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Effect of Friction Pressure on the Mechanical Properties of CDFW Dissimilar Aluminium 6061-T6 and Stainless Steel 304 Welding Joints

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Abstract

Welding technology has significantly developed in the industrial sector along with advances in manufacturing technology. The demand for joining methods combining dissimilar metals is increasing in the industrial sector. However, joining dissimilar metals is challenging because of differences in physical and mechanical properties. Continuous drive friction welding is a solid-state joining method widely used to join dissimilar metals. The research aimed to determine the effect of variations in friction pressure on the mechanical properties of continuous drive friction welding joints with dissimilar materials, Aluminum 6061 T6 and Stainless Steel 304. The process parameters used in this welding were the friction pressures used were 30 MPa, 35 MPa, and 45 MPa. The friction time is 2 seconds, the rotation speed is 1000 rpm, and the upset pressure is 50 MPa. Then, welded joints were evaluated for Vickers microhardness and microstructure observations. Based on the research results, it shows that the temperature distribution and microstructure results show that there is a change in the hardness value of the aluminum material. In contrast, the 304 stainless steel material experiences an insignificant change in the hardness value.

INTRODUCTION

Welding technology has significantly developed in the industrial sector due to the advancement in manufacturing technology. The demand for joining methods that can merge identical and different metals has been steadily increasing in industrial sector. An encouraging sign of progression in welding technology is finding a new methods to tackle various issues in joining material. Friction welding is one of the new method used to improve on welding technology. Friction welding is a welding technique in the solid state. Solid-state welding is the joining of two material surfaces at a temperature below the melting point of the materials being joined and without the addition of filler metal (Suwanda et al., 2020a; Tashkandi & Gamil, 2022; Zhu et al., 2022). The two metals will be joined by combining heat and forging pressure (Husodo et al., 2013). Compared to other types of welding, the strengths of friction welding are not required flux, has minimum defects, can merge various types of metal, quick, energy efficient, and does not require the addition of any materials (Kumar & Jain, 2020). Methods for friction welding include friction stir welding (FSW), linear friction welding (LFW), and continuous drive friction welding (CDFW).

Previous researchers explained that the strength of CDFW welding joints is influenced by process parameters, including friction pressure, tempering pressure, rotation speed, friction time, and tempering time (Liu et al., 2020; Sahin & Misirli, 2012; Suwanda et al., 2020b). This parameter can directly influence the strength of the welded joint (Liang et al., 2017; Reddy et al., 2008). The effect of high pressure and a short time can conduct the connection between the two materials. However, the yield tensile strength might not attain the tensile strength of the source metal. This can be attributed to the fact that temperature will only increase the plastic accuracy of the two materials but not their tensile strength (Irwansyah, 2016; Rajalingam et al., 2024). Welding process can cause the surface area of to the joined workpiece to become brittle due to excessive heating, and heat affected zone (HAZ) area, become more extensive, thus affecting the mechanical properties of the material.

A higher temperature, atoms are denser and more homogenous, so the strain that occurs is smaller, which indicates the material is stiff and robust (Iswar & Syam, 2012).

The effects of friction pressure and forging pressure on joint strength are interdependent. The strength of welded joint of AISI 1045 material increases as the frictional pressure and forging pressure increase. However, the fractured material in the joint during the impact test may not establish a good bond at the joint interface since duration of friction and applied friction pressure not achieved a tight bond between the two material surfaces (Prasetyono & Subiyanto, 2012). The joint strength increases as the friction time increases. A short friction time will produce insufficient heat for atomic diffusion, thus limiting the metallurgical bonding of AA 6061-SS 304. However, a long friction time will cause excessive formation and defects at the interface (Abdulla et al., 2018; Wang et al., 2020).

The connection that use continuous drive friction welding has been successful in previous research. Process parameters have an important role as they may influence the strength of the CDFW welded joint. Several CDFW process parameters that influence joint strength include spindle rotation speed, friction pressure, upset pressure, friction time, and upset time. Therefore, further research is needed regarding process parameters for joining similar and dissimilar materials to produce optimal joint strength. This research aims to determine the effect of friction pressure on connection quality.

