JES, Vol. 52, No. 5, Sept. 2024 DOI: 10.21608/JESAUN.2024.258411.1298 Part C: Mechanical Engineering

Journal of
Engineering Sciences
Faculty of Engineering
Assiut University

مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط

journal homepage: http://jesaun.journals.ekb.eg

Rotary Friction Welding of Aluminum Alloy Tube to Tube with Edge Using External Tool

Received 26 December. 2023; Revised 19 Iune 2024; Accepted 20 June 2024

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Keywords
Rotary Friction Welding, Aluminum Alloy, Tube to Tube, External Tool.

Abstract: This friction welding process is characterized by the fact that there are no springs or deformations at the welding point, neither from the outside nor from the inside, and an unmistakable and ideal welding shape is obtained. The experiment was conducted on a flat sample without grooves, and it was welded, but it was very weak. Then grooves were made on the outer edge, and the welding took place, and it was a stronger weld. The idea was to increase the grooves to the end of the entire thickness of the sample, not just on the edge, and it was the strongest weld and optimal in shape. Several experiments were also performed. Experiments were conducted at different speeds until the four speeds used in this thesis were reached, the best of which was 1000 rpm. Experiments were conducted at different forces, and the four forces used became the best among those used in many experiments. The best of them was the force of 30 kg_F, at a fixed time of 4 minutes, while the temperature was 200oC on surface welding at 4 minutes the welding process. For every speed and force, this appeared in the tensile test conducted on the samples after welding and was demonstrated that tensile dismantled force was 6160 N at 30 kg_F of welding pressure. The study proved the success of this method, and it is also possible try it with other metals and changes it as necessary.

1. Introduction

When two pieces of metal are heated to their melting temperature and then permanently joined together, the process is called welding. To strengthen the bond between the two components, more metal, also called filler metal, is introduced as the two parts are heated. In general, it is

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https://doi.org/10.21608/JESAUN.2024.258411.1298
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a process whereby two identical (or different) pieces of metal can be fused, with (or without) the need for additional material, by heating them to a sufficiently high temperature [1, 2]. Friction welding is the welding process in which the heat required for welding is generated by friction between the ends of the two parts to be joined [1]. One of the parts to be joined is rotated at a high speed of about 3000 rpm and the other part is aligned axially with the second part and pressed firmly against it. The friction between the two parts increases the temperature at both ends [3]. The rotation of the part is then abruptly stopped and the pressure on the fixed part is increased so that the connection is made [1, 2]. Friction welding can be considered as forge welding because the welding is done using pressure. In friction welding, the heat required for the welding process is generated by the friction between two surfaces to be joined. Sufficient heat can be generated and the temperature at the point of connection rose to a level where the surfaces subjected to friction can be welded together [3, 4].

Friction welding is a series of solid-state processes that use the frictional heat generated by the direct interaction between moving work-pieces, with added compressive force to plastically diffuse the material between the two work-pieces. Many different combinations of materials can be joined and there are several operations where this is possible [2, 4]. Friction welding of smaller parts can be done using a center lathe with proper fixtures, jigs and machining settings, but larger parts require the use of dedicated machinery [1, 3 and 4]. This is because the power available in a lathe may not be sufficient to rotate a larger part at the desired speed and to provide sufficient axial force required for friction welding (Power requirements for friction welding larger parts can range from 25kVA to 25kVA vary to 200KVA). Another consideration is that quick release and instantaneous braking of rotating parts would be impossible on general purpose lathes [5].

In the RFW, one of the two work-pieces is rotated relative to the stationary other while compressive axial frictional pressure is applied. The interfaces of the material are plasticized as heat is generated by the friction between the two work-pieces [6, 7]. The axially applied pressure from the interface displaces the plasticized material, forcing the interfacial oxide layers and other contaminants out of the way to allow the bond. This deforestation process creates a burr collar and reduces the axial length of both work-pieces [2, 5 and 8]. Once the desired reduction (burn-off distance) is achieved, the rotation is stopped, and forging pressure is applied for a period to help strengthen the joint [1]. For aluminum alloys, RFW weld settings and conditions are still being explored to produce strong welds. By varying the rotation speed from 500 to 2100 rpm when welding the 6061-T6-Al alloy, Li et al. (2018) observed the frictional behavior of RFW and found that after reaching the rotation speed of 1500 rpm, an infinite area is manifested in the weld [9]. The friction welded Al samples from 2014 were also published by Etesami et al. tested. (2015) who found that increasing the rotation speed minimizes weld defects while increasing the hardness and strength of the material. By maintaining the same rotational speed while varying the friction pressure and friction time, Kimura et al. (2006) increased joint efficiency by friction welding and studied the effects of welding conditions on the mechanical properties of 5052 Al alloy.

