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Experimental Study of Microstructure and Mechanical Properties of Gray Cast Iron Welded Joint Using Est and Nickel Electrode

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Abstract

Gray cast iron is most prominently used material in industry. Many times, repair of the cast products are required to save production cost. Welding is very frequently used to repair gray cast iron components. The weldability of gray cast iron is always considered to be poor. The formation of martensite after cooling resulting cracks is the main concerns. In this work weldability of gray cast iron was investigated by using ESt electrode and ENiFe-CI electrode. Measurement of hardness and impact tests was conducted to study the quality of welded joints. Micro-structural observations were also done in as-welded and PWHT condition. In case of welding with nickel electrode microstructure of various zones i.e. fusion zone, HAZ and base metal in as welded condition shows austenite matrix, martensite, and flakes of graphite respectively. In case of steel electrode in as-weld condition fusion zone, HAZ and base metal exhibit two phases of ferrite, martensite and flake of graphite respectively. After applying PWHT martensite and carbide present in the phase were dissolved and they were converted into ferrite and graphite, consequently, reduces the hardness of the weldment.

Hardness of HAZ was found maximum in as-weld condition. After PWHT hardness of different zones reduces significantly in both the welding conditions. Toughness of the welded joints using nickel electrode were found higher than the toughness of welded joints made by ESt electrode. Enhancement in toughness value was seen after PWHT as compared to as-weld condition.

Keywords: Gray cast iron, Microstructure, Post weld heat treatment, Hardness, Toughness.

Introduction

The welding of cast iron is more complex because of two primary reasons: (i) its inherent brittleness and (ii) the weld thermal cycle's effect on the structure of the iron. Cast iron has a high carbon content which forms martensite and carbides in the fusion zone (FZ) and in the heat-affected zone (HAZ) of the weld. These phases are hard and brittle and have a negative effect on the weld's ductility, toughness, machinability, and may even cause cracks in the weld joint [1, 2]. The FZ's inability to yield and relieve welding stresses may cause cracks in the surrounding cast iron HAZ [3].

Filler Metal Selection

Currently, there are three types of filler metals available for cast iron welding: (mild/low) carbon steel filler metals, cast iron filler metals, and nickel/nickel-iron based filler metals [4]. Many scientists have reported the use of mild steel electrodes for welding cast gray irons. This is due primarily to the low cost of mild steel electrodes. Nonetheless, these electrodes encounter certain metal shrinkage issues which include steels that shrink more than gray cast iron during solidification which renders the fusion zone sensitive to solidification cracking as a result of the formation of tensile stresses in the fusion zone. Coupled with the dilution of the mild steel electrode by the high carbon cast iron, the FZ will have a carbon concentration that is more than adequate to produce a solidification structure that is hard and brittle, and that will be present in the FZ. The Ni and Ni-alloy covered electrodes improves the toughness of weld metal zone by forming austenite phase. Due to presence of nickel in their composition, they are relatively expensive.

Objective

The primary objective of this work was to experimentally study the microstructure of different region of gray cast iron welded joint, hardness variation along different weld zones and toughness of welded joint using Est electrode and Ni electrode in as-weld and after post weld heat treatment (PWHT).

Experimental Procedure

Cast iron plate was cut using power hacksaw as per specimen dimension shown in Fig. 1. V-groove included angle of 60^0 was cut on shaper machine. The specimen was welded using the Shielded Metal Arc Welding (SMAW) technique. For the welding of the plates, ADOR made Cast Nickel Electrode and Est electrode were used. The chemical compositions of the electrodes and the cast iron work-piece are provided in Table 01. Table 2 shows the welding parameters. Condition and process

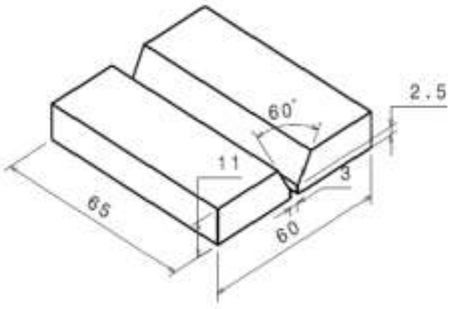


Fig. 1 Dimensions of V butt joint (in mm)

