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MECHANICAL PROPERTIES CHARACTERIZATION OF THE FRICTION WELDING OF ALUMUNIUM WITH COPPER USING VARIATIONS IN ROTATIONAL SPEED AND CONTACT SURFACE ROUGHNESS

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Graphical abstract

Welding Results

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Abstract

One of the welding used for different materials is by using friction welding. Friction welding is a welding method by swiping the two materials until they reach some of the melting points of the materials to be joined and then subjected to constant pressure. In this study, the materials to be joined were aluminum and copper. By using variations of rotational speed and contact surface roughness, the mechanical properties of the welds were investigated. The speed variations used were 1230, 1500, and 2500 rpm. Meanwhile, for variations in surface roughness, sandpaper grades 100, 800, and 1500 were used. The results of this study were that at a rotational speed of 1230 rpm, the highest tensile strength and hardness values were obtained, namely 59.6 MPa and 54.6 HVN (Al), 112.1 HVN (Cu). For variations in surface roughness, the highest hardness value was found in surface roughness using sandpaper grade 1500, namely 54.18HVN (Al), and 112.1HVN (Cu). And the highest tensile strength is obtained on grade 100 sandpaper with a value of 52.48MPa. The results of the microstructure test in the weld joint area with a magnification of 1000x showed that the welding of aluminum and copper using the friction welding method was successful, as evidenced by the diffusion of aluminum and copper in this area.

Keywords: aluminum: copper, friction, mechanical roughness, speed welding

Abstrak

Salah satu jenis pengelasan yang digunakan untuk material yang berbeda adalah dengan menggunakan Friction Welding. Metoda friction Welding adalah pengelasan dengan cara menggesekkan kedua material hingga mencapai titik lebur material yang akan disambung kemudian diberikan tekanan secara konstan.Sstudi ini material yang disambungkan adalah tembaga dan aluminium menggunakan variasi kecepatan putar, kekasaran permukaan kontak. Penelitian ini bertujuan mengetahui sifat mekanis dari hasil pengelasan gesek antara aluminium dan tembaga. Variasi kecepatan yang digunakan adalah 1230rpm, 1500rpm, dan 2500rpm. Untuk variasi kekasaran permukaan yang digunakan adalah menggunakan amplas grade 100, 800, dan 1500. Hasil dari penelitian ini adalah bahwa kecepatan putar yang paling tinggi mendapatkan nilai kekuatan tarik dan kekerasan adalah pada kecepatan 1230 rpm yaitu 59,6 Mpa dan

54,6 HVN (Al), 112,1 HVN (Cu). Dan untuk variasi kekasaran permukaan, nilai yang paling tinggi adalah pada kekasaran permukaan yang menggunakan amplas grade #1500 yaitu 54,18 HVN (Al), 112,1 HVN (Cu). Dan amplas grade 100 dengan nilai 52,48 Mpa. Hasil uji struktur mikro pada daerah sambungan las perbesaran 1000x menunjukkan bahwa pengelasan aluminium dan tembaga dengan menggunakan metode friction welding berhasil dilakukan, dibuktikan dengan terdifusinya aluminium dan tembaga pada daerah ini.

Kata kunci: aluminum: copper, friction, mechanical roughness, speed welding

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1.0 INTRODUCTION

Welding is a method for joining two metals by heating and melting the base metal. In practice, the two ends of the metal to be joined are heated to their melting point with an arc of flame so that the metal is connected. Welding performed in the production process is very diverse, including Shield Metal Arc Welding (SMAW), oxyacetylene welding, Metal Inert Gas (MIG) welding, Tungsten Inert Gas (TIG) welding, and others [1] [2][3].

The use of this type of welding depends on the needs because each type of welding has different characteristics. Dissimilar metal welding is a development of modern welding technology as a result of the need to join materials that have different metal types [4][5][6]. Welding of two dissimilar materials is widely used in the chemical, construction machinery, and electronics industries. The joining of these two materials will produce new material properties. For example, the connection of copper and aluminum materials used in Schoen cable. Schoen cable is often also called cable shoe/cable lug. This Schoen cable is tubular and is usually used for aluminum cable terminals to be connected with copper components [5][6].

