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The Effect of Arc Voltage and Welding Current on Mechanical and Microstructure Properties of 5083-Aluminium Alloy Joints used in Marine Applications

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Abstract

The aluminium and its alloys are widely used in marine applications such as ship hull and its components due to its lightweight and corrosion resistance. The aluminium alloys require special tool and skill to weld due to high thermal conductivity. A research vessel "RV Discovery" is currently being constructed exclusively using 5083-aluminium alloy for University Malaysia Terengganu and the welding properties were investigated. The aluminium welded joint specimens were prepared using the Metal Inert Gas (MIG) welding process by certified welders at different current and voltage settings. The mechanical characteristics of the welded alloys were carried out for tensile and hardness tests. Further, metallographic examination was conducted to identify and observe the various fusion zones. The results of these tests are presented in this paper. This study revealed that, the different welding voltage and current settings in which specimens were prepared remarkably affect the mechanical properties of 5083-aluminium alloy joints.

Keywords: 5083-Aluminium alloy, Mechanical properties, Metal Inert Gas welding

Introduction

Aluminium and its alloys are widely used in marine applications such as ship hull, its structural members and wheel house due to its lightweight and corrosion resistance. The aluminium alloys require special tool and skill to weld due to high thermal conductivity. A research vessel "RV Discovery" is currently being constructed exclusively using 5083-aluminium alloy for University Malaysia Terengganu. Aluminium is not just a single material, but a family of a variety of alloys grouped according to the alloy elements added and that provide the best combination of properties for a particular application.

The end-user requirement to use alloy in ship construction may include strength, corrosion resistance enhancement and ductility, ease of welding, formability or combinations of some of these properties. A 5xxx series contains up to 5% magnesium and widely used for engineering components, pressure vessels and transport equipment used in road, rail and shipping applications. The common alloys are 5083, 5454 and 5251. Filler materials normally match the base material and can be of types AWS ER 5356, ER 5183 and ER 5554.

Aluminium and its alloys are routinely welded and brazed in industry by a variety of methods. As expected they present their own requirements for the welded joint to be a success. Welding aluminium alloys are not more difficult or complicated than welding steel as it is just different and requires specific training. Aluminium and its alloys are easy to weld, but their welding characteristics need to be understood and the proper procedures employed. Aluminum is an excellent conductor of heat, thus it requires large heat inputs when welding starts, since much heat is lost in heating the surrounding base metal.

A variety of welding processes can be used to join aluminium, including the fusion methods GMAW (standard MIG, plasma and pulse) and GTAW (standard TIG and plasma) giving high quality, all-position welding, manual, either mechanised or fully automatic. Furthermore, resistance, MMA (metal arc, stick) and advanced processes such as solid state and friction stir welding are used. Choice of the process is based on technical and/or economic reasons. For the most structural, economic and quality welds, TIG and MIG are recommended for aluminium.

TIG welding is widely used for welding aluminium, and it produces welds of good appearance and quality. A constant current AC power source with a continuous high frequency is used with a water or air-cooled TIG torch and an externally supplied inert shielding gas. The AC process is used to provide a degree of cleaning of the aluminium surface during the electrode positive cycle though this is not a substitute for proper cleaning of the base material. The tungsten electrode diameter is usually about 2, 4 mm, and the method can be used with or without filler metal. The filler material is fed into the weld bead from outside (see Fig. 1). TIG welding gives the welder very good control, but welding speed is normally slower than for MIG which requires higher welder competence.

