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Comparative Analysis of Friction Stir Welding on Different Alloys of Aluminium

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Abstract: Friction stir welding is well known welding process which is used for joining of dissimilar aluminum alloys by the use of heat which is produced by friction and mechanical mixing of the alloys at joint location. Friction stir welding is used in different mechanical industries like aerospace, automotive, railways and other different industries. Not only aluminium but also magnesium etc and other hard material are also joined by this welding process. The welding quality of the joint is dependent on the rotation speed of tool, tilt angle and welding speed used at the process of welding. Since this welding is light in weight and so welded parts can easily utilized in road transport and is also used in other such industries where light weight materials where welding should have good mechanical properties is preferred. Also it is found that if two dissimilar metals are joined by other fusion welding technique, then the mechanical properties of the welding part is reduced. But the benefit of friction stir welding is that after the welding the mechanical properties of the materials to be joined are not lowered. It is due to the reason that the welding takes place only due to the forging effect and so there is no melting of materials happens. The present research work contains the comparison of welding of different alloys of aluminium using friction stir welding. Different process parameter will be used that affects the attributes of welded products.

I. INTRODUCTION

A. Development

Friction stir welding which is primarily known as FSW is a methodology of joining or combining of two dissimilar metals. In the beginning FSW methodology was developed by Wayne Thomas with the help of National Aeronautics and Space Administration (NASA). The one of prime target of this welding process is to keep the weight of orbital space craft as minimum as possible and also it was designed solely for the aluminium alloys only. But as the time passes this FSW welding process is also utilized for various other different alloys of other metals like copper, titanium as well as for magnesium alloys and of some other metals also like zinc, nickel and etc. [1]

When we compare it with other traditional metallic material then the composite materials fall into the category of materials having high metallic matrix. One of the prime advantages of using composite materials is that their low weight and also are much reliable. When we talk about internal properties of composite material like modulus of elasticity, rigidity, tensile strength, hardness, fatigue strength, and other attributes then all of these have very high values. Hence due to these advantages the FSW welding process is highly recommended and vastly utilized in the industry. [2]

When there is a comparison between the fusion and friction stir welding then one difference is that in case of fusion welding there is melting of material happens while in case of friction stir welding there is no melting of materials. Also along this process there is no emission of harmful gases and also there have no need of any type of filler material to make it environmental friendly. FSW process also significantly improves the mechanical attributes of a welded joint and with this advantage the surface interface lowers the emission of various brittle compounds. [2]. In the welding process of friction stir there is localized heating is generated and also there is deformation occurs of plastic amid the pin and shoulder and the work pieces and also here it is a non consumable tool. In this process there is a relative steady motion in amid the tool and the work piece and it this behavior produces friction as well as heat. Now this heat is utilized to bind together various materials by the theory of plastic atomic diffusion. The mechanical energy gets transformed into thermal energy and it is all without the aid of some external agency to appear heat in friction stir welding process. It is found that similar as well as dissimilar materials and also other metals which earlier by traditional methods are not easy to weld will get easily welded by the FSW process. This FSW process seems to be easy but actually in this process the heat and pressure applied to weld the materials require very accurate values of variables like tilt angle, welding speed, rotation speed of tools and etc. [3] By the literature survey it was found that Friction stir welding is known for its defect free and for strong welding joints. This process is also known for cost cutting as there are no consumable materials appear. If the thickness of material is more than the welding can be done in one or two passes easily. Besides this the process has very low energy consumption. Also this process is fully automatic and so there is no labor cost. [3]

B. Welding

Welding is known as a secondary procedure or a process in the manufacturing sector. In the last two decades there is a huge demand of producing complex structures which are not possible to manufacture as a one piece. So welding has now become the one of the most significant and critical step in the manufacturing processes in the industry.

Different process had been developed since last 3 decades for joining different types of metals. It was found that some of these methods were good in terms of cost cutting and while some are best in yield time of the manufacturing process. But still there is a need of technique which can make the joint light weight and the process will be highly efficient and also it should be helpful to join complex structures and the Friction stir welding (FSW) is falls into this category. This methodology is regarded as an energy-efficient also eco friendly way to combine metals.

In reference to alloys of aluminium there are various series which ranges from 2xxx to 7xxx and is known as precipitation hardenable series. In reference to this series there are various alloys which are very much sensitive to cracking which are resulted from the solidification process of welding and can only be joined or welded by friction stir welding (FSW).

C. Friction Stir Welding

Friction stir welding methodology is one of the famous welding methodologies which is also known as a state of art solid state combining method which is supposed to be the one of best advancement over the last three decades. The experimental setup for FSW is shown in Figure 1.1. In this method since there is no melting of material happen and also there is no heat is set up internally by utilizing friction amid the material and the surface of tool. After this step there is a deformation in the plastic properties of material occurs and all of this occurs without heating. Hence FSW is found to be immune towards the defects as well as various distinct internal attributes.

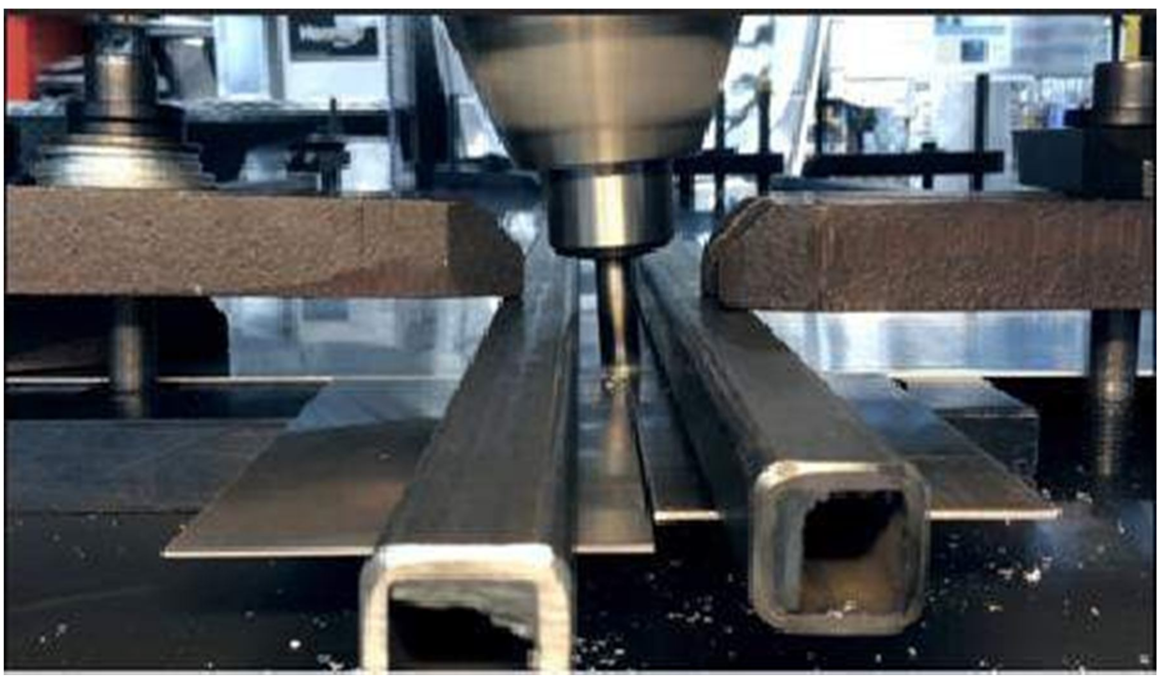

Figure 1.1: FSW of two different plates and tool bit image [5]

In the world various mechanical engineers performed friction stir welding process to weld amid dissimilar materials of aluminium alloys of 6082 – T6 and 7075 – T6 in the aerospace structures which was earlier mostly manufactured by using rivets. As a result of riveting there is a increase in the stress as well as enlarges the weight of the output joints. It is always acceptable that welding process should cost minimum and should be efficient and if we consider aircraft manufacturing there is a huge demand of producing minimal cost as well as there should be maximum efficiency of dissimilar welding of distinct aluminum alloys and utilization of FSW technology to meets its demand. At present various researches is going on in this area of producing dissimilar aluminum alloys.

