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Effect of friction time on the mechanical properties of AA 6061-T6 continuous drive friction welded joints

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Abstract

Continuous drive friction welding (CDFW) is a solid-state method used to join solid cylindrical metals. This process involves several key parameters that influence the strength of the connection, including friction time, friction pressure, and machine speed. The aim of this research was to determine the effect of different friction times on the mechanical properties of Aluminium 6061 CDFW joints. Friction time variations of 2, 3, 4, 5, 6, 7, 8, 9, and 10 seconds were used in the welding process, while other parameters remained constant: friction pressure at 30 MPa, upset pressure at 70 MPa, upset time at 2 seconds, and engine speed at 1000 rpm. Microstructure observations, Vickers microhardness testing, and tensile testing were conducted to assess the impact of friction time on the joint results. Analysis of the microstructure revealed changes, such as recrystallization, in the joint area. It was observed that the grain size in the joint area was smaller compared to that of the heat-affected zone (HAZ) and the parent metal. Hardness testing showed a decrease in hardness value with increasing distance from the joint. In the tensile test, the highest tensile strength of 215.76 MPa was achieved with a friction time of 6 seconds, while the lowest tensile strength of 78.60 MPa was obtained with a friction time of 2 seconds.

1. Introduction

Metal joining using the welding method is widely used in the manufacturing industry. As per DIN (Deutsche Industrie Normen), welding refers to the metallurgical bonding of metal alloy joints carried out in a liquid state. Welding can be categorized into two types: fusion welding and solid-state welding. Fusion welding involves melting the base metals by adding additional materials to the joined parts. However, fusion welding has limitations in terms of joint strength and is not suitable for solid metal joints. This drawback can be overcome by employing solid-state welding, which involves joining two material surfaces at a temperature below the melting point of the materials being joined without the addition of a filler metal [1], [2]. Solid-state welding is very suitable for joining solid cylindrical metals using friction welding [3] . Friction welding offers several advantages over fusion welding, including material savings, environmental friendliness, and the ability to join similar or different materials without needing a filler metal [4].

Some variations of friction welding include Friction Stir Welding (FSW), Friction Stir Spot Welding (FSSW), and Rotational Friction Welding (RFW). Continuous drive friction welding (CDFW) is a form of RFW that can be used to join similar and dissimilar cylindrical materials. The amount of heat input in friction welding depends on the spindle speed and time. In the CDFW process, one material is constantly rotated, whereas the other material is held and subjected to a friction force [5], [6]. Process parameters play an important role in continuous drive friction welding. Several parameters of the continuous drive friction welding process include the spindle rotation speed, friction time, friction pressure, forging pressure, and forging time [7]–[9]. These parameters directly impact the strength of the welded joint [10]. The joint strength increases in direct proportion to an increase in the friction time, friction pressure, and forging pressure. The friction time and chamfer angle also affect the strength of the 6061 aluminum joints. However, excessively long friction times can reduce connection strength [11]. CDFW has been extensively studied in many material configurations, whether comparable or different [12]. The setups involve welding various materials such as aluminum, AA 6061-T6 [13], AA 6061 to SS 316 [14] and AA6061-T6 to AISI 316L [15].

Aluminum is a material that does not bond easily due to its high thermal conductivity and surface oxides. The fusion welding of aluminum results in low joint efficiency, with a weld efficiency of approximately 86% and the presence of intermetallics at the interface [16]. In this case, continuous drive friction welding (CDFW) as a type of friction welding acts as the preferred solid-state welding method to overcome this problem because this process can remove oxides on the aluminum surface. A6061 aluminum has good corrosion resistance, moderate tensile strength, and good welding characteristics in many applications, such as automobiles, airplanes, and trains [17], [18]. The aim of this research was to determine the effect of friction time on the tensile strength and hardness and to observe the microstructure of aluminum 6061.