The influence of rotational speeds when combining different metals was also investigated in friction welding. Speeds in the range of 1400 to 1600 or 1700 rpm have been described as ideal for making strong welds [1, 4 and 7]. In addition, the influence of rotation speeds on the microstructure (deformed zones) of the alloy of aluminum oxide and 6061 aluminums was investigated. It has been found that increasing the rotation speed leads to an increase in the deformed zone that is fully plasticized [10]. Al alloys melted by friction welding are expected to have good mechanical properties. However, with the best welding settings, flawless welds with excellent mechanical properties should be achieved [11, 12]. If the material is artificially aged (at a temperature between 150 and 300 °C) after cooling from high extrusion temperatures (without solution treatment), the mechanical properties of the 6061 Al alloy are improved (ASM Handbook, 1981). To study the mechanical properties of the alloy, RFW selected and welded the 6060 Al alloy. Mechanical tests were then carried out on the welds at different rotation speeds [8, 10].

By parametric optimization of the friction welding process, numerous researchers attempted to maximize the UTS for friction welded joints. [1, 13] Researchers consider the following parameters in parametric optimization: friction time (FT), friction pressure (FP), spindle speed (SS), and length burn (BOL) [11, 14]. Friction welding parameters can also be further divided into sub-branches based on upset time, upset pressure and break time [13, 15]. Researchers focused on studying the microstructure of friction welded joints under the electron microscope and characterizing the microstructure of friction welded joints made of different metals. Researchers also reported interesting findings from joint microstructure studies on new layer formation and grain structure at welded joints. Friction time, Friction was determined by Moomin Sachin et al. discovered. Pressure has a direct impact on the tensile strength of connections [2, 5].

There are not many studies on aluminum alloys in the literature and the only one dealing with non-MMC compounds is this one [7, 11]. Using only one set of process settings for the experiments, the research authors focus on the microstructural and mechanical characterization of AA 2024 compounds from both static and dynamic perspectives. It is important to note that the high thermal conductivity of aluminum alloys creates additional challenges for LFW. This narrows the process parameter window for proper connections and requires large frequency and pressure values for material flow stress at processing temperatures [11]. The potential of the technique is significantly greater than what has been explored to date, based on the results of the cited studies have identified for LFW materials other than titanium and nickel alloys. The prior art lacks expertise as the thermo-mechanical properties of the material makes it difficult to effectively tune the process [16].

Low carbon steel 304, stainless steel, and aluminum-copper were the two different combinations that D. Ananthapadmanaban [2011] studied in weld growth. He also studied how the mechanical properties of the welds are related to the microstructure. The parameters of the low-carbon stainless steels included the friction pressure (40, 120 MPa), forging pressure (127.5, 180 MPa), rotation speed (1000, 2000 rpm) and burning length (2, 6) mm. For aluminum-copper, the parameters included friction pressure (63.5, 82.2, 95.4 MPa), forging pressure (127.2, 159, 190.8 MPa), rotation speed (500, 750, 1000 rpm), and burn length (1, 2, 3mm). Results were evaluated using the means of mechanical property data from flexure, hardness, impact and tensile tests [17, 18]. Microstructure and SEM fractography were used to study how friction welding parameters affect the type and nature of the fracture. For low carbon steel and type 304 stainless steel, the ideal friction pressure, forging pressure, and speed were 120 MPa, 127.5 MPa, and 1000 rpm, respectively; For aluminum and copper, the ideal values were 63.5 MPa, 127.2 MPa and 750 rpm [15]. Tensile strength appears to improve when the crush pressure increases to a certain maximum value before decreasing. Strength was affected by rotation speed for aluminum and copper, as well as low carbon steel, stainless steel and aluminum [6, 13].

In this work, solid state welding involves welding two pipes together using rotary friction welding. However, this welding differs from other welds in that the two tubes rotate together in the same direction on the lathe. Welding is done between the thicknesses of the outer edge wall of the two tubes. First, the tool is pressed onto the outer edge wall. Next comes the friction and then the head is created to make the weld. Note that the welding tool is attached to a force measuring device. This welding process is characterized by the fact that there are no springs or deformations at the welding point, neither from the outside nor from the inside, and an unmistakable and ideal welding shape is obtained.

2. Methods and tools

2.1. Samples Dimensions

Aluminum alloy materials were used; pairs of Al cylindrical rods of 26 mm in outer diameter, 22 mm in inner diameter and 20 mm in length were bonded to the RFW. In this work 16 samples were used, Figure 1.

