

Weldability of spheroidal graphite ductile cast iron using Ni / Ni-Fe electrodes^(*)

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Abstract Weldability of spheroidal graphite ductile cast iron was established using a cheap Ni-Fe and a high purity Ni electrode. A preheating treatment at 350 °C and an annealing treatment at 850 °C were carried out to improve mechanical properties of welded pieces. The pure Ni electrode showed graphite diffusion in the bead with a uniform distribution of phases, improving weldability and decreasing fragility. Preheating and annealing treatments increased ductility and improved weldability.

Keywords Weldability; Ductile iron; Electrodes; Microstructures; Arc welding.

Soldabilidad de aleaciones dúctiles de grafito esferoidal utilizando electrodos de Ni y Ni-Fe

Resumen Se establece la soldabilidad de funciones dúctiles de grafito según las características mecánicas alcanzadas, utilizando un electrodo puro de Ni mientras se compara con uno más económico de Ni-Fe. Diferentes tratamientos térmicos son propuestos y analizados. El electrodo de Ni puro mostró difusión de grafito desde el material original al cordón de soldadura, dando como resultado una fase homogénea que mejoró la soldabilidad y redujo la fragilidad. Un pre tratamiento a 350 °C y un recocido a 850 °C incrementaron la ductilidad y mejoró la soldabilidad.

Palabras clave Soldadura; Electrodo; Microestructuras; Soldadura por arco.

1. INTRODUCTION

In fabrication industries, there exists high interest to establish a welding procedure for ductile cast iron as this material has high mechanical properties as well as low cost. Studies were reported earlier about the influence of thermal treatments and welding techniques on the weldability of ductile iron using Ni electrodes^[1 and 2]. Studies on mechanical properties of ductile cast iron welded by means of oxyacetylene and arc welding techniques using either nickel or gray cast iron electrodes showed that mechanical properties of the weld metal welded with gray iron electrodes were inferior than that welded with Ni electrodes^[3]. As nickel can dissolve graphite present in ductile iron (parent material) germinating as spherulites with a lower average size fragile carbides and martensite structures are not

formed facilitating uniform compositions in the weldment providing a high ductility and a low fragility.

The aim of the present work is to establish a welding procedure for spheroidal graphite ductile cast iron and compare the weld quality obtained using a low priced Fe-Ni electrode with that obtained using a pure Ni electrode. The weldability is evaluated from the mechanical properties and microstructures of weldments.

2. EXPERIMENTAL PROCEDURE

Ductile cast iron samples of size 300 mm × 95 mm × 6 mm were obtained by casting in a sand mould. The microstructure of the samples was found to consist of ferritic-pearlitic matrix containing uniform distribution

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of graphite spherulites. Its chemical composition was obtained using dispersive X-ray technique as: C, 3.83 %, Mn, 0.15 %, Ni, 0.01 %, Cu, 0.03 %, Si, 2.62 %, P, 0.03 %, Cr, 0.04 %, Mo, 0.01 %, Mg, 0.04 % and its mechanical properties are given in table I.

Manual metal arc welding was employed to join the ductile cast iron plates. The welding current of 140 A, a.c., with a root gap of 1.5 mm was used in order to obtain a good weld penetration. Two electrode having compositions of 57.2 % Ni + 41 % Fe (other elements were 0.66 % C, 0.16 % Si, 0.85 % Mn) and 97.6 % Ni (0.30 % C, 0.20 % Si, 0.005 % P, 0.005 % S, 0.2 % Mn and 1 % Fe) were 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. 1 b)). The welding speed used for the unpreheated and preheated pieces with a 57.2 % Ni electrode was 16.8 cm·min⁻¹ and 22.8 cm·min⁻¹ respectively, and the speed for the 97.6 % Ni was 19.2 cm·min⁻¹ and 15.6 cm·min⁻¹ respectively.

In order to establish the effects of preheating and annealing treatments, three types of welding were performed. In the first case the plates to be joined were preheated at 350 °C and joined. In the second case, the plates were joined without preheating and postheating. In the third case, the plates joined without preheating were annealed at 850 °C for one hour.

