THE EFFECT OF ALLOYS ON WELD BEAD GEOMETRY OF ALUMINUM BY TIG WELDING

Sujiyo

ABSTRACT

The basic aim of this work is to investigate the influence of the composition of the aluminum alloys on the arc voltage. The chemical composition of aluminum alloys really affects the thermal conductivity of the aluminum alloys. Consequently, the thermal conductivity of the aluminum alloys can be used to represent the chemical composition. Besides that, investigation on the effect of the base metal on the dimension of weld bead is reported. In addition, this paper provides basic principles and related process of TIG welding as well as its application for aluminum alloys.

Keywords: tungsten inert-gas welding, aluminum alloys.

INTRODUCTION

The tungsten inert-gas (TIG) welding is the technical term that is commonly used in most of Europe and recommended by the International Welding Institute. In Germany, wolfram inert-gas (WIG) is more usual for the same process, meanwhile gas tungsten arc welding (GTAW) is used in United States and some other countries. Actually, all of these terms is related to the same welding process and still referred to the original trade names hefaric or argon arc welding (Norrish, 1992).

The tungsten inert-gas welding has been used in various fields, such as in the aerospace, nuclear reprocessing, power generation industries, chemical process plant, food processing and brewing equipment. A wide range of engineering materials that have been joined by this process, such as stainless steel, titanium alloy and aluminum alloy. In recent decade, the applications of the tungsten inert-gas welding for joining aluminum increase significantly. The increase is caused by the fact that the material is used in widespread application and offers a combination of low weight, high strength, good corrosion resistance, formability, and weldability.

The TIG welding has advantages for welding of aluminum alloys. The welding process can be used for joining of the thickness from 0.25 to 150 mm and can be used in all weld position. Excellent penetration and welds can be achieved by using this process. What is more, there are many parameters that can be controlled to achieve the optimum results (David, 1996). Besides that, it only introduces heat to the part being welded, so the risks of inclusion, lack of fusion, and lack of penetration can be reduced (Cornu, 1988).

Some welders considered that the aluminum alloys are too difficult to be welded. The opinion is based on the fact that several problems occur in the welding of aluminum. The problems commonly are related to the physical and chemical properties of the aluminum. For this reason, good understanding in the properties of aluminum will reduce or overcome the problem in the welding of aluminum. Extensive researches prove that aluminum alloys can be welded to get high quality result by proper understanding of their properties.

TIG WELDING AND RELATED PROCESS

It is accepted that the best weld is one that has the closest properties to those of the base metal. Actually this rule is difficult to be fulfilled because there are physical and chemical processes involved during the welding process. The understanding of physical and chemical processes is very important to optimize the process and the results of the welding. Besides that, it also becomes the foundation for the development of the welding technology.

The tungsten inert-gas welding is commonly classified as fusion welding. In the welding process, the heat is generated by an arc, which is maintained between the workpiece and a non-consumable tungsten electrode. The heat generated in the process occur when there are electron flow from the cathode to the anode. Because of the electron flow, the heat is generated in the arc between the tungsten electrode and the workpiece. The tungsten electrode can be the cathode and the workpiece becomes the anode or on the contrary. The cathode and anode position is determined by power supplies used in the welding process. The heat generated by the arc column is shielded by inert-gas from atmospheric contamination. The schematic equipment of the TIG welding is shown in Figure 1.

1 Sujiyo, ST., Department of Mechanical Engineering Gadjah Mada University
In the tungsten inert-gas welding, it is known three basic power supplies. They are direct current straight polarity (DCSP), direct current reverse polarity (DCRP), and alternating current (AC). The direct current straight polarity is also known as positive polarity and the direct current reverse polarity is known as negative polarity.