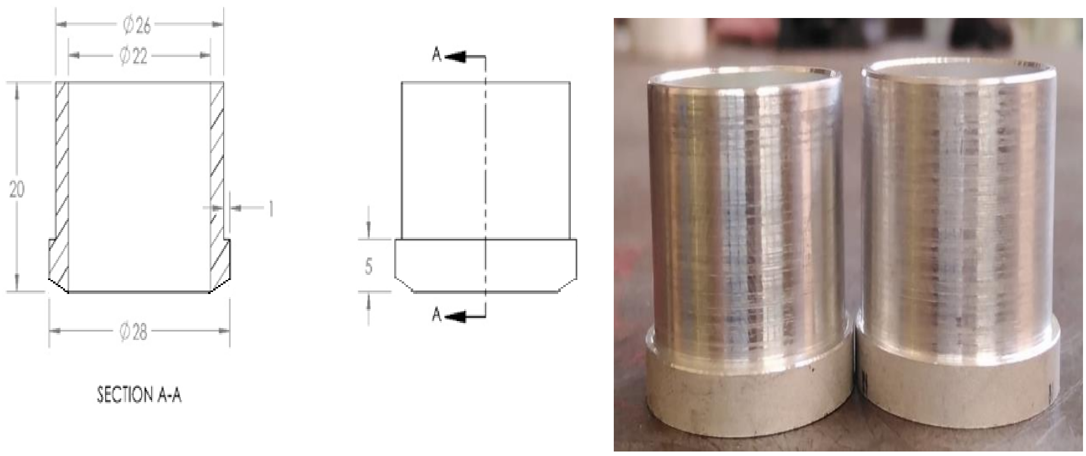


Figure 1: The sample dimensions of Al cylindrical rods

2.2. Materials and chemical compositions

The analysis report was prepared by Belec Vario Lab 210607 at TIMS Tabbin Institute, Cairo, Egypt. The chemical compositions of the 6061-T5 Al alloy are given in Table 1. The physical, mechanical, thermal and electrical properties of the 6061-T5, all materials are listed in the table.

Table 1: The chemical compositions and properties of 6061-T5 Al alloy

The chemical compositions of the 6061-T5 Aluminum alloy			**Alloy properties**	
Symbol	**Unite**	**Observed Value**	**Physical properties**	
Si	%	0.497	Density (P)	2.70 g/cm3
Fe	%	0.600	**Mechanical properties**	
Cu	%	0.037	Young Modulus (E)	68 GPa (9.900Ksi)
Mn	%	0.022	Tensile strength	124 – 290 MPa
Mg	%	0.420	Elongation at break	12 – 25 %
Cr	%	0.013	Poisson ratio	0.33
Ni	%	0.004	**Thermal properties**	
Zn	%	0.067	Melting Temperature	585 C^0
Ti	%	0.019	Thermal conductivity (K)	151 – 202 W/(m-k)
			Specific heat capacity	897 J/(Kg.K)
			Electrical properties	
Bi	%	0.005	Volume Resistivity	32.5 – 39.2 nOhm.m
Ca	%	0.0111		
Co	%	0.001		
Pb	%	0.011		
Sn	%	0.015		
V	%	0.005		
Zr	%	0.004		
Al	%	98.27		

2.3. Experimental set up

In this study, friction welding was used for two pipes rotating together in the same direction, using the flat and curved tools installed on the lathe at different speeds between 630 and 1250 rpm. In addition, forces between 20 and 35 kg_F and period times of 4 minutes were used. An examination of the welded samples was performed using a tensile test study to identify relationships that differentiate the strength of the method in welding two metals from other methods.

2.4. Experimental procedures on the lathe

1. The pipe was cut into pieces with a length of 20 mm, and an outer diameter of 26 mm. It was filtered and the diameter of the sample became 24 mm, the diameter of the sample at the outer edge was 26 mm, and the inner diameter was 22 mm.

2. Then he made grooves of 22.5 angles for each part to complete an angle of 45.
3. The sample was mounted on the column prepared for it, then an internal rosette, an external rosette, and a nut were placed to connect the sample, and the column was placed in the lathe chuck.
4. The device was installed on the lathe clip and secured with the tool used to press on the sample to weld it.
5. The lathe was operated at one of the speeds used, then touch and contact was made with the external tool graduated with sample, and the pressure was applied with the desired force and fixed so that no change occurred except a slight and ineffective change, and this was done for 4 minutes for the welding to occur.
6. The temperature was measured with a laser on the outer surface of the welding area, which at the fourth minute was 200 C^0.

The main parameters used for the present work to perform the friction welding were three different rotation speeds, namely 630, 800, 1000 and 1250 rpm, respectively. The welded bars were grouped as a friction time of 4 minutes, and 5 min, regarding the rotational speeds. The forces (frictional pressure) were 20 kg, 25 kg, 30 kg and 35 kg, and the frictional forces resulting in heat input were generated, resulting in mixing of the material. The lathe (lathe models ND-195E and ND-220E) was adapted and used for this RFW process before starting the process due to its stability and precision. Therefore, two tools of the lathe were used for welding, the tool was flat (Figure 2).
Description of lathe: 1. Lathe chuck, 2. The sample, 3. Measuring device of force, 4. The tool of welding.

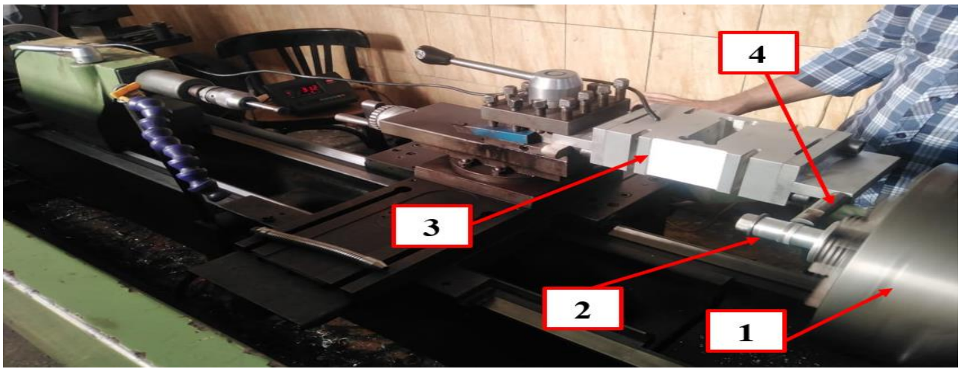


Figure 2: Experimental set-ups on lathe models ND-195E and ND-220E with strain gauges and weighing indicator