Samples were prepared from all as-welded and treated plates by cutting it at its centres and polished

Table I. Mechanical properties of the parent metal and weld joint

Tabla I. Propiedades mecánicas del material original y del metal soldado

Type of treatment	Electrode used	Ultimate strength (MPa)	Yield limit (MPa)	% Elongation	Vickers hardness of weld joint			Place of failure
					MR	Bead	HAZ	
No preheating	Fe-Ni	520	460	8	618	210	360	MR
	Ni 97.6 %	400	360	11	480	180	330	MR
350 °C preheating	Fe-Ni	480	410	12	330	180	240	MR
	Ni 97.6 %	340	335	14	300	175	230	Bead Region
850 °C annealing	Fe-Ni	400	379	14	321	185	180	Bead Region
	Ni 97.6 %	388	342	16	251	170	178	Bead Region
Parent material	—	470	330	6	—	—	230	—

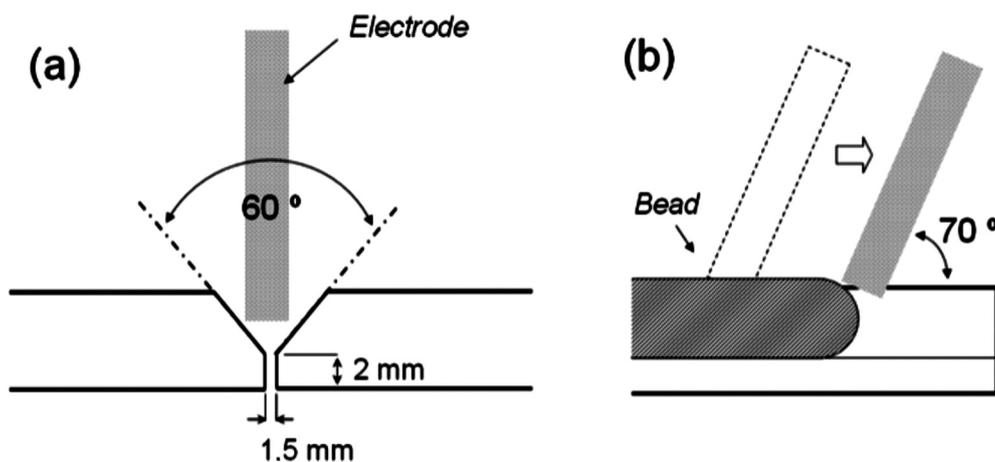


Figure 1. Joint design and position of electrode. (a) Joint design. (b) Electrode's angle and bead's scheme viewed from the front of the bead.

Figura 1. Esquema de soldadura y posición del electrodo. (a) Esquema de dos piezas visto desde el frente. (b) Esquema del ángulo del electrodo y cordón de soldadura mostrado desde el avance de la soldadura.

as well as etched using standard metallurgical procedure. Photomicrographs were taken to analyse the microstructures at various zones. Vickers Microhardness values were obtained on three distinguished regions such as weld metal, fusion zone or melt region (MR) and heat affected zone (HAZ) using a Matsuzawa machine (model MHT2) under a load of 300 N. Yield and ultimate tensile strengths of all welded plates were evaluated by a Instron tensile machine (model 4204) at a constant crosshead speed of 1 mm/min. Both hardness and strength values obtained are presented in table I.

3. RESULTS

The influence of thermal treatments on weldability of ductile iron and comparison of weld quality obtained using a low priced Fe-Ni electrode with that obtained using a pure Ni electrode were carried

out in order to improve the mechanical properties of welded joints. Those thermal treatments would result in: (I) relieving residual stress, (II) diminishing the cooling rate and (III) increasing the fluidity and diffusion of the molten material.

3.1. Ni and Fe-Ni electrode results

Figure 2 a) shows a photomicrograph of the as-welded weld joint obtained with a 57.2 % Ni electrode without preheating and cooled in air. Three regions are shown clearly in the figure. The HAZ is observed to be a nodular ferritic pearlitic structure (dark matrix) very similar to the parent metal structure. The dispersed dark flakes correspond to graphite concentrations and had hardness of 360 HV. The hardness of the parent metal is found to be 300 HV. The MR contains an acicular structure or needle like structure having

