Challenges and opportunities to develop the method of joining dissimilar material aluminium-steel by using Rotational Friction Welding (RFW)

Akhmad Rasyid¹, Rachmat Hidayatullah¹, Priyo Adiwibowo¹, and Indra Siregar¹
¹Universitas Negeri Surabaya, Surabaya, Indonesia

Abstract. The combination of the lightweight AL 6061 and high-strength steel SWRM 1008 is utilized by the industrial sector, including the automotive industry to make bumper reinforcement. The properties of AL 6061 and SWRM 1008 steel have specific differences so an appropriate welding method is needed. This is a challenge and an opportunity for its application in the future. Rotational friction welding (RFW) is one of several welding processes that can be applied to join AL 6061 with SWRM 1008 and furthermore, the welding is environmental. The occurrence of diffusion between AL 6061 and SWRM 1008 is influenced by the heating temperature and forging pressure. Due to different melting temperature the steel in this research has been preheated. AL 6061 has a lower melting temperature than SWRM 1008 and a male-female shape has been made so that excessive upset did not be overformed and the forging process ran optimally. The welding process used rotational friction welding between AL 6061 and SWRM 1008 with preheat temperature 3500°C, rotational speed 800 rpm, friction pressure 2 Mpa, and forging pressure 3 Mpa. The results of the joining were then tested for tensile strength and micro-photos. The preheat to SWRM 1008 before the welding process causes softening of the aluminium surface immediately after contact. Excessive softening of the aluminium surface establishes an upset before diffusion occurs. IMC will form well under high shear stress and forging pressure. The welding process at low pressure obtained a connection tensile strength value of 65.2Mpa even though it had been preheated before welding took place. From this research, we can know if rotational friction welding gives opportunities to join the AL 6061 with SWRM1008.

1 Introduction

The petroleum use as fuel for motorized vehicles has reached its limit. If no new sources of petroleum are found, within the next nine years, oil in Indonesia will run out, as said Indonesian Ministry of Energy and Mineral Resources (ESDM), Arifin Tasrif in the Indonesian Energy Portrait webinar, on Tempo Energy Day [1]. The energy crisis is happening almost all over the world so vehicle manufacturers are transitioning the source of

* Corresponding author: akhmadrasyid@unesa.ac.id

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vehicle engines, from internal combustion engines to hybrid and electric. Energy consumption is a problem for all types of vehicles. One of the factors that affect the amount of energy consumption in vehicles is the weight of the vehicle. Vehicle manufacturers continue to develop lightweight materials for vehicle construction in order to reduce the total weight of the vehicle. Steel contributes approximately 975 kg of weight of one vehicle [2]. The steel used in vehicles has high strength and low cost, but the components are heavy. To reduce the weight of the vehicle without reducing its function and strength, dissimilar materials can be used as an option.

The combination of light lightweight AL 6061 and high-strength steel SWRM 1008 is used by the industrial sector, including the automotive industry to make vehicle components. One of which is bumper reinforcement. AL 6061 and SWRM 1008 have significantly different properties. To combine them requires the right method. This is a challenge as well as an opportunity in its application. The method for making a permanent connection is the welding process.

There are various kinds of welding that can be applied to dissimilar materials such as AL 6061 and SWRM 1008. One of the welding methods that produces good joint strength for dissimilar materials is friction welding. Dissimilar materials can be joined properly using the friction welding method because the process has a solid-state nature and low heat input [3], minimal welding shrinkage [4] and an environmentally friendly process [5].

The shape of the components is cylindrical generally welded by friction welding [6] but there are significant differences in material properties such as melting point. The coefficient of thermal expansion and specific heat of the aluminium material is almost twice that of the steel material. The thermal conductivity of the aluminium material is six times higher than that of the steel material. The aluminium material has three times higher modulus of elasticity than steel, so it is necessary to process engineering so that the two materials can be connected properly. However, welding of these metals has been always a kind of dilemma for engineers so dissimilar material welding parameters are still being developed [4].

The increasing temperature as a result of friction between aluminium and steel is different. Aluminium temperature increases faster than steel. The application of preheating to steel before the welding process can reduce the difference in temperature rise. The shape of the friction surface affects the mechanical properties [7]. A male-female shape has been made, so that excessive upset did not be formed so the forging process ran optimally and unbalanced rotation during the forging process when aluminium has softened can reduce.

2 Experimental Procedure

2.1 Materials and friction welding method

The materials used in the welding are AL 6061 and SWRM 1008. The welding machine used is a turning machine with modification. The machine has a rotation capacity of up to 3600 rpm with a welding pressure of 4 Mpa. Friction and forging pressures are controlled by a hydraulic spring valve. The heating machine uses a type of magnetic induction so that only magnetic material is heated.

