MARMARA UNIVERSITY

FACULTY OF ENGINEERING

DESIGNING WELDING OF DIFFERENT ALUMINUM ALLOYS USING ROTARY FRICTION WELDING CONSIDERING BURR WIDTH AND BURR HEIGHT

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GRADUATION PROJECT REPORT

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by Osman ACAR

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ABSTRACT

Designing welding of different aluminum alloys using rotary friction welding considering burr width and burr height

Friction welding is widespread used in various industries nowadays. In the friction welding, heat is generated by conversion of mechanical energy into thermal energy at the interface of the work pieces during rotation under pressure. Generally, friction welding can easily be used to joint the components that have circular or non-circular cross sections. Friction time, friction pressure, forging time, forging pressure and rotation speed are the most interesting parameters in friction welding method. High material save, low production time and low energy expenditure are some of the other advantages of friction welding.

The main aim of this thesis is to investigate the most suitable friction welding process for the cylindirical aluminium materials.Also to see the rotation speed,friction pressure and forging pressure effects on conduct experimental investigation.Burr width and burr height were calculated in terms of comparing welded materials. Tensile testing was also performed to support these calculations.

Aluminium alloy (6013-T6) and Aluminium alloy (6082-T6) were welded with continuous-drive friction welding technique. The main aim was to evaluate the performance of aluminium alloy weld joint in comparison to the parent material and to evaluate the integrity of the weld joint. This was accomplished by varying process parameters during welding. Axial pressure ranging from 40 MPa to 55 Mpa, forge pressure ranging from 80MPa to 110MPa and rotational speed ranging from 1250 RPM to 2500 RPM were utilized. Rotary friction welded material and parent material samples of aluminium alloy were examined in terms of mechanical properties.

ABBREVIATIONS

RPM : Revolutions per minute

MPa : Megapascal

Mm : millimeter

kN : kilonewton

s : second

RFW : Rotation friction welding

HAZ : Heat Affect Zone

DDFW : Direct drive friction welding

IFW : Inertia friction welding

Al : Alumunium

Mg : Magnesium

Si : Silicon

Cu : Copper

Fe : Iron

Zn : Zinc

Cr : Chromium

Ti: : Titanium

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1.INTRUDUCTION

1.1 Introduction to Rotary Friction Welding

Friction welding is one of the solid-state welding process in which two work pieces are joined under a pressure providing an intimate contact between them and at a temperature essentially below the melting point of the parent material.Mechanical energy produced by friction ,in the interface of parts to be welded is utilized.

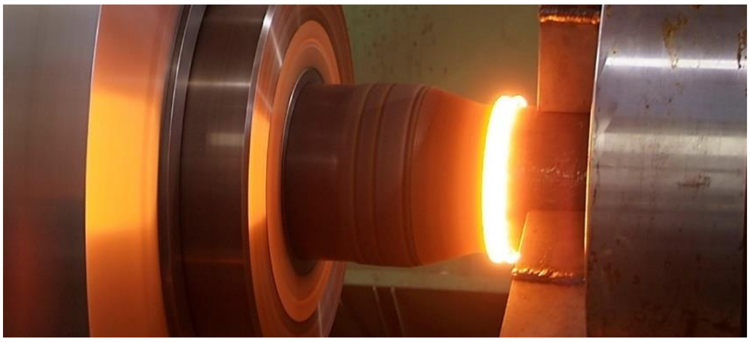

Figure 1.1 Rotary friction welding in process

Rotary friction welding (RFW) is a solid state joining process in which heat is generated by the relative motion at the interface between the work pieces. The heat softens the material, which flows into the burr. This material flow is essential in removing contaminants from the weld interface.Furthermore, rotary friction welding process is also applied to produce the parts which need mechanical properties joining of dissimilar materials as high precision parts, such as crankshaft in engine, core of turbo engine and high-load shaft .

Beside similar material welded joints application, rotary friction welding also is used to weld dissimilar materials. Two of the applications are Al alloy - carbon steel joining, carbon steel - stainless steel joining . Nowadays, in some organizations such as manufacturing company, university or cooperation between company and academic institute, they have studied dissimilar material welded joint by using friction welding process.

In dissimilar materials welding process, the welding temperature determination is a challenge, for example temperature determination for Alloy 6082 - Alloy 6013 joining, because of different properties such as liquid temperature point,structure, heat conduction, alloy element. So, in dissimilar material welded joints application, the welding temperature determination at interface is a crucial factor, it directly affect weld quality and properties. Moreover, the other welding parameters are determined from the temperature such as friction speed, friction force. However, there is not much information which is related to the welding temperature finding. So far, it is difficult to find a reference material to determine the possible welding temperature.

1.2 Aim of Thesis

1.Investigate the rotary friction welding process.

2. To study the parameters in friction welding that would be able to produce good mechanical bending strength i.e. friction time, rotational speeds and friction pressure with constant forging pressure and time on the joining between two dissimilar materials.

3.To study the effect of different rotation speed and friction pressure with forging pressure on the speciments 6013-T6 Alloy - 6082-T6 Alloy.

4. Measure burr width and burr height of the speciment and relate it to the friction welding parameters.

5.Calculate the tensile strength of the speciment and relate it to the friction welding parameters.

1.3 Research Approach

The process was divided into two stages.6013 Alloy and 6082 Alloy preparation and the joining process.Al metal alloy rods were machined into required lengths.Figures (2, 3) show the flowchart of the various stages in this research. The effect of the various parameters investigated (rotational speed, friction time, friction pressure and forging pressure) were characterized for their physical and mechanical properties.

