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Effect of Shielded Metal Arc Welding on Microstructure, Hardness, and Tensile Strength of Nodular Cast Iron

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Abstract. Welding plays an important role in the component joining process. This study aimed to determine the effect of shielded metal arc welding on the microstructure, hardness, and tensile strength of nodular cast iron. Shielded metal arc welding was performed using AWS A5.15 Eni-CL electrodes. Scanning Electron Microscope is used for metallographic observation. Hardness testing was carried out on base metal, heat-affected zone, and weld metal. This hardness test uses the Vickers technique. Tensile testing was carried out to determine the effect of welding on tensile strength. The results of the metallographic investigation showed the disappearance of the ferrite phase and the appearance of the ledeburite phase in the heat-affected zone and weld metal. The area with the highest hardness occurs in the heat-affected zone while the lowest hardness occurs in the weld metal. There is a decrease in the tensile strength of nodular cast iron due to the welding process.

Introduction

Nowadays, the development of new cast iron materials seems to offer greater competition with other materials and makes cast iron a competitor for components that are not traditionally made. Nodular cast iron has gained popularity and is rapidly replacing other cast iron and some low-strength steel. The increasing use of nodular cast iron concerns many applications, especially in the automotive, heavy-duty equipment, and non-automotive transportation industries [1-5].

Nodular cast iron, also known as ductile cast iron, contains graphite in the form of nodules [6-8]. The spherical shape of graphite does not cause high-stress concentrations like flake graphite. Therefore, nodular cast iron has higher tensile strength and plasticity, as well as higher fatigue strength than flat cast iron [9-12].

Welding has an important role in metal engineering and repair [13, 14]. Welding is a metal joining technique by melting some of the base metal and filler metal with or without additional metal and produces continuous metal [15]. The scope of the use of welding techniques in construction is very broad, including steel frames [16], pipelines [17], gas turbine engines [18], engineering structures [19], shipping [20], vacuum vessels [21], and bridges [22].

One of the most frequently used welding techniques is Shield Metal Arc Welding (SMAW). SMAW is an electric flame arc welding that uses electrodes as added materials and these electrodes come in many sizes and types, depending on the needs of the welding process itself. To get a good and perfect weld, it is necessary to set the correct and proper current, not only that, the selection of a welding machine will also affect the results of the welding. SMAW welding is the most widely used type for almost all welding jobs. The voltage used is only 23 to 45 Volts AC or DC, while for melting welding a current of up to 500 Amperes is needed. but in general, used ranges from 80 – 200 Amperes [23-25].

The welding process is carried out at high temperatures, this will affect the microstructure and mechanical properties of the material. Hardness and tensile strength are important material properties in machine components [26, 28]. Therefore, this study aimed to investigate the effect of SMAW on the microstructure, hardness, and toughness of nodular cast iron.

Materials and Methods

The material investigated in this study is nodular cast iron. Nodular cast iron has spherical graphite. The composition of this nodular cast iron is shown in Table 1.

Table 1. Nodular cast iron composition

C%	Si%	S%	P%	Mn%	Mg%	Ni%	Cr%	Mo%	Cu%	Ti%	Sn%	Al%	Nb%
3.51	2.60	0.01	0.02	0.53	0.03	0.01	0.01	0.00	0.02	0.04	0.01	0.01	0.00

The welding process is carried out with an electric current of 90 amperes, AWS A5.15 Eni-CL welding electrode wire, and a 1G/PA (down hand) welding position. To prevent deformation, the material is only cooled by letting it sit in the sand for a while. In the welded seams, 3 layers of welds are provided with the welding sequence starting from root, filler, and camping without back gouging. The dimensions of the welding specimen are shown in Fig. 1.

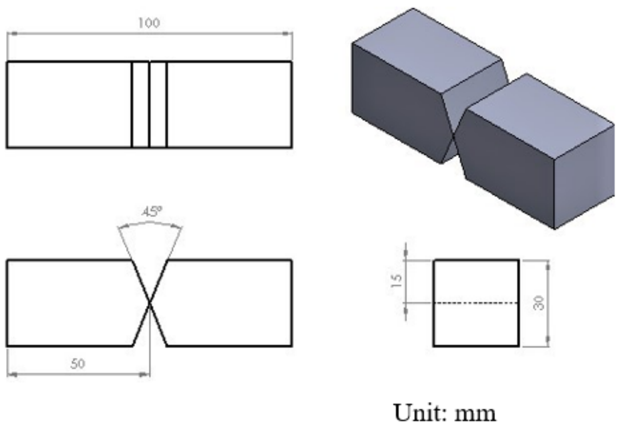

Fig. 1. Welding specimen

Metallographic tests were carried out to determine changes in the microstructure on the surface of nodular cast iron due to the influence of Shielded Metal Arc Welding (SMAW). This test was carried out using a Scanning Electron Microscope (SEM) based on ASTM E986 which was carried out on the weld metal, Heat Affected Zone (HAZ), and base metal parts.