Table 1: Chemical composition of electrodes and work piece

Chemical Composition (%)								
	C	Ni	Si	S	P	Mn	Fe	Cu
Ni based electrode	2	85	4	.03	--	1.0-2.5	8	2.5
Est electrode (Casten)	0.15	--	0.15	0.30-0.60	0.04	0.04	--	--
Gray cast iron	3.79	--	1.55	0.195	0.286	0.76	--	--

Table 2: Welding conditions and process parameter

Base Material	Gray cast iron	
Plate Thickness (mm)	11	
Electrode	AWS S/SFA 5.15 ENI CI	AWS A/SFA 5.15 Est.
Electrode diameter (mm)	3.2	4.0

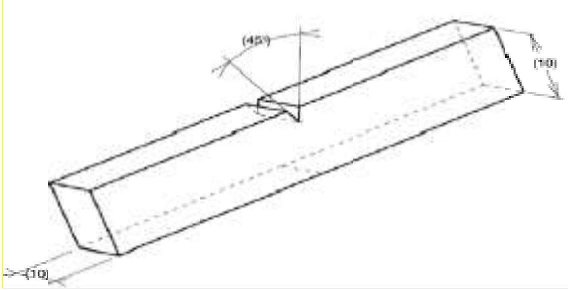
Welding Current (amps)	80	160
Welding voltage (volts)	23.2	23.2
Welding speed (mm/min)	59.6	55.6

After welding, some of the samples were directly sent to the electrical furnace for heat treatment. The specimens were heat treated at 900°C for 3 hours and then allowed to cool in the furnace to room temperature. In the majority of cases, post weld heat treatment is a necessity in order to reduce the large carbides and martensite that are formed in the HAZ and the partially molten zone during cooling.

Welded joints were cut normal to the welding direction using power hacksaw and then machined to the required dimensions for preparing specimens for micro-structural analyses. Specimens were etched with nital reagent to reveal the microstructure. Micro-structural examinations were done using a light optical microscope. Photographs of microstructure of different weld zones were taken at suitable magnification (100×).

Hardness of the specimens was measured after studying the microstructure. A Rockwell hardness testing machine using 150 gm load was employed for measuring the hardness of different zones of welded joint. The spatial variation of hardness values (HV) of each weld zones was recorded The Charpy test assesses the ability of a material to absorb energy during a singular impact. Energy is absorbed by a specimen experiencing a break from a single impact of a pendulum. In accordance to standard procedures for the impact test, a material is tested after being notched and supported at the ends, laying the notch opposite the impact. The impact hammer shatters the test bar and the energy absorbed during the process is a measure for material resistance

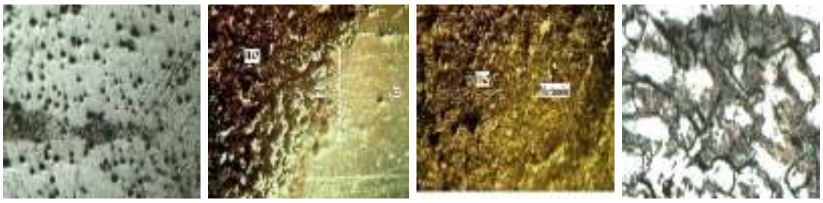
Fig. 2 Dimensions of specimen for impact test to impact shock. The dimensions of the specimen for the Charpy test are illustrated in Fig. 2.



Results and Discussion

Microstructure in the as-welded condition (Ni Rod)

The microstructures of fusion zones of welded joints employing Ni rods as electrodes are displayed in Fig. 3. The microstructure of a fusion zone comprises predominantly an austenitic matrix with a minor fraction of dispersed solidified graphite constituents (see Fig. 3a). The nickel filler metal has an ability to stabilize free carbon which is picked up from the BM (base metal) as graphite, as the fusion zone (FZ) of a nickel-based weld has a level of carbon (beyond the solubility limit (which is 0.5% at the eutectic temperature of the Ni–C system) in nickel) in fusion zone which is well above the limit. The excess carbon in the zone is precipitated as graphite at the solidification of the fusion zone (FZ). Fig. 3(b) Micrographs of the partially melted zone (PMZ) which of the microstructure shows the presence of eutectic ledeburite along with some martensite constituents.



