CHARACTERIZATION OF FRICTION STIR WELDED DISSIMILAR POLYMERIC MATERIALS

Capstone Project

Submitted in Fulfillment of the

Requirement for Award of the Degree

Of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

Mamidala Siva Durga Teja (11405042)
Bandla Sai Vishal (11407543)
Suraj Prasad (11508280)

Under the Guidance of

Dr. SUNPREET SINGH

DEPARTMENT OF MECHANICAL ENGINEERING

LOVELY PROFESSIONAL UNIVERSITY

PHAGWARA, PUNJAB (INDIA) -144402

2017-18

Lovely Professional University Jalandhar, Punjab

CERTIFICATE

I hereby certify that the work which is being presented in the capstone entitled **"FRICTION STIR WELDING DISSIMILAR POLYMERIC MATERIALS"** in partial fulfillment of the requirement for the award of degree of **Bachelor of Technology** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of my own work carried out during period of Capstone under the supervision of **Dr. SUNPREET SINGH**, **Assistant Professor**, Department of Mechanical Engineering, Lovely Professional University, Punjab.

The matter presented in this capstone has not been submitted by me anywhere for the award of any other degree or to any other institute.   .

Date:

B Sai Vishal (11407543)
Suraj Prasad (11508280)
M Siva Durga Teja (11405042)

This is to certify that the above statement made by the candidates is correct to best of my knowledge.

Date: **(Dr. Sunpreet Singh)**

Supervisor

The B-Tech capstone examination of CHARACTERIZATION OF FRICTION STIR WELDED DISSIMILAR POLYMERIC MATIRIALS, has been held on _____________

Signature of Examiner

TOPIC APPROVAL PERFORMA

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Supervisor Name : Dr. Sunpreet Singh **UID :** 21624 **Designation :** Assistant Professor

Qualification: ________________________ **Research Experience:** ________________________

SR.NO.	NAME OF STUDENT	REGISTRATION NO	BATCH	SECTION	CONTACT NUMBER
1	Bandla Sai Vishal	11407543	2014	M1412	9041236899
2	Mamidala Siva Durga Teja	11405042	2014	M1406	8288959015
3	Suraj Prasad	11508280	2014	M1417	8917209749

SPECIALIZATION AREA: Materials Engineering **Supervisor Signature:** ___________________

PROPOSED TOPIC: Characterization of friction stir welded dissimilar polymers.

Details are not entered

PAC Co ımittee Members		
PAC Member 1 Name: Ankur Bahl	UID: 11108	Recommended (Y/N): NA
PAC Member 2 Name: Jasvinder Singh	UID: 15854	Recommended (Y/N): NA
PAC Member 3 Name: Dr. Uday Krishna Ravella	UID: 18604	Recommended (Y/N): NA
PAC Member 4 Name: Anil Kumar	UID: 20296	Recommended (Y/N): NA
DAA Nominee Name: Kamal Hassan	UID: 17469	Recommended (Y/N): NA

Final Topic Approved by PAC: Characterization of friction stir welded dissimilar polymeric materials.

Overall Remarks: Approved (with minor changes)

PAC CHAIRPERSON Name 12174::Gurpreet Singh Phull **Approval Date:** 25 Nov 2017

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ABSTRACT

Friction stir welding (FSW) is relatively a new welding method where heat generated by friction is used to forge components together under an axial force. In this process, the heat generated does not exceed the material melting point.

This study is focused on welding of dissimilar polymers with a newly developed tool, in order to evaluate the effect of the welding parameters on the mechanical strength. This project describes the process of stationary Friction Stir Welded tool for welding thin plates of High Density polyethylene (HDPE), Nylon 66. The welds produced with this tool improved the weld surface quality and strength significantly.

The use of the proposed rotating tool showed to improve the stability in the axial force magnitude during the welding procedure in comparison with a conventional FSW tool.

Effect of FSW process parameters on Tensile and Bending Strength of dissimilar polymer joints.

For Analysis purpose, Taguchi L9 orthogonal tool gives Optimized results.

It has been find that the optimized setting for Tensile strength is Tool Speed ≈ 1400, Feed Rate Speed ≈30, Plunge in Time ≈ 40 and In case of Bending Strength is Tool Speed ≈ 1200, Feed Rate Speed ≈50, Plunge in Time ≈ 60.

Contents

Chapter 1
Introduction

1.1. Welding

In today's scenario, welding is one of the most widely used joining process which provide potential quality characteristics in comparison of other techniques such as mechanical fasteners, adhesives and other joints. It has been attracted numerous manufacturing sectors such as: aerospace, automobile, assembly lines, oil and natural gas, etc. There are numerous types of welding processes available commercially for fulfilling the requirements of the industries, as illustrated in Figure 1.1

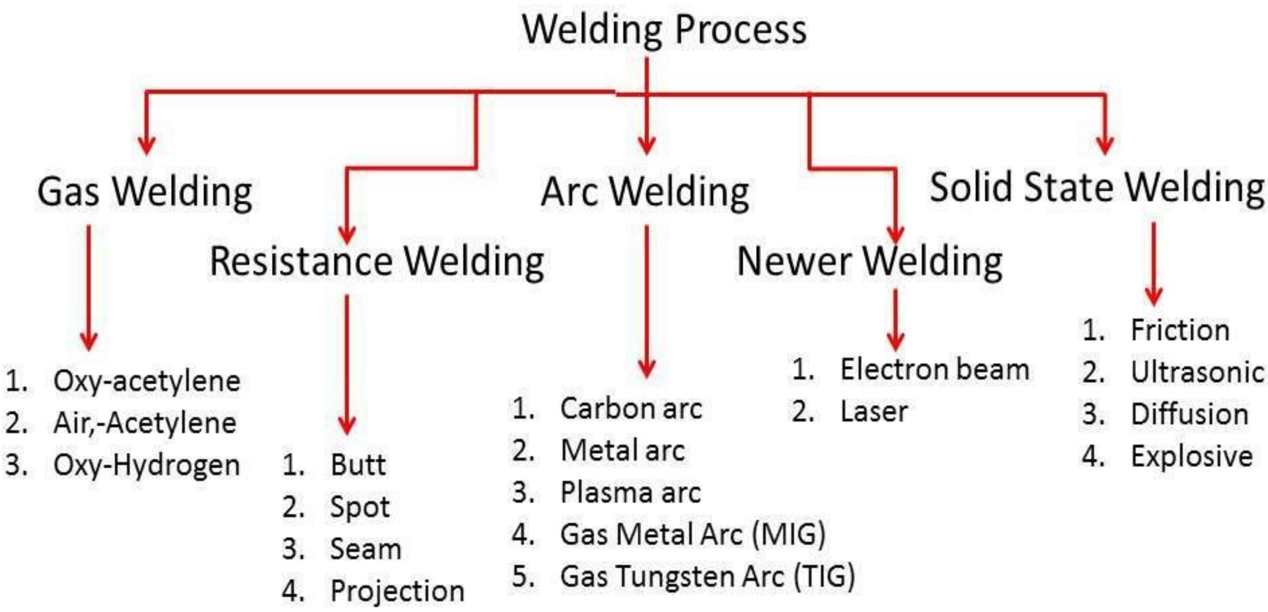


Figure 1.1 (Classification of welding process types)

Friction stir welding (FSW) is one of the latest and established processes for joining of similar as well as dissimilar polymer/plastics and metals. In past 20 years number of applications in different areas using this process have been highlighted, but very limited contributions have been reported on properties of friction welded joints of dissimilar Polymer/Plastic materials. This has been proved that such joining technology allows achieving high quality joints over conventional welding processes. Utilization of lightweight materials such as thermoplastics and reinforced polymer composites has been increasing in order to reduce product weight. Thermoplastic materials are widely employed in different industrial and engineering applications in order to reduce product weight, thermal conductivity and to enhance toughness and stress-to-weight ratio. Joining methods for similar and dissimilar polymer structures are used in the automotive industry [1].

