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COMPARATIVE STUDY OF TIG AND SMAW ROOT WELDING PASSES ON DUCTILE IRON CAST WELDABILITY

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This work compares the weldability of ductile iron when: (I) a root weld is applied with a tungsten inert gas (TIG) process using an Inconel 625 source rod and filler welds are subsequently applied using coated electrodes with 97,6 %Ni; and (II) welds on ductile iron exclusively made using the manual shielded metal arc welding technique (SMAW). Both types of welds are performed on ductile iron specimen test plates that are subjected to preheat and post-weld annealing treatments. Samples with TIG root-welding pass shown higher hardness but slightly lower ductility and strength. Both types of welding achieved better ductile and strength properties than ones found in literature.

Key words: weldability, ductile cast iron, chemical composition, microstructure, mechanical properties

INTRODUCTION

The cast irons are useful materials due to the low-cost and non-massive production, wide design versatility, ease of casting and machinability, and acceptable levels of mechanical behaviour. A relevant question that restrains a wider number of technical applications is their weldability. The poor mechanical properties of some castings are caused by the presence of graphite that produces discontinuities in the matrix and so leads to the presence of stress concentrators. The SMAW process is commonly employed in industry because it uses low cost fillers and can be more easily performed than other welding techniques. The welding filler is a determining factor for the microstructure and mechanical properties of the welds. In processes with high thermal input alloying elements such as Cr and Mo, the presence of dendritic or hard phases could result in reduced ductility and brittleness – even if the material is hard and strong [1 - 5]. The result is also influenced by preheating treatments and cooling rates. A subsequent annealing process also improves the properties. The aim of this work is to investigate the weldability of ductile cast iron using an Inconel 625 as highly alloyed weld filler in the root TIG welding pass versus the standard SMAW welding procedure.

EXPERIMENTAL PROCEDURE

The chemical composition of ductile cast iron is shown in Table 1. Figure 1a presents the microstructure of ductile cast iron before heat treatment. The mechanical properties of the casting material of this study are shown in Table 2.

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Table 1 **Chemical composition / wt. %**

C	Si	S + P	Ni + Cu + Cr	Mg	Fe
3,7	2,5	< 0,03	< 0,08	0,03	rest

Table 2 **Mechanical properties of cast iron**

Mechanical characteristics	Ductile cast iron
Tensile strength, R_m / MPa	370
Yield strength, R_y / MPa	320
Break strain, *A* / %	6
Toughness index, T_I / MJ·m^{-3}	11,1
Elastic modulus, *E* / GPa	160

Table 3 **Chemical composition of fillers used to ductile iron welds / wt. %**

Filler	Ni	Cr	Mo	Ta	Nb	Fe
Inconel 625	58	23	10	4,5	3,5	rest
Ni97,6	97,6					rest

Sample plates are produced by a sand casting process and subsequently milled to 300 / 95 / 10 mm to produce coupons. The specimens of ductile iron are welded using

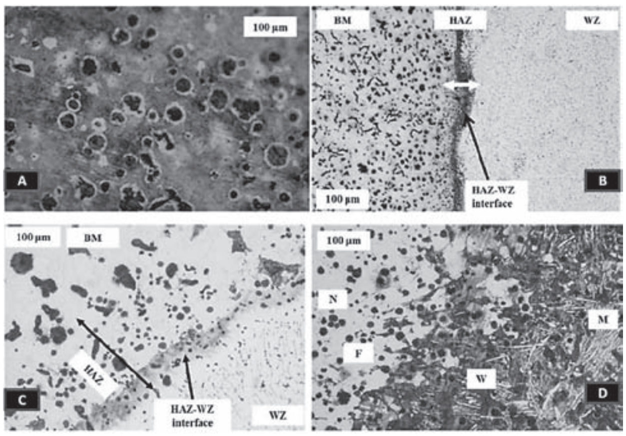

Figure 1 Ductile cast iron (a); SMAW ductile iron weld after annealing and cooling (b); SMAW top-beads on Inconel 625 - TIG root weld (c); and Inconel 625 root weld (d).

TIG and SMAW processes. It is recommended for root welding pieces of greater thickness than 8 mm. The filler material is added with two SMAW passes over the TIG root weld. A second batch of test plates were welded together using only Ni97,6 rod fillers. The composition of electrodes is shown in Table 3. All the welds are carried out on a series of test plates that were pre-heated to 350 °C because of the difficulty of welding the castings. Once the welds are finished, the plates were immediately annealed at 900 °C and cooled in a furnace.