The XK3190-A12 (E) weighing indicator is a non-automatic weighing indicator for platform scales. It can be connected to electric platform scales, electric floor scale and 1-4 350-ohm load cells of the scale model. It is mainly used in enterprises with factories, wholesale markets, bus stations, ports, mines, warehouses, etc. and all kinds of weighing occasions. To measure the force, the weighing indicator was connected to a strain gauge.
Description of the specimens clamped using the lathe chuck: 1. Bar of sample, 2. Washer, 3. Frist half of work piece, 4. Second half of work piece, 5. Nut.

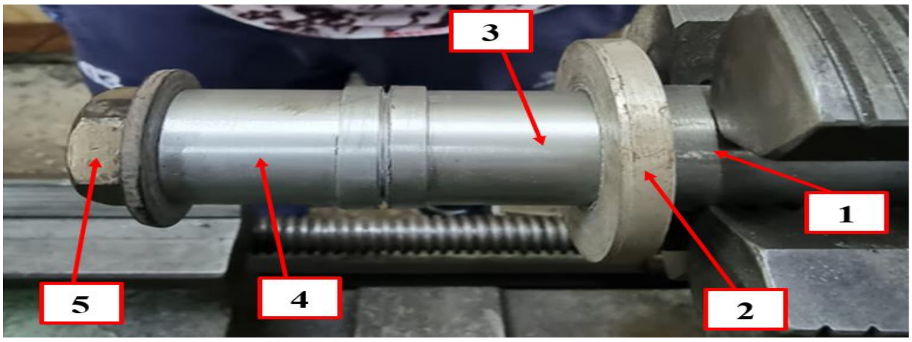


Figure 3: The specimens clamped using the lathe chuck in the welding position

2.5. Tension Test

All tensile specimens were tested on a computer-controlled servo-hydraulic universal testing machine (DFM-300KN) with a maximum load capacity of 30 tons and a crosshead speed range of 0.1 to 50mm/min as shown. The encoder resolution is 0.0005mm and the load accuracy is 0.5%.

2.6. Temperature examination

The Crown CT44037 thermometer was used, which can measure temperature from 50 to 600 °C. The measurement accuracy is below zero °C. It can take a frequency measurement every half second. The measuring distance is 12 cm to 12 meters. The temperature was measured manually at the end of welding time during the welding process, and it was about 200 ^{o}C on the surface of weld.

3. Results and Discussion

When the excess edge is rotated and then subjected to intense pressure, grooves are made in the excess edge with a thickness of 1 mm. The sample is then tensioned after welding, and the result is less than the complete grooves on the edge and the thickness of the sample combined with a thickness of 2 mm. This is done to improve the weld, and the tensioning result is better. As such, the current study is distinct from earlier research in a number of ways. To create the weld, significant force is applied to the extra edge once rotation has been completed. Next, for a better outcome, grooves or gaps are created to strengthen the weld. As a result, the study at hand is distinct from earlier research in a number of respects.

1. In this investigation, the entire sample rotated in the same direction, as opposed to earlier experiments where one end of the sample was fixed while the other rotated.
2. In this study, pressure is applied with an external tool to both sample parts simultaneously in the opposite direction of the rotational movement, as opposed to previous studies where pressure was applied with one sample part on the other within the same direction as the rotation.
3. In previous studies, the welding is done face to face, but in this study, the welding is done on an extra edge on the pipe, as shown in the picture.

The experiments began with the knowledge that rotary welding depends on the speed, pressure, and heat generated between them. We discuss what these laboratories were like and how the welding occurred with them during the experiments. The temperature depends on the rotation speed, and the higher the rotation speed, the higher the temperature. The welding temperature is related to the degree of hardness of the metal, and the higher the degree of hardness of the metal, the higher the required temperature.

In the initial stages, several experiments were conducted at different speeds close to those used previously, with previous research in the same direction, and it was found that the following speeds were better than others (630, 800, 1000, and 1250) rpm. Experiments were also conducted at several applied force until the best one was reached, which is (20,25,30 and 35) kg_F, and the time was at 4 minutes.

3.1. The flat tool at 630 rpm

The dismantled force in tension seemed to be 2284 N when the welding pressure was set to 20 kg_F. Tensile dismantled force at 25 kg_F welding pressure was 2176 N. It appeared that the tensile dismantled force was 2771 N at 30 Kg_F of welding pressure. Tensile dismantled force at Fa 35 kg_F of welding pressure was 2002 N.

3.2. The flat tool at 800 rpm

The dismantled force in tension seemed to be 2955 N when the welding pressure was set to 20 kg_F. The tensile dismantled force was 3512 N when the welding pressure was 25 kg_F. Tensile dismantled force at 30 kg_F of welding pressure was 3647 N. Tensile dismantled force at 35 kg_F of welding pressure was 1921N.

