TENSILE STRENGTH AND MACRO-MICROSTRUCTURES OF A6061 CDFW WELD JOINT INFLUENCED BY PRESSURE AND HOLDING TIME IN THE UPSET STAGE

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Abstract

This paper aims to analyze the effect of pressure and holding time in the upset stage on tensile strength and macro-microstructures of continuous drive friction welded (CDFW) joints of aluminum alloys A6061. Friction weld specimens were welded using variations of upset pressure (40, 80, 120 MPa). The upset holding time was varied from 3, 10, to 20 seconds. Tensile strength test was conducted based on the AWS standard. The result showed that the higher upset pressure and the longer holding time in the upset stage are able to reduce the porosity of the CDFW weld joint and cause a higher tensile strength of the specimens. Meanwhile, from macro-mic restructures observation results, it was found that the specimen with maximum tensile strength has a wider partly deformed area (ZPD) and finer grains in the center of the specimen longitudinal section compared to those of the specimens with minimum tensile strength. It was occurred due to plastic deformation as the result of the higher pressure and the longer holding time in the upset stage. Fracture surface observation results indicate that in the specimen with a higher upset pressure and a longer holding time, has inflated fracture surface and the fracture zone exists in the heat affected zone, not in the interface like that of the specimen with lower tensile strength due to the lower upset pressure and the shorter holding time.

Keywords*: Aluminum alloys, Continuous Drive Friction Welding, Upset Pressure, Tensile Strength, Macro- Microstructures*

INTRODUCTION

Aluminum is as a material, which is not easily joined because of its characteristic of high thermal conductivity and the presence of oxide on its surface. In regard to that, continuous drive friction welding (CDFW) as one type of friction welding plays a role as a solid-state welding method which preferable to solve the problem, because the process can eliminate the oxide in the surface as a flash that flows out from the interface [1].

There have been many studies on continuous drive friction welding (CDFW) in combining aluminum alloys, for example, A6061 which possesses good corrosion resistance, medium tensile strength, and good welding characters in many applications such as in cars, airplanes, and trains. One study analyzed the tensile strength of the welded joints generated by the rotating friction welding of spherical aluminum A6061 with different chamfer angles [2]. The result reported that the angle of the chamfer affects the tensile strength of A6061 rotating friction welding joint with the 30-degree chamfer angle giving the maximum tensile strength.

In addition, another study discusses the effect of rotation variation and compression time on tensile strength and porosity of friction welding. The result showed that the material has three zones of the undeformed zone (UZ) which are almost as hard as the parent metal, plasticized zone (PZ), and partial deformation zone (PDZ). The hardness level in PZ is the highest compared to that in PDZ and in UZ. The hardness in PZ rises because of the zone's fine grain size [3]. Also, a study done for friction welding using Aluminum Alloy 6061-T6 indicated a better result of friction welding compared with conventional welding in the porosity analysis. This is because the friction welding produced by welds hardly contains porosity [4]. Sathiya observed the friction welding by the use of the frictional pressure of 15-25 bar and forging pressure 35-45 bar and the main shaft speed of 1125 rpm [5].

Moreover, another study reported the material's ability in heat absorption that caused a grain size gap in the connection area between the two material sides. Therefore, the contact surface area causes the range in the heat generated in the connection process at the same time and pressure. Besides, the heat also affects the welded joint strength [6].

Many parameters bring impacts on the strength of friction welding joints, most likely in the CDFW process. They include friction time, rotational speed, friction pressure, burn off length, upset pressure, and shock resistance time [6]. Some researchers reported on the effect of rotational speed on the mechanical properties of the friction weld joint of steel [7,8]. Irawan et.al found that higher upset force can increase tensile [9] and torsion strength of Al-Mg-Si friction weld joint [10-12]. Meanwhile, tensile strength is as one important mechanical property for the components such as the shaft on the engine to ensure the strength and safety of the shaft on the engine. However, the effect of pressure and holding time in the upset stage on tensile strength are not uncovered yet in aluminum alloys A6061 friction weld. Therefore, this paper analyzed the result study on the effect of upset pressure and holding time on tensile strength and macro-microstructures of aluminum alloys A6061 continuous drive friction welded (CDFW) joint.

