DESIGN AND DEVELOPMENT OF BOBBIN FSW TOOLS FOR JOINING OF METALS

A DISSERTATION

Submitted in partial fulfilment of the

requirements for the award of the degree

of

MASTER OF TECHNOLOGY

In

Mechanical Engineering

(With Specialization in Welding Engineering)

By

HARSH PANDEY

17542003

MECHANICAL AND INDUSTRIAL ENGINEERING

DEPARTMENT INDIAN INSTITUTE OF TECHNOLOGY,

ROORKEE-247667

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HARSH PANDEY

Enrollment Number: 17542003

M.TECH-2 YEAR

MIED, IIT ROORKEE

CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this report of dissertation entitled, **"DESIGN AND DEVELOPMENT OF BOBBIN FSW TOOLS FOR JOINING OF METALS",** is presented on behalf of partial fulfillment of the requirements for the award of degree of "Master of Technology" in Mechanical Engineering with specialization in Welding engineering submitted to the Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee, under the guidance of **Dr. Dheerendra Kumar Dwivedi** (Department of Mechanical and Industrial Engineering). I have not submitted the record embodied in this report for the award of any other degree or diploma.

Date: June, 2019 (**HARSH PANDEY**)

Place: Roorkee

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of our knowledge and belief.

(Dr. Dheerendra Kumar Dwivedi)

Professor, MIED

IIT ROORKEE

ABSTRACT

The bobbin friction stir welding tool is a double sided friction stir welding tool. It has many advantages over conventional single sided friction stir welding tool are rectangular processed zone, zero net axial force on work piece and the problems like root defect and lack of penetration is also eliminated. Friction stir welding (FSW) is a technique used initially for welding of aluminium alloys as it is a solid state process so no melting takes place thus there is no defects of liquid state welding can be seen that are arise in the process of solidification. There is also no need of filler material in FSW so the problems regarding compositional variables are also absent and a sound joint can be produced without any metallurgical discontinuity. The bobbin friction stir welding (BFSW) procedure has further points of interest over ordinary friction stir welding in the decrease of welding powers, quicker welding, and reduce fixturing.

The primary motivation behind this examination was to know the appropriate design and process variables that affect weld quality. Report starts with the definition of friction stir welding, the explanation of the process and parameters that are used in friction stir welding and the different conventional tool design and then some brief on the design of bobbin friction stir welding tool. It was purely an experimental work in which many designs at different parameters were tested until a joint was made then research was continued to optimize the parameters to get a sound weld.

Design of tool pin is very important in case of friction stir welding. After selection of diameter of pin, we have to maintain a proper ratio between pin diameter and shoulder diameter to impart appropriate amount of heat during joining. A proper design is achieved by different trials at different parameters. Microstructure, metallographic and mechanical properties of the samples was studied to find out the effect of parameters used.

Optimum parameters were found to be 386 rpm, 26 mm/min and zero-degree tilt angle in friction stir welding machine. Maximum strength of 164.539 MPa was obtained at this set of parameters.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF FSW

Friction stir welding (FSW) is a technique used initially for welding of aluminium alloys as it is a solid state process so no melting takes place thus there is no defects of liquid state welding can be seen that are seen in the process of solidification. There is also no need of filler material in FSW so the problems regarding compositional variables are also absent and a sound joint can be produced without any metallurgical discontinuity.

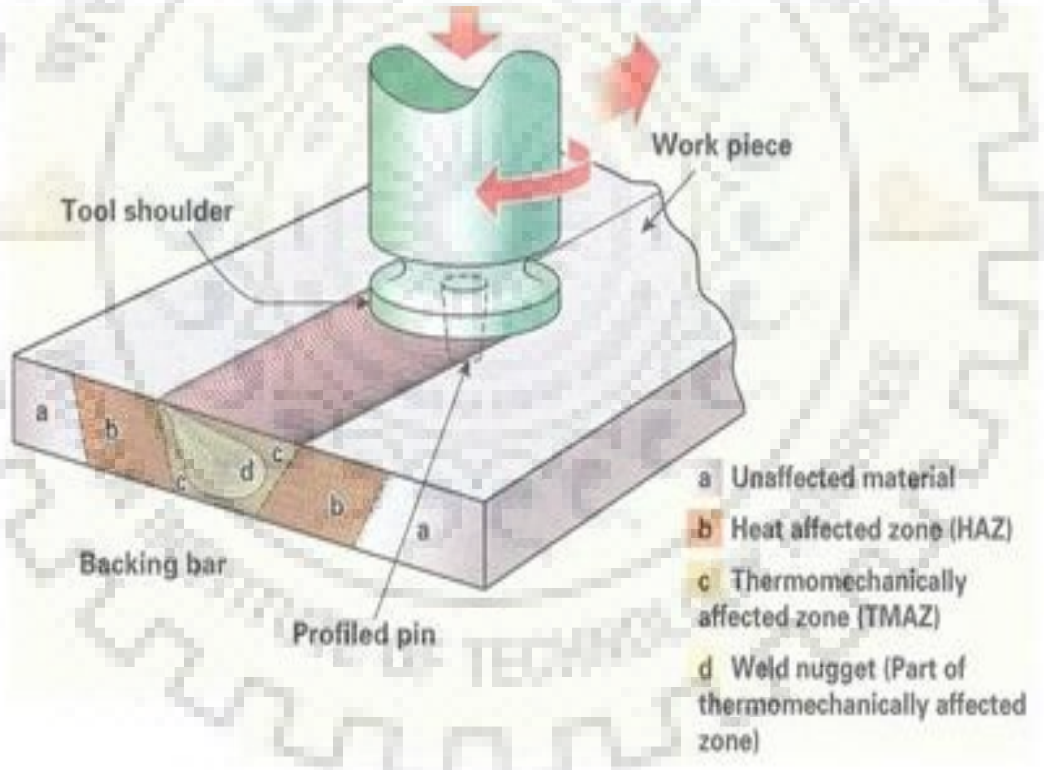

Fig.1: A schematic diagram of FSW process [11]

1.2 FSW SETUP

The Friction stir welding set up has-

a. Vertical Milling machine

b. Fixture

c. Backing Plate

d. Tool

e. Specimen

Fig.2: Conventional FSW machine [Reference: WRL Lab, IIT Roorkee]

1.3 PRINCIPLE OF OPERATION

The contact mix welding procedure has four stages: 1) diving step, 2) staying step, 3) welding step, and 4) withdraw step. It starts with the initial phase in which device goes towards the material, and dives in it to get the best possible warmth. In the second step we need the working temperature to start the working. It has a predictable power which is to be in the middle of the apparatus and the work piece that produces the mechanical vitality as grating. This proceeds underneath the material's versatile modulus then we apply required weight power among device and material which results as drops that means that we have wanted temperature is come to and we can begin the working. Presently the welding step is accomplished through a thermo-mechanical strategy that has joined method for warming thermally just as in charge of plastic distortion. Getting welding in the rubbing mix welding procedures tends to blend the "sticky" chip of the material along the ideal line of joint. It is embroiled that the temperature accomplished along these lines of warming don't have a legitimate dissemination, materials of both the work pieces which are to be joint required to be idle blended precisely with the apparatus test. Mechanical change is a significant factor in this grinding mix welding strategy since it the two influences the warm vitality created as contact just as it shows the total blending of work piece materials in the "raw" advance so as to get a quality and a sound weld. In the Final advance, apparatus expels from the work piece totally by the upward development of hardware so the cycle is finished.

The grinding mix welding procedure has its greatest use in butt and lap welding, in which to make joints is totally conceivable. The ideal warmth is created utilizing a legitimate instrument which has a body with a bigger measurement as shoulder and a littler breadth as stick.

Fig.3: A typical macrograph with various microstructural zones in FSW [1]

1.4 PROCESS PRAMETERS

These fall into the three categories as machine parameters, tool design parameters and the material behavior. Material properties of the work piece are important in choosing process parameters. Many of the process variables are always decided by knowing the mechanical properties of the base material.

Table 1: Summary of major FSW parameters and their impact on the working

Process variables	**Impact on FSW working**
Rotational speed of tool	Maximum temperature increases with increasing rotational speed.
Welding speed	Maximum temperature decreases with increasing welding speed.
Tilt angle	Proper tilt angle help the tool to hold the material and transferred the material from the start to the end.
Vertical force	More pressure does overheating, whereas low pressure causes inappropriate heating.

There is an agreement that the most significant welding parameter is the revolution speed, however that the transverse speed furthermore, dive profundity are likewise noteworthy. Rotation speed not only decides the total heat and desired temperature but also total shear force acted on the welds. Therefore, this impacts the microstructural phenomenon and properties of these welds. Other welding parameters incorporate tilt angle, power, torque, force in z direction.

1.4.1 MACHINE PARAMETERS

The Important machine parameters are rotational speed and the traverse speed. The rotational and the transverse speeds confines the total amount of the heat generated in material. The tilt angle and the depth of penetration also affect the Stir Zone (SZ), but usually these are put constant. The contact of tool with the material creates heat because of friction and the mechanical deformation. Heat in the SZ determines the flow of material and the microstructure property which has an impact on the properties of work-piece. The rotational speed and the axial speed determine the heat generation in worked zone. Peak temperature can be seen for the aluminium alloys to be near about 0.5 times melting temperature. The proper amount of the heat generation in SZ is necessary for making of the defect-free worked zone. So in Friction stir welding heat generation in worked zone is totally dependent on the rotational and the traverse speeds of tool.

