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The effect of current strength on tensile strength and impact toughness of cast iron welded joints

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ABSTRACT

Cast iron is a high-carbon iron-carbon alloy. Cast iron is difficult to weld because of the high carbon concentration. A good connection necessitates the application of specific strategies and processes. This study investigates the effect of current strength on the mechanical properties of tensile strength and impact toughness of cast iron welded joints. The main materials used are gray cast iron and CIN 3 filler. The welding process uses an AC TIG welding machine. The welding seam is made of a single V with an angle of 70°, and the electric current variations are 80A, 90A, and 100A, respectively. Tensile testing is carried out with a UTM machine referring to ASTM E8M, while the Charpy impact test refers to ASTM E23. From the study results, it was found that the higher the use of electric current resulted in the mechanical properties of the tensile strength and impact toughness of the weld being also higher, which occurred at 100A electric current, reaching 181.05 MPa and 0.22 J/mm^2.

ABSTRAK

Besi cor merupakan paduan antara besi dan karbon di atas 2.5%. Kadar karbon yang tinggi ini menyebabkan besi cor sulit untuk dilas. Perlu teknik dan proses tertentu untuk mendapatkan sambungan yang baik. Penelitian ini bertujuan menyelidiki pengaruh kuat arus terhadap sifat mekanik kekuatan tarik dan ketangguhan impak sambungan las besi cor. Bahan utama yang digunakan adalah besi cor kelabu dan filler CIN 3. Proses pengelasan menggunakan mesin las TIG AC. Kampuh las dibuat V tunggal bersudut 70°, variasi arus listrik berturut-turut adalah 80A, 90A dan 100A. Pengujian tarik dilakukan dengan mesin UTM mengacu pada ASTM E8M, sedangkan pengujian impak charpy mengacu pada ASTM E23. Dari hasil penelitian didapatkan, pemakaian arus listrik semakin tinggi mengakibatkan sifat mekanik kekuatan tarik dan ketangguhan impak hasil lasan juga semakin tinggi, yaitu terjadi pada kuat arus listrik 100A, mencapai 181.05 MPa dan 0,22 J/mm^2.

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1. Introduction

Welding is a significant aspect of everyday life, particularly in the construction industry. Cast iron is an iron-carbon alloy with a certain content that is frequently used in engine parts, engine blocks, flywheels, pipelines, and agricultural equipment. Because of the high concentration of graphite in the iron, cast iron is difficult to weld [1]. To achieve satisfactory results when welding cast iron in this condition, specific techniques and processes are required. Methods and process advancements for producing high and tough weld strengths, particularly for cast iron materials, are still desperately needed [2-8]. A fracture or break in one of the spare parts on the machine made of cast iron at PT Indocali Plast is a common occurrence, and it requires immediate repair so that the production process is not delayed.

The selection of filler metal for welding cast iron is critical. Because it possesses mechanical qualities similar to cast iron, Inconel alloy filler metal is ideal for welding. Multilayer welding can also create high mechanical strength by reducing the amount of martensite in the HAZ. Heat treatment, both before and after welding, can also improve weld mechanical strength [2]. Temperature management throughout the cooling process is required in the cast iron welding process to increase the tensile strength and hardness of the weld metal. Heat treatment of cast iron weld metal increased tensile strength and hardness relative to the untreated weld [3].

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The creation of a martensitic structure in the weld region and HAZ causes the brittle mechanical strength of cast iron welds. By changing the cooling rate and heat input, the martensitic structure can be decreased. Heat treatment before and after welding has been shown to reduce the rate of cooling in the welding process [4]. The geometry of the weld has little effect on the physical and mechanical qualities of cast iron welds, but the type of filler employed does. NiCl filler outperforms EB 150 and ES 18-8-6B fillers in terms of weld quality [5].

Welding on cast iron above the furnace can simplify the welding process and increase the fluidity of the weld metal. On cast iron welding with 97.6 percent Ni filler, heat treatment annealed 350ºC produced higher mechanical characteristics but lower ductility than heat treatment annealed 900ºC. [6] studied the microstructure of martensite with a ferritic graphite matrix. Heat treatment before welding, followed by heat treatment after welding, can be used to improve the mechanical properties of welds. When compared to no heat treatment, the amount of martensite and ledeburite microstructure was dramatically reduced. For welds of 2-4 passes evaluated, heat treatment at 300ºC for 2 hours is preferable to 400ºC for 2 hours [7].

