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International Journal of
Materials Technology and Innovation
Volume 3, Issue 1 (2023), pages 70-74

IJMTI
Online ISSN 2682-4299

A study on the Microstructure of Heat Affected Zone of Austempered Ductile Iron Alloyed with 1.6% Cu and 1.6% Ni

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Received 15 October 2022
Accepted 19 December 2022
Published 6 April 2023

Abstract

Heat Affected Zone (HAZ) is the area where one or more changes from the starting state to the solid state engaged in heating have occurred as a result of the welding heat cycle. In this study, we attempted to weld Austempered Ductile Iron (ADI) of the initial alloy ferritic matrix using Shielded Metal Arc Welding (SMAW) with an E6013 electrode. A total of six alloys of ADI were austempered at 360 °C for 180 minutes after being austenitized at 900 °C for 15, 30, 60, 120, 180, and 360 minutes. An optical Microscope (OM) and an image-processing technique characterized the weld joint's microstructures. The microstructure of the partial fusion zone (PFZ) has nodular graphite, pearlite, and a small fraction of martensite; the austenite transformation zone (ATZ) consists of nodular graphite plus pearlite. Only a part of the austenitic- ausferritic matrix can transform to austenite at the repeated transformation zone (RTZ). No obvious change in the microstructure at the base metal zone (BMZ).

Keywords: Austempered, Ductile Iron, Microstructure, Affected zone, ADI, welding.

1. Introduction

Austempered ductile iron (ADI) can be considered a suitable alternative to steel in many new applications due to its unique combination of hardness, strength, and wear resistance with good material machinability [1]. ADI is a special type of ductile cast iron that combines alloying elements with precise and controlled heat treatment [2-4]. The microstructure of ADI weld metal mainly consists of bainitic ferrite, retained austenite, and graphite nodules. The bainitic ferrite plate width and retained austenite volume fraction in the weld increase with increasing austenitizing temperature and austempering temperature [5,6]. There are two problems during the welding process of ADI; the formation of massive cementite in the as-welded ductile iron because of the rapid cooling rate; the properties of ADI weld should match those of ADI base material [6,7]. Some aspects of the welding characteristics and formation of microstructures in a newly developed coated electrode for ADI were investigated. The conclusion was that FZ microstructures consist of ledeburitic carbide surrounded by alloyed pearlite and graphite nodules; In PFZ, the portion of the base metal matrix near the primary graphite nodules melted during welding, while the remainder of the matrix transformed to austenite [8]. In this paper, the microstructure of the welding heat-affected zone of austempered ductile iron alloyed with 1.6% Cu and 1.6% Ni will be investigated.

2. Experimental Procedures

This work prepared a squared cross-section area of ADI alloys (10 mm×10mm ×100mm) dimensions for welding and microstructure investigation. Its chemical composition is listed in Table 1. The samples were machined for welding with a single U-groove with 70◦

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of groove angle. The depth of the groove was 7 mm as illustrated in Fig. 1. These alloys were subjected to austempering heat treatment as shown in Table 2 [9-12].

Table 1. Chemical Composition of material under investigation.

Element	Weight (%)
C	3.3
Si	2.6
Mn	0.35
S	0.008
P	0.01
Mg	0.05
Ni	1.6
Cu	1.6
Fe	rest

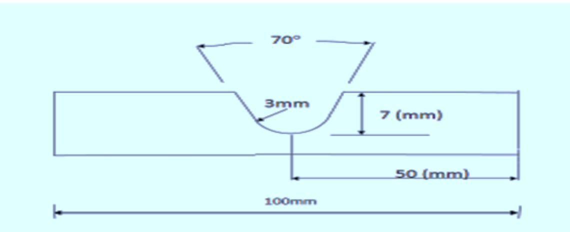

Fig. 1 Configuration and dimension of Arc welding specimen.

Table 2. Heat treatment conditions.

Austenitizing conditions		
alloy	Temperature °C	Time, min
ADI 15	900	15
ADI 30	900	30
ADI 60	900	60
ADI 120	900	120
ADI 180	900	180
ADI 360	900	360
Austempering conditions for all austenitizing conditions were 360 °C for180 min		

The microstructure of the material austenitized at 900 °C contains graphite and circular ferrite surrounded by high carbon austenite as shown in Fig. 2.

