

Characterisation of welds of Ni-Cr-Cu electrodes on cast-iron substrate

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Abstract. In this study, two nickel-based non-coated electrodes were manufactured to test their suitability and compatibility for welding austempered ductile iron (ADI). Welding conditions were established to obtain a crack-free weld deposit on ADI plate by preheating (300°C for 1 hour) as well as post-weld heat treatment (PWHT) at constant heat input using two selected electrodes (Ni-Cr) alloys with varying composition of copper. Current work was aimed at preventing hot cracking, which is the most common and serious issue that occurs when welding with nickel alloys. The work aims to assess the performance of the two Ni-Cr-Cu electrodes compared to Ni-Cr electrodes that cause hot cracking.

1 Introduction

Currently, most of the welding performed on cast iron is repair welding [1-2]. It is either the repair of discontinuities produced during the casting process or those developed in the cast component itself while in service [1]. In the case of austempered ductile iron (ADI), which offers excellent mechanical properties similar to steel, it can be weld-repaired or joined [1]. Thus, successful welding of ADI would render these materials suitable to be used for structural applications. Regarding the welding of conventional ductile iron, a substantial amount of work was conducted to find suitable welding conditions by varying filler material, preheat temperatures, and heat input [1-6].

Filler metals such as ENi-CI and ENiFe-CI were able to overcome the problems of carbon-pick up from pearlitic ductile iron and high carbon content deposition on either Ni or Ni-iron weld. [5] In addition, these filler materials provided the necessary strength and ductility [3-6]. Preheat temperature reduces residual stress and deformation to prevent cold cracking and reduces hardness in the heat-affected zone (HAZ) [1-6].

Unfortunately, the available information on the consumables for welding DI, which will respond to isothermal heat treatment and converting it into ADI, is very limited [1-6]. Key enabler towards overcoming the challenge of welding ADI, therefore, lies in developing welding electrodes which will be compatible with ductile iron (DI), as well as the ability to respond to austempering heat treatment, to produce a welded metal that has a microstructure similar to ADI, and to find suitable welding conditions to obtain a crack-free weld [1-6]. This study aims to investigate the suitability of the currently produced Ni-Cr-based electrodes when welds are deposited on an ADI plate. Welds with the above-mentioned Ni-Cr-Cu

electrodes will then determine if a crack-free weld can be achieved. The corresponding methodology is explained in broader detail [1-6].

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2 Methodology

2.1 Casting

These experimental developments of Ni-Cr-based alloys as filler material involved melting and casting of Ni-16Cr-6Cu and Ni-16Cr-12Cu weight percent (wt.%) ternary alloys into ingots, as shown in Figure 1. The system used for casting is a 75kWh induction thermal melting system. The casting was followed by rolling the filler blocks into thin sheets, then sectioned to wire with no flux for the welding process at a later stage. A cut-off wheel machine with a lubricated water jet was used for sectioning the samples.

2.2 The rolling process

For hot rolling, the ingots were solutionized for 4h at 1200 °C before forging from 40 mm to 30 mm thickness in a furnace. The ingots were placed in the Linton furnace and subjected to the same temperature for 30 min, followed by hot rolling performed in 10-25% reduction passes, with the ingots reheated at 1200 °C for 5 min after every two or three passes. The time before the final pass was monitored to control the finishing temperature. In addition, the final pass during the rolling process for these samples was set to 1-2mm on the VT Scada software program. These were to ensure a reduction in thickness of 10-20%. The ingots were hot rolled with a Carl Wezel hot rolling machine down to 12 mm first step. Then the final stage 12 mm plate, will need to be hot rolled down to 4 mm after only 2h soaking at 1200 °C. The soaking is achieved by immersing the rolled samples in a Linton furnace set at 1200 °C to avoid rolling defects that can occur when rolling due to lower temperatures.



Fig. 1. Photographs of two Ni-Cr-Cu alloys in the as-cast ingots (A) and rolled (B) conditions.