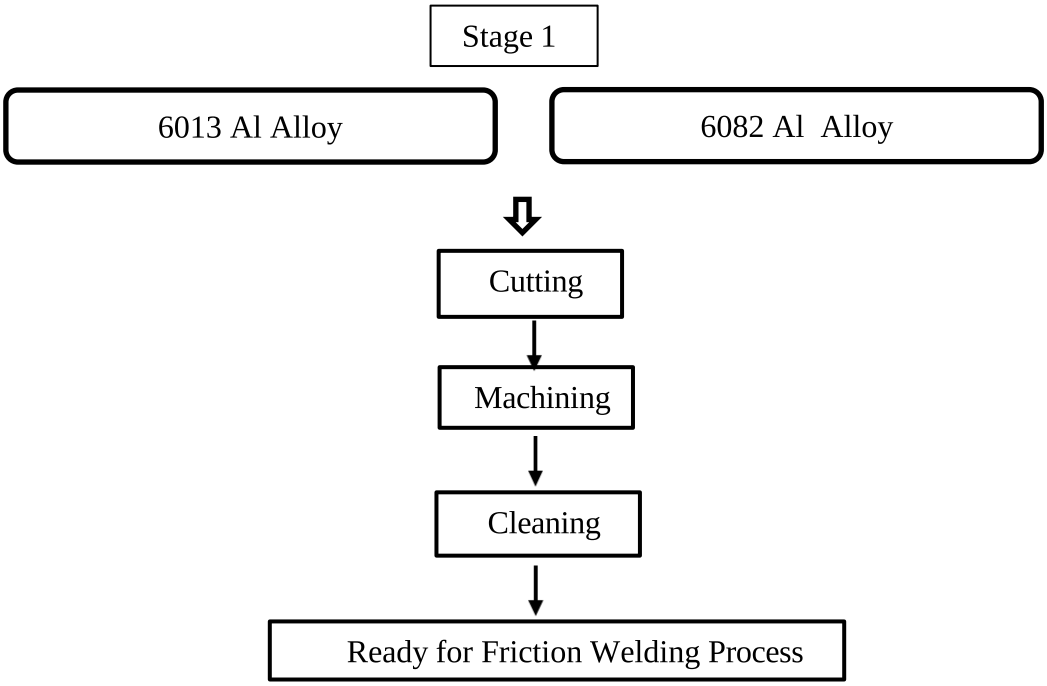

Figure 2 Flowchart of research stage one, 6061,6082 Al alloy

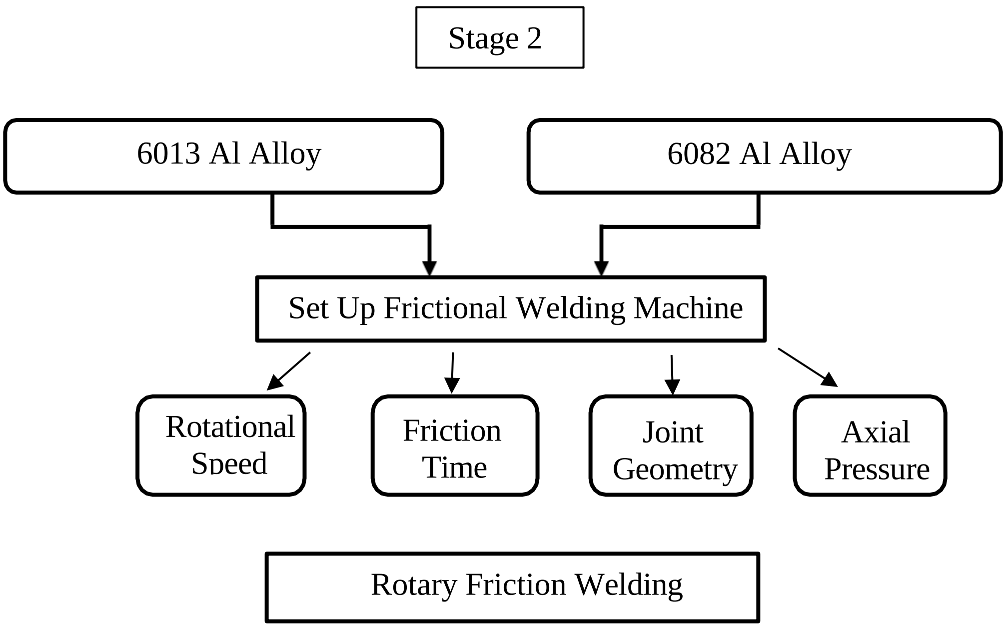

Figure 3 Flowchart of research stage two, friction welding process

2. LITERATURE REVIEW

2.1Introduction

This chapter mainly focuses on rotary friction welding, and Aluminium and its alloys, the history, applications, process theory and sequence. The general process parameters,advantages and disadvantages of rotary friction welding are discussed. In addition, classifications, applications and general properties of Aluminium alloys are also coveredin this chapter. The purpose of this chapter is to reflect on what other researchers have done pertaining to RFW.

2.2 Rotary Friction Welding

Rotary friction welding (RFW) is a solid-state joining process. It was first developed in 1956 and was formally defined by the American Welding Society in 2008. This technique is also known as spin welding, and involves one part being spun at a high rotational speed against the other part, which is mounted on the stationary fixture.

There are two types of RFW: inertia friction welding (IFW) and direct drive friction welding (DDFW). In IFW, the rotating piece is attached to a flywheel, whereas in DDFW rotating piece is spun by a motor. In both types of RFW, the system is in a quasi-steady state between the initial torque peak and the forging phase.

2.2.1 Direct Drive Friction Welding

Direct Drive Friction Welding (DDFW) is a solid-state welding process that joins two separate pieces of metal together by applying axial pressure while simultaneously rotating one of the pieces at high speed. This combination creates friction between the two materials, which then melts them at their interface, creating a strong bond. This method has several advantages over other types of welding, including greater strength and reliability, faster production times, reduced cost, improved material characteristics, and more precise control over heat input. DDFW also requires minimal post-weld cleaning or machining.

The main variables in the rotary continuous direct drive friction welding process are rotational speed, axial force, burn-off, forging force, heating time and welding time These variables determine the amount of energy input to the weld and the rate of heat generation at the interface. It is to be noted that the rate of heat generation is not constant across the interface and that it also varies during the different phases of the welding cycle. During welding, axial shortening and resisting torque of friction undergo changes. The relationship of friction welding parameter characteristics is shown in Figure 4.

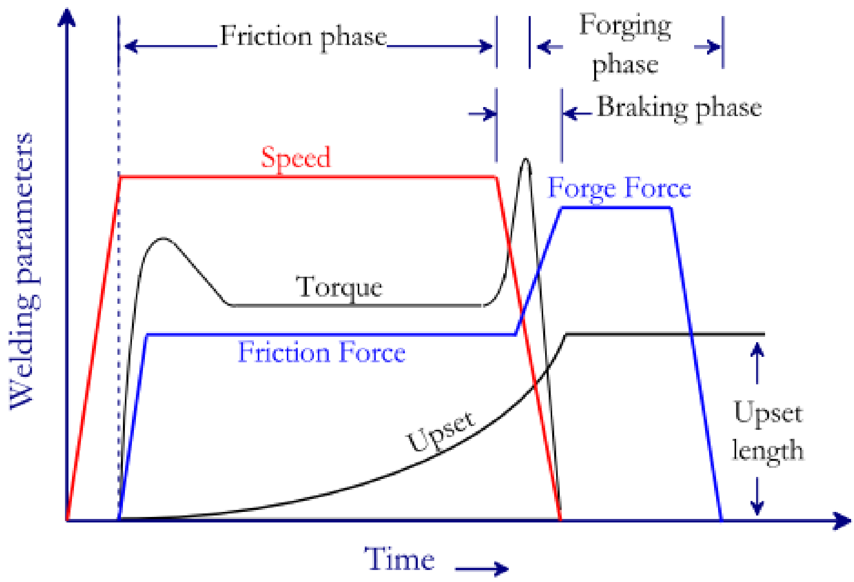

Figure 4 Direct drive friction welding parameter characteristics (Maalekian, 2007)

In continuous drive method, a rotating sample is pressed against a stationary sample as shown in Fig. 5(a and b). The friction at the interface generates the welding heat, which upset the samples (Fig. 5c). Finally, the rotation stops and a forging pressure is introduced to achieve the bonding (Fig. 5d) . As it is reported, several welding parameters affect the quality of friction welds, such as friction time, forging time, friction pressure, forging pressure, and rotational speed . Figure 4 and Figure 5 show the parameters and the phases of continuous drive friction welding. In general, RFW consists of two phases: a friction phase to generate the necessary heat and a forging phase to consolidate the weld.

