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BONAFIDE CERTIFICATE

Certified that this project report **"INVESTIGATION OF HEAT GENERATION DURING BOBBIN TOOL FRICTION STIR WELDING ON DISSIMILAR ALUMINUM ALLOY."** Is the Bonafide work of **"AAKASH K (312319114001)**, **ASWIN RAJ A** (**312319114026)"** who carried out the project work under my supervision.

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This report of project work submitted by the above students in partial fulfilment for the award of Bachelor of Engineering in Mechanical Engineering in Anna University was evaluated and confirmed to be reports of the work done by the above students.

Submitted for UNIVERSITY VIVA EXAMINATION held on ____________

INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

The effects of rotational and welding speeds on the temperature distribution andmechanical properties of bobbin tool friction stir welded (BT-FSW) were investigated using varying cross section (cylindrical, triangular and square) of the pin. Tensile properties of the specimens were investigated. In triangular Pin Bobbin tool Excellent welds with no degradationin hardness were produced using a low heat input. The use of a bobbin tool in FSW introduces additional complexities to the temperature distribution due to the varying diameter of the tool. This can result in non-uniform heat generation and temperature distribution, which can impact the microstructure and mechanical properties of the weld. Mechanical tests revealed that the ultimate tensile strengths gradually increased with increasing welding speed while keeping the rotational speed constant. The rotational and welding speeds had only slight influences on the yield stress and fracture elongation. Overall, the temperature distribution in FSW using a bobbin tool is affected by several parameters, such as tool geometry, rotational speed, traverse speed, and material properties. Understanding the temperature distribution in FSW using a bobbin tool is essential for optimizing the welding process and achieving high-quality welds. This work investigated the temperature distribution in FSW using a bobbin tool. These studies have utilized various techniques, such as thermocouples, infrared cameras to measure and model the temperature distribution.

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LIST OF SYMBOLS

SL.NO	SYMBOL	DESCRIPTION
1	Mm	Millimeter
2	M	Meter
3	Cm	Centimeter
4	Kg	Kilogram
5	Mpa	Mega Pascal
6	Min	Minute
7	Sec	Second
8	Rpm	Revolution Per Minute

CHAPTER 1

INTRODUCTION

In the Modern industrial companies place a high value on being lightweight and energy efficient. Nearly all industries are switching to aluminum-magnesium alloy products to become more energy efficient. When these materials are joined using the fusion technique, flaws like Weld beads frequently exhibit hot tearing, hardening fissures, porosity, and deformation. Such flaws significantly lower mechanical characteristics and fatigue strength.

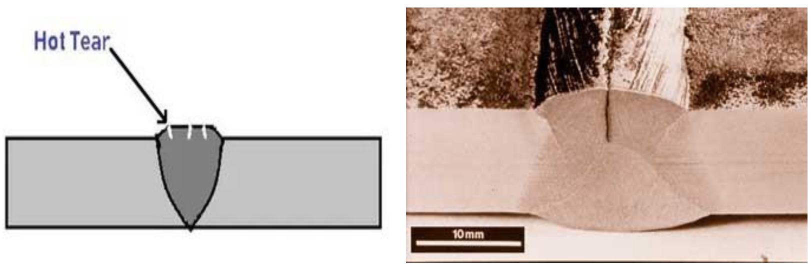


Fig 1.1 Hot tear

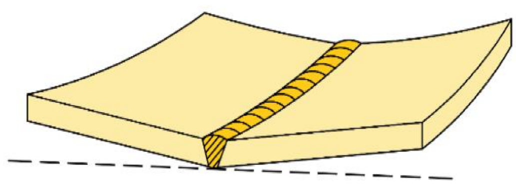


Fig 1.2 Distortion

1.1 Welding:

A connect is formed as two or more components cool during the welding process, Which involves the use of heat, pressure, or both. The most common materials for welding are metals and thermoplastics, however wood can also be utilized. A weldment is the term used to describe the finished welded junction. Certain materials demand the employment of particular procedures and methods. A few are deemed “unweldable," a phrase that is useful and descriptive in engineering but is rarely seen in dictionaries.

1.2 Types of Welding:

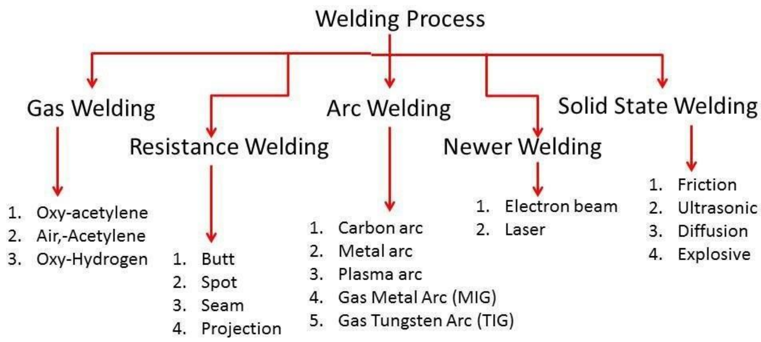


Fig 1.3 Types of welding

1.3 Solid state welding:

Without the use of brazing filler metal, solid-state welding is a class of welding techniques that results in coalescence at temperatures that are basically below the melting points of the base materials being connected. These welding methods are a diverse set that draw on several Multiphysics phenomena.

High shear stresses at the tool-workpiece interface promote viscous dissipation in the workpiece material, which is the main technique used in friction stir welding (FSW). Butt, overlap, T-section, fillet, and corner welds have all been created using this method. The butt weld configuration is shown in Figure 8. It is necessary to use particular tool designs that are being improved and further developed for each of these joint geometries. As a result, the behavior of the contact surface and the material's viscous dissipation behavior must be represented in the heat generation simulation.

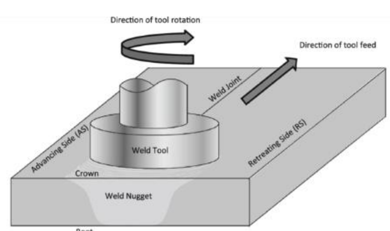


Fig 1.4 Solid State Welding

1.4 Friction stir welding (FSW):

FSW became advanced and patented with means of The Welding Institute in the year 1991. Due to its distinctive and well-liked qualities, FSW has since been required by and used by numerous industries. This results from the way friction stir welding is carried out rather than work parts. A welding method called friction stir welding (FSW) uses the heat produced by friction to fuse particular materials. This joining method no longer requires any consumables outside of the process. The range of characteristics and welding conditions that FSW can handle is one of the key advantages of using it. Tools used in friction stir welding rotate rapidly over the gaps that need to be welded together. Warmth can be produced among them when the device rotates over the steel.

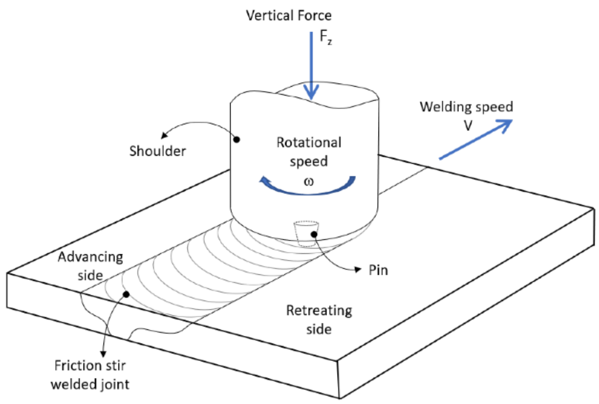


Fig 1.5 Friction stir welding

FSW offers lap and butt joints as examples of welding joints. The FSW steel tool consists of two sections. The first is a cylindrical component called the shoulder, which rotates on a seam, and the second is a profiled pin that extends from the shoulder. First training pin for the metal seam during welding. After the desired temperature is attained, which is close to the melting temperatures of the weld metals, the shoulder rotates to melt the two metals and unite them by fusion on welds, forming an uninterrupted weld seam across the joint.

1.5 Friction stir welding vs friction welding:

The most popular welding techniques that use this method are friction welding and friction stir welding, which melt the two metals and join them by fusion on welds to create a non-stop weld seam that use this method. across when a desired temperature is reached that is close to the melting points of the weld metals. There are very few welding techniques

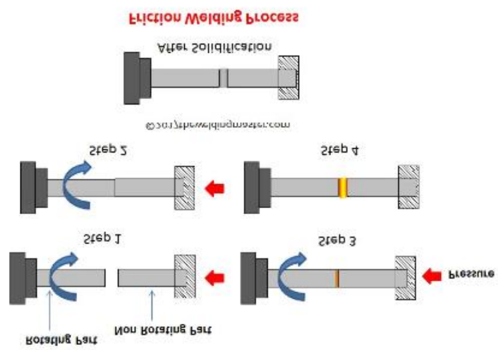


Fig 1.6 Friction welding

Yet, the way the work piece is handled in these two welding techniques makes them different from one another. Friction stir welding (FSW welding) overcomes the disadvantage of friction welding by fixing the work pieces and using a rotating tool to move along a seam to generate heat by friction. Friction welding is an alternative to friction welding, which has a greater disadvantage in that handling work pieces at high speeds can be challenging (produced by action of rotating tool between the work pieces).

1.6 Bobbin Tool Friction Stir Welding:

At TWI, friction stir welding on aluminum plate up to 25mm thickness has been successfully demonstrated. The method enters the joint line either directly or from a milled 'floating' bobbin-shaped instrument. The edge of the material has a recess. TWI’s massive, specifically designed FSW machine has successfully demonstrated that thick section friction stir welds up to 25mm may be produced. The method is perfect for combining materials that soften at low temperatures, such 6082 aluminum. Moreover, TWI has had success joining a number of grade 5083 and two and seven thousand high strength aluminum alloys. The method is useful for joining closed sections when using a well-supported backing bar is challenging or impossible. he bobbin produces a complete penetration weld, eliminating the possibility of kissing bonds, which are typically brought on by inadequate tool penetration. The technique uses a single piece of tooling, as opposed to some FSW variations that call for complex multi-piece tooling, and it has around a centimeter of freedom to move up and down in the vertical or Z plane. The material slides between the bobbin's shoulders as the tool is moved across it. Thus, the technique uses no vertical force, unlike earlier FSW modifications. Because the lower shoulder supports the underside of the weld, a backing bar is not necessary.

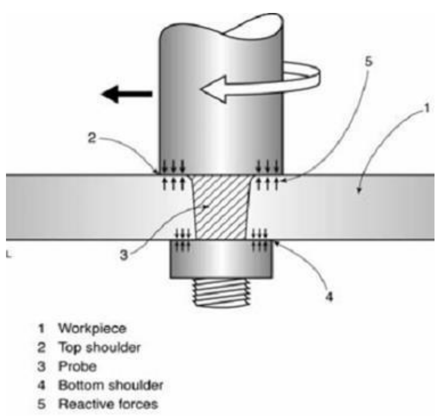


Fig 1.7 Bobbin Tool Friction Stir Welding

1.7 Advantages of BTFSW:

By attaching the work piece to a holder, FSW has an advantage over friction welding. However, there are many other benefits to FSW as well, including having an aesthetic welding finish, being automated (because the work piece is fixed and other factors are controlled by the machine), and not needing a shielding agent because the factors of welding are largely dependent on the welding parameters (tool speed, weld speed, tilt angle, etc.) and type of materials to be welded.

In order to verify out its stability with the previously used materials in the industries, FSW is typically used to weld Al (limited to Al because to low peak temperatures in FSW) with itself of other grades or with other materials.