2. Research Methods

This research uses a solid 6061-T6 aluminum cylinder material which is cut to a length of 75 mm, then machined to a length of 70 mm, a large diameter of 20 mm with a length of 40 mm at a taper, and 30 mm turned with a diameter of 14 mm. The process parameters after the finished specimen was prepared for the joining process are presented in Table 3. Fig. 1 shows a schematic illustration of the CDFW welding process. After the connection was complete, the test specimen was subjected to tensile strength testing using the Japanese industrial standard Z 2201, as presented in Fig. 2.

Table 1. Chemical composition of AA 6061-T6 [19]

Element	Content weight %
Mg	1.2
Si	0.81
Fe	0.7
Mn	0.15
Cu	0.4
Cr	0.35
Zn	0.25
Ti	0.15
Al	Balance

Table 2. Mechanical properties of AA 6061-T6 [20]

Tensile strength (MPa)	310
Yield strength (MPa)	275
Elongation (%)	17
Hardness (HB)	64

Table 3. Process parameters for joining AA 6061-T6 CDFW

Process parameters	Values
Rotation speed (Rpm)	1000
Friction pressure (MPa)	30
Fricton time (seconds)	2, 3, 4, 5, 6, 7, 8, 9, 10
Upset Pressure (MPa)	70
Upset time (seconds)	2

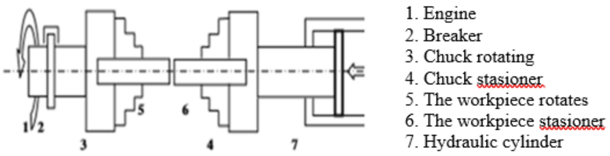

Fig. 1. Illustration scheme of the merging process using CDFW

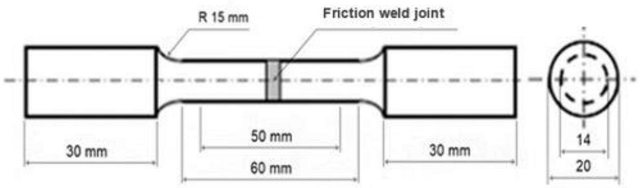

Fig. 2. Tensile test specimen according to Japanese industrial standard Z 2201

Tensile strength testing was performed on all the specimens using a Gotech GT-7001-LC50 universal testing machine. After completing the tensile strength test, microstructural observations were performed. Before the microstructure observation process, the specimen underwent cutting, resin, sanding, and etching using NaOh. Microstructural observations were carried out using an Olympus optical microscope type BX53MRF-S with 200x magnification. Subsequently, the specimens with the highest and lowest tensile strength results were tested for Micro Vickers hardness using a Shimadzu type HMV-M3 machine and a loading of 200 gf. The position of the point where hardness was tested on the test object is shown in Fig. 3.

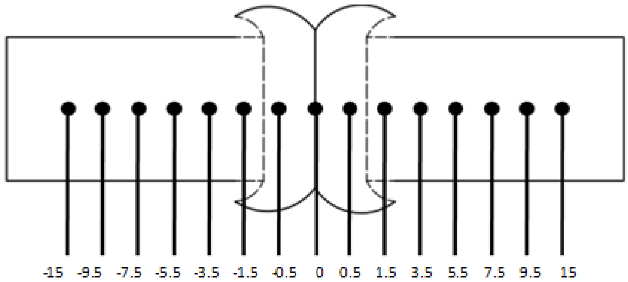

Fig. 3. Distance of hardness testing points

3. Results and Discussion.

The results of joining aluminum 6061 using the CDFW method are shown in Fig. 4. Apart from that, the results of the connection experience shortening and flash formation at each connection. Table 2. presents the results of joint shortening. This was caused by the friction time used. The greater the friction time used, the greater the shortening results.

Fig. 4. Results of joining 6061 aluminum CDFW

Table 3. Shortening results connection CDFW AA 6061

Fricton time (seconds)	Initial length (mm)	Length after welding (mm)	Shortening (mm)
2	60	59	1
3	60	57	3
4	60	51	9
5	60	49	11
6	60	45	15
7	60	41	19
8	60	40	20
9	60	37	23
10	60	32	28

3.1 Tensile strength testing

Based on Table 3, the amount of friction time has an influence on the obtained tensile strength. This can be explained by the increasing tensile strength value as the friction time used increases. However, if the friction time used is above 6 seconds, the resulting tensile strength value will be lower. The highest tensile strength result in this study was 215.76 MPa with a friction time variation of 6 seconds, while the lowest tensile strength value was 78.60 MPa with a friction time variation of 2 seconds.