1.1.1 Friction Stir Welding

FSW is a solid-state thermo-mechanical joining process which is a combination of extruding and forging, The Welding Institute (TWI) in 1991 invented this which has now become a viable manufacturing technology of metallic sheet and plate materials for applications in various industries, including plate materials for applications in various industries, including aerospace, automobile, defense and shipbuilding.

FSW process is a relatively new joining process that is presently attracting considerable interest. FSW is emerging as an appropriate alternative technology with high efficiency due to high-processing speeds. Since the joint is obtained well below the melting temperature, this method is suitable for welding a number of materials that are extremely difficult to be welded by conventional fusion techniques. FSW produces welds by employing a rotating, non-consumable welding tool with a specific geometry which is plunged into and traversed through the material which locally soften the work piece, through heat produced by friction and plastic work, thereby allowing the tool to “stir” the joint surfaces. The two key components of the tool are the shoulder and the pin (probe). During welding, the pin travels in the material, while the shoulder rubs along the surface. Heat is generated by the tool shoulder rubbing on the surface and by the pin mixing the material below the shoulder. This mixing action permits the material to be transferred across the joint line, allowing a weld to be made without any melting of the material. FSW offers

- Ease of handling.
- precise external process control
- high levels of repeatability

Thus creating very homogenous welds. Friction heats the material which is then essentially extruded around the tool before being forged by the large down pressure. The weld is formed by the deformation of the material at temperatures below the melting temperature, this process of FSW is illustrated in the Figure 1.1.1(a) and Figure 1.1.1(b)

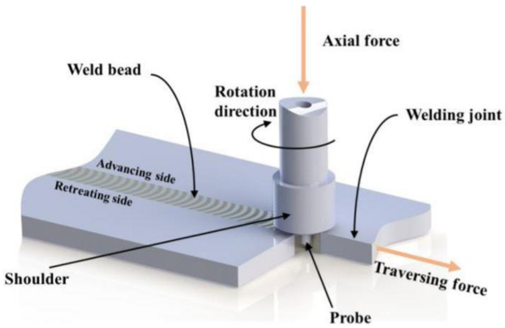


Figure 1.1.1(a) Butt-joint welding procedure by a rotating shoulder.

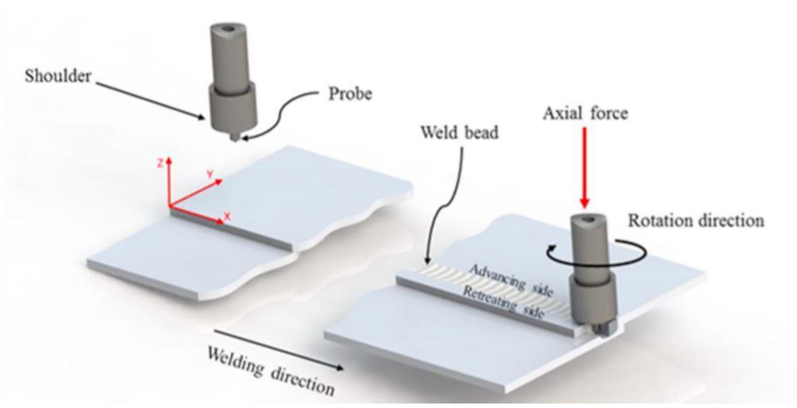


Figure 1.1.1(b) Lap Joint welding

The parameters that are considered while doing welding are given in the following flow chart.

