Jurnal Asiimetrik: Jurnal Ilmiah Rekayasa Dan Inovasi
Terakreditasi "**Peringkat 3**" berdasarkan SK Dirjendiktiristek, Nomor: 225/E/KPT/2022
Volume 6 Nomor 2 Tahun 2024, Juli 2024, Halaman 309-318
Website : http://journal.univpancasila.ac.id/index.php/asiimetrik/

p-ISSN 2655-1861
e-ISSN 2716-2923

The Effect of Rotation Speed on the Quality of Friction Welding Joints in Aluminum and Copper

Pengaruh Kecepatan Putaran Pengelasan Gesek Terhadap Kekuatan Tarik dan Struktur Mikro pada Bahan Aluminium dan Tembaga

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Article information:

Received:
02/12/2023
Revised:
20/01/2024
Accepted:
23/06/2024

Abstract

Welding of two different materials has high difficulty. It will cause porosity and hot cracks. To improve this, a friction welding (FRW) process has been developed to weld materials in a molten state. In this process, the material will be clamped so as not to be thrown, one other material will be rotated and brought together with the other clamped material and the pressure that causes the two sides of the material to meet. The purpose of this study is to determine the strength of welded joints of various materials through tensile and microstructure testing in friction welding (FRW) welding. This study used 6061 aluminium and ASTM B187 copper for welding. The cylinder had a diameter of 16 millimetres and a length of 70 millimetres, and the spindle rotational speeds were 1200 rpm, 1400 rpm and 1800 rpm. Welding results were assessed by measuring the strength of weld joints between different types of materials. Test results on welding with different spindle rotational speeds showed that friction welding with 1800 rpm was stronger with a maximum tensile strength of 2762.8 N and a tensile strength of 13.7N/mm^2 when compared to 1200 rpm and 1400 rpm. In testing the microstructure of different types of materials, it can be seen that the mixture of the two metals at a rotational speed of 1800 rpm is more melting, so that the unification of the joining of the two materials is better when compared to the rotational speed of 1200 rpm and 1400 rpm.

Keywords: friction welding, aluminum, copper, tensile test, microstructure.

***SDGs*:**

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Abstrak

Pengelasan dua bahan yang berbeda memiliki kesulitan yang tinggi. Hal ini akan menyebabkan porositas dan retakan panas. Untuk memperbaikinya, proses pengelasan gesek (FRW) telah dikembangkan untuk mengelas material dalam keadaan leleh. Dalam proses ini, material akan di jepit agar tidak terlempar, satu material lain akan di putar dan di pertemukan dengan material lain yang dijepit serta penekanan yang menyebabkan pertemuan dua sisi material. Tujuan dari penelitian ini adalah untuk mengetahui kekuatan sambungan las dari berbagai material melalui pengujian tarik dan uji struktur mikro pada pengelasan pengelasan gesek (FRW0. Penelitian ini menggunakan aluminium 6061 dan tembaga ASTM B187 untuk pengelasan. Silindernya memiliki diameter 16 milimeter dan panjang 70 milimeter, dan kecepatan putar spindelnya adalah 1200 rpm, 1400 rpm, dan 1800 rpm. Hasil pengelasan dinilai dengan mengukur kekuatan sambungan las antara berbagai jenis material. Hasil uji pada pengelasan berbeda kecepatan putar spindel, menunjukkan friction welding (Kata asing dibedakan dengan putaran 1800 rpm lebih kuat dengan kekuatan tarik maksimal adalah 2762,8 N dan kekuatan tarik sebesar 13,7N/mm^2, jika dibandingkan dengan 1200 rpm dan 1400 rpm. Dalam pengujian struktur mikro yang berbeda jenis material, terlihat bahwa campuran kedua logam pada kecepatan putar 1800 rpm material lebih banyak mengalami lelehan, sehingga penyatuan sambungan kedua material lebih baik jika dibandingkan dengan kecepatan putar 1200 rpm dan 1400 rpm.