The figure 1.2 displays two dissimilar aluminum metal plates alloys named AA6061 and AA 6062 which are being welded by friction stir welding and it is the final product of above given figure 1.1. As the figure 1.2 shows that this join by Friction stir welding has no slag and appear to be very hard in comparison to other welding.

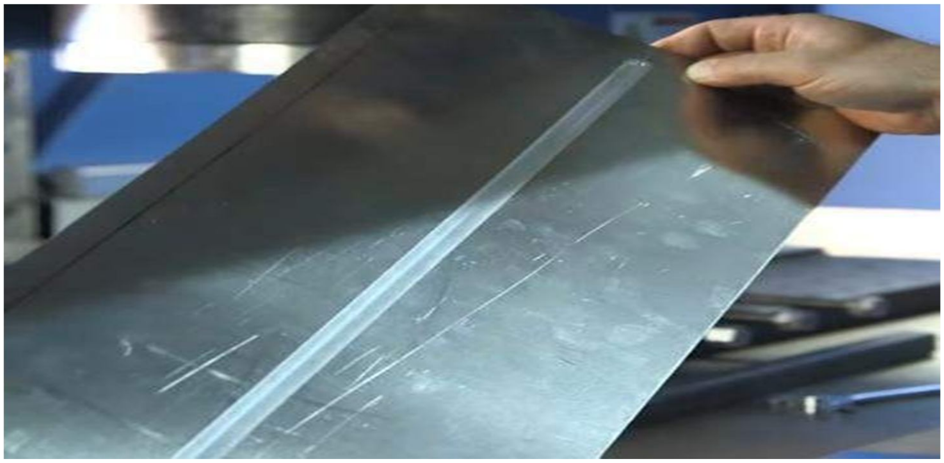

Figure 1.2: Displaying end product after applying FSW on plates of dissimilar aluminum alloys having series number AA6061 and AA6062

D. Friction Stir Processing

Friction stir processing (FSP) is known as an alternative of friction stir welding (FSW). Friction stir processing is utilized as a novel surfacing technique which is generally utilized for microstructure alterations that have both superplasticity as well as presence of surface composites and also the micro structural restriction of cast aluminium. Superplasticity is the potential of a polycrystalline material which have very high tensile elongation precedent failure. FSP is a method which is usually utilized to clarify the grain size which range from 19–22 which is just close to 5 microns and has a good efficiency of enhancing the shock behavior of metallic materials at very large temperatures.

In the aerospace structure superplasticity is found to be one of the most notable attributes for various joints of metals. FSP is similar to FSW also utilizes a non-consumable rotating tool that is getting drived into the workpiece and then further moved in the processing direction and in the end backed off from the workpiece. During this method, FSP tool is being activated and very high plastic deformation of the workpiece occurs.

The principle of FSW is shown in Figure 1.3.

Figure 1.3: The schematic scheme of friction stir welding [34]

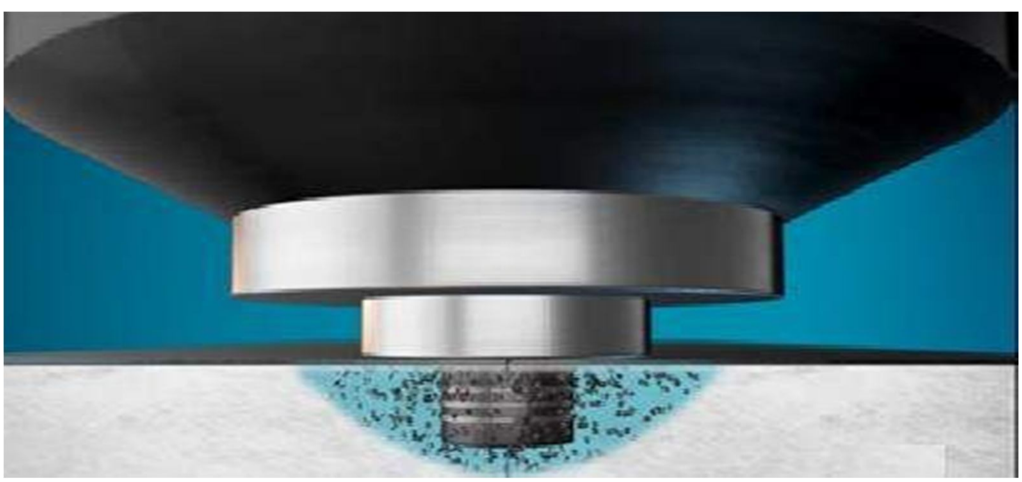

Figure 1.4: Internal behavior of material during FSW process [34]

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E. Methods Of Friction Stir Welding Operations

1) *Rotary FSW:* There are various distinct techniques that are utilized in friction stir welding. One of the most commonly and widely utilized method is known as rotary FSW. In this rotary process a single bit tool is made to rotate and allowed to move into attached faces of both the material which have to be joined. It is then moved along as well as inside the material to form a firm joint.

There are distinct variations of FSW methods which are discussed here.

a) *Single Pass:* In this specific pass the tool bit is not lifted from the surface of metal till the process of welding is not being get completed. Hence in the single pass the effective process is being completed in just one single movement of the tooling.
b) *Multiple Pass:* In this pass there is more than one movement is being completed by the help of tooling bit. Here movement can be performed one of the two ways. First one is by the applying of multiple passes on the top surface of the material. Second one involves two passes in which first pass on the top and then second pass is applied on the bottom surface of the material. These passes can be simultaneous, but there is always some delay amid each and every pass.

F. Advantages and Limitations of FSW

1) *Advantages:* There are numerous benefits of friction stir welding over one of the most used fusion welding method. Some of these significant advantages are listed here.
a) The FSW process utilizes solid state attributes of materials and is always operated below the melting point of the materials which has to be welded, and so this process can be utilized to combine materials which are hard to fusion the weld.
b) Dissimilar aluminum alloys as well as distinct varieties of composites can also be easily welded
c) This process is found to be independent of weld defects such as shrinkage as well as porosities.
d) FSW method has the benefit that it does not utilize of any filler metal amid materials which has to be weld and so the weld can be undertaken without any considerations on the compatibility of the composition of the filler wire and weld alloys. As a benefit of it is that there is no slag inclusion in the FSW joints.
e) In the process of FSW the heat required for is very low in contrast to other various welding processes so it makes it quite suitable for thin plates as there is no shrinkage and distortion.
f) In the FSW process it is found that there is no loss of alloying elements.
g) One of the prime benefits is that there is no need of surface preparation before welding process.
h) Other benefit is that there is no nee of post-weld surface treatment.
i) FSW process is known as a green technology as it does not produce smoke because of its environment friendliness as well as energy efficiency feature.
j) FSW consumes considerably very small amount of energy.
k) FSW method is utilized for welding by robots so it can be automated easily.