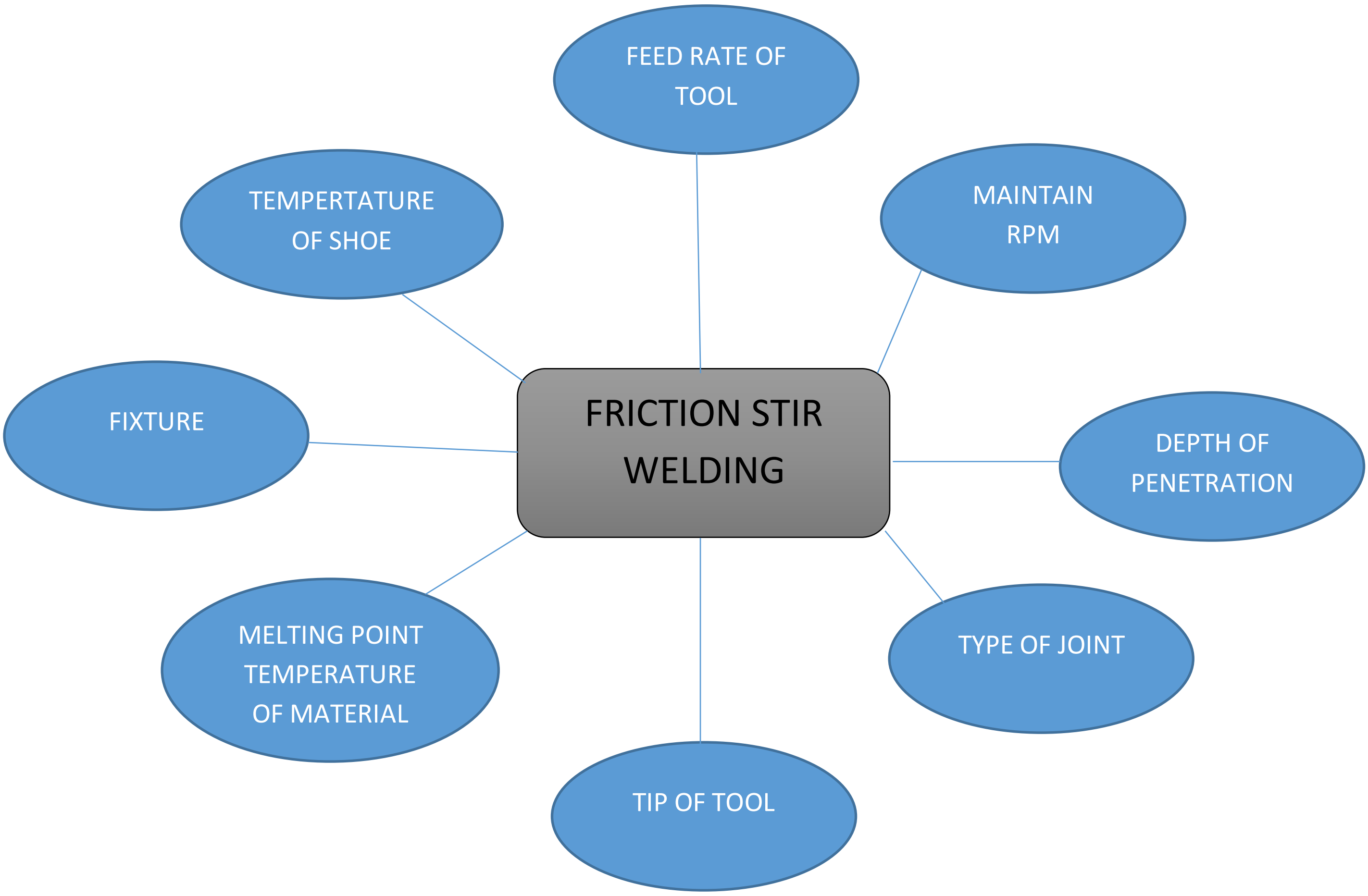


Figure 1.1.1(c) Basic parameters for FSW

1.2 Benefits of FSW

- It provides high quality welds with increased tensile strength, outstanding fatigue properties and corrosion resistance.
- Reduced training, labor and certification costs.
- Fully automatic.
- Reduces energy consumption.
- While welding there is no exposure or toxic gases, arc, fumes. So it is environment friendly.
- Low environmental impact.

- Can operate in all positions.
- This welding process can be used on thinner materials with same joining strength
- Enhanced weld properties in mechanical as well as corrosion
- Lower defect rates, therefore reduced re-work and, possibly, lower NDT (non-destructive testing)
- It can be used in both similar and dissimilar materials
- It required little maintenance
- Easy to operate and does not involved in any environmental pollution
- Lower power consumption due to absence of external heating

1.3 MATERIAL PROPERTIES & WELDABILITY

The following table illustrates the properties of the materials.

Table 1.3.1 Mechanical Properties of HDPE and Nylon-6,6

BASE MATERIAL	MELTING TEMPARATURE $°C$	TENSILE STRENGTH (MPa)	BENDING STRENGH (MPa)	COMPRESSIVE STRENGTH (MPa)	IMPACT STRENGTH (MPa)
HDPE	$120 - 180\,°C$	32	-	20	-
NYLON-6,6	$264\ °C$	70-110	-	22	-

Weldability:

materials are chosen based on the weld ability and the properties they show when they are welded with other polymers. The table below shows different polymeric materials and their weld abilities. In table 1.3.2, ‘blank’, ‘x’, ‘-‘ and ‘?’ Indicates ‘not weld able’, ‘Some grades weld able’ and ‘some reports of successful welding’. In this Online data doesn’t show that HDPE and Nylon-6,6 are weld able. It should be added in online data.

Table 1.3.2 (a)

Other polymers do not form dissimilar welds.

		ABS	ABS/PC	Acrylic	Modified PPO	PA 12	PBT	PC	PE	PEI	PET	Polysulphone	PP
Acrylonitrile butadiene styrene	ABS	x	x	x	?		?	x		?			
Acrylonitrile butadiene styrene/polycarbonate blend	ABS/PC	x	x	-				x					
Polymethylmethacrylate	Acrylic	x	-	x				-					
Noryl	Modified PPO	?			x			?					
Nylon 12	PA 12					x		?					
Polybutylene terephthalate	PBT	?					x	?		?			
Polycarbonate	PC	x	x	-	?	?	?	x		-	?	-	
Polyethylene	PE								x				?
Polyetherimide	PEI	?					?	-		x			
Polyethylene terephthalate	PET							?			x		
Polysulphone	Polysulphone							-				x	
Polypropylene	PP								?				x
Polyphenylene oxide	PPO				x								
Polystyrene	PS	-		-	x			-					
Polyvinylchloride	PVC	-		?			?						
Styrene acrylonitrile	SAN	-	-	-	-								
Styrene block copolymer	SBC								?				
Styrene-butadiene-styrene	SBS	-		x									

Table 1.3.2 (b)

		PPO	PS	PVC	SAN	SBC	SBS
Acrylonitrile butadiene styrene	ABS		-	-	-		-
Acrylonitrile butadiene styrene/polycarbonate blend	ABS/PC				-		
Polymethylmethacrylate	Acrylic		-	?	-		x
Noryl	Modified PPO	x	x		-		
Nylon 12	PA 12						
Polybutylene terephthalate	PBT			?			
Polycarbonate	PC		-				
Polyethylene	PE					?	
Polyetherimide	PEI						
Polyethylene terephthalate	PET						
Polysulphone	Polysulphone						
Polypropylene	PP						
Polyphenylene oxide	PPO	x					
Polystyrene	PS		x		-		-
Polyvinylchloride	PVC			x			
Styrene acrylonitrile	SAN		-		x		-
Styrene block copolymer	SBC					x	
Styrene-butadiene-styrene	SBS		-		-		x

Chapter 2
Literature review

2.1 Literature

Various research work has been carried out on the development of friction stir welding process, design for fabrication, workable materials and process parameter studies. In this section, a state of the art review is presented in the light of latest trends in FSW. Along with this, the applications of FSW for different materials such as: metals, alloys, thermoplastics, etc., has been explore.

1. Automobile industries are interested in joining aluminum and magnesium alloys because they are recognized as light weighted structural materials with high performance and efficiency. Albeit, steels are still widely used for structural components because of their high absolute strength and good cost efficiency. Hence, it is becoming very important to join thin Al or Mg sheets to thin steel ones to fabricate structural components. The main goal of dissimilar material joining is weight reduction, optimization of properties or the tailoring of the properties for specific applications in combination with an efficient joining technologies. [1]

2. Researchers at the University of Michigan have developed self-piercing rivet to join dissimilar materials, in particular, for joining aluminum, magnesium, composite, and plastic components to steel components. [1]

3. This study focuses on joining of dissimilar materials by friction stir processing. The welding institute (TWI) investigated friction stir welding (FSW), where the tool follows a linear motion alongside the works piece, and heat is generated within the work piece both by friction between the rotating tool pin and shoulder and by severe plastic deformation of the work piece. [2]

4. Due to high corrosion resistance and exceptional mechanical properties and the reference phase diagram of Al-Fe systems [3], Baker (1993) states that the low solubility of iron in aluminum promotes the formation of brittle intermetallic compounds (IMCs) such as Fe_2Al_5, $FeAl_3$ and FeAl in the weld zone. Therefore, it seems that obtaining strong joint between aluminum and steel sounds impossible or very difficult by using common fusion welding techniques. Different techniques such as diffusion welding and friction welding have been used to join aluminum to steel. Based on the research done, it is proven that at low melting speeds due to the formation of thick IMCs (which was characterized as Fe_2Al_5, $FeAl_5$) in the weld zone the tensile strength of joints was very poor. Even at low welding speeds the tunnel defect was formed. At higher welding speed and lower tool plunge depth, the joint strength decreased due to lack of bonding between aluminum and steel. [3]

5. Comprehensive study of fatigue life of friction stir welded dissimilar polypropylene-to-polyethylene in lap shear configuration was presented. There was a lack of research work published on that topic to the author's knowledge that was the first paper concerning the fatigue behavior of polymeric friction stir welded lap joints. The life of the strongest welds was compared with the highest performing base material. [4]

6. Saied Hoseinpour Dashthan discussed and investigated the feasibility of friction stir spot welding (FSSW) for two dissimilar polymers, PMMA and ABS. For that purpose, an improved tool equipped

