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Hardness Analysis of Aluminium 5083 A-TIG Welding Due to The Effect of Active Flux and Current

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Abstract

Aluminium allow has been widely used recently due to their high strength to mass ratio, good formability and high corrosion resistance have a wide range of applications in aerospace, ship-building and railway industries. The 5083 series aluminum is the most widely used due to good strength and corrosion resistance properties. Tungsten Inert Gas Welding (TIG welding) is the most common welding method for aluminum alloys. This research was conducted A-TIG welding on 150 x 100 x 8 mm of 5083 aluminium and added by oxide powder ($MgCl_2$ and TiO_2) as active flux and various of current consist of 100, 130, and 160 A. The result of this research was obtained that the deepest penetration was 4.94 mm with TiO_2 active flux and the current of 160 A, the highest hardness came from weld metal which using $MgCl_2$ as an active flux with 100 A of current with 69.80 HVN. The hardness was increased by adding magnesium due to effect of it could be increased grain coarse. The lowest hardness was on weld metal with TiO_2 active flux with 160 A of current due to the maximum heat input which decreased the hardness The recrystallization was occurred due to increase of heat input, so did the grain growth. The coarse grain which caused the decreasing of hardness was affected by the increase of heat input.

1. Introduction

Aluminum alloys have a high strength to mass ratio, good formability, and high corrosion resistance. Widely applied in various applications such as in aviation, shipbuilding, and rail industries. With the increasing application of aluminum in various industries, the importance of joining aluminum with the same or dissimilar metal parts has increased [1][2]. Although there are many types of aluminum alloys that can be used, the 5083 series aluminum is the most widely used because it has good strength and corrosion resistance properties.

Tungsten Inert Gas Welding (TIG welding) is the most common welding method for aluminum alloys. The welded joints are of good quality and all position welding can be carried out. But the limited current carrying capacity of the tungsten electrode and the heat scattered from the electric arc results in shallow weld penetration than single-pass welding, low deposition rate and low production efficiency. So that the application of conventional TIG welding is limited. Activated Tungsten Inert Gas Welding (A-TIG welding) can increase the penetration of the weld and increase production efficiency by coating a certain activating flux. The method has advantages of high efficiency, high quality, low energy consumption, low cost, small heat input, small welding deformation and good weld formation [3].

In this mechanism, the heat density has been increased by activating the flux in the root region of the anode. As a result, the activating flux increases the depth of penetration. The second mechanism is the reversal of the surface tension gradient indicating that the active e surface elements including sulfur and oxygen which decompose from the flux during welding change the direction of fluid flow in the weld pool [4]. The use of flux in A-TIG can provide much higher production rates without compromising the high quality of conventional TIG welding. Dept of penetration is important because thicker sections can be welded in one pass reducing costs. In many A-TIG applications, savings are achieved in welding time and welding costs. The formation of low distortions during A-TIG welding is another advantage of this process for conventional TIG [5][6].

This technique was invented by the Paton Electric Welding Institute to overcome the limitations of conventional inert gas (C–TIG) tungsten welding such as: shallow penetration in one pass and low productivity. In A-TIG welding, a thin layer of active flux is applied to the joint surface, increasing the depth of penetration and depth-to-width ratio by at least two or three times compared to conventional TIG, with arc narrowing and marangoni convection reversal [7]. Aluminum welding poses a great challenge to all industries to produce joints with the least defects. The use of TIG welding for aluminum is almost critical for a perfect joint when time is a factor. This major defect can be controlled by using active flux during welding. The welding process is referred to as active gas inert tungsten welding (A-TIG). Flux plays an important role in the welding process in terms of raising the temperature in the welding zone (W-zone), removing impurities from the welding zone, etc. Metal oxides and metal chlorides are activating fluxes that primarily support the A-TIG welding process. Each activating flux affects the welding process individually, when joining dissimilar metals [8][9].

Therefore, an attempt was made to analyze the effect of single component flux namely TiO_2 and $MgCl_2$ on 8 mm thick 5083 aluminum plate by A-TIG welding with AC polarity. In addition, variations in current are also applied, respectively 100 A, 130 A, and 160 A to the depth of penetration formed. Hardness value, and microstructure that occurs after the welding process in this work.