Heat treatment is applied both before and after welding to improve the mechanical qualities of cast iron welds. Heat treatment after welding is more successful than heat treatment before welding in enhancing the mechanical properties of welds. After welding, a temperature of 700ºC for 2 hours produced better outcomes than a temperature of 800ºC for 2 hours. Because of the microstructure of martensite and ledeburite in HAZ and weld metal, the material becomes brittle and hard [8]. The welding process necessitates the consideration of numerous parameters, one of which is electric current: heat input and cooling rate after welding influence the mechanical characteristics of the welded metal. The electric current employed in the welding process is strongly related to the heat input [9]. The welding current has a significant impact on the weld's qualities, particularly its tensile strength. The tensile strength of the dissimilar welded metal of carbon steel and stainless steel on HAZ carbon steel is the lowest [10].

Welding gray cast iron presents challenges in both the HAZ and PMZ sectors, specifically increased hardness due to the production of martensite and ledeburite structures in the PMZ and pearlite and martensite in the HAZ [11]. Weld hardness is affected by variations in welding current strength. According to the results of transgranular fracture fractography, the fracture cross-section on the tensile strength test for all specimens was brittle. The size of the electric current utilized influences the strength of the welded metal. A strong connection is produced by a substantial electric current [12-14]. On TIG welding equipment, welding medium carbon steel with an electric current of 160A, 180A, and 200A yielded the maximum tensile strength results at an electric current of 200A, which was 680 MPa [12]. The electric current used in welding also affects impact toughness. The striation form is a feature of the cross-section of the fracture that undergoes ductile fracture in the impact test [13].

Unless PAW is employed, ferrous and non-ferrous materials lose tensile strength during fusion welding. To some extent, FSW increases tensile strength. The tensile strength increases with increasing ferrite content. Tensile strength decreases are determined by the electrode material, filler material, welding speed, and heat input. Damage to the base material or the welding zone is largely influenced by the parent material and the welding procedure. Almost every experiment demonstrates a ductile failure mode (good impact toughness). The ferrite and ferrite phases are related to the material's toughness. The impact toughness of the welded junction is also determined by the filler material [14]. The heat input, particularly the electric current used in the welding process, has a significant impact on the impact toughness of the weld metal [15,16]. The HAZ region is impacted by heat during welding because of the high temperatures, which affect the microstructure of the metal surrounding the weld. As a result, the impact strength and hardness vary. The impact toughness of TIG welding rose as the electric current used for welding increased, according to the impact test results [16].

In the Al-Mg alloy TIG welding process, using welding angles of 70º, 80º, 90º, and electric currents of 100A, 125A, and 150A yielded better results for 90º seam angles and 100A electric currents than the others. The tensile strength of the welded metal is 78.85 MPa, 96.82 MPa, and 135.05 MPa at an electric current of 100A and weld angles of 70º, 80º, and 90º, respectively [17]. The tensile strength of the varied material welded joints between SS304 and ST37 metals in SMAW welding at 60A, 70A, and 80A electric currents is 48.724 kg/mm^2, 51.656 kg/mm^2, and 48.175 kg/mm^2, respectively. The magnitude of the weld metal's tensile strength exhibits erratic results [18]. The tensile strength of the weld metal increases as the electric current increases. The tensile strength of the base metal, welded metal, and welded metal at 100A, 125A, and 150A electric currents, respectively, is 36.711 kgf/mm^2, 31.863 kgf/mm^2, 40.827 kgf/mm^2, and 48.503 kgf/mm^2 [19].

The results of dissimilar GMAW metal welding between low carbon steel and SS316L steel using a variation of electric current is 330 MPa the tensile strength is at 90A electric current usage, while at 60A electric current, the tensile strength is 275 MPa. The value of hardness on using an electric current of 90A is obtained higher than the use of an electric current of 60A. The weakest area of the connection is in the low carbon steel base metal, characterized by all tensile fracture test results in that area [20]. The use of AWS E316L filler metal in welding AISI 444 metal with variations in electric currents of 40A, 60A, and 75A produces a tensile strength that is lower than the tensile strength of the parent metal. The tensile strength of the base metal, welded metal at an electric current of 40A, 60A, and 75A are 555 N/mm^2, 395 N/mm^2, 511 N/mm^2, and 502 N/mm^2, respectively. This decrease in tensile strength is also possible due to defects in the weld metal in the form of porosity [21].