Kata Kunci: las gesek, aluminium, tembaga, uji tarik, struktur mikro.

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1. INTRODUCTION

The most common metal materials used in transportation, aviation and electrical industries are copper and aluminium (Tan *et al.*, 2013). The use of aluminium is increasing every year (Zhou, Wan and Li, 2015). Many industries are interested in finding ways to join and weld dissimilar materials (Manickam, Rajendran and Balasubramanian, 2020). Conventional fusion welding processes result in significant changes to the material structure, stresses, and intermetallic compounds, making welding of dissimilar alloys impossible (Gotawala and Shrivastava, 2020).

Arc fusion joints are commonly used for folding joints, bolt nuts and cable connectors. Arc welding is not suitable for welding metals in the form of solid cylinders as it cannot produce maximum strength. Solid state joining occurs when two materials are joined at temperatures below the melting point of the materials, resulting in melting by welding between the edge and the center. Therefore, it is necessary to use a new welding technique for joining materials, namely friction stir welded (Liu *et al.*, 2023). Friction stir welding (FSW) technique can replace conventional joining methods due to its ability to produce defect-free welds on dissimilar metals and alloys (Khojastehnezhad and Pourasl, 2018).

Friction welding uses the heat and pressure that occurs when two materials rub together, where a high-speed rotating tool is used to soften and mix the materials, thereby achieving welding (Huang *et al.*, 2018). Welding with melting or electric arc methods has several drawbacks and constraints. Among these is the thickness of the material to be welded. Joining large cylinders becomes difficult because the process must be done in stages to ensure a full metal layer. Previous studies have shown that weld tensile strength results can increase with longer welding turns. The solid state welding method known as stir pull welding (FSW) has diffusion and allows good joining of various metal structures (Singh, Deepak and Brar, 2023).

With low heat input during welding, FSW shows considerable potential for the joining of Al-Cu (Barekatain, Kazeminezhad and Kokabi, 2014; Shi *et al.*, 2017).

Joining metals, either of the same or different types, is called welding. The heat applied to the metal without pressure reaches the melting point corresponding to the welding temperature. Friction welding saves a lot of material and saves time to join two same or different materials (Husodo, 2011).

Welding can be used for various types of repairs, such as filling holes in castings and thickening worn parts. Based on the rubbing method, welding is classified into four: Friction Welding, Rotary Friction Welding, Friction Stir Welding (FSW) and Linear friction welding.

Friction Welding is one of the solidstate welding techniques. Friction welding is the joining of metals that occurs due to heat generated by pressure or friction that occurs when two metals rub against each other (Darmulia, 2016). By combining heat and temperature pressure, two metals will be connected. Because the friction time is relatively fast, the process runs quickly. Because the heat does not reach the temperature of the metal and the pressure, the HAZ heat influence area on the joined metal is narrow. The strength and joining efficiency of thick Al alloy plates welded using FSW are higher than those welded using fusion welding. The parameters to be considered in this welding process are: tool rotation, welding speed, pin shape, and penetration depth (Pitchipoo *et al.*, 2021). To obtain good weld joint quality, these welding parameters are very important (Shrivas *et al.*, 2020).

The temperature pressure allows the metal to be eliminated from the adverse effects of heat. Friction welding technology is one of the solid state welding methods (Husodo *et al.*, 2013). Rotary Friction Welding is a welding that occurs due to heat generated by friction of the surface ends of two fused parts (Saefuloh *et al.*, 2023).

Friction Stir Welding (FSW) is usually used to join plates. Friction welding is the joining of metals that occurs due to heat generated by pressure or friction from the rotation of one metal against another along the same axis (Firmansyah, 2021). FSW is classified as a solid body joining process as it operates below the surface with the help of base metal (Khaliq *et al.*, 2023). In the friction welding process, one of the materials rotates while the other is fixed, which generates heat force, as shown in **Figure 1**.