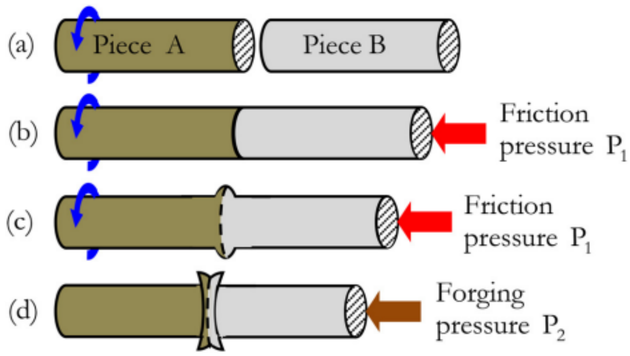

Figure 5 Rotary Friction Welding Process

One work piece is held in a stationary. The second part is rotated in a spindle, which is then brought up to a pre-defined rotational speed. After the predetermined period of time, pre-defined axial force is applied.

These conditions are maintained for a predetermined time. A second step of pressure is applied until the desired temperatures and material state exist. It's during this stage that the two materials are plasticized.The green line indicates measurement of length loss and triggers the stopping point when the part reaches planned overall length.

Rotational speed is stopped. Then increased axial force is applied to create "forge pressure" for another predetermined time - completing the weld. This provides grain refinement and molecular bonding through the weld zone.

2.2.2 Inertia Friction Welding

The inertia welding process, like direct-drive rotary friction welding, uses part rotation under pressure as friction heats the faying surfaces. It differs by use of a flywheel to generate the rotational momentum in the part-holding chuck. The flywheel-driven chuck spins until it stops when the weld zone seizes. This inertia method is also sometimes described by the colloquial term, spin weld. Conversely, our direct-drive method provides continuous speed control through the cycle and stops according to a computer parameter developed specifically for part. The relationship of friction welding parameter characteristics is shown in Figure 6.

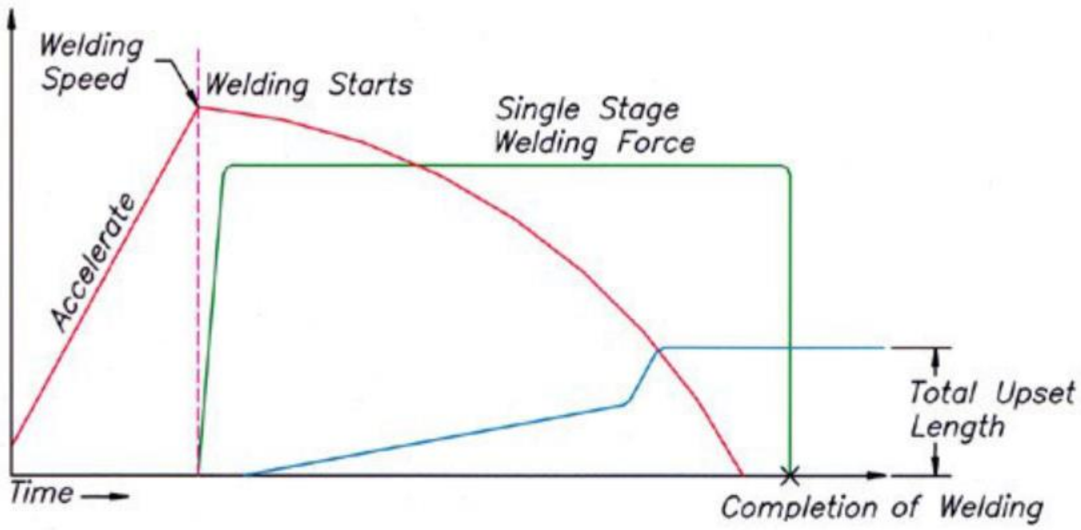

Figure 6 Inertia Friction Welding Process

One component inserts into a rotating chuck, and the other component inserts into a fixed tail clamp. Components consist of the same or dissimilar materials. The head is then accelerated to a preset speed.

The rotating component or the fixed tailpiece is then forced against the remaining component at the weld interface.

Rotation stops under its own kinetic mass and then a forge pressure completes the welding cycle.

2.3 Advantages and Disadvantages of Friction Welding Process

The main advantages of friction welding is that it produces strong, high quiality welds.Unlike other types of welding processes, friction welding does not require filler material or flux.This means that resulting joint is stronger than other methods.Additionally, since there is no need for prehearing or post-weld treatments such as grinding or sanding, the entire process can be completed in one step.This makes it an ideal choice for large production runs and complex parts.Some of advantages are shown below.

- Dissimilar metal combinations can be joined
- High production rates
- Joint strength equal to or greater than the parent metal
- Self-cleaning action reduces or eliminates surface prep time and cost
- Joint preparation is not critical; machined, saw cut, and even sheared surfaces are weldable
- The integrity of welded joints is very reliable
- Cost reduction for complex forgings/castings
- Highly precise and repeatable process

Despite its many benefits, friction welding has some drawbacks compared to traditional arc welding processes.One drawback is that it can be difficult to control the tempreraturе during the proces, welds may be stronger with more accurate temperature regulation.Also, this process only can be used on metals such as plastics and composites.The cost can be high because of using special equipment during the process.Additionally , the processs is not suitable for large and sensitive materials.

2.4 Journal References

Mumin Sahin, [1] have worked on friction welding of high speed steel (HSS—S 6-5-2) and medium carbon steel (AISI 1040) (both of 10 mm dia.). He investigated optimum welding parameters for these combinations of metals. Also, he finds that the tensile strength of welded part is close to that of medium carbon steel (AISI 1040).i. e. the part having weaked of medium carbon steel (AISI 1040).

Satyanarayana et al., [2] have carried out a study on continuous drive friction welding of austenitic ferritic stainless steel. The parent metal used for that study was AISI 304 austenitic stainless steel and AISI 430 ferritic stainless steel. He used ANOVA technic of Yate's algorithm to analyze the results obtained by experiments.