2. Research Methods/ Materials and Methods

The material which used in this research is aluminum 5083, the chemical composition of the material can be seen in Table 1 which is data from the mill certificate. For the dimensions of the specimen used in this study, it has a size of 150×100×8 mm which is used for the A-TIG welding process.

Table 1. Chemical composition of aluminum 5083 base metal

Element	Si	Fe	Mn	Mg	Cu	Ti	Cr	Zn	Al
Wt. %	0.082	0.239	0.507	4.715	0.056	0.008	0.059	0.128	Balance

Prior to the welding process, the surface of the plate is cleaned using a steel brush to remove the oxide film attached to the surface of the aluminum material. The active fluxes used in this study are TiO_2 and $MgCl_2$ which have the same weight. The flux is mixed with liquid acetone in a ratio of 1:1 and coated on the surface of the material with a paint brush. The welding parameters used in this study can be seen in Table 2.
After the welding process, the plate is cut using a grinder for further analysis. Specimens were polished using sandpaper ranging from grade 240-5000 and then polished using a woolen cloth with the addition of metal polish to ensure a mirror-like glossy finish. Specimens were etched with HCl, HF, and H_2O solutions of each ratio (15:10:85 ml) to display the geometry of the weld bead on macro and microstructure on an optical microscope. Hardness testing was carried out on each part of base metal, HAZ, and weld metal using a load of 1 kgf and a dwell time of 15 seconds using a Vickers microhardness tester machine.

Table 2. Parameters of the welding process

Code	*Active flux*	*Current* (A)	*Time* (min)	*Travel speed* (mm/min)	*Heat input* (J/mm)
A	TiO_2	100	0.57	263.16	167.81
B	TiO_2	130	0.52	288.46	199.01
C	TiO_2	160	0.48	312.50	226.10
D	$MgCl_2$	100	0.56	267.86	164.86
E	$MgCl_2$	130	0.49	306.12	187.53
F	$MgCl_2$	160	0.47	319.15	221.39

3. Results and Discussion.

The dept of penetration in A-TIG welding, each variation of active flux and current strength can be seen in Fig. 1. Welding A-TIG aluminum 5083 with a single pass produces a deeper penetration as the current strength increases which causes the heat input value to also increase. increase. As shown in (Fig. 1(a, b, and c)), namely the type of active flux TiO_2, the depth of penetration was increases as the increase of current, with depth of penetration of 4.61 mm, 4.87 mm, and 4.94 mm respectively. However, the width of the weld is inversely proportional to the current. Meanwhile, the use of active flux $MgCl_2$ with increasing variations in current makes the depth of penetration and width of the weld were increase. This is explained in (Fig. 1 (d, e, and f)) with the respective of depth values of 2.98 mm, 3.31 mm and 4.25 mm. The comparison of the depth of penetration and width of the weld with a value of 0.46 with the use of active flux TiO_2 and a current of 160A has the highest value compared to the other variations (Fig. 2).

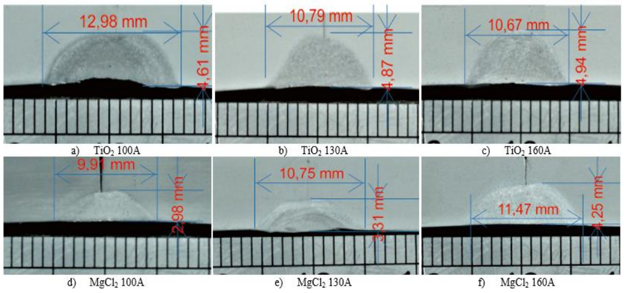

Fig. 1. Macro photo showing the depth of penetration of the weld formed (a) TiO_2 100A, (b) TiO_2 130A, (c) TiO_2 160A, (d) $MgCl_2$ 100A, (e) $MgCl_2$ 130A and (f) $MgCl_2$ 160A