1.8 Disadvantages of BTFSW:

- The hole made with the tool remains empty at the exit.
- An enhanced clamping configuration is required to clamp the work piece during welding.
- A great downward force is required to insert the pin inward.
- In many cases, this welding process is not quicker than many other processes. It takes a while for welds to form.
- When metal cladding is required, friction stir welding is not allowed to form a weld.
- The acquisition cost of FSW machines is not cheap
- Manual and arc welding processes are more flexible

1.9 Advancement of BTFSW:

The conclusion for the study of advancement in the FSW of aluminum-based alloys are mentioned below:

- Great alternative material for steel are aluminum alloys and is used widely in the manufacturing of complicated industrial applications.
- Alloys of aluminum cannot be welded and hence treated as such.
- It's difficult and expensive to perform fusion welding and resistance welding on aluminum alloys.

- FSW is said to be a solid-state welding. It uses rotating tool which cannot be consumed for welding of alloys of aluminum with frictional energy

- Preparation for weld joint and melting of material is not needed for FSW.

- For better quality of weld and performance of welding the selection of the proper welding parameters, distribution of temperature during the process are kept in mind. With correct procedure, better quality is recorded.

- For welding of same or different aluminum alloys FSW method could be used.

- To join aluminum alloys with material such as high strength steel or various materials with light weight properties, FSW are generally used.

1.10 Applications of BTFSW:

- Shipbuilding
- Trains
- Aero Industry
- Auto Industry
- Rolling stock – Railways
- Robotics

1.11 Micro structural zones in BTFSW:

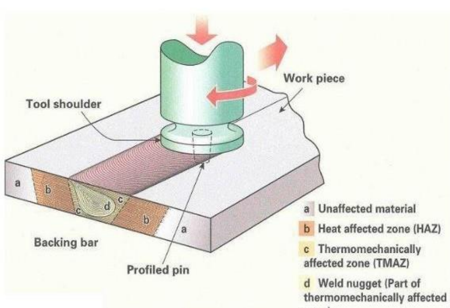


Fig 1.8 Zones in FSW

- **Unaffected or parent material:** Forms far away from the weld zone, a result of the conductive spread of warmth from the weld zone, isn't impacted by warmth with respect to microstructure or mech properties the level of temperature exposed are far enough below.
- **Heat affected zone (HAZ):** Forms around at the center of the weld. In this Metallurgical alteration zone are like those happening amid conventional combination welding forms.
- **Thermo-mechanically affected zone (TMAZ):** In this zone mech properties are changed by the grating warmth and extreme disfigurements brought about by the rotational and translational movement of the device.
- **Stir zone (SZ):** In this zone the first grain limits convert to fie crystallized grains. The zone genuinely is under the work bear to the grinding mix welding device is exposed to expansive plastic mis sharpening and furthermore high pinnacle temperature achieving incredible recrystallization.

CHAPTER 2

LITERATURE REVIEW

1.Samson Jerold Samuel Chelladurai, et.al.,[1] This study shows how response surface approach may be utilized to optimize process parameters in various manufacturing processes such as welding and advanced material machinability investigations. It also reduces the number of experiments required for a given problem.

2.Hakan Aydin, et.al.[2] Concluded that Taguchi method is very effective toll for process optimization under limited runs. Results shows that the tensile strength and elongation of welded aluminum alloy are improved by using grey based Taguchi method

3.Mohamadreza Nourani, et.al.,[3] When temperature field factors of the weld, such as the HAZ distance to the weld line and/or the peak temperature in the workpiece, are included in the objective function, the study shows that the Taguchi optimization result is efficient and no large interaction effects are predicted. The tool's rotational speed was found to be responsible for 51 percent of the HAZ distance to the weld line.

4.S Verma Meenu J P Misra,et.al.,[4]

In this paper, the temperatures distribution is captured using k-type thermocouples during FSW of AA6082 for varying tilt angle and dwell time. It is observed that the temperatures on advance side are more as compared to retreating side for all working conditions. The maximum temperature is obtained on AS with 2o tilt angle, 30sec dwell time,500 rpm and 20mm/s feed rate. It can be concluded that the maximum temperature recorded increases with increasing dwell time results in easier transverse movement of FSW tool. The effect of maximum temperature recorded on weld quality and microstructural characteristics of weld zone can also be included as future research work.

5.Hwang et al. (2008) AA6061 HSS ¬ Three different types thermocouple arrangement are used for predicting temperature. ¬ Regression analysis is carried out for predicting temperature at center line. ¬ Temperature on advancing side is found higher than retreating side.

6.M.V.R. Durga Prasad, et.al.,[6] The most important factor was welding speed, which accounted for 54.88 percent of the effect of percent elongation, whereas tool rotation speed had the least effect, accounting for 5.39 percent. Welding speed was the most important factor in determining the impact of hardness at the weld zone, accounting for 67.52 percent of the total, whereas tool rotation speed had the least impact, accounting for just 4.39 percent. The best parameters for obtaining good hardness at the weld zone were found to be tool rotation speed of 800rpm, welding speed of 20mm/min, and tool tilt angle of 2 degrees.

7.R. Muthu Vaidyanathan, et.al., [7] The D/d ratio, tool rotational speed, and weld speed all have a significant impact on the mechanical properties of the weldment, according to the findings. The use of a tool material resulted in increased weld strength. On a similar and dissimilar aluminum alloy joint, a three-to-one ratio results in higher mechanical strength and fine grain structure. The considerable heat generated throughout the operation results in low mechanical strength.

8.Mohammad Hasan Shojaeefard.et.al.,[8] Friction Stir Welding Microstructural and Mechanical Properties Optimization the Traverse Speed is a significant component that determines the grain size, hardness, and UTS of the weld, according to the Cellular Automation and Taguchi Method. Increases in rotating speed and shoulder diameter, as well as decreases in traverse speed, resulted in a decrease in tensile strength and hardness, as well as an increase in grain size.

9.Faiz F. Mustafa,.et.al..,[9] Pin groove shape (D) is the most important element affecting UTS Skins, followed by pin angle (C), shoulder diameter (A), and pin diameter (B), according to Tool Geometries Optimization for Friction Stir Welding of AA6061-T6 Aluminum Alloy T-Joint Using Taguchi Method to Improve the Mechanical Behavior (B). The most essential factor affecting UTS Stringers is pin angle (C), followed by pin diameter (B), shoulder diameter (A), and pin groove form (D).

10. Balaji Naik.Da,. et.al.,[10] The results reveal that the form of the tool pin has a significant impact on the joint structure. The greatest quality weld was achieved using the hexagon tool profile. A mathematical model was developed to predict the corrosion resistance and hardness of friction stir. Welded AA 2219 aluminum alloy joints with a 95 percent confidence level. By optimizing friction stir welding conditions, the RSM was used to increase corrosion resistance and hardness in welded items. When hexagon tool pin profile, rotating speed 1363 rpm, welding speed 715 mm/min, and axial force 8 KN were used, enhanced corrosion resistance and hardness were achieved.

11.M. Kalil Rahiman,et.al.,[11] According to experimental analysis on friction stir welded AA 7075/AA 6061 using Taguchi grey relational analysis, the tensile strengths have gradually increased, and uniform particle distribution on the surface of the weld nugget has also been achieved after the solidification and recrystallization processes.

12.S. M. Bayazida, et.al.,[12] Noted that ANOVA analysis revealed that rotational speed, travel speed, and plate position tensile strength of joint were all effective to a degree of 59 percent, 30%, and 7%, respectively

13. P H Shaha,et.al.[13] experimental results show that the appropriate temperature for a defect free friction stir weld of Al 7075 T651 is within the range of 375-4200 c, which can be used to control process parameters and achieve defect free , sound and good quality welds.

14.M. Shiva chander, et.al.,[14] Review of Aluminum 5083 Friction Stir Welding Thermal Analysis The rotating speed affects the peak temperature, fault formation and sizes, and the mechanical properties of friction stir welded joints. A positive relationship exists between axial load and tensile strength. As the axial load increases, so does the tensile strength. In addition, as dwell time grows, joint strength increases until a certain point, after which it begins to decline.

15.R Raja, et.al.[15] The paper demonstrates that the lower the specimen value, the greater the tensile strength. For different rotating speeds and the tensile strength of the material was discovered to be low due to insufficient heat generation and increased heat generation respectively.

16.R. Padmanaban V.Ratna Kishore , V.Balusamy.,et.al.,[16] this study shoes that Increasing TRS and SD increases tool life and enhances material mixing, while increasing WS increases loads acting on the tool and affects material flow.

17.Vahid M Khojastehnezhad,. et.al.,[17] The calculated values were found to be in agreement with the experimental results. The rotating speed and number of passes were increased, which improved hardness and wear resistance. The material's hardness and wear resistance were also improved by slowing down the traverse speed. The results demonstrated that the existing models might be utilized as a stand-in for optimizing hardness and weight reduction for certain process parameters.

18.Morteza Ghaffarpour., et.al., [18] The tool's rotational and linear speeds are more effective than the tool's pin and shoulder sizes in creating friction and consequently input heat in the weld line. When the effects of each variable on the output variable are considered, rotating speed is shown to be the most useful parameter for determining the tensile strength of TWB sheets generated by FSW.

19.B. R. Sankar, et.al., [19] Speed, welding speed, and tool diameter were the variables in the procedure, and the results predicted hardness and tensile strength. The response surface method was utilized to optimize the process parameters. GRA was implemented. The results of the experimental test using the best process settings were the best.

20.Sabry, et..al [20] welding of AL(6063) aluminum alloys was accomplished effectively, allowing for high-quality welds for UWFSW usage. The UWFSW increases tensile strength while minimizing plasticity in all joints. The UWFSW joint breaks at the intersection of NZ and TMZ.

2.1 SUMMARY OF LITERATURE REVIEW:

For the past two decades, researchers have overcome many difficulties and made considerable advancement in submerged friction stir welding of heat treatable aluminum alloys. The results hold high hopes of useful applications. SFSW have the capability of joining of heat treatable aluminum alloy with excellent weld strength through control of the welding thermal cycles. The advantages of submerged friction stir welding process that have transformed aluminum alloy may not witness quick progress, but many applications will get the benefit over the coming years.