3.3. The flat tool at 1000 rpm

Tension dismantled force was 2154 N at 20 kg_F welding pressure. Tensile dismantled force at 25 kg_F welding pressure was 4618 N. Tensile dismantled force was 6160 N at 30 kg_F of welding pressure. The tensile dismantled force was 4015 N when the welding pressure was 35 kg_F.

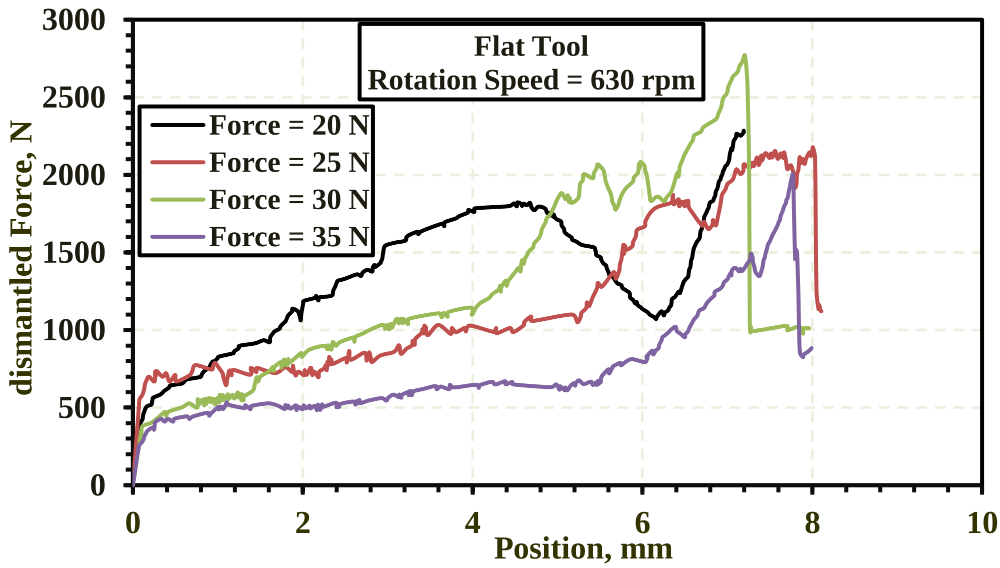


Figure 4: The relationship between (F_d) and (P) at 630 rpm for flat tool with different (F_a)

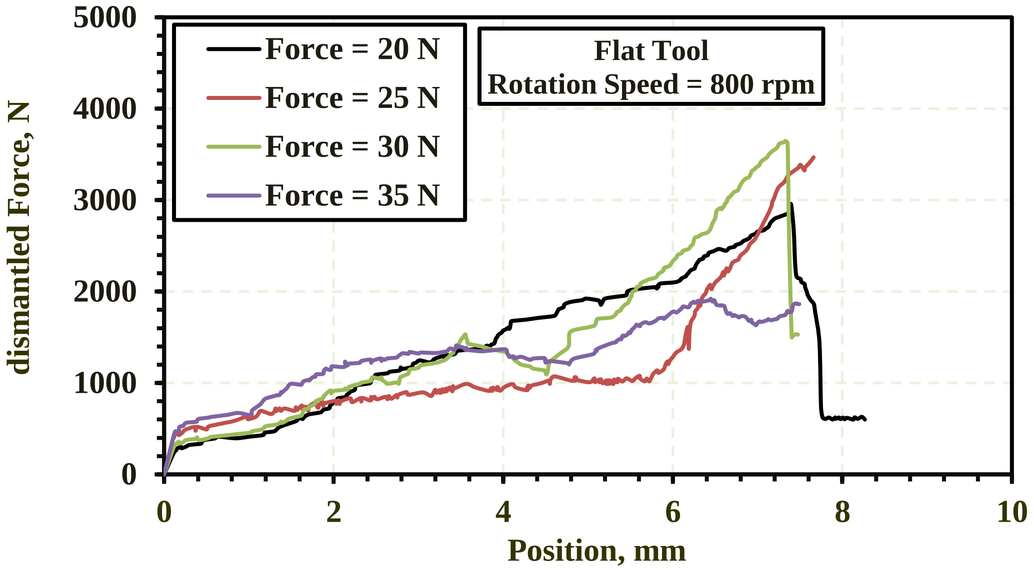


Figure 5: The relationship between (F_d) and (P) at 800 rpm for flat tool with different (F_a)

