AN INVESTIGATION ON THE WELDABILITY OF GREY CAST IRON USING NICKEL FILLER METAL

M. Pouranvari

Materials and Metallurgical Engineering Department, School of Engineering, Islamic Azad University, Dezful Branch, Dezful, Iran

E-mail: mpouranvari@yahoo.com

Abstract
Shielded metal arc welding process using a nickel electrode was used to join a grey cast iron. The effect of post weld heat treatment (PWHT) on the microstructure and hardness was studied. By using of nickel filler metal, formation of hard brittle phase (e.g. carbides and martensite) in fusion zone is prevented. Before PWHT, heat affected zone exhibits a martensitic structure and partially melted zone exhibits a white cast iron structure plus martensite. Applied PWHT was successful in prevention of martensite formation in heat affected zone and reduction of partially melted zone hardness. Results showed that welding of grey cast iron with a nickel filler metal and PWHT applying can serves as a solution for cast iron welding problems.

1. INTRODUCTION
The welding of ductile cast iron is not normally practised in the foundry industry for the reclamation or fabrication of castings, due to the inconsistency of the mechanical and physical properties achieved. Ductile irons contain higher amounts of carbon compared to steels which diffuses into the austenite during welding, forming hard brittle phases, namely martensite and carbides at the weld interface. These give rise to poor fracture toughness properties and high hardness values (El-BANNA, 1999).

Weldability of cast irons depends on several factors including:
(i) Original matrix structure
(ii) Chemical composition
(iii) Mechanical properties of the base metal
(iv) Welding process and preheat/post heat treatment (KISER and IRVING, 1994; VOIGHT and LOPER., 1983; OGI et al. 1988)

In this paper, microstructure of grey cast iron welds is investigated in as-weld condition and after applying a post weld heat treatment (PWHT). The effect of PWHT on the hardness of the microstructural zones of the weld is also examined.

2. EXPERIMENTAL PROCEDURE
A grey cast iron was used as the base metal in this study. Shielded metal arc welding (SMAW) process using a nickel electrode was used to join a gray cast iron. A single V-shaped groove was considered as the preferred joint design. Welding parameters are given in Table 1.

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>Polarity</th>
<th>Speed (mm/min)</th>
<th>Electrode diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>DCEP</td>
<td>100</td>
<td>4</td>
</tr>
</tbody>
</table>

After welding, the specimens were immediately transferred to an electric furnace, kept there at 850°C for 1 h and then furnace cooled to room temperature.
Cutting of samples for metallographic examination was carried out avoiding excessive heating that might have led to local alterations in microstructure. Standard metallographic procedure was used to microstructural examinations. Nital 2% solution was used to reveal various microstructure constituents in the weldment.

Vickers microhardness test using 200 g load was carried out to obtain average hardness of various microstructural zones in the weldment.

3. RESULTS AND DISCUSSIONS

3.1. As-weld microstructure

Fig. 1 shows as-weld microstructure various microstructural zones in the weldment. Four distinct regions are formed when a weld is made in cast iron, as follows:

(i) Fusion zone (FZ) which is melted during welding process and is resolidified.
(ii) Heat Affected Zone (HAZ) which is not melted but undergoes microstructural changes.
(iii) Partially melted zone (PMZ) which is the area immediately outside the FZ where liquation can occur during welding.
(iv) Base metal (BM) which its structure remains unaffected during weld thermal cycle.

Fig.1 Microstructure of various regions in grey cast iron weld in as-weld condition
Fig. 2 Temperatures experienced by various microstructural zones in a cast iron weld (KOU, 2003)

Fig. 2 shows relationship between Fe-C phase diagram and the temperature experienced by each microstructural zone.

As can be seen in Fig. 1a, BM exhibits a ferritic matrix plus graphite phase. In FZ, BM is melted and mixed with filler metal. Cooling rates are high in this zone producing very hard, brittle ledeburitic carbides in as-welded condition, if a Fe-C alloy filler metal is used (MARTINEZ and SIKORA, 1994). To reduce the risk of formation brittle phase in FZ, nickel based filler metal is used to join of cast irons. As can be seen, in Fig. 1b, FZ microstructure consists of mainly an austenitic matrix plus small amount of dispersed graphite particles.