2) *Limitations*

First of all workpiece should be very tightly or rigidly clamped along the process.

a) FSW technique can be implemented when material is fastened by backing plate.
b) Other prime limitation is that a keyhole is left at the final stage of each weld by the pin of the tool bit.
c) FSW cannot be utilized to create joints where there is need of deposition of metals.
d) Other limitation is that materials which are very high in strength and high melting point cannot be easily joined.
e) For implementing the FSW process on thicker plates there is requirement of special tool bits and powerful machines.

G. Applicatons of FSW

Applications of Friction Stir Welding in Aluminum Alloys as well as in other Mmterials can be utilized for joining many types of materials and material combinations. Sustaining evolution of the FSW tool, its design and materials have permitted initial welds to be well manufactured in:

1) Aluminum alloys 2xxx (Al-Cu), 5xxx (Al-Mg), 6xxx (Al-Mg-Si), 7xxx (Al- Zn), 8xxx (Al- Li) series.
2) Copper and its alloys
3) Lead
4) Titanium and its alloys

5) Magnesium alloy, magnesium to aluminum
6) Zinc
7) MMCs based on aluminum (metal matrix composites)
8) Plastics
9) Mild steel

H. Classification and Weld ability Of Different Aluminum Alloys

Wrought aluminium alloys are essentially categorized as non-heat-treatable alloys and heat- treatable alloys.

1) *Heat-Treatable Aluminium Alloys:* These types of heat treatable aluminium alloys fall into the category of wrought alloys which can reply to durability with the treatment of heat. These alloys range from 2xxx, 6xxx to 7xxx. The improved power or strength of these aluminum alloys is controlled by effect of age hardening. During fusion weld of aluminium alloys there is a concern of alloys due to their high thermal conductivity and coefficient of thermal expansion. These types of aluminium alloys have very good amounts of alloying elements and so are very much susceptible to weld cracking. This is due to the evidence of that the alloying elements have low melting points and these melt along welding process.
2) *Non-Heat-Treatable Aluminium Alloys:* These are distinct category of alloys that do not display either feedback to stability by analysis of heat. Strength is generated by strain toughening by cold working as well as solution hardening which is also known as alloying. This category constitutes of aluminium alloys which have magnesium and manganese as the prime alloying components. The power and durability of these alloys is gained with the solidifying effect of their different alloying elements. Non-heat- treatable aluminium alloys have series ranging from 1xxx, 3xxx, 4xxx to 5xxx series.

II. LITERATURE SURVEY

M. Shunmugasundaram et al. [1] in 2020 performed friction stir welding of two dissimilar plates of aluminum alloys having series number AA6063 and AA5052. Authors utilized distinct process parameters and were optimized with the help of Taguchi L9 orthogonal design of experiments.

The novel range of the various process parameters and their limits which further depends upon the strength of the weld joints were analyzed by famous ANOVA method. Authors from the experiments analyzed that the welding speed was very much effective in comparison to feet as well as the tilt angle to join dissimilar metals. From the results authors showed that for getting the high tensile strength the tool rotation speed should be near to 850 rpm also the speed of welding should be near to 20mm/min as well as tilt angle should be two degrees for the particular experimental setup.

A Viscusi et al. [2] in 2019 performed various experiments on the lap joints of AA2024T3 by friction stir welding and then investigated the effect of various parameters like rotational as well as transverse speed on the strength of given materials. Authors performed various distinct tensile tests on small samples which were earlier taken from various areas. Authors then applied a central composite design for the given analysis and also confirmed their outcome with the help of shear analysis. Form their experiments authors found the optimized performance in their analysis which was approximated at 1250 Hz.

R Kosturek et al. [3] in 2019 investigated the effect of various parameters of friction stir welding process on both the microstructure as well as mechanical attributes of Sc-modified AA2519 extrusion joints. Authors in their relevant experiment utilized seven distinct sets of welding parameters and then executed various testing of tensile as well as impact strength. Authors found that FSW joints of Sc-modified AA2519 in the non-heat-treated condition had very good joint efficiency which was very much in the limit of 87 to 95%.

D. Texier et al. in 2018 [4] investigated the fatigue properties of assemblies of aluminum alloy AA6061-T6 which were structure extensions. Here gas metal arc and as well as friction stir welding was performed on the given metals. Different tests like uniaxial tensile and fatigue tests like force motivated constant amplitude were performed. Different analysis like Microstructural and fractographic were performed to discover the effect of the process on the microsturcture evolution, fatigue crack initiation sites as well as propagation that accompanied to the breakage of the assemblies in the end. This all was done just to figured the fact that the crack initiation process was propagated due to two factors. First one was the microstructural state of the joint and second one was the structural contact-fretting happened at the notch root. The examination of fatigue properties of gas metal arc welded and friction stir welded joints showed following outcomes showed that the tomography analyses focused on elevated porosity level for GMAWed joints in areas having very high strain localization.

A. K. Kadian in 2018 et al. [5] studied the movement of material flow along the welding zone of joint of plates of aluminium alloy (AA-6061) and copper alloy (Cu-B370). Actually a new model of material flow for dissimilar material friction stir welding was proposed. This above said model was based on the temperature as well as the strain rate dependent material properties. Experiments were also managed to authenticate the prototype with thermal profiles and as well as the optical micrographs. Moreover, the influence of tool bit rotational and as well as the welding speed were discovered on the material movement. It was found that the tool bit rotation and as well as the welding speed directly transforms the volume of platisized material mixing. Different outcomes showed the authenticity of welding.
A. Barbini et al. in 2017 [8] performed shouldering by friction stir welding as well as stationary shoulder friction stir welding of forming butt joint of dissimilar AA2024-T3 and AA70750- T7651 aluminium alloys having thickness of just 2mm. A contrast amid the two processes was implemented by changing the welding speed while maintaining the rotational speed at same value. With the analysis of the force and torque generated in between welding and a normal analytical prototype, it was achievable to demonstrate that in SSFSW technique there was enough effective coupling was produced with the tool bit and the heat produced was more efficiently distributed.