1.4.1.1 TOOL SPEEDS

The Rotational speed (w) and the traverse speed (v) determine amount of heat input in SZ, which affects microstructure and the resultant properties. Lower heat input results in the more grain refinement and vice-versa is also true, but there must be some heat input to plasticize or soften the required material. In the surface composite fabrication, higher rotational speed(w) is required for the distribution and breaking up of clusters of the reinforcement particles. So high rotational speed affects grain refinement due to the high heat input. Rotational and the traverse speed must be optimized to get a defect-free stir zone and the reduced grain size as much as possible for requires application.

1.4.2 TOOL DESIGN VARIABLES

Tool design plays a significant role in friction stir welding. So first we have to understand the difference between the geometries of conventional FSW tool and bobbin FSW tool.

1.4.2.1 CONVENTIONAL TOOL GEOMETRY

The material stream ought to have satisfactory bearing and amount during welding which is reliant upon the geometry of your device. The Tool geometry for the most part comprises of the shoulder breadth, the shoulder include, the test shape, the test measure and the test highlight. The Flow of plasticized material in the prepared zone is completely influenced by the device geometry just as the navigate and the rotational movement of hardware. Instrument geometry is likewise a significant part of Friction stir welding as it straightforwardly influences the warmth age, material stream just as resultant microstructure. General apparatus geometry of Friction stir welding has shoulder of hardware having the sunken molded profile is utilized as it fills in as departure volume or a repository for dislodged plasticized material from test. The Tilt edge is required to keep up material repository underneath device and it empowers trailing edge of shoulder device to expel handled material. The device shoulder is absolutely in charge of the warmth age. The utilization of enormous distance across shoulders prompted the high warmth age and the improved material stream while the littler breadths prompts the imperfections in weld. In plan of customary FSW device geometry we need to deal with stick and shoulder. When we think about the plan of stick, in this we ought to have an emphasis on the stick profiles and stick breadth as per the thickness of plates which we are going to weld and after choice of stick profile and stick distance across, presently we will way to deal with the choice of shoulder profile and shoulder width. The thing which we need to remember is that we need to deal with a shoulder to stick width proportion.

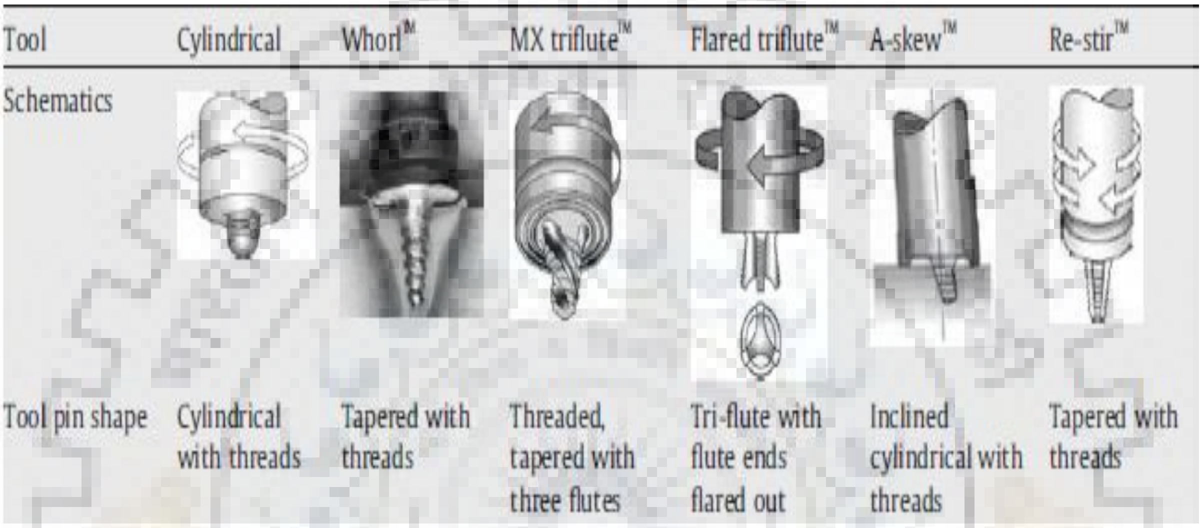

Fig.4: Different tool pin profiles [6]

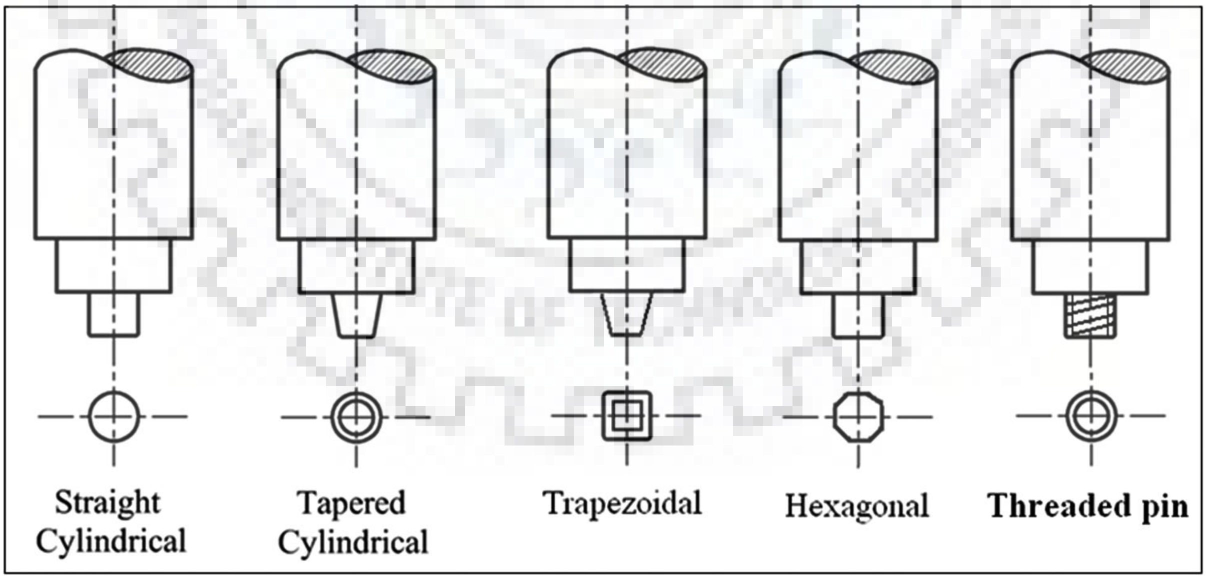

Fig.5: Different FSW tool geometries [3]

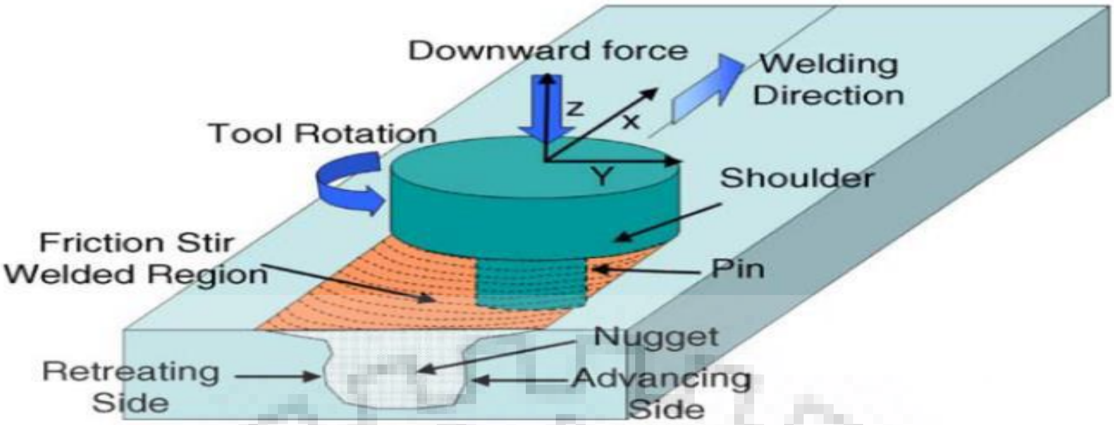

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Fig.6: Conventional FSW Tool [30]

1.4.2.2 BOBBIN FSW TOOL GEOMETRY

The bobbin friction stir welding (BFSW) mechanical assembly has two shoulders with one shoulder on the top surface and the other on the base surface of the weld plate, with a test totally contained inside the material. This reduces the essentials of wide supporting and setup going before welding. The reason is in light of the fact that the normal down power constrained by CFSW is decreased and the responsive powers inside the weld are contained between the bobbin shoulders. The spaces are fixed between the two shoulders all through the system and the common Z-rotate improvement of the gadget can be either fixed or controlled subject to structure limit. This is known as the fixed bobbin FSW apparatus.