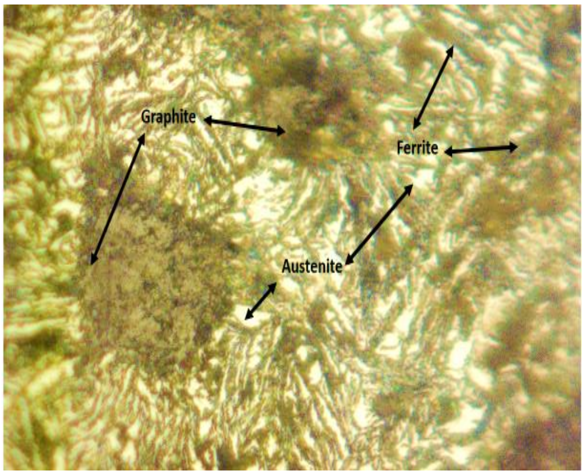

Fig. 2 microstructure of base metal (Ausferrite structure) X1000.

The phases were measured by using an image-processing technique using image Dewinter Material plus 4.2 (AOB Test System) software to estimate the ferrite, austenite, and graphite percent in ADI base metal. Fig. 3 illustrates the volume fraction percentage of Austenite and Ferrite for the initial material under the study. Increasing the austenitization time resulted in increasing the amount of ferrite while decreasing the austenite contents in the matrix. The microstructure of the samples austenized for short periods at 900 °C contains a considerable volume of pro-eutectoid ferrite. This phase is replaced by ausferrite as the soaking period extends.

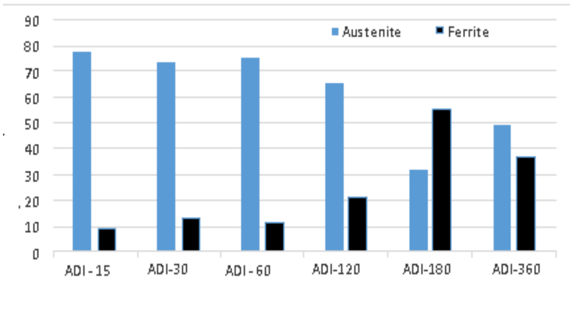

Fig. 3 Volume fraction percentage (Austenite and Ferrite) of ADI alloys under study.

In this investigation, Shielded Metal Arc Welding (SMAW) process was used for welding ADI alloys with AWS E6013 electrodes. The welding process variables needed to hold constant during the welding procedure. The welding current was about 110 A; the volt was 50 V, and the electrode diameter was 2.5 mm, with the chemical composition shown in Table 3.

To make clear temperature distribution at the welding joint; the temperature was measured by an

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infrared sensor and recorded when the test material was welded. The distribution of the highest temperature in the welding joint is plotted in Fig. 4.

Table 3. Chemical compositions of weld metal (wt. %).

Element	Weight (%)
C	0.2
Si	0.3
Mn	1.2
S	0.3
P	0.04
Cr	0.2
Mo	0.3
Ni	0.3
V	0.02

The first number in each bracket represents the distance of the marked point to the welding fusion line and the second represents the highest temperature. These points are linked to show the highest temperature distribution in welding joints. In this figure, the solidus line (S line) temperature is indicated by line S. The Upper limit and lower limit temperature of the eutectoid temperature interval;(723- 910)°C based on the Iron-Carbon Phase Diagram; are indicated by lines AC1.2 and AC1.1 respectively. By these means, the welding joint is divided into five zones: weld zone, partial fusion zone, austenite transformation zone, repeated transformation zone, and base metal zone.

A (dist.= 0.1mm, temp = 1210C°)	fusion zone (FZ)
B (dist.= 0.9mm, temp = 1077C°)	Partial fusion zone (PFZ)
C(dist.= 1.5mm, temp = 968C°)	Austanite transformation zone (ATZ)
D(dist.= 2.5mm, temp = 805C°)	Repeated transformation zone (RTZ)
E(dist.= 3.5mm, temp = 643C°)	Base metal (BM)

3. Results and Discussion

To make a clear effect of the welding heating cycle on the microstructure of the HAZ; the microstructures of the weld joint were observed under the optical microscope (OM), (Carl Zeiss – Axiotech 100 HD), connected with computer imaging software to characterize the grain structure of weld region.