After metallographic inspection, hardness testing is carried out on the weld metal, HAZ, and base metal. The method used for hardness testing is the Vickers ASTM E92 method, which uses a diamond pyramid indenter with an angle of 136° at the top of the pyramid. The Vickers hardness test uses a loading of 200 gf.

Furthermore, tensile testing was carried out to determine the tensile strength of nodular cast iron specimens before and after the SMAW welding process was carried out. In this study, tensile testing was carried out using a tensile testing machine according to the ASTM E8 standard.

Results and Discussions

Metallography Test. The base metal has a microstructure that does not change with nodular cast iron before welding because there is no effect of heat that occurs. The phases contained in the parent metal are graphite, ferrite, and pearlite which can be seen in Fig. 2. The graphite phase shows a black color with a spherical shape and is quite large in size. The ferrite phase is light in color and surrounds the graphite. While the pearlite phase is gray (Fig. 2a) [29].

The microstructure in the HAZ region shows that there are several phases, the phases are graphite, fine pearlite, and ledeburite. Graphite in the HAZ area tends to be spherical in shape with a black color and is quite large. The ledeburite phase looks light in color with a bit of dark color that is layered (lamellar) with a fairly large size. The pearlite phase is formed as fine gray grains (Fig. 2b).

Figure 2c depicts the microstructure of the weld metal. The ledeburite microstructure is surrounded by pearlite and graphite nodules [30].