Meshram et al., [3] conducted an investigation of dissimilar metal joining combinations: Cu–Ni, Fe– Cu, Fe–Ti, Cu–Ni Fe–Ni and Cu–Ti. They observed the influence of interaction time on microstructure and tensile properties of the friction welding of five dissimilar metal combinations.

Moat et al., [4] have studied Microstructural variation across inertia friction welded SCMV (high strength low alloy Cr–Mo steel) and Aermet 100 (ultra-high strength secondary hardening steel). They carried out micro-hardness testing and hard X-ray diffraction mapping on inertia friction welded samples of SCMV steel and super high strength Aermet 100 steel in the as-welded postweld heat-treated condition.

Dey et al. [5] chose titanium (18 mm dia. & 100 mm length) and 304L stainless (14 mm dia. & 100 mm length) steel to weld by continuous drive friction welding. During this work they have investigated optimum friction welding parameters that produce joints that are stronger than the Ti base material as confirmed by tensile test, and tensile test failure occurred in the Ti base material. As-welded bend test samples failed with almost zero bend ductility..

Seli et al., [6] have studied mechanical properties of mild steel and aluminum welded rods to understand the thermal effects. They used an explicit one-dimensional finite difference method to approximate the heating and cooling temperature distribution of the joint. They observed thermal effects of the friction welding to have lowered the welded materials hardness compared to the parent materials.

Winiczenko et al., [7] have investigated friction welding of ductile iron with stainless steel (both 20 mm dia. & 100 mm length). They used stainless steel interlayer in two ductile iron bars to weld it by continuous drive friction welding.

Udayakumar et al., [8] have carried out experimental investigation of mechanical and metallurgical properties of super duplex stainless steel bars welded by friction welding. They carried experiments on specimens of super austenitic stainless steel (UNS S32760) of 16 mm diameters and 100 mm length. A four factor, three level central composite designs (CCD) was used to determine optimal factors of friction welding process of super duplex stainless steel.

Alves et al. [9] studied the rotary friction welding of AA 1050 aluminum alloy to AISI 304 austenitic stainless steel and showed that the strength of the joints varied with friction time and other welding parameters. Meshram et al. [10] developed a rotary friction welding of AISI 4340 austenitic-stainless steel with AA6061 aluminum alloy, using a silver interlayer as a diffusion barrier for Fe. They found that silver interlayer avoids the formation of the brittle IMC layer, and increases the tensile strength of welds.

2.5 Variables and parameters that govern the quiality of the welded components

The variables and parameters that govern the quiality of the welded components during continous drive rotary friction welding are given in the Table 1 below.

Table 1 Variables and parameters govern the quality of the friction weld

	Machine	**Material**
1	Friction pressure	Type of metal
2	Forging pressure	Part configuration
3	Friction time	Size
4	Braking Time	Initial condition of the friction surface
5	Forge time	Shape of the parts to be welded

1) Friction pressure:The pressure applied normal to the faying surfaces during the time that there is relative movement between the components.

2) Forging pressure:The pressure applied normal t the faying surfaces at the time when relative movement between the components is ceasing or has ceased.

3) Friction time:The time during which relative movement between the components takes place at rotational speed and under application of the driction force.

4) Barking time:The time required by the moving component to decelerate from friction speed to zero speed.

5) Forge time:The time for which the forge force is applied to the components.

3. METHODOLOGY AND EXPERIMENTAL WORK

3.1 Introduction

In order to conduct the experiment , selected 16mm diameter machined rod of varios aluminium combinations and have made three sets of experiments in six combinations with three different rotation speed 1250RPM,1800RPM and 2500RPM.Also, experiment has made in two different friction pressure 40Mpa and 55Mpa.Forge pressure has taken two times of friction pressure wich were 80Mpa and 110Mpa.Friction time was selected six seconds in the beginning but couldn’t get the correct results so it was dropped to three seconds as forge time.

The experiment has made three times to calculate burr weidth and burr height values correctly.One of them was used for tensile test.During the test one specimen of 110mm length work piece was held on jaw chuck fixed on the lathe machine.This is rotating part which rotated 1250rpm,1800rpm and 2500rpm.Other non-rotating work piece was held on the tailstock attachment.The tailstock attachment is connected to the hydrolic system to measure axial pressure applied during friction and forge.Parameters which were used during the experiment is shown Table 2 below.

Table 2 Parameters used in the experiment of Aluminium 6013-T6 - Aluminium 6082-T6

Trial	Initial length of specimen (mm)	Initial diameter of specimen (mm)	Rotation speed (rpm)	Friction time (s)	Friction pressure (Mpa)	Forge time (s)	Forge presssure (Mpa)
1	110	16	1250	3	40	3	80
2	110	16	1800	3	40	3	80
3	110	16	2500	3	40	3	80
4	110	16	1250	3	55	3	110
5	110	16	1800	3	55	3	110
6	110	16	2500	3	55	3	110

3.2 Properties of Aluminiums

3.2.1 Aluminium 6013-T6

Aluminum 6013-T6 alloy is a wrought alloy type with high strength, improved formability, excellent compressive properties, and good corrosion resistance.

Table 3 Chemical composition of the aluminum 6013-T6 alloy.

Element	Content (%)
Aluminum, Al	94.8-97.8
Magnesium, Mg	0.80-1.2
Silicon, Si	0.60-1
Copper, Cu	0.60-1.1
Manganese, Mn	0.20-0.80
Iron, Fe	≤ 0.50
Zinc, Zn	≤ 0.25
Chromium, Cr	≤ 0.10
Titanium, Ti	≤ 0.10
Remainder (each)	≤ 0.15
Remainder (total)	≤ 0.050

The mechanical properties of aluminium / aluminum 6013-T8 alloy are shown Table 4.

Table 4 Mechanical Properties of Aluminium 6013-T6

Properties	Metric
Tensile strength (at thickness 38.13-82.5 mm)	≥ 392 MPa
Yield strength (at strain 0.200 %)	≥ 379 MPa
Elongation at break (at thickness 3.17-19 mm)	≥ 5%
Hardness, Brinell	130
Hardness, Knoop (estimated from Brinell)	163
Hardness, Rockwell A (estimated from Brinell)	49.5
Hardness, Rockwell B (estimated from Brinell)	80
Hardness, Vickers (estimated from Brinell)	149
Machinability	70

3.2.2 Aluminium 6082-T6

Aluminium alloy 6082-T6 is a medium strength alloy with excellent corrosion resistance. It has the highest strength of the 6000 series alloys. Alloy 6082-T6 is known as a structural alloy. In plate form, Aluminium alloy 6082 is the alloy most commonly used for machining.