CHAPTER 3

METHODOLOGY

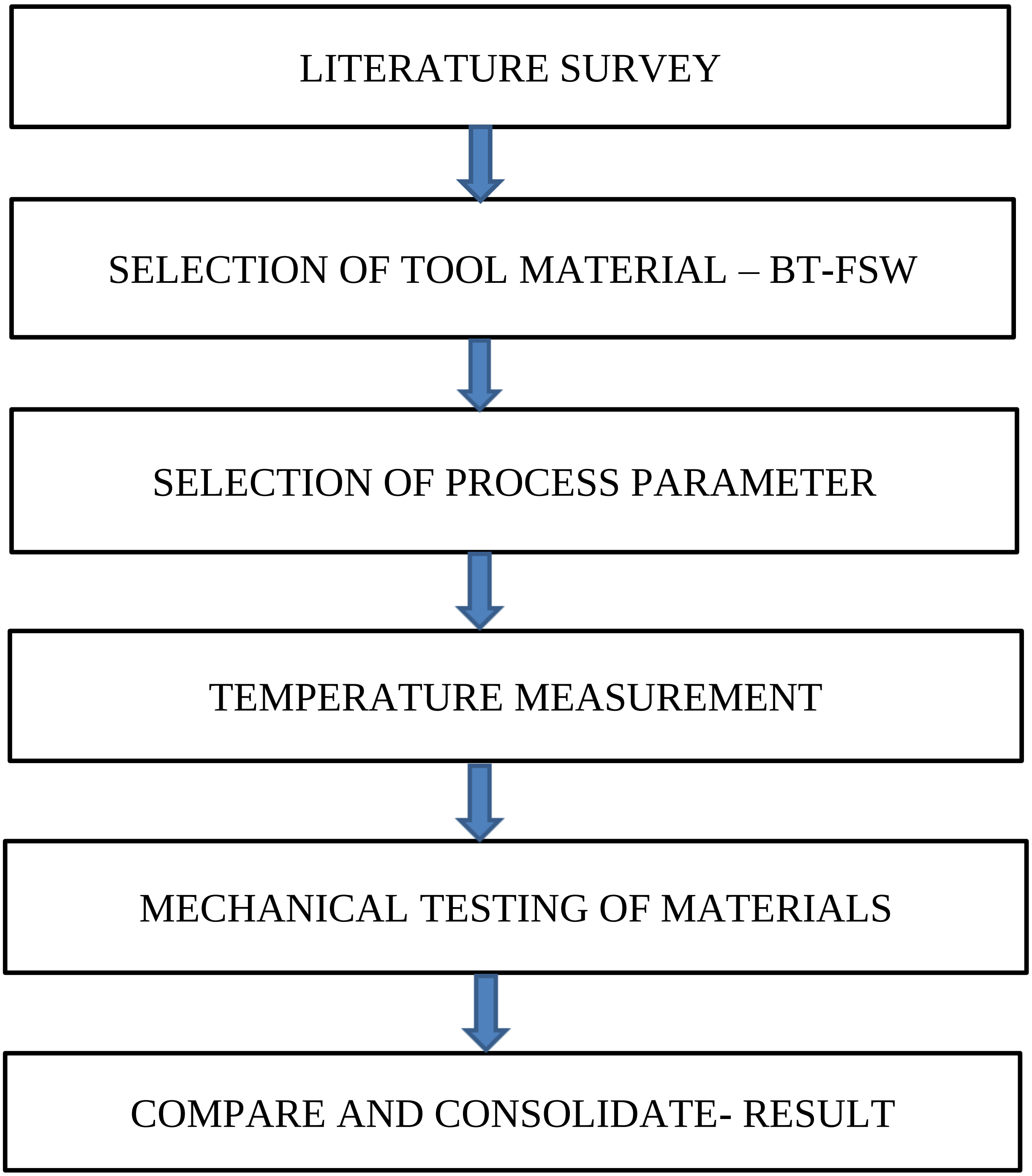


Fig 3.1 Illustrates the diagram represents the

flow chart of the processes involved

CHAPTER 4

TOOL AND WORKPIECE MATERIAL SELECTION

4.1 H13 TOOL MATERIAL:

H13 tool steel is a popular material choice for friction stir welding (FSW) tools due to its high toughness, resistance to thermal fatigue, and good wear resistance. H13 has high toughness and can resist cracking and deformation under the high pressures and temperatures involved in FSW. H13 has good resistance to thermal fatigue, which is important for FSW tools that are subject to repeated heating and cooling cycles during use. H13 has good wear resistance, which helps to prolong the lifespan of FSW tools. H13 has good thermal conductivity, which allows for efficient heat transfer during the FSW process, reducing the risk of overheating and damage to the tool.

H13 BEFORE MACHINING

Fig 4.1 Steel H13 before machining

H13 AFTER MACHINING

Fig 4.2 H13 after machining

5mm pin length, upper shoulder 7mm length, lower shoulder 7mm length, 22 diameter both.

Table 4.1 Physical properties of the tool Table

Properties	Metric	Imperial
Density (@19°C/66.2°F)	7.90 g/cm^3	0.2.72 lb/in^3
Melting Point	1501°C	2500°F

Table 4.2 Tool Chemical Properties

Elements	Contents (%)
Chromium (Cr)	4.4-5.3
Molybdenum (Mo)	1.2-1.9
Silicon (Si)	0.79-1.13
Vanadium (V)	0.79-1.19
Carbon (C)	0.31-0.42
Nickel (Ni)	0.29
Copper (Cu)	0.3
Manganese (Mn)	0.19-0.49
Phosphorus (P)	0.029
Sulfur (S)	0.029

4.2 TOOL HARDENING:

Fig 4.3 Hardened bobbin tool

Tool hardening is done in Friction Stir Welding (FSW) to ensure the longevity and durability of the welding tool. FSW involves using a rotating tool to create friction and heat, which softens the metal being welded and causes it to become plasticized. The rotating tool then moves along the joint, pushing the softened metal together to form a weld.

The high heat and pressure generated during FSW can cause significant wear and tear on the tool, leading to tool failure or reduced performance over time. Tool hardening is done to make the tool more resistant to wear, deformation, and damage**.**

4.3 MATERIAL SELECTION:

Table 4.3 Types of Aluminum alloy

Sr. No	Alloy Series	Principle alloyingElement
1	1XXX	99.00% minimum Al
2	2XXX	Copper
3	3XXX	Manganese
4	4XXX	Silicon
5	5XXX	Magnesium
6	6XXX	Magnesium & Silicon
7	7XXX	Zinc
8	8XXX	Other elements

Aluminum is a versatile material that is widely used in various industries, and different grades of aluminum alloys are available to suit different applications. Here are some common grades of aluminum:

- 1000 series: These are the purest forms of aluminum, with a minimum aluminum content of 99%. They are highly ductile, and can be easily worked into different shapes. 1000 series aluminum is commonly used in chemical processing equipment and food industry containers.
- 2000 series: These aluminum alloys are alloyed with copper, and have high strength and hardness. They are commonly used in aerospace applications and structural components.
- 3000 series: These aluminum alloys are alloyed with manganese, and have good corrosion resistance and formability. They are commonly used in cooking utensils, heat exchangers, and chemical processing equipment.
- 5000 series: These aluminum alloys are alloyed with magnesium, and have high strength and good weldability. They are commonly used in marine and automotive applications.
- 6000 series: These aluminum alloys are alloyed with magnesium and silicon, and have good strength and corrosion resistance. They are commonly used in architectural applications, such as window frames and curtain walls.
- 7000 series: These aluminum alloys are alloyed with zinc, and have high strength and good fatigue resistance. They are commonly used in aerospace and military applications.
- 8000 series: These alloys are commonly used in aerospace and defense applications where high strength-to-weight ratios, corrosion resistance, and durability are essential. They are also used in other industries such as transportation, construction, and sports equipment.

4.3.1 MATERIALS USED:

- **AA6061 T6**
- **AA8011**

Before machining to the required size:

Fig 4.4 6061 T6 **Fig 4.5 8011**

The materials shown in the above fig 4.3 and fig 4.4 are cut and machined as per the dimension of 100 x 50 mm.

After machining to the required size by wire cut machining:

Fig 4.6 Required size of 6061 & 8011

Table 4.4 Physical Properties of Materials used

	AA6061 T6	AA8011
Melting Point	1080- 1205ºF	750ºF
Density	2.70g/cc	2.71g/cc
Thermal conductivity	218 W/m*K	218 W/m-K
Electrical conductivity	0.39 x 10-6 ohm-cm	0.37 x 10^{-6} ohm-cm
Hardness	95	71
Modulus of Elasticity	68.9 GPa	69 GPa
Yield Strength	240 Mpa	140 Mpa
Ultimate tensile strength	290 MPa1	221 MPa
Elongation	18-33%	19%

Table 4.5 Chemical composition of materials used:

Alloy	Mg	Mn	Cu	Fe	Si	Zn	Ti	Al	Tensile strength Mpa	Density kg/m^3
AA 6061-T6	1	0.15	0.27	0.7	0.6	0.6	0.15	Balance	310	2700
AA 8011-H24	0.1	0.1	0.1	0.75	0.7	0.1	0.05	Balance	140	2689

CHAPTER 5

PROCESS PARAMETER

5.1 Flow of Material:

During previous works a material works was used to enhance the material flow around the tool, which produces a substitute to the base material as the contraption passes it can be clearly seen through an amplifying instrument. So, this flow materials is accompanied by ejection known as in-situ, where the plasticized material is compelled by using a mechanical assembly, cold base material’s and a backing plate overall creating a removal chamber through which the material flows. So in the current models there is no flow of materials around the front of tool, rather the flow is flow through the either sides.

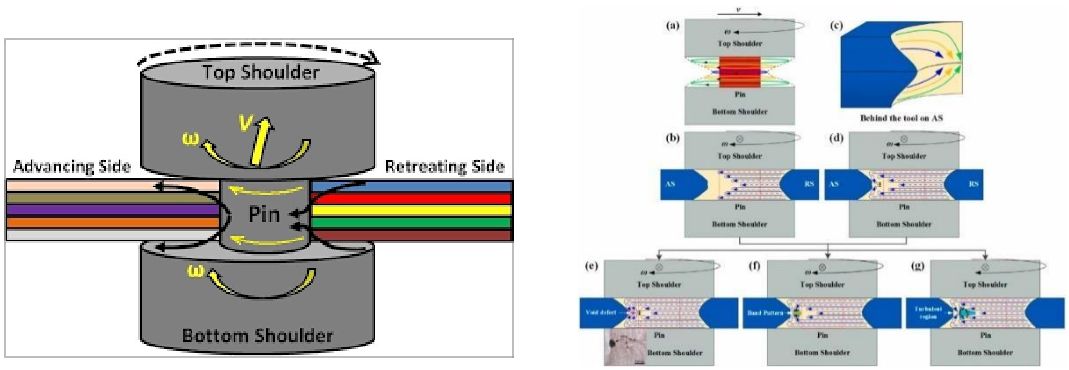


Fig 5.1 Flow of Material

Previous works mentioned that material motion occurs in two processes:

- Material which advances with the probe at the advancing side, the flow of material has a rotational motion. This material flow forms a arc-shaped flow behind the tool and is very highly deformed.
- Lighter material is dragged to the rear end of the tool and used to fill the gaps on the advancing side of the welds. The lighter material don't rotate around the tool and has a lower deformation.

5.2 Flow of Heat:

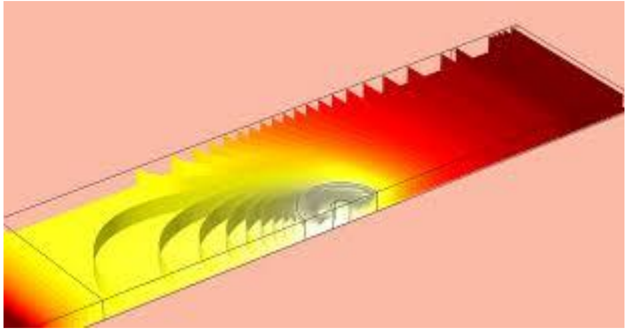


Fig 5.2 Flow of Heat

It was always necessary to reduce the heat produced and consumed, and increase the speed of a welding process. The resultant will bean increase in the productivity of welds and reduce mechanical properties impacting the process. It's also worth noting that the tool's temperature is highenough to allow the flow of materials with bigger thermal gradients as described above. There is one point in the process where the speed of the toolwill be too high and the materials ahead of the tool will be inadequately coldproducing higher stress to the tool resulting in its fracture. This can be prevented if the hot zone is subsequently large enough to eliminate the cold zone in front. The above Fig:5.2 shows flow of heat

Welding cycles are derived into multiple stages in which the heat flow of material is different for each other:

- Dwell: During this stage the materials is said to be pre-heated by a feed of stationary and having a rotation at particular speed.
- Transient heating: This second stage is where the tool has a feed and moved along the joint axis and alteration in temperature around the tool occurs until it reaches a steady state.
- Pseudo state: This is a microscopic state in which there is a constant thermal field around the tool despite the heat value fluctuations.
- Post steady state: This is the end state in which additional heat is sufferedby

the tool which is due to reflection by heat fluctuations occurred in the previous stages.