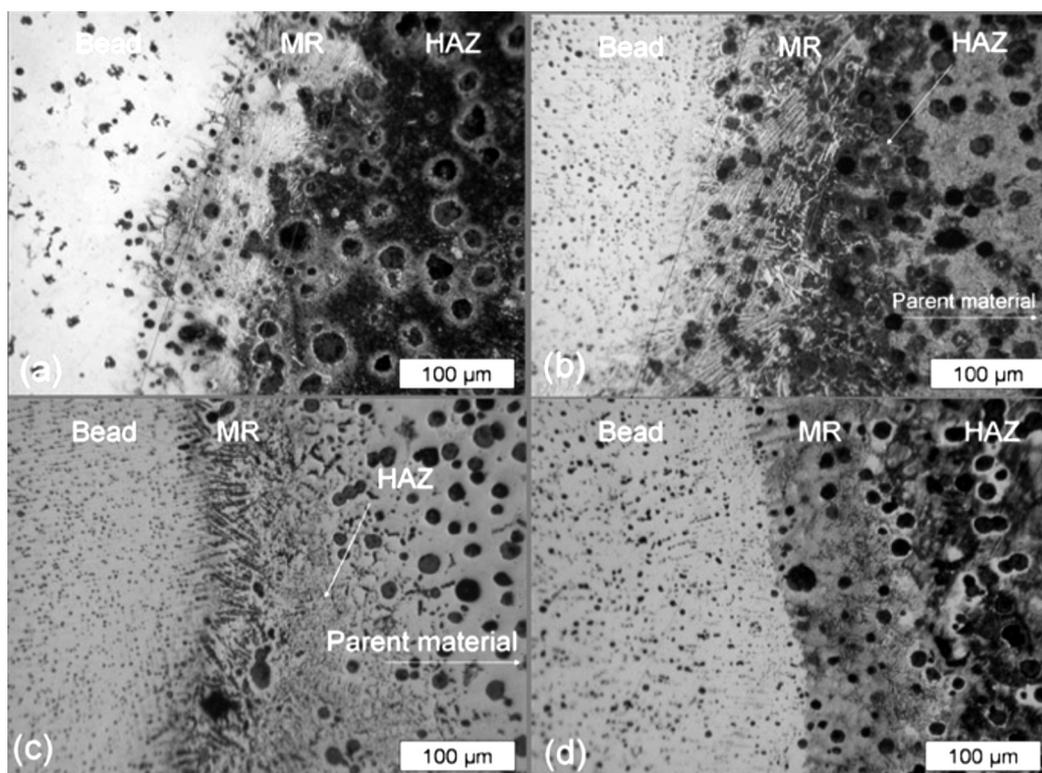


Figure 2. Optical photomicrographs of the weld joint welded and treated at different conditions: (a) as-welded with 57.2 % Ni-Fe electrode, (b) as-welded with 97.6 % Ni electrode, (c) preheated and as-welded with 57.2 % Ni-Fe electrode (d) welded with 97.6 % Ni electrode and annealed.

Figura 2. Imagen de microestructuras de la pieza soldada con un (a) electrodo de 57,2 % Ni-Fe y sin tratamiento térmico, (b) electrodo del 97,6 % Ni sin tratamiento térmico, (c) electrodo de 57,2 % Ni-Fe con precalentamiento de la pieza a 350 °C, (d) electrodo 97,6 % Ni y posterior recocido a 850 °C durante 1 h.

hardness of 618 HV (268 % higher than that of the parent material). It also has some smaller graphite flakes. From the tensile test, cracks were observed in MR which could be due to its higher fragile character. It is clear from the figure that weld metal contains a brilliant matrix of nickel containing smaller graphite spherulites compared with that in the parent metal and has hardness value of 210 HV.

Figure 2 b) shows a typical microstructure of the weld joint welded with a 97.6 % Ni electrode without preheating. From the figure it is found that the HAZ is visually darker due to less amount of ferritic matrix structure resulting from the dissolution of ferrite in nickel. The hardness of HAZ was found to be 330 HV (143 % higher than that of parent metal) and was very close to the hardness value of HAZ obtained using Fe-Ni electrodes. From the figure it is found that the MR contains several long needles acicular structures (ferritic-pearlitic structures) combined with some small needle acicular structures (martensite). It was found that the amount of martensite present was lesser than that was present in MR of previous weld joint obtained using Fe-Ni electrode which was also confirmed with its corresponding hardness value of 480 HV. From the figure it is found that the weld bead contains ferritic-pearlitic structure with a high concentration of small graphite flakes distributed uniformly in the matrix resulting due to the dissolution of graphite in nickel. From table I it is found that the weld metal hardness value is less. Though the bead had higher ductility due to the uniform distribution of graphite flakes fragile fracture cracks were observed in the MR which would be due to the higher hardness value of martensite present.

3.2. Effects of preheating

From table I it is evident that when thermal treatments were performed, the elongation is increased and hardness is decreased in all regions irrespective of the type of electrode used.

Figure 2 c) shows a photomicrograph of the weld bead obtained with 57.2 % Ni electrode at preheated condition. The brilliant metallic matrix observed in the HAZ and in the parent material, indicates the dissolution of graphite in nickel. An open pearlitic structure inside an austenitic matrix grew in that region. Nevertheless, graphite in the HAZ was dissolved and small dots were observed instead of flake structures. The width of the MR is also decreased due to nickel contribution

and its structure is found to be a pearlitic structure in the austenitic matrix. A laminar structure was observed at higher magnification. 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 twice and the rest of values were very similar. The mode of failure observed from tensile test was found to be ductile in the bead.

Nevertheless, differences in the welded piece obtained with a 97.6 % Ni electrode were observed. Figure 2 d) shows the typical microstructure of a welded cast iron using a 97.6 % Ni electrode at preheated condition. It is observed that the concentration of pearlitic structure in MR is decreased. Graphite in form of smaller spherulites grew in the bead region and got distributed uniformly. This decreasing of the pearlitic structure concentration and the smaller spherulite forms may be due to nickel metal, which absorbs carbon^[4], dissolving it in its metallic matrix^[5 and 6]. From table I it is found that the ductility is increased to 14 % and hardness diminished. It is also found that the yield limit is not affected significantly.