The base material used for this investigation is a cast ductile iron part, collected from a local foundry, sectioned into 220 x 125 x 20 mm plates.



Fig. 2. Photographs of two ductile iron (DI) alloys in the (A) as cast ingots form, and (B) after sectioned form ready for the welding process.

A Lenton muffle furnace was employed to conduct the heat-treatment process. Heat treatment performed was by heating the ductile iron samples to 950 °C in a Linton furnace for 2 hours, followed by austempering in a salt bath at 350 °C for an hour as per the schematic diagram in Figure 3.

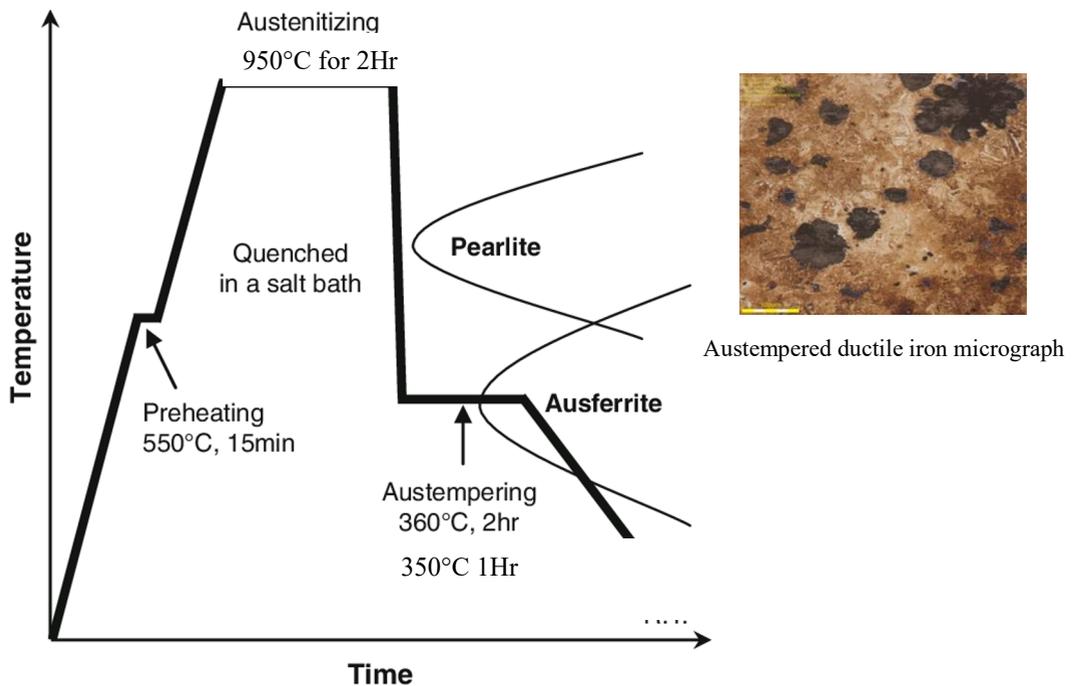


Fig. 3. Schematic representation of the austempering process of ADI [1].

Welding process of ADI was performed through a single to three pass bead-on-plate weld deposited on the SG42/52 DI or ADI base plate using each Ni-Cr-Cu developed electrodes, then followed by post-weld heat-treatment conducted at 300 °C for stress relieving purposes [7].