As a relatively new alloy, the higher strength of Aluminium alloy 6082 has seen it replace 6061 in many applications. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy.

Table 5 Chemical composition of the Aluminum 6013-T6 alloy.

Element	% Present
Si	0.7-1.3
Fe	0.0-0.5
Cu	0.0-0.1
Mn	0.4-1.0
Mg	0.6-1.2
Zn	0.0-0.2
Ti	0.0-0.1
Cr	0.0-0.25
Al	Balance

Table 6 Mechanical properties for aluminium alloy 6082 T6

BS Rod Up to 20mm Dia. & A/F Property	Value
Proof Stress	250 Min MPa
Tensile Strength	295 Min MPa
Elongation A50 mm	6 Min %
Hardness Brinell	95 HB
Elongation A	8 Min %

3.3 Experimental Procedure of Rotary Friction Welding

Following are the different procedures followed to conduct experiment.

1)Preparation of work pieces

2)Experimental setup

3)Steps in welding

4)Testing

3.4 Preparation of Work Pieces

First of all, to carry out the experiment, three-meter aluminum pieces were cut into 110mm pieces. Then, machining was done to clean the surface of the 110mm pieces and make them smooth.

Figure 7 110mm cut aluminiums

Machining process can be seen in Figure 3.2 and Figure 3.3 below.

Figure 8 Machining Process of Al 6013

Figure 9 Machining Process of Al 6082

3.5 Experimental Setup

Celmak FW01 brand friction welding machine was used during the experiment.Properties of the machine are shown below.

-Motor power 7.5 Kw

-Rev range is between 100rpm to 4500rpm

-Machine pressure force 10 Knots

-Continuous drive friction welding

-Electromechanical brake

-Hydraulic unit and all equipment are PLC controlled

-Hydrolic pressure between 10-250 Mpa

-Low rates with linear guideways worn bearings available

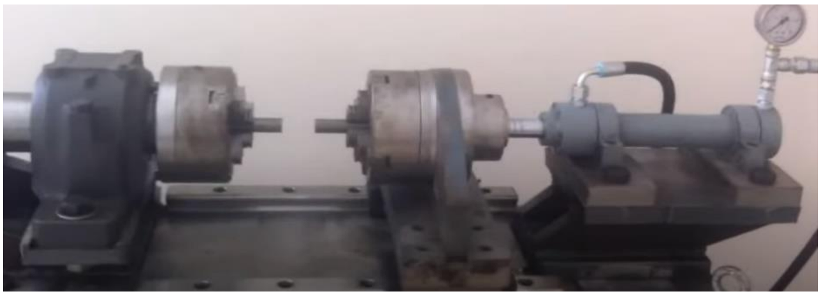

Figure 10 Rotary Friction Welding Machine

Figure 11 Hydrolic Unite

Figure 12 Parameters Display

3.6 Steps in Friction Welding

3.6.1 First contact

Parts are mounted in the jaw chuck in the rotating part and drill chuck in the fixed part on the lathe machine.Rotating part is spun up to the speed of 1250rpm 1800rpm and 2500rpm.Friction pressure has taken 40Mpa and 55Mpa.Forge pressure has taken 80Mpa and 110Mpa.Friction time 3s and and forge time is 3s as well.

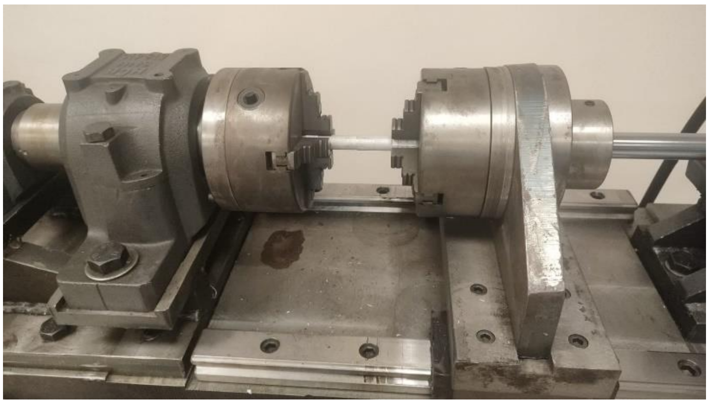

Figure 13 First contact

3.6.2 First Friction

First friction starts when rotation speed reach to the maximum.Welding process is realised and contact zone heats up.This is called as heat affected zone(HAZ).

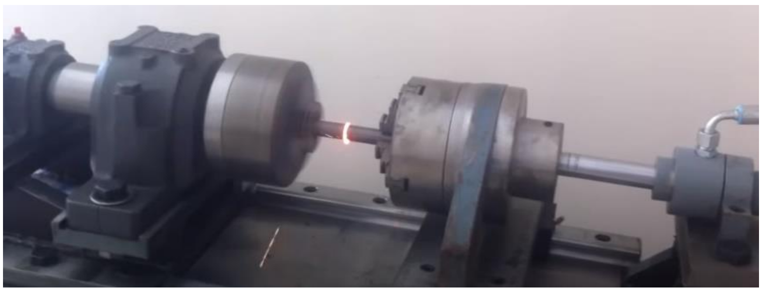

Figure 14 First Friction

3.6.3 Second Friction

In the second friction, friction pressure becomes zero and forge pressure is used to get stronger welding pieces.In literature forge pressure is used 200% more than friction pressure.Forging time is used 3s as friction time.The increased pressure brought about during second friction causes aluminium become plastic and flows outward from center to form of the characteristic burn-off.Forging state can be seen in Figure 3.8 and the welded specimen can be seen in Figure 3.9.

Figure 15 Second Friction

Figure 16 Welded specimen Al6013-Al6082

The experiment has made three times in order to measures becomes accurate and to use one of them in tensile test. Since there were six parameters in the experiment and made three times finally 18 pieces have gotten.Figure 3.10 below shows the components formed at the end of the process.

Figure 17 Welded materials (18 pieces with six different parameters)

3.7 Tensile Test

Tensile testing is a destructive testing method that is done early when testing weld performance. This easy-to-perform assessment provides a wealth of information that is critical for selecting the best filler metal for an application.

A sample of specified dimensions is loaded in tension until the point of failure. The sample piece is pulled apart to understand the strength, ductility and other characteristics of the weld. The test equipment calculates and displays the ultimate tensile strength the maximum stress withstood before failure in pounds per square megapascals MPa, the yield strength (the stress where plastic deformation occurs in Mpa) and the percent elongation of the sample.

The process involves creating a welded test plate, machining the plate to produce an appropriately sized test specimen, conducting the test and then analyzing results. Different base metals, joint designs and welding parameters can result in significantly different mechanical properties, even when using the same filler metal. For this reason, filler metal manufacturers and companies test plates in accordance with specifications that control all of these factors.