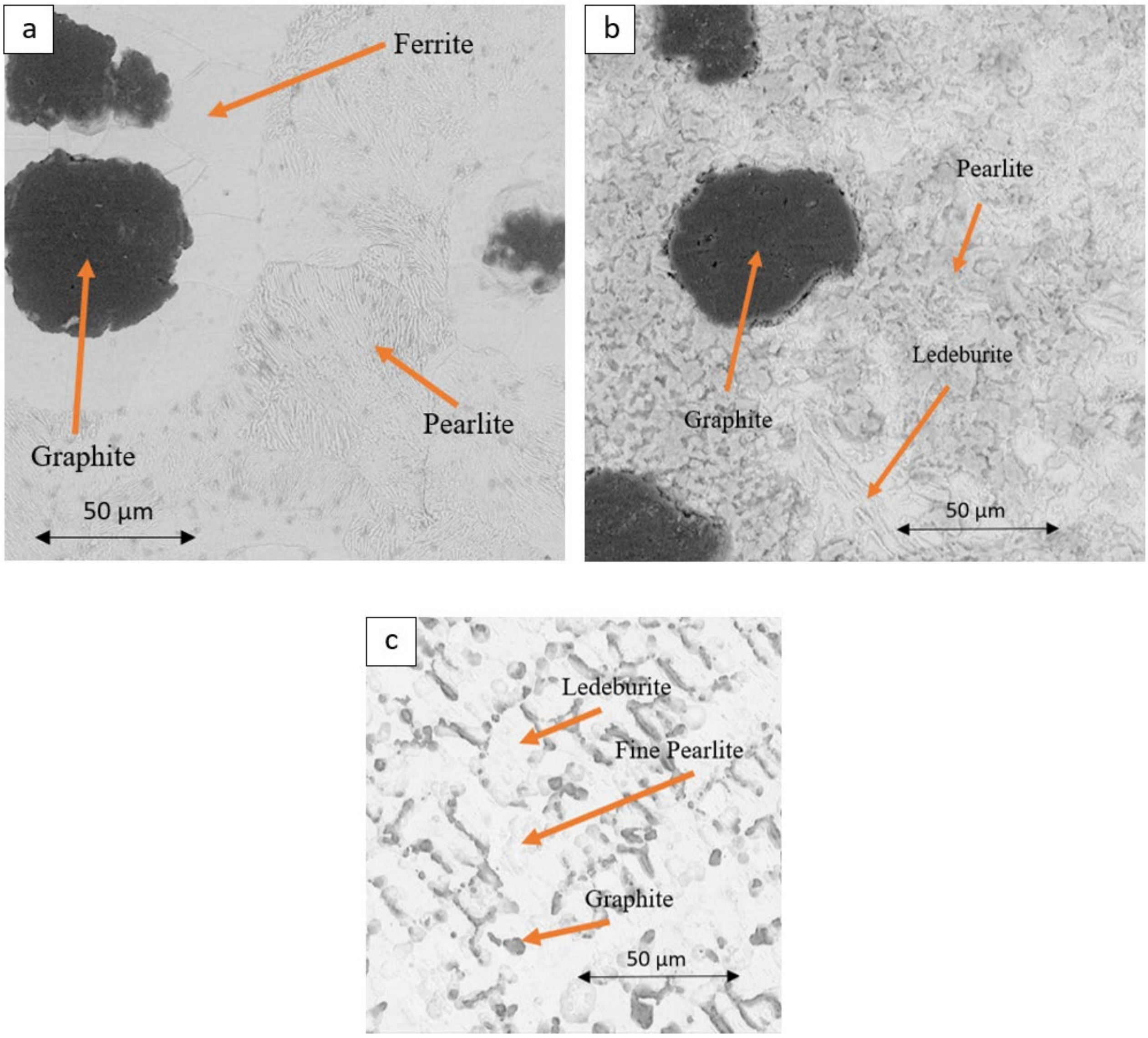

Fig. 2. Microstructure of (a) base metal (b) HAZ (c) welded metal

Hardness Test. The test results showed that the base metal, HAZ, and weld metal hardness were 303.85, 466.56, and 229.11 VHN, respectively (Fig. 3). HAZ has a higher hardness than base metal due to a large decrease in graphite, the disappearance of ferrite, the reducing of pearlite grain size, and the appearance of a ledeburite phase. While the welding metal which is dominated by nickel makes the hardness decrease.

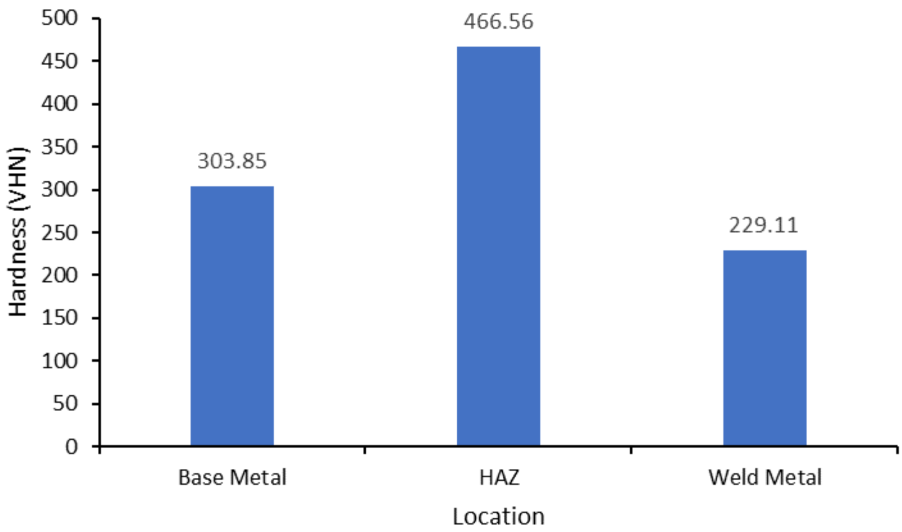

Fig. 3. The effect of the welding process on hardness

Tensile Test. The presence of Shielded Metal Arc Welding affects the tensile strength value of nodular cast iron. Nodular cast iron without welding process has a tensile strength of 562.99 N/mm^2. Whereas after being welded it decreased to 191.79 N/mm^2 (Fig. 4). This is due to the strength of the weld metal which is lower than that of nodular cast iron [31].

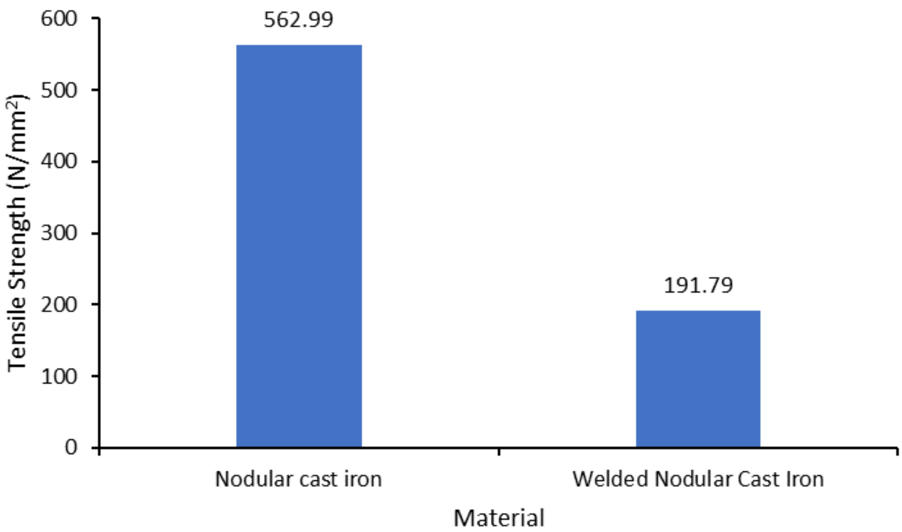

Fig. 4. The effect of the welding process on tensile strength

Summary

SMAW welding performed on nodular cast iron provides changes in the microstructure around the weld area. In the area around the weld, three zones are formed, namely the weld metal, HAZ, and base metal. The hardness in the HAZ is the highest compared to the hardness of other zones. SMAW welding also has an effect in the form of a decrease in the level of tensile strength.

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