There are two important sources for heat generations in BTFSW process:

- Heat generation in lower shoulder and upper shoulder due to the material deformation because the friction created by the tool movement.
- Heat generation by workpiece due to having a greater surface area thanthe tool causing it to predominate.

5.3 BTFSW Tool Geometry:

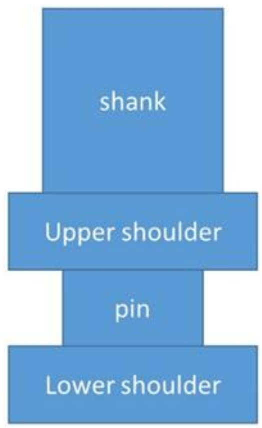


Fig 5.3 Tool geometry

- Tool shoulder: The tool shoulder diameter and concavity angle has a lot of influence in the plastic deformation in FSW welding, at a particular rpm, if there's a increase in shoulder diameter, the flow volume of the driven shoulder significantly reduces.

- Tool pin or tool probe: tool probe factors such as pin size, pin angle, pin length depends upon the material to welded it UTS and other factors, it also depends upon the maximum rotational speed to be reached during the experiment. The pin is where the heat generation begins via friction and material deformation starts.

- The technology of the tool is the heart of the FSW method. The heating,forging pattern, and plastic flow of the weld metal are all determined by the tool form.

The shape of the tool defines welding speed, welding size and strength of the tool. The equipment specifies the ratesof heating by friction, strength of tool and working temperature of the welds, and fids out the components which can be eventually welded.

- The concept of BTFSW tool is the development of CFSW tool with an extra shoulder at the bottom.
- The pin stirs the material and extrudes it to retreating side by taking from the advancing side.
- The features on shoulder and pin surfaces affect the weld quality

5.4 Tool Material:

- The characteristics such as high wear resistance, low coefficient of thermal expansion, sustainability at high temperature, higher thermal resistivity, high fracture toughness.
- Refractory alloy, Highspeed tool steel, H13 tool steel, and Nickel-cobalt alloy MP159 are commonly used tool materials.

5.5 Tool size and features of BTFSW:

- The objective of the upper shoulder is to produce heat at the top of abutting surfaces by frictional heating.
- Generating heat at the bottom of abutting surfaces due to frictional heat is the main function of the lower shoulder.
- This was attributed to lowering frictional contact and frictional resistance at the lower surface, hence less torque and bending moment will occur

- The general range of upper shoulder diameter is found to be 2.5–3.5 times the thickness of the workpiece.
- The range for the lower shoulder is 0.85–0.9 times of the upper shoulder diameter. Excessive lower shoulder diameter forms flash on the bottom surface of the joint and also forms a groove defect on the top and the bottom surface of the joint. Pin length is found to be 0.9–1.0 times.
- Pin diameter reported by several researchers is observed to be 1.25–1.6 times the thickness of the workpiece.
- According to available literatures, no empirical relations or correlation between the dimensions of the upper shoulder, lower shoulder and probe are investigated so far for BTFSW tools creating research scope in this area.
- Researchers found interest in studying design features impact on microstructure formation and mechanical properties in BTFSW [7,29,30].

5.5.1 The features can be classified as

(1) shoulder features and

(2) pin features

5.5.2 Shoulder Features:

- Flat, concave and convex are primary design features in terms of the overall shape of the shoulder.
- The main limitation of the shoulder with a flat surface is that it is not able to effectively trap the softened material concealed between both the shoulders.
- Concave design provides a reservoir for the plasticized material.
- Convex design helps in maintaining continuous contact with the plate surface.
- According to the available literatures, no one has studied the secondary features such as concentric circles, grooves, ridges, knurling in BTFSW.

5.5.3 Different Pin Profiles:

Fig 5.4 Different pin profiles

- Cylindrical, triangular, square shapes are preferred for the pin profile shown in Fig:5.4 is used BTFSW.
- The triangular shape of the pin allows for better material flow during the welding process. This helps to create a more uniform and consistent weld, which can improve the strength and quality of the final product.
- The use of a square cross section pin can lead to a better weld quality, as it helps to minimize defects such as porosity and voids in the weld.
- The cylindrical shape of the pin is relatively simple, which makes it easier to manufacture and maintain compared to other pin designs.

5.6 WELDING PARAMETERS:

5.6.1 Tool Design:

In order to increase the conditional quality of workpiece which is to be welded, the design of tool is critical. At the welding temperature, the tool material must be adequately solid, tough, and long-lasting to achieve a successful job finish. To reduce heat loss and reduce damage to the machine's equipment’s which is primarily due to the heat generated, less conduction of heat should be employed by the tool.

Heat generation, plastic flow, necessary strength, and welded joint uniformity are all influenced by tool design. The tool geometry, such as probe shape, probe length, and shoulder size, are critical parameters since they influence heat generation and plastic matting. Tool geometry that is probe length, form, and size of shoulder, are critical parameters since they influence heat generation and stream of plastic material.

The tool design is a critical process to find out how the whole welding process will turnout. The tool consists of two parts that is the shoulder and pin. The material flow and welding speed regulations the profile of pin plays an important part. The tool shoulder creates the vast majority of the heat and holds the plasticized material to get away from the welding workpiece, as the material stream is influenced by bot pin and shoulder of tool Friction stir welds have almost spherical weld nugget and flow contours, which are shaped by the apparatus layout, welding boundaries, and cycle circumstances used

5.6.2 Tool Rotational Speed:

Since the cylindrical shaped tool turns at the seam to create heat by friction prior togoing down towards the seam of the joint to transfer the frictional heat, as it was stated that FSW is a slower process in the welding area. The cylindrical portion of the probe tool rotates between 200rpm and 2000rpm. Tool traverses the joint line ata rate of 10 to 500 millimeters per minute (mm/min). For FSW, the tool rotation speed (rpm) in a clockwise or counter-clockwise direction, as well as the tool traverse speed (mm/min) toward the joint axis route, are crucial.

Table 5.1 Welding parameters

S.No	Rotational Speed	Traverse speed	Tool pin profile
1	600	25	Circular
2	600	30	Square
3	600	35	Triangular
4	700	25	Square
5	700	30	Triangular
6	700	35	Circular
7	800	25	Triangular
8	800	30	Circular
9	800	35	Square

CHAPTER-6

EXPERIMENTAL WORK

6.1 SAMPLE PREPARATION:

In this investigation, at various process setting butt welding of dissimilar alloy materials AA6061 T6 - AA8011 is done. All specimens were prepared to a size of 50*100*5 mm for welding the samples of AA6061 T6 - AA8011.All specimens were positioned and firmly fixed with backing plates to avoid separation of the attached butting edges. Because the forces are quite significant, additional alarms were required to ensure that the plates did not separate in a butt configuration during the tool's initial dive The tool was transverse forward after a time of waiting, and the joint was created in a single pass.

6.1.1 Wire Cut:

Fig 6.1 CNC Wire-Cutting Machine

A CNC wire cutting EDM is shown. in Fig:6.1. It uses an electrode, which is electrically charged, so that when i comes close to a conductive material, the electricity wants to jump across to it. This causes a spark, which lands on the conductive material and erodes it and cut the material.

6.2 Materials and specifications:

Aluminum 6061 t6:

Dimensions: 50mm x 100mm x 5mm

Quantity: 9 Pieces

Fig 6.2 AA6061 T6

Aluminum 8011:

Dimensions: 50mm x 100mm x 5mm

Quantity: 9 Pieces

Fig 6.3 AA8011

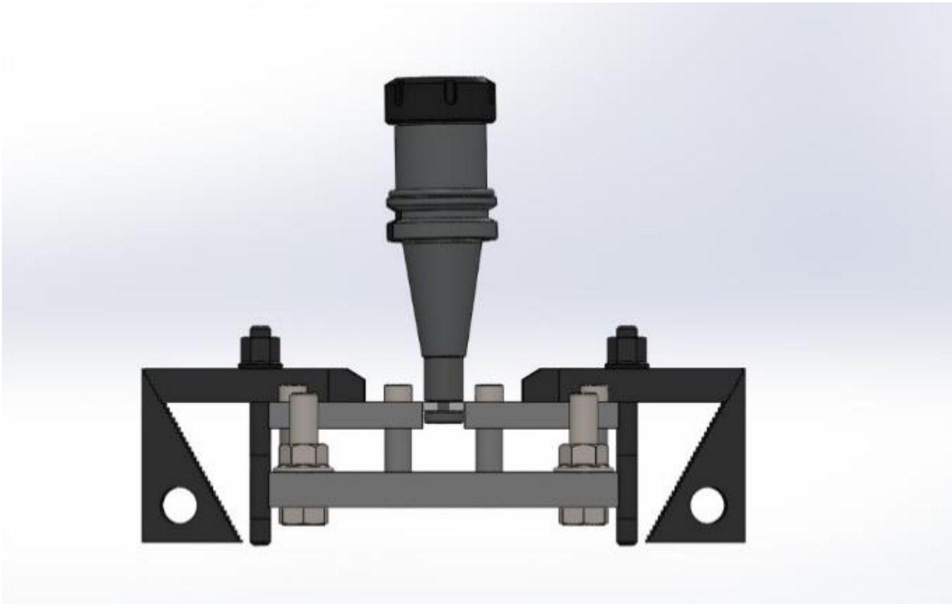


Fig 6.4 BTFSW setup fixture design front view

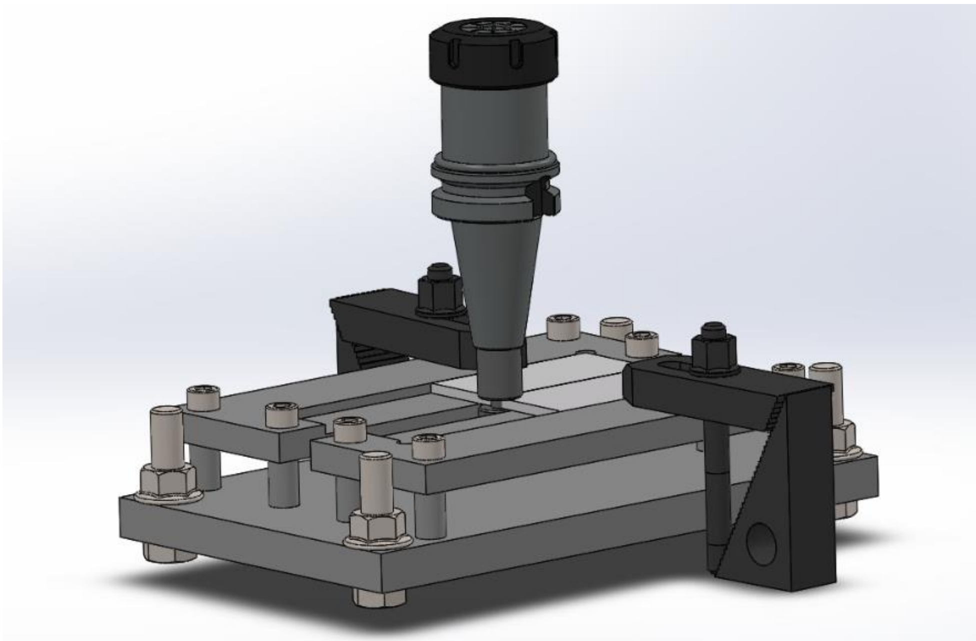


Fig 6.5 BTFSW setup fixture design Isometric view

6.3 Working Process of Bobbin tool Friction Stir Welding (BTFSW)

Fig 6.6 Fixture setup Fabricated

Fig 6.7 Bobbin Tool and fixture setup after fabrication

Fig 6.8 LiTz Hitech (MV-800) vertical machine

Table 6.1 specifications of machine

Spindle Speed	8000 rpm
Number Of Tools	24 one of a pair
X-Axis Travel	800mm
Y-Axis Travel	500mm
Z-Axis Travel	540mm

Firstly, clamp the workpiece in a heavy-duty setup, so that it does not moveor shake at the time of welding in LiTz Hitech (MV-800) vertical machine.