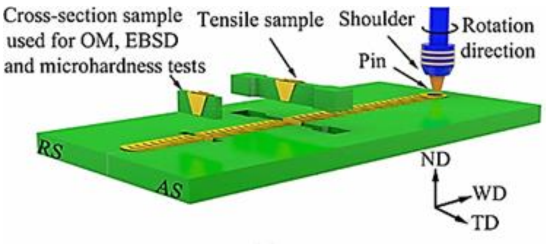


Figure 1. Friction stir welding process (Liu *et al.*, 2023).

Linear friction welding is a method in which the mandrel moves sideways separately instead of rotating. The factors that affect the friction welding results are the friction rotation speed, the applied friction pressure, the friction time, the flatness of the material surface, the position of the material, and the material used (Dzulfikar, Purwanto and Munif, 2020).

At typically much lower speeds, linear friction welding requires more complex machining than rotary friction welding but has the advantage of being able to join parts of any shape. Linear friction welding (LFW) is a solid body joining process that is the state-of-the-art technology for manufacturing titanium alloy bladed discs (blisks) in aero engines (McAndrew *et al.*, 2018). Another example of the process is also shown in Figure 2.

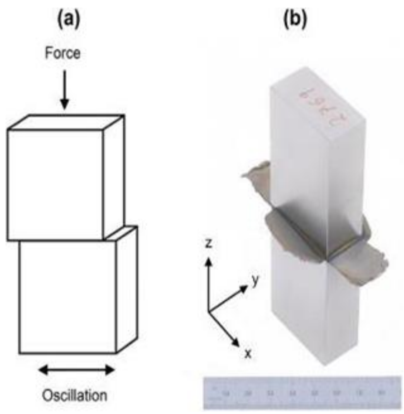


Figure 2. Linear friction welding (McAndrew *et al.*, 2018).

Advantages and disadvantages of friction welding Compared with the joining process using the fusion welding method, the friction welding process has several advantages. The advantages are:

a. No filler metal is required for welding.
b. No flux, filler metal or gas is required for friction welding.
c. Possible slag ingress and porosity can be avoided.
d. Suitable for large quantity production.

To calculate the energy input of the friction welding process, the heating of the interface of the two metals to be joined is solved using the following equation:

$$E = m.c.\Delta T \quad (1)$$

where:
E = Heat energy (J)
m = heated mass (kg)
c = specific heat of material (J/kg.K)
ΔT = temperature difference (K)

The friction force on the contact surface can be calculated using the following formula:

$$dFnormal = p.2\pi.r.dr \quad (2)$$

$$dFfriction = \mu.P.2\pi.r.dr \quad (3)$$

$$dMT = Ffriction.r = \mu.p.2\pi.dr \quad (4)$$

$$MT = \mu.p.2\pi.d \quad (5)$$

where:
$dFnormal$ = Torque moment appearing on the contact surface (Nm)
dFriction = radius of friction surface (m)
P = power (W)
P = pressure (Pa)
N = rotation (rad/second)
μ = coefficient of friction

From the above calculations, the radius of the object to be determined can be determined continue with the following formula:

$$R_0^3 = \sqrt{\frac{3.MT}{2.\mu.\pi.p}} \quad (6)$$

Based on the results of these calculations, the relationship between rotational power and the diameter of the parts to be joined can be determined. Various experiments and tests of friction welding are carried out to obtain better results such as the strength of the welded joint and effectiveness with the discovery of the ideal friction welding method, it can be a method that can be applied in the industry. the results of tensile and microstructure tests can be reinforcing data that prove the effectiveness of the selected welding method.

2. METHODOLOGY

This research methodology uses a research method using the friction welding process, with aluminium (Aluminium6061 in the form of a solid cylinder with a diameter of 16 mm and a length of 1000 mm) and copper materials (ASTM B187 copper in the form of a solid cylinder with a diameter of 16 mm and a length of 1000 mm).