After welding for metallographic examination, the section was prepared perpendicular to the weld surface in order to examine the microstructural variation through the weld thickness. [7] Metallographic preparation included grinding from a 600-micron paper, followed by polishing to a 1-micron finish paper. Then each specimen was etched with 5% nital. [7]

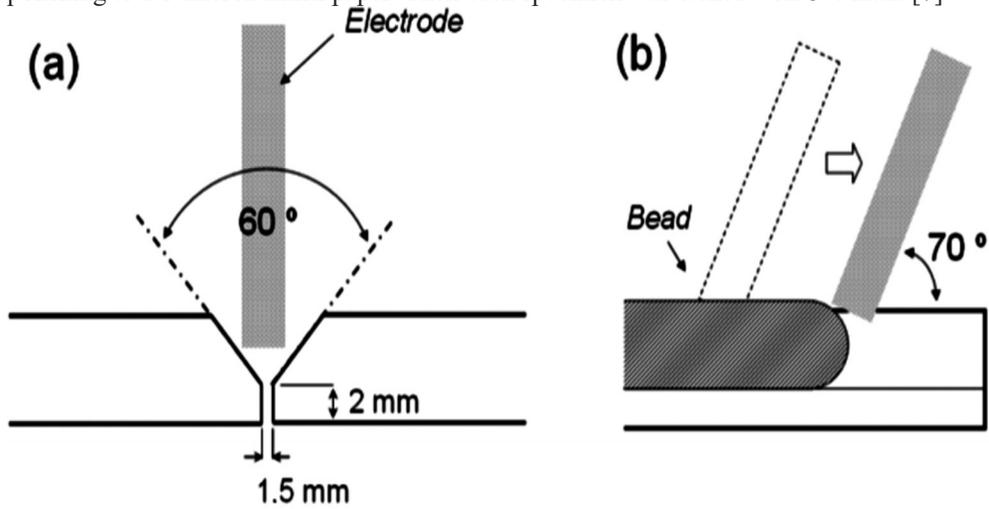


Fig. 4. Schematic representation of the welding process used for the ADI blocks when using Ni-Cr-Cu alloys as electrodes [7].

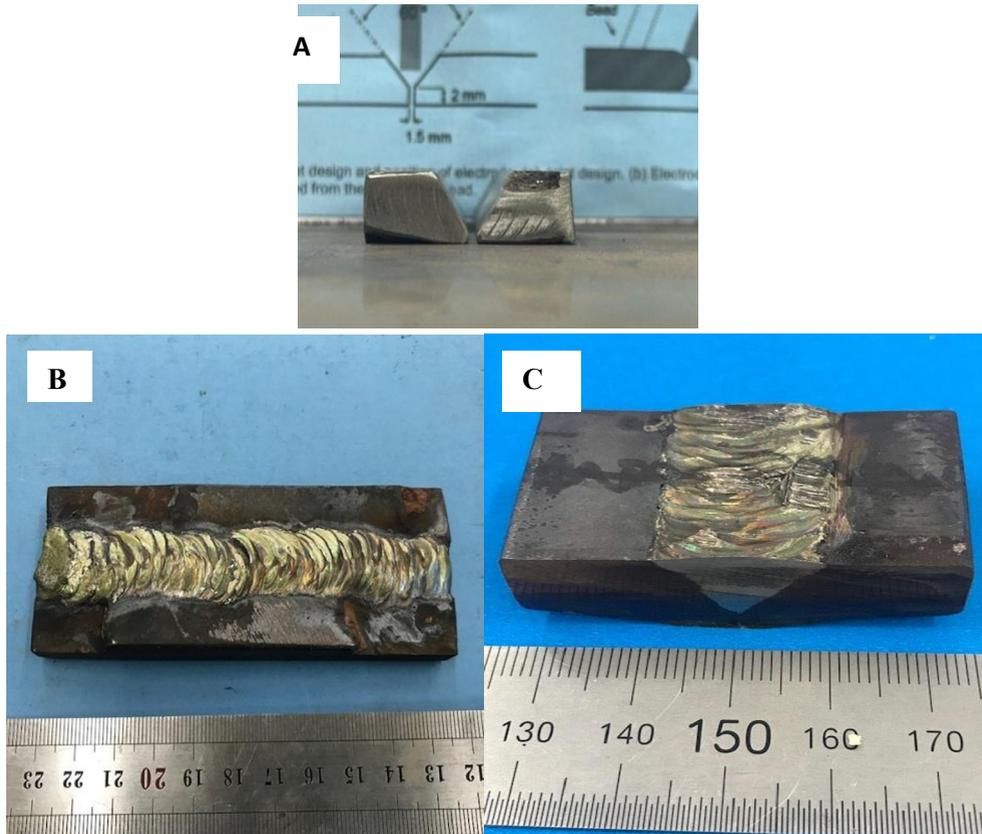


Fig. 5. Pictures of the welding process used for the ADI blocks when using Ni-Cr-Cu alloys as electrodes.