EXPERIMENTAL METHOD

The chemical composition of the round bar of Aluminum alloy A6061 is presented in Table 1.

Table 1. The chemical composition of aluminum alloys A6061 (% of weight)

Al	Mg	Si	Fe	Cu	Zn
97.749	0.810	0.530	0.250	0.160	0.0210
Mn	**Cr**	**Pb**	**Ti**	**Ni**	**Sn**
0.110	0.085	0.250	0.014	0.017	0.004

The controlled variables were 1600 rpm spindle spin speed and 6 mm burn-off length. Tensile strength test was conducted based on AWS (American Welding Society) standard. During the manufacture of friction welding specimens, a saw machine was used to cut the aluminum alloy A6061 bar. Water was then used as a coolant during the process. After that, the machining surfaces were polished and the rotating friction welding specimens, as shown in Fig.1, were generated by rotating the process on the lathe. The variables in this study include the upset pressure of 40, 80, 120 MPa and upset retention time of 3, 10, 20 seconds, as the independent variable. The controlled variables consisted of 1600 rpm spindle rotational speed and 6 mm burn-off length. The test of the tensile strength was performed following the AWS (American Welding Society)[13].

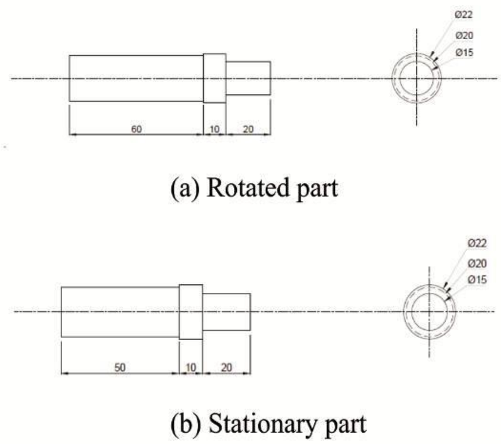

Figure 1. The geometry of A6061 friction weld specimens

In a continuous process of drive friction welding, the left rod was gripped by a chuck connected to a rotating electric motor at a speed of 1600 rpm. Whereas, the right rod was also gripped in a chuck which is able to provide 120 MPa compression pressure from the hydraulic pump system. Prior to the beginning of the friction welding process, the two contact surfaces of the specimen were cleaned with acetone. Welding was done by involving two parts for 6 mm burn of length (BOL); and once the BOL was reached, the spinning machine was turned off, and the rod on the right was continuously pressurized at 40, 80, 120 MPa for 3, 10, 20 seconds. Furthermore, the welded specimen was cooled in air. At the time of the CDFW process, using an infra-red thermal gun the temperature on the CDFW flash was measured to monitor the input heat and the correlation to the CDFW joint tensile strength.

The test specimens as illustrated in Figure 2 were proceeded in a machine on the lathe with water as a coolant for the tensile strength. The friction of the welded joint lies at the center of a testing specimen of the tensile strength. The tensile strength test was performed on AWS B4.0:2007 [13]. The tensile strength test was conducted employing a universal test machine with a crosshead speed of 2 mm/min. Moreover, the porosity of the specimen was measured using the Pycnometric method prior to the process of the tensile strength test.