3.3. Annealing treatment results

Post weld annealing of welded pieces was carried out to reduce the concentration of hard phases, forcing them to form other structures such as less hard ferritics or pearlitics. Figure 3 shows a typical photomicrograph of the welded piece joined with a 57.2 % Ni and 97.6 % Ni electrode at annealed condition. It is found that the MR is not clearly visible in the piece welded with the 97.6 % Ni electrode, having very small width which may probably be due to the martensite transformation and also due to the dissolution of nickel into all zones. The spherulite graphite in the HAZ was found to be transformed into a ferritic phase. In the bead, graphite flakes are found to be smaller in size and distributed uniformly which is very similar to the structure that is obtained when a Fe-Ni electrode is used except the presence of some amount of martensite. For both electrodes used, failures were found to be ductile and it occurred always at the bead region (not in the MR as in previous cases). Mechanical properties of weld metal were similar to the parent metal. Ductility was found to be higher than that of preheated welded pieces.

Figure 3 shows a photomicrograph of the welded piece with a 97.6 % nickel electrode and an

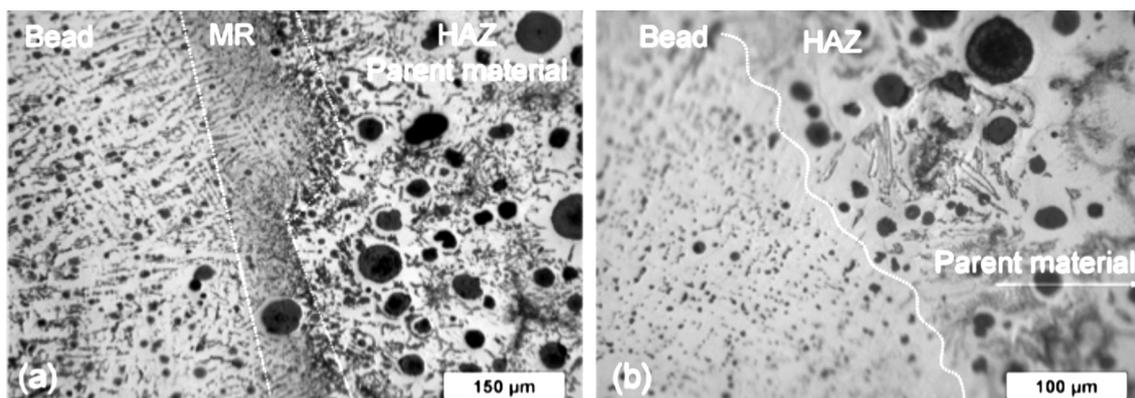


Figure 3. Optical photomicrograph of the post weld annealed weld joint welded using (a) a 57.2 % Ni electrode and (b) a 97.6 % Ni electrode.

Figura 3. Imagen de la microestructura de la soldadura realizada con (a) un electrodo del 57,2 % Ni y (b) un electrodo del 97,6 % Ni. En ambas piezas se realizó un recocido a 850 °C.

annealing treatment at 850 °C. The MR was not visible probably due to the martensite transformation and also due to nickel dissolved into all zones. The spherulite graphite in the HAZ was transformed into a ferritic phase. Graphite flakes grew in the bead smaller in size and distributed uniformly. A very similar structure was obtained when a Fe-Ni electrode was used (in this case some amount of martensite grew). For both electrodes used, fractures were ductile and were always found in the bead region (not in the MR as in previous cases). Mechanical properties were similar to the ones in the parent material. Elongation resulted from stress experiments was higher than results obtained from the welded pieces with preheating.

It is clear from the results that pure Ni electrodes are better than Fe-Ni electrodes to weld ductile cast iron due to the fact that a high nickel concentration improves the graphite dissolution. In a Fe-C diagram at 3.8 % C the enhanced dissolution is found to be due to the ability of nickel to self-dissolve into the austenite. Thus, when the liquid phase of the MR cools, nickel retains the austenite, preventing formation of hard cementite. Furthermore, the carbon, instead of forming cementite, grows as a nodular graphite structure very similar to that of the parent material, as a result of the uniform growth of microstructures in the three regions. The absence of hard structures and the uniform composition provide it with enhanced ductility.

4. CONCLUSIONS

Ductile iron plates were welded using two different electrodes at three different conditions and its effects were analyzed. The following conclusions were arrived at:

- High purity Ni electrodes showed a better weldability than Ni-Fe electrodes resulting from 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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