Table 3. Tensile strength test results

Paraameter CDFW aluminum 6061				Tensile strength (MPa)
Fricton time (seconds)	Friction pressure (MPa)	Upset time (seconds)	Upset pressure (MPa)	
2				78.60
3				146.35
4				208.64
5				214.52
6	30	2	70	215.76
7				188.99
8				153.31
9				151.31
10				144.94

The connection results in this study show shortening, which is influenced by the friction time. So shortening can also be related to tensile strength which is also influenced by friction time. This relationship indicates that greater shortening is not proportional to the magnitude of the tensile strength obtained. The tensile strength decreases owing to the heat in the weld joint area during the welding process. The higher the heat of the welding process on aluminum, the lower the tensile strength . Another factor is that the heat produced does not meet the friction welding temperature, causing the atoms to be unable to bond. Therefore, deformation can be more optimal when applying forging pressure [3]. Increasing the friction time excessively results in the failure of the welding interface with minimal material mixing [4].

3.2 Microhardness testing

Hardness testing determines the position of the hardness point for data collection. Fifteen points were from which violence would be drawn. Determining the hardness point starts from 0 to the right 0.5, 1.5, 3.5, 5.5, 7.5, 9.5, 15 then to the left -0.5, -1.5, -3.5, -5.5, -7.5, -9.5, -15. A positive scale indicates that a hardness value exists in the rotating material. Meanwhile, a negative scale indicates that the hardness comes from the still material. The hardness test results for the test objects are shown in Fig. 5.

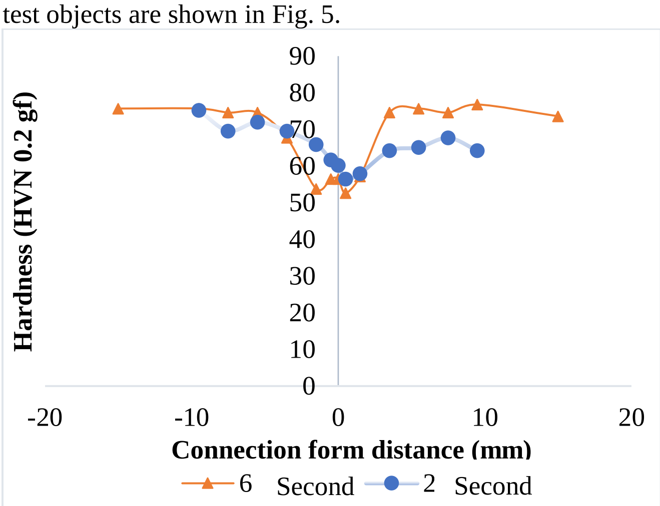

Fig. 5. Hardness test results object

Fig. 5 shows the changes in each test object, where the hardness value decreased as it approached the joint area. The hardness value decreased in the aluminum area with a friction time difference of 6 seconds compared to the aluminum area with a friction time of 2 seconds. In the joint with a friction time variation of 6 seconds, the lowest hardness value of 52.6 VHN was observed in the welded joint area. Meanwhile, the highest hardness value of 76.8 VHN is found in the base metal area. Meanwhile, considering the time variation of 2 seconds, the lowest hardness value of 56.5 VHN occurred in the welded joint area, while the highest hardness value of 75.2 VHN occurred in the base metal area.

3.3 Microstructure observations

This observation was carried out in three areas: the joint area, heat-affected zone of the rotating material, and heat-affected zone of the non-rotating material. The results of the microphotographs showing the highest and lowest tensile strength values are shown in Fig. 6. The magnification used was 200x.