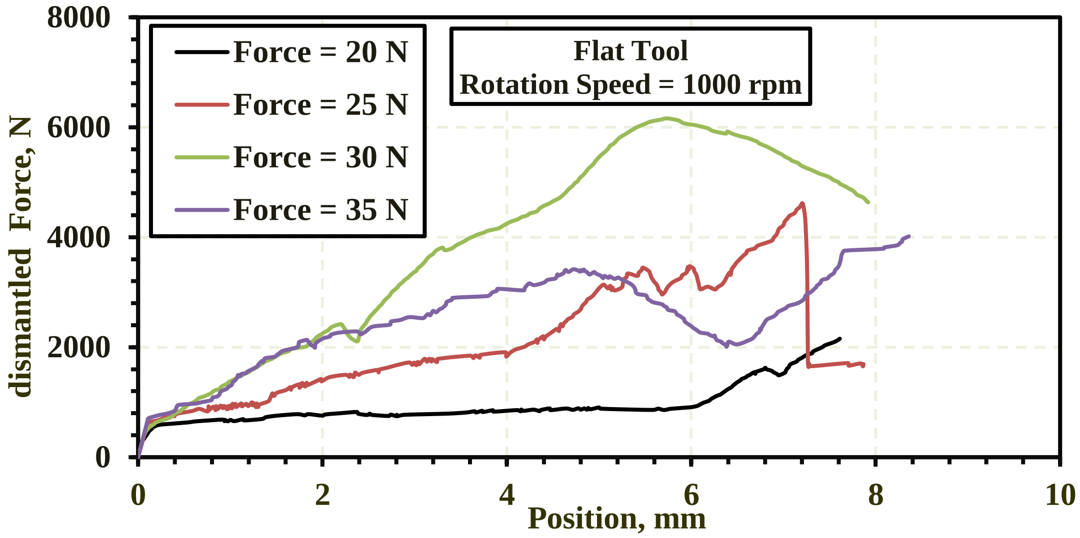


Figure 6: The relationship between (F_d) and (P) at 1000 rpm for flat tool with different (F_a)

3.4. The flat tool at 1250 rpm

The dismantled force in tension seemed to be 3651 N when the welding pressure was set to 20 kg_F. Tensile dismantled force at 25 kg_F welding pressure was 4527 N. Tensile dismantled force was 5420 N at 30 kg_F of welding pressure. The tensile dismantled force was 3254 N when the welding pressure was 35 kg_F.

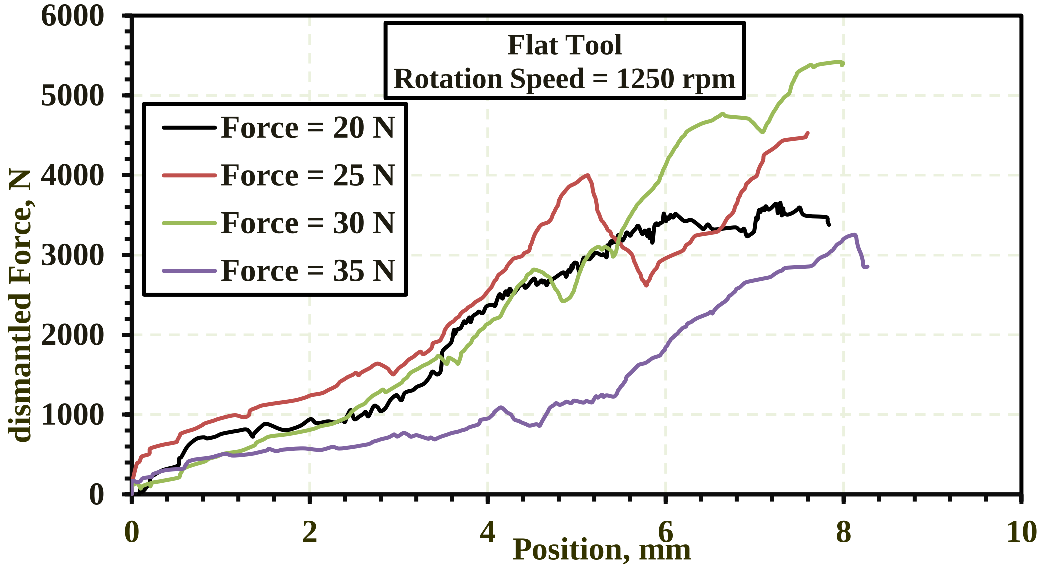


Figure 7: The relationship between (F_d) and (P) at 1250 rpm for flat tool with different (F_a)

Table 2: The welding samples with used flat tool

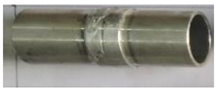
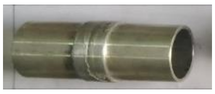
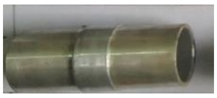
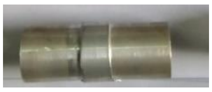
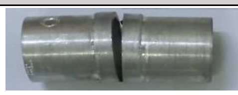
Speed Force	630 RPM	800 RPM	1000 RPM	1250 RPM
20 Kg_F				
25 Kg_F				
30 Kg_F				
35 Kg_F				

Figure 8: live view of flat tool with sample on the lathe

After tension test: Speed & Force for each sample using flat tool after tension test.

Table 3: The cutting samples after tensioning with flat tool

Speed Force	630 RPM	800 RPM	1000 RPM	1250 RPM
20 Kg_F				
25 Kg_F				
30 Kg_F				
35 Kg_F				

To support the findings of experiments showing that the optimal speeds are 1000 rpm, a comparison was done between the speeds and the fair performance on the curve between the maximum dismantled forces in tension and the various welding pressure forces.