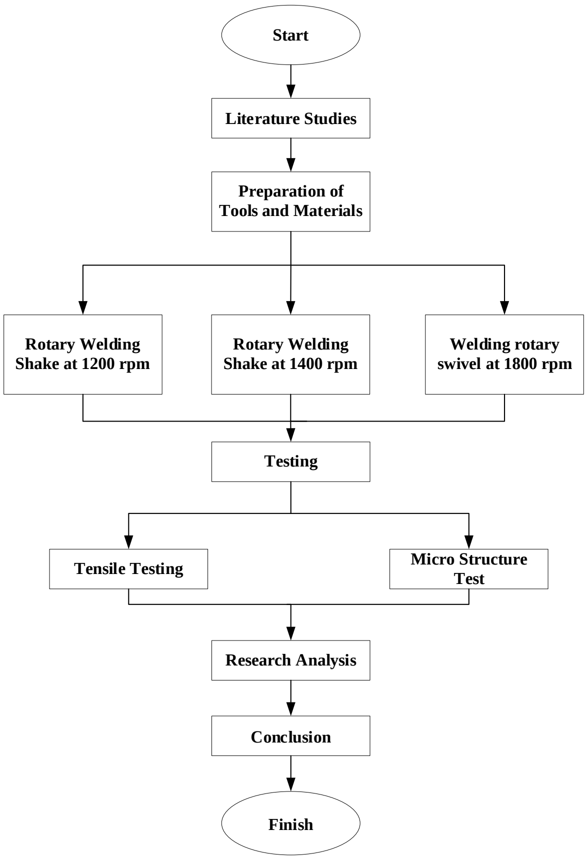


Figure 3. Research flow chart.

The friction welding process uses a lathe with a spindle rotational speed of 1200 rpm, 1400 rpm and 1800 rpm and a pressing distance of 10 mm (8 mm pressing when the spindle rotation is constant). The time required for friction welding with speed parameters of 1200 rpm, 1400 rpm and 1800 rpm is measured using a mobile phone stop wacth, while the temperature is used thermogun (Infrared Thermometer Ti 600 Wipro -50c to 600 c). After completion, tensile testing (Tensile testing using a Universal Testing Machine with a capacity of 5 Tonnes with the type JTM-500kn HS 360 V with the brand Technology Co. Ltd made in Taiwan), microstructure testing (Microstructure tester Keyence VH-Z1000R microscope, this tool can see the microstructure with magnification from 100x to 1000x magnification) and analysis were carried out. The flow of this research is as shown in Figure 3.

3. RESULTS AND DISCUSSION

3.1. Friction Welding Results

This study is to determine the effect of process parameters used in the friction welding process, namely the spindle rotational speed of 1200 rpm, 1400 rpm and 1800 rpm and also the pressing distance of 10 mm (8 mm pressing at constant spindle rotation). The process of joining aluminium with copper by means of friction welding, using a lathe machine.

The time required for friction welding with speed parameters of 1200 rpm, 1400 rpm and 1800 rpm using a stop wacth phone, while the temperature is used thermogun. Data on the time required during the welding process can be seen in Table 1, the temperature data that occurs can be seen in Table 2.

Based on the friction welding results data in Table 1 and Table 2 with a rotational speed variation of 1800 rpm, the specimens with an average time of 44 seconds can complete the friction welding process. The temperature of all rotational speed variations on a given specimen averages more than 112^{0}C when welding occurs. In the friction welding process with rotational speed parameters and a pressing distance of 10 mm. the time required \pm 28 seconds to \pm 51 seconds, this welding is solid state welding (does not require high temperatures when welding).

3.2. Analysis and Discussion of Tensile Testing Results

Tensile tests are carried out on the results of a good friction welding process. The process steps include preparing test samples by cutting and

Table 1. Time data during welding.

No	Rotational Speed (rpm)	Time 1 (Seconds)	Time 2 (Seconds)	Time 3 (Seconds)	Average Time (Seconds)
1	1200	51	50	49	50
2	1400	28	30	29	29
3	1800	45	44	44	44

Table 2. Temperature data of the friction welding process.

No	Rotational Speed (rpm)	T 1 (° C)	T 2 (° C)	T 3 (° C)	T Average (° C)
1	1200	127	123	112	121
2	1400	110	113	112	112
3	1800	150	148	149	149

Table 3. Tensile test results at 1200 rpm.