3 Results and discussion

Figure 6 shows a clearly defined structure made of a weld zone and parent material. The weld morphology is observed on an ADI (sectioned weld) below using an electrode made from Ni-16Cr-6Cu and Ni-16Cr-12Cu alloys. A metallographic examination of the Ni-16Cr-Cu6 used as an electrode reveals thin columnar grains in the weld, with pearlitic or ledeburite on the HAZ, see figures 7A and 7B. This is indicative of the weld being bonded to the substrate perfectly with no defects, see Figure 7

Ductile iron with composition is first heated to the austenitizing temperature of 950°C. This is usually from 800°C to 950°C, where Fe atoms assume the FCC crystal structure, thus transforming to γ -austenite phase. The austenitizing temperature is maintained to dissolve some carbon from the graphite nodules in austenite, and also to uniformly dissolve the alloying elements in the γ -austenite phase. The austenitizing temperature and duration is controlled to ensure the formation of austenite grain and uniform carbon content in the matrix. Figure 7A shows the phase transformation that occurred during the heat treatment and welding process. SG transformed to Austempered ductile iron during heat treatment. Whereas the weld morphology of the two electrodes differs, due to the different chemistry of the electrodes and which affects the parent HAZ and weld structure.

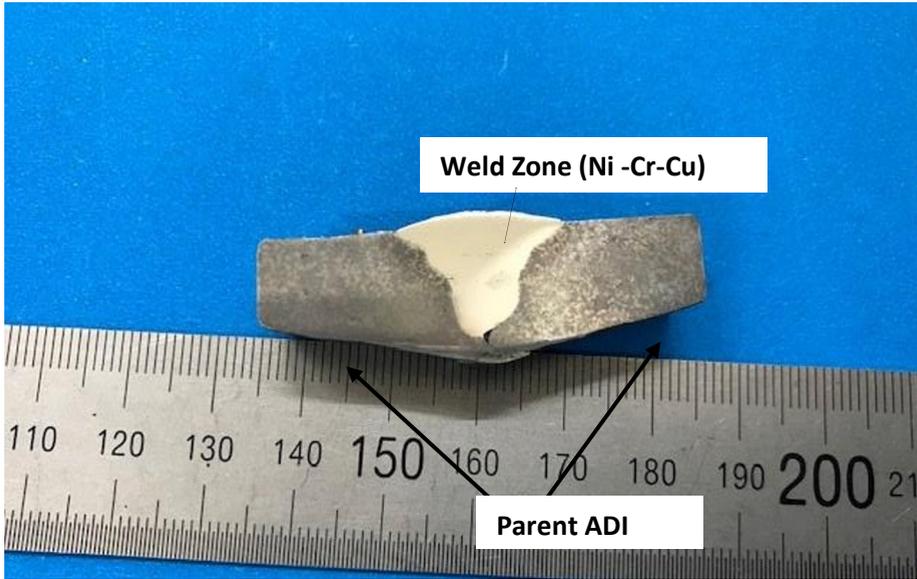
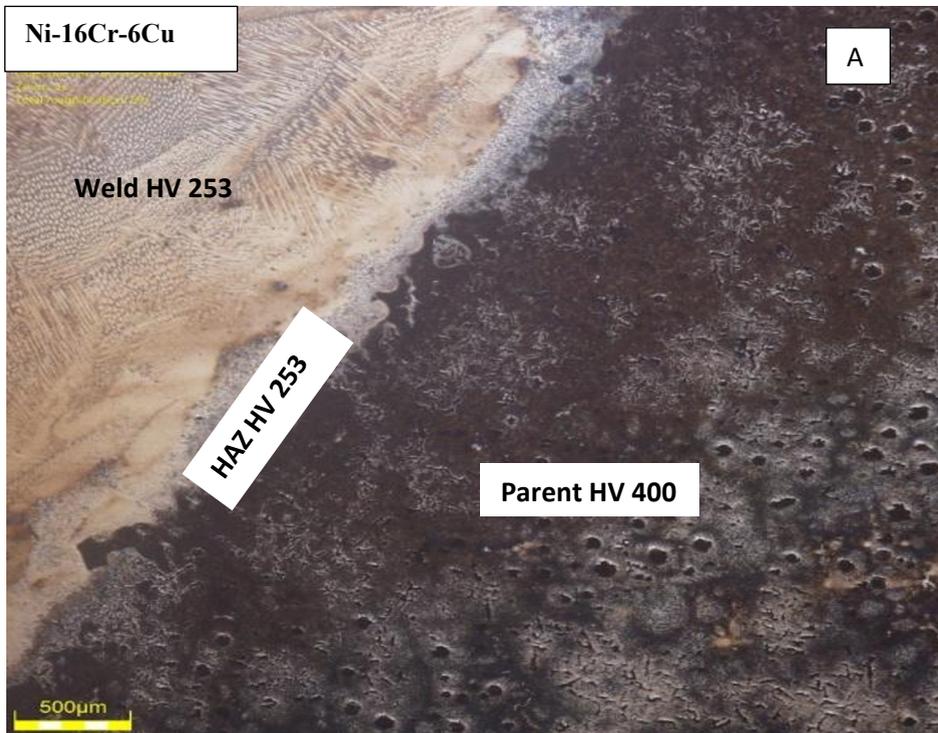


