Compensation for Boron in Pearlitic Ductile Iron

Project Proposal presented to the Ductile Iron Society

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OBJECTIVE
Tramp levels of boron can promote ferrite in pearlitic ductile iron, thus requiring excess Mn and Cu to produce pearlitic iron with adequately low levels of free ferrite. The goal of this investigation is to determine the relationship between boron and the Mn, Cu and Sn requirements in pearlitic ductile iron.

COST and ESTIMATED TIME TO COMPLETION
The proposed research consists of pouring several heats with varying levels of boron and with additions of Mn, Cu and Sn to restore a pearlitic microstructure. The same test castings used in DIS Research Projects 52 and 54 will be poured from these heats, and the microstructures will be analyzed for ferrite and pearlite contents. Multiple 200-lb. heats are proposed with 4 splits per heat. The proposed chemistries are as follows.

<table>
<thead>
<tr>
<th>Heat</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cu</th>
<th>Sn</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.6</td>
<td>2.4</td>
<td>0.35</td>
<td>0.6, 0.8</td>
<td>0</td>
<td>0.04</td>
</tr>
<tr>
<td>B</td>
<td>3.6</td>
<td>2.4</td>
<td>0.35</td>
<td>0.4, 0.6, 0.8, 1.0</td>
<td>0</td>
<td>0.0010</td>
</tr>
<tr>
<td>C</td>
<td>3.6</td>
<td>2.4</td>
<td>0.35</td>
<td>0.4, 0.6, 0.8, 1.0</td>
<td>0.04</td>
<td>0.0010</td>
</tr>
<tr>
<td>D</td>
<td>3.6</td>
<td>2.4</td>
<td>0.35</td>
<td>0.4, 0.6, 0.8, 1.0</td>
<td>0</td>
<td>0.0020</td>
</tr>
<tr>
<td>E</td>
<td>3.6</td>
<td>2.4</td>
<td>0.35</td>
<td>0.4, 0.6, 0.8, 1.0</td>
<td>0.04</td>
<td>0.0020</td>
</tr>
</tbody>
</table>

Ferrite content will be determined in three cast sections – ½”, 1” and 2” sections. Chemical analysis and metallographic examinations will be performed to demonstrate the boron effect. Both nodularity and ferrite content will be assessed. The results will be presented at the DIS annual meeting and in a written research report. The proposed cost of the project is $31,950. It is anticipated that the project will require 6 months to complete.

ECONOMIC JUSTIFICATION
Our understanding of how composition affects the properties of ductile iron is still incomplete. There is a need for a better understanding of how to counteract the effect of tramp boron on the microstructure of ductile iron castings. In particular, there is a need to identify ways to neutralize the ferritizing effect of boron. With better control of the microstructure, there will be higher yields and reduced cost in the foundry. The results of this study should greatly increase our ability to control the microstructure and properties of the higher-strength ductile iron grades.

POSSIBILITY OF SUCCESS
The possibility of success is good. It has been reported that with sufficient alloying the ferrite content can be brought under control in boron-contaminated ductile iron.
HISTORY AND THEORY

Several investigators have reported that boron increases the propensity to form ferrite and carbides in ductile iron. Levels above 0.0005% (5 ppm) can influence the ability to develop fully pearlitic microstructures in ductile iron. The normal additions of Mn, Cu and Sn must be increased to counteract the ferritizing tendency of boron in pearlitic ductile iron. Various reports have been given on the influence of boron. One report stated that when B exceeded 0.0008% in pearlitic ductile iron, raising the Cu level from 0.23% to 0.47% was sufficient, but that additions of up to 0.16%Mn were ineffective. The ferrite promoting tendencies of boron were reported in DIS Research Project 39, see photomicrographs from Project 39 below.

Boron can be introduced in ductile from charge materials including both iron units and additives. Sources of boron include tool steels, interstitial-free steels, hardenable steels, enameled cast irons and steels, and malleable iron. It has been reported that some silicon carbide sources can contain boron. Boron can also be picked up from a variety of furnace lining materials. Boron is not reduced or eliminated in normal melting practice. Recovery is considered to be >90 % from most sources when oxygen contents are low.