- Workpiece should be abutting i.e., both parts should be kept side to side at a particular distance from each other.
- Now touch the bobbin pin with the clamped workpiece.
- Now the shoulder gets in touch with the abutting edges.
- The tool starts rotating within contact with the job.
- Due to contact of the workpiece, friction is applied and as a result of it, heat is generated.
- This heat makes the metal plastically melt.
- When the metal gets plasticized the high downward forces or pressure makes a strong, clean and solid-state weld

6.4 TEMPERATURE MEASUREMENT:

In bobbin tool friction stir welding, temperature can be measured using a thermal gun (shown in Fig:6.7) or a thermocouple (shown in Fig:6.8), as well as by drilling micro holes in the surface of the base metal and measuring the temperature using a thermocouple.

A thermal gun is a handheld device that measures the temperature of a surface by detecting infrared radiation. To measure the temperature during friction stir welding using a thermal gun, the operator simply points the gun at the surface of the base metal and reads the temperature from the display

Fig 6.9 Temperature gun

A thermocouple, on the other hand, is a device that measures temperature by detecting changes in voltage caused by temperature differences. To measure temperature using a thermocouple during friction stir welding, a small hole is drilled into the surface of the base metal and the thermocouple is inserted into the hole. The thermocouple is connected to a data acquisition system, which records the temperature readings over time.

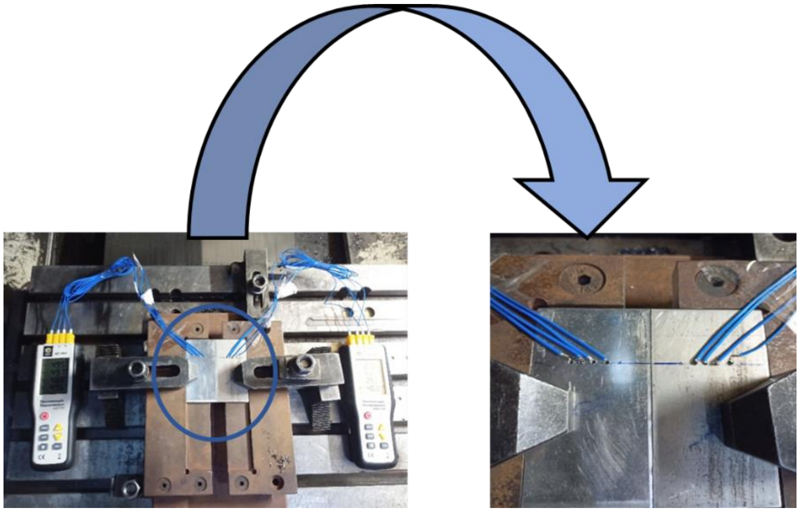


Fig 6.10 Illustrates welding setup of test specimen

In addition to thermal guns and thermocouples, micro drills can also be used to measure temperature during friction stir welding. The micro drills are inserted into the surface of the base metal at specific locations, and thermocouples are placed in the holes. The thermocouples are then connected to a data acquisition system, which records the temperature readings over time.

Overall, temperature measurement during bobbin tool friction stir welding is critical to ensure that the welding process is carried out under optimal conditions. The choice of measurement method depends on the specific requirements of the welding process and the equipment and tools available.

6.5 TENSILE TEST:

Specimen standard - ASTM E8M04

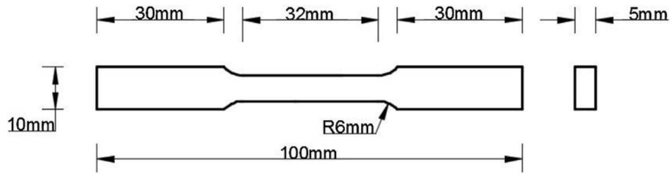


Fig 6.11 Illustrates test specimen of ASTM E8M04 Standard Tensile

The tensile test was conducted to develop stress and strain curve for the given specimen. According to ASTME (American Society of Testing of Metals) Standards number ASTM E8M04 (9numbers) the specimen was prepared by Wire cut EDM as shown in Figure 6.10 according to the standards. Test specimen that was grasped ateach end by a universal testing machine was subjected to a tensile axial load with the capacity of 40Tons. The specimen was loaded into a universal testing machine that can apply a load to the specimen at a specific rate. As the specimen was axially loaded in tension, the distance between the gaugemark was monitored.

Fig 6.12 Sample prepared for Tensile Test

CHAPTER 7

TESTING

7.1 TENSILE TESTING:

A tensile test is a mechanical test used to determine the strength of a material under tension. The test involves applying a tensile force to a specimen of the material, typically a cylindrical or rectangular shape, until it breaks or fractures. During the test, the amount of deformation or elongation of the specimen is measured, and this data is used to determine the material's tensile strength, yield strength, and other mechanical properties.

The tensile test is commonly used to evaluate the properties of metals, plastics, and other materials used in engineering and manufacturing applications. The test can provide important information about the material's suitability for a particular application and can help engineers and designers make informed decisions about materials selection, design, and fabrication.

In a typical tensile test, a specimen is placed in a testing machine and a tensile force is applied to it in a controlled manner. The force is gradually increased until the specimen breaks, and the force and elongation data are recorded throughout the test. The resulting stress-strain curve can be used to determine various mechanical properties of the material, such as its elastic modulus, yield strength, ultimate strength, and ductility of the sample

Fig 7.1 Universal tensile machine

Fig 7.2 Specimen after tensile test

7.2 MICROSTRUCTURE TESTING:

Microstructure testing is a method used to examine the microscopic structure of a material. It involves analyzing the arrangement and distribution of the constituent atoms or molecules, as well as any defects or imperfections in the material's crystal lattice structure. Microstructure testing is used to gain insight into a material's properties and performance, such as its mechanical strength, corrosion resistance, and thermal conductivity.

Aluminum alloys are widely used in a variety of applications because they have excellent strength-to-weight ratios, good corrosion resistance, and good thermal and electrical conductivity. There are several techniques used for microstructural analysis of aluminum, including optical microscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), and electron backscatter diffraction (EBSD). These techniques allow researchers to examine the microstructure of aluminum alloys at different length scales, from the macroscopic level to the atomic level.

Some of the key microstructural features that can be analyzed in aluminum alloys include:

Grain size: The size and distribution of grains in aluminum alloys affect their mechanical properties, such as strength, ductility, and toughness. Small grain sizes generally lead to higher strength and hardness, while larger grain sizes can improve ductility.

Second-phase particles: Aluminum alloys often contain second-phase particles, such as precipitates or intermetallic compounds, which can have a significant effect on the material's mechanical properties. The size, shape, and distribution of these particles can be analyzed using microscopy techniques.

Texture: The crystallographic orientation of grains in aluminum alloys can influence their mechanical behavior, such as their anisotropic properties. Texture analysis can help researchers understand the relationship between microstructure and mechanical behavior.

By analyzing the microstructure of aluminum alloys, researchers can gain insights into their mechanical properties, understand how they respond to different processing conditions, and develop new alloys with improved properties. This information is important for designing and optimizing aluminum alloys for a wide range of applications, including aerospace, automotive, and construction. Overall, microstructure testing is an important tool for understanding the behavior and properties of materials at a microscopic level, and can help researchers and engineers make informed decisions about materials selection and design.

7.2.1 SAMPLE PREPARATION:

Fig 7.3 Microstructure sample preparation

Microstructure sample preparation is a critical step in the analysis of materials using microscopy techniques. The goal of sample preparation is to create a thin, flat, and defect-free sample that can be analyzed using microscopy methods such as optical, electron, or X-ray microscopy. Proper sample preparation is essential for obtaining accurate and reliable microstructural information about the material.

The specific steps involved in microstructure sample preparation can vary depending on the type of microscopy being used and the material being analyzed. However, there are some general steps that are commonly followed:

Cutting the sample: Begin by cutting a small piece of the aluminum material using a saw or a similar cutting tool. The sample should be cut to a size that is slightly larger than the desired final size.

Mounting the sample: The sample should be mounted onto a mounting press or a similar device using a mounting resin. The resin should be allowed to cure for several hours.

Grinding the sample: Start by using a coarse grade emery paper with a grit size of around 40-60 to remove any surface irregularities or roughness. Hold the emery paper firmly and apply pressure while rubbing it in a back-and-forth motion over the surface of the sample. Continue grinding for several minutes until the surface becomes smooth and even.

Sanding the sample: After using the coarse grade emery paper, switch to a medium grade emery paper with a grit size of around 80-120. Repeat the grinding process, applying pressure while rubbing the emery paper over the surface of the sample. This step will further smooth the surface of the sample.

Polishing the sample: Finally, use a fine grade emery paper with a grit size of around 240-400 to polish the surface of the sample. Use light pressure and rub the emery paper in a circular motion over the surface of the sample for several minutes. This step will help to remove any remaining scratches or imperfections on the surface of the sample.

Fig 7.4 Microstructure sample polishing setup

Etching the sample: Once the sample has been polished, it should be etched using a suitable etchant to reveal the microstructure. The specific etchant used will depend on the particular aluminum alloy being analyzed. The etching time should be carefully controlled to avoid over-etching.

Microstructural analysis: The sample can now be analyzed using a microscope or other suitable tool to study its microstructure.

Overall, microstructure sample preparation requires careful attention to detail and the use of specialized equipment and techniques. Proper sample preparation is essential for obtaining high-quality microstructural information and ensuring accurate and reliable analysis of materials. The samples after mold preparation are shown in Figure.