However, for welding on different materials, using welding that is often used such as SMAW, GMAW, and others is not very effective. Joining aluminum and copper materials can use brazing. Brazing tend to be complex, and the mechanical properties are not of high value, especially for dissimilar materials such as aluminum and copper. Thus, friction welding is the most effective alternative for dissimilar material welding and produces high mechanical properties [7][8][9][10].

2.0 METHODOLOGY

The field measurement area is in Mersing River at Johor, Malaysia (Figure 1). This river is directly connected with South East China Sea. Therefore, the relevant environment effects are tidal rise and fall, sea current and wind generated wave. The traffic in this river is high mostly fishing boats accessing the Mersing fishing port. Other users are patrol boats, fast ferries and sampans. Data collection in this study used documentation, observation, and direct experimentation methods, namely research data collection methods that deliberately and systematically carry out observational actions, to look for causal relationships between several influential factors or variables [11][12][13].

This research includes two main activities, namely the welding process and testing. The welding process was carried out at the Manufacturing Technology Laboratory, Faculty of Engineering, University of Sultan Ageng Tirtayasa, and mechanical properties testing, namely hardness and metallographic testing were carried out at the CRM Metallurgical Laboratory and Metallographic R&D Laboratory, PT. Krakatoa Steel. Tensile testing was carried out at the Metallurgical Engineering Laboratory, University of Indonesia.

Independent variables are variables whose magnitude is determined before the research is conducted. The independent variables used are:

• Rotational Speed (1230, 1500, 2500 rpm)

• Contact Surface Roughness (#100, #800, #1500)

Controlled variables are variables whose magnitude is controlled during the study. The control variables in this study are:

- 5 minute contact time
- The materials used are non-alloy copper and aluminum 6063 (solid round)
- Diameter of the puncture on copper 9 mm.
- Long stab (shock) on copper 10 mm

2.1. Welding Procedure

The process of welding or joining aluminum and copper has several stages including the following:

2.1.1. Preparation and manufacture of specimens

In this process the material was made and prepared according to the length and width to meet the standardization of the welding results testing process at a later stage[11].

2.1.2. Readiness check of welding equipment

Checking the readiness of the welding equipment aimed to ensure that the welding equipment was ready and could be used in the friction welding process so that there are no problems in the welding process [13]. The process of checking this equipment includes the following stages:

- Electricity can work properly
- The electric motor can rotate
- The head can still move

2.1.3. Installation of material on the chuck

At this stage, the welding material (copper and aluminum that had been adjusted according to size) was attached to the two chucks and locked tightly so that there was no shifting or movement during the welding process.

2.1.4. Welding Process

After the 3 stages above had been fulfilled, the welding process included rotating the test specimen so that heat arouse from the friction of the two surfaces. Heat rose from room temperature to welding temperature, then the constant pressure was given to the specimen so that the connection of the two welding materials occurred. The welding machine was then turned off, and the specimen was cooled in the air so that it reached room temperature [15].

2.2. Specimen Manufacture

The materials to be joined by friction welding are aluminum (Al) and copper (Cu). The steps for making a specimen are as follows:

- Prepare tools and materials for friction welding
- Cuts aluminum and copper to a length of 80 mm
- Make a shock diameter on the copper specimen by turning it to a length of 10 mm and a diameter of 9 mm at the tip/contact surface.
- Sand the contact surface with a #100 #800 #1500 roughness

Figure 1. Map of Field Measurement Location

2.3. Welding Process

The steps for friction welding are as follows [7][16][17][18]:

- Installing aluminum in the head stock chuck (rotating) and copper in the tail stock (not rotating, but moving linearly).
- Bring the copper closer to the aluminum so that there is contact between the copper and aluminum. Then lock the tail stock.
- Set rotation according to the specified parameters, namely 1230, 1500, 2500 rpm.
- Turn on the lathe
- Start the welding process with a contact time of 5 minutes.
- After achieving the set time, then provide a constant thrust along approximately 20 mm.

