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The effect of welding current on the mechanical properties of aluminium to copper material using Tungsten Innert Gas welding technology

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Abstract

Welding copper and aluminium is a major challenge due to the differences in physical and metallurgical properties of the two materials. Copper has a much higher melting point than aluminium, making it difficult to achieve uniform fusion without overheating. In addition, copper's very high thermal conductivity causes rapid heat transfer, making it difficult to maintain optimal temperatures during welding. The purpose of this study was to determine the effect of TIG welding current on the shear test value and hardness of aluminium-copper material. The stages of the research method began with welding variations in welding current and filler rod types. Furthermore, shear and hardness tests were carried out. Based on the results of the hardness test, the hardness value of the welded material was higher than the parent material. The hardness value of the weld metal was higher at a current of 130A compared to currents of 120A and 140A. While the optimal welding current for copper and aluminium joints in shear test testing using BCuP-2 filler rods is 130 A, where the highest shear strength is achieved.

1. Introduction

Heat pipe (HP) is a thermal device used to transfer heat from one location to another very efficiently[1]. Currently, HP is widely used in various industries as a cooling system because it is effective and energy efficient. One of them is the nuclear industry in Indonesia which is currently managed by the Nuclear Reactor Technology Research Center - National Innovation Research Agency (BRIN), where this reactor will be prepared to be part of the Nuclear Power Plant (PLTN) by utilizing the desalination process.

In addition, HP will also be used as a passive cooling system when the active cooling system does not work optimally in the reactor to prevent accidents such as those that occurred at the Fukushima Dai-ichi Nuclear Power Plant [2][3][4].

The construction of HP consists of an Evaporator, Adiabatic Process, and Condenser as shown in Fig. I.1[1]. All of these parts are usually made from one type of material that has a high thermal conductivity (k) value such as copper [2][3]. Copper has a relatively expensive price. To reduce the high costs, a cheaper HP is needed, namely an HP with a combination of 2 materials, namely aluminium and copper.

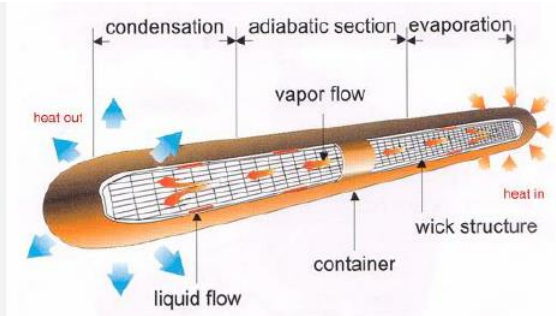

Fig. 1. Part of the Heat Pipe.

Previously, several previous research results have been conducted to analyze the relationship and novelty of research related to HP products[5-11]. The construction of the heat pipe is carried out by the process of connecting parts using welding, so that the type of welding process and current are required that are appropriate to the type of material. The materials used are copper and aluminium.

The problem of the research is the use of inappropriate welding process parameters for dissimilar aluminium and copper materials which can cause the welding quality characteristics to be less than optimal. In addition, when welding different materials, intermetallic compounds (IMC) are often formed which can cause the welding results to experience brittle fracture. Copper has a much higher melting point (1085°C) than aluminium (660°C). This makes it difficult to control the temperature during welding so that the two metals can melt and unite properly without damaging one of the materials. When copper and aluminium are heated together, the materials can form hard and brittle intermetallic alloys, such as $CuAl_2$. These alloys tend to have poor mechanical properties and can reduce the strength of the weld joint.

Copper and aluminium have different coefficients of thermal expansion, meaning they expand and contract at different rates when heated and cooled. This can cause distortion, cracks, or internal stresses in the weld joint. Welding two metals that differ greatly in thermal and electrical properties can cause the arc to become unstable, resulting in poor heat control and poor joint quality. Based on this, the formulation of the problem in this study is how the welding current and filler rod or filler metal affect the hardness of dissimilar aluminium-copper materials. The purpose of this study is to examine the characteristics of welding quality on aluminium-copper materials with variations in welding current and filler rod using the Tungsten Inert Gas (TIG) welding process. So that the welding current and type of filler rod are obtained that are suitable for joining dissimilar aluminium and copper materials.