3.5. Trend of flat tool for different rotational speed

The trend at Figure 9 The relationship between maximum dismantled force and applied force for different rotational speed with the flat tool point out that rotational speed 1000 rpm is the best.

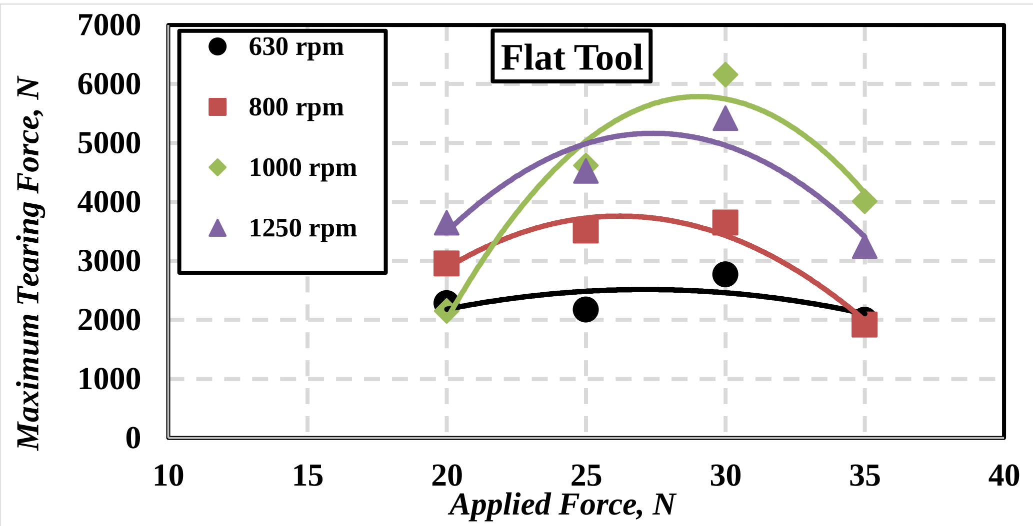


Figure 9: Trend for relationship between maximum dismantled force and applied force for comparing rotation speed with flat tool

3.6. Trend of flat tool for different applied forces

The trend at Figure 10 The relationship between maximum dismantled force and rotational speed with fat tool to compare different applied forces point out applied force 30 kg_f is the beast.

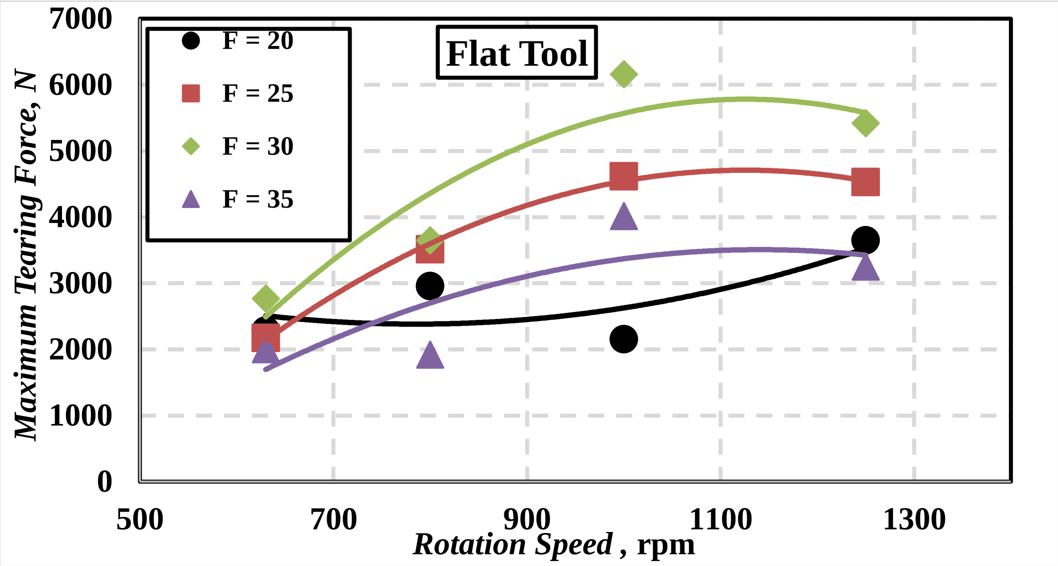


Figure 10: trend for the relationship between maximum dismantled force and rotation speed with flat tool for comparing applied force

The previous studies stated that the speeds were various ranges from 500 to 2800 rpm. The ranges speeds of this study was from 630 to 1250 rpm. Yilbas¸ et al. have conducted the research that concern the friction welding of aluminium and steel. For testing, they have used no alloy carbon steel with a five times higher tensile strength than the tensile strength of aluminium. They have used three different rotational speeds: 2000, 2500, and 2800 rpm, at various parameters of the friction pressure and friction time [2,17, 18]. According to preliminary experiments and the parameters used in RFW process such as rotation per minute, burn-off length, and friction time, we found that the proper rotation speed ranging from 1550 to 1900 rpm to bond the specimens [9, 19].