3.0 RESULTS AND DISCUSSION

In Figure 3 below is the result of the friction welding process between aluminum and copper:

Figure 2. Welding Results

3.1. Hardness Testing Results

Hardness testing was carried out at the CRM Metallurgical Laboratory, PT. Krakatau Steel, uses a Vickers Hardness Testing Machine with a diamond pyramid indenter and a load of 5 kgf or 49.03 N, according to JIS Z 2244:2009 standard. Data collection on hardness was carried out at 10 points per specimen at a predetermined distance.

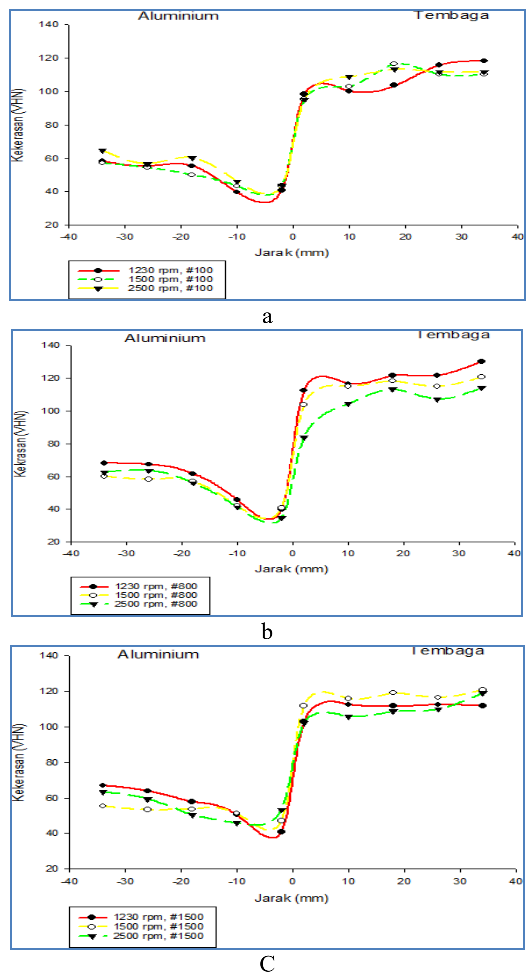

Figure 3. Relationship between hardness and friction welding rotational speed a) 1230 RPM b) 1500 RPM and c) 2500 RPM

From the graph above it can be seen that the hardness value of aluminum and copper materials shows that in the area that is getting closer to the welding zone, it decreases significantly compared to the base material. This is caused by variations in the speed parameters and different surface roughness, in this case, the rotational speed has the most influence in changing the hardness value of the two materials.

At a rotational speed of 1230, the average value is 54.2 VHN for Aluminum, and 112.7 VHN for Copper. The Speed 1500 scores 51.1 VHN on aluminum and 112.8 HVN on Copper. Speed 2500 gets an average value of 53.5 VHN on Aluminum and 107.6 VHN on Copper. So, the hardness value of the 1230 rpm variation is the highest.

When viewed from the variations in surface roughness, the results obtained are as follows: the average hardness value on Aluminum #100 surface roughness is 51.27 VHN, 800 is 53.28 VHN, and #1500 is 54.18 VHN. Whereas for copper material, the hardness value for the variable surface roughness #100 is 107.54 VHN, roughness #800 is 113.26 VHN, and roughness #1500 is 112.17 VHN. So the highest hardness value is the variation of surface roughness #1500 for Aluminum material and surface roughness #800 for Copper material.

.2. Tensile Testing Results

Tensile testing was carried out using the ASTM E-8 standard, at the Metallurgical Laboratory, Faculty of Engineering, University of Indonesia. The following is a graph of the tensile test that has been carried out on the 9 test specimens that have been made.