This method decreased both the welding area as well as the diffusion at inter coarse of the two alloys as contrasted with FSW. The minimum micro hardness happened at the advancing side (AS) at the inter coarse amid the thermo-mechanically affected zone (TMAZ) and the stir zone (SZ) in all the techniques. But it was found that the fall was more gradual in SSFSW. The torque implemented in FSW is more than that of SSFSW.
T. Navaneethakrishnan et al. in 2017 [9] investigated the success of non-identical tool pin profiles across the welding using friction stir process on dissimilar alloys of aluminium AA 6082 –T6 and AA 7075 – T6. The variables used by authors in the experiment were the tool bit rotating speed, welding speed, tool pin profiles and last one was count of passes. Here both the metallurgical as well as the mechanical identification of friction stir welding was conveyed. Also the multi pass friction stir weld of the given alloys had been conveyed. Authors also performed different examination like microstructure and different tests like micro hardness test and tensile tests. In the experiment it was found that the tensile strength for single pass is comparatively higher than multipass friction stir welding. Further it was found that the hardness character reduces while increasing the count of passes. Also in the single grain improvement was also discovered. The important outcome of the discussion was the single pass friction stir welding hardness value also decreased.
V. V. Patel et al. in 2017 [10] studied the friction stir processing (FSP) and its abiltity to achieve superplasticity in different aluminum alloys. Authors showed that pin profile of FSP tool was one of the significant method parameter which controls the mechanical and metallurgical attributes of stir zone (SZ). It was similar to other unknown values like rotational speed, travel speed, and tool tilt of tool bit.
In their experiment authors demonstrated that the high strength 7075 aluminum (Al-Zn-Mg-Cu) alloy was subjected to friction stir processing to examine consequences of pin profiles on the superplastic bearing. Authors utilized hot tensile testing which was carried out for square pin under the superplastic condition of 3×10^{-4} s^{-1} and 400 degrees C. Three parameters that were microstructure, microhardness and grain size measurements were applied for all FSP samples. It was observed that only square pin was able to create excellent grain uniform microstructure without cavitation in the SZ in the earlier sample. It was observed that uniform superplastic elongation of 227% was acquired in the gage area of the square pin collection.
A. Fall et al. [13] in 2016 performed deep testing on the microstructure as well as on the tool wear utilizing various techniques like energy-dispersive spectroscopy (EDS) and optical and scanning electron microscopy (SEM).
After conducting the investigation the prime result of this research outlined that the there was no need of radial tool wear of the pin to be regular. Titanium alloy (Ti-6Al-4 V) with a length, width and thickness of 100 mm, 50 mm and 2 mm respectively was welded by the above stated methods utilizing a tungsten carbide tool (WC) with the use of friction stir welding.
After performing annealation operation of the titanium alloy authors found that its various mechanical properties which had value of 344 VHN for hardness, value of 910 MPa for the yield strength, value of 994 MPa for the tensile strength and finally 17.2% the value for the elongation parameter. Authors utilized different 5 rotational speeds which were 500, 700, 1000, 1250, and 1500 rpm and had utilized travel speed which was remained fixed at 100 mm/minute for the given experimental process. Authors demonstrated that the size of particles of tungsten carbide could vary from 3 to 200 lm, which did not affect the crystallization of the materials.

M. M. Krishnan et al. in 2016 [14] studied the friction stir welding process which was an solid state process in which there was combining of two dissimilar alloys of aluminium, copper, magnesium and zinc. The weld quality of FSW process was dependent on the various parameters like rotation speed of tool bit, tool, speed of welding, force applied on the axis etc. Authors designed a prototype which is mathematical concept based on the different experiments conducted in lab.

Experiments were based on the design of central composite circumscribed and were contrasted utilizing ANN technique to discover the tensile stiffness of alloys of dissimilar alloys. From the experiments it was found that the discovered error rate of the regression ANN technique was very much low as compared to collected by the other ANN techniques. The model was validated for confidence level of 95 percent. The outcomes of the experiment showed that the gain in rotational speed of tool bit and as well as gain in axial load had enhanced the responses to a certain point. But after crossing a particular maximum value there was sudden fall of all the values. Further with gain welding speed there was opposite impact on the responses. Also the fabrication of dissimilar joints utilizing FSW showed a fall in value of hardness for high heat input joint.

R. Kumar et al. [16] in 2015 performed various lab experiments with the help of friction stir welding process on the stainless-steel with the help of other materials. Authors demonstrated that the composite carbides could also be utilized as a tool material that incorporated reinforced particles. Further authors showed that the parameter of practical toughness as well as outstanding resistance to wear was also crucial for the given tool material. Authors also found that the amount of displacement may be additionally would lead to the operations of the screw for getting approximation of degrees displaced then there was need of an efficient radius. Authors further showed that the depth of the pin was utilized to provide the strict measurements for the outer and inner radii.

S. Kumar et al. in 2013 [28] performed investigations with the help of Taguchi method and tried to discover the behavior of dissimilar alloys A6061 and AA6062 by applying the optimal method parameters for the optimum tensile strength and hardness of welded alloys. Authors implemented an orthogonal array of L9. Also authors investigated the outcomes of the analysis of variance and finding the importance of parameters on results. The various outcomes showed that that the out of all the parameters the rotational speed is most significant process parameter and it had the greatest effect on tensile strength and hardness which was further accompanied by tool pin profile as well as tool tilt. Different experiments were performed to perform verifications. Authors showed that the value of tensile strength of friction stir welding was 267.74 MPa and hardness of dissimilar joints produced was 80.55 HRB.

III. PROBLEM FORMULATION

Friction stir welding is well known welding process which is used for joining of dissimilar aluminum alloys by the use of heat which is produced by friction and mechanical mixing of the alloys at joint location. Friction stir welding is used in different mechanical industries like aerospace, automotive, railways and other different industries. Not only aluminium but also magnesium etc and other hard material are also joined by this welding process. The welding quality of the joint is dependent on the rotation speed of tool, tilt angle and welding speed used at the process of welding.

The present research work contains the comparison of welding of different alloys of aluminium using friction stir welding. Different process parameter will be used that affects the attributes of welded products. The work was carried on Dynamic Gantry Friction Stir Welding Machine at Trikuta Aluminium Industries, Udhampur, (J&K).

IV. RESEARCH GAP AND OBJECTIVES

A. Research Gap

After having a comprehensive literature survey, the various research gaps that were identified which are described here

1) Different alloys of same metal can have different properties.
2) Weld quality of different alloys of same material can have different strength which can depend on different parameters at the time of welding process.
3) The weld quality of the joined material should also be noted which can also influence the results.

B. Research Objectives

This research work will be focused to achieve the following objectives:-

1) To design, study and implement the results of friction stir welding of different alloys.
2) Prime stress is on improving the parameter values of the welded part.

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V. RESEARCH METHODOLOGY

A. Research Methodology

The following steps will be performed to complete this research work:-

1) Take different aluminium alloys namely AA2024, AA6061 and AA6063.
2) Remove the noise present on the surface of these alloys.
3) Perform the friction stir welding on these alloys.
4) Check the parametric values of these alloys.
5) Check the accuracy of result obtained from the process.

B. Various Properties Of Materials Used

The dissimilar material aluminium alloys AA 2024, AA 6061 and AA6063 are used in this investigation. Chemical compositions and other properties of the above alloys materials are tabulated.

Table 5.1: Chemical Composition of AA 2024

AA2024	
Component	Weight Percentage
Cu	4.45
Mg	1.57
Mn	0.56
Fe	0.17
Zn	0.16
Si	0.06
Others	0.04
Al	92.99

Table 5.2: Physical Properties of AA2024

Physical Property	Density (Kg/m^3)	Melting Point (^0C)	Modulus of Elasticity	Poisson's Ratio
Base Metal	3000	640	73.1	0.33

Table 5.3: Mechanical Properties of AA2024

Mechanical Property	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Hardness Number (BHN)	Elongation (%)
Base Metal	370	480	75	12.7

Table 5.4: Thermal Properties of AA2024

Thermal Property	Thermal Conductivity (MPa)	Thermal Capacity (J/KgK)	Coefficient of Thermal Expansion ($10^{-6}/^0C$)
Base Metal	121	880	23

Table 5.5: Mechanical Properties of AA6061

Mechanical Property	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Hardness Number (BHN)	Elongation (%)
Base Metal	233	283	94	10.1-13.1

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Table 5.6: Chemical Composition of AA 6061

AA6061	
Component	Weight Percentage
Cu	0.25
Mg	1.1
Mn	0.14
Fe	0.7
Zn	0.22
Si	0.7
Ti	0.14
Others	0.05
Al	96.7

