	112,800	19.3	51.4	SLC
12	3	91,000	111,000	21.4	59.9	C
14	3/8	86,000	107,400	15.7	43.2	LLC
14	1-1/4	86,500	109,000	20.7	56.3	C
14	2-1/8	89,500	111,800	15.7	57.0	C
14	3	92,500	112,400	18.6	51.0	SLC
15-1/2	3/8	84,500	105,100	15.0	32.6	LLC
15-1/2	1-1/4	85,000	107,400	21.4	51.7	LC
15-1/2	2-1/8	87,000	109,300	20.0	56.3	C
15-1/2	3	87,000	108,400	20.7	59.6	C
17-1/2	3/8	84,000	105,400	15.0	36.3	LLC
17-1/2	1-1/4	85,000	107,600	22.1	58.5	C
17-1/2	2-1/8	84,500	109,600	22.9	59.9	C
17-1/2	3	88,000	107,600	20.0	59.6	C

Fracture:

- LLC - Large Lustrous Cavities
- LC - Lustrous Cavities
- SLC - Small Lustrous Cavities
- C - Cupped - No Lustrous Cavities