Fig. 6. Photograph sampled from a weld sample of an ADI block welded with Ni-Cr-Cu alloy.



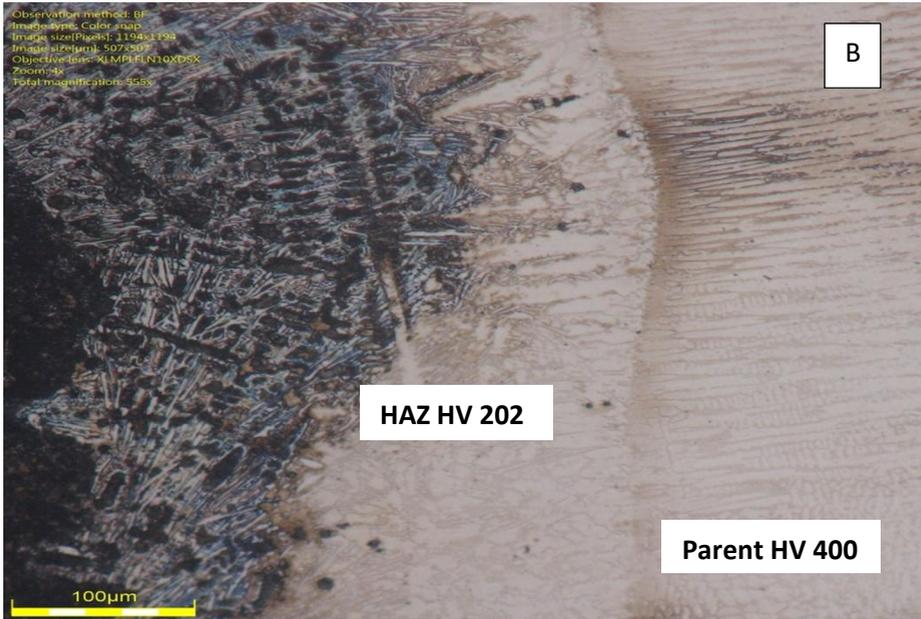


Fig. 7. Microstructures of the: A top and B bottom of the ADI block welded with Ni-16Cr-6Cu (A) and Ni-16Cr-12Cu (B) alloys, revealing the weld profile.