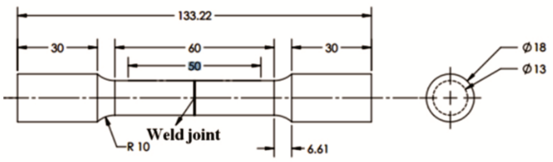

Figure 2. The geometry of A6061 tensile strength test specimens (dimensions in mm) [13]

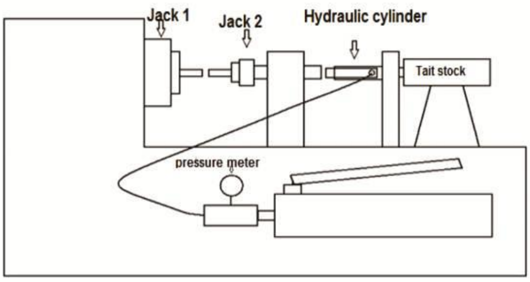

Figure 3. Friction Welding Tool Scheme

Figure 3 illustrates a simple friction welding machine. At the right moment, the rotation is halted and between the two components is a force applied. The pressure and heat combination creates a solid state bond at the interface of two merges [8].

RESULT AND DISCUSSION

The relationship among the joint CDFW tensile strength, setup pressure and holding time is depicted in Figure 4. As seen for any retention time, acceleration in upset pressure can cause a rise in the tensile strength of CDFW joint. Longer holding times provide adequate time to strengthen a more perfect metal bond in the interface. Maximum tensile strength is found on specimens with a shake pressure of 120 MPa and a hold time of 20 seconds. Meanwhile, minimal tensile strength is found in specimens with setup pressure of 40 MPa and a hold time of 20 seconds. It indicates that a higher interference pressure may cause a higher level of plastic deformation at the interface, followed by a longer hold time at the interference stage making the metal bond in the interface stronger.

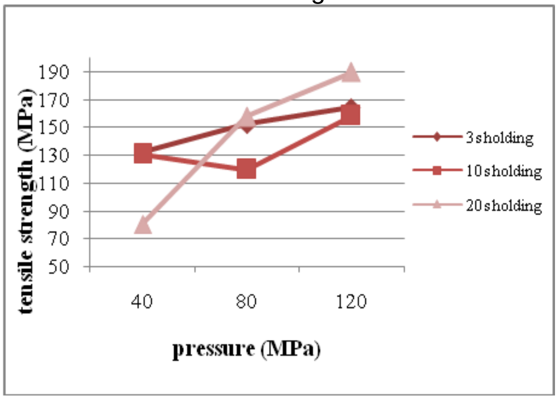

Figure 4. The tensile strength of A6061 friction weld specimens influenced by upset pressure and holding time.

The porosity test on the CDFW joint is illustrated in Figure 5. The result shows that when the upset pressure implemented on the specimen is higher, the porosity of the weld joint goes smaller. Similarly, a longer upset holding time reduces the weld joint porosity. This indicates that a higher upset pressure and longer retention time provide more energy to the compressed interface in order to make cavity occur from the specimen flash. The less porosity brings positive impact for increasing the CDFW joint strength.

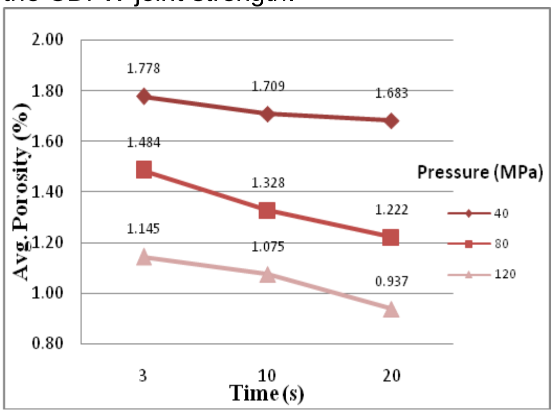

Figure 5. The porosity of A6061 friction weld specimens under the effect of upset pressure and the holding time.

The heat input during the CDFW process can be evaluated from the temperature of CDFW interface flash. Figure 6 shows the temperature cycle on the flash of the CDFW joint that has high tensile strength (120 MPa upset pressure) and low tensile strength (40 MPa upset pressure). It can be seen that the temperature of the specimen with higher upset pressure is slightly higher than that of the specimen with lower tensile strength. The higher temperature is due to higher mechanical energy that applied by the higher upset pressure that causes a higher degree of plastic deformation.