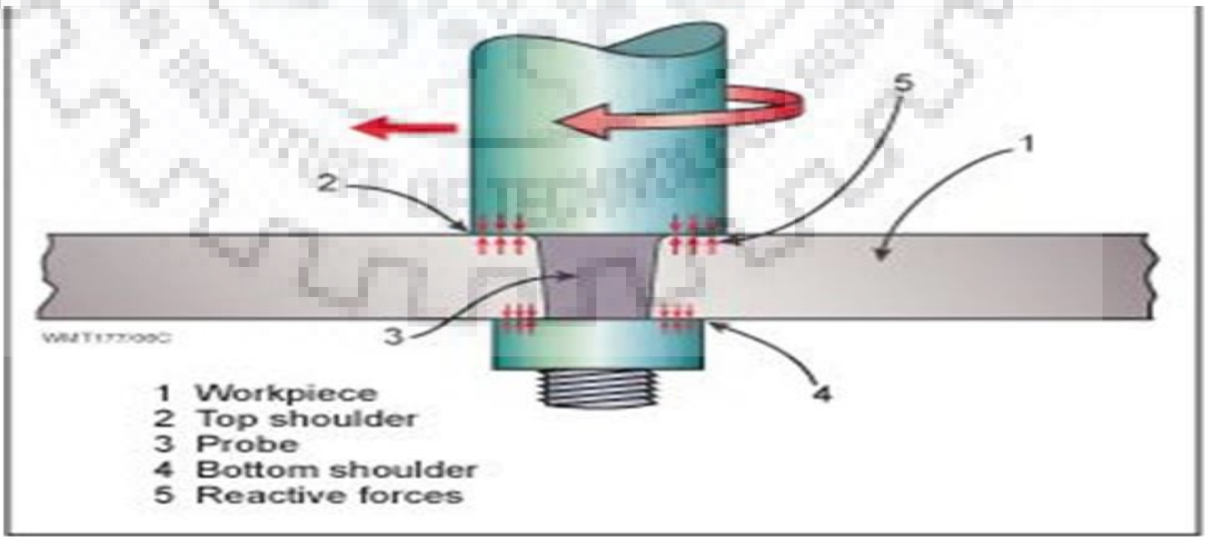


Fig.7: Bobbin FSW Tool [8]

1.2.4.3. SHOULDER EFFECT

High clasping powers and authentic setup before welding is crucial for Conventional FSW. The occurrences of typical imperfections that can be found in Conventional FSW on account of unseemly strategy setup are insufficient weld invasion and support plate polluting. Also, when lower temperatures are conveyed during the system, the material stream from the driving device edge to the pulling back instrument edge can't by and large be done, thusly blemishes, for instance, burrow deformities and kissing bonds are made. To keep up a sufficiently high welding temperature, it is all things considered acknowledged that high welding shaft speeds and moderate travel rates are required. Inquisitively, the present work exhibits this is a dishonest supposition, in any occasion in the BFSW case, as will be showed up.

Welding setup and weld imperfections are observed to be limited or wiped out when the bobbin tooling is presented. The reason is on the grounds that the nearness of the twofold shoulders decreases the clamping forces and produces enough warmth for mixing and blending the materials in the weld region.

Bobbin FSW tool has following advantages:

- Processed zone in work piece is rectangular in cross section.
- Net axial force on work piece is almost zero.
- Eliminates root defect and lack of penetration.
- Ease of fixturing.
- Rotational speed is lower than conventional FSW tools.
- No need of backing plate.
- Permits more travel speeds because of heating from both shoulders.

CHAPTER 2

LITERATURE REVIEW

2.1 BASIC STUDY

In building up the examination thoughts and understanding the procedure, the writing overview was to a great extent worked around Conventional FSW. The reason was little assemblage of data accessible for the Bobbin FSW.

2.1.1 FRICTION STIR WELDING PARAMETERS

Mechanical duty of FSW instrument with substrate produces warmth and weight. These reason materials particles of connecting surfaces to come into closeness to frame joints. The oxide and defilement layer that are accessible on the plates are upset during the system. The dimension of warmth and weight are affected by various elements. In perspective on past examinations for Conventional FSW, if the welding objective is to obtain disfigurement free welds, a couple of components that should be considered are pivotal power, rotational speed, transverse speed, instrument tilt edge and apparatus geometry. Even more generally, Researchers communicated that the essential issue affecting the FSW technique are device geometry, joint structure and procedure factors, for instance, instrument revolution and transverse speed. Despite the sort of FSW process (CFSW or BFSW), factors that impact the weld yield quality and consistency are showed up in Figure 8, a conditions and legitimate outcomes chart.

As expressed before, two fundamental components for joint arrangement in FSW are heat and pressure. Be that as it may, weld quality likewise requires great material flow, which emerges from the movement. The overwhelming procedure parameters (inputs) which are regularly expressed by past analysts are spindle speed, travel speed and design of tool. So we always have to take care of spindle speed and travel speed also with the design of tool to get a sound weld because these are the factors which we have to optimize to get a weld of maximum ultimate strength.

Fujii et al. [2006] described Effects of tool shape on mechanical properties and microstructures and he has used Simplest Shape (Column without thread), Ordinary shape (Column with thread), Triangular Prism shape were used to weld aluminium alloys and Columnar tool without thread has not -significantly affect the joint in welding of and further he described for speeds that at 1500 RPM- Triangular prism tool is best, at 800 RPM- Column with thread is best and at 600 RPM- Tool shape doesn't significantly affect the joint. [1]

D'Urso et al. [2009] described Effect of process parameters and tool geometry on mechanical properties and he has used Two different tools Flat shoulder with cylindrical pin and flat shoulder with threaded probe and explained Threaded tool design for this study proved to be effective in FSW of even though no significant differences were found in terms of UTS. [2]

Biswas et al. [2012] have done friction stir welding of Al alloy with varying tool geometry and process parameter and Different FSW tool geometries used Straight Cylindrical, Tapered Cylindrical, Trapezoidal, Hexagonal, Threaded and explained Tapered cylindrical, Trapezoidal pin is best and max load bearing capacity when ratio of tool rotation speed to tool traverse speed is between 95 rad/mm to 100 rad/mm. [3]

Padmanaban et al. [2009] used the approach for Selection of FSW tool pin profile, shoulder diameter and material for joining Magnesium alloy with different type of tool pin profile Straight Cylindrical, Tapered Cylindrical, Threaded, Triangular, Square and material Mild Steel, Stainless Steel, Alloy Steel, High Carbon Steel, High Speed Steel and different shoulder diameter 15mm, 18mm, 21mm and concluded that High Carbon Steel with threaded pin profile and shoulder diameter of 18mm exhibit superior tensile properties.[4]

Bilici et al. [2012] have explained the Influence of tool geometry and process parameter on microstructure and static strength in friction stir spot welded polyethylene sheets with six different tool pin profile Straight Cylindrical, Tapered Cylindrical, Threaded, Triangular, Square, Hexagonal and concluded Tapered Cylindrical tool yielded higher weld strength than other tools. [5]

Nandan et al. [2008] described the Effect of tool rotation speed and pin profile on microstructure and tensile strength of dissimilar FSW Al alloy with different tool rotation speed 600, 950, 1300 rpm and different tool pin profile Straight square, straight hexagon, straight octagon, tapered square, tapered octagon and concluded Using 950 rpm Straight square pin profile yielded higher strength. [6]

Palanivel et al. [2012] used double sided friction stir welding tool (bobbin tool) for Friction Stir Welding of Al alloy and concluded fine grained microstructure with processed zone rectangular in cross section is achieved. [7]

Threadgill et al. [2010] used Semi stationary shoulder bobbin FSW tool which is bobbin tool with one stationary and one rotating shoulder and concluded Fine crystallized layer is formed due to sliding of stationary shoulder flawless weld featuring a high surface finish. [8]

Goebel et al. [2017] have seen the effect of welding parameter by stationary shoulder FSW of AA 6061-T6 butt welded joint with a rotating pin and non-rotating shoulder and got defect free weld, fine and smooth appearance at 750-1500 rpm and welding speed is 100-300 mm/min. [9]

S. J. Vijay et al. [2010] have seen the Influence of tool pin profile on the metallurgical and mechanical properties of friction stir welded metal matrix composite and it is found that joints welded with straight square pin profile have good mechanical properties compared to the other different pin profiles. [13]

S.Yu. Tarasov et al. [2014] proposed diffusion-controlled wear mechanism of alloy steel friction stir welding (FSW) tools used on an aluminum alloy and it is suggested that the layers of materials of FSW tool are fractured along grain boundaries that are embrittled under the development of shear stresses on surface of tool during the experiment. [14]

N. R. Mandal et al. [2013] have discussed the effect of threaded tool design effect for FSW of AA 7039 and concluded that the most influencing factor is pin diameter and the the optimum range is between 6 to 8 mm and he also summarized that we should have to prefer pin diameter of shoulder diameter. [3]

D. G. Hattingh et al [2007] characterized the influence of FSW tool geometry on welding forces and weld tensile strength using an instrumented tool and provided the data of interaction between tool profile and plastic stir zone. [15]

W. M. Thomas et al. [1995] developed a flared triflute probe and A-skew probe for butt and lap FSW welding and concluded Whorl and MX-Triflute Frustum shaped probes for butt weld gave sound welds. [29]

Shayan Eslami et al. [2015] have developed shoulder design for FSW lap joints of dissimilar polymers and it has been detailed that sound welds are obtained by stationary shoulder made out of polymer materials**.** [16]

M. Maeda et al. [2013] showed temperature field in the vicinity of FSW tool during FSW of aluminium alloy: the same material FSW and dissimilar materials FSW and explained the weld structure is changed not only by tool rotation speed but also the design of tool. [18]

K. Kumar et al. [2007] explained the role of FSW tool on material flow and weld formation and concluded pin driven flow and shoulder driven flow were two ways of material flow and onion rings pattern is also found in weld zone. [19]

A. Arora et al. [2010] proposed optimum friction stir welding tool shoulder diameter using a numerical heat transfer and material flow model and concluded the optimum shoulder diameter as 18 mm at 1200 rpm. [20]

W. Yuan et al. [2010] have seen the effect of tool design and process parameters on properties of Al 6016 friction stir spot welds and explained different separation mechanism as interfacial separation, nugget fracture separation and upper sheet fracture separation. [21]