Table 5.7 Physical Properties of AA6061

Physical Property	Density (Kg/m^3)	Melting Point (^0C)	Modulus of Elasticity	Poisson's Ratio
Base Metal	2695	579	68.71	0.3265

Table 5.8: Thermal Properties of AA6061

Thermal Property	Thermal Conductivity (MPa)	Thermal Capacity (J/KgK)	Coefficient of Thermal Expansion ($10^{-6}/^0C$)
Base Metal	178.99	895	23.57

Table 5.9: Chemical Composition of AA 6063

AA6063	
Component	Weight Percentage
Cu	0.0047
Mg	0.58
Mn	0.0076
Fe	0.325
Zn	0.076
Si	0.271
Ti	0.038
Others	balance
Al	98.5

Table 5.10 Physical Properties of AA6063

Physical Property	Density (Kg/m^3)	Melting Point (^0C)	Modulus of Elasticity (GPa)	Poisson's Ratio
Base Metal	2700	635	68.9	0.33

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Table 5.11: Mechanical Properties of AA6063

Mechanical Property	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Hardness Number (BHN)	Elongation (%)
Base Metal	214	241	96	12

Table 5.12: Thermal Properties of AA6063

Thermal Property	Thermal Conductivity (MPa)	Thermal Capacity (J/KgK)	Coefficient of Thermal Expansion ($10^{-6}/^0C$)
Base Metal	200	900	25.6

Table 5.13: Selected Process Parameters

Process Parameters	Values
Rotational Speed (RPM)	800, 1200, 1600
Welding Speed(mm/min)	28
Axial Force	7 KN
Tool Material	High carbon with high chromium
Tool Dimensions	Shoulder dia 18mm
Tool Pin Profiles	Straight Cylindrical

C. Tensile Test

The experimental will be performed with the above and Tensile Test will be performed for calculating different parameters. Mechanical properties will be obtained by straight cylindrical tool pin profile for constant welding speed and axial force.

D. Brinell Hardness Test

The Brinell Hardness Number (BHN) which is the pressure per unit surface area of the indentation in kg per square meter is calculated as follows:

$$BHN = \frac{2F}{\pi D * [D - \sqrt{D^2 - d^2}]}$$

Where: F is test force, D is diameter of ball,
d is mean diameter of indentation, mm

E. Examination Of Joints

Visual inspection will be performed on the welded sample in order to verify the presence of possible macroscopic external defects, such as surface irregularities, excessive flash, and lack of penetration or surface-open tunnels. Tensile tests will be performed on samples cut perpendicularly to the weld line. The tests were carried out at constant speed of 2.8mm

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VI. RESULTS AND CONCLUSTION

A. Results

1) Evaluation of Mechanical Properties

a) Tensile Test

The following experimental data is created after performing the Tensile test.

Table 6.1: Mechanical properties are derived by straight cylindrical tool pin profile for Constant welding speed of AA2024 with AA6061

Total Rotational Speed (RPM)	Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation (%)
800	151.8	183	3.4
1200	176	202.15	6.5
1600	170.51	189.32	4.9

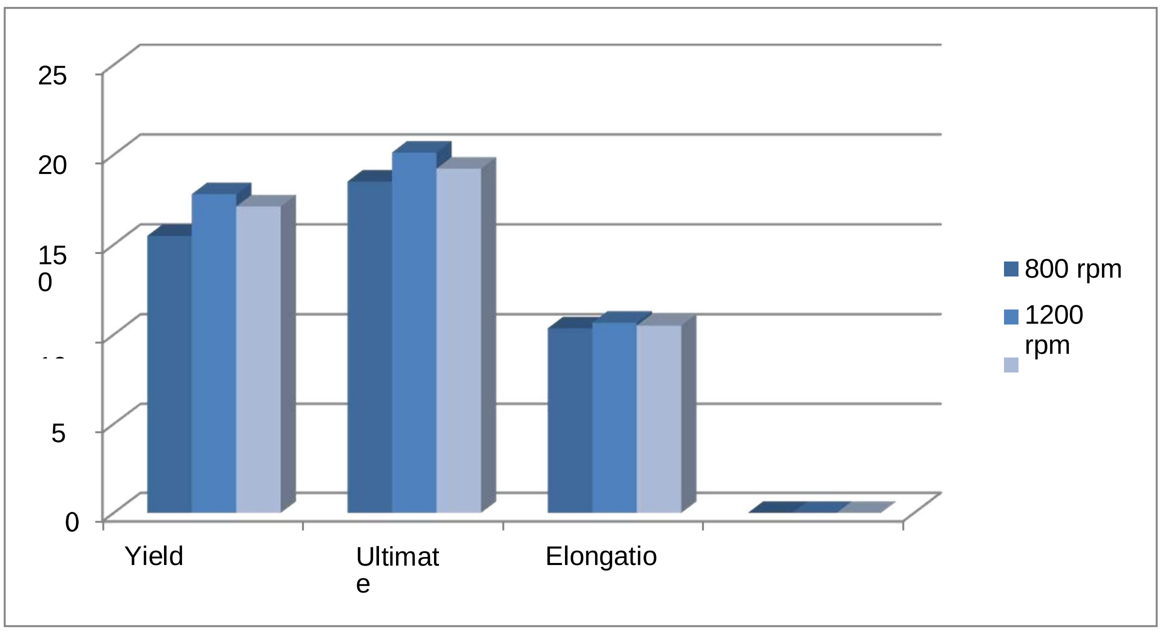

Figure 6.1: Graph displaying different parameter values at different rotation speed for AA2024 and AA 6061

b) Brinell Hardness Test: The Brinell hardness test was performed and different values are calculated are defined in the following table.

Table 6.2: Hardness values are obtained by straight cylindrical tool pin profile for constant welding of AA2024 with AA6061

Total Rotational Speed	Distance from the weld centre		
	Advanced Side 9mm	Weld center 0	Retreating Side 9mm
800	52.9	47.9	50.9
1200	57.2	51.9	53.9
1600	51.5	50.7	50.1

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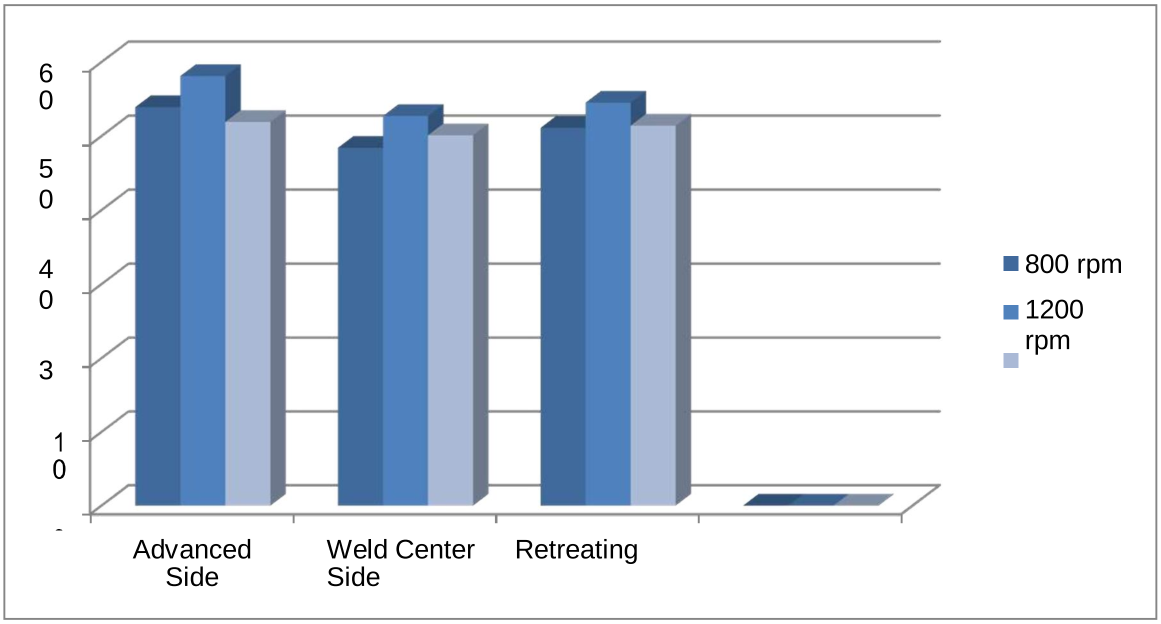