No	Rotational Speed (rpm)	Extensive Area (mm^2)	Tensile Load (N)	Yield Strength (N/mm^2)	Description
1	1200	201	2228.9	11.1	Disconnection
2			1923.6	9.6	Disconnection
3			1684.3	8.4	Disconnection
Average			1945.6	9.7	Disconnection

Table 4. Tensile test results at 1400 rpm.

No	Rotational Speed (rpm)	Extensive Area (mm^2)	Tensile Load (N)	Yield Strength (N/mm^2)	Description
1	1400	201	1602.4	8.0	Disconnection
2			1775.4	8.8	Disconnection
3			1696.2	8.4	Disconnection
Average			1691.3	8.4	Disconnection

Table 5. Tensile test results at 1800 rpm.

No	Rotational Speed (rpm)	Extensive Area (mm^2)	Tensile Load (N)	Yield Strength (N/mm^2)	Description
1	1800	201	2762.8	13.7	Disconnection
2			2523.4	12.6	Disconnection
3			2601.3	12.9	Disconnection
Average			2629.2	13.1	Disconnection

forming according to standardized dimensions for tensile testing, then testing using a machine (Santoso, 2017).

From the test results using a Universal Testing Machine tensile tester with a capacity of 5 tons with type JTM-500kn HS 360 V with the brand JTM Technology Co. Ltd in the testing laboratory of PT. Guna Sukses Inti. The testing standard used in SNI 8389-2017 tensile testing obtained testing data as in the Table 3, Table 4, and Table 5.

From the tensile testing data of friction welding specimens, a maximum load value is produced, the tensile strength of the specimen is tested. From this data can be used to find the tensile strength value. The use of formulas can be used to find the tensile strength value. The following test data is used with a rotational speed specimen of 1200 rpm test sample 1 as an example of calculation.

$$YS = \frac{F_y}{A_o} = \frac{2228{,}9\ N}{201\ mm^2} = \ 11{,}1\ N/mm^2$$

where:

YS = Yield Strength / yield strength N/mm^2
Fy = Tensile Load / Maximum tensile load (N)
Ao= area (mm)

The tensile testing value graph can be seen in Figure 4 while the tensile strength value can be seen in Figure 5.

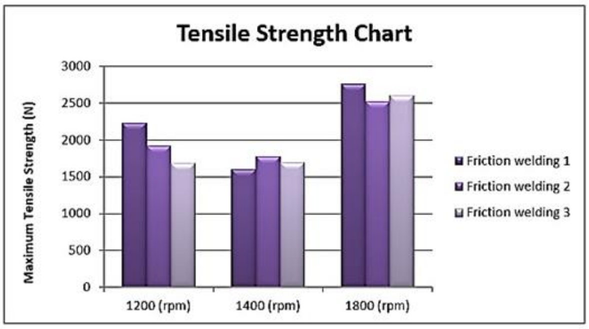


Figure 4. Graph of tensile testing results.

From the test results, it is obtained that the highest average value of maximum tensile strength is the welding specimen with a rotating variation of 1800 rpm, namely 2726.8 N/mm^2 for its tensile strength and welding with a rotating variation of 1400 rpm gets the lowest average value of 1602.4 N/mm^2 for its tensile strength. Based on the 3 sample data above, it can be concluded that to get the highest tensile strength is at a rotational speed of 1800 rpm.

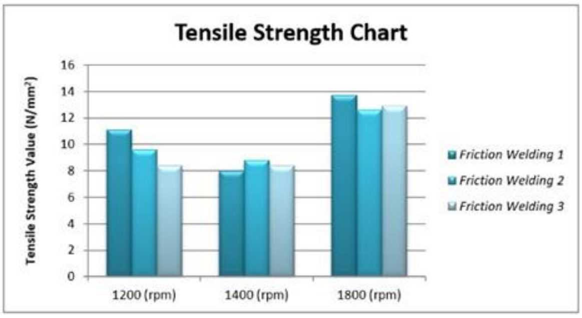


Figure 5. Tensile strength results chart.