CHAPTER 8

RESULT AND DISCUSSION

8.1 TEMPERATURE DISTRIBUTION:

8.1.1 Sample 1 [circular pin, 600rpm, 25mm/min]

Table 8.1 Temperature distribution – Advancing side – Sample 1

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	321	277	246	219

Table 8.2 Temperature distribution – Retreating side – Sample 1

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	233	212	190	163

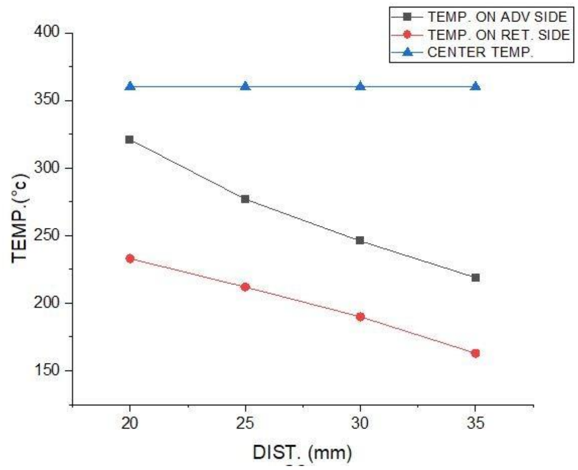


Fig 8.1 temperature distribution graph- sample 1

8.1.2 sample 2 [square pin, 600rpm, 30mm/min]

Table 8.3 Temperature distribution – Advancing side – Sample 2

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	342	322	281	280

Table 8.4 Temperature distribution – Retreating side – Sample 2

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	274	246	201	197

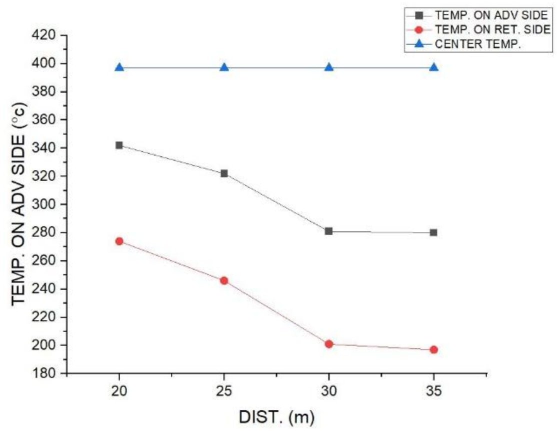


Fig 8.2 temperature distribution graph- sample 2

8.1.3 sample 3 [triangular pin, 600rpm, 35mm/min]

Table 8.5 Temperature distribution – Advancing side – Sample 3

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	322	279	259	207

Table 8.6 Temperature distribution – Retreating side – Sample 3

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	298	233	188	154

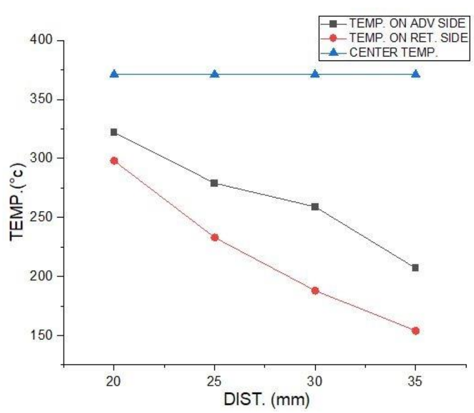


Fig 8.3 temperature distribution graph- sample 3

8.1.4 sample 4 [square pin, 700 rpm ,25 mm/min]

Table 8.7 Temperature distribution – Advancing side – Sample 4

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	351	308	289	272

Table 8.8 Temperature distribution – Retreating side – Sample 4

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	292	264	214	192

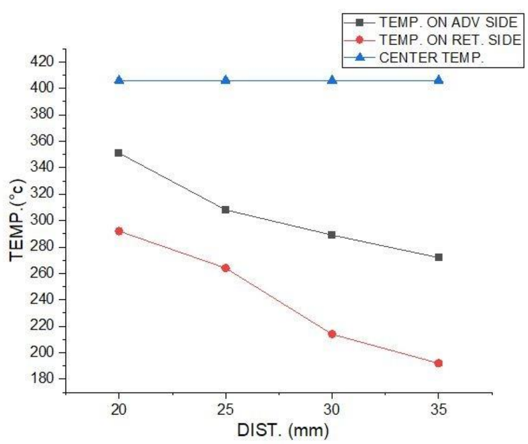


Fig 8.4 temperature distribution graph- sample 4

8.1.5 sample 5 [triangular pin, 700rpm, 30mm/min]

Table 8.9 Temperature distribution – Advancing side – Sample 5

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	312	301	273	255

Table 8.10 Temperature distribution – Retreating side – Sample 5

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	299	262	230	188

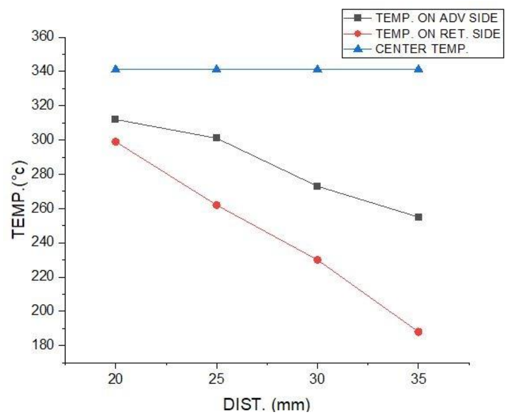


Fig 8.5 temperature distribution graph- sample 5

8.1.6 sample 6 [circular pin, 700rpm, 35mm/min]

Table 8.11 Temperature distribution – Advancing side – Sample 6

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	344	310	268	211

Table 8.12 Temperature distribution – Retreating side – Sample 6

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	280	259	211	185

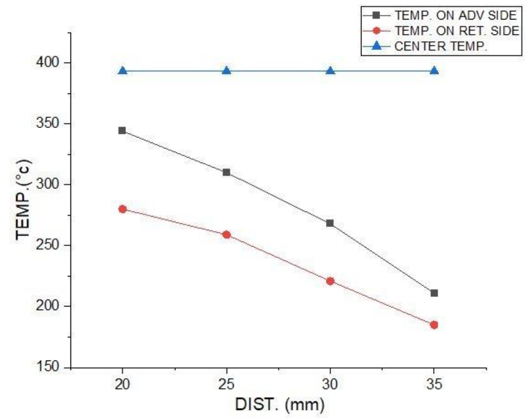


Fig 8.6 temperature distribution graph- sample 6

8.1.7 Sample 7 [triangular pin, 800rpm, 25mm/min]

Table 8.13 Temperature distribution – Advancing side – Sample 7

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	384	321	285	271

Table 8.14 Temperature distribution – Retreating side – Sample 7

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	322	277	241	201

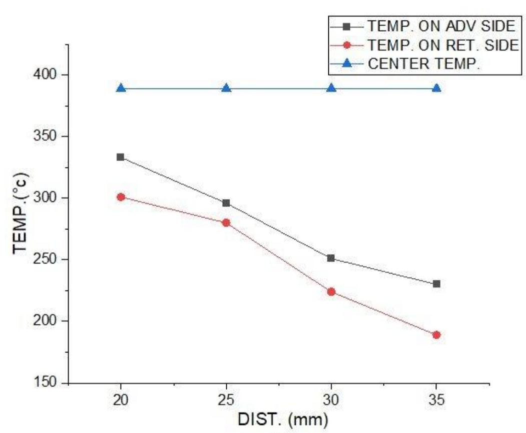


Fig 8.7 temperature distribution graph- sample 7

8.1.8 Sample 8 [circular pin, 800rpm, 30mm/min]

Table 8.15 Temperature distribution – Advancing side – Sample 8

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	333	296	251	230

Table 8.16 Temperature distribution – Retreating side – Sample 8

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	301	280	188	341

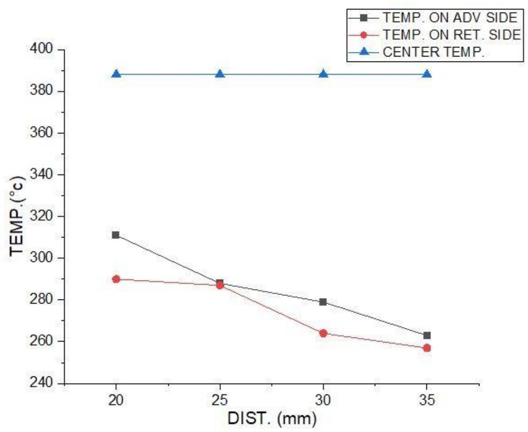


Fig 8.8 temperature distribution graph- sample 8

8.1.9 sample 9 [square pin ,800rpm, 35mm/min]

Table 8.17 Temperature distribution – Advancing side – Sample 9

Distance from center towards advancing side				Temperature over advancing side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	311	288	279	263

Table 8.18 Temperature distribution – Retreating side – Sample 9

Distance from center towards retreating side				Temperature over retreating side			
D1	**D2**	**D3**	**D4**	**T1**	**T2**	**T3**	**T4**
20	25	30	35	290	287	264	257

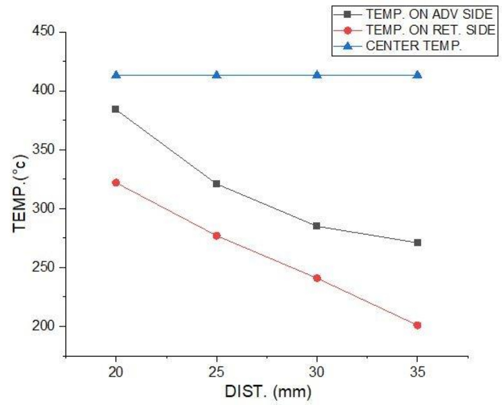


Fig 8.9 temperature distribution graph- sample 9

It is observed that the temperatures on advance side are more as compared to retreating side for all working conditions.

8.2 BASE MATERIAL STRENGTH:

Fig 8.10 Illustrates the tensile test in basematerial of AA6061 & AA8011

The below graph shows the base material tensile strength values.

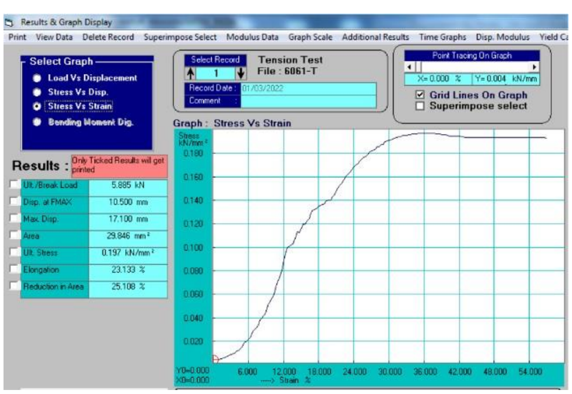


Fig 8.11 Tensile test on AA6061

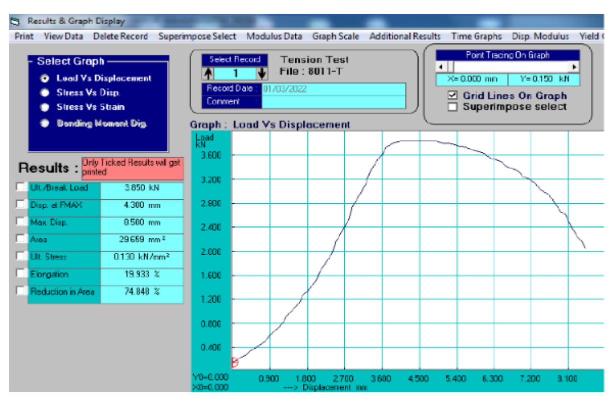


Fig 8.12 Tensile test on AA8011

After finding all the observation S/N ratio and Means are calculated and various graph for analysis is drawn by using Minitab 19 software. The S/N ratio for MRR and Surface roughness are calculated on Minitab 19 Software using Taguchi Method and Surface roughness are calculated on Minitab 19 Software using Taguchi Method.

8.3 OPTIMIZATION OF TENSILE STRENGTH

Taguchi method stresses the importance of studying the response variation using thesignal-to-noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The tensile strength was considered as the quality characteristic with the concept of “the larger-the-better”.

The S/N ratio for the larger-the-better is:

$$S/N = 10\log_{10}\left(\frac{1}{n}\sum y^2\right)$$

Where n is the number of measurements in a trial/row, in this case, n=1 and y are the measured value in a run/row. The Tensile strength values measured from the experiments and their corresponding S/N ratio values are listed in

Table-8.19

Rotational Speed (rpm)	Traverse speed (mm/sec)	Tool pin profile	Tensile strength (Mpa)	SNRA
600	25	Circular	76	37.61627
600	30	Square	83	38.38156
600	35	Triangular	45	33.06425
700	25	Square	98	39.82452
700	30	Triangular	86	38.68997
700	35	Circular	104	40.34067
800	25	Triangular	85	38.58838
800	30	Circular	96	39.64542
800	35	Square	68	36.65018

Table 8.19: Experimental results and Corresponding S/N Ratio for Tensile Strength

8.3.1 RESULT AND DISCUSSION

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the Welding parameters is the level with greatest value.