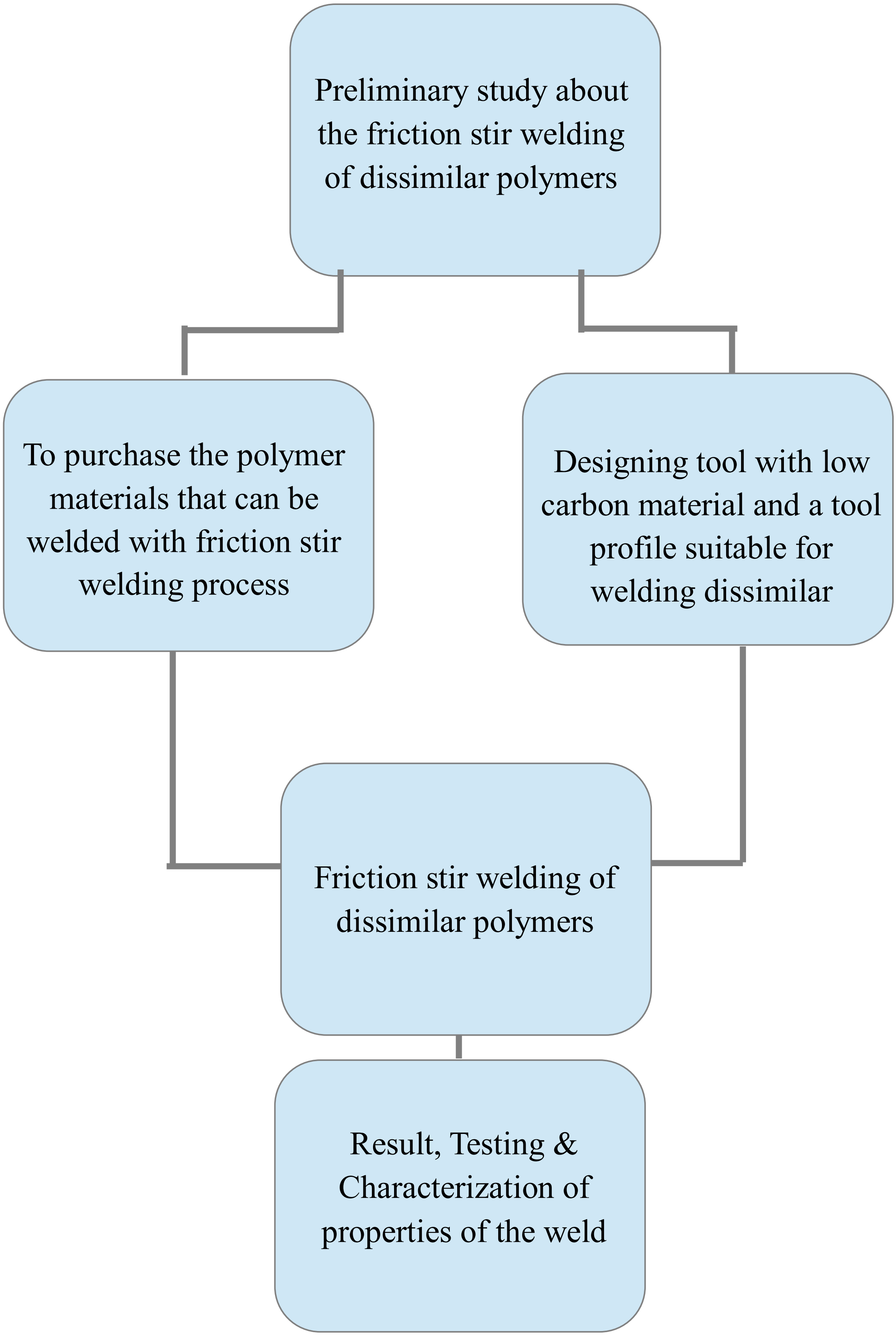
with an additional plate was used to make lap joint welded specimens. That study also investigated the effect of FSSW parameters on mechanical properties of welded specimens. Experimental test was conducted according to a 3^3 full factorial design of experiment in which tool rotational speed, tool plunge rate and dwell time were determined as the process parameters. This study demonstrated that welding of PMMA to ABS by FSSW was feasible and process parameters had a significant effect on weld strength. [5]

7. D. Fersini worked on the characterization of the fatigue behavior of AA2024-T3 friction stir welded overlap joints produced at German Aerospace Center (DLR) of Cologne (D). In those joints, two crack like unwelded zones were present at overlap ends. The stress intensity factor at the crack tip and the fatigue crack path had been studied using the FE code Franc2d and the lifetime had been estimated by integrating the material propagation law with the software A Fgrow, in which the stress intensity factor calculated with Franc2d was introduced. The numerical results predicted lifetime shorter than the experiments. [Fatigue behavior of Al2024-T3]

Chapter 3
Problem Formulation

The friction stir welding is a modern welding process which made joining of two materials either similar or dissimilar without fasteners which may increase weight. The interesting fact about to select friction stir welding to join dissimilar material is the weight reduction. As polymers are having less weight as compared to today alloys used for automotive bodies so as to reduce the weight of the +vehicle or any machinery bodies or parts it will be the suitable method in both strength and joint efficiency. Friction stir welding is not still yet explored well in the industry since it was invented in 1991 by TWI. This is a modern method of welding which is quite better than the conventional welding processes. In the joining process, most of the weight added due to the joining of different metals or plastics using adhesive, fasteners, filling material. This above weight adding methods can be removed by friction stir welding. The joining of polymers using friction stir welding is still in development and need more investigations and to be fully employed into industry.

4.1 Process Flow Chart



4.2 Objectives

- To weld dissimilar polymer materials with friction stir welding
- To study the friction stir welding parameters on mechanical properties of the joint
- To optimize the process parameters of friction stir welding

To weld dissimilar polymer materials with friction stir welding

There are only a few dissimilar polymers that can be welded in friction stir welding. Among them these are some dissimilar polymers which can be welded through friction stir welding process [6].

In the selection of polymers there are 2 polymers which can be welded [6] with dissimilar polymers. They are:

1. High Density Polyethylene
2. Nylon-6,6

To study the friction stir welding parameters on mechanical properties of the joint

The friction stir welding of dissimilar polymers have adverse effects on mechanical properties of the joint such as joint efficiency, tensile strength, bending of the joint.

To optimize the process parameters of friction stir welding

In Friction stir welding, process parameters are vital components that ensure the good quality of weld with better optimization. In friction stir welding there are majorly three parameters they are

- Tool speed
- Tool feed rate
- Plunge in time

In process parameters optimization, corrosion is one of the main problem that can be ejected by optimization of process parameters. Corrosion resistance is managed by optimum process parameters

Chapter 5
Experimentation

5.1 Study & Research

A keen study with respective research objectives have been done and we have made several assumptions based on our study for selection of dissimilar polymers to be welded with friction stir welding process. Among the mentioned 2 below we have made assumptions based on our study to weld these below combination of dissimilar polymers.

- High Density Polyethylene – Nylon 66

Thus we have selected our polymers under an expected assumption.