Tensile Test Setup

Hssdtest / WAW-600D brand force machine was used for the tensilet test.The spesifications sof the machine are shown below.

Brand / Model is Hssdtest / WAW-600D

Measuring capacity is 600kN

Load Range is 12kN to 600kN

Force measasuring system is numeric display

Resolution 0.01kN

Test force accuracy +1%

Bending test branch area 450 mm

Branch width 140mm

Branch diameter 30mm

Inside piston 250mm

The machine can be seen in Figure 3.11.

Figure 18 Hssdtest / WAW-600D Force Machine

From the tension test , various parameters like yield strength, ultimate tensile strength, breaking load are calculated.Figure 19 is an image of friction welded joints, required for tensile test.In order to the burrs at the weld point were cleaned.Figure 20 is an image of tensile test process.Figure 21 is materials after the tensile test.

Figure 19 Burr-free materials

Figure 20 Tensile test process

Figure 21 Materials after the test

4. RESULTS AND DISCUSSIONS

4.1 Burr Width and Burr Height Results

Rotary friction welding between Al 6013-T6 and Al 6082-T6 was done with three spindle speed of 1250rpm, 1800rpm and 2500rpm.Two different friction pressure which was 40MPa and 55MPa with two different forge pressure which was 80MPa and 110MPa.Friction and forge pressure controlled by hydraulic gauge.Friction time and forging time was set to 3s.The length of the work piece used for the experiment was 110mm each.The experiment was made three times for ensuring the correct results. Out of three sets of samples, one set used for tensile test.Burr width and burr height have been calculated.

Table 7 Measurements of parameters controlling rotation friction welding quality

Trial	Initial overall length of work (mm)	Rotation speed (rpm)	Friction time (s)	Friction pressure (Mpa)	Forge presssure (Mpa)	Forge time (s)	Final length after welding (mm)	Burn off length (mm)
1	220	1250	3	40	80	3	205	15
2	220	1800	3	40	80	3	210	10
3	220	2500	3	40	80	3	211	9
4	220	1250	3	55	110	3	191	29
5	220	1800	3	55	110	3	198	22
6	220	2500	3	55	110	3	203	17

Table 8 Measurements Burr width and Burr length of trials

Trials	Burr Width 1 (mm)	Burr Width 2 (mm)	Burr Width 3 (mm)	Burr Height 1 (mm)	Burr Height 2 (mm)	Burr Height 3 (mm)
1	6.79	6.67	6.64	5.73	5.56	5.99
2	4.53	4.67	4.63	5.09	5.18	5.36
3	3.09	3.14	3.07	5.30	5.36	5.19
4	8.61	8.59	8.67	6.91	6.72	6.69
5	6.37	6.31	6.18	6.47	6.63	6.54
6	5.01	5.19	5.03	7.44	7.46	7.63

Table 9 Average Burr width and burr height

Trials	Average Burr width (mm)	Average Burr height (mm)
1	6.7	5.69
2	4.61	5.21
3	3.1	5.28
4	8.62	6.77
5	6.28	6.55
6	5.08	7.51

Materials which were gotten after the test are shown below Figures.

Figure 22 Test 1

Figure 23 Test 2

Figure 24 Test 3

Figure 25 Test 4

Figure 26 Test 5

Figure 27 Test 6

4.2 Tensile Test Results

Tensile test results are shown Table 10

Table 10 Tensile test Results

Test sample no	Maximum Load (kN)	Tensile Strength (Mpa)	Upper Yield Strength (Mpa)	Upper Yield Load (kN)
1	51.26	255	254	51.10
2	59.58	296	139	28.00
3	62.50	311	310	62.33
4	61.88	308	179	36.06
5	65.23	324	174	34.97
6	62.59	311	307	61.82

Graps below show the tensile test results.