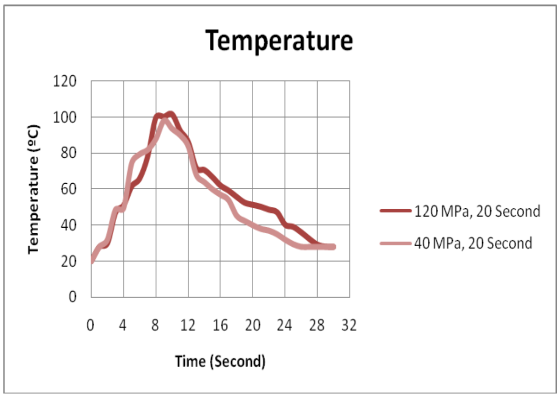

Figure 6. Flash temperature cycle for a specimen with high and low tensile strength, 120 MPa, 40 MPa upset pressure respectively

Figure 7 and 8 shows the microstructures of the center of the friction weld specimen with the highest and the lowest tensile strength. It can be seen that grain of specimen with the highest tensile strength as the result of 120 MPa upset pressure and 20 seconds holding time is smaller or finer than that of the specimen with the lowest tensile strength (Figure 8). It is thought that due to higher upset pressure can make a higher degree of plastic deformation so that the grain becomes smaller. Longer holding time give time more to the weld joint to be united longer to form metallic bonding under condition of high plastic deformation.

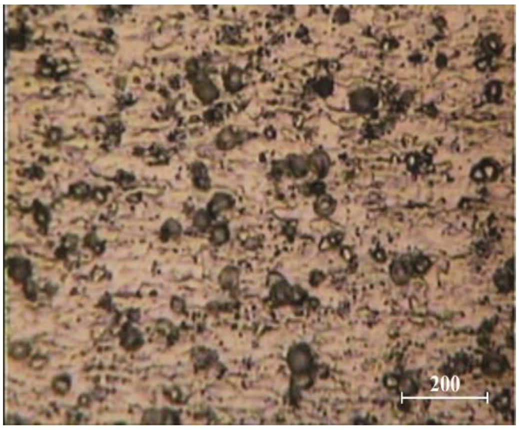

Figure 7. Photo microstructure of the specimen with highest tensile strength: a highest tensile strength with the upset pressure of 120 MPa, 20 seconds holding time and magnified photo 400x (scale in µm).

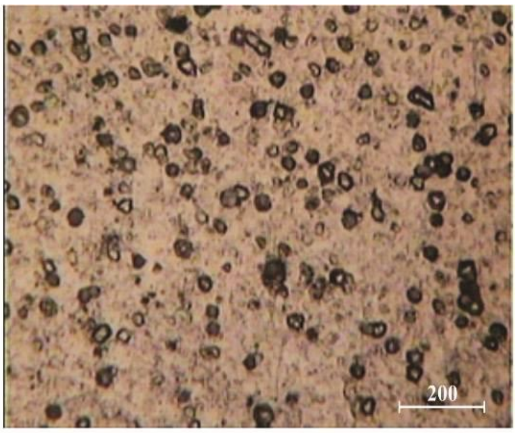

Figure 8. Photo microstructure of the specimen with the lowest tensile strength on the center A6061 welding joint: a lowest tensile strength with the upset pressure of 40 MPa, 20 seconds holding time and magnified photo 400x (scale in µm).

Figure 9 and 10 are longitudinal section macrostructures of CDFW specimens with holding time of 20 seconds and upset force of 40 MPa of the CDFW joint specimen with low tensile strength and 120 MPa upset pressure and 20 seconds holding time which has maximum tensile strength. It can be seen that both sizes of Zpl are the same, but the Zpd size of the specimen with maximum tensile strength is wider (Figure 10) than that of the specimen with lower tensile strength (Figure 9).

The differences between the macrostructure surfaces and Zpd size of the specimens are the result of the upset pressure and holding time during the CDFW process.