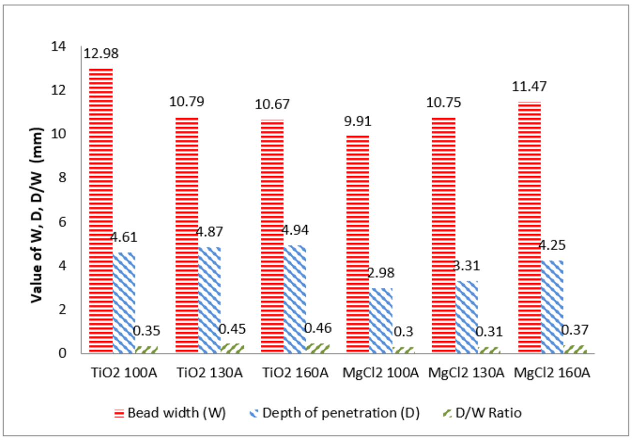

Fig. 2. Variation of depth of penetration, weld width, depth and width ratio with differences in active flux and current

When TiO_2 flux is used, the surface tension in the middle of the weld pool becomes higher than near the edge. This results in a larger increase of the depth and a relatively lower increase in width. This is caused by the Marangoni effect, which states that the surface tension at high temperature is lower than at low temperature. When TiO_2 is applied to the metal, the reversal of the Marangoni effect occurs because free oxygen is available in the weld pool due to the decomposition of TiO_2. This causes more surface tension in the weld pool than near the edge [10]. The depth of penetration has different values with different active fluxes. The both halides and oxides can increase weld penetration, among which TiO_2 is the most significant [3].

Based on the results of microstructural observations in Fig. 3 on the aluminum 5083 base metal area, this area did not experience much change due to A-TIG welding. A-TIG welding with active flux TiO_2 and $MgCl_2$ did not cause much change in the microstructure in the base metal region, variations in current of 100 A, 130 A, and 160 A also did not significantly affect the microstructure of the base metal. By observing the microstructure, the phases Mg_2Si, $Al_{18}Mg_3Cr_2$ were obtained, and Al_6Mn. The Mg2Si phase is shown in blue-black which is scattered between the aluminum forming phases. The phase that forms most of the 5083 aluminum that has a spreading location is $Al_{18}Mg_3Cr_2$ which is shown in grayish white. The next forming phase is Al_6Mn which is shown as granules with an elongated shape, gray in color and has a border [11].

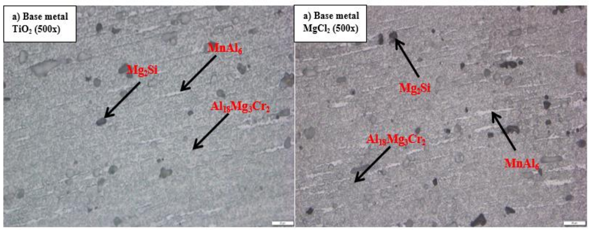

Fig. 3. Microstructure of aluminum 5083 base metal at 500x magnification (a) TiO_2 and (b) $MgCl_2$

In Fig. 4 below, the heat input has an important role in widening the HAZ region and grain size, when the heat input increases it can widen the HAZ region and the grain size also becomes coarser, this can ultimately reduce the hardness in that area. [9]. From the observation of the microstructure, the parent metal previously had a fine microstructure, the presence of small grains that spread and the composition of the aluminum 5083 $Al_{18}Mg_3Cr_2$ and Al6Mn compounds which were marked with bright colors were seen dominating that part of the area. Furthermore, the differences begin to be seen clearly in the microstructure images of the HAZ section which has a rougher shape than the previous area, namely the parent metal [11]. Where in both the active flux TiO_2 and active flux MgCl2 microstructures, the Mg_2Si particles are getting bigger along with the increase in current strength which can reduce the strength of the material.