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Figure 4: Microstructures obtained from test castings with and without boron additions.

![Microstructures](image1.png)

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Figure 1: Effect of Boron Content on the Hardness of Pearlitic Ductile Iron Castings (Courtesy of Farrar Corporation).
Farrar Corporation reported that hardness steadily decreased with increasing boron content, as shown in the figure below.

DIS Research Project 39 investigated possible methods for removing boron through reactions with fluxing agents containing sodium. A small amount of boron had entered the slag and was removed; however, the ferrite-forming tendencies of boron were not fully ameliorated. For this investigation, it is proposed that the neutralization of boron can be accomplished by inhibiting BN formation. As with steels, boron will be protected with additions of strong nitride formers. The Ellingham diagram for nitrides is shown below, and it reveals that boron is a relatively weak nitride former when compared to Ti and Zr.

![Ellingham diagram for nitride formation with various elements in molten iron.](image)

**Figure 2.** Ellingham diagram for nitride formation with various elements in molten iron.

More recently, the investigation of boron was conducted and reported on in DIS Research Reports 52 and 54. In Project 52, an attempt to use boron to offset the pearlitizing effect of manganese in ferritic ductile iron was studied. The project confirmed the ferritizing potential of boron, but was largely unsuccessful due to an inconsistent response to boron additions. It was later learned that late additions of ferro-boron to the pouring ladle produced inconsistent results.
In the most recent study, Project 54, the inconsistent response to boron additions was remedied by making boron additions in the furnace prior to Mg treatment and transfer to the pouring ladle.

As an addition in steels, boron works by suppressing the nucleation (but not growth) of proeutectoid ferrite on austenitic grain boundaries. One of the theories is that the presence of B on or near these boundaries lowers the driving force for ferrite nucleation, because it reduces strain- or interfacial energies. It has been proposed that boron carbides (M23C6 carbides) promote hardenability, whereas boron nitrides promote ferrite. The aim composition in many steels is 0.0010% B. Its effectiveness increases linearly up to about 0.0020% with 0.0030% being the usual maximum.

DIS Project 54 focused on methods to overcome the ferritizing potential of boron in pearlitic ductile iron. In that study, late additions of Ti and Zr were made to the melt in order to remove dissolved nitrogen from the metal. Nitrogen is known to defeat the hardenability benefit produced by boron additions in steel, and all boron steels are treated with combinations of Al, Ti and Zr to tie up free nitrogen and obtain the proper boron effect. It was proposed that a similar practice might benefit ductile iron. However, in DIS Research Project 54, the ferritizing effect of boron was unaffected by additions of the powerful nitride formers Ti and Zr.

WHAT’S BEING PROPOSED THAT HASN’T BEEN DONE BEFORE

What is proposed is new to the ductile iron producers of North America. While there is substantial evidence that boron promotes ferrite, there is no published data showing what levels of Mn, Cu and Sn are required to counteract the ferritizing effect of boron in ductile iron.

PROCEDURE

The experimental procedure consists of producing up to five heats with three levels of boron to demonstrate the ferrite promoting effect of boron, followed by additions of Cu (4 levels) and Sn (2 levels) to restore a pearlitic microstructure. A total of five heats (4 split heats) will be poured employing a casting with a cluster of test bars ranging in section size from ¼” to 2”. The chemical compositions and microstructures of the castings will be analyzed and reported. The results will be evaluated and a formal report will be prepared.

BENEFITS TO THE MEMBERSHIP

There are a number of member foundries that make pearlitic ductile iron castings that are required to meet minimum specified properties but may not consistently achieve these properties. Many have chosen to avoid making pearlitic iron following the relining of the furnace or after long periods of time in the holding furnace. There are still others who unwittingly purchase boron-containing scrap and encounter problems meeting the mechanical properties in their pearlitic castings. When boron interferes with the production of pearlitic iron, the foundry will often need to increase Cu to meet the required properties of the grade. The goals of this research project develop methods to counteract the anticipated and unanticipated increases in boron and its deleterious effect on properties, and thereby save money in the foundry.

REFERENCES

11) DIS Research Project 39, R. Naro, J.F. Wallace and Yulong Zhu