After selection of polymers to be welded we have to make tool with respective to the Polymeric material to be welded. From study we get to note that

- Tool should be made of low carbon steel
- Tool pin should be cylindrical threaded for better joint efficiency
- Pin length of the tool should be enough for the penetration through both polymer sheets but not till the other end

The tool made with above qualities will give a better quality weld along with this we have to maintain proper welding parameters such as tool speed, tool tilt angle and horizontal displacement of tool along the joint. Tool parameters need to be varied from one combination to the other as the material of the weld changes. Melting points of the polymers should be well known to achieve the optimum tool parameters.

5.2 Scope of Study

Friction stir welding is a solid state welding process which involves low work piece distortion and provides better strength in joining of materials. It is preferred to be used in light weight requirements Friction stir welding has many benefits over the conventional methods. In FSW there is good dimensional stability, repeatability, No loss of alloying elements, Fine micro structure and absence of cracks. In FSW, no shielding gas and surface cleaning is required. It eliminates grinding wastes and saves consumable materials. Improved materials use as it can join materials of different thickness. Due to fabrication of joints by FSW fuel consumption in light weight aircraft automotive and ship applications. Friction stir welding of dissimilar polymeric materials has variant characteristics which is not fully employed in industry. The recent developments in friction stir welding of dissimilar polymeric materials makes more possible ways of using composite materials in a product. After a few testing and analysis of results it gives the joint efficiency of welded dissimilar polymeric materials which may help in industry for using combined materials rather than using same materials.

5.3 TIME vs ACTIVITY CHART

S no	Task description	Task duration	Start date	End date	02-02-2018	8-02-2018	09-02-2018	15-02-2018	16-02-2018	22-02-2018	23-02-2018	01-03-2018	2-03-2018	08-03-2018	09-03-2018	15-03-2018	16-03-2018	22-03-2018	23-03-2018	29-03-2018	30-03-2018	05-04-2018	06-04-2018	12-04-2018	13-04-2018	19-04-2018	20-04-2018	26-04-2018	27-04-2018	28-04-2018
1	Discussion about the project (how to start)	1 week	02-02-2018	8-02-2018																										
2	Preparing Tool and cause failure	2 week	09-02-2018	15-02-2018																										
3	Again preparing Tool, wooden block and fit bearing in wooden block	3 week	16-02-2018	22-02-2018																										
4	CNC machine is Busy, due to some research work is going	4 week	23-02-2018	01-03-2018																										
5	Exam time and asking permission for allotting time for doing project on CNC machine	5 week	2-03-2018	08-03-2018																										
6	Exam time and asking permission for allotting time for doing project on CNC machine	6 week	09-03-2018	15-03-2018																										
7	Trial work on CNC machine and Failure cause	7 week	16-03-2018	22-03-2018																										
8	Brought HDPE, Nylon-6,6 material from Ludhiana and from Chandigarh	8 week	23-03-2018	29-03-2018																										
9	Trial work on HDPE and Nylon-6,6 was success	9 week	30-03-2018	05-04-2018																										
10	Cutting the HDPE, Nylon-6,6 sheet for specific dimension at our required Quantity	10 week	06-04-2018	12-04-2018																										
11	Perform Experiment and Material testing	11 week	13-04-2018	19-04-2018																										
12	Analysis done on resultant data and starting Report	12 week	20-04-2018	26-04-2018																										
13	Report Preparation and submission	13 week	27-04-2018	28-04-2018																										

5.4 Specification of Tool

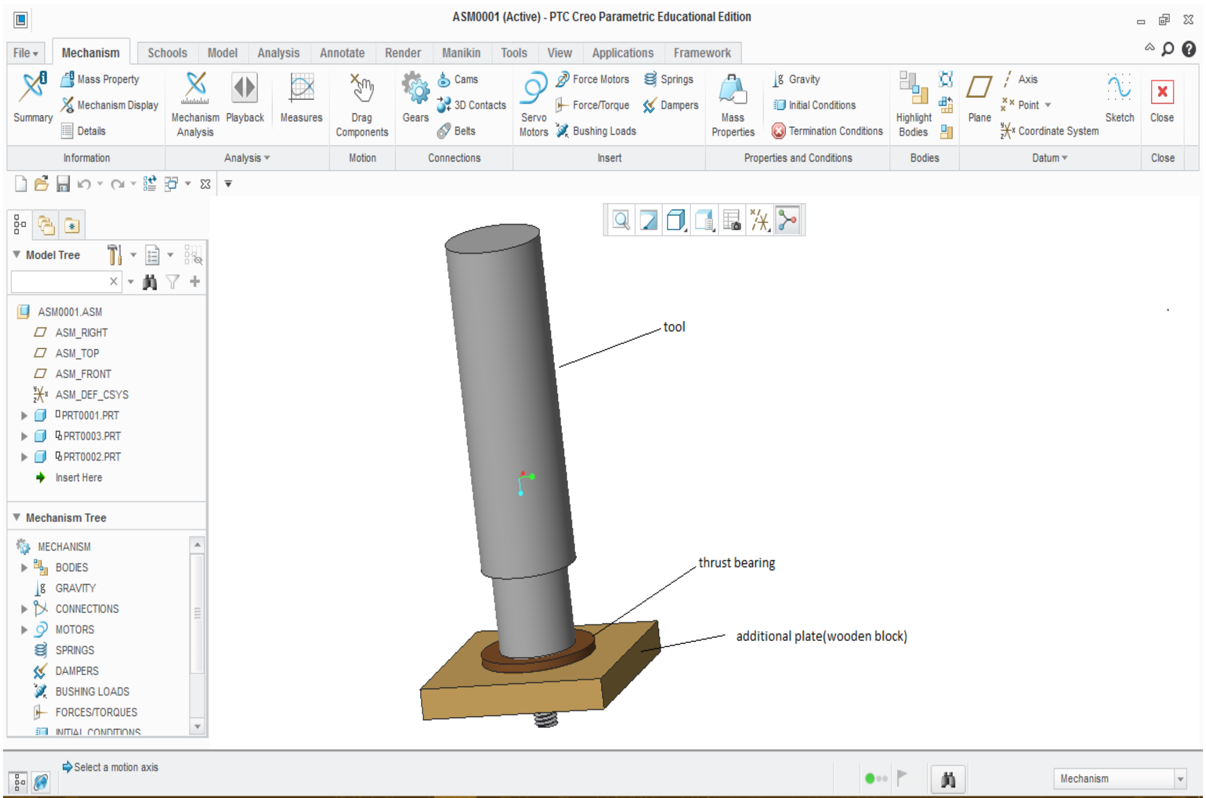
Tool length: 110 mm

Tool Diameter: 25 mm

Shoulder diameter: 20 mm

Pin diameter: 6 mm.

5.5 CAD Model



5.6 Cost of materials

The table 5.6 shows the cost of materials for the specified dimensions of work piece which is required for sampling and characterization of friction stir welded dissimilar polymeric materials.