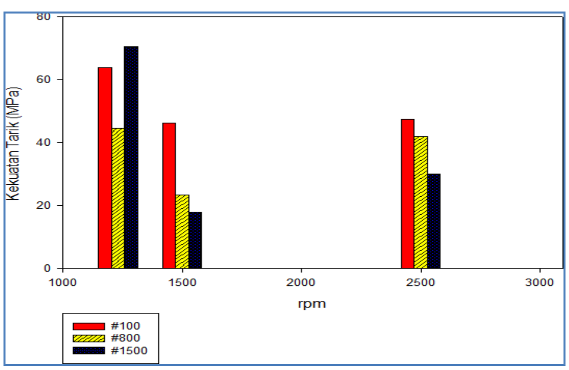

Figure 4. Relationship between tensile strength and friction welding speed

From the results of the tensile test that has been carried out, the tensile strength is obtained at a variation of the rotational speed of 1230 rpm, the average value is 6.08 kg/mm2 or 59.6 MPa. For variations of the rotational speed of 1500 rpm, the average value is 2.98 kg/mm2 or 29.2 MPa. The variation of speed 2500 rpm average value is 4.1 kg/mm2 or 39.8 MPa. For variations in surface roughness, roughness #100 gets the highest value, which on average is 5.36 kg/mm2 or 52.48 MPa. Thus, the maximum tensile test results are with variations in rotational speed of 1230 rpm and surface roughness #100. If related to the macrostructure, the connection at a rotational speed of 1230 rpm has the fewest defects or cavities. The tightest distance between interfaces is at a speed variation of 1230 rpm. So, it has the highest tensile strength value.

The results of the hardness test also show that the hardness at 1230 rpm is higher than the other variations of rotational speed, which is the result that is closest to the hardness of the base metal. This causes the material to stick together because its properties have not changed too much because it is still similar to the base metal. Then when viewed from the microstructure, the speed of 1230 rpm produces a smooth and dense structure compared to other rotational speed variations. The microstructure at 1500 and 2500 rpm looks more spread out and bigger. This also produces the highest tensile strength at 1230 rpm variation.

3.3. Microstructure Observation

Microstructure testing was carried out at the Metallographic R&D Laboratory of PT. Krakatoa Steel. By using an Optical Microscope with a magnification of 50x and 100x on the connection, HAZ, and Base Material. The etching solution used is Keller's Reagent for Aluminum and $FeCl_3$ for Copper.

Based on the results of microstructural observations that have been carried out, the black part of Aluminum is Mg_2Si. In the 1230 rpm variation, the black grains look tighter and smoother than in the 1500 and 2500 rpm variations. For the Copper section, the grains appear to be smaller and tend to spread to the part near the joint, with not too visible a difference that occurs in each variable. This causes the highest tensile strength to be experienced by the 1230 rpm speed variation with a value of 6.08 kg/mm2 or 59.6 MPa and for the surface roughness variation the highest value is the #100 surface roughness variation with a value of 5.36 kg /mm2 or 52.48 MPa. And for the hardness test, the highest hardness value is at a rotational speed variation of 1230 rpm, namely with a value of 54.15 VHN for Aluminum, and 112.73 HVN for Copper.

In order to see more clearly the area of the welded joint, the SEM-EDS test was carried out to find out what elements are present in the joint, and how the mixture occurs in the two materials. The results can be seen in Figures 5 and 6 below:

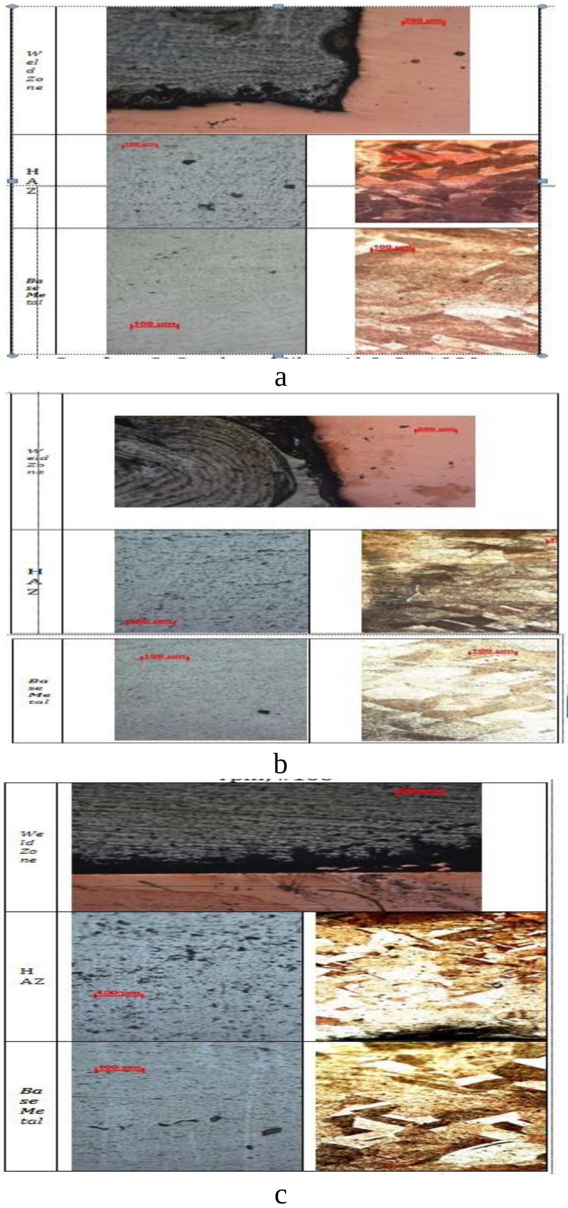

Figure 5. Results of observations of the microstructure of the microscope magnification 1000x a) 1230 b) 1500 and c) 2500 RPM

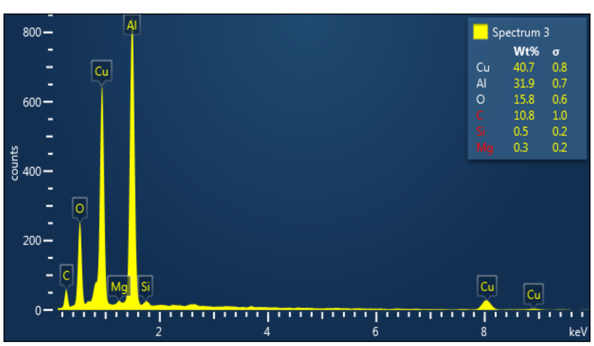

Figure 6. Percentage of elemental content in joints

In the connection section, the elemental content contained is 17.13% Cu atoms and 31.62% Al atoms. This is because when welding Al melts faster than Cu, so the more content is the Al element. There are also ingredients produced besides Al and Cu, namely Si, Mg, C and O. With 0.47% Si atoms, 0.37% Mg atoms, 24.06% C atoms, and 26.34% O atoms.

In this study digital video cameras were used to record the wave heights video footages and the images were processed to obtain wave heights and directions. In this field measurement five scaled poles were used as targets, while five digital video cameras were used to record the movement of waves on every pole, the recorded video footage was then processed by imaging method to find wave heights time series.

4.0 CONCLUSION

From the results and discussion that have been processed, it can be concluded that the tensile strength obtained by Al-Cu welded joints using variations of rotational speed tends to decrease with increasing rotational speed. In the hardness test, it can also be seen that the value of hardness that is getting closer to the part being welded decreases. The highest hardness value, if averaged, was obtained at a variation of the rotational speed of 1230 rpm, namely 54.15 HVN for aluminum and 112.73 HVN for copper, and for variations in surface roughness, the difference in hardness values obtained was not too significant seen in the results of the three variations of coarseness used. However, the highest surface roughness value was obtained from variations in surface roughness using sandpaper grade #1500, namely 54.18 HVN for aluminum and 112.1 HVN for copper.

For the observation of microstructure, it can be concluded as follows. On the aluminum part, the visible black grains are Mg2Si, from Base Metal – HAZ the black grains are wider and more numerous. At the speed variation of 1230 rpm, the structure is tighter and smoother than the results of the 1500 and 2500 rpm speed variations. As for the copper part, from the Base Metal – HAZ the grains are smaller and tend to spread. For the EDS SEM test which aims to find out what elements are present in the Al-Cu welding results, the result is that the elemental content present in the welded joint is 17.13% Cu atoms, 31.62% Al atoms, 0.47% Si atoms, Mg 0.37% atoms, C 24.06% atoms, and O 26.34% atoms.

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