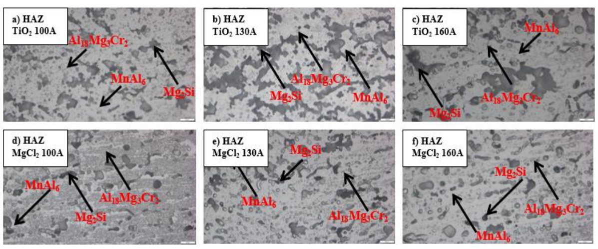

Fig. 4. Microstructure in the HAZ (Heat Affected Zone) region of aluminum 5083 with 500x magnification (a) HAZ TiO_2 100A, (b) HAZ TiO_2 130A, (c) HAZ TiO_2 160A, (d) HAZ $MgCl_2$ 100A, (e) HAZ $MgCl_2$ 130A, and (b) HAZ $MgCl_2$ 160A

Based on the results of microstructural observations in Fig. 5 in the weld metal area, A-TIG aluminum welding in the weld metal area underwent significant changes, the area experienced the phenomenon of strain hardening which was lost due to the welding process due to recrystallization in the fusion zone accompanied by grain growth and the difference in heat input also affects grain growth where the greater the heat input, the grain growth is also coarser which can reduce the hardness value [12].

From the picture of the weld metal structure, there is a larger and more grain size growth compared to the HAZ area, where the increase in current strength also affects the shape of the grains which are also getting bigger and bigger. In the active flux TiO_2 microstructure, it could be seen that the Mg_2Si particles are getting bigger and there is not much difference between the variations in the current strength. Meanwhile, for the active flux MgCl2 there is a Mg_2Si compound which is finer than the active flux TiO_2 and there is an increase in the size of the grain boundaries as the current strength increases. In the weld area, it could be seen that many grains are evenly marked with Mg_2Si compounds and experience thickening but are still dominated by the light phase forming aluminum 5083, namely $Al_{18}Mg_3Cr_2$ compounds, and Al_6Mn [11].

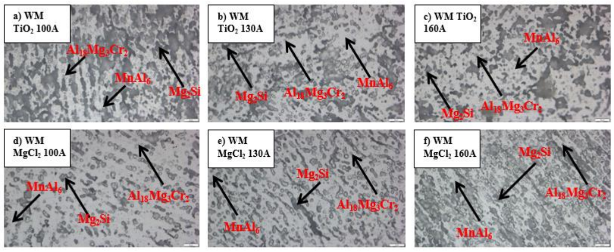

Fig. 5. Microstructure of WM (Weld Metal) aluminum 5083 with 500x magnification (a) WM TiO_2 100A, (b) WM TiO_2 130A, (c) WM TiO_2 160A, (d) WM $MgCl_2$ 100A, (e) WM $MgCl_2$ 130A, and (b) WM $MgCl_2$ 160A

This hardness test uses the vickers method using a microhardness machine with the specification "Load Cell Type Multi-Vickers Hardness Tester FLC-50-VX", where hardness testing is carried out on the base metal, weld metal, and HAZ areas. The following is Table 3 which contains the hardness values in each section. If seen from the results of the hardness value on HAZ Aluminum 5083 in Fig. 6 below, there is a decrease in the hardness value for each current strength. The hardness value of HAZ aluminum 5083 active with TiO2 flux is lower than the HAZ hardness value of aluminum 5083 active with MgCl2 flux. The current strength has an impact on changes in the hardness value in the HAZ area because in this area the material is affected by heat during the welding process and the highest hardness value after the base metal occurs in the HAZ area because this area is the boundary between the weld metal and the base metal so that on one side the fusion line receives high heat input from the weld metal and on the other hand receives cooling from the base metal so that the cooling rate is faster than the weld metal so that it has a higher hardness value than the weld metal area.

This is also in accordance with the explanation that the decrease in hardness is directly proportional to the increase in current due to changes in heat input as well, thus changing the microstructure. As a result, the grain size becomes coarser in the HAZ region than in the base metal region and decreases there due to changes in heat input [13].

Table 3. The hardness values of the various types of active flux against current.

