INVESTIGATION OF MICRO-ADDITION OF ANTIMONY ON THE WELDABILITY OF PRE-HEATED TREATED AT 400 °C CARBIDIC AUSTEMPERED DUCTILE IRON (CADI)

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Abstract

In this research, impact of micro-addition of antimony powder (70 µm) on the weldability of pre-heat treated carbidic austempered ductile iron was investigated. Carbidic austempered ductile iron of different amount of micro-addition of antimony powder was produced by employing sand casting techniques. The cast samples were subjected to preheating treatment at a temperature of 400 °C to reduce the inherent stresses in the cast samples before welding the work pieces together. The preheated samples pieces were welded together using shielded metal arc welding. The microstructure of the welded antimony modified CADI showed graphite diffusion in the bead with uniform distribution of phases, improving weldability. The presence of antimony in the produced CADI helped in reducing the size of the carbides to granular form, thereby making this material possess good weldability.

Keywords: Antimony, Weldability; CADI; Electrodes; Microstructures; Electric Arc welding.

1. INTRODUCTION

Poor welding property of most cast irons originates mainly from the high carbon content of cast irons. By subjecting cast irons to welding (heating and cooling), many different undesired microstructures of carbon may be formed, thereby decreasing the weldability in all regions related to welding. Two likely routes for welding cast irons are invoke, which are cold and hot welding. The two methods are principally separated from each other in accordance to the preheating temperatures ranges used. Cold welding for instance, uses lower preheating temperatures, which are not sufficient for lowering the cooling rate of the cast iron to the desired values, as a result of brittle phases that are obtainable (martensite and carbides). Weldability of cast iron has been found to be very poor due to the heterogeneity of matrix phase and non-wettability of the graphite phase. These phases undergo a series of microstructural changes in the heat affected zone during weld repairing by fusion welding [1] (Martin J. W, 2006).

The welding of ductile cast iron is not normally practiced in the foundry industry for the reclamation or fabrication of castings, due to the inconsistency of the mechanical and physical properties achieved [2]. Grey irons contain higher amounts of carbon compared to steels which diffuses into the austenite during welding, forming hard brittle phases [3], namely martensite and carbides at the weld interface [4]. These give rise to poor elongation properties and high hardness values. Weldability of ductile cast iron depends on its original matrix, chemical composition, mechanical properties and structure of welding process and working condition [5]. The preheating temperature range depends on the hardenability of the iron chemical composition or carbon equivalent, the size and complexity of the weld and the type of filler materials used in the course of welding the work pieces together [6,7]. Preheating must be sustained for a time sufficient to avoid martensite formation and to prevent secondary graphite from developing in the matrix upon annealing or multi-pass welding. The effect of preheat is to reduce residual stresses, distortion, prevent cold cracking and reduce the hardness in the HAZ [8-10].

Ductile cast iron is an important cast material to the designer which combines the advantages of cast iron, such as cheapness, ease of machining, low melting temperature, good fluidity, good wear resistance properties, high damping capacity, excellent heat resistance properties [11-12] than those of steel even in terms of high strength, ductility, toughness, hot workability and hardenability [11,13]. Therefore, such material can economically replace steel in a very wide variety of applications.

The poor weldability of ductile cast iron can be attributed to two factors, the formation of martensite in the heat affected zone HAZ, and the development of hard, brittle iron carbide in the zone of partial fusion [14]. Most of the welding performed on cast iron is repair welding. It is either the repair of discontinuities produced during the casting process or those developed in the cast component itself while in service. Industries that are involved in fabrication do show high interest in creating a welding procedure for ductile cast iron; hence, this material possesses lofty mechanical properties as well as affordable cost [15]. This work investigated the role of micro – addition of antimony powder on the weldability of carbidic austempered ductile iron for fabrication of agricultural and mining sector applications.