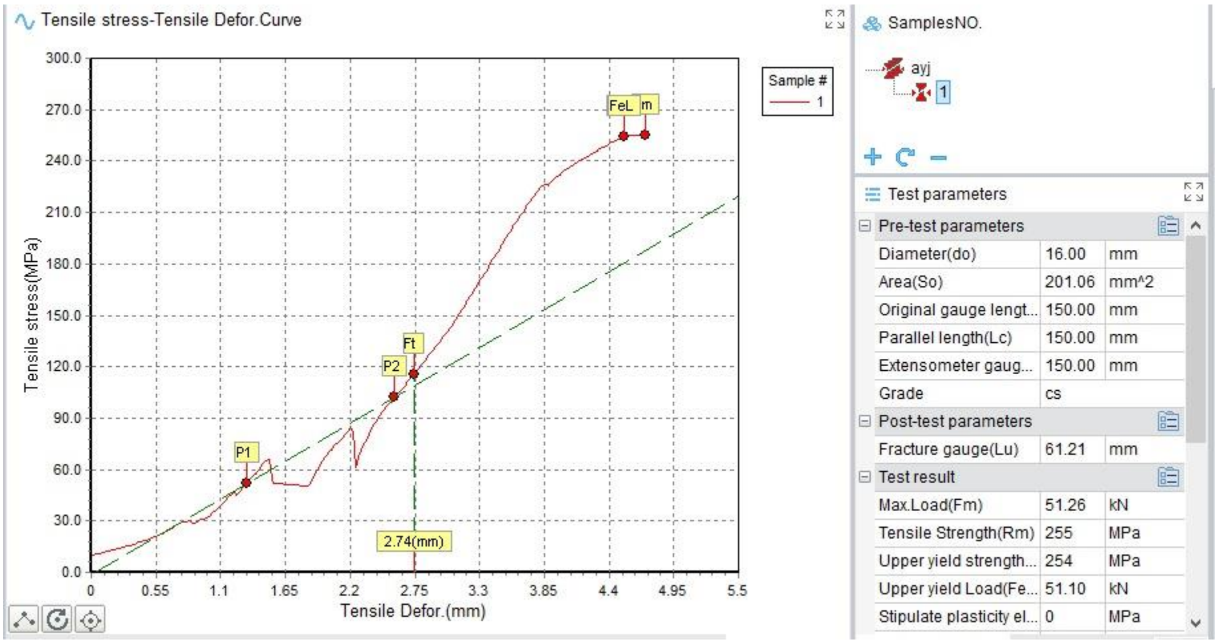

Figure 28 Tensile test result of test no 1

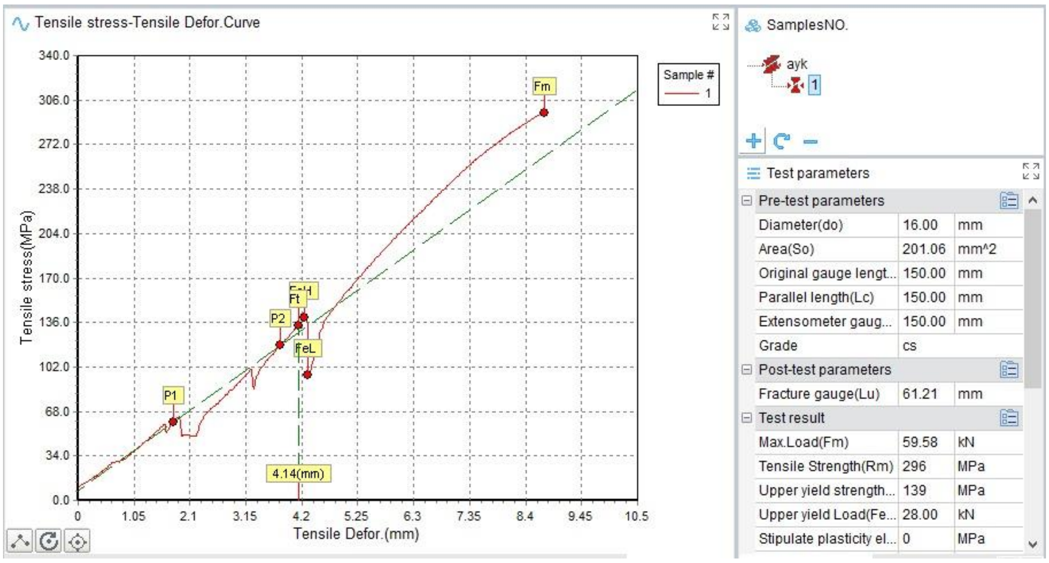

Figure 29 Tensile test result of test no 2

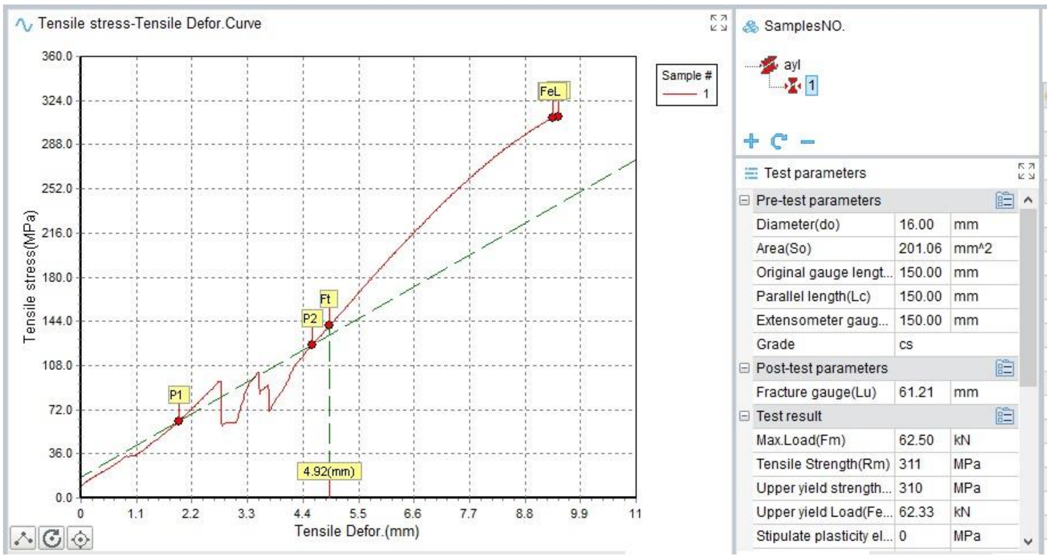

Figure 30 Tensile test result of test no 3

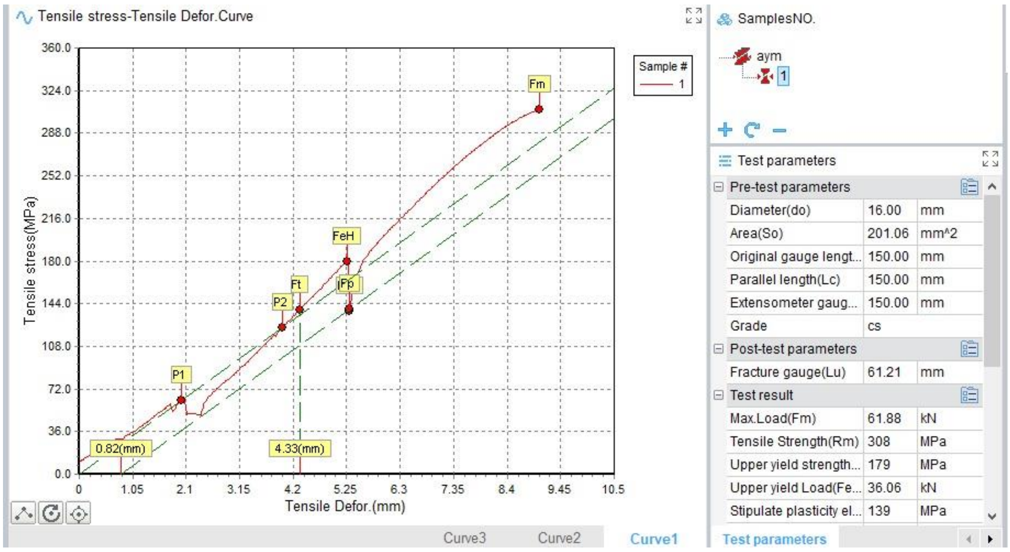

Figure 31 Tensile test result of test no 4

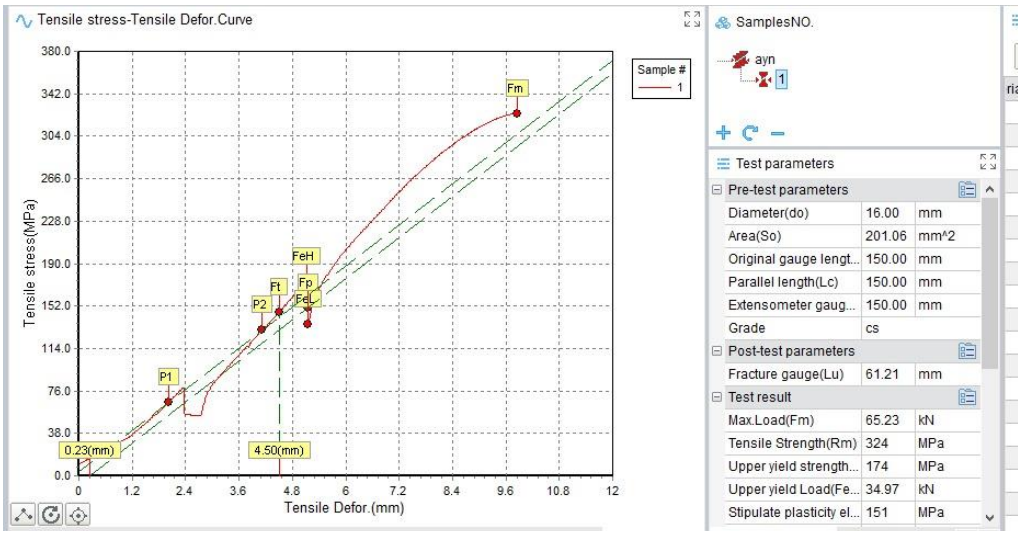

Figure 32 Tensile test result of test no 5

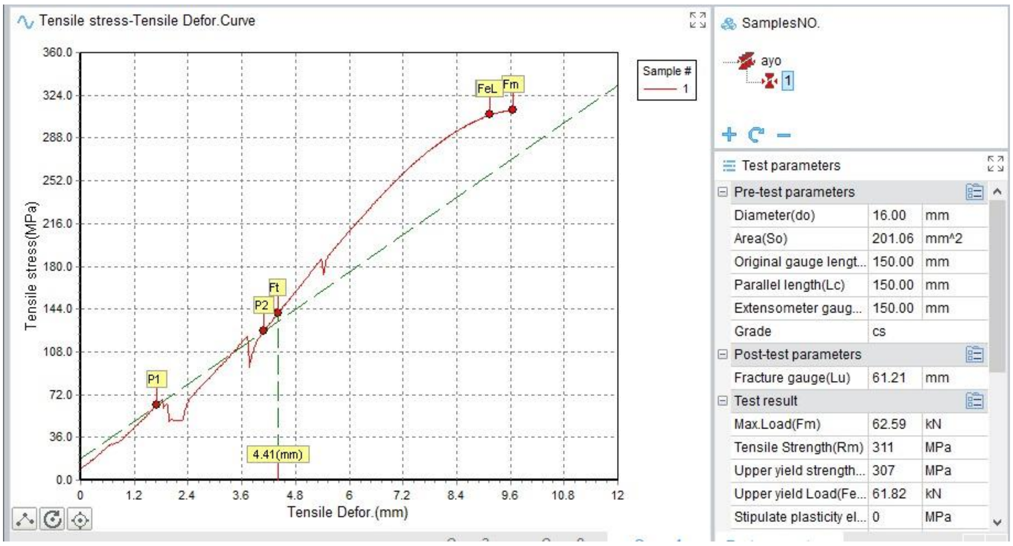

Figure 33 Tensile test result of test no 6

4.3 Comparison With Studies In The Literature

Suresh[11] conducted experiments between dissimilar materials (copper, metal, aluminium).Rotation speed was between 1210rpm to 2040 rpm. In his study, tensile strength has increased as rotation speed increases.He got the best results at the highest rotation speed.Khalfallah[12] investigated the rotary friction welding of AA1100 aluminum alloy with mild steel.He used 70 mm length and 12 mm diameter metal. RSM analysis shows that the maximum strength of joints could be attained under the maximum level of forging pressure/time, while the minimum level product a minimum hardness in the weld joints. In Wang[13]'study, continuous drive rotary friction welding was conducted on dissimilar metals of aluminum and brass.

In these studies and general studies in literature show that we can get stronger welded joints with higher rotation speed and forge pressure.However, some studies show that it is necessary to reduce the rotational speed to increase the friction in order to reach the temperature in the contact surface without reaching the melting temperature.Generally,ultimate tensile strength is 70% of metal itself.In this study, ultimate tensile strength was between 255 Mpa to 324MPa which is 85% of metal itself.Some of studies couldn't get good results because of vibration in the machine.In some studies, time couldn't measure automatically so it caused cracks in material.In our study, it is obtained that burr width and burr height decrease with higher rotation speed.

4.COST ANALYSIS

Aluminium 6013-T6 3m length 16 mm diameter with 20% tax is 400₺

Aluminium 6082-T6 3m length 16 mm diameter with 20% tax is 550₺

Lathe machine was used in order to get 110mm pieces of aluminiums. The labor cost for each cutting process was 50₺, a total of 1300₺ was paid to get 26 pieces of each aluminium material. Machining was performed to obtain a smooth surface.The total cost for the machining process was 2000₺. A total of 26 pieces of aluminum material were obtained.

Rotary friction welding process was made in Celmak FW01 brand friction welding machine.The cost for one welding process was $10 which is 300₺.A total of 18 operations were performed on this machine, 3 times on 6 different parameters.The total cost for the entire process was 5400 ₺ .