No	Active Flux	Current (A)	Hardness (HVN)		
			BM	HAZ	WM
1	TiO_2	100	77.83	73.19	58.06
2		130	76.64	71.88	57.48
4		160	75.30	70.62	57.30
4	$MgCl_2$	100	78.19	74.02	69.80
5		130	77.53	71.91	68.78
6		160	76.06	71.63	61.35

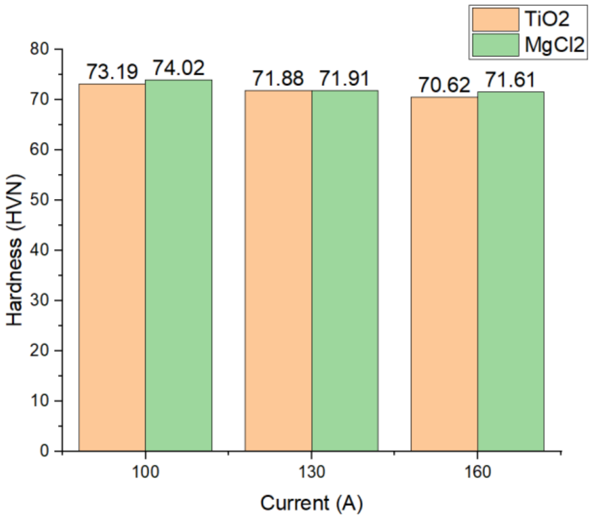

Fig. 6. Hardness of the HAZ of 5083 aluminum A-TIG welding

Fig. 7 shown there is a decrease in the hardness value for each current. The hardness value of the active flux $MgCl_2$ weld metal is higher than the hardness value of the active TiO2 flux weld metal. This is related to the use of active flux on the surface of the area to be welded, the use of active flux MgCl2 containing the element Mg where the addition of this element to aluminum can increase strength through solid solution strengthening and improve strain hardening capabilities, while the use of active flux TiO2 contains elements of titanium which can smoothing the weld structure and helps prevent cracks in the weld area, so the hardness value of active flux MgCl2 is higher than active flux TiO_2 in the weld area [14]. The decrease in the hardness value is quite low in the weld metal area because the aluminum material itself is a non-heat treatable type and has undergone a strain hardening (cold working) process [15], so that if this material is heated it will change the shape of the microstructure into coarser grains. which can reduce the hardness value.

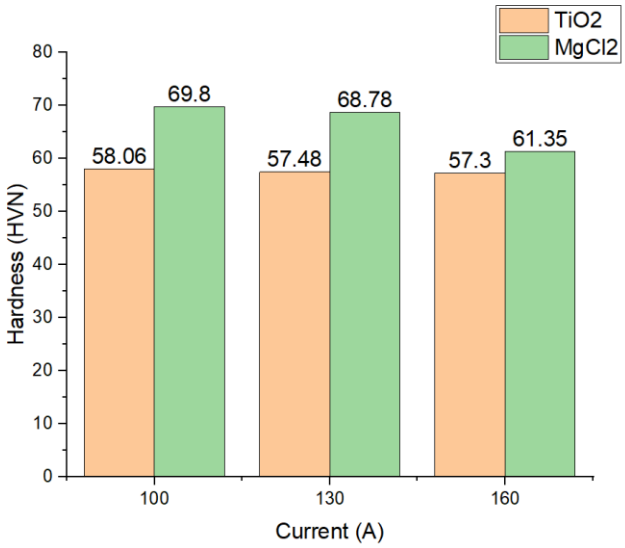

Fig. 7. Hardness of the weld metal area of A-TIG aluminum 5083 welding

4. Conclusions.

The A-TIG welding of aluminum 5083 in this research was carried out by 8 mm-thick plate. The TiO_2 active flux with current of 160 A from A-TIG single pass welding obtained the deepest penetration. The welding zone of A-TIG welding shown Mg_2Si was bigger due to the increase of heat input, in the other hand, the microstructure still dominated by 5083 aluminium forming of $Al_{18}Mg_3Cr_2$ and Al_6Mn. Those elements had obtained the coarse grain which could decrease the strength of material. The hardness test had shown that the decrease of the hardness on the HAZ and weld metal due to the 5083 aluminium has occurred the strain hardening or cold working.

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