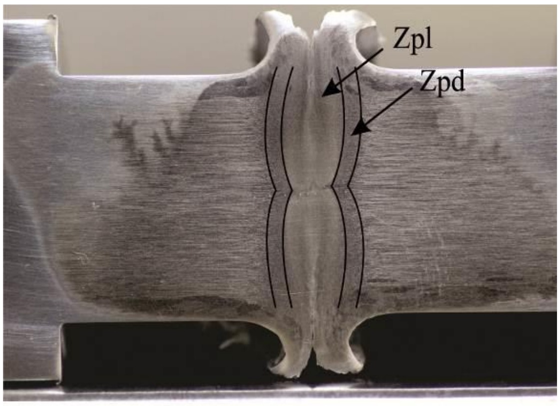

Figure 9. Longitudinal section macrostructure of CDFW specimen with holding time of 20 seconds and upset pressure of 40 MPa.

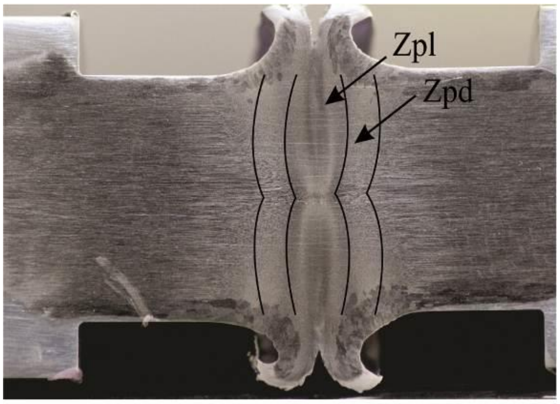

Figure 10. Longitudinal section macrostructure of CDFW specimen with holding time of 20 seconds and upset pressure of 120 MPa.

Figure 11. The fracture surface of the A6061 friction weld specimens with low tensile strength with the upset force of 40 MPa and 20 seconds retention time.

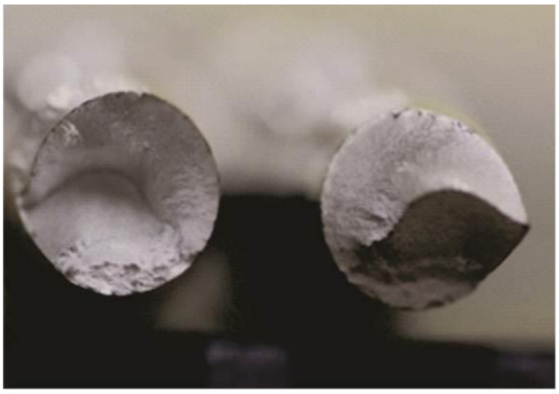

Figure 12. The fracture surface of the A6061 friction weld specimens with high tensile strength with the upset force of 120 MPa and 20 seconds retention time.

Figure 11 and 12 are a fracture surface photo of a CDFW joint specimen with high and low tensile strength. It can be seen in Figure 11 that there is a spinning-like mark that can be observed on a flat fracture surface. This shows that the specimen fractured in the interface where spinning occurs. Meanwhile, specimens with high tensile strength have a fracture surface without spiral marks and nonflat fracture surface. This is also confirmed by measuring the location of the fracture that the specimen is not cracked at the interface but in the heat affected zone. The difference from the surface of the specimen fracture is caused by the upset pressure and hold time during the CDFW process which higher upset pressure and holding time yield strong metallic bond in the interface.

CONCLUSIONS

In summary, there are three major conclusions in this study, including:

1. The pressure and holding time in the upset stage affected the tensile strength and macro-microstructure and tensile strength of the A6061 CDFW joint.
2. The higher upset pressure and longer holding time were able to increase the CDFW specimen tensile strength because of the higher heat input and the existence of plastic deformation in the interface.
3. The maximum tensile strength of the A6061 CDFW joint was found in the specimen with the upset pressure of 120 MPa and holding time of 20 seconds, which has wider partly deformed plastic zone (ZPl) and finer grains in the interface.

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