The tensile strength results shown in Figure 5, namely the tensile strength testing graph, get results that are directly proportional to the maximum tensile strength. In tensile strength, the highest value is the 1800 rpm variation, so the highest tensile strength also occurs at the rotating speed with an average value of tensile strength of 13.1 N/mm^2. The lowest average value of tensile strength occurs in the 1400 rpm rotary variation with a tensile strength value of 8.4 N/mm^2.

Based on the data from the tensile test results conducted by varying the rotation speed of 1800 rpm has the highest tensile strength with a value of 2762.8 N. This is because the heat generated is evenly distributed and tightly welded together to form a ductile structure. And the highest tensile strength or tensile strength results are carried out by varying the rotation speed of 1810 rpm with a value of 13.7 N/mm^2. Fault shape after tensile testing as shown in Figure 6.

(a) Rotating speed 1200 rpm

(b) Rotating speed 1400 rpm

(c) Rotating speed 1800 rpm

Figure 6. Fracture shape after tensile test.

3.3. Microstructure Testing Results

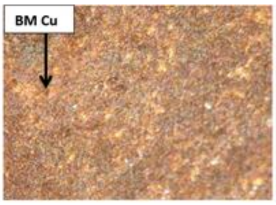
Microstructure testing is intended to determine the microstructure contained in the test sample (Santoso, 2017). Microstructure testing on this research sample uses a Keyence VH-Z1000R microscope microstructure test tool. With ASTM E3 and ASTM E407 testing standards.

The results of the observation of the microstructure of the welded joint are shown in the figure below. When observing the changes in the microstructure of aluminum and copper after friction welding in the aluminum weld center zone (WCZ), grains will appear.

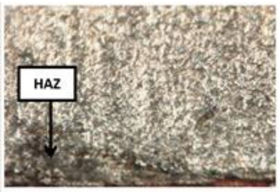
The higher the rotation speed, the higher the temperature, so that when the temperature reaches the point above, recrystallisation will change the shape of the microstructure of aluminium and copper. In aluminium and copper, we find the heat affected zone (HAZ).

Photo results of friction welding with rotating speed 1200 rpm shown in Figure 7. Microstructure Photograph Results with 1000x Magnification at 1200 rpm Friction Welding. Many aluminum alloy metal grains penetrate the copper alloy at the joint area, and the metal grains are mixed.

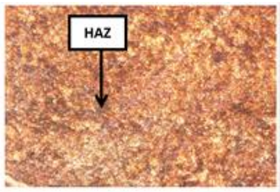
(a) Base material Al



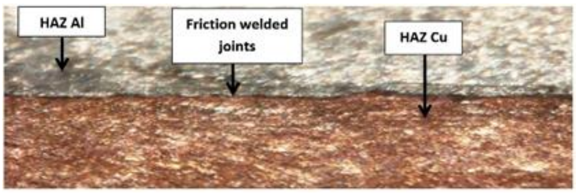
(b) Base material Cu



(c) Heat affected zone Al



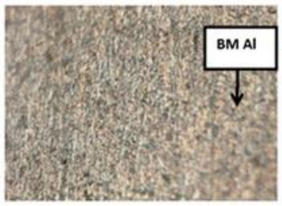
(d) Heat affected zone Cu



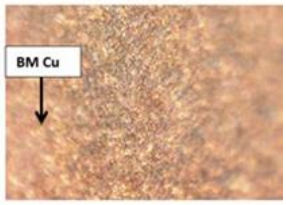
(e) Friction welded joints

Figure 7. Microstructure of friction welding rotating speed 1200 rpm.

Photo results of friction welding with rotating speed 1400 rpm shown in Figure 8. Microstructure Photograph Results with 1000x Magnification at 1400 rpm Friction Welding. The grains of both alloys at the weld joint boundary are small and mixed.