ANOVA analysis on SMAW and GTAW dissimilar welding processes between AISI 1045 and AISI 316L steels shows that the tensile strength of 99.9% is influenced by electric current, while other factors influence the remaining 0.1%. The tensile strength of welded metal with SMAW welding at 50A electric current is the lowest, namely 61.97 kg/mm^2, while at the use of 70A electric current is the highest, which is 64.01 kg/mm^2. However, in GTAW welding, the use of an electric current of 60A produces a maximum tensile strength of 49.54 kg/mm^2, while an electric current of 70A produces a minimum tensile strength of 46.64 kg/mm^2 [22]. The high and low electric current used for dissimilar RSW welding between 316L steel and ST37 steel impacts the HAZ area that occurs. The high electric current results in a large HAZ area where the effect is that the amount of pearlite decreases while the number of ferrite increases. The results in a decrease in the tensile strength of the dissimilar weld metal, which may also decrease its physical properties, other mechanical properties, and corrosion resistance [23].

The type of filler and the current strength has a significant effect on the welding result. An increase in current strength results in an increase in heat input to the weld, and high heat input will reduce the tensile strength and hardness of the weld metal. The use of filler E7016 produces maximum tensile strength, while filler E7018 produces maximum hardness. The welding current of 80A is more optimum than 90A used in welding [24]. The purpose of this study was to investigate the tensile strength and impact toughness of the cast iron welded joints that have been made. This research uses gray cast iron material with CIN 3 as the filler. Underhand AC TIG welding is performed to join materials. The electric current is varied from 80A, 90A, and 100A at the time of welding.

2. Research Methodology

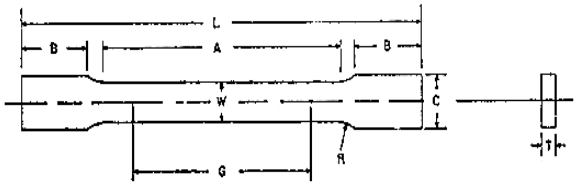
As the dependent variable, destructive testing, especially tensile and impact tests, was used in the experiment. Gray cast iron with cast iron nickel 3 (CIN 3) as a filler is the control variable. Alternating polarization and Argon shielding gas are used in TIG welding equipment. The connection is created using a butt joint welded junction, a V seam, and a 70o rib angle. The base metal has 300 mm in length, 100 mm in width, and 10 mm in thickness. According to Table 1, the chemical composition of the parent metal is gray cast iron with an iron and carbon alloy of 3.68 percent by weight and silicon 2.28 percent by weight. The filler's chemical makeup is nickel alloy with 5% iron by weight, 3.5 percent carbon by weight, and 3% sulfur by weight. At the same time, the chemical composition of the weld metal is a combination of the parent metal and the filler, specifically an alloy of nickel with 22.85 percent iron by weight and 1.21 percent silicon by weight. The test specimens were created under ASTM guidelines. In each test, three specimens were prepared for each treatment variant. Meanwhile, the welding electric current fluctuates as an independent variable between 80 Ampere, 90 Ampere, and 100 Ampere.

Table 1. Chemical composition of base metal (CI), filler (CIN 3), and weld metal.

Chemical elements	wt%			Chemical elements	wt%		
	CI	CIN 3	welding metal		CI	CIN 3	welding metal
Fe	Balance	5	22.85	W	0.0008	-	-
S	0.0682	3	0.012	P	0.1257	0.03	0.068
Al	0.0020	-	-	Cu	0.1445	0	0.041
C	3.6673	3.5	0.042	Ti	0.0240	-	-
Ni	0.0657	Balance	Balance	N	0.0049	-	-
Nb	0.0002	-	-	B	0.0020	-	-
Si	2.2809	0.8	1.21	Sb	0.0026	-	-
Cr	0.1385	-	-	Ca	0.0008	-	-
V	0.015	-	-	Mg	0.0023	-	-
Mn	0.8465	1	0.18	Zn	0.0032	-	-
Mo	0.0092	-	-	Co	0.0076	-	-

2.1. Tensile Strength Test

Tensile test specimens were made according to the ASTM E8M standard, as shown in Figure 1 [25]. Tensile strength testing is done by a universal testing machine (UTM). Dimensions of the specimen using sheet type are 200 mm long, 20 mm wide, and 10 mm thick. The position of the weld is in the transverse direction, that is, in the middle of the specimen.



Dimensions			
	Standard Specimens		Subsize Specimen
	Plate-Type, 40 mm [1.500 in.] Wide	Sheet-Type, 12.5 mm [0.500 in.] Wide	6 mm [0.250 in.] Wide
	mm [in.]	mm [in.]	mm [in.]
G—Gage length (Note 1 and Note 2)	200.0 ± 0.2 [8.00 ± 0.01]	50.0 ± 0.1 [2.000 ± 0.005]	25.0 ± 0.1 [1.000 ± 0.003]
W—Width (Note 3 and Note 4)	40.0 ± 2.0 [1.500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T—Thickness (Note 5)		thickness of material	
R—Radius of fillet, min (Note 6)	25 [1]	12.5 [0.500]	6 [0.250]
L—Overall length, min (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A—Length of reduced section, min	225 [9]	57 [2.25]	32 [1.25]
B—Length of grip section, min (Note 9)	75 [3]	50 [2]	30 [1.25]
C—Width of grip section, approximate (Note 4 and Note 9)	50 [2]	20 [0.750]	10 [0.375]

Figure 1. ASTM E8M tensile test specimen standard [25].

2.2. Impact Toughness Test

An impact test may be used to measure the impact toughness of the weld metal. The Charpy impact testing machine was used in this study's tests. The test specimens were manufactured in accordance with the ASTM E23 standard [25], with dimensions of 55 mm length, 10 mm breadth, and 10 mm thickness, with a notch depth of 2 mm.

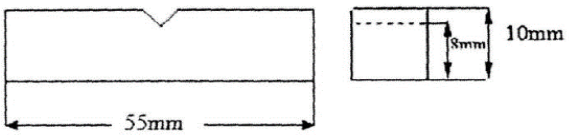


Figure 2. Dimensions of the ASTM E23 . impact test specimen [25].

3. Results and Discussion

3.1. Tensile Strength Test

Figure 3 depicts the average tensile strength test results for cast iron TIG welded joints utilizing welding current variations of 80A, 90A, and 100A.

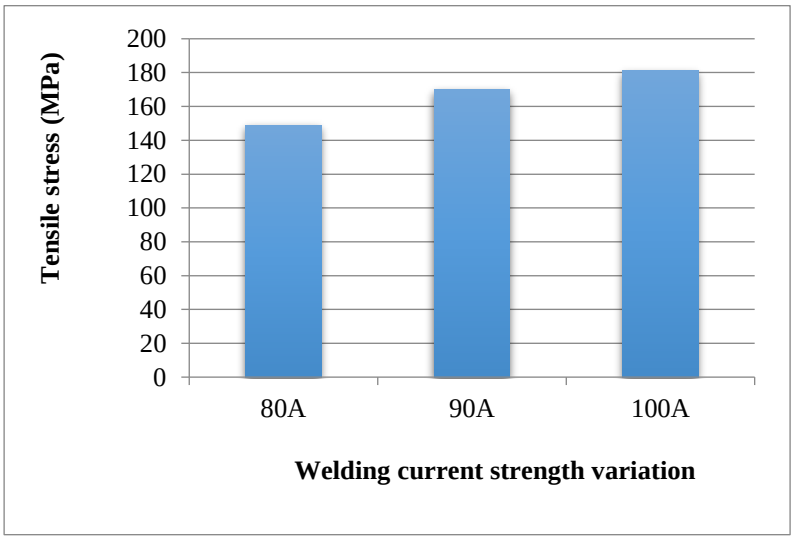


Figure 3. Graph of tensile stress-variation of current strength in cast iron welding joints.

Figure 3 indicates that the electric current used for TIG welding of cast iron is 80A, 90A, and 100A, resulting in varied mechanical characteristics of the weld metal tensile strength. The tensile strength of cast iron TIG-welded metal increases directly to the amount of electric current employed during the welding process. The tensile strength of cast iron welded metal is 148.89 MPa, 169.87 MPa, and 181.05 MPa during TIG welding with an electric current of 80A, 90A, and 100A, respectively. Using a larger electric current in the TIG welding process results in a higher heat input during the welding process, which results in a quicker cooling rate. Because of the quick cooling, the microstructure of the weld metal tends to form pearlite. Pearlite is a strong and hard mineral. Tensile test results yielded high values at high current utilization [2-4], [7,8], [11], [24].

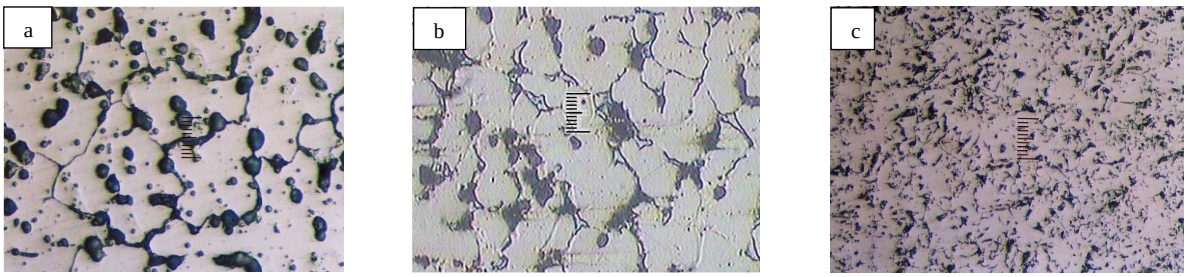


Figure 4. Microstructure of cast iron welding area (a) 80A, (b) 90A, and (c) 100A (200X).

The microstructure in Figure 4a and Figure 4(b) shows that ferrite and graphite separate in groups, resulting in low strength. While in Figure 4c, ferrite and graphite in the form of cementite are arranged together to form pearlite. Where this pearlite has properties that are stronger and harder than ferrite, based on these results, it can be concluded that in TIG welding of cast iron, the mechanical properties of the weld metal, in this case, is its tensile strength, which is strongly influenced by the welding electric current. This result follows research [12], [18,19], which states that a high electric current in the welding process results in high tensile strength. In [9-11], [13,14], [17], and [20-23] also revealed that the mechanical properties of the weld metal, especially tensile strength, are strongly influenced by the high and low electric current used during the welding process.

3.2. Impact Toughness Test

The Charpy impact toughness test was carried out on all weld metal test specimens. The average results of the TIG weld metal impact toughness test with a welding current of 80A, 90A and 100A are shown in Figure 5.

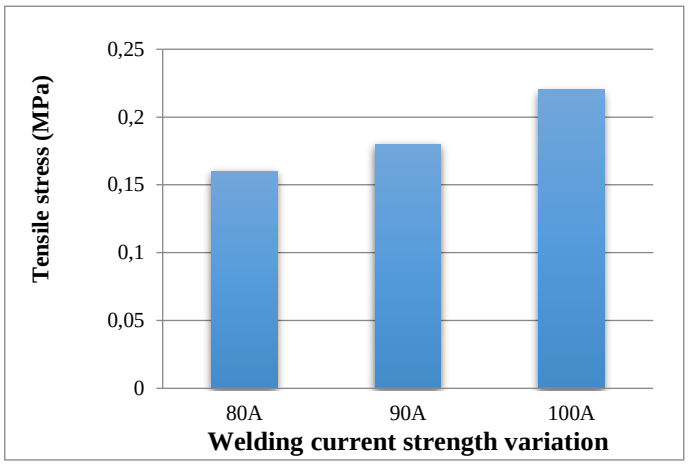


Figure 5. Graph of impact toughness-variation of current strength in cast iron welded joints.

Figure 5 shows that the average value of the impact toughness of the cast iron TIG welding metal increases with the increase in the welding electric current. The highest impact toughness value reaches 0.22 J/mm2 at the use of 100A electric current. The impact toughness of cast iron TIG-welded metal using an electric current of 80A, 90A, and 100A, are 0.16 J/mm2, 0.18 J/mm2, and 0.22 J/mm2, respectively. These results indicate that in cast iron TIG welding, the electric current is very influential on the results of the weld; in this case, it is the impact toughness. The impact happens because the current affects the heat input in the welding process, especially in the thermal cycle during heating and cooling. The heat input is also high with the high current input, resulting in a faster cooling process. Rapid cooling in the welding process will result in high tensile strength and impact toughness test results, as shown in Figure 3 and Figure 4. These results follow research in [9], [13-16], i.e., if the current strength is higher in the process of welding, the value of impact toughness is also higher on the weld metal.

4. Conclusion

Based on the results and discussion, it is concluded that the use of electric current is increasing from 80A, 90A, and 100A in the TIG welding process of cast iron with CIN 3 filler to increase the mechanical properties of the welded joint, namely tensile strength and impact toughness. The maximum tensile strength and impact toughness of cast iron TIG-welded metal at the use of an electric current of 100A, namely 181.05 MPa and 0.22 J/mm^2.

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