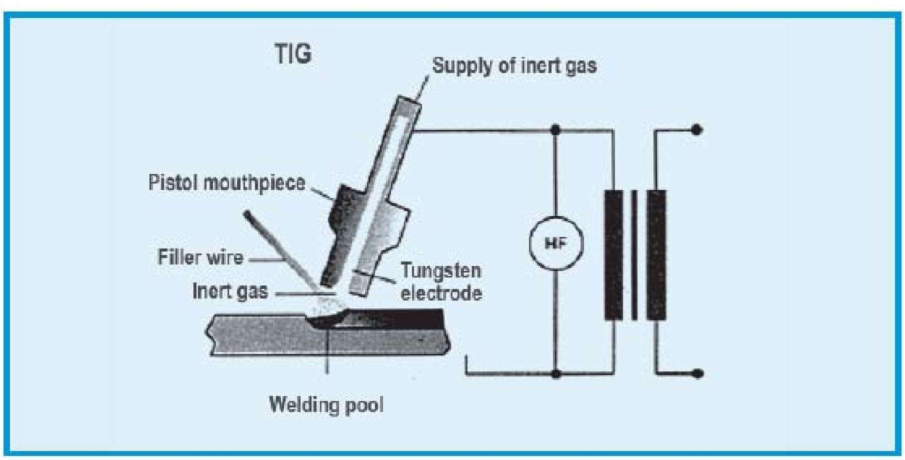


Fig. 1: TIG welding

The TIG welding process is best suited for thin gauge materials up to about 6 mm thick, but preferably only up to 4 mm for the best economy. Thicker material can be TIG welded, but this would require many more weld passes, resulting in high heat inputs, leading to distortion and reduction in mechanical properties of the base metal. High quality welds with good appearance can be achieved due to the very high degree of control available - the heat input and filler additions are controlled separately. TIG welding can be carried out in all orientations and the process is always preferred for tube and pipe work and small, thin components.

In arc welding, voltage and current are voltage of the machine which can be controlled. The length of the arc is directly related to the voltage and the amount of heat input is related to the current [1]. The variation of welding voltage and welding current can affect the strength and mechanical properties of 5083 aluminium alloy joints. Higher strength aluminum alloys are more susceptible to hot cracking in the Fusion Zone and the Partially Melted Zone and losses of strength or ductility in the Heat Affected Zone [2]. Thus, this study revealed the effect of arc welding voltage and current on mechanical and microstructure properties of 5083 wrought aluminium alloy.

Materials and Methods

Parent material

The main material used in this study was marine wrought aluminium 5083-H116 alloy. The Composition analysis as revealed by mill certificate is as shown in Table 1.

Table 1: Chemical Composition of the 5083 Aluminum Alloy (in wt %).

Typical Analysis (Ave. values %)	Mg	Mn	Fe	Si	Zn	Cr	Ti	Cu	Al
	4.5	0.7	0.4	0.4	0.25	0.15	0.15	0.1	93.0
NEAREST STANDARD	BS				ISO				
	EN AW-5083				Al Mg4.5Mn0.7				

Wrought aluminium alloy is the term used for the alloy that is suitable for shaping by a working process such as forging, rolling and extrusion. Al-Mg-Si alloy is a typical example of wrought aluminium alloy widely used for structural applications with medium strength [3].

Welding procedure

Three samples of tensile test and charpy impact test were prepared while two samples for hardness test and microstructural examination. Three plates were used for test with each plate has dimension of 300 mm x 150 mm x 8 mm. Three sets of plates were welded together with different current settings but at a constant voltage and vice versa. One set of plates was used as a standard reference sample. All specimens thickness were 8mm. Each plate was cut into 8 samples; 3 samples for tensile test and charpy impact test, 2 samples for hardness test and metallographic examination.

At constant voltage; the welding current are varied as:
Sample A: 179 A, Sample B: 185 A

Control Sample condition used by the welder for aluminium alloy with thickness 8mm:
I_1 = 182 A and V_1 = 13.5 V.

The plate edge and welding joint preparation are shown in the figure 2.

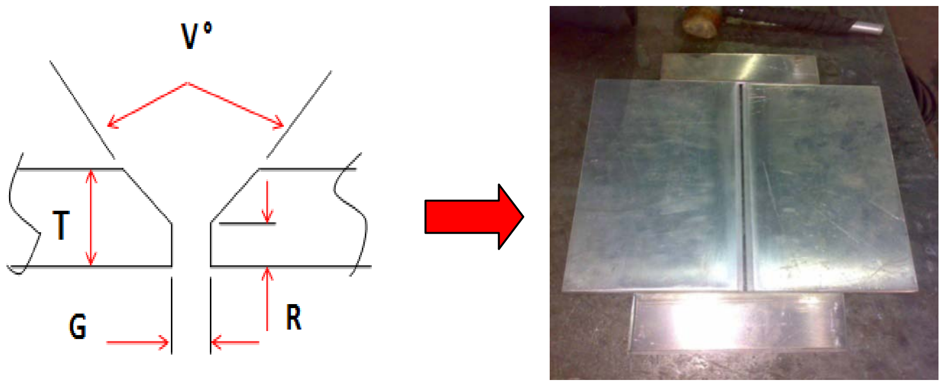


Fig. 2: Plate Edge and Welding Joint Preparation

The joint type used is Single V butt joint welding with the following particulars:

Thickness (T) = 8mm

Root Gap (G) = 3mm to 4mm

Root Face (R) = 2mm to 3mm

Bevel Angle (V) = 45 ° - 60 °

Mechanical Tests

Tensile test

The welded samples were tested for tensile strength using the Instron tensile machine. The edges of the test samples were fitted into the jaws of the testing machine and subjected to tensile stress until the sample fractured. During the test, the various stress-strain diagrams were drawn for each of the samples from where the tensile load is determined. This is used in determining the strength and stiffness of the materials.