a. Fusion zone, b. Partially melted zone, c. Heat affected zone, d.Base metal

Fig. 3 Microstructure of welded joint using Ni-rod as weld condition (100×)

Figure 3(c) illustrates the microstructure of the HAZ, characterized by the presence of a large concentration of martensite in addition to some amount of graphite. During the welding thermal cycles, the HAZ reaches temperatures exceeding the A1 (eutectoid transformation) of the Fe-C phase diagram. Under such elevated temperatures, the graphite flakes begin to dissolve, and austenitization occurs. Given the high cooling rates, however, the process of graphitization is arrested, and the high-hardness austenite transforms to a hard and brittle martensite [5]. Figure 3(d) illustrates the base metal microstructure, which also consists of a ferrite matrix with graphite flakes dispersed throughout the phase.

Microstructure after PWHT (Ni Rod)

a. FZ, b. HAZ, c. Base metal

Fig. 4 Microstructure of welded joint using Ni. Rod after PWHT (100×)

Fig. 4 depicts the microstructure of welded joint using Ni rod after post weld heat treatment. No significa**n**t change in fusion zone (Fig. 4a) microstructure was seen after PWHT. Austenite gets coarser and carb**o**n composition becomes homogenous throughout the zone, i.e. .diffusion of carbon takes place. However**,** heat affected zone microstructure (Fig. 4b) was significantly affected by PWHT. It is observed seen in Fig. 4(b) heat affected zone consists of graphite flakes in a ferritic matrix. Holding the work-piece at 900□ C for 3 hours provide sufficient driving force to dissolve the eutectic carbide and the martensite phases formed during normal cooling of welding.[6] During the slow furnace cooling, graphite is formed in a ferritic matrix but not Fe_3C. Therefore, the applied PWHT will reduce the formation of brittle phases in heat affected zone.

Microstructure in the As-welded condition (ESt electrode)

Fig. 5 shows microstructures of various zones in As-Weld using ESt. Rod. In FZ (Fig. 5a), due to low carbon content in filler metal ferritic may be formed but due to higher percentage of carbon in base metal and high cooling rate cementite was formed. In HAZ (Fig. 5b) the microstructure obtained is the matrix of ferrite, and the cementite. Cementite was nucleated and grown on the ferrite grain boundaries. A distinctive characteristic of this microstructure is the presence of ferrite that formed at the original or grain boundaries upon cooling from the austenite phase. Such ferrite is termed proeutectoid ferrite. The microstructure also contains ferrite and pearlite, but the predominant phase is ferrite, which is only accompanied by a small amount of pearlite (the dark-appearing constituent). The ferrite represents what is termed as equiaxed ferrite.

a. Weld zone, b. HAZ, c. Base Metal

Fig. 5 Microstructures of various zones in As-Weld condition using ESt. rod (100X)

Microstructure in post weld heat treated condition (ESt electrode)

Figure 6 illustrates the microstructural evolution of the weld zone following post weld heat treatment (PWHT). The partially melted zone (Fig. 6b) and the heat-affected zone (Fig. 6c) exhibited the absence of martensite. After heat treatment martensite and cementite were dissolved. Martensite was converted into ferrite and carbon of cementite was precipitated as graphite. This reduces the hardness of the welded joint and improves the toughness [7]. The base metal (Fig 6d) displays a matrix with a mixture of ferrite and graphite flakes.