RESEARCH METHODS

This research used various parameters of forging pressure which were 30, 35, and 40 MPa. Other parameters used were engine speed of 1000 rpm, forging time of 2 seconds, friction time of 2 seconds, and forging pressure of 50 MPa. Some supporting tools for conducting research are type K thermocouples, load cells, data loggers, and a set of computers. Solid cylinders from AA 6061-T6 and SS 304 are the materials used for this research. The steps to produce the specimens by preparing the materials and equipment. Cutting both AA 6061-T6 and SS 304 using a band saw with a length of 75 mm. The resulting pieces were turned into a lathe with the dimensions in Figure 1. Then, drilling is carried out on the aluminum part, which would later be used to place a thermocouple to measure the temperature distribution.

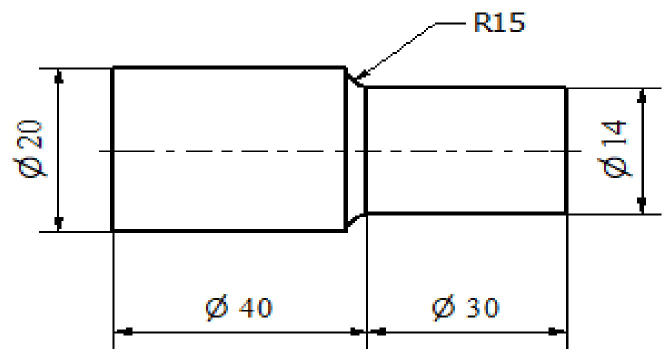


Figure 1. Workpiece dimensions

The thermocouple installation consists of preparing the specimen to be tested, a hand drill machine, and a drill bit with a diameter of 1.5 mm. Drill four holes in the test specimen with 5 mm in each hole, as places for T1, T2, T3, and T4, and install a thermocouple in each hole, as shown in Figure 2. In addition, the specimen is prepared for the connection process with variable parameters. The research is shown in Table 1.

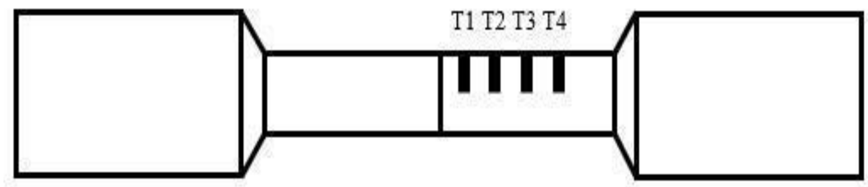


Figure 2. Thermocouple installation position

Table 1. Research parameter variables

No.	Friction Pressure (MPa)	Friction Time (second)	Upset Pressure (MPa)	Upset Time (second)
1	30	2	50	2
2	35	2	50	2
3	40	2	50	2

AA 6061 T6 is installed on a stationary spindle, the thermocouple installation process is carried out, and SS 304 is installed on a rotating spindle. The spindle rotation speed on the CDFW machine used is 1000 rpm. The stationary spindle is given a pressure of 30 MPa; after rubbing for 2 seconds, the motor is stopped, and an upset pressure of 50 MPa for 2 seconds. After that, the material that has been connected is removed and replaced with the next connection, namely 35 MPa and 40 MPa.

Hardness testing used a Micro Vickers hardness tester with a loading of 200 gf. Determining the hardness testing point starts from size 0 or in the middle of the connection results to the right 0, 0.5, 1.5, 3.5, 5.5, 10 mm, then to the left 0, -0.5, -1.5, -3.5, -5.5, -10 mm using a vernier caliper. An illustration of the position of the data collection point can be seen in Figure 3.

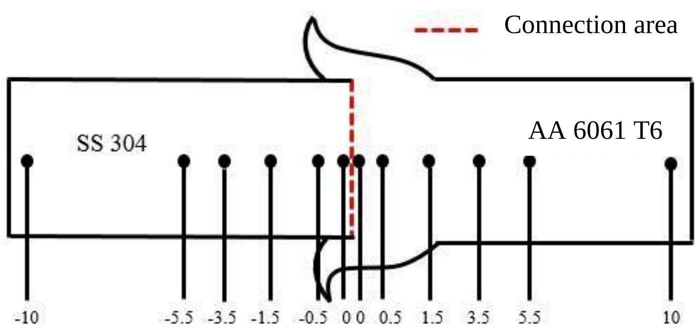


Figure 3. Position of hardness testing point

RESULTS AND DISCUSSION

1. Shortening of welding results

The results of welding using the CDFW AA 6061-T6 and SS 304 methods are shown in Figure 4. The shortening and flash that occur look different in each friction pressure variation. The shortening measurement results are provided in Table 2. Table 2 shows that the amount of shortening that occurs caused by the friction pressure used. Considerable friction pressure is directly proportional to the shortening that occurs.