Pairs of 6060-T5 Al cylindrical rods with the size of 12 mm diameter and 75 mm length were joined with the RFW using three different rotation speeds: 1500, 1600 and 1700 rpm. The welded rods were grouped as S1, S2 and S3 regarding the rotation speeds [10, 20]. The main parameters for rotation speeds are 1550, 1700 and 1850 rpm and for burn of length are 2, 2.5 and 3 mm, respectively. After experiment found that both materials showed strong weld ability although it has a different chemical composition [18, 20].

The parameters were set up as follows: friction pressure 40 MPa, burn-off length5 mm. Yet, the rotation speeds were designed as 500,800, 900, 1000, 1200, 1350, 1500, 1800, and2100 rpm, corresponding to the periphery linear velocity ranging from 0.66 to 2.73 m/s [3, 21]. The rotation speed increases from 500 to 2100 rpm, the curves of friction time and friction work present like ‘V- curve’ with a minimum value at 900 rpm and the ratio of friction work in the first stage to that in the whole process increases and then decreases after reaching a maximum value at 900 rpm [15, 22]. The curve of temperature at quasi-steady stage as a function of rotation speed presents like the inversed “V” curve with the maximum of about 550 °C at 900 rpm, which possessing the same tendency as that of friction work at the first stage [9, 11, 22]. Friction pressure 40 MPa, burn-off length5 mm. Yet, the rotation speeds were designed as 500,800, 900, 1000, 1200, 1350, 1500, 1800, and2100 rpm, corresponding to the periphery

linear velocity ranging from 0.66 to 2.73 m/s [11, 17, 18, 20]. The ranges welding pressure of this study were from 25 to 35 Kg and the previous studies have reported that the force or pressure of welding were ranged from 20 to 30.5 Kg [21, 23].
A rotary friction welding machine, GATWIK brand, was used with fixed rotational speed of 3,200 RPM, P1=2.1 MPa, t1=32 seconds, P2=1.4 MPa and t2=2 seconds. These parameters refer to welding procedures by friction between the related materials described in a previous paper [2, 21, 22]. The welding temperature of this study was from 165 to 225 ºC, while the mechanical properties of 6061 Al alloy are improved with the heat treatment of T5 which is artificially aging process applied (at a temperature between 150 and 300 ºC) on the material cooled from the elevated extrusion temperatures (without solution treatment) (ASM Handbook, 1981) [22, 23, 24]. The result of this study is agreeing with the temperature ranges and speeds rpm of previous studies, but there are some different in ranges because the different in method of study.
The temperature should cool after every sample because the tool and bar that use to connect sample together was remarkably high, to prevent deformation and impact of welding strength of the next sample, all that because the present temperature during operation of welding.

4. Conclusions

The optimal speed to achieve this in this study was 1000 revolutions per minute with the straight tool, and the optimal force to achieve this was 30 kg in this study, which differs from previous studies in terms of shape, method of operation, direction of rotation of the sample and use. A pressure tool, as previous studies did not use a pressure tool, but rather one part of the sample was used to press the other face to face. Also, one part of the sample is fixed, and the other is moving, and the pressure is in the same direction of rotation, while in this study the pressure is perpendicular to the direction of rotation. In the end, the study proved the success of this method, and it is also possible to try it with other metals and change it as necessary.

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لحام الاحتكاك الدوار لأنبوبين من سبيكة الامونيوم ذات حافة زائدة باستخدام اداة خارجية

الملخص

في هذا العمل الحام بالاحتكاك الدوار لأنبوبين من سبيكة الامونيوم، وتم اللحام بطريقة غير تقليدية حيث يتم دوران الانبوبين معاً في نفس الاتجاه مع الضغط عليها من الخارج. ويحدث اللحام علي السمك الزائد حتى لا يحدث تشوه لأصل الانبوبين اثناء وبعد عملية اللحام. وتم إجراء التجربة على عينة مسطحة بدون جروف عند السطح المراد لحامه وتم إجراء عملية الحام عليها لكنها كانت ضعيفة جداً. ثم تم عمل جروف على الحافة الخارجية وتم اللحام وكان لحام أقوى، فكانت فكرة زيادة الجروف لنهاية سمك العينة بالكامل أفضل وليس على الحافة فقط، وكان اللحام الأقوى والأمثل في الشكل كما تم إجراء عدة تجارب على سرعات مختلفة حتى تم التوصل للأربع سرعات المستخدمة في هذه الرسالة. وكانت أفضلها ١٠٠٠لفه في الدقيقة واجريت التجارب على قوي مختلفة واصبحت الاربع قوي المستخدمة هي الافضل من بين المستخدمة في التجارب العديدة. وكانت لأفضل من بينها القوة ٣٠ كجم وذلك عند وقت ثابت ٤دقائق ودرجات حرارة متقاربة كلها عند درجة تشكل الالمونيوم. ثم تم عمل اختبار الشد للعينات كلها واكدت ان السرعة ١٠٠٠لفة في الدقيقة والقوة ٣٠ كجم هما الأفضل في عملية اللحام بالاحتكاك الدوار، وتم قياس درجة الحرارة يدويا بالليزر في نهاية وقت اللحام، وكانت ٢٠٠درجة مئوية تقريباً على سطح العينة.