EXPERIMENTAL PROCEDURE

Antimony modified carbidic austempered ductile iron samples of size 120 mm × 18 mm × 18 mm were obtained by casting the samples in a sand mould. The microstructure of the samples was found to consist of pearlitic matrix containing non-uniform distribution of graphite and granular carbides. Its chemical composition was obtained using spectrometer: which reveals that the cast samples have elemental compositions of approximately: C = 3.62 wt. %, Si = 2.4wt. %, Mn, = 0.58wt. %, Cr =2.6wt. %, Mg = 0.06wt. %, Cu = 0.69wt. %, S = 0.004wt. %, P=0.04 %, with varying antimony content of Sb = 0, 0.1wt. %, 0.2 wt. %, 0.3 wt. %, 0.4 wt. %, 0.5wt. % respectively. Shielded metal arc welding was adopted to join the antimony modified carbidic austempered ductile cast iron work piece together. The welding speed used for the preheated pieces was 15.9 cm/min. In the first case the rod-like samples joined were heated in a muffled furnace at temperature 400 °C. The welding current of 140A, A.C., with a root gap of 1.2 mm was used in order to obtain a good weld penetration. Cast iron electrode was used. Figure 1 shows the joint design (Fig. 1 a) and electrode angle of 70° with respect to the top surface of the plates (Fig. 1b).

Figure 1: Joint design and position of electrode. (a) Joint design. (b) Electrode's angle and bead's scheme viewed from the front of the bead in consistence with (a)

Effects of preheating

The distinct metallic matrix observed in the heat affected zone (HAZ) and in the fusion zone, indicates the dissolution of graphite in the nickel element in the antimony modified CADIs. Nevertheless, graphite in the HAZ was dissolved and small dots were observed instead of granular structures. The width of the melted region is not wide due to nickel contribution and its structure is found to be a pearlitic structure in the austenitic matrix. The (weld metal) bead region has smaller spheroidal graphite than that of parent material. Hardness obtained in the HAZ was

249 HV, very similar to the hardness value of the parent material. The ductility was increased appreciably and the rest of values were very similar. It is observed that the concentration of pearlitic structure in melted region is decreased. Graphite in form of smaller spherolytes grew in the bead region and got distributed uniformly. This decreasing of the pearlitic structure concentration and the smaller spherolyte forms may be due to nickel, which absorbs carbon [16], dissolving it in its metallic matrix [17 and 18].

RESULTS AND DISCUSSION

The micro-structures of the pre-heated (400°C), six different carbidic austempered ductile irons (CADI) of varying antimony contents of 0wt.%, 0.1wt.%, 0.2wt.%, 0.3wt.%, 0.4wt.% and 0.5wt.%, welded monolithically using shielded metal arc welding with cast iron electrode are shown in Figures 2(a – f). The first thermal treatment (400°C) carried out the CADI work pieces, assisted in relieving residual stress, drastic reduction of the cooling rate, fluidity improvement and diffusion of the molten material. This is due to the fact that the pre – heating temperature used is within the range of 300 – 600°C (Kumar et al., 2016).

Four demarcating zones were observed in the micrographs of virtually all the six welded Sb modified CADIs, the fusion zone which melted during welding process and re-solidified on cooling the CADI work piece, the zone that is closest to fusion zone, where liquation arise during welding operation – this zone is designated as partially melted zone, the third zone is the heat affected zone where microstructural transformation occur without undergoing melting. Figure 2 shows:

- (a) Sample with 0wt. % Sb, has coarse carbides with some graphite, HAZ has a resemblance with based metal. FZ has some indication of martensite with dissolved graphite, PMZ partially melted carbides zone
- (b) Has less coarse carbides in the based metal, with some graphites, HAZ seems to have a structure that resemble that of the based metal. PMZ showed unfully melted structure, FZ is very fine structure with dissolved smaller spheroidal graphites.
- (c) PMZ is pearlites matrix, with numerous dissolved small graphites, with highly disintegrated carbides, FZ is ferritic and pearlitic matrix, with many dissolved small graphite, less resolved carbides. HAZ dissolved small graphite, with few medium size graphite, with deformed carbides.
- (d) FZ = pearlitic matrix, fine structure, small nodular graphites dissolved. PMZ = not wholly melted region, HAZ is minute size graphites well distributed in secondary carbide structure, BM = small size graphites.
- (e) FZ is spongy network of carbides with few dissolved small graphite. PMZ is partially dissolved spongy carbides
- (f) FZ = pearlitic matrix, few graphites, spongy carbides, PMZ = abundantly clear region of partially melted region. HAZ has some differences from the BM

Figure 2: a, b c and d

HARDNESS VALUES

Sample (a) has hardness value of 33HRc in its base metal because of its coarse carbides in its matrix as reflected by the micrographs. Its heat affected zone (HAZ) has hardness value of 34HRc which is slightly higher than that of base metal zone, at the fusion zone, the hardness value is not correspondingly very high (52HRc) which indicate formation of martensite and hard carbide at this zone, which could cause brittleness and failure at this fusion zone.