2. Research Methods

Materials used in this research are aluminium type 6061 and copper as shown in Fig. 2.

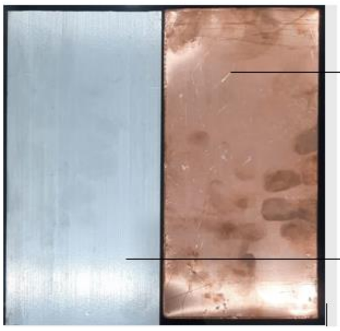

Fig. 2. Aluminium and copper materials

The research method begins with the preparation of materials, namely copper and aluminium. Where both materials are made with a 300 slope. The type of cleavage used is a single V. In the second method, a lap joint type is used where the copper material is placed on top of the aluminium material with a ratio of the copper size larger than the aluminium size. The setting and welding process are shown in Fig. 3. The welding process is carried out by a certified welder. The second material is clamped using a clamp to facilitate welding so that the material does not shift when welded and prevents distortion due to heat received by the material.

Fig. 3. TIG welding settings and process

Next, NDT testing is in the form of a visual test. If a defect is found in the welding results, re-welding will be carried out. Then continued with the manufacture of tensile shear test specimens. Mechanical property testing consists of tensile testing and hardness testing as in Fig. 4.

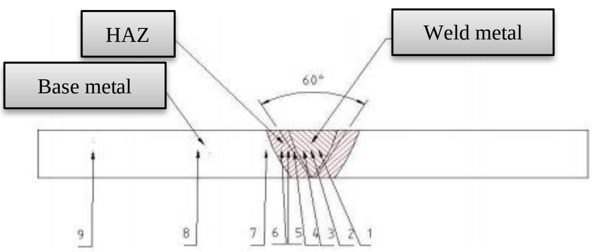

Fig. 4. Location of hardness test

The purpose of the shear test is to evaluate the strength of the welded joint against shear force. This test is carried out to determine how much shear force the joint can withstand before it fails. With the results of this test, the strength of the joint against the load that causes shifting between the welded materials can be known. In addition, the shear test is also used to assess the quality of the welded joint, including the adhesion and cohesion strength between materials in the weld area. Low-quality joints will be more susceptible to failure under shear loads.

3. Results and Discussion

Based on the welding results using the TIG welding process with current variations of 120A, 130A and 140A, the welding results were obtained with lap joints or overlapping type joints as in Fig. 5.

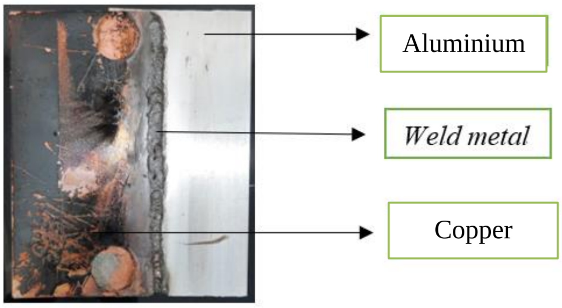

Fig. 5. Welding results

Welding copper with aluminium using TIG (Tungsten Inert Gas) welding faces several complex problems such as copper has a much higher melting point (1085°C) than aluminium (660°C). This makes it difficult to control the temperature during welding so that the two metals can melt and unite properly without damaging either of them. When copper and aluminium are heated together, they can form hard and brittle intermetallic alloys, such as $CuAl_2$. These alloys tend to have poor mechanical properties and can reduce the strength of the weld joint. The results of welding using the Tungsten Inert Gas (TIG) welding process using the BCuP-2 filler rod. This is influenced by the properties of the BCuP-2 Phos-Copper (BCuP-2) filler rod alloy which is very suitable for most copper to copper or brass joints that have good compatibility, and the joints are able to withstand vibration or movement. BCuP-2 was developed primarily for use on copper, this alloy can also be used on other nonferrous copper base alloys such as aluminium. BCuP-2 contains phosphorus which functions as an internal flux. This reduces the need for external flux when welding copper to copper or other nonferrous metals, making the process simpler and more efficient.