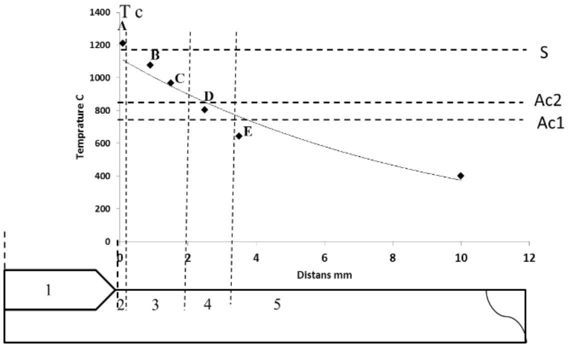

Fig. 4 The highest temperature distribution across welding joint.

Fig. 5 shows the microstructure of the fusion zone and HAZ of the joint welded at room temperature without preheating. The fusion zone has many alloy elements (such as Ni and Mo) that were added in by the electrodes and a matrix of austenitic-bainitic could be obtained in the as-welded condition.

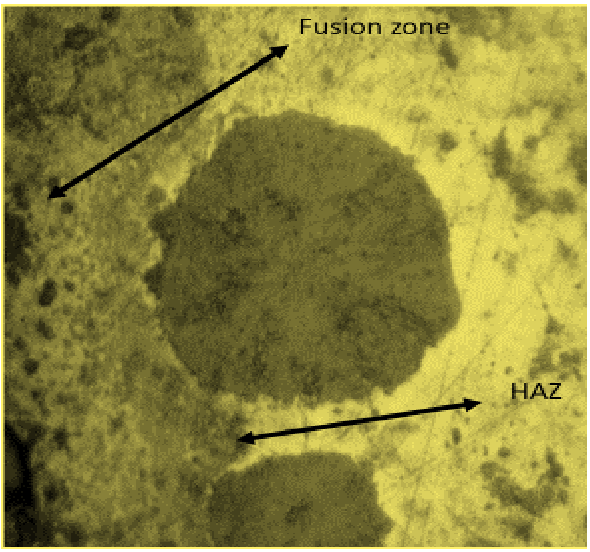

Fig. 5 Microstructure of the fusion zone of heat-affected zone X1000.

As seen in Fig. 6 the microstructure of the partial fusion zone is similar to FZ. It has nodular graphite, pearlite, and a small fraction of martensite due to fast cooling. The martensite usually appears near the fusion line. As the cooling rate in this zone is extremely fast and the alloy element in the weld metal such as Ni and Mo may be diffused to the zone, which may promote the formation of the martensite.

At Austenite Transformation Zone (ATZ), the highest heating temperature in this zone is higher than

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the upper limit temperature of the eutectoid temperature and lower than the temperature of the solidus line. The microstructure in this zone consists of nodular graphite plus pearlite and ferrite as shown in Fig. 7.

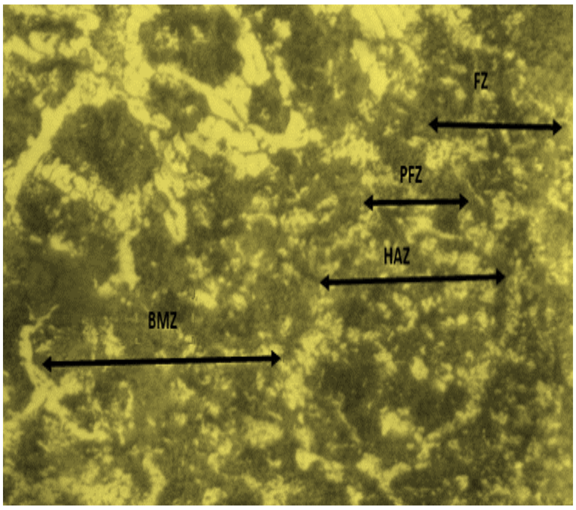

Fig. 6 Microstructure of partial fusion zone, X 1000.