(a) Weld Zone (b) Fusion Boundary (c) Haz (d) Base Metal

Fig. 6 Microstructures of various zones of welded joint after PWHT using ESt rod (100×)

Effect of PWHT on weld hardness

The main factor controlling the grade of cast iron welds is the hardness variation across the different weld zone. Hardness significantly affects the fracture behaviour of a weldment. In the present work hardness of welded joint in different zones were measured in as welded condition and after PWHT and compared. The measured values of hardness are shown in Table 3. **Table 3: H**ardness data (HV value) across different zone

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	FZ				**HAZ**			
	As-weld condition		After PWHT		As-weld condition		After PWHT	
S no.	ESt. Rod	Ni Rod	ESt. Rod	Ni Rod	ESt. Rod	Ni Rod	ESt. Rod	Ni Rod
1	36	32	32	32	42	33	32	35
2	35	32	32	32	37	40	32	38
3	46	34	33	32	43	40	33	34
4	40	33	34	31	42	35	31	32
5	41	32	33	31	41	36	33	35
Avg.	**39.6**	**32.6**	**32.8**	**31.6**	**41**	**36.8**	**32.2**	**34.8**

Average value of hardness (HV) of base metal as weld condition: 35.8 Average value of hardness (HV) of base metal after PWHT: 34.9

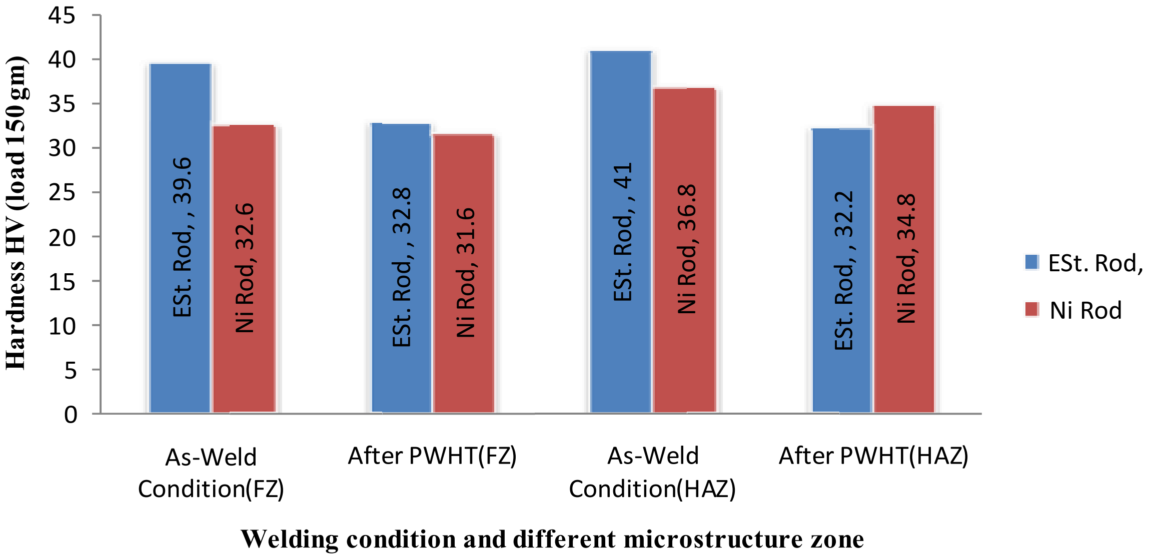

Fig. 7 Variation of hardness in different zones under different welding conditions

Fig. 7 compares the values of hardness in different zones under various conditions. The figure it depicts that hardness of fusion zone in as-welded condition using steel electrode is more as compared to nickel electrode due to presence of ferrite and martensite in fusion zone of steel welded joint. In case of nickel electrode softer phase austenite was formed. After PWHT the hardness value was reduced due to softening of ferrite and austenite. Hardness of HAZ was found more in both the cases as compared to fusion zone and this is due to presence of martensite in HAZ. Fig. 7 shows a significant reduction in the hardness value after applying PWHT as compared with as-welded condition. After heat treatment hard phase of cementite and martensite were dissolved. Hardness of base metal was also reduced due to heat treatment.

Effect of PWHT on toughness of welded joint

Toughness indicates how much amount of energy absorbed by a material at the time of fracture under impact loading. Heat affected zone toughness of multi pass weld joint have a possibility to provide scattered data. Table 4 contains the measured values of toughness in different conditions. In each case three specimens were used to measure the average value of toughness.