Figure 4. CDFW welding results (a) 30 MPa, (b) 35 MPa, (c) 40 Mpa

Table 2. CDFW connection shortening results

No	Friction pressure (MPa)	Initial length (mm)	Length after welding (mm)	Shortening (mm)
1	30	153	150	3
2	35	153	148	5
3	40	153	145	8

2. Temperature Distribution

Figure 5 compares the maximum temperature distribution at varying friction pressures at 30 MPa, 35 MPa, and 40 MPa, forging pressure at 50 MPa, forging time at 2 seconds, and friction time at 2 seconds. The results show that variations of friction pressure affect the attainability of the temperature distribution. The higher the friction pressure applied, the higher the temperature distribution. The result of the maximum temperature comparison proves that the high friction pressure is linearly proportional with the temperature increase that occurs.

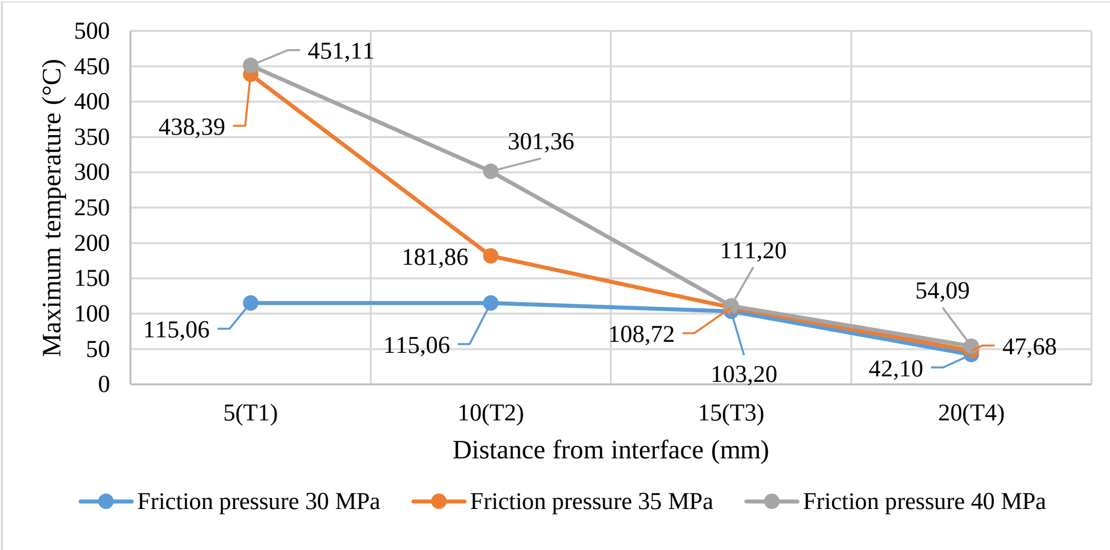
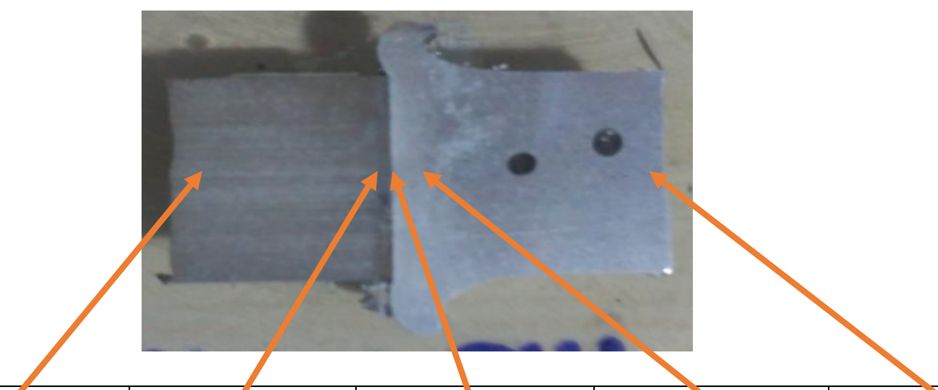
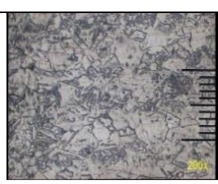
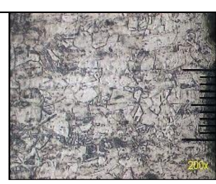
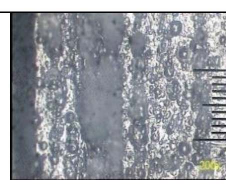
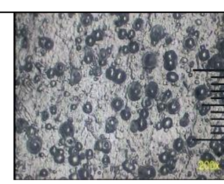
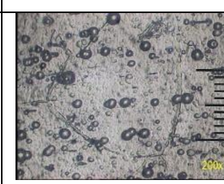