Figure 6.2: Graph displaying hardness values at different position of the joint for AA2024 and AA 6061

c) Tensile Test of AA 2024 and AA 6063

The following experimental data is created after performing the Tensile test.

Table 6.3: Mechanical properties are obtained by straight cylindrical tool pin profile for Constant welding speed of AA 2024 and AA 6063

Total Rotational Speed (RPM)	Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation (%)
800	151.8	189	3.6
1200	183	209.36	6.7
1600	174.15	198.21	5.3

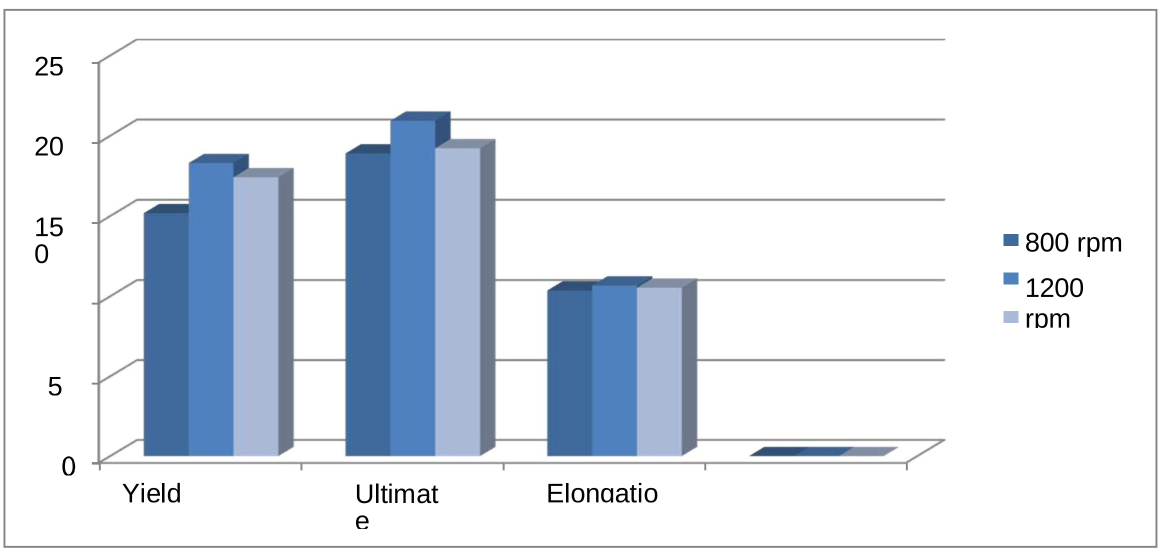

Figure 6.3: Graph displaying different parameter values at different rotation speed for AA2024 and AA 6063

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d) Brinell Hardness Test of AA 2024 and AA 6063

The Brinell hardness test was performed and different values are calculated are defined in the following table.

Table 6.4: Hardness values are obtained by straight cylindrical tool pin profile for constant welding of AA 2024 and AA 6063

Total Rotational Speed	Distance from the weld centre		
	Advanced Side 9mm	Weld center 0	Retreating Side 9mm
800	54.4	49.3	52.3
1200	59.8	54.1	55.6
1600	52.6	51.8	51.9

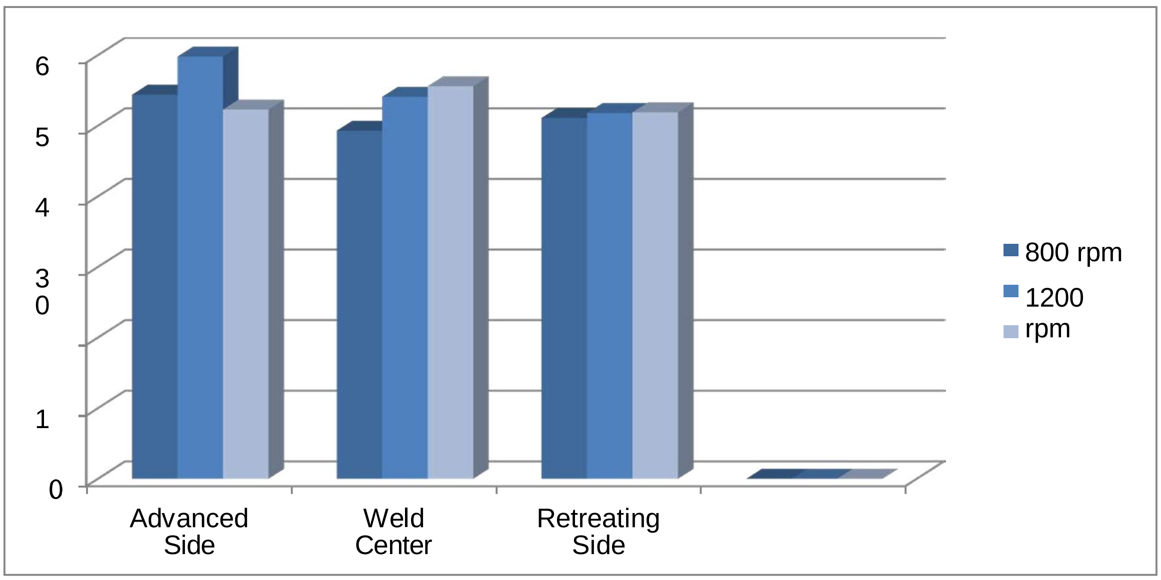

Figure 6.4: Graph displaying hardness values at different position of the joint for AA2024 and AA 6063

B. FSW Processed Images

Friction stir welding (FSW) is described in the following images.

1) *Step 1:* First of all mould is created from the raw aluminium plates of dissimilar alloys. Step 2: Tool bit is fixed in the FSW machine and is fastened.
2) *Step 3:* Two dissimilar aluminum plates are fastened in the jaws as there is no gap in between the plates.
3) *Step 4:* Tool bit is gently rotated as well as translated over the joined surface. Step 5: The operation is performed for only single pass.