The Vickers microhardness (*HV*) test was performed in accordance with EN ISO 876. Mechanical properties (EN ISO 10002-1) measured were yield (R_y) and tensile strength (R_m), and break strain (A). A conventional toughness index (T_I) is taken into account to discriminate the differences between the ductile/brittle behaviour of the cast irons welds. It is calculated from the expression $T_I = \alpha R_m A$, where α is $5 \cdot 10^{-3}$ (dimensionless). The results for the average values obtained from five samples per batch are shown in Table 4.

Table 4 **Mechanical properties of welds**

Filler	Ni97.6 SMAW	Root TIG	+ Beads SMAW
R_m / MPa	320	300	
R_y / MPa	310	285	
A / %	8	7	
T_I / MJ·m^3	12,8	9,0	
HV HAZ	194	210	
HV Interface	320	610	325
HV WZ	227	520	160

RESULTS AND DISCUSSION

In the SMAW-only welds, Figure 1b reveals three defined zones: (a) the heat affected zone HAZ; (b) the weld zone (WZ) with the interface between both HAZ and WZ; and (c) the ductile iron base material zone (BM). In the latter zone it is possible to observe the ferrite structure with uniformly distributed *spheroid* nodules that decrease in size as we near the HAZ. The HAZ and HAZ-WZ interface hardness are given in Table 4. It is the consequence of tempered martensite precipitated in the ferrite matrix which was not completely eliminated in the annealing treatment.

Finally, Ni is the most common material in the WZ. The microstructure consists of uniformly distributed spheroids in an austenitic matrix with a hardness of 227 *HV*. R_y and R_m were 310 and 320 MPa. (86 % of the ductile cast iron R_m). The mechanical properties of the coupons welded with Ni electrodes are lesser than those from other authors [1, 6]. In latter references the ENi-CI electrodes contained less Ni and more C, and the welds were basically constituted by cementite-martensite (partially melted zone) and perlite-martensite (HAZ). This effect produced welds of low ductility (0,7 %) and greater brittleness (1,3 MJ·m^{-3}) compared with the same welds in this work (8 % and 12,8 MJ·m^{-3}). The fractures were localised between the partially melted and HAZ while fractures in this work occur between the base material and the HAZ.

The microstructure of the cast iron weld in Ni97,6 electrode coated filler second pass zone on the Inconel weld root is shown in Figure 1c. Nodular graphite in the ferritic matrix is observed in the interface close to the base metal. In the WZ the precipitated nodules are smaller than in the interface [7, 8]. The hardness in the HAZ is 210 *HV* while mechanical properties are somewhat lower: 285 MPa (R_y), 300 MPa (R_m). However, the ductility is 7 % to A and 9 MJ·m^{-3} in the T_I. The fracture is more ductile than in previous cases and usually occurs in the cast zone near the interface [9]. Weld ductility and Ni-based consumables are closely related because: (a) the formation of brittle products in the WZ is prevented [10]; (b) the precipitation of graphite increases in the WZ and reduces both metal shrinkage and thermal stress during solidification – thereby causing a reduction in susceptibility to cracking; (c) improvements in tolerance to phosphorus and sulphur and reduction in the risk of hot cracking [6].

Figure 1d shows the interface of the TIG-root. It is appreciable that small traces of white iron (W, blue zone) in a martensitic matrix (M, white needles) remain undissolved. The hardness level reaches from 520 *HV* (root) to 610 *HV* in the interface zone. This is below that obtained if air cooling were applied because the Cr content in the Inconel has retained part of the carbides formed in the weld. More and smaller graphite nodules are shown in Figure 1d. The fracture was brittle in this zone and started near the interface. T_I reaches 70 % of the SMAW-Ni weld coupons. Askari [6] reports that samples welded with electrode EN-CI on the root and post filled with EN7018 showed improved resistance – but that A reached 2,5 %. However, ductility deteriorated and the toughness dropped to 5,3 M·m^{-3}. The WZ hardness in the Ni-beads is less than the original casting (160 *HV*) but ductility and fracture strain are greater. The microstructure consists of smaller spherulites strung in an austenitic matrix because of Ni content.