Table 8.20: Response table for signal to noise ratios

ROTATIONAL TRAVERSE			
LEVEL	**SPEED**	**SPEED**	**TOOL**
1	36.35	38.68	39.20
2	39.62	38.91	38.29
3	38.29	36.69	36.78
DELTA	3.26	2.22	2.42
RANK	1	3	2

Table 8.21: Response table for means

ROTATIONAL TRAVERSE			
LEVEL	**SPEED**	**SPEED**	**TOOL**
1	68	86.33	92
2	96	88.33	83
3	83	72.33	72
DELTA	28	16	20
RANK	1	3	2

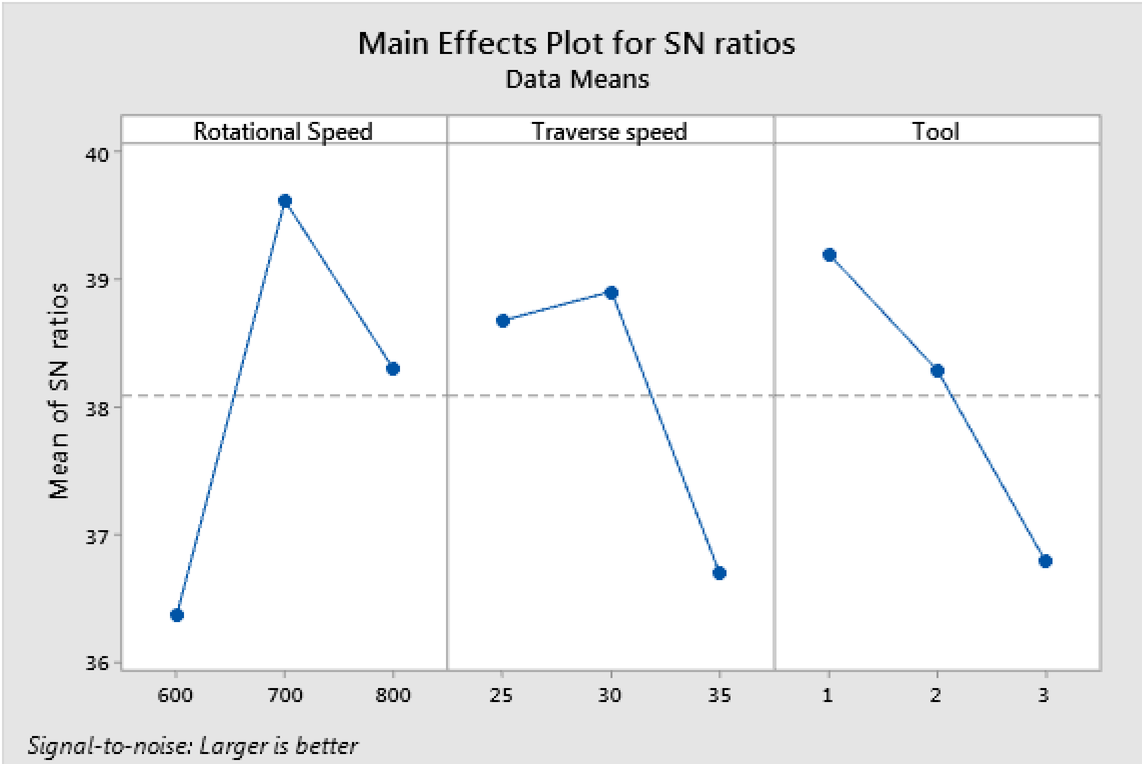


Fig 8.13 Effect of BTFSW parameters on Tensile strength for S/N ratio

8.4 INTERACTION PLOT FOR BTFSW PARAMETERS:

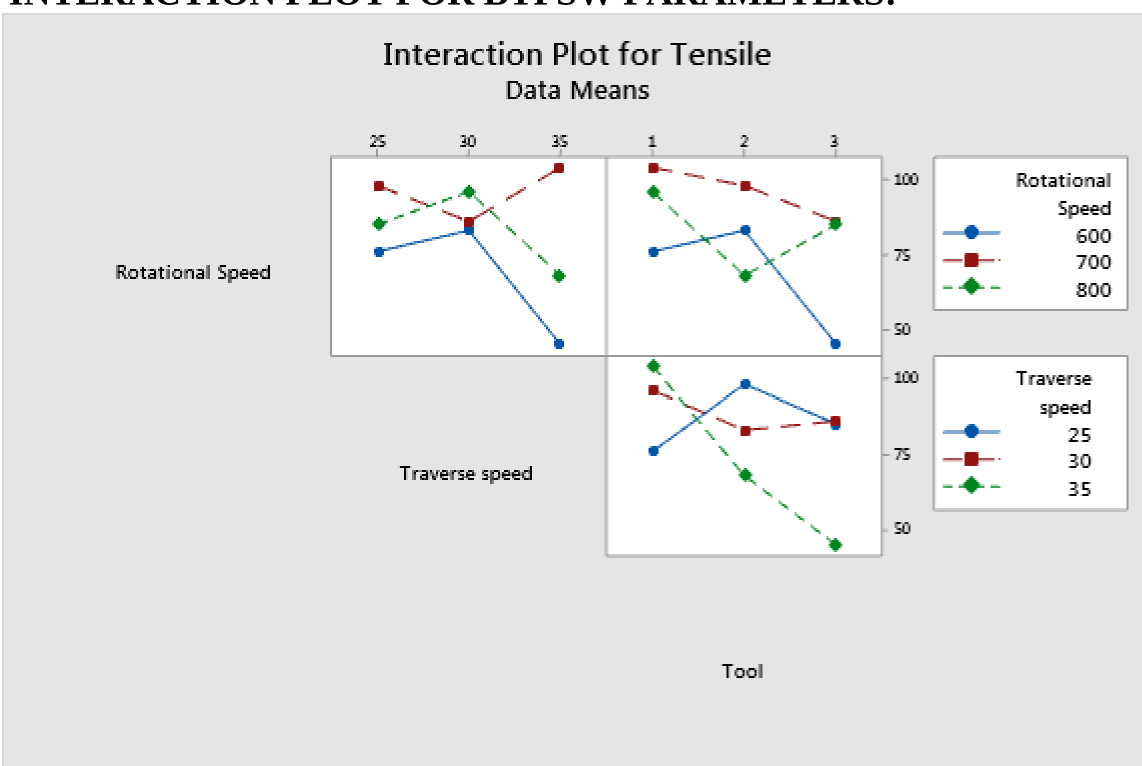


Fig 8.14 Interaction plot for Tensile strength

8.5 RESIDUAL PLOTS FOR BTFSW PARAMETERS:

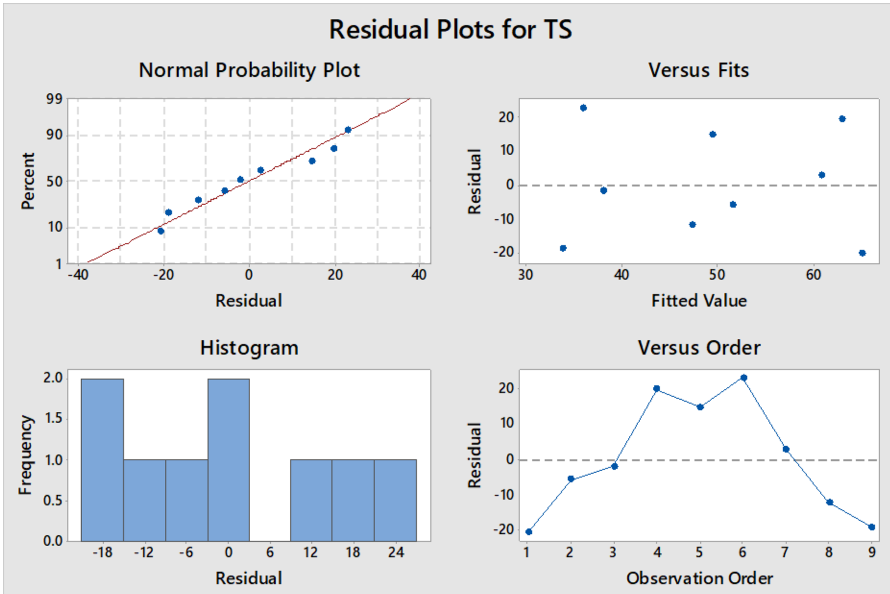


Fig 8.15 Residual plots for tensile strength

8.6 REGRESSION EQUATION

TENSILE STRENGTH = 91.8 + 0.0750 Rotational Speed - 1.40 Traverse speed - 10.00 Tool

Coefficients

Table 8.22

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	91.8	63.1	1.46	0.205	
Rotational Speed	0.075	0.0666	1.13	0.311	1
Traverse speed	-1.4	1.33	-1.05	0.341	1
Tool	-10	6.66	-1.5	0.194	1

- In this graph, darker regions indicate higher hardness values. These higher hardness values seem to form a ridge running from the lower left of the graph.

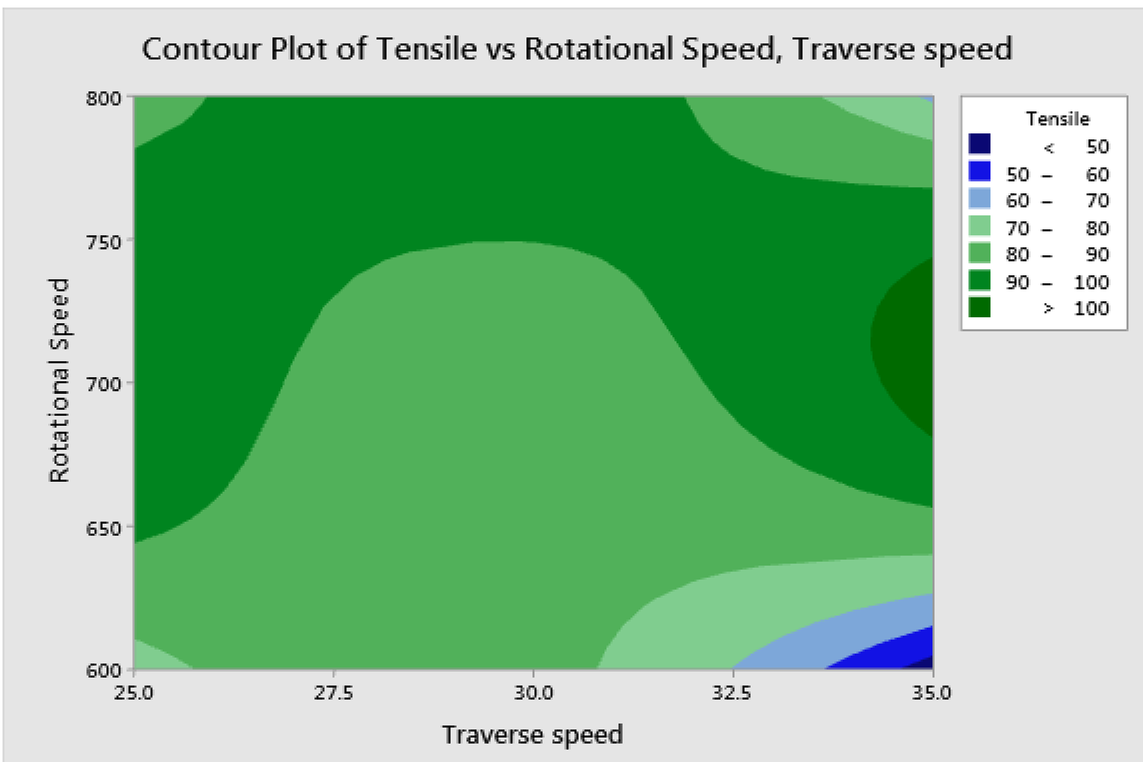


Fig 8.16 Contour plots for tensile strength

- In this graph, darker regions indicate higher tensile strength values. These higher tensile strength values seem to form a ridge running from the middle left of the graph.