Impact test

The impact test was carried out using the Charpy impact machine. The charpy impact test used a 10mm square bar notched in the center of one face. A standard length of 55mm ($\pm$ 0. 1mm) samples was used. The V-notch was 2 mm deep and of angle 45°. The energy absorbed in breaking the test piece is measured in joules. The ability of the material to withstand the applied load is referred to as toughness.

Hardness test

Hardness test was carried out using Rockwell and Vickers hardness testing machine. The surface was first polished, and diamond indentor was used to make a dent on the polished surface and the diameter of the dent measured.

Metallographic examination

The microstructural details of the welded and the control samples were studied. The samples were cut to small pieces using metallographic cutter and put in a furnace at about 500°C for heat treatment. The base was made by using a hydro-press mounting machine and ground with emery paper of finer grade (180, 320, 600, 800 and 1000) and polished using the 6μ, 3μ and 1μ of diamond particles. The samples were etched with chemical solution that contained 190 ml distilled water, 5ml nitric acid, 3ml hydrochloric acid and 2ml hydrofluoric acid for about 80 seconds before being observed under the microscope (20x, 50x and 200x magnification).

Results and Discussions

Effect of Varying Welding Parameter (Welding Current) on Tensile Properties of The Samples.

Figure 3 shows the ultimate tensile results. It was revealed that the samples serve as control sample has the best ultimate tensile strength of 230.87 MPa followed by the samples B with ultimate tensile strength of 215.77 MPa which more than the values obtained for sample A with ultimate tensile strength of 211.69 MPa.

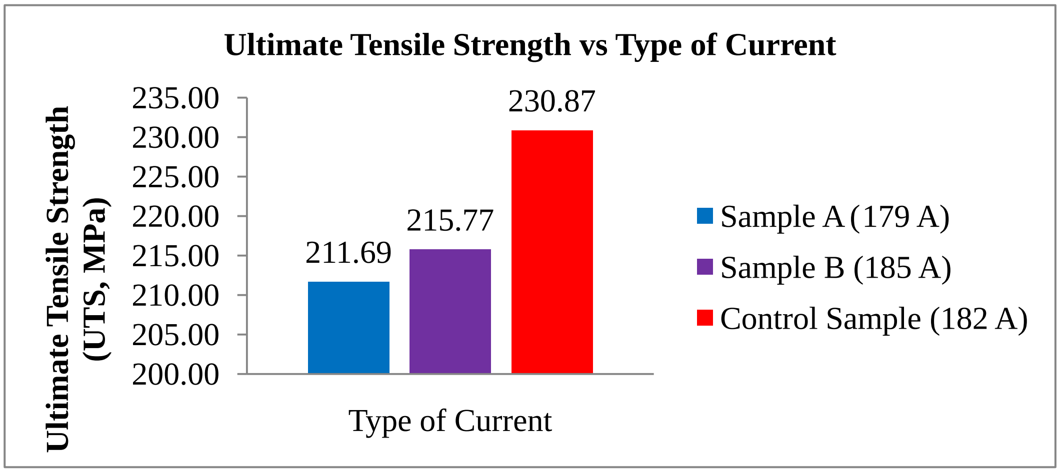


Fig. 3: Average values of the ultimate tensile strength of the samples at the various current welding conditions

The Effect of Variation of the Welding Parameter (Welding Current) on the Charpy Impact Properties of The Samples.

From Figure 4, it was observed that the impact strength of the control sample has the best value with an average value of 18.17 J while the welded sample has low impact strength with respect to the control sample. This is followed by the samples B with impact strength of 14.00 J. Sample A has the impact strength of 12.50 J. The impact energy is a measure of the toughness of the materials.