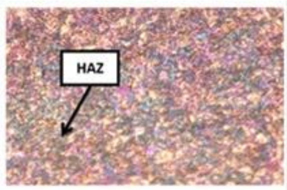


(a) Base material Al

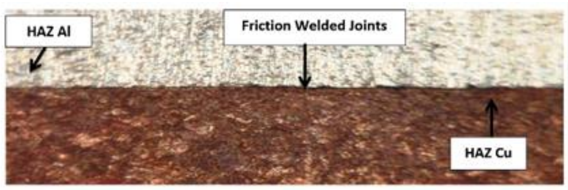


(b) Base material Cu

(c) Heat affected zone Al

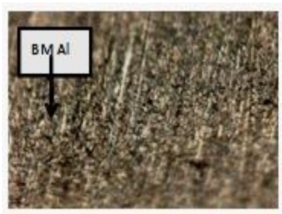


(d) Heat affected zone Cu

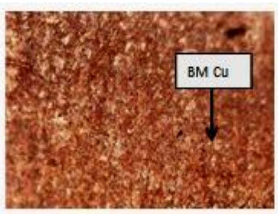


(e) Friction welded joints

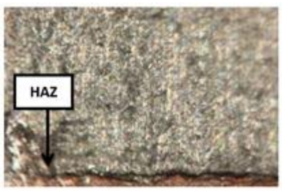
Figure 8. Microstructure of friction welding rotating speed 1400 rpm.



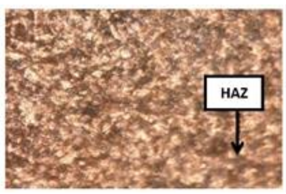
(a) Base material Al



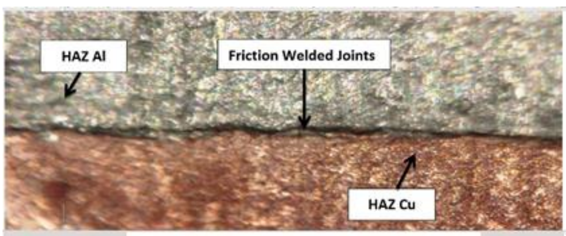
(b) Base material Cu



(c) Heat affected zone Al



(d) Heat affected zone Cu



(e) Friction welded joints

Figure 9. Microstructure of friction welding rotating speed 1800 rpm.

Photo results of friction welding with rotating speed 1800 rpm shown in Figure 9. Microstructure Photograph Results with 1000x Magnification at 1800 rpm Friction Welding. Many aluminium alloy metal grains enter the copper alloy metal at the joint area, the metal grains are mixed and widened.

Based on the results of microstructure testing of 3 samples, it is concluded that friction welding is better in the union and attachment of both copper and aluminium materials is 1800 rpm which can be seen in the microstructure test results when compared to 1200 rpm and 1400 rpm.

4. CONCLUSION

Based on the results of tensile testing on test samples with a rotation of 1200 rpm, 1400 rpm and 1800 rpm, from the test results, it is obtained that the highest average value of maximum tensile strength is the welding specimen with a rotating variation of 1800 rpm, namely 2726.8 N/mm2 for its tensile strength and welding with a rotating variation of 1400 rpm gets the lowest average value of 1602.4 N/mm2 for its tensile strength. The highest tensile strength was achieved at a rotational speed of 1800 rpm, with an average tensile strength of 13.1 N/mm2. The lowest tensile strength was achieved at a rotating speed of 1400 rpm, with an average tensile strength of 8.4 N/mm2. The tensile test results, which were carried out with a rotational speed variation of 1800 rpm, showed the highest tensile strength of 2762.8 N. The even heat and tight density of the weld formed a ductile structure.

Based on the results of 1000x magnification microstructure testing on 3 samples, it is concluded that friction welding is better in the union and attachment of the two copper and aluminium materials is 1800 rpm showing many aluminium alloy metal grains entering the copper alloy metal in the joint area, the metal grains are mixed and widened, when compared with 1200 rpm and 1400 rpm.

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