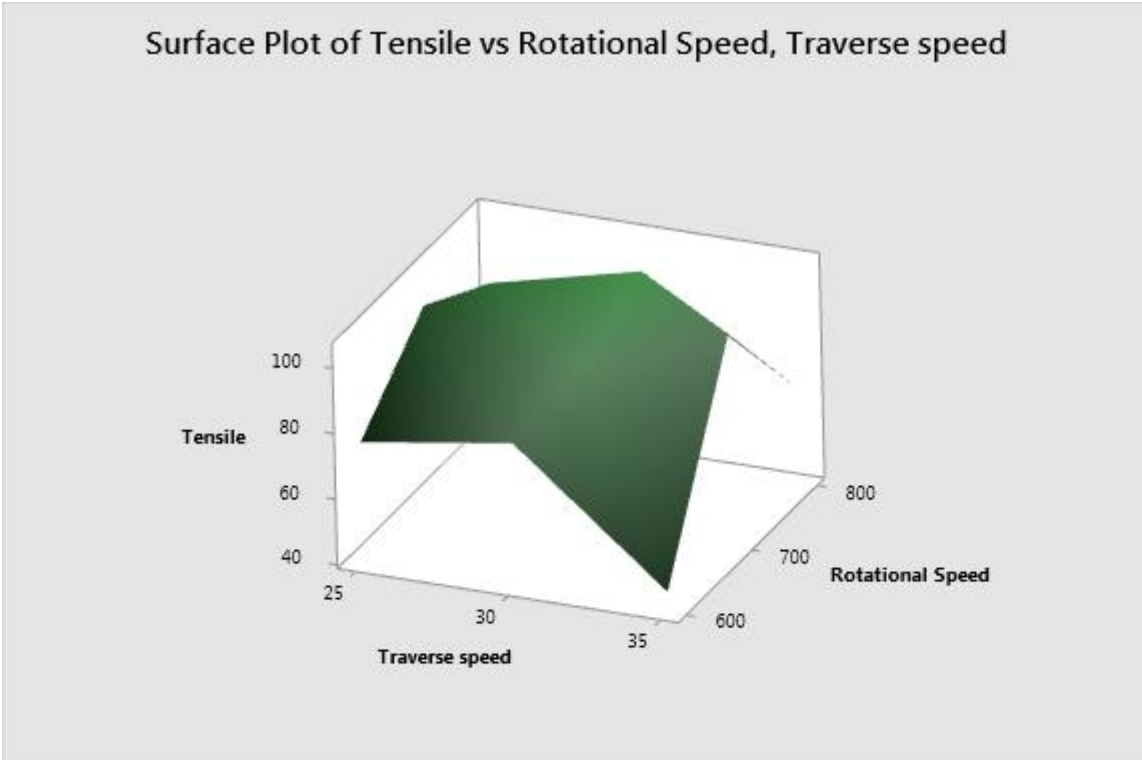


Fig 8.17 Surface plots for tensile strength

8.7 MACROSTRUCTURAL ANALYSIS

Bobbin Tool Friction Stir Welding (BT-FSW) is a variation of the FSW process that uses a cylindrical tool with a concave shoulder and a protruding pin to create a unique macrostructure in the weld. The macrostructure of a BT-FSW weld typically includes the following features:

Weld nugget: This is the region where the tool has plunged into the workpiece and created a consolidated, defect-free weld.

Transverse band: This is a band that appears perpendicular to the welding direction and is formed due to the axial compression and radial expansion of the material caused by the tool.

Circumferential band: This is a band that appears parallel to the welding direction and is formed due to the rotation of the tool and the flow of material around the tool.

Thermo-mechanically affected zone (TMAZ): This is the region around the weld nugget where the material has undergone plastic deformation and recrystallization due to the heat generated by the tool.

Heat-affected zone (HAZ): This is the region around the TMAZ where the material has been heated by the tool, but has not undergone significant plastic deformation.

The macrostructure of a BT-FSW weld is important because it can affect the mechanical properties of the welded joint. The transverse and circumferential bands provide additional strength to the weld and improve its fatigue life. The TMAZ and HAZ, however, can be weaker than the base material due to changes in microstructure and mechanical properties. Therefore, the design and optimization of BT-FSW processes aim to produce a macrostructure that maximizes the strength and durability of the weld. The macrostructure can also be examined using non-destructive testing techniques such as X-ray and ultrasonic inspection to ensure the quality of the weld.

8.8MICROSTRUCTURE ANALYSIS :

The parent's material microstructure shown in the below figure. Here the grain sizes and the precipitants can be seen clearly.

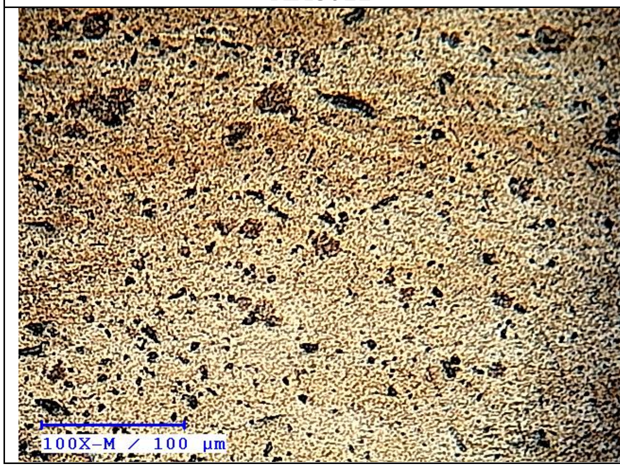
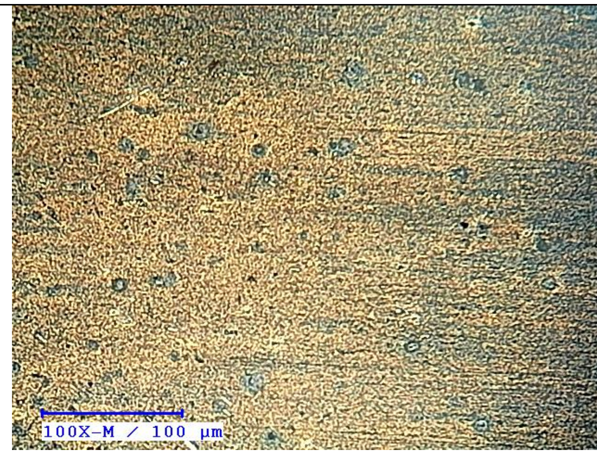
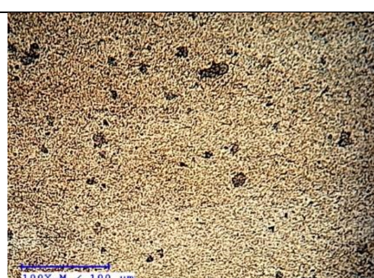
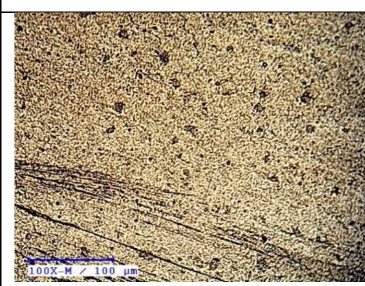
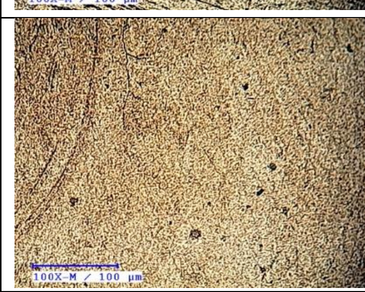
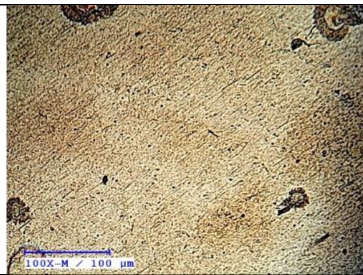
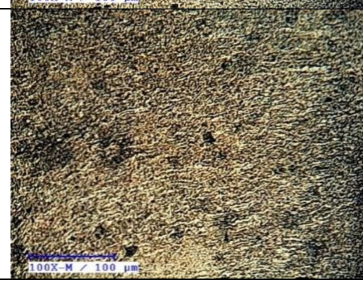
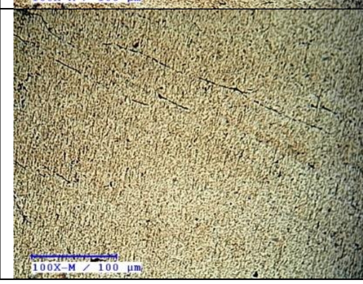
AA8011	AA6061
	

Fig 8.19 Microstructure of parent material

Out of the 10 samples the 5 samples were selected for microstructure analysis. Based on the tensile strength the best, medium, low Mpa samples were selected. The below table shows the high to low order tensile value parameters. It shows the different zones in the weld.

Table 8.23 Microstructure

V S.NO	Tensile Strength (Mpa)	HEAT AFFECTED ZONE	INTERFACE	WELD ZONE/ SZ
6	104			
4	98			

7	85	100X-M / 100 µm	100X-M / 100 µm	100X-M / 100 µm
9	68	100X-M / 100 µm	100X-M / 100 µm	100X-M / 100 µm
3	45	100X-M / 100 µm	100X-M / 100 µm	100X-M / 100 µm

CHAPTER 9

CONCLUSION

In the earlier chapters, the effects of process variables on response characteristics hardness and tensile of the Bobbin Tool friction stir welding (BTFSW) have been discussed. The important conclusions from the present research work are summarized in this chapter.

- In this work, an attempt was made to determine the important welding parameters to join AA8011 and AA6061-T6 using a threaded pin profile.
- Factors like higher feed rate and low speed leads to poor strength. Also, from the microstructure shows that the formation of onion ring pattern is obtained when the feed rate as medium (30mm/min), Speed (700rpm) with cylindrical pin plays a significant role in the strength. Taguchi's 3 level, 2 factorial design is used to obtain theoptimum welding parameters for the maximum strength and hardness.
- The precipitates in Al6061 is between 250°C and 350°C, depending on the aging conditions and the composition of the alloy. At these temperatures, the precipitates gradually dissolve, resulting in a decrease in strength and hardness of the material. Its clearly found in the samples whose nugget temperature is more than 350^{0} during the process.
- The pin triangle and square generates more amount of heat it dissolved the precipitates and due to this that samples got less tensile strength values.
- The microstructure of the
- The macrostructure of the sample 6,4,8 shows the weld nugget and the HAZ with good penetration and bonding. The changes in microstructure of those samples in the TMAZ and HAZ is low comparing to the low tensile samples.
- Also the failure of samples taking place in the HAZ of advancing side.
- Almost 65% of the parent material strength was obtained.

- Regression Model relationship is found by using a continuous response using the ordinary least squares method to find the other set of readings.

FUTURE WORK

Although the BTFSW has been thoroughly investigated with the different pin profile, still there is a scope for further investigation with threaded, hexagonal pin, concave, convex profiles.

- The effect of process parameters such as upper shoulder length, diameter, type of material, post heating, preheating, addition of nano-powders in the weld zone etc. may also be investigated
- Higher order orthogonal array can be incorporate all possible interactions of the process parameters.

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