BCuP has a relatively low melting point compared to other alloys, reducing the risk of thermal deformation of the base material and allowing welding at lower temperatures. Joints produced with BCuP-2 have good corrosion resistance, especially in environments containing water vapor and air. The resulting joints have good electrical conductivity because BCuP-2 contains a relatively high copper content.

Welding current also has a very significant effect on the results of copper and aluminium welding as shown in Fig. 4. Higher currents produce more heat. This can help melt copper faster, but it can also cause too much heat, which can result in deformation or damage to the base material. Based on the experiment, the three welding currents, namely 120A, 130A and 140A, produced good joints visually. The results of the shear test were obtained as shown in Fig. 6.

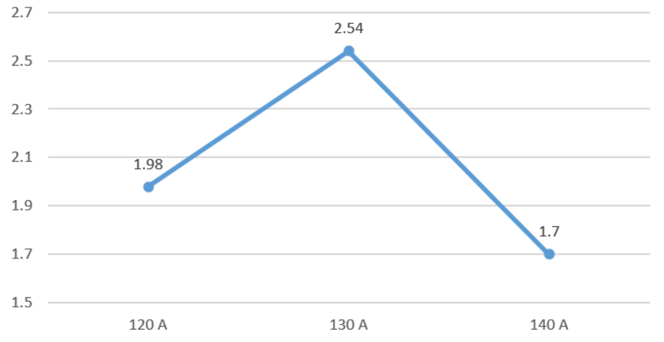

Fig.6. Shear test

Fig. 6. shows the variation of shear test results on the welded joint between copper (Cu) and aluminium 6061 (Al 6061) using filler rod BCuP-2 (Phos-Copper) in the TIG welding process. In this graph, changes in shear strength are seen at currents of 120 A, 130 A, and 140 A. The shear strength value increased from 1.98 at a current of 120 A to a maximum value of 2.54 at a current of 130 A, then decreased significantly to 1.7 at a current of 140 A.

The increase in shear strength at a current of 130 A is likely due to the optimal melting and blending of the BCuP-2 filler rod with copper and aluminium materials. The BCuP-2 filler rod contains copper (Cu) and phosphorus (P), which function as deoxidizers and help improve the flexibility and strength of the joint. At a current of 130 A, the phosphorus content in the filler may have a positive effect on the quality of the joint, resulting in higher shear strength. Phosphorus in the filler also helps lower the melting point and increase the fluidity of the weld metal, which is important for achieving strong bonds between dissimilar materials, such as Cu and Al.

However, at a current of 140 A, the shear strength actually decreases. This decrease can occur because the higher current produces excessive heat which can cause oxidation and decrease the quality of the bond between Cu and Al. In addition, excessively high temperatures can cause cracks or micro deformations in the joint area due to the difference in expansion coefficients between copper and aluminium, which tend to affect the integrity of the weld joint and reduce the shear strength.

In this microhardness test, a Vickers indenter is used and is carried out based on the ASTM E384 standard. Vickers Hardness is one method for measuring the hardness of materials, especially metals and ceramics. This test uses a diamond pyramid-shaped indenter that is pressed into the surface of the material with a certain load. Vickers hardness is symbolized by HV and is calculated based on the magnitude of the applied load and the diagonal size of the indenter trace formed. The results of the Vickers Hardness test are as shown in the graph in Fig. 7.