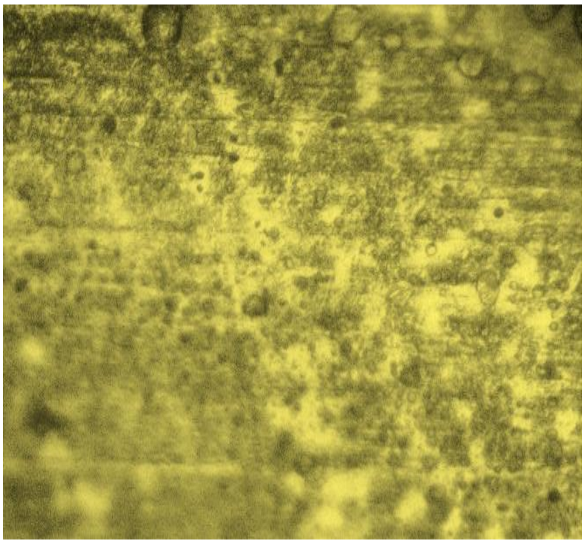

Fig. 7 Microstructure of the austenite transformation zone, X1000.

Repeated Transformation Zone (RTZ): The maximum heating temperature in this zone lies between the upper limit and the lower limit of the eutectoid temperature. The temperature range is quite narrow, and the heating rate is very rapid during welding; only a part of the austenitic-Ausferritic matrix can transform to austenite, that is to say, a part of ausferrite in the austenitic- Ausferitic matrix transforms to austenite. During the following cooling, all the austenite will transform to pearlite, the untransformed ausferrite will remain the same at room temperature as shown in Fig. 8.

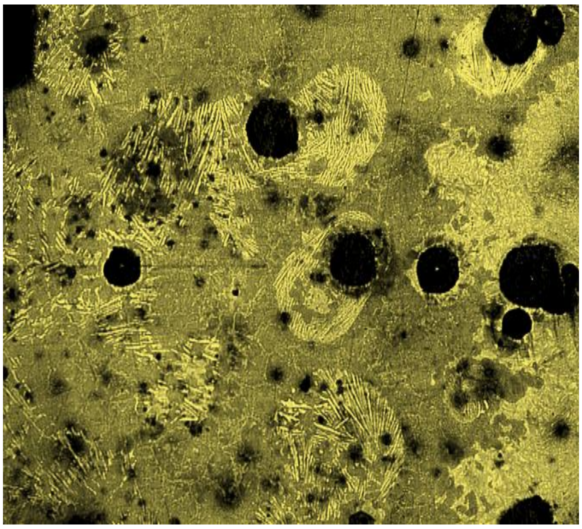

Fig. 8 Microstructure of repeated transformation zone, X1000.

Base Metal Zone (BMZ): The maximum heating temperature in this zone is lower than the lower limit of the eutectoid temperature. No obvious change can be seen in the microstructure of this zone as shown in Fig. 2. The microstructure contains acicular ferrite surrounded by high-carbon austenite and graphite. These results are in agreement with previous work on another alloy carried out by Deyuan, L et.al (2004) [2].

4. Conclusion

The following conclusions can be drawn from this study on the microstructure of the heat-affected zone of ADI alloyed with 1.6% Cu and 1.6% Ni.

The microstructure of the fusion zone has many alloy elements such as Ni, and Mo added in by the electrodes, and a matrix of austenitic-bainitic could be obtained in as-welded condition for the whole alloys. The microstructure of the Partial Fusion Zones (PFZ); which is similar to Fusion Zone (FZ) has nodular graphite, pearlite, and a small fraction of martensite. As the cooling rate in this zone is extremely fast, the alloy element in the weld metal such as Ni and Mo may be diffused to the zone, which may promote the formation of the martensite. For the austenite transformation zone, the microstructure consists of nodular graphite, pearlite, and ferrite. In the Repeated Transformation Zone (RTZ), only a part of the austenitic- Ausferritic matrix can transform to austenite. That is to say, a part of the ausferrite in the austenitic- Ausferritic matrix transforms to austenite. During the following cooling; all the austenite will transform to pearlite, and the untransformed ausferrite will remain the same at room temperature. No obvious change can be seen in the

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microstructure of the Base Metal Zone (BMZ). It contains a circular ferrite surrounded by high-carbon austenite and graphite.

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