BRITTLE FRACTURE IN
A WCB STEEL CASTING

Published by the
STEEL FOUNDERS SOCIETY OF AMERICA

Malcolm Blair
Technical and Research Director

July 1995
BRITTLE FRACTURE IN A WCB STEEL CASTING

ABSTRACT

A steel casting showing a "rock candy" type of fracture was submitted for examination. The brittle fracture was suspected to be caused by aluminum nitride precipitation on primary austenite grain boundaries. The purpose of the study was to examine the casting for other microstructural features that would confirm the suspected cause of low ductility fracture.

The fracture followed prior austenite grain boundaries, and the fracture surface was covered with fine, lath-like features. A macroetch of the steel produced a clear acid attack along prior austenite grain boundaries. The visual appearance, macroetch delineation of austenite grain boundaries, and lath-like features on the fracture surface are consistent with aluminum nitride formation during cooling.

In large castings, aluminum nitride can form at much lower concentrations of aluminum and nitrogen than in smaller castings where the cooling rate is higher. The deoxidation practice employed when producing large castings must be altered to decrease the residual aluminum concentration to eliminate this type of fracture.
EXPERIMENTAL PROCEDURES

A test bar had been removed from a 4500 pound, WCB steel casting. The bar was tested in three-point bending, fractured, and submitted for analysis. The cause of the brittle fracture was suspected to be aluminum nitride. The examination was conducted to verify the suspected cause of embrittlement.

The fracture surface was macrophotographed upon receipt. A portion of the fracture surface was examined in a scanning electron microscope (SEM) equipped with energy dispersive x-ray spectrometer (EDXRS).

A second section of the fracture surface was removed and mounted so the microstructure perpendicular to the fracture surface could be examined. The section was polished, etched in Nital, and examined on an optical microscope.

A third section was removed, austenitized at 1650°F (900°C) for 1.5 hours, water quenched, and surface ground through 600 grit silicon carbide paper. This sample was macroetched in a 1:1 solution of HCl and water at 185°F (85°C) and examined for attack on primary austenite grain boundaries.

RESULTS AND DISCUSSION

A macrophotograph of the fracture surface of the bent and fractured bar is shown in Figure 1. The fracture surface exhibited features commonly referred to as a rock candy fracture which is caused by the fracture following prior austenite grain boundaries. Rock candy fracture can be caused by aluminum nitride, borides, carboborides, alloy carbides, and ferrite plus precipitates along grain boundaries.(1-4)

The microstructure of the metal perpendicular to the fracture surface is shown in Figure 2. The microstructure consisted of uniformly distributed pearlite and ferrite typical of a normalized structure. The unetched microstructure was examined under an optical microscope for grain boundary precipitates but none were found.

A 50X SEM image of the fracture surface is shown in Figure 3. Two distinct types of fractures were found at 250x as illustrated in Figures 4 and 5. A cleavage or "river-pattern" fracture area within a grain is illustrated in Figure 4.

The majority of the fracture surface, however, exhibited needle-or lath-shaped features illustrated in Figures 5 and 6. This feature has been associated with aluminum nitride embrittlement.(5) An EDXR spectrum from point A of Figure 6 is shown in Figure 7. The aluminum nitride precipitate has a needle-like morphology, but only iron and small amounts of manganese were detected in the needle-shaped features.
This implies that the nitride layer is too thin to be detected with energy dispersive x-ray analysis.

Some manganese sulfides and deoxidation inclusions containing titanium, calcium, and aluminum were present on the fracture surface. The density, shape, and distribution of these inclusions did not suggest that they caused the brittle fracture.

A surface of a sample that had been macroetched following austenization and quenching is shown in Figure 8. Austenite grain boundary attack by the macroetchant is consistent with the presence of aluminum nitride. (5)

The composition of the steel is presented in Table I. The iron rich corner of the ternary Fe-N-A1 system is shown in Figure 9.(2) The aluminum and nitrogen concentrations were 0.064% and 0.0176%, respectively, and this point is labelled point A on Figure 9. Temperatures greater than 2282°F (1250°C) are required to completely dissolve the aluminum nitride in this steel.(3) Lower temperatures may partially dissolve aluminum nitride precipitates, but they usually re-form during cooling because the undissolved particles provide centers for nucleation and growth.