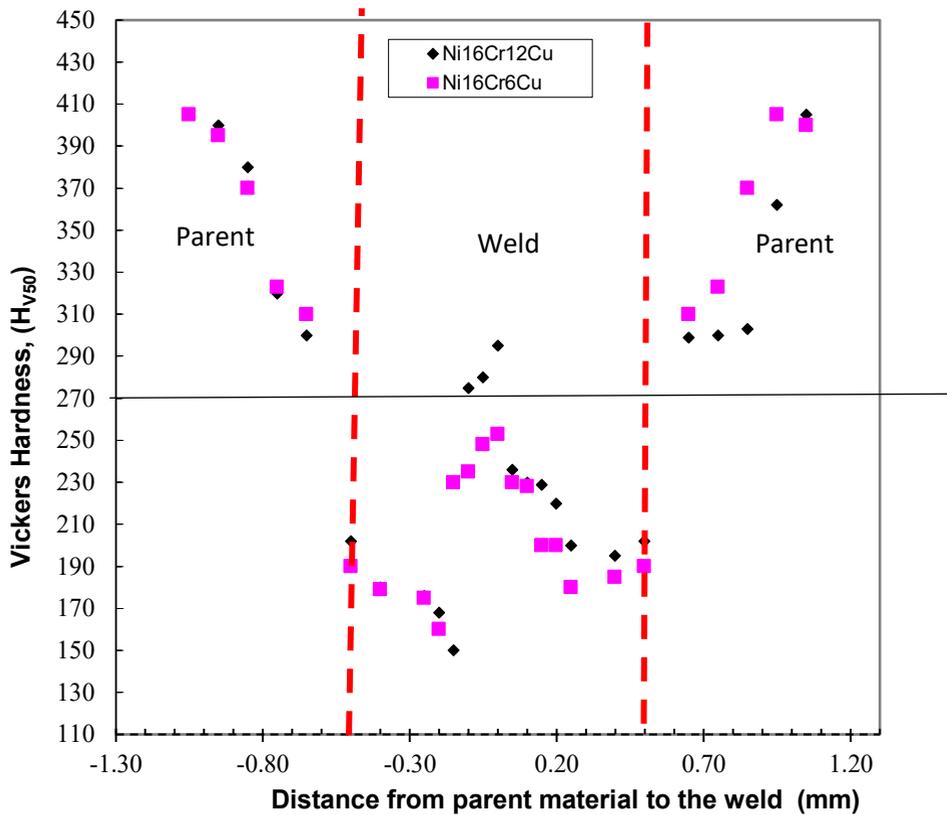


Fig. 8. Vickers micro hardness profile of the ADI block welded with two different Ni-Cr-Cu alloys electrodes after PWHT.

As shown in Figure 8, the Vickers microhardness of the as-welded weldment showed the highest values at the parent (base) material due to austempering of the DI into ADI. The austempering process led to the formation of the upper bainitic structure and ledeburitic at heat heat-affected zone, which has the lowest hardness compared to the weld as per the presented profile.

4 Conclusion

It was concluded that the PWHT has slightly reduced the maximum hardness values, while applying multipass welding lowered the width of the melt region and micro hardness of HAZ. By using Ni-Cr-based filler materials, the welds made purpose of this work managed to achieve a carbide-free heat-affected zone (HAZ). Conversely, the use of the filler did reduce the Vickers microhardness values of both welds, ranging from 295HV to 253HV. These hardness values were much lower than the hardness of the base material. Therefore, despite obtaining successful welds and managing to avoid the formation of carbides, it is recommended that the electrodes require further alloying in order to improve their hardness to be closer to that of the ADI base material.

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