Sample (b) of 0.1wt. %Sb has hardness value of 54HRc at its base metal zone because of the antimony element that has modified its carbides to granular form, thereby improving its hardness value at this zone. The HAZ hardness value is slightly lower than that of the base metal with value of 51 HRc.

Sample (c) 0.2wt.%Sb has helped in improving the hardness value of the CADI from 33HRc to 49HRc as a result of transformation of coarse carbide to granular carbides, HAZ hardness value is 48HRc which is almost the same as that of the base metal, this showed that this quantity of Sb has assisted in improving the microstructure of the HAZ, of this CADI, FZ has hardness value of

38HRc which is higher than that of the control sample and then that of 0.1,0.3,0.4,and 0.5 wt.% Sb and still lower than the hardness value of its base metal and HAZ, indicating that at this weight % of Sb, martensite was not formed which could have introduced brittleness in this zone.

Sample (d) base metal zone hardness value of 43HRc which also experienced increase in hardness values as a result of modification caused by 0.3wt. %Sb on its carbide size in the CADI, HAZ hardness value is 52HRc, which showed likelihood of brittle structure (hard carbide) formation at this zone, fusion zone hardness value of 31HRc, there is no sign of brittle structure in this zone though its value has wide disparity with that of its base metal and HAZ.

Sample (e) based metal has hardness value of 27HRc, which shows that 0.4wt%Sb is not beneficial to CADI in terms of hardness improvement, HAZ hardness is 44HRc because of drastic change with formation of martensite in this zone. Fusion zone hardness value is 33HRc, the difference between the three zones is high which could mean poor corrosion property.

Sample (f) BM hardness is 49HRc, HAZ of 33HRc, and FZ hardness value of 50 HRc, though the hardness value of base metal is almost the same as that of fusion zone which would have earned this sample a good one, but the hardness value of its HAZ is significantly lower than both revealing that galvanic corrosion can set in.

Table 1: Hardness Values of the Samples at Three Different Welding Zones

Sample name	Fusion Zone (HRc)	Base Metal (HRc)	HAZ (HRc)
0% wt.%Sb	52	33	34
0.1wt.% Sb	30	54	51
0.2 wt.% Sb	38	49	48
0.3 wt.% Sb	31	43	52
0.4 wt.% Sb	33	27	44
0.5 wt.% Sb	50	49	33

Figure 3: Hardness Values (HRC) of the Samples at the Fusion Zone

Figure 4: Hardness Values (HRC) of the Samples at the HAZ Zone

Figure 5: Hardness values (HRC) of the samples at the Base Metal Zone

CONCLUSIONS

Antimony modified – carbidic austempered ductile iron rods of varying amount of antimony content were first pre-treated by heating them at temperature of 400°C in a muffle furnace, before using cast iron electrodes to weld the pieces together at welding current of 120 ampere, with welding speed of 15.9 cm / min. Coarse graphite found in the control sample (0wt.%) Contributed to brittleness in the fusion zone. While the refined graphite clusters in some of the antimony modified CADI assisted in the ductility of the fusion and heat affected zones which improves weldability in conformity with El-Banna, 2008.

The following conclusions were arrived at:

- The CADI sample with 0.2 wt. %Sb, with fusion zone of 38HRC, heat affected zone of 48 HRC, and based metal of 49HRC showed a better weldability than the other samples, it has enhanced ductility due to lower acicular structures formed and better uniform distribution of graphite in the bead.
- The preheating treatment increases the ductility of the welded piece through minimizing hard and fragile microstructures.
- An annealing treatment can be substituted for the preheating treatment which also improves the ductility.

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