Figure 6.5: Mould production of the aluminum alloys

Figure 6.6: Sample of AA2024 and AA6061 for performing FSW

Figure 6.7: Sample of AA2024 and AA6063 for performing FSW

Figure 6.8: Initial Stage of FSW welding

Figure 6.9: State of FSW welding after 25 seconds

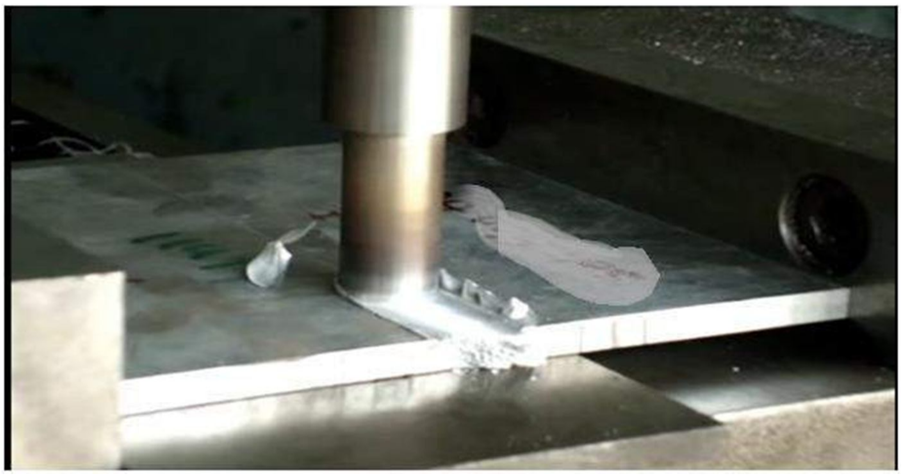

Figure 6.10: State of FSW welding after 50 seconds

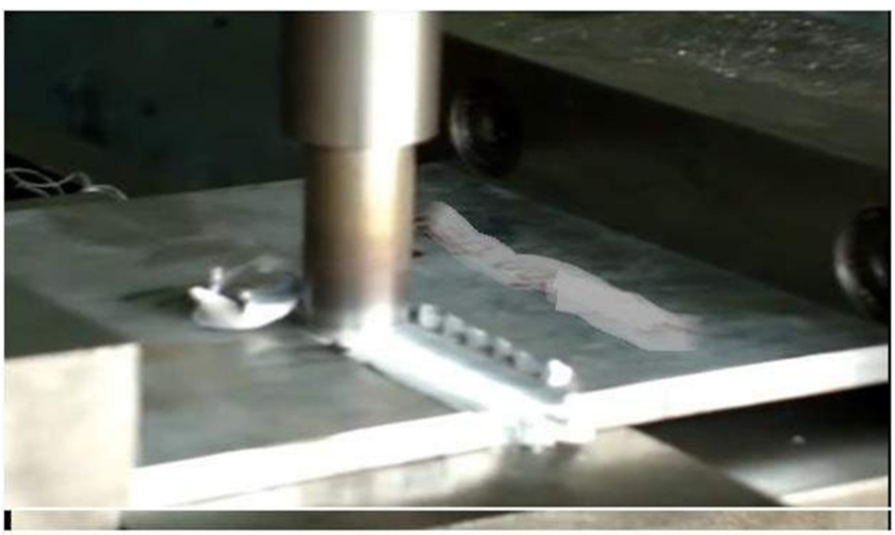

Figure 6.11: State of FSW welding after 90 seconds

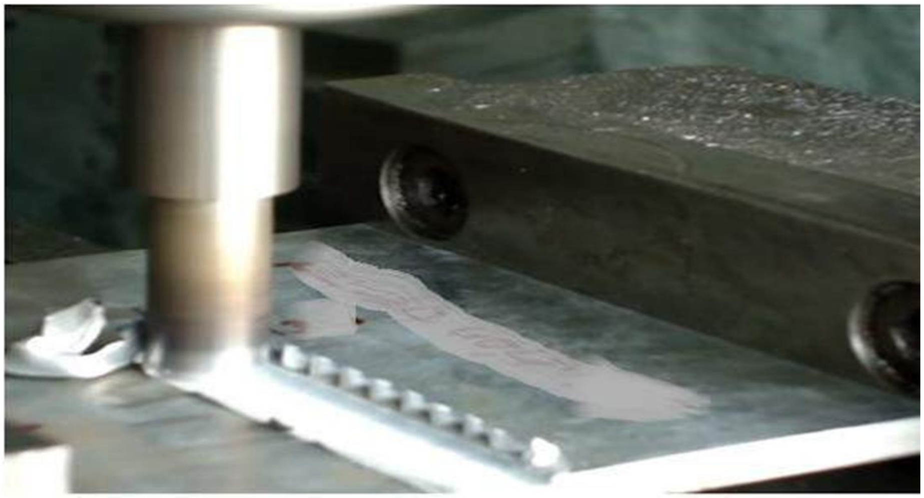

Figure 6.12: State of FSW welding after 120 seconds

Figure 6.13: State of FSW welding after 205 seconds

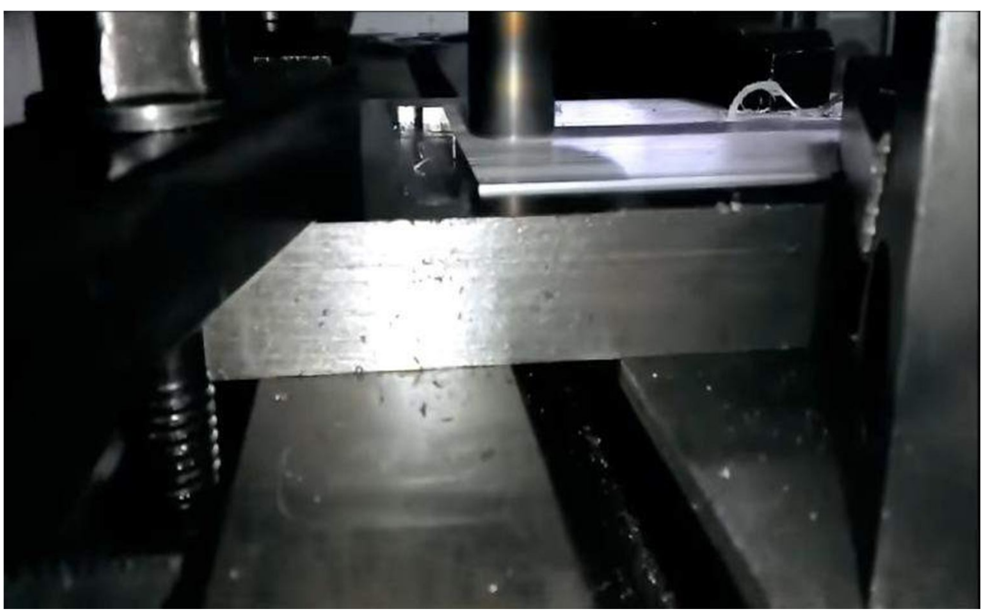

Figure 6.14: Final state of FSW welding after 290 seconds

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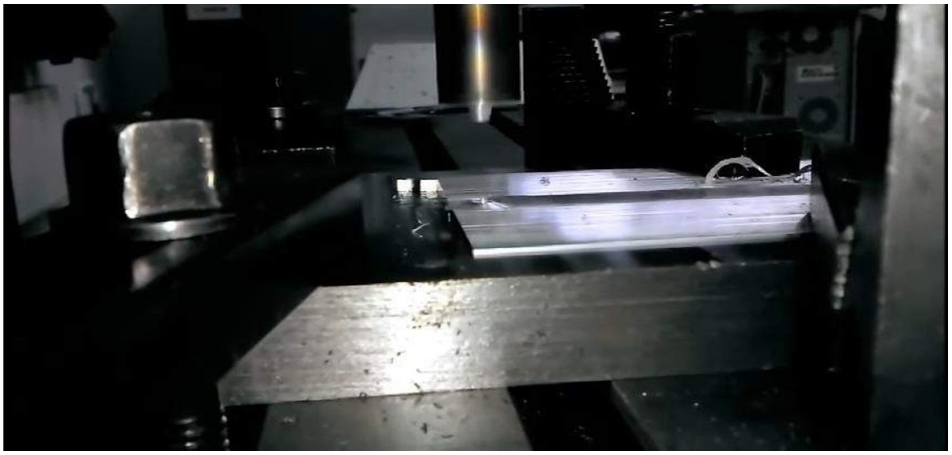