Hssdtest / WAW-600D brand force machine was used for the tensilet test. The tensile test was absolutely necessary to compare different parameters. The cost of each test on this machine was 600₺. Since the experiment was carried out on 6 different parameters, a total of 3600₺ was paid for this process.

The total cost for this investigation was 400₺ + 550₺ + 1300₺ + 2000₺ + 5400₺ + 3600₺ = 13250₺.

5.CONCLUSION

The experiment of Al 6013-T6 and Al 6082-T6 is succesfully done in this thesis. The objective was to study the possibilies of rotary friction welding with dissimilar aluminiums as per given parameters.It is observed that burrs occurred in all taken parameters.

It is arrived a conclusion that quality of friction welding always depends on the changes in welding parameters.From the experiment, it can be seen that quality of weld is increased when rotation speed increases.

In all combinations of welding , weld strength has been increased when rotation speed increase from 1250rpm to 2500rpm.

It is also arrived a conclusion that burr width and burr height decrease when rotation speed increases.Besides burr width and burr height increase with higher friction and forge pressure.The lowest burr width and burr height values were taken in the 3rd test with 2500rpm rotation speed 40Mpa friction pressure and 80MPa forge pressure.

After tensile testing of all combinations of weld joints, its seen that measurements of mechanical properties are hight in the welded joint made with 1800rpm, 55Mpa friction pressure and 110MPa forge pressure.It can be observed that when friction pressure and forge pressure increase tensile strength also increases.Friction and forge pressure are not much effective at hight friction speed processes as seen in the last test of the experiment.

Tensile strength of 6013-T6 is approximately 390 MPa and tensile strength of al 6082-T6 is between 310- 340 MPa.It's found in our investigation that average ultimate tensile strength of welded material was 300 MPa which is 85% of metal itself.

In other studies, the higher friction pressure of aluminum materials and the effect of material diameter and material length on the welding quality can be examined.Also other surfaces such as square can be investigated for rotary friction welding. Since the welding of non-identical materials with the friction welding method is successful in this thesis, steel and other alloys with different hardness compared to aluminum can be welded with this method can be researched.

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