CONCLUSIONS

The brittle fracture in a specimen removed from a 4500 pound, WCB steel casting was a result of the formation of aluminum nitride along the austenite grain boundaries during cooling of the steel. The fracture followed prior austenite grain boundaries, and the fracture surface was covered with fine, lath-like features. A macroetch of the steel produced a clear acid attack along prior austenite grain boundaries. The visual appearance, macroetch delineation of austenite grain boundaries, and lath-like features on the fracture surface are consistent with aluminum nitride formation during cooling. Although the aluminum and nitrogen concentrations would be acceptable for smaller, faster-cooling castings, the concentrations are excessive for a casting of this thickness. The deoxidation practice should be altered to reduce the aluminum concentration in order to minimize the risk of aluminum nitride formation.

Submitted by,

Robin Griffin, Ph.D.
Optics Laboratory Manager

Zoe B. Dwyer, Ph.D.
Postdoctoral Fellow

Approved by:

Charles E. Bates, Ph.D.
Research Manager
REFERENCES


Figure 1. Optical Macrograph of a Bent and Fractured 4 inch Section from a 4500# Casting. (2X)
Figure 2. Optical Microstructure of the Bent and Fractured Bar. (100X, Nital)
Figure 3. SEM Microstructure of Fracture Surface From Aluminum Nitride Embrittled Steel. (50X)
Figure 4. SEM Microstructure of Fracture Surface from Aluminum Nitride Embrittled Steel. (250X, secondary electron)
Figure 5. SEM Microstructure of Fracture Surface from Aluminum Nitride Embrittled Steel. (250X, secondary electron)
Figure 6. SEM Microstructure of Fracture Surface from Aluminum Nitride Embrittled Steel. (350X, secondary electron)
Figure 7. EDXR from the Fracture Surface of an Aluminum Nitride Embrittled Steel. (Figure 7, Point A.)
Figure 8. Macrograph of macroetched sample that had been austenitized at 1650°F for 1½ hours and then water quenched.
# TABLE I

## Composition of Brittle Fracture Specimen

<table>
<thead>
<tr>
<th>Element</th>
<th>Measured Weight Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>0.064</td>
</tr>
<tr>
<td>O</td>
<td>0.0075</td>
</tr>
<tr>
<td>N</td>
<td>0.0176</td>
</tr>
<tr>
<td>C</td>
<td>0.250</td>
</tr>
<tr>
<td>Si</td>
<td>0.577</td>
</tr>
<tr>
<td>Mn</td>
<td>0.856</td>
</tr>
<tr>
<td>Ni</td>
<td>0.040</td>
</tr>
<tr>
<td>Cr</td>
<td>0.098</td>
</tr>
<tr>
<td>Mo</td>
<td>0.014</td>
</tr>
<tr>
<td>Cu</td>
<td>0.060</td>
</tr>
</tbody>
</table>
Figure 9. Effect of Temperature on Equilibrium Solubility of AIN in Steel. From Wilson and Gladman.
USE OF THIS REPORT AND INFORMATION CONTAINED THEREIN

Publicity

This report and the information contained therein is the property of the individual or organization named on the face hereof and may be freely distributed in its present form. However, the University of Alabama at Birmingham (UAB) hereby reminds Sponsor that no advertising or publicity matter, having or containing any reference to the University of Alabama at Birmingham, shall be made use of by anyone, unless and until such matter shall have first been submitted to and received the approval in writing of UAB. (UAB does not usually approve any type of endorsement advertising.)

Limitation of Liability

The faculty and staff of UAB associated with this project have used their professional experience and best professional efforts in performing this work. However, UAB does not represent, warrant or guarantee that its research results, or product produced therefrom, are merchantable or satisfactory for any particular purpose, and there are no warranties, express or implied, to such effect. Acceptance, reliance on, or use of such results shall be at the sole risk of Sponsor. In connection with this work, UAB shall in no event be responsible or liable in contract or in tort for any special, indirect, incidental or consequential damages, such as, but not limited to, loss of product, profits or revenues, damage or loss from operation or nonoperation of plant, or claims of customers of Sponsor.

Report No.: UAB-MTG-CLS-B

To: Steel Founders' Society of America
455 State Street
Des Plaines, IL 60016

Date: July 18, 1995

UAB Account No. 635890 and 634950

E-File: TSR-123 .efr