Bilici et al [2011] have explained the influence of tool geometry and process parameters on macrostructures and static strength in friction stir spot welded polyethylene sheets and have seen the effect of different process parameters on the strength of weld joint. [3]

S. Rajakumar et al. [2010] have seen the influence of friction stir welding process and tool parameters on strength properties of aluminium alloy joint and it is concluded that joint is formed at a rotational speed of 1400 rpm and at welding speed of 60 mm/min using tool with shoulder diameter 15 mm and pin diameter 5 mm. [22]

R, Nandan et al. [2008] have explained the recent advances in friction stir welding- Process, weldment structure and properties and emphasize was on plastic flow during process, tool design element, heat generation and understand the phenomenon of defect formation in welding. [6]

2.3 RESEARCH GAP

High clamping forces and legitimate setup before welding is fundamental for Conventional FSW. The instances of normal defects that can be found in Conventional FSW because of inappropriate procedure setup are inadequate weld infiltration and bolster plate tainting. Moreover, when lower temperatures are delivered during the procedure, the material flow from the propelling tool edge to the withdrawing tool edge can't generally be finished, consequently imperfections, for example, tunnel defects and kissing bonds are created. To keep up an adequately high welding temperature, it is by and large accepted that high welding shaft speeds and moderate travel speeds are required and here welding setup and weld imperfections are observed to be limited or wiped out when the bobbin tooling is presented. The reason is on the grounds that the nearness of the twofold shoulders decreases the clamping forces and produces enough warmth for mixing and blending the materials in the weld region.

2.4 OBJECTIVE OF STUDY

Friction stir welding utilizing the fixed bobbin tool of this thin plate substrate is known to be especially troublesome: it has poor weldability. That makes various difficulties. It additionally makes a few chances. From an examination point of view, there is an open door in that utilizing a troublesome procedure and compound trademark offer the possibilities of having the option to build up a comprehension of the more profound mechanics of the welding procedure. From a professional viewpoint, there is a great deal of welding to be done on say a ship, and the possibility of having the option to do this with Friction stir welding is very appealing. The main objective of the present investigation is to develop bobbin FSW tools for joining of metals. The study includes the following specific objectives:

1. Design and development of fixture needed for welding by a bobbin tool.
2. Design of tool and selection of material for manufacturing bobbin tool.
3. Trial welds on aluminium alloy using newly designed tool.
4. Characterisation of joint made and comparison from a conventional FSW joint.

It is an experimental work so after the weld an explanation regarding failure mechanism of weld is also be presented to suggest important instruction for welding of thin sheet aluminium alloy with the use of bobbin friction stir welding tool.

CHAPTER 3

METHODOLOGY

Tool design on lathe machine

↓

Performed experiments on each tool

↓

Development of welds

↓

Sample preparation

↓

Perform all tests

↓

Comparison of result obtained by bobbin tool to conventional tool

3.1 TOOL DESIGN

The material flow should have adequate direction and quantity during welding which is dependent upon the geometry of your tool. The Tool geometry mainly consists of the shoulder diameter, the shoulder feature, the probe shape, the probe size and the probe feature. Tool geometry is also an important aspect of Friction stir welding as it directly affects the heat generation, material flow as well as resultant microstructure. First Fixture was designed according to available slots in the FSW machine table and height of fixture was set for variable sheet thickness and then Bobbin tool was designed by selecting threaded pin over cylindrical pin. The tool material was taken as die steel. Tool pin length was set to accommodate the plates of various thicknesses. A lock nut assembly was applied to act as bottom shoulder.

Fig. 8: Backing Plate

(a) (b) (c) (d) (e)

Fig.9: Different design of tool (a) Threaded pin with diameter 5 mm (b) Threaded Pin with Diameter 7mm (c) Adjustable bottom shoulder with pin diameter 7 mm(d) Fixed bottom shoulder with pin diameter 7 mm and shoulder gap 4.8 mm (e)Fixed bottom shoulder with pin diameter 7 mm and shoulder gap 2.8 mm

3.2 PERFORMED EXPERIMENTS ON EACH TOOL

After successfully design of tool, experiments were performed using each tool until we got a joint and in this process many times tool failure took place which can be seen in the figure below.

Fig. 10: Failure of tool during trial

3.3 DEVELOPMENT OF WELDS

Trial was done on aluminium alloy 6061 with parameters taken from previous literature. I have performed the experiments on different rotational speeds and different feeds to optimize my parameters to get a sound weld.

Properties of aluminum alloy AA6061-T6 are given below.

Table 2: Chemical Composition of AA 6061-T6

Elements	Mg	Mn	Fe	Si	Cu	Cr	Al
Base Metal (6061-T6)	1.1%	0.12%	0.58%	0.22%	0.04%	0.35%	Balance

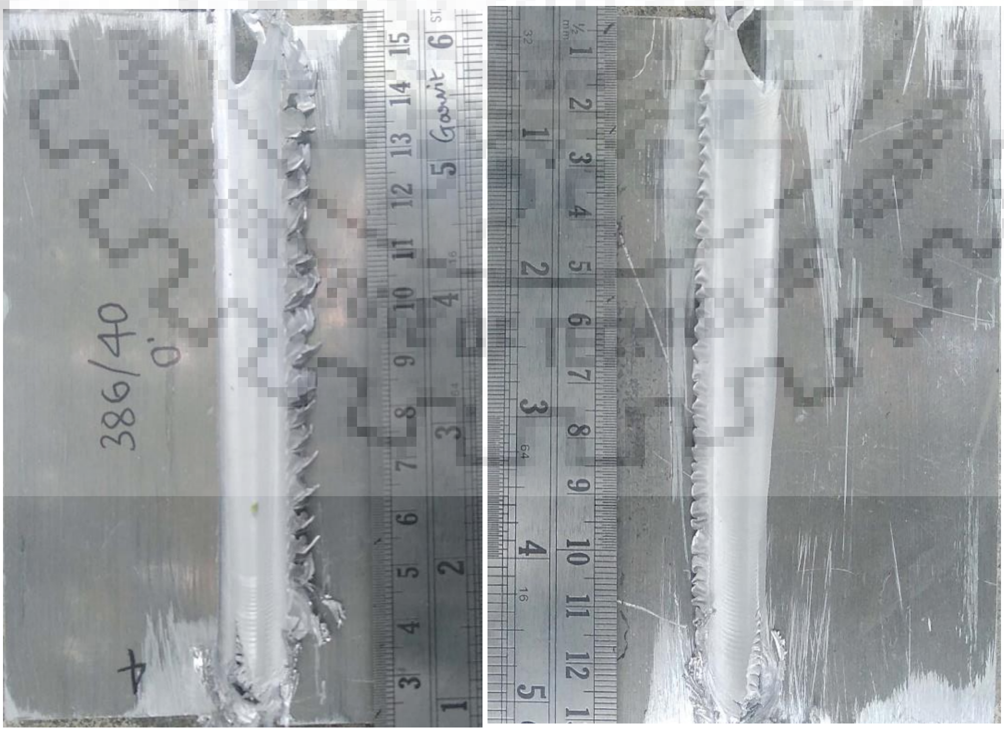
Table 3: Physical Properties of AA 6061-T6

Physical Property	Density (Kg/m^3)	Melting point (^0C)	Modulus of Elasticity, GPa	Poisson Ratio
Base Metal (6061-T6)	2700	580	69	0.33

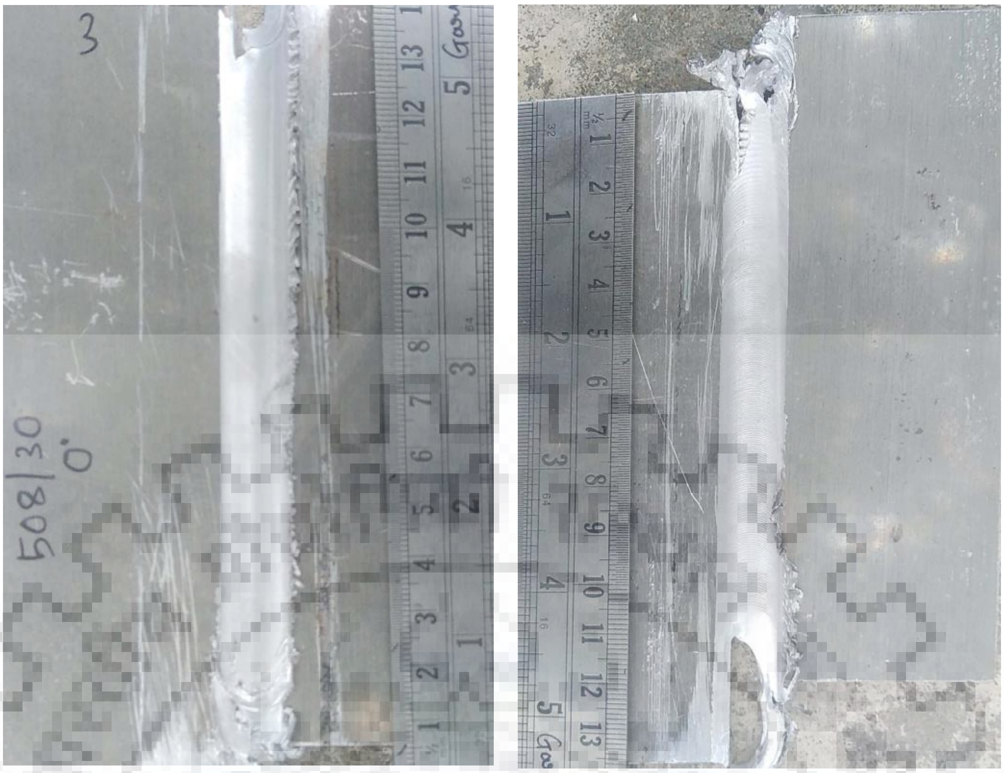
Table 4: Mechanical Properties of AA 6061-T6

Mechanical Property	Yield Stress, MPa	Ultimate tensile strength, MPa	Hardness Number,BHN	Elongation, %
Base Metal (6061-T6)	235	283	95	10-13

The diagram of top and bottom plates after welding at different parameters are shown below in the figure [11].