Figure 6.15: Lifting of tool bit after performing FSW welding

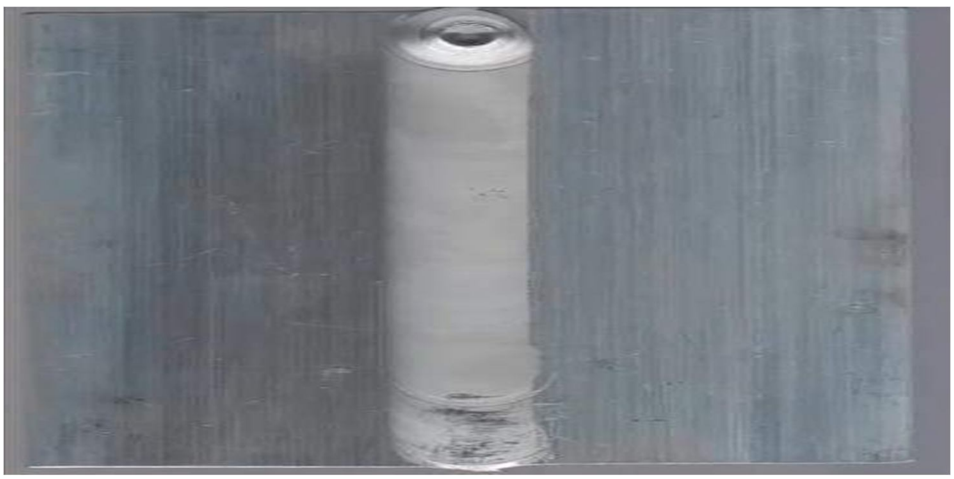

Figure 6.16: Final state of FSW welding

Figure 6.17: Final workpiece by performing FSW welding of AA2024 with AA6061

Figure 6.18: Final workpiece by performing FSW welding of AA2024 with AA6063

C. Conclusion

The joining of AA 2024 with AA 6061 and joining of AA2024 and AA6063 of aluminum alloy was successfully carried out utilizing FSW welding technique. The optimum operating conditions of FSW have been obtained for plates of aluminum alloy AA2024 with AA6061 and AA2024 with AA6063 welded in joint.

From the experimental results, the better performance was

1) Achieved by the cylindrical tool pin profile. The optimal FSW process parameter combinations are rotation. Joints obtained by AA2024 with AA6063 are stronger than AA2024 with AA6061.
2) Rotational speed at 800, 1200, 1600 and welding speed at 28mm/min.
3) Strength and percentage of elongation are 176, 202.15 MPa and 6.5% respectively was observed for square tool pin profile for AA2024 and AA6061 at 1200 rpm. For AA2024 with AA6063 strength and percentage of elongation are 183, 209.36 MPa and 6.7% respectively was observed for square tool pin profile at 1200 rpm.

D. Future Work

In the future work other dissimilar alloys can be taken for investigation. Also various other objective parameters could also be taken for various different kinds of investigations. A good comparison can also be done with the various other samples with other welding types with the friction stir welding (FSW). The consequences can be utilized for further investigations in future work.

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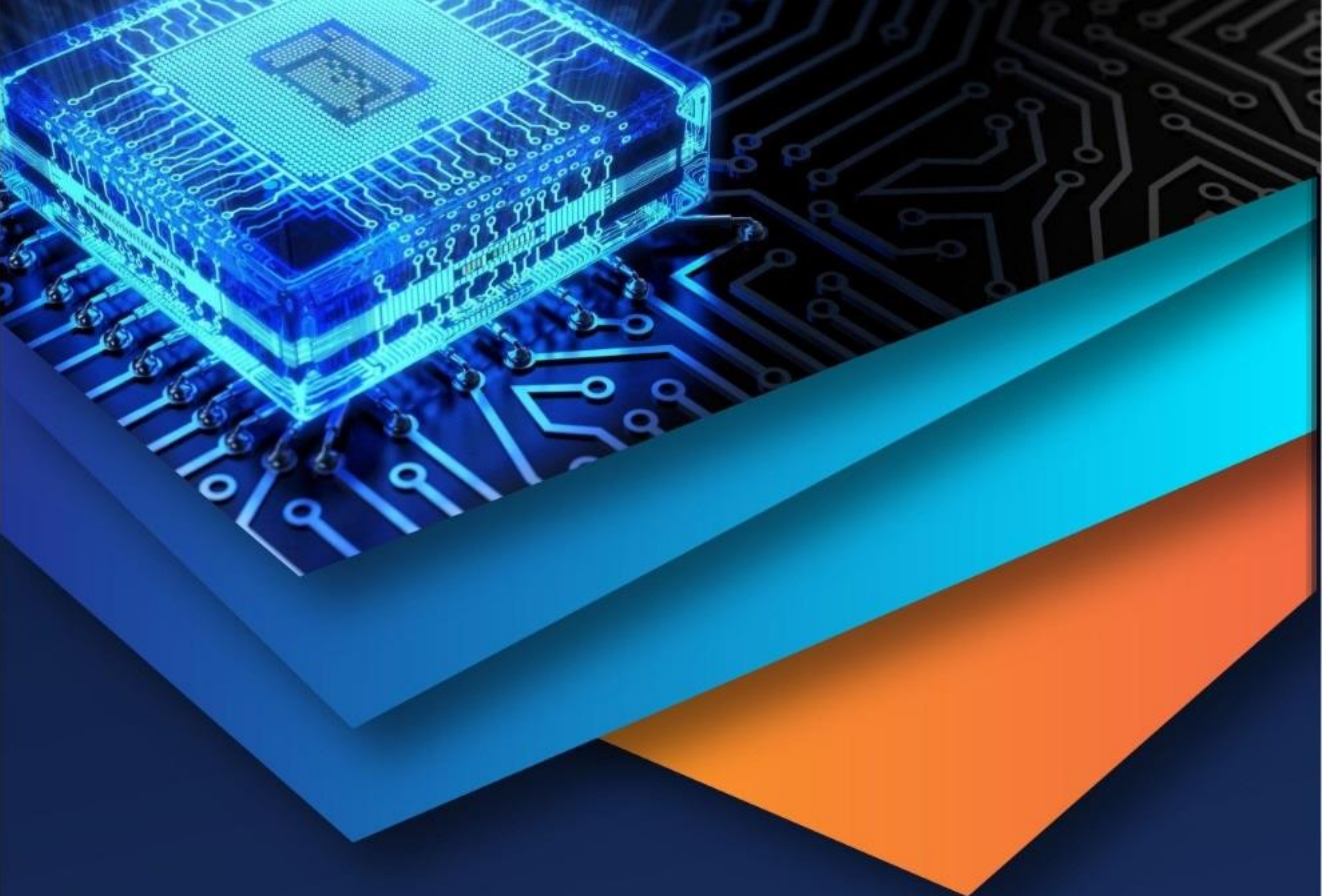

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