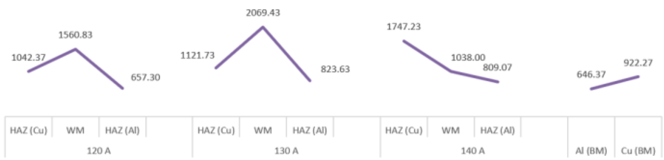

Fig. 7. Hardness value (HV)

Fig. 7. Shown results of the copper base metal (BM) are 922 HV and aluminium is 646 HV. The hardness value of the welded material both in the weld metal zone (WM) and heat affected zone (HAZ) is higher than the BM value at currents of 120A, 130A and 140A. Because during the welding process, it can cause alloy elements or impurities to dissolve in the weld metal matrix more homogeneously, producing a harder solid solution compared to the parent material which may have a less homogeneous distribution of alloy elements. During the welding process, the weld metal undergoes plastic deformation and thermal stress. This can cause strain hardening, which increases the hardness of the weld metal compared to the parent material. The filler material used in welding has a different chemical composition from the parent material. The filler material has better mechanical properties, including higher hardness, to increase the strength of the weld joint. The welding process can cause grain refinement in the weld area, producing finer grains. Finer grains tend to increase the hardness of the material due to more grain boundaries that inhibit dislocation movement.

The highest weld metal (WM) hardness value is at a welding current of 130 A of 2069.43 HV, then at a current of 120 A of 1560.83 HV and the lowest at a current of 140 A of 1038 HV. From the graph it can be seen that at a high current of 140 A it can cause hardening around the weld zone due to rapid cooling after welding. This can cause increased hardness around the weld zone especially in copper, which can cause residual stress and potential cracks. Welding with high currents will also produce significant heat that can change the microstructure of the material. In hard materials, this can cause the formation of martensite or other brittle structures in the weld zone and HAZ, which can reduce the overall toughness and strength of the material. So to get high hardness on WM, a current of 130 A is the best. All hardness values on WM are above the base metal (BM) values of copper and aluminium.

The highest heat affected zone (HAZ) hardness value on the copper side is at a welding current of 140 A of 1747 HV, then at a current of 130 A of 1121 HV and the lowest at a current of 120 A of 1042 HV. All hardness values in the HAZ are above the copper base metal (BM) value. While the highest heat affected zone (HAZ) hardness value on the aluminium side is at a welding current of 130 A of 823 HV, then at a current of 140 A of 809 HV and the lowest at a current of 120 A of 657 HV. All hardness values in the HAZ are above the aluminium base metal (BM) value.

At a current of 140 A, the hardness value in the HAZ is the highest of all other current variations, this is because during the welding process, the HAZ experiences heating to a high temperature and then rapid cooling. This process can cause microstructural changes in the copper in the HAZ, such as the formation of finer grains or hard phases that increase hardness. High current welding causes thermal stresses and plastic deformation in the HAZ. As a result of these stresses and deformations, the material can undergo strain hardening, which increases the local hardness in the HAZ. Copper has some alloying elements or impurities that can dissolve in the copper matrix during heating. Rapid cooling after welding due to high currents can cause the formation of a harder solid solution in the HAZ, increasing the hardness compared to the weld metal. During welding, some alloying elements or impurities can burn or evaporate from the weld metal due to the high temperature. This can cause the weld metal to be softer compared to the HAZ which still contains these elements. The HAZ is also affected by the thermomechanical cycle of welding, which can create different conditions from the weld metal. Changes in dislocations, grain boundaries, and phase distributions can cause higher hardness in the HAZ.

4 Conclusion

Visually, the test shows that there is a good connection of the welding results using the Tungsten Inert Gas (TIG) welding process using the BCuP-2 filler rod. This is influenced by the properties of the BCuP-2 Phos-Copper (BCuP-2) filler rod alloy which is very suitable for most copper joints. The optimal welding current for copper and aluminium joints in shear test using the BCuP-2 filler rod is 130 A, where the highest shear strength is achieved. The use of BCuP-2 filler containing Cu and P contributes significantly to the strength of the weld, with phosphorus helping the melting process and good bonding between the welded materials. However, too high a current can damage the joint because it increases the risk of oxidation and thermal incompatibility between the materials, which ultimately reduces the shear strength. The results of the copper base metal (BM) hardness test were 922 HV and aluminium was 646 HV. The hardness value of the welding material in the weld metal zone (WM) and heat affected zone (HAZ) is higher than the BM value at currents of 120A, 130A and 140A.

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