(a)



(b)

(c)

Fig.11: Trial welds (a) At 386 rpm, 40 mm/min (b) At 508 rpm, 30 mm/min (c) At 508 rpm, 40 mm/min

3.4 SAMPLE PREPARATION

Sample is prepared for different tests to characterize the weld joint.

3.4.1 MICROSTRUCTURAL ANALYSIS

Accuracy metallurgical sample preparation, likewise called Metallographic Specimen Preparation, is a key advance in performing solid metallurgical testing. This kind of testing regularly includes assessing the microstructure of materials using optical amplification or Scanning electron microscopy (SEM). It is significant that all microscopy test planning, including SEM test readiness, be finished cautiously and appropriately for picture lucidity.

We should have to take following steps before micro structural analysis:

1. Selection of material of an appropriate size so that it can easily be handled for polishing.
2. Cutting of material cautiously so that shape of material could not be destroyed.
3. After cutting, material is mounted on polishing machine to grind.
4. Smooth and scratch free surface is obtained after grinding with different grit size papers of grain size decreasing in diameter.
5. Now the etching is done for clear visibility of grain structure.

   These are the steps to prepare the specimen ready for microstructural analysis and now we can do optical microscopy and scanning electron microscopy to understand the microstructural phenomenon for our weld.

3.4.2 TENSION TESTING

Consider the ordinary tensile specimen example appeared in Fig. 12. In my tension test specimen, I have considered 100 mm as the overall length, 30 mm as the grip section length, 25 mm as the gage length, 10 mm as the width of grip section and 6 mm as the width of gage length.

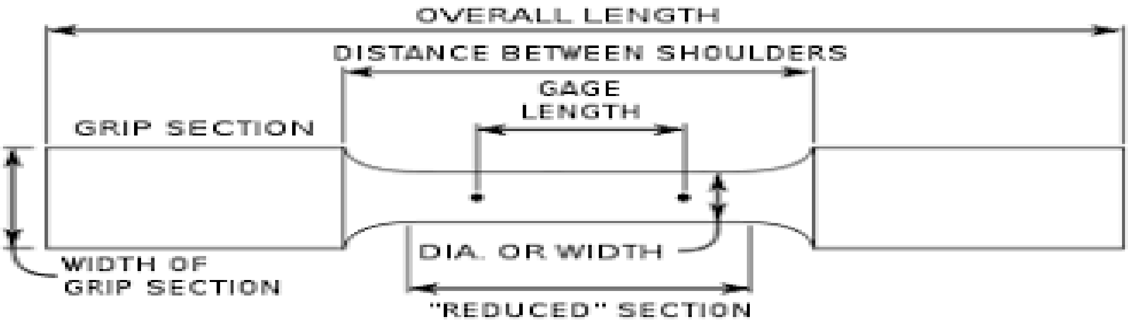


Fig.12: Tensile Test Specimen [ASTM E8]

The tension testing is a way to find the strength of our welded joint with the following ways:

1. This test is done to know the material properties.

2. An increasing load ia applied to the sample until it fails to calculate the strength of joint.
3. This is the method to know how our material is responding towards the applies load.

4. To know whether the material is ductile or brittle one should have to do the tension test.

5. The test gives the result in the form of graph between stress and strain.

6. We can know the point where our material breaks after doing test.

These are some samples after failure during tension test.

Fig.13: Tensile Test Specimen after failure

3.4.3 HARDNESS TESTING

The microhardness testing is done on vicker hardness testing machine which includes following steps:

1. This test is done to know the hardness property of material that shows the limit to which material is resistant to indentation.
2. First the sample is cut into a desired shape so that it can fit in testing machine and should be properly polished so we can see the indentation and measure the accurate value because this testing is optical based testing.
3. Vicker hardness test is done to know the micro hardness in which we supplied 100 kg of load for a dwell time of 10 seconds with a diamond shaped indentor.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 MACROSTRUCTURAL ANALYSIS

As we can see from the macrostructure the nugget shape is not triangular which generally can be seen in conventional FSW, here it is rectangular in shape. This shape of nugget in Bobbin friction stir welding is also known as glass shaped nugget. In conventional FSW we have seen from the previous literature that size of weld nugget always reduces from top surface to center and in bobbin FSW we can see it again increases towards bottom surface. The reason behind the decrement in the area of weld nugget towards center is due to the smaller pin diameter in comparison to shoulder diameter.

The process parameters which we decide for the welding process not only decides the shapes of weld zone but also has an impact on grain sizes.

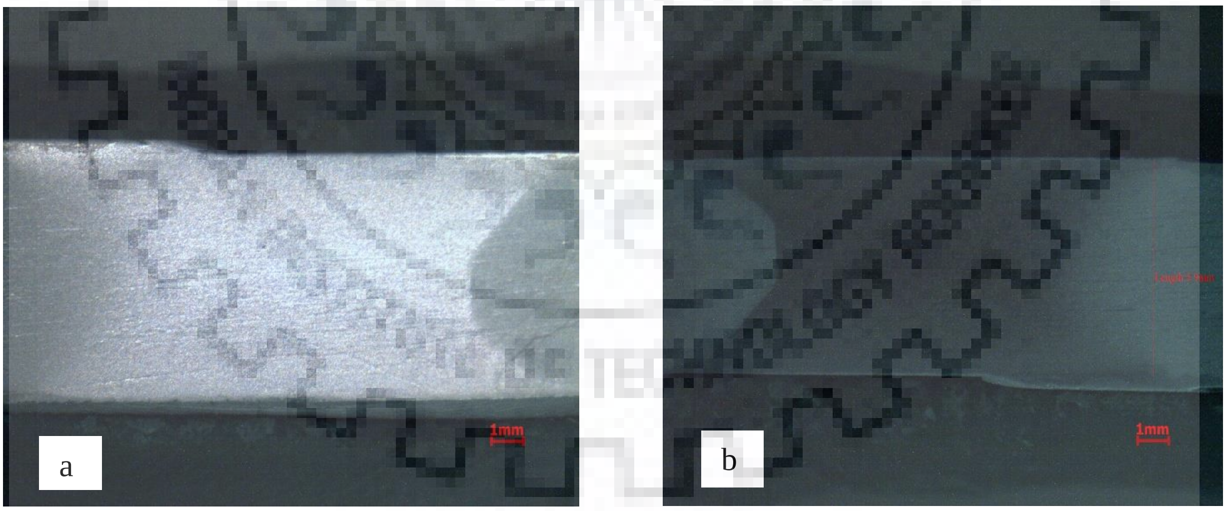


Fig. 14: Bobbin FSW macrostructural cross-section of welded AA 6061

4.1 MICROSTRUCTURAL ANALYSIS

Optical microscopy was done on a sample size of dimension 20 mm * 5 mm and then it was rubbed on emery paper from grit sizes of 80 to 2000 and then it was published on a polishing cloth using polishing machine and using magnesium oxide powder for polishing after that it was etched by keller's etchant for 20 seconds and then it was placed on optical microscope to read the microstructure. On viewing on microstructure three distinct zone weld nugget, thermos mechanically affected zone and heat affected zone were observed. In weld nugget fine and recrystallized particles are there. In thermo- mechanically affected zone grains were oriented in the direction of tool rotation and in heat affected zone coarser grains were seen as compared to weld nugget. The pure base metal having elongated grains.

The composition of keller's etchant is as follows:

Distilled water- 190 ml

Nitric acid- 5ml

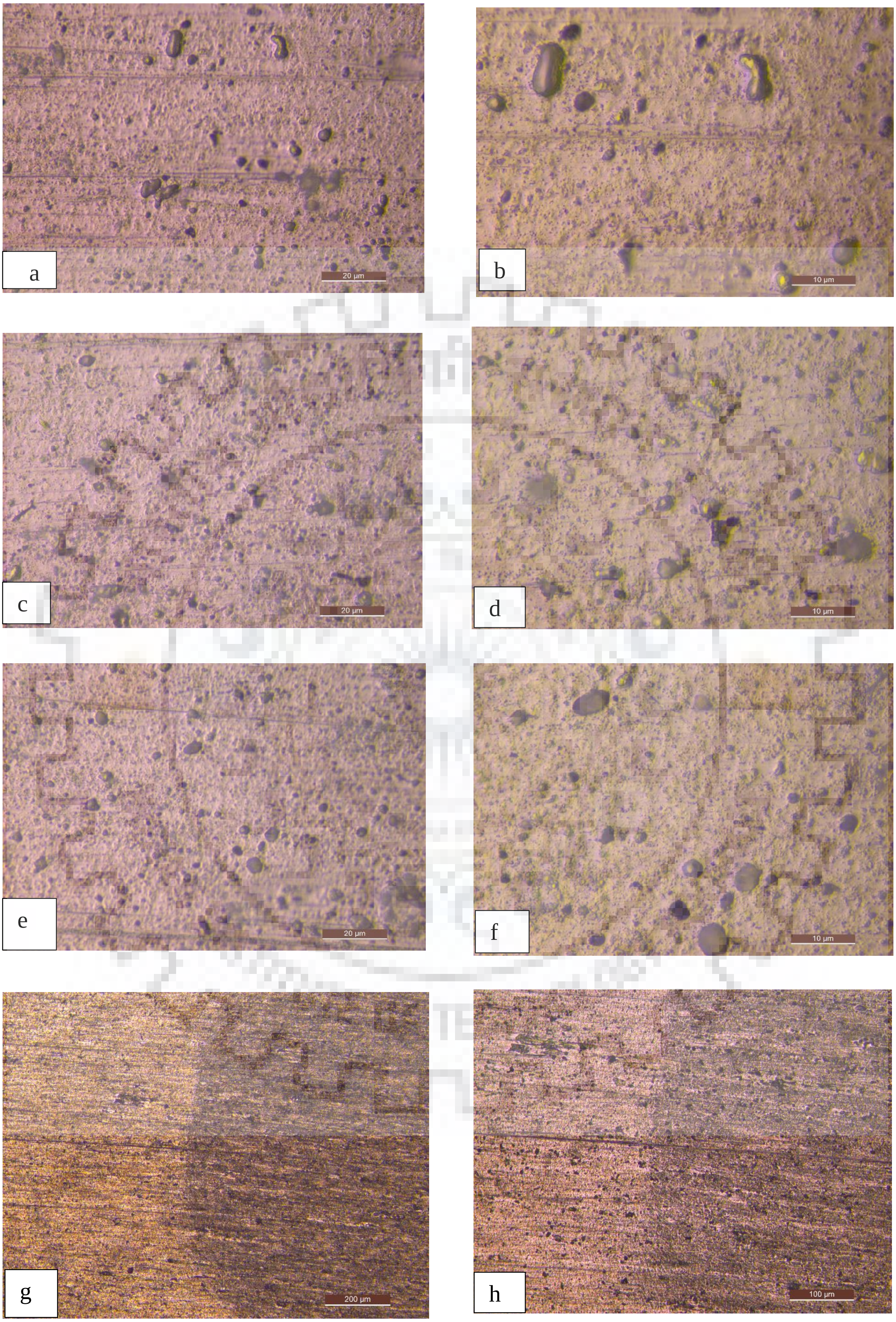
Hydrochloric acid- 3ml

Hydrofluoric acid- 2ml

The time for etching is between 10 to 30 seconds and always it is used fresh.

At higher magnification dissolved precipitate was observed at weld nugget. In nugget zone fine and equiaxed grains were present. In thermo-mechanically affected zone grains were elongated due to the rotation of tool in perpendicular direction as compared to elongated grains that are present in base metal in parallel direction.

I have also used a etchant of composition 5 ml HF, 10 ml H_2SO_4 and 85 ml water for etching it properly so that one can see the images in optical microscope more clear. The immersion time with this composition is 30 seconds after which the grains are more clear as compared to when we use keller's etchant.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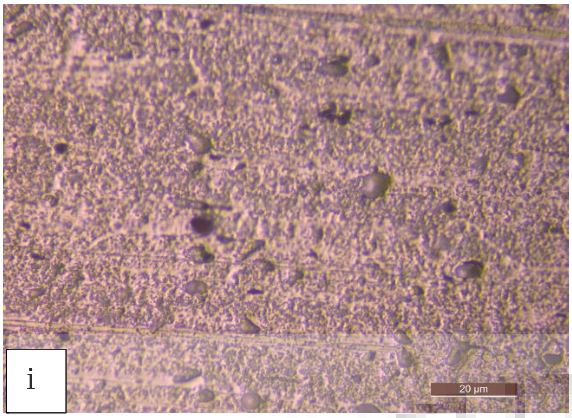


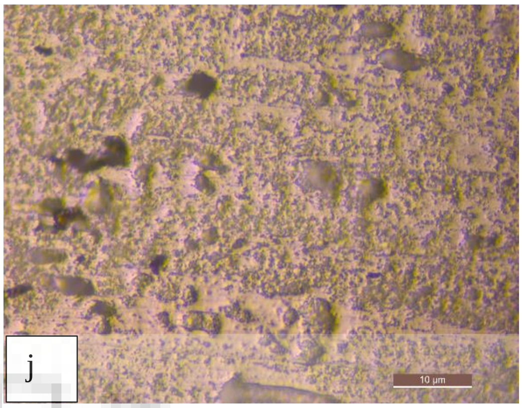


Fig. 15: Optical micrograph of welded AA 6061 (a) base metal at 500x magnification (b) base metal at 1000x magnification (c) far from base metal at 500x magnification (d) far from base metal at 1000x magnification (e) HAZ at 500x magnification (f)) HAZ at 1000x magnification (g) interface at 50x magnification (h) interface at 100x magnification (i) nugget at 500x magnification (j) nugget at 1000x magnification

In the weld nugget area due to stir action refinement of grains takes place and fine and recrystallized grains can be seen in weld nugget and FSW tool in the working process deformed the material plastically near weld nugget zone that area is called thermo- mechanically affected zone and then the area near TMAZ is called heat affected zone because it has influence of heat.

Basically our weld region has categorized into three different zones, weld nugget zone, thermos mechanically affected zone and heat affected zone. The weld nugget zone is also called as stirred zone and these are classified in three zones to make it different from base metal that is unaffected region.

4.2 MECHANICAL PROPERTIES

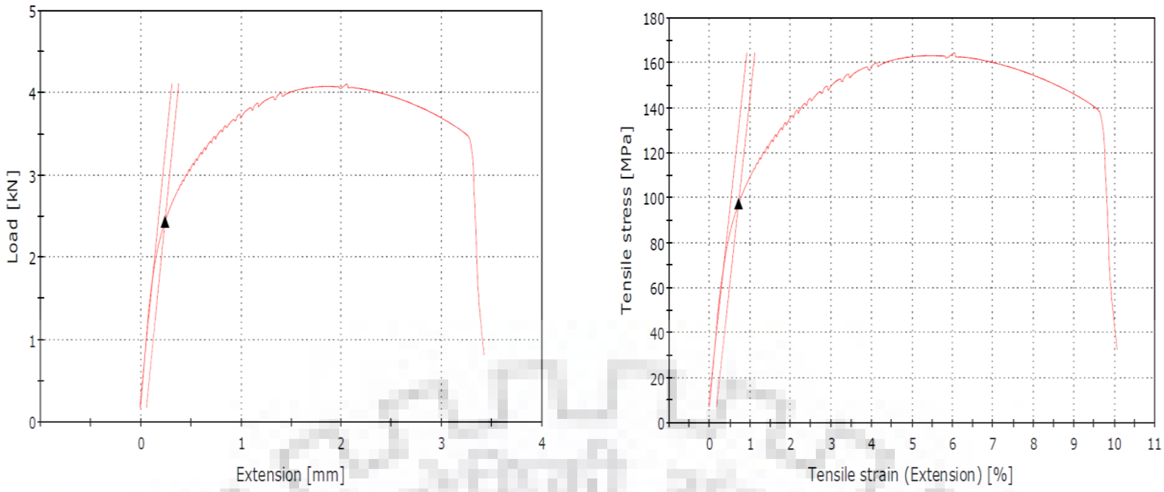
4.2.1 TENSILE TESTING

The performance of any component is dependent on its application and how and where it is utilized and the performance can be predicted by testing these components in laboratory. So mechanical behavior is used to calculate mechanical and various important properties.

Tension Testing is the most basic test and the necessary test. It gives the information regarding the ultimate strength of the material, yield strength of material, ductility values, elongation in the material, young's modulus of the material and a lot of information. Tension testing consider a stress vs strain plot obtained via UTM machine through a controlled displacement module.

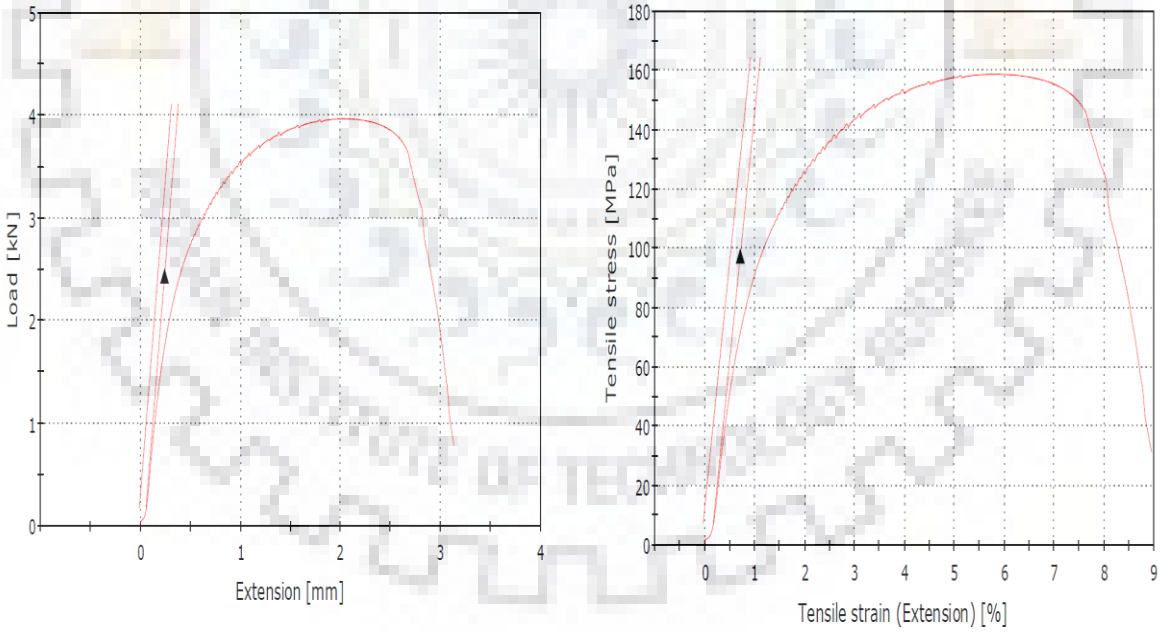
The failure of each weld has taken place at weld joint because these are precipitate hardenable alloy and they are present at grain boundary but in the process of welding due to stirring action dissolution of precipitate takes place so joint strength decreases at these points.