Table 5.6

BASE MATERIAL	DIMENSION OF MATERIAL		COST
	THICKNESS	LENGTH*BREATH	
HDPE	5mm	1m*1m	₹ 1300.00
NYLON 66	6mm	1m*0.5m	₹ 800.00
TOTAL COST			₹ 2100.00

Chapter 6
Material and Method

6.1 The physical Properties of HDPE and Nylon-6, 6

Table 6.1

BASE MATERIAL	MELTING TEMPARATURE $^\circ C$	TENSILE STRENGTH (N/mm^2)	COMPRESSIVE STRENGTH (N/mm^2)
HDPE	$120 - 180\ ^\circ C$	32	20
NYLON-6,6	$264\ ^\circ C$	70-110	22

6.2 Tool material used

- The material used to make tool is mild steel with low carbon.
- Low carbon steel is considered for its malleable and ductile nature.
- It has easy tendency to form any shape with respective machining process.
- The carbon percentage is 0.05-0.25%.
- It provides lower wear rate and friction coefficient.
- It is easily available and low cost.

6.3 Methodology

Proper planning should be taken by every individual in creating successful report writing. Before carrying on the report writing, studies must be performed related to the problem. Besides that, irregular planning will create problem in producing the report writing. Methodology can be used as guidelines for every step in complete the project successfully.

6.3.1 Selection of FSW process parameters

Table 6.3.1

PARAMETERS	L1	L2	L3
TOOL SPEED	1200	1400	1600
TOOL FEED RATE	20	30	40
PLUNGE IN TIME	20	40	60

6.3.2 Design of experimentation

In design of experimentation, many combinations of process parameters are possible. Rather than making all possible combinations, it's better to make less combinations with best results out of them. Taguchi L9 is one of the method with nine best combinations to give out better results than the performing whole possibilities.

Table 6.3.2

S. No.	Tool speed (rpm) A	Feed rate speed (mm/min) B	Plunge-in time (sec) C
1	1200	30	20
2	1200	40	40
3	1200	50	60
4	1400	30	40
5	1400	40	60
6	1400	50	20
7	1600	30	60
8	1600	40	20
9	1600	50	40

Taguchi Method is a statistical approach to optimize the process parameters and improve the quality of components that are manufactured. The objective of this study is to illustrate the procedure adopted using Taguchi method. The orthogonal array, signal-to-noise ratio and analysis of variance are employed to study the performance characteristics by using Minitab 18 software. In this analysis, three factor namely Tool speed, Feed rate speed, Plunge-in-time were considered. A suitable L9 orthogonal array was selected and experiments were conducted accordingly.

6.3.3 Experimental procedure

Step1: cut 30 samples from each materials at 50mm*50mm.

Step2: file all samples by using hard file.

Step3: Divide (15 samples*2) and numbering all samples from (1-15) *2.

Step4: Fix the fixture on CNC machine.

Step5: By taking series of samples from either material.

Step6: take one sample from either material and perform experiment on CNC machine by using Taguchi method.

Step7: Perform experiment twice, samples that are welded 9*2 samples.

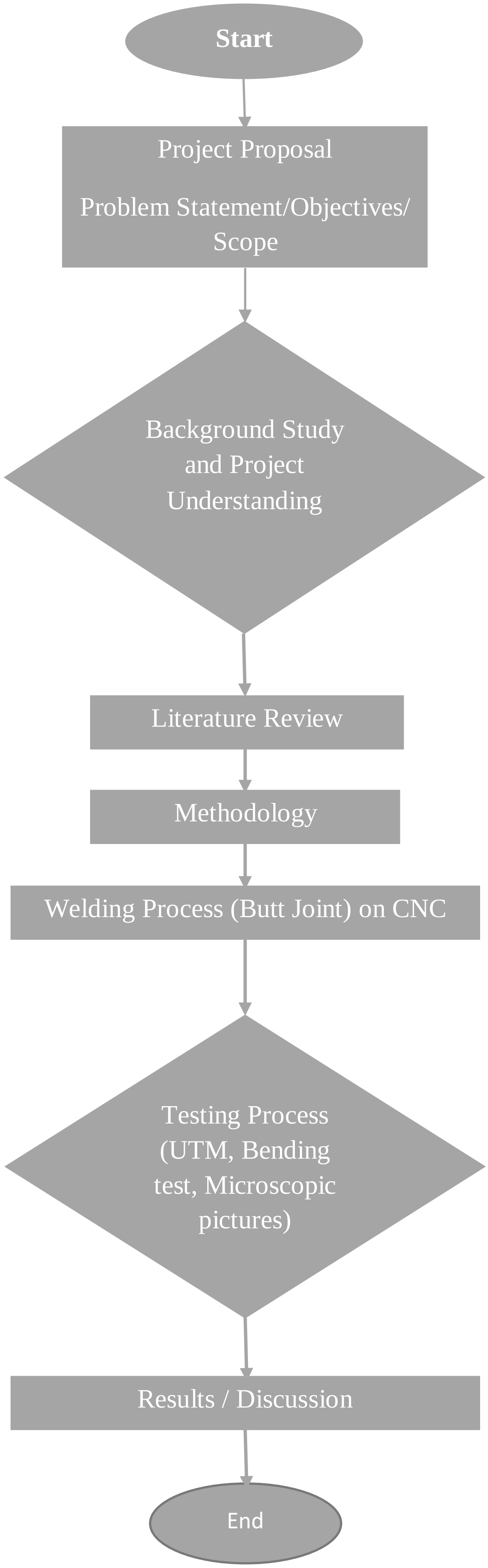
Step8: one 9 samples for tensile strength test and other for bending test.

Step9: take microscopic picture of 9 samples

Step10: perform tensile strength, bending test and get Resulting data.

Step11: For analysis, fill that data in Minitab software by using Taguchi method and get analysis graph for analysis.

6.3.4 Work Flow Chart



Chapter 7
Material Testing

7.1 Tensile Test Using UTM:

- This machine has Multi unit display in Kg, pound, Newton mm, cm, inch selectable.
- Direct display on controller and numeric printout facility.
- Tests programming facility for Tensile, Flexural, compression…etc.
- Cyclic endurance based on load, travel, time

Specification:

Load capacity	Various different capacities can be offered up to 5000kg
No. of load cells	Optional One or Two
Vertical Travel	up to 1000mm
Speed	Variable between 0.5mm/minute to 800mm/minute depending on model
Power	230 Volts, single phase.
Dimensions of material given to machine manually.	

All results such as Peak load, Elongation at Peak load, Elongation at break load, % elongation at Peak load, % elongation at Break load, Tensile strength at Peak load, Tensile strength at Break load, Yield load, Elongation at Yield load, Yield strength, % Elongation of Yield strength and Graph will display on resultant.

Fig 7.1 Universal Testing Machine for testing composite material

7.2 Bending Test Using UTM

- This machine has Multi unit display in Kg, pound, Newton mm, cm, inch selectable.
- Direct display on controller and numeric printout facility.
- Tests programming facility for Tensile, Bending, compression…etc.
- Cyclic endurance based on load, travel, time.

7.3 Microstructure Study Using Optical Microscope

- Metallurgical microscope is used for metallurgical inspections, include metals, Ceramic and other materials.
- Microscope is an instrument capability to producing a magnified image of a small objects
- Most common configuration of metallurgical microscope are student, benchtop, and research.
- Student microscope is smaller and least expensive type of microscope
- This microscope is connected to system, magnified image is displayed over there that image can capture.