Tungsten inert-gas welding, as the term indicates, the tungsten metal is used as an unconsumable electrode. The specific property of the metal is the melting point that is extremely high, about 3380 °C for pure tungsten. In general, there are four types of the tungsten electrode now, namely: pure tungsten, tungsten alloyed with 1-2% of thorium oxide, tungsten alloyed with 0.3-0.5% of zirconium, and the composite tungsten electrode with strips of tungsten with thorium attached. The tip shapes of the electrode are important in arc stability and weld penetration. Hemispherical shape and conical shape are used for alternating current and direct current respectively. The hemispherical shape is formed from a flat cylindrical electrode that slightly melts, and over current density is indicated by the formation of a droplet shape. For the conical shape, the smaller the cone angle will result in the deeper the penetration.

Shielding gas play a vital role in TIG welding. The main functions of the shielding gases are in the three important. The first is to provide a suitable medium for stable operation of a sustained low-voltage arc. The second is to provide shielding of the tungsten electrode, the arc, and the weld pool from the atmospheric contamination. Tungsten electrode should be protected from the oxidation, and for this reason it is usually used argon or helium gas. The protection of the weld pool is actually to diminish or to reduce the formation of porosity, inclusions, surface oxidation, and embrittlement that are caused by the adverse gas-metal reaction. The third function of the shielding gas is to control the weld bead geometry and mechanical properties. There are specific gasses or mixture of two gases in specific amount, which is obviously influenced the bead profile and fusion characteristic in welding, for example a "wired glass" penetration profile can be achieved by pure argon and a more modified profile can be achieved by mixture of argon and helium (Blisnet, 1991). In addition the shielding gasses that are usually used in TIG welding are argon, helium, mixture of argon and hydrogen, argon and helium. High quality welds can be obtained by used TIG welding process if the welding parameters that influence the quality are identified and controlled. The primary control parameters are current and travel speed, while the secondary control parameters are arc length, polarity, shielding gas and filler addition, and electrode angle. The control parameters are the common objects in conventional TIG welding, while for advanced TIG welding system there are other parameters that should be controlled.

The current and travel speed are the most important parameter in TIG welding, because the combination of both determines the penetration and the fusion characteristics for a fixed set of secondary parameters. Variation of travel speed and current is usually set to get the optimal results. The variation of both is limited by a discontinuous bead, undercut or bumping for too high current, and by lack of fusion for too low current. The relation of the current and welding speed are described in the equation as follows:

\[ q = \eta \frac{V}{I} \]

Where \( q \) is the heat applied per unit length of weld bead, \( \eta \) is the efficiency in %, \( V \) is voltage, \( I \) is current and \( V \) is the welding speed. From the equation it can be inferred that to find constant heat, the increase of welding speed must be balanced by the increase of the current for a given voltage and efficiency. The efficiency of the welding provides the measure of the heat used in welding. This efficiency is based on the fact that only a part thermal energy generated by the arc is actually used to melt the joint edges and filler metal, the remainder is lost by radiation and convection.

The heat generated by the arc is conducted to the base metal which then the base metals melt. Obviously the properties of the base metals to conduct
the heat is the important parameter. The conductivity of the base metals will influence the geometry of the weld bead (area, width and depth as shown in Figure 2).

Fig. 2. Weld bead geometry

Theoretically, the relation of thermal energy generated by the arc is stated in the form of the heat flow equation:

\[ \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 2k \frac{\partial T}{\partial (x-vt)} \]

In the equation, it is assumed that the arc moves along the x-coordinate and the resulting heat is distributed in a three-dimensional solid plate. The parameter x, y, and z are defined in Figure 3, t and v is time and the welding speed respectively.

Fig. 3. Coordinates x, y, z in welding

Solution of the equation gives the temperature distribution about the moving heat source in the form of isotherm in the solid metals. The distance between the isotherm in a given direction (x, y, z) are approximately given by:

\[ r_{is,t,z} \approx \frac{q}{k v} \]

The solution indicates that the width, depth, and area of the weld bead as function of thermal conductivity k, (Poster, 1995).

The control of the secondary parameters is done to support the primary parameters. The arc length is set to be the same as the separation distance between the electrode tip and the workpiece. The variation of this length influences the arc voltage and the efficiency caused by radiation losses. The shielding gas influences the thermal characteristic of the arc and fusion. The proper control and choice of the gas can increase the travel speed of the welding. The control of polarity is usually done in relation with the penetration and cleaning action. The setting of the polarity should be chosen so that the high speed welding and optimal result can be obtained (Norrish, 1992).