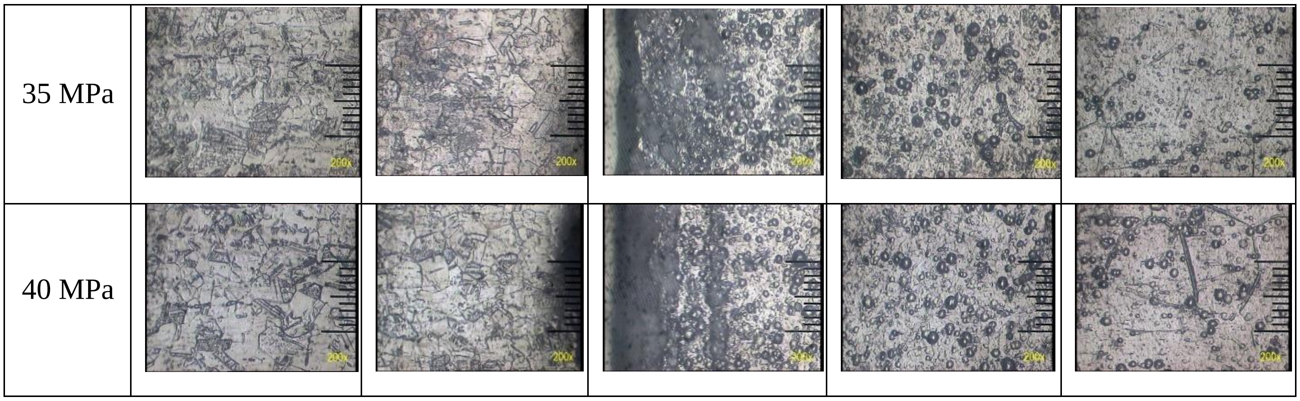
Figure 5. Comparison of maximum temperature distribution

3. Microstructure Observation

After observing each specimen at friction pressures of 30, 35, and 40 MPa. Figure 6. (A) the parent metal stainless steel 304 shows large grains piling up in the same order as the other variations. In addition, HAZ on stainless steel was not observed. Figure 6. (B) is the area where the 304 stainless steel connection has not changed, where the structure is the same as the parent metal. Figure 6. (C) the area of the 6061 T6 aluminum joint experiences the most obvious microstructural changes where the smaller grain sizes stick together and fuse more tightly. Figure 6. (D) in the HAZ area of aluminum 6061 T6, we can see where the grain size increases and gets closer to each other. Figure 6. (E) is the parent metal area of aluminum 6061 T6.