Chapter 8

Results and Discussion

8.1 Tensile Test Result and Discussion

Based on Table 8.1, Fig 8.1 show plots of main effects of signal to noise ratios and main effects of means respectively using Minitab-18 with larger is better option. It has been found that with an increase in tool speed, the tensile strength of the joint first increased, but then started to decrease when tool speed level further increased. Thus second level of tool speed is the optimal parameter in the present work. Decrease in tensile strength is due to high tool speed which causes pores at joint where material undergoes melting and expelling of material from the joint. The below shown figures are showing the expelled material from the joint.

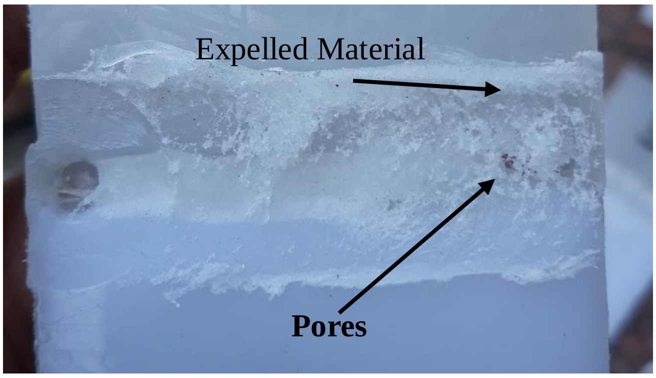


Fig 8.1(a) FSW welded specimen with more pores and expelled material

Fig 8.1(b) FSW welded specimen with no pores and less expelled material

On increasing the feed rate speed, it is found that tensile strength of the joint is increasing. Feed rate is one of the parameter which enhances the strength of the joint.

Plunge in time is one of the important factor to make good tensile strength of the FSW welded joint. From analysis using Taguchi design of experimentation we get various signal to noise ratios and means with respect to plunge in time and its variation with tool speed and tool feed rate. On increasing the plunge in time the tensile strength of the joint decreases due the excessive melting of the material at the joint. The melting of material causes expelling due to more plunge in time. So the first level parameter is optimum for good tensile strength.

Fig 8.1(c) All Specimens before performing tensile test

Table 8.1 Resulting Data for Tensile Test

S. No.	Tool speed (rpm)	Feed rate speed (mm/min)	Plunge-in time (sec)	Tensile strength at peak Load(N/Sq.mm)	S\N Ratio	Means
1	1200	30	20	2.015	6.08550	2.015
2	1200	40	40	0.924	-0.68656	0.924
3	1200	50	60	1.548	3.79542	1.548
4	1400	30	40	2.109	6.48153	2.109
5	1400	40	60	1.581	3.97864	1.581
6	1400	50	20	1.826	5.23002	1.826
7	1600	30	60	0.361	-8.84986	0.361
8	1600	40	20	1.583	3.98962	1.583
9	1600	50	40	1.225	1.76272	1.225

The below mentioned table shows the analysis of variance with respective parameter and response table.

8.1.1 Signal to Noise Ratios:

Table 8.1.1(a) (Analysis of Variance for SN ratios)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Significance
Tool Speed(rpm)	2	60.696	60.696	30.348	0.89	0.528	Yes
Feed Speed(mm/min)	2	8.333	8.333	4.167	0.12	0.891	Yes
Plunge in time(sec)	2	44.766	44.766	22.383	0.66	0.603	Yes
Residual Error	2	67.910	67.910	33.955			
Total	8	181.705					

Table 8.1.1(b) (Response Table for Signal to Noise Ratios- Larger is better)

Level	Tool Speed(rpm)	Feed Speed(mm/min)	Plunge in time(sec)
1	3.0648	1.2391	5.1017
2	5.2301	2.4272	2.5192
3	-1.0325	3.5961	-0.3586
Delta	6.2626	2.3570	5.4603
Rank	1	3	2

Optimum parameter level as suggested by Taguchi L9 for Tensile Strength is: 2 level of Tool Speed, 3 level of Feed Speed, 1 level of Plunge in time. Hence, the optimum condition for Input parameter is Tool Speed, Feed Rate Speed, Plunge in time. Theoretical value of η at optimum condition denoted by η_{opt} could be calculated.

Calculation:

$$\eta_{opt} = m + (\mathbf{m_{ts2}} - m) + (\mathbf{m_{fs3}} - m) + (\mathbf{m_{pt1}} - m)$$

$$\eta_{opt} = 2.4208 + (5.2301 - 2.4208) + (3.5961 - 2.4208) + (5.1017 - 2.4208)$$

$$\eta_{opt} = 9.0863$$

Where 'm' is the overall mean of S/N data; '$\mathbf{m_{ts2}}$' is the mean of S/N data for factor 'Tool Speed' at level 2; '$\mathbf{m_{fs3}}$' is the mean of S/N data for factor 'Feed Speed' at level 3 and '$\mathbf{m_{pt1}}$' is the mean of S/N data for factor 'Plunge in time' at level 1.

Corresponding value of Tensile Strength is

$$\mathbf{y_{opt}}^2 = 1/\mathbf{10}^{-\eta_{opt}/10}$$

$$\mathbf{y_{opt}} = 2.84$$

The predicted optimum strength is 2.84 N/mm^2 but from the design of experimentation, the maximum strength obtained is 2.10 N/mm^2 which is nearer to predicted value. The predicted value can be obtained by performing experiment with other optimum parameter different from the design of experimentation.