The microstructure and EDX-spectrum in Figure 2a corresponds to a weld obtained using only Ni97.6 electrodes. The interface zone reveals the high Ni content (diluted together with Fe). Si appears as the element that causes graphite precipitation. There is no trace of white iron and graphite is distributed in nodules of intermediate size. This verifies that the structural constituents generate a solid union, as Figure 1b shows. The spectra and composition of the interface between the weld root with Inconel and Ni97.6 obtained using SMAW are shown in Figures 2b and 2c.

Figure 2b corresponds to the second pass of the filler (Ni97,6). The absence of Cr directly influences the structure of the welding interface dissolving the carbides, eliminating the white iron, and producing a substantial decrease in hardness. This contributes to the ductile behaviour of the weld. The ferritic matrix microstructure is observed in Figure 2a. Tensile fracture occurs in this zone near the base material. Figure 3c corresponds to the interface of the root welded with Inconel 625 rod. The spec-

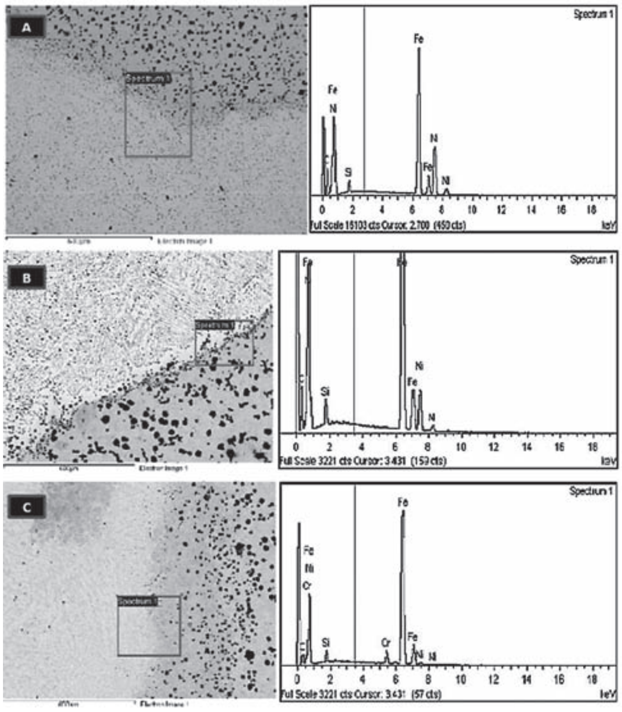

Figure 2 Interface zone in the weld made with a Ni electrode (a), filler weld interface of the top pass (b), root weld interface (c)

trum shows less pronounced decreases in Cr. The result is a partial reduction in the presence of carbides as a consequence of an incomplete dissolution through annealing and the furnace cooling. Several authors have found that when large amounts of C, Cr, Fe, Mo and Ni are present in combination with high temperatures and post air-cooling the formation of γ - (Fe, Ni), martensite, Ni - Fe - Cr - C phase, Cr_7C_3 and other complex carbides is possible [1, 4, 11, 12]. In this research, the use of very low C content electrodes, the complete solubility of graphite above 800 ºC, and the moderate presence of Mo-Nb-Ta in the composition of Inconel 625 cause most of the Cr to be dissolved (as Figure 2b shows). There is a reduction in hardness at the interface (325 *HV*) although it remains hard. The fracture is brittle and starts at the root zone – but the result is a substantial increase in ductility since the *A* is 7 % and the T_I is 9 MJ/m^3.

CONCLUSIONS

In this work has been studied that it is possible to weld short ductile cast iron sections using the TIG technique and Inconel 625 for the root welding pass.

For TIG-root Inconel welding coupons, the annealing treatment does not significantly change the initial weld conditions and maintains part of the white iron structures with martensite in ferritic matrix. There is an increase in hardness in the welding zones – but not with respect to mechanical strength, ductility, and toughness.

The toughness, ductility, tensile, and the yield strength of the ductile cast iron coupons welded exclusively using Ni electrodes and SMAW method are better than those made with TIG Inconel root welding followed by Ni-SMAW passes – but the differences in mechanical and toughness properties between both welding methods are not dramatically different. Inconel root TIG welding exhibits somewhat lesser properties but better behaviour and structural quality than those reported by other authors.

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Note: The responsible translator for English language is theService of the Languishes Department of Universitat Politècnica de València, Spain