Friction pressure	A	B	C	D	E
30 MPa					



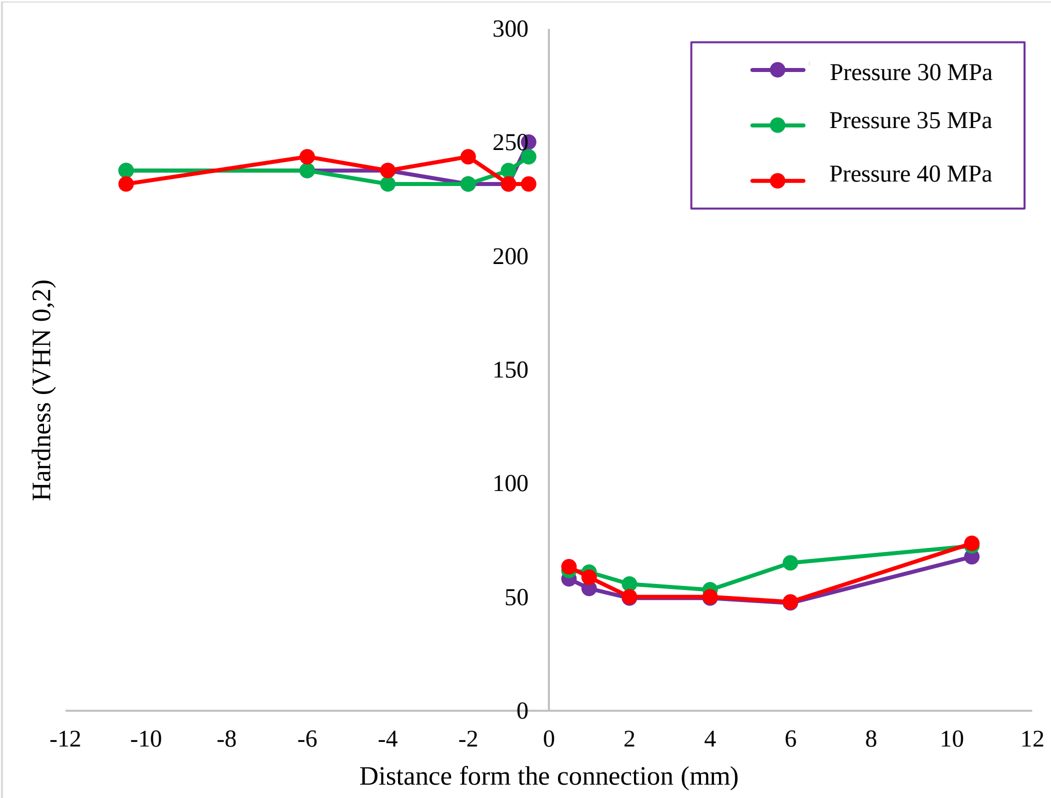
SS 304 AA 6061 T6

Figure 6. Microstructure (A) SS 304 base metal (B) SS 304 connection (C) AA 6061 Connection (D) AA 6061 HAZ (E) AA 6061 base metal

From the whole microstructure test result, it can be observed that the friction pressure and temperature distribution affect microstructure observation result. As higher friction pressure and temperature distribution obtained, the larger and denser the grain size is. Nurdiansyah et al., (2012) explained that the grains in the HAZ area changed from the original flat and long shape in the base metal area to oval and almost round. This is caused by the weld metal area experiencing higher heat input than the HAZ and base metal areas. The grain size in the weld metal area is much larger than in the HAZ and base metal areas. This causes the grain size in the weld metal area to become more prominent.

4. Hardness Testing

Figure 7 presents the results of the friction pressure variation of 30 MPa with a hardness value at the joint of 67.7 VHN, 35 MPa with a hardness value at the joint of 72.5 VHN, and 40 MPa with a hardness value at the joint of 73.6 VHN. The lowest hardness value for aluminum metal occurs in the HAZ section—the HAZ section of AA 6061 experiences metal softening caused by the welding heat that arises. Nurdiansyah et al. (2012) explained that the larger the Mg grain size, the lower the level of hardness to decrease. Friction welding parameters supported by temperature distribution and microstructure results prove that friction pressure of 35 MPa has the best hardness value compared to 30 and 40 MPa pressures. The data above shows that friction pressure is not directly proportional to the hardness results obtained. The best hardness is obtained from friction pressure that is not too high and temperature distribution that is not excessive.



Sahin (2007) explained that the hardness test values performed were similar to this research, and the hardness results were not much different. The hardness value in the aluminum region is between 50 to 60 VHN. A distance of 0.2 millimeters from the joint in stainless steel material produces a hardness value of 290 VHN, a distance of 1-2 millimeters from the joint produces 225 VHN, and a distance of 3-4 mm from the joint produces 230 VHN. His research determined that the best parameterswere 30 Mpa friction pressure, 60 Mpa upset pressure, and 4 seconds for friction duration. These values are determined based on the research result. Meanwhile, the rotation speed was 1410 revolutions per minute, and the upset time is 12 seconds.

CONCLUSION

The results of research on welding CDFW dissimilar AA 6061 T6 – SS 304 using variations in friction pressure of 30 MPa, 35 MPa, and 40 MPa can be concluded that: (1) The higher the friction pressure variation, the higher the temperature distribution value obtained. (2) The results of microstructure observations show that the temperature distribution will influence the microstructure changes in the aluminum 6061 T6 area, and in the stainless steel 304 area, there is no change in microstructure. (3) Vickers method hardness testing with a loading of 200 gf for 5 seconds and supported by the results of temperature distribution and microstructure shows that there is a change in the hardness value in the aluminum material, while in the 304 stainless steel material, the change in hardness value that occurs is assumed to be the same as the hardness value of the parent metal.

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