The dimensions of the AL 6061 and SWRM 1008 materials are adjusted to the dimensions of the tensile test specimens with a friction diameter of 12.5 mm and a length of 90 mm for each material. In the welding process, the material that moves in rotation is SWRM 1008, while the material that moves in translation motion is AL 6061. On the rubbing surfaces, a male-female shape is made with an angle of 300. The male surface is on AL 6061 and the female is on SWRM 1008.
The welding process begins with placing the material on the welding machine, setting a rotational speed of 800 rpm, friction pressure of 2 Mpa, and forging pressure of 3 Mpa. The welding process has been completed when the SWRM 1008 steel material is heated until 350 °C and the two materials together are rubbed.

2.2 Testing method

The welded material is then tested for tensile strength using a universal testing machine. The test results show the value of tensile strength and stress-strain graphs. Diffusion depth between AL 6061 and SWRM 1008 is seen through micro-photo.

3 Results and Discussion

3.1 Morphology of joint

The AL 6061 and SWRM 1008 are joined through a friction welding process. The SWRM 1008 material is heated to 350 °C then the AL 6061 material is rubbed against the material surface with a pressure of 2 Mpa. AL 6061 and SWRM 1008 whose surfaces are subjected to heating and softening are then subjected to a forging pressure of 3 MPa. During pressing, an upset is formed only from AL 6061. Upset is only established in the AL 6061 section because the reason should be that the tensile yield of AL 6061 decreases with the increasing of temperature [8]. The upset width depends on the given welding parameters, where the forging pressure is a more dominant parameter.

Fig. 1. The typical morphology of AL 6061 and SWRM 1008 metal joint.

3.2 Tensile strength of joint

Tensile strength testing was carried out on three test specimens. From the final calculation, the value of the first material was 61 Mpa, the second material was 65.25 Mpa, and the third material was 69.33 Mpa. The average of the tensile strength is 65.2Mpa.

This value is lower than the results of the tensile strength research from the study of [8] which yielded a value of 301 Mpa. The value of tensile strength is also lower than that of [9] which yielded a value of 242 Mpa. The significant difference is caused by the difference in the forging pressure used. Researchers do not provide high forging strength due to differences in welding parameters used. Preheat on the SWRM 1008 has been done before friction is applied.
The preheat of 350 ℃ has an impact on the AL 6061 surface which is in contact with the SWRM 1008 to become soft before the friction process. If AL 6061 undergoes excessive softening, it will form too wide upset with not completed diffusion. Excessive upset formation also means a lot of material loss. Large material loss during the welding process is undesirable because material loss correlates with increased welding process costs.

Forging pressure has an impact on joint strength so the preheat temperature must be re-evaluated. Because the preheat temperature which is intended to soften the SWRM 1008 can cause softening on the surface of the rubbing AL 6061 as well, softening of the frictional surface affects the diffusion process between the AL 6061 and SWRM 1008.

The fracture of the connection between the AL 6061 and SWRM 1008 can be seen in figure 2. Fractures occur at the joints indicating that diffusion has not completed yet from the two materials. The unbonded region is defined as the region where the adhesion between materials and the interdiffusion of each element is insufficient, and elements are not metallically bonded to each other [9]. If the diffusion has been perfectly formed then the fracture will occur in the AL 6061 metal base. The incomplete diffusion process can also be seen from the strains formed during the tensile strength test.

![Fracture joining from AL 6061 and SWRM 1008.](image)

**Fig. 2.** Fracture joining from AL 6061 and SWRM 1008.
In figure 3 it can be seen that the strain occurs very short and the material has broken. If the AL 6061 and SWRM 1008 have been diffused well, the strain line gets longer because the elastic modulus of AL 6061 is quite high.

### 3.3 Micro-photo of joint

The micro-photo result from the connection shows that an intermetallic compound (IMC) has been established due to a diffusion between Al6061 material and SWRM 1008 steel. The centre line is the area where diffusion occurs.

Figure 4 shows the microstructure of base metal AL 6061, SWRM 1008, and IMC at 0.05 mm scale. The dark part on the left is AL 6061, and the right part is SWRM 1008. The centre part showing a line is the area where diffusion occurs. Based on the existing micro-photos, it can be seen that the diffusion has been not perfectly formed so the bond between the two materials is not strong.
Figure 5 shows the ratio of the width of the area where the aluminium diffuses with steel. The diffusing part is shown in the black line on the IMC [10]. The tensile strength value is 65.2Mpa on the left image and the tensile strength value is 301 Mpa on the right image. The black line in the right image is clearer and wider, compared to the left image which looks not complete and less clear. The fracture in the tensile strength test in the study [8] occurred in the aluminium base metal. This indicates that diffusion is occurring well.

4 Conclusion

The preheating process of the SWRM 1008 before the welding process causes softening of the AL 6061 surface shortly after contact. Excessive softening of the AL 6061 surface causes an upset to form first, before diffusion occurs. The high tensile strength of IMC is obtained at high friction and forging pressures. The welding process at low pressure, at a friction pressure of 2 Mpa, and forging pressure of 3 Mpa only gets a tensile strength value at the joint of 65.2 Mpa.

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