This is the important factor of failure from the weld joint. Surprisingly the welds that are produced are not so good as we know that no sound were able to join. The sound weld will be produced when we use shoulder with minimum interference because here both sholders are responsible for heat generation. So the amount of heat generation was maximum in the investigation case that is friction stir welding with bobbin tool. More heat results in lower tensile strength and there were no visible defects in tensile specimen before testing, may be this low tensile strength was also the reason of lower hardness but further it has been found that maximum hardness can be seen in weld region and lowest in thermo mechanically affected region when compared to hardness in weld region to TMAZ but coarsening of grains due to heat dissipation is also one of the important factor in the lower value of hardness in TMAZ.



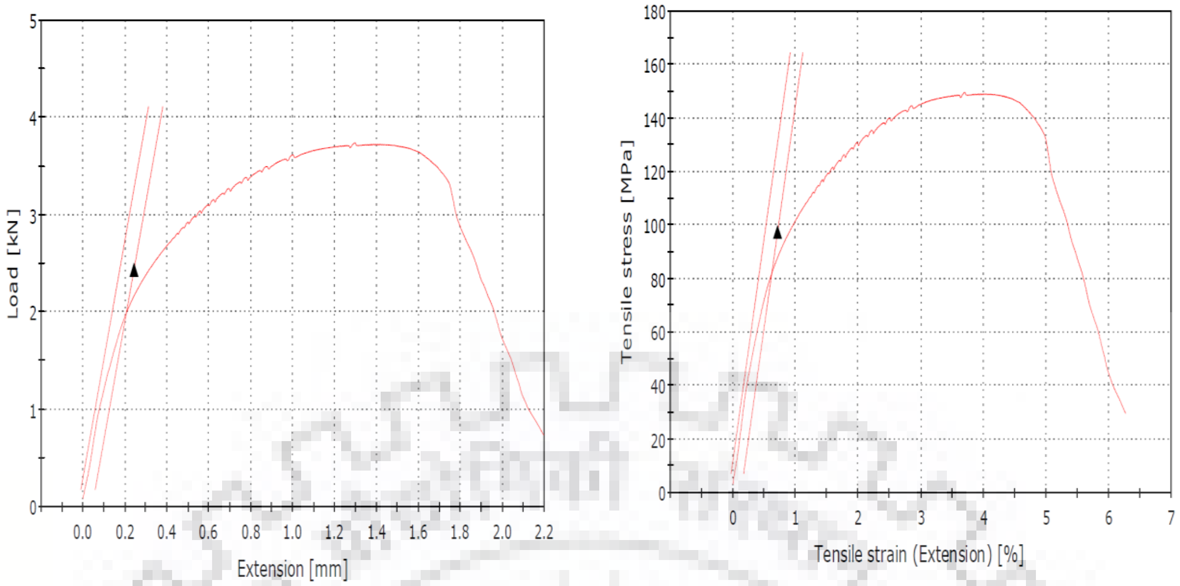
(a) (b)

Fig. 16: Tensile testing of welded AA 6061 at 386 rpm & 26 mm/min (a) Load vs Extension curve (b) tensile stress vs tensile strain curve



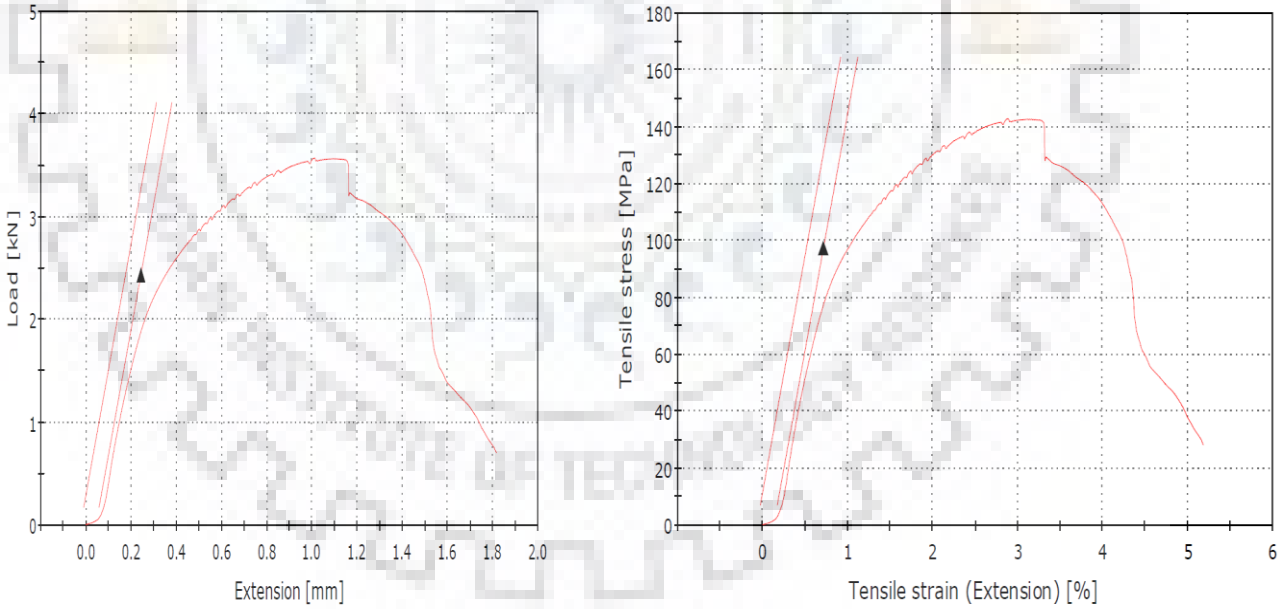
(a) (b)

Fig. 17: Tensile testing of welded AA 6061 at 386 rpm & 26 mm/min (a) tensile stress vs tensile strain curve (b) Load vs extension curve



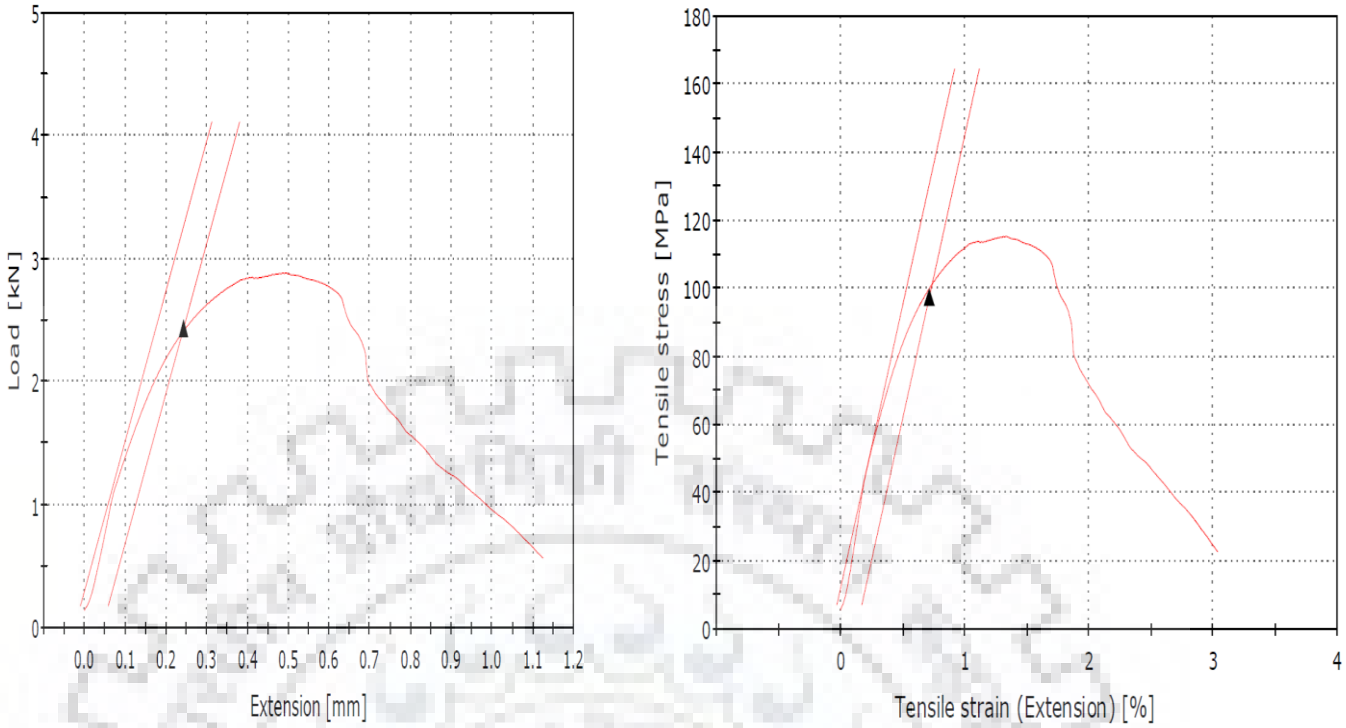
(a) (b)

Fig. 18: Tensile testing of welded AA 6061 at 386 rpm & 40 mm/min (a) tensile stress vs tensile strain curve (b) Load vs extension curve



(a) (b)

Fig. 19: Tensile testing of welded AA 6061 at 386 rpm & 40 mm/min (a) Load vs Extension curve (b) tensile stress vs tensile strain curve



(a) (b)

Fig. 20: Tensile testing of welded AA 6061 at 508 rpm & 40 mm/min (a) Load vs Extension curve (b) tensile stress vs tensile strain curve

Table 5: Tensile test results

Rotational speed, rpm	Feed , mm/min	Tensile strength, MPa	Yield strength, MPa	Fracture Location
386	26	164.539	97.604	Weld joint
386	26	158.934	98.49	Weld joint
386	40	143.037	100.715	Weld joint
386	40	149.766	96.419	Weld joint
508	40	115.495	104.688	Weld joint

Optimum parameters were found to be 386 rpm, 26 mm/min and zero-degree tilt angle in friction stir welding machine. Maximum strength of 164.539 MPa was obtained at this set of parameters.