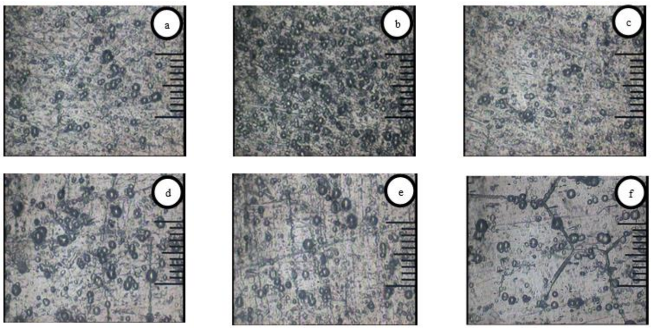

Fig. 6. a) HAZ area when friction of a rotating object is 6 seconds b) HAZ area when friction of a rotating object is 6 seconds c) HAZ area when friction of a rotating object is 6 seconds d) HAZ area is friction time of a rotating object is 2 seconds e) Joint area friction time is 2 seconds f) HAZ area friction time of stationary material 2 seconds.

Fig. 6 shows the results of micro photos with the highest tensile strength value, namely 6 seconds and the lowest tensile strength value, namely 2 seconds. In the joint area with a friction time of 6 seconds, recrystallization of the grain size is visible compared to a friction time of 2 seconds. Fig. 6 b) shows that the grain size in the joint area with a friction time of 6 seconds tends to be denser. This is caused by sufficient friction time so that the material can produce heat due to friction between the two material interfaces, so that it reaches the thermoplastic temperature. Meanwhile, in the HAZ area, rotating and stationary materials with friction times of 2 and 6 seconds tend not to experience changes in grain size.

3.4 Fractography

Based on Fig. 7, the connection at a friction time variation of 6 seconds shows that the fracture results do not break in the welded connection. This is because, during the friction welding process, the heat flow resulting from friction flows evenly so that the surfaces of the two pieces of aluminum blend well and produce a ductile joint. Meanwhile, with a friction time variation of 2 seconds, cracks can be seen at the joint. The friction time was too short; therefore, the heat was not evenly distributed over the joint. Therefore, the two aluminum surfaces were not connected properly. Fractures in joints are ductile and are characterized by plastic deformation in the area before fracture.

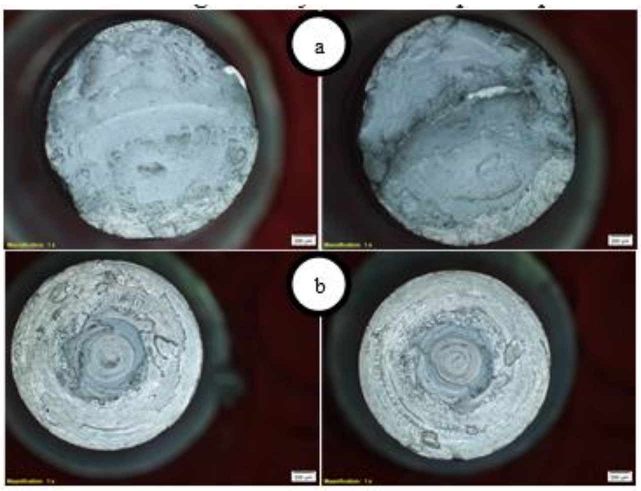

Fig. 7. a) photo broke in the tensile test with time swipe 6 seconds b) photo broke in the tensile test with time swipe 2 seconds

4. Conclusion.

Based on the results of the experiments, the following findings were obtained. The tensile strength value showed a significant increase with an increase in friction time variation. However, a further increase in time resulted in a reduction of the tensile strength, reaching its maximum at a friction time of 6 seconds. On the other hand, the hardness value of the aluminum material varied at different points. As the proximity to the joint area increased, the hardness value decreased. The lowest hardness value of 52.6 VHN was observed in the joint area with a friction time variation of 6 seconds, while the highest value of 76.8 VHN was found in the base metal area. Similarly, in the joint area with a friction time variation of 2 seconds, the lowest hardness value measured was 56.5 VHN, while the highest value of 75.2 VHN was observed in the parent metal area. Furthermore, upon observing the microstructure in the welded joint area, a change in the grain size was observed, and the fracture in the joint was determined to be ductile.

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