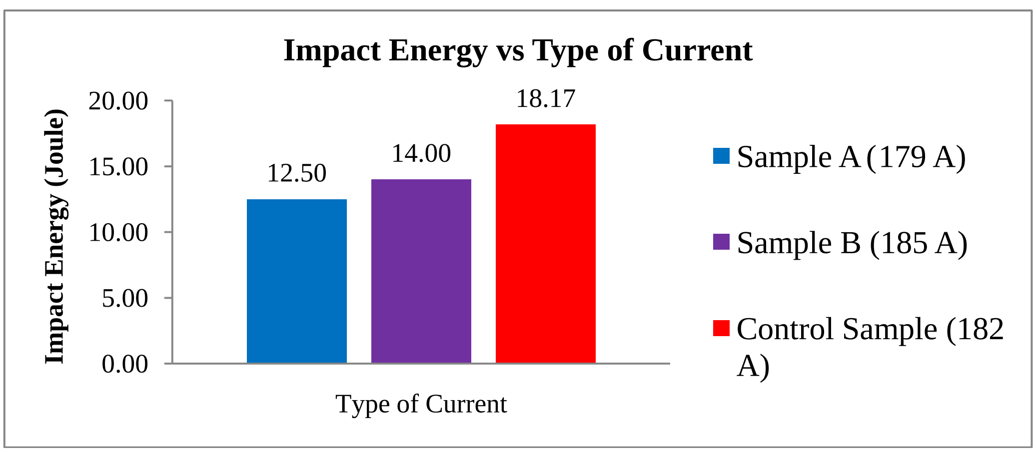


Fig. 4: Average values of the impact energy of the samples at the various current welding conditions in Joule

The Effect of Variation of the Welding Parameter (Welding Current) on Hardness Properties of The Base Metal Area Samples.

Figure 5 shows the average hardness on base metal area for Rockwell hardness test. Sample A has the highest hardness value of 78.16 Rockwell followed by Sample B with value 76.61 Rockwell and Control with value of 75.66 Rockwell. The hardness value is a measure of the resistance of a material to indentation.

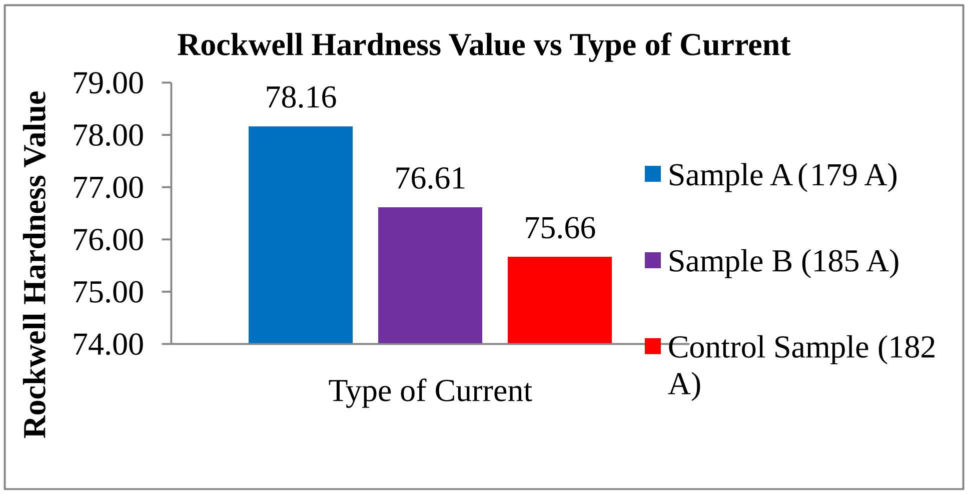


Fig. 5: Average values of base metal area of the samples for Rockwell indenter at the various current welding condition

Effect of Variation of Welding Parameter (Welding Current) on Hardness Properties of Heat Affected Zone (HAZ) Area.

Figure 6 shows the average hardness on heat affected zone (HAZ) area. Sample A has 77.50 Rockwell hardness followed by Sample B of 77.46 Rockwell whereas Control Sample has the highest value of 78.19 Rockwell for HAZ area.