Table 4: Toughness value of welded joint

	Filler Type	I	II	III	Avg.
As-weld condition(kg-m)	Ni Rod	1.3	0.3	0.3	0.63
	ESt.Rod	0.5	0.6	0.5	0.53
After PWHT(kg-m)	Ni Rod	0.8	0.8	1.1	0.90
	ESt.Rod	0.8	0.9	0.8	0.83

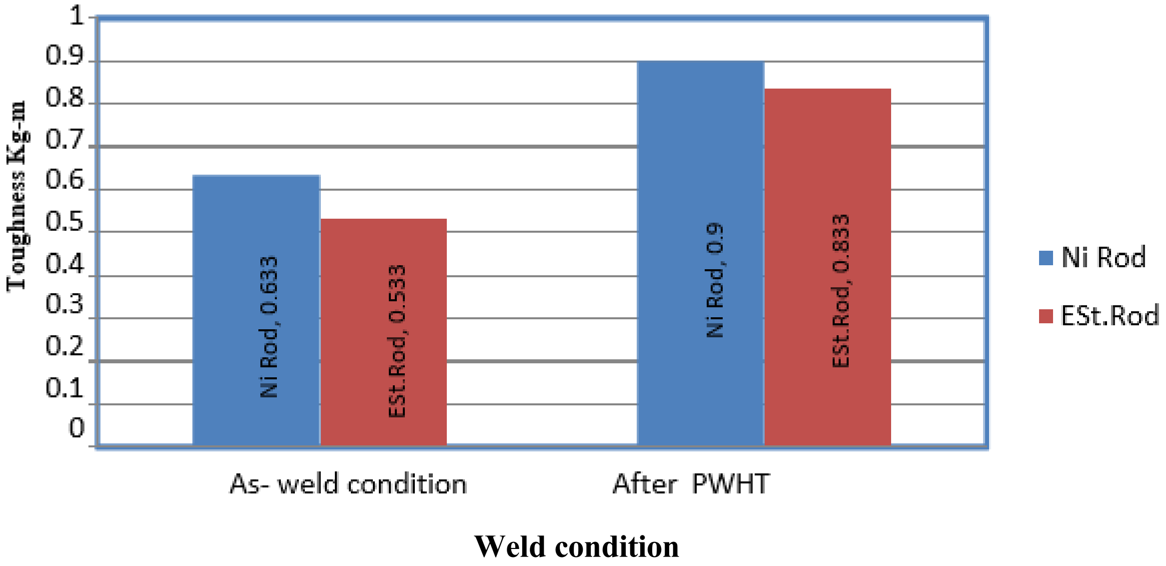

Fig. 8 Toughness comparison of welded joints in various conditions

Fig. 8 compares the toughness of welded joints in different conditions. It can be seen that toughness of welded joint increases by using nickel filler metal due to formation of austenite in the fusion zone. The recorded values show scattered behaviour of toughness value, which is due to in-homogeneity of weld structure. Fig. 8 also shows enhancement of toughness value after applying PWHT. By using PWHT brittle phase of microstructure were dissolved in softer phase. Thus, it can be concluded that toughness value of welded joint of gray cast iron can be improved by using nickel-based electrode. Further toughness can be improved by PWHT.

Conclusions

The use of nickel filler metal allowed the development of the brittle martensite and carbides to be avoided. Fusion zones become austenitic with the presence of some globular graphite which makes the fusion zone ductile and tough. This also increases the ductility and toughness of the weld. Additionally, the tough austenite can absorb the ductile and thermal stresses thus lowering the likelihood of cracks. This means that with nickel filler metal all the fusion zone problems are solved and the dilution and weld thermal cycle do not need to be controlled. The affected zone microstructure of the gray cast iron exhibited martensite and the microstructure of the partially melted zone exhibited hard eutectic carbides and martensite. Post weld heat treatment can be used to convert the martensite and carbides to softer micro-constituents. By using steel electrode ferritic structure can be expected, which is soft and easily deformable, but upon cooling cementite was formed which makes the joint hard. Fast cooling rates led into very hard and brittle ledeburites carbides. Hardness value in all zones of the weldment reduces after PWHT. Toughness value of welded joint of gray cast iron was improved by using nickel-based electrode. Further toughness was improved by PWHT (full annealing).

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