WATERFORD ARSENAL LABORATORY

EXPERIMENTAL REPORT

No. WAL 311/57

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Associate Technical Director

V. T. Bender
Captain, Ordnance Department

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WATERFORD, MASS.

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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.

J. N. Pappas
Associate Metallurgist

V. E. Bender
Captain, Ordnance Dept.

APPROVED:

H. H. Zeising
Colonel, Ord. Dept.,
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 melt\(^1\), 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:

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>.23</td>
<td>.71</td>
<td>.29</td>
<td>.011</td>
<td>.020</td>
<td>.84</td>
<td>.51</td>
<td>.07</td>
</tr>
</tbody>
</table>

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

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\(^1\) 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:

- \(1650^\circ F\) - 6 hours - water quench
- \(1300^\circ F\) - 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:

<table>
<thead>
<tr>
<th>Type of Fracture</th>
<th>Ave. Red. of Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Lustrous Cavities</td>
<td>32.2%</td>
</tr>
<tr>
<td>Lustrous Cavities</td>
<td>46.4</td>
</tr>
<tr>
<td>Small Lustrous Cavities</td>
<td>52.4</td>
</tr>
<tr>
<td>No Lustrous Cavities</td>
<td>58.1</td>
</tr>
</tbody>
</table>

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.
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
W.T. 223-4740
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
WTRN. 223-467647
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 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 W.T.N.223-467889
MACROETCHED VIEW OF HALF CROSS SECTIONS 6\textfrac{1}{4}\textquoteright (UPPER) AND 8\textquoteright (LOWER) BELOW TOP OF 8\textquoteright x 8\textquoteright x 27\textquoteright 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.223-468081
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.223-468243
MACROETCHED VIEW OF HAFT CROSS SECTIONS 13 1/4" (UPPER) AND 15" (LOWER) BELOW TOP 8"X8"X27" 
'NGOT. 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 
WTT.223-468485
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
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.223-467647
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
MACROETCHED VIEW OF HALF CROSS SECTIONS 6.4" (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.223-468081
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&8
MACROETCHED VIEW OF HALF CROSS SECTIONS 13*/4" (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.223-468443
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.

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WATERTOWN ARSENAL

5 May 1944
WPN.223-4686
APPENDIX A

Physical Properties of Tensile Test Bars Taken From 8" x 8" x 27" Ingot - Heat X-1755

<table>
<thead>
<tr>
<th>Approximate Location</th>
<th>Vertical Distance From Top</th>
<th>Horizontal Distance from Center-line</th>
<th>Yield Strength (P.S.I.)</th>
<th>Tensile Strength (P.S.I.)</th>
<th>Elong. %</th>
<th>R. A. %</th>
<th>Fracture</th>
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<td>2-1/2&quot;</td>
<td>2-1/8&quot;</td>
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<td>112,200</td>
<td>20.0</td>
<td>53.7</td>
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<td>SLC</td>
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<tr>
<td>2-1/2</td>
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<td>93,000</td>
<td>116,000</td>
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<td>23.6</td>
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<tr>
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<tr>
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<td>112,000</td>
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</table>

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