4.2.2 MICROHARDNESS MEASUREMENT

The Vickers microhardness was measured across the weld center line at a regular interval with 100 g load and 10 s dwell time for both the samples. Microhardness value was measured at 30 points (fifteen points each side) for both the samples to find out hardness pattern corresponding to each set of parameters. After the micro-hardness values were obtained for all the samples, a graph was drawn to know the pattern of hardness variation across the weld. As we can see from the graph the hardness value is more near the weld center line and reduces in thermo-mechanically affected zone and further increases in heat affected zone and in base metal.

In the base metal, the grains are elongated in shape due to tempering so the value of hardness is more in base metal but due to plastic deformation in the weld nugget region the value of hardness is also more in comparison to the value in heat affected zone because due to heat dissipation, coarsening of grains takes place which leads to the reduced value of hardness in subsequent zones.

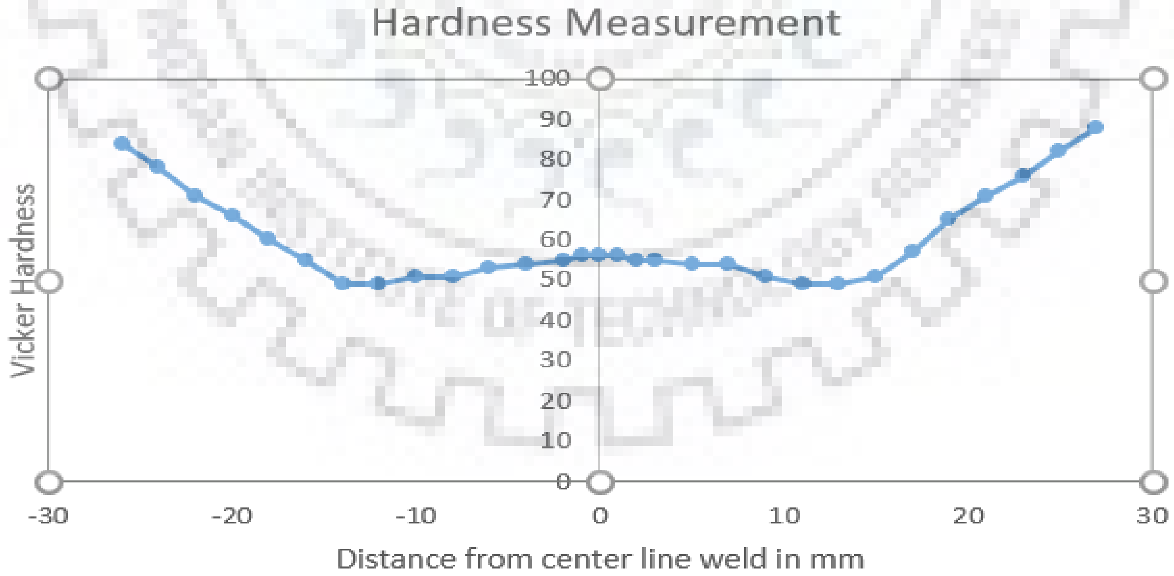


Fig.21: Hardness of welded AA 6061 at 386 rpm & 26 mm/min

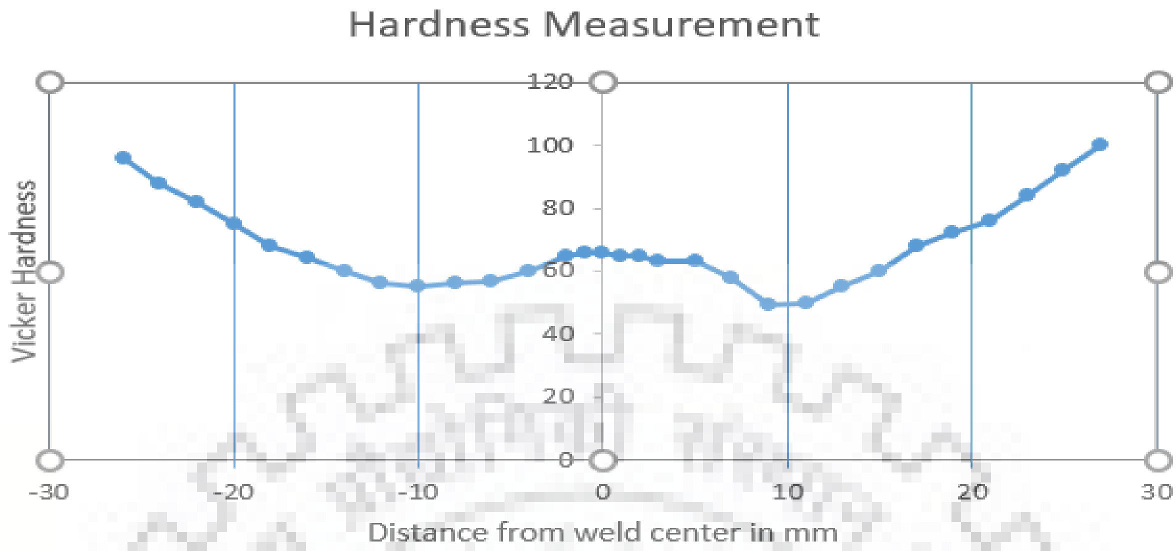


Fig.22: Hardness of welded AA 6061 at 386 rpm & 40 mm/min

I have tabulated all the measured values at different location from the center weld line at both the parameters from that tabulated value I have calculated the average value of hardness at each zone. The average values of hardness at 386 rpm and 26 mm/min are as follows:

Hardness value at base metal at extreme left- 69 HV

Hardness value in TMAZ at left - 51 HV

Hardness value at weld nugget- 55 HV

Hardness value in TMAZ at right- 51 HV

Hardness value at base metal at extreme right- 73 HV

Table 6: Hardness at different location using 386 rpm and 26 mm/min

Base Material	TMAZ	Weld nugget	TMAZ	Base Material
84	49	55	54	57
78	49	56	54	65
71	51	56	51	71
66	51	56	49	76
60	53	55	49	82
55	54	55	51	88

The average values of hardness at 386 rpm and 40 mm/min are as follows:

Hardness value at base metal at extreme left- 78 HV

Hardness value in TMAZ at left - 57 HV

Hardness value at weld nugget- 65 HV

Hardness value in TMAZ at right- 55 HV

Hardness value at base metal at extreme right- 82 HV

Table 7: Hardness at different location using 386 rpm and 40 mm/min

Base Material	TMAZ	Weld nugget	TMAZ	Base Material
96	60	65	63	68
88	56	66	58	72
82	55	66	49	76
75	56	65	50	84
68	57	65	55	92
64	60	63	60	100

Out of all joints the maximum hardness is 66 at weld center was observed at 386 rpm and 40 mm/min.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 CONCLUSION

The overall work has explained the effect of process parameter and design of tool on the joint strength.

The implications of work are:

- There should be an appropriate shoulder gap because less gap results in excessive heat generation and more material flow outside the weld zone and more gap results in improper contact between shoulder and plate which results in less heat generation.
- The pin diameter is also an important feature to ensure a sound weld because if pin diameter is less then there will be a chance of breakage of pin and if pin diameter is more then it will move in cut through manner.
- The tool rotational speed and feed is also important aspect since due to two shoulders more heat generates so we should have to keep our feed more to acquire proper heat generation.
- Tool require as simple shape as possible to reduce the cost and should have sufficient stirring effect to produce sound welds.
- Sometimes it is more convenient to use a concave shoulder as it acts like a reservoir for displaced plasticized material.
- It is also be concluded that the tilt angle maintain material reservoir.

5.2 FUTURE WORK

As bobbin tool friction stir welding process is a new technology and limited literature have been present regarding bobbin tool.

1. We can go for addition of flats and flutes in tool and we can add some more feature in design of a pin.
2. We can do thermal modelling to get the information about peak temperature and maximum torque to know the proper process parameters.
3. This present experimental work can also be performed in the simulation environment to prevent tool fracture.

This work was purely an experimental work but by simulation we can prevent tool fracture and damage to machine. Loss of work material can also be prevented if work in simulation environment, this can save a lot of money and time and which results in improving productivity and quality of work.

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