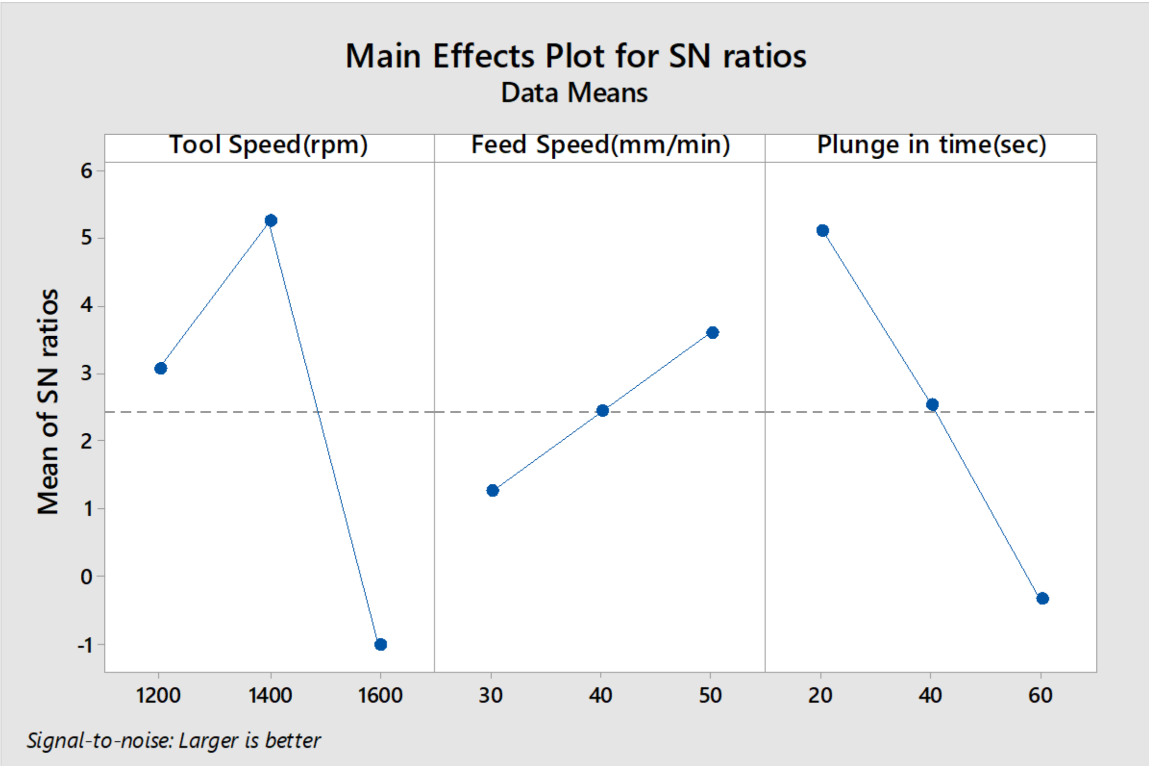


Fig 8.1 Main effect plot for SN ratios

8.2 Bending Test Result and Discussion

Here Table 8.2 shows the Bending result data and Fig 8.2 show the plots for main effects of signal to noise ratios and main plots for main effect of means of the resulting data using Minitab-18 taking larger is better option.

On increase in tool speed, the bending strength goes on decreases up to level 2 parameter of tool speed and further increases in tool speed to level 3 parameter slightly increases bending strength. This is because of expelling of material and causes gap at weld joint. Thus, higher tool speeds cause easy deformation within the material.

On increase in feed rate speed, bending strength decreased first and increased by increase in feed rate speed this is due to the improper pores formed due to high tool speed and plunge in time. The resultant of these two parameters affected the bending strength of the joint irrespective of feed rate speed.

On increase in plunge in time, the bending strength of the joint increases first and slightly decreases by further increase in plunge in time. At level 1 parameter expelling of material is less comparatively with other two levels where as at level 2 parameter expelling of material within in the joint region is slightly increased but it increases the bending strength. At level 3 parameter the expelling is more and due to this pores are formed. These pores cause the easy deformation within the material and decreases the bending strength.

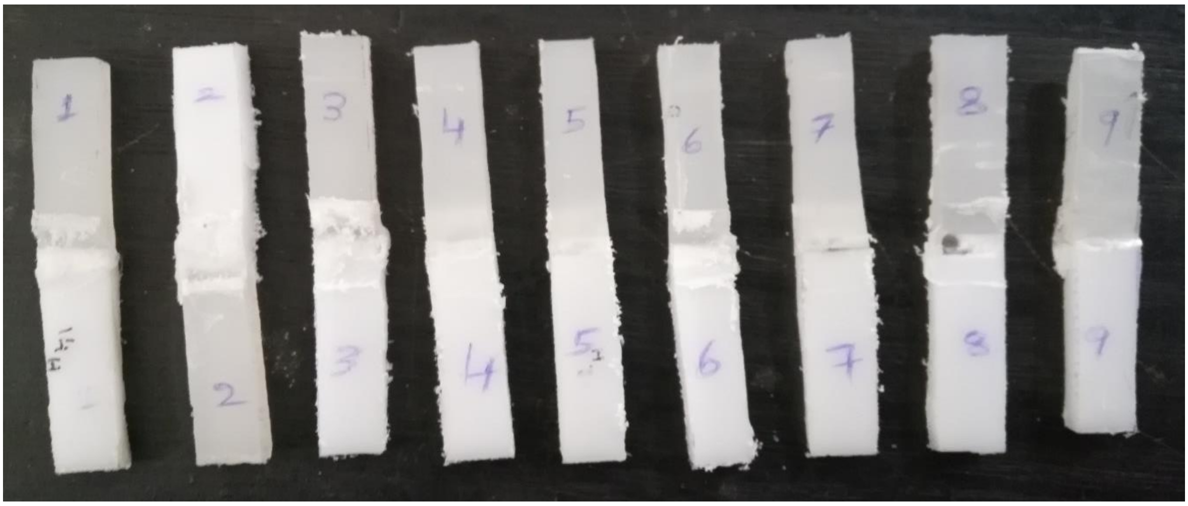


Fig 8.2 All Specimen before performing bending tests

Table 8.2

S.No	Tool speed (rpm)	Feed rate speed (mm/min)	Plunge-in time (sec)	Peak Strength (Mpa)	S\N Ratios	Means
1	1200	30	20	1.590	4.02794	1.59
2	1200	40	40	2.910	9.27786	2.91
3	1200	50	60	3.300	10.3703	3.30
4	1400	30	40	1.590	4.02794	1.59
5	1400	40	60	0.330	-9.62972	0.33
6	1400	50	20	1.080	0.668475	1.08
7	1600	30	60	2.250	7.04365	2.25
8	1600	40	20	0.720	-2.85335	0.72
9	1600	50	40	0.600	-4.43697	0.60

The below mentioned table shows the analysis of variance with respective parameter and response table.

8.2.1 Signal to Noise Ratio:

Table 8.2.1(a) (Analysis of Variance for SN ratios)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Significance
Tool Speed	2	156.973	156.973	78.487	1.15	0.465	No
Tool Feed Rate Speed	2	55.939	55.939	27.970	0.41	0.709	Yes
Plunge in Time	2	9.537	9.537	4.769	0.07	0.935	Yes
Residual Error	2	136.228	136.228	68.114			
Total	8	358.678					

Table 8.2.1(b) (Response Table for Signal to Noise Ratios- Larger is better)

Level	Tool Speed	Tool Feed Rate Speed	Plunge in Time
1	7.89203	5.03318	0.61436
2	-1.64443	-1.06840	2.95628
3	-0.08222	2.20059	2.59474
Delta	9.53646	6.10158	2.34192
Rank	1	2	3

Optimum parameter level as suggested by Taguchi L9 for bending strength is: 1 level of Tool Speed, 1 level of Feed Speed, 2 level of Plunge in time. Hence, the optimum condition for Input parameter is Tool Speed, Feed Rate Speed, and Plunge in time. Theoretical value of η at optimum condition denoted by η_{opt} could be calculated.

Calculation:

$$\eta_{opt} = m + (\mathbf{m_{ts1}} - m) + (\mathbf{m_{fs1}} - m) + (\mathbf{m_{pt2}} - m)$$

$$\eta_{opt} = 2.0551 + (7.8920-2.0551) + (5.0332-2.0551) + (2.9563-2.0551)$$

$$\eta_{opt} = 11.7713$$

Where ‘m’ is the overall mean of S/N data; ‘$\mathbf{m_{ts1}}$’ is the mean of S/N data for factor ‘Tool Speed’ at level 1; ‘$\mathbf{m_{fs1}}$’ is the mean of S/N data for factor ‘Feed Speed’ at level 1 and ‘$\mathbf{m_{pt2}}$’ is the mean of S/N data for factor ‘Plunge in time’ at level 2.

Corresponding value of bending strength is

$$\mathbf{y_{opt}}^2 = 1/\mathbf{10}^{-\eta_{opt/10}}$$

$$\mathbf{y_{opt}} = 3.87$$

The predicted optimum strength is 3.87 N/mm^2 but from the design of experimentation, the maximum strength obtained is 3.30 N/mm^2 which is nearer to predicted value. The predicted value can be obtained by performing experiment with other optimum parameter different from the design of experimentation.