In PMZ, the portion of the matrix of the base metal near the primary graphite melted during the weld pass, while the remainder of the matrix transformed to austenite. This region is highly carbon-enriched, and therefore, at the fast cooling rate typical of welding, coarse carbides can form directly from the liquid as the weld metal cools. These can form a continuous brittle network along the weld fusion line. The matrix surrounding these carbides can also transform to martensite at lower temperatures. This phase is also very hard and brittle when its carbon content is high. As can be seen in Fig. 1d, PMZ consists of eutectic ledeburit and martensite.

During weld thermal cycle, HAZ experiences a temperature higher than \( A_1 \) (Eutectoid temperature in Fe-C phase diagram). Therefore, it is expected that some amounts of graphite is dissolved and austenite is formed in this zone (EL-BANNA, 1999). The amount of austenite formation depends on the time and temperature experienced by a point and the primary matrix microstructure of cast iron. The rate of austenite formation in a pearlitic structure is higher than in a ferritic structure due to its lamellar structure (i.e. the diffusion distance for carbon atoms from iron carbide to ferrite is shorter). During cooling, HAZ microstructure transforms to a brittle structure. Since, the cooling rate is high, the graphitization process can not be completed and a large amount of \( Fe_3C \) is formed. Moreover, formed austenite is decomposed to a hard brittle martensite. Fig. 1e shows HAZ microstructure indicating that there is high amount of martensite plus some graphite in this zone.

3.2. Microstructure after PWHT

Fig. 3 shows microstructure various microstructural zones in the weldment after PWHT. As can be seen microstructure of FZ is remained unchanged after PWHT thermal cycle. However, HAZ microstructure significantly is affected by PWHT. As can be seen in Fig. 3c, HAZ consists of graphite flakes in a ferritic matrix. Holding in 870°C for 1h provide sufficient
driving force to dissolve of Fe$_3$C and martensite phases formed during welding. During slow furnace cooling, graphite and not Fe$_3$C is formed in a ferritic matrix. Therefore, the applied PWHT can reduce formation of brittle phases in HAZ.

![Microstructure of various regions in grey cast iron weld after PWHT](image)

**Fig. 3 Microstructure of various regions in grey cast iron weld after PWHT**

### 3.2. Effect of PWHT on hardness

Hardness variation across the weldment of the cast irons is one of the most important factors controlling quality of cast iron welds.

Table 2 shows the hardness value corresponding to FZ, PMZ, HAZ and BM, before and after PWHT. As can be seen in as-weld condition, PMZ has the highest hardness value. This can be related to its brittle microstructure consisting hard eutectic ledeburit and martensite. High hardness value of HAZ can be related to the present of high amount of martensite in this region. The low value of hardness in FZ, comparable to BM hardness, is due to its austenitic structure. Therefore, nickel filler metal can reduce hardness of FZ in cast iron, as one of the big problem of cast iron welding.

As can be seen in Table 2, HAZ and PMZ hardness significantly reduces after PWHT. FZ hardness remains unchanged after PWHT.

<table>
<thead>
<tr>
<th></th>
<th>FZ Hardness</th>
<th>PMZ Hardness</th>
<th>HAZ Hardness</th>
<th>BM Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-weld</td>
<td>190</td>
<td>620</td>
<td>580</td>
<td>180</td>
</tr>
<tr>
<td>After PWHT</td>
<td>180</td>
<td>250</td>
<td>210</td>
<td>180</td>
</tr>
</tbody>
</table>

### 4. CONCLUSIONS

From this research the following conclusions can be drawn:
1-By using of nickel filler metal, formation of hard brittle phase (e.g. carbides and martensite) in FZ is prevented.

2-Before PWHT, HAZ exhibits a martensitic structure and PMZ exhibits a white cast iron structure plus martensite. This can reduce the fracture toughness of the weldment.

3-Applied PWHT was successful in prevention of martensite formation in HAZ and reduction of PMZ hardness.

4-According to the results presented in this paper, it can be concluded that welding of grey cast iron with a nickel filler metal and PWHT applying can serves as a solution for cast iron welding problems.

REFERENCES