ALUMINUM PROPERTIES

The important properties that should be well understood in relation with the welding of aluminum are: the oxide characteristics, the solubility of hydrogen in molten aluminum, thermal characteristics, magnetic characteristics, the lack of color change when heated, and the heat treatable and non heat treatable of the aluminum.

Aluminum is an active metal, which has a strong chemical affinity for oxygen. Due to the strong affinity, it will oxidize immediately upon exposure to air. The formation of the oxide contributes to the high corrosion resistance, nevertheless, gives rise to welding problems. The problems are caused by the fact that the aluminum oxide melts at about 2050° C (3720° F), while the melting point of the aluminum is only about 650°-1000° C. The difference in the melting point will result in incomplete fusion if the oxide is not removed prior welding. Besides that the aluminum oxide is an electrical insulator, which prevents arc initiation. Accordingly, the oxide removal is not only required in the weld joint but also at the location of the ground connection (Cornu, 1988).

The solubility of hydrogen is relatively high in molten aluminum, on other hand the hydrogen almost has no solubility in solid aluminum. The solubility is considered as the main cause of the porosity in the
The thermal conductivity of aluminum alloys is high, so that more heat must be put into the materials to melt. Sometimes, preheat is needed for welding of thick sections. Apart from this, the high thermal conductivity is also helpful in the solidification process that is very fast. Another thermal property of aluminum alloys is thermal expansion that is relatively high. This property causes the decrease of aluminum weld at about 6% in volume when solidifying from the molten state. The shrinkage may cause distortion and cracking (Howard, 1989).

The absence of color change as temperature approaches the melting point is another feature of aluminum alloys. The property becomes problem in controlling the degree of melting as the weld progress. If the degree of the melting is uncontrolled, lack of fusion or undercut will occur in the welding of aluminum alloys (Howard, 1989).

Aluminum alloys are classified in heat-treatable alloys and non-heat-treatable alloys. The first alloys acquire their strength by precipitation hardening and enhancement by cold working. The alloys commonly contain copper, magnesium, zinc, silicon, or combination of the elements. The 2xxx, 6xxx, 7xxx series are classified as the heat-treatable aluminum alloys. The non heat-treatable aluminum alloys acquire their strength from solution alloying element, by strain hardening and cold rolling. These alloys consist of three groups: pure aluminum, alloys with low manganese content, and alloys containing magnesium. The 1xxx, 3xxx, and 5xxx series are considered as the non heat-treatable aluminum alloys (Corru, 1988).

**EXPERIMENT**

In this experiment, five aluminum alloys of 100 mm width, 250 mm length, and 3 mm thick were welded by tungsten inert-gas welding. The materials were AA7020, AA1050, AA5083, AA5754, and AA6082. The materials represent a different thermal conductivity. The shielding gas used was argon that its flow rate was 12 liter per minute. A 3.2-mm diameter of tungsten electrode was used and the distance of the electrode and the base metal was 3 mm. Alternating current (AC) of 50% balance was used. During the investigation, the current was constant at 144 Ampere while the variation of voltage was measured. The cross section area, width, and depth of the weld pool were measured by optical microscope enhanced by quantametry after particular preparation was done. The preparation consists of cutting, grinding, polishing, and etching of the materials. The parameters measured in this investigation were plotted in graphs to get relationship between the thermal conductivity and the parameters.

**RESULTS AND DISCUSSION**

The parameters measured in this experiment are plotted in graphs that are shown in Figure 4, 5, 6 and 7. Chemical compositions of the materials (in % weight) that are analyzed by using X-ray fluorescence spectrometry (XRF) are shown in Table 1.

| Table 1. Chemical compositions of the materials. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | AA5083          | AA5754          | AA7020          | AA6082          | AA1050          |
|                | 117             | 125             | 149             | 149             | 231             |
| Cr              | 0.10            | <0.01           | 0.17            | 0.01            | <0.01           |
| Cu              | 0.03            | 0.02            | 0.35            | 0.05            | 0.04            |
| Fe              | 0.33            | 0.28            | 5.27            | 3.88            | 0.47            |
| Mg              | 4.08            | 3.09            | 1.19            | 0.92            | 0.05            |
| Mn              | 3.59            | 0.26            | 0.18            | 0.62            | 0.06            |
| Ni              | <0.01           | <0.01           | <0.01           | <0.01           | 0.01            |
| Pb              | <0.01           | <0.01           | 0.01            | 0.01            | 0.02            |
| Si              | 0.11            | 0.17            | 0.12            | 0.86            | 0.79            |
| Sx              | <0.01           | <0.01           | <0.01           | <0.01           | <0.01           |
| Ti              | 0.02            | 0.02            | 0.06            | 0.02            | 0.02            |
| Zn              | 0.04            | <0.01           | 0.52            | 0.01            | 0.14            |

**Figure 4.** Welding voltage as a function of thermal conductivity.
Figure 4 is a graph about the relation between the thermal conductivity and the voltage. From the figure, it can be inferred that the increase of the thermal conductivity will cause the considerably increase of the voltage and it also can be stated that the chemical composition of the aluminum alloys has an effect on the arc voltage. The probable reason is that the increase of the thermal conductivity is related to the increase of heat input, while the heat input is proportional to the voltage, efficiency and current, besides conversely proportional to speed welding. Because the current and the welding speed is set constant and the efficiency is also assumed constant, so the voltage will be changed. Apart from those, the data of AA7020 is questionable. Its voltage is very low in comparison with the other data. Evaluation on the chemical composition of AA7020 shows that this material contains 4.82% of zinc and 1.19% magnesium, beside other component which the amount is lower than both component. The high content of zinc is suspected the most probable cause for this anomalous data.

![Graph showing depth of weld bead as a function of thermal conductivity.](image)

**Figure 5.** Depth of weld bead as a function of thermal conductivity.

Figure 5 represents the relationship between the thermal conductivity and the depth of the weld pool. The figure shows that the depth tends to decrease with the increase of the thermal conductivity. The relation between the depth of weld bead and thermal conductivity is not linear as predicted by mathematical model. This fact is caused by the influence of temperature on the thermal conductivity, in other word the thermal conductivity is not constant with temperature. Under those circumstances, it can be inferred that to obtain a certain penetration the welding current should be increased if the thermal conductivity increases. The results for the relation between thermal conductivity and the width and the area of weld pool are showed in Figure 6 and 7. The trend of the results is considerably similar to the relation between thermal conductivity and the cross section area of weld pool.

![Graph showing width of weld bead as a function of thermal conductivity.](image)

**Figure 6.** Width of weld bead as a function of thermal conductivity.

![Graph showing area of weld bead as a function of thermal conductivity.](image)

**Figure 7.** Area of weld bead as a function of thermal conductivity.

Based on the results of this experiment, it is found that there are particular relation between the thermal conductivity and welding voltage as well as thermal conductivity and weld bead dimension. These findings are very useful to determine parameter in the welding of aluminum alloys. It is also proved that thermal conductivity of the aluminum alloys can be used to determine the parameter in welding.
addition, there are correlation between mathematical model and the experiment results. However the anomalous data of the experiment results occur which is needed further investigation, particularly the effect of specific chemical content on the voltage and the dimension of weld bead. Besides that, the further experiment on the effect of particular alloys is needed to get more precise data of welding parameter on aluminum alloys.

CONCLUSION

It can be concluded that the chemical composition of the aluminum alloys has an effect on the arc voltage, besides that it also has influence on the cross section area, depth and width of the weld pool. It has been showed that the chemical composition of the aluminum alloys can be represented by the thermal conductivity of the aluminum alloys to determine the welding parameter. Further investigation is needed to get more precise effect of particular alloys on welding parameters.

REFERENCES


Coman, Jean, Fundamentals of Fusion Welding Technology. IFS Ltd/Springer-Verlag, UK. 1988

Coman, Jean, TIG and Related Process. IFS Ltd/Springer-Verlag, UK. 1988