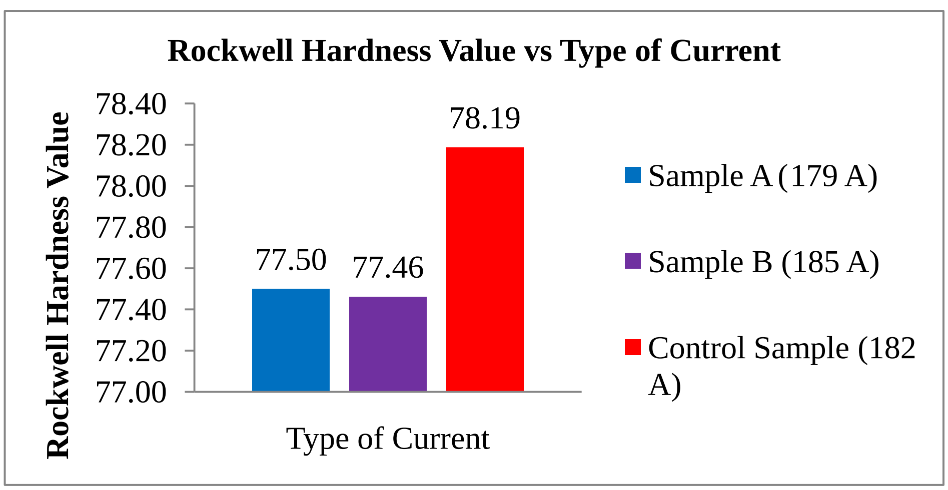


Fig. 6: Average values of heat affected zone (HAZ) area of the samples for Rockwell indenter at the various current welding conditions

The Effect of Variation of the Welding Parameter (Welding Current) on Hardness Properties of The Weld Metal Area Samples.

Figure 7 shows the average Rockwell hardness test on welded metal area. Sample A has the highest hardness value of 83.28 Rockwell followed by Sample B and Control Sample which was 79.58 and 79.66 respectively.

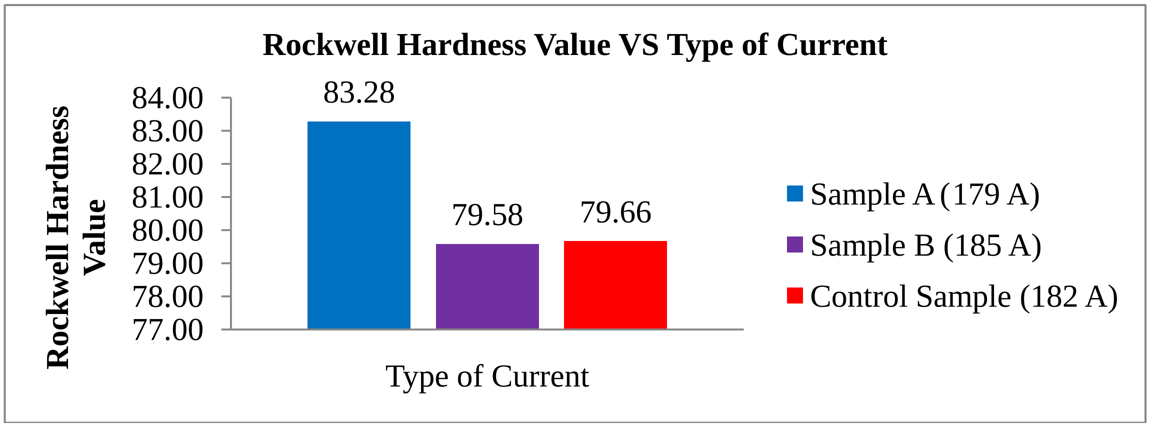


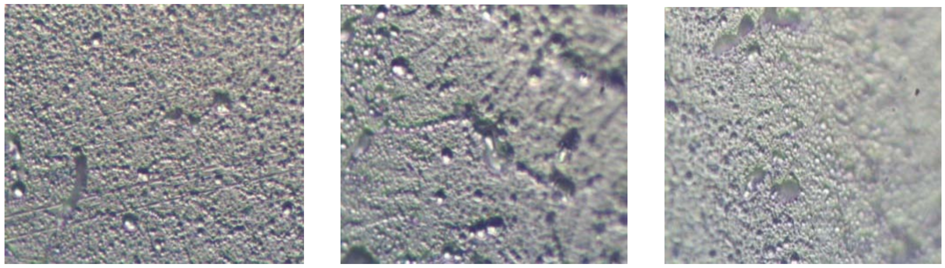
Fig. 7: Average values of weld metal area of the samples for Rockwell indenter at the various current welding conditions

The Effect of Variation of The Welding Parameters on The Microstructure of The Samples.

The micrographs show the melting reaction of secondary magnesium (Mg) particles surrounding Al's matrix. The general behavior of the different samples depends on the effect of precipitation that takes place at the microstructural level as shown in the Figure 8-10. The micrograph of welded sample A subjected to current 179A shows well diffused Mg compound in the Al matrix. These fine particles are responsible for the high hardness values and improved ultimate tensile strength and impact strength obtained.

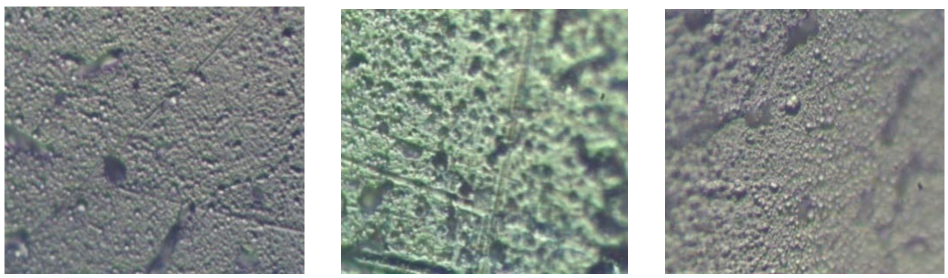
The micrographs of welded sample B subjected to current 185A shows fine grains of well diffused size compound of Mg in Al's matrix. This structure also enhanced good mechanical properties for the sample in terms of the ultimate tensile strength and impact strength.

Whereas the micrograph for Control Sample shows fine grains of well diffused Mg compound in the Al matrix. It possesses the best ultimate tensile strength and impact strength with good hardness values as shown in previous figure. These fine particles are responsible for the good mechanical properties obtained.



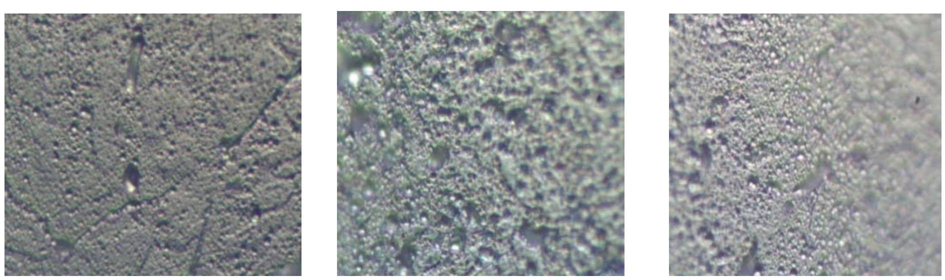
Control Sample (182A) Sample A (179A) Sample B (185A)

Fig. 8: Weld metal section (x100 magnification)



Control Sample (182A) Sample A (179A) Sample B (185A)

Fig. 9: Heat affected zone section (x100 magnification)



Control Sample (182A) Sample A (179A) Sample B (185 A)

Fig. 10: Fusion zone section (x100 magnification)

The above results shows that the 5083 aluminium alloy which serves as Control Sample had the highest ultimate tensile strength of 230.87 MPa and impact strength of 18.17 J. The hardness value competes favorably with the hardness values from the welded sample A as shown in above figure. Samples B that was welded at current, 185A was observed to have the best performance close to the Control Sample with ultimate tensile strength of 215.77 Mpa, hardness value of 77.64 Rockwell and impact strength of 14.0 J. These were followed by samples A that were welded at current 179A. It has the best hardness value of 79.13.

It was observed that increasing the welding current caused the decreasing in mechanical properties of welded metal. These phenomena can be related to metallurgical behavior of weld melt during solidification and chance of formation the defects in different conditions of welding. It related when increasing in arc voltage and welding current or reducing in welding speed increases the welding heat input. With increasing the input energy, grain size in welded microstructure increases and grain boundaries are reduced in the background. Reduction in grain boundaries as locks for movement of dislocations, increases possibility and amount of dislocation movement as line defects in structure. It will cause a reduction in strength and hardness of welded metal.

Conclusion

As a conclusion, the increasing of arc welding current in 5083 aluminium alloy will increase the welding heat input. Accordingly, the chance of defect formation such burns in welded metal also increases. This will affects on the mechanical properties and quality of welded metal badly. Besides that the high welding current also reduces the yield strength, ultimate tensile strength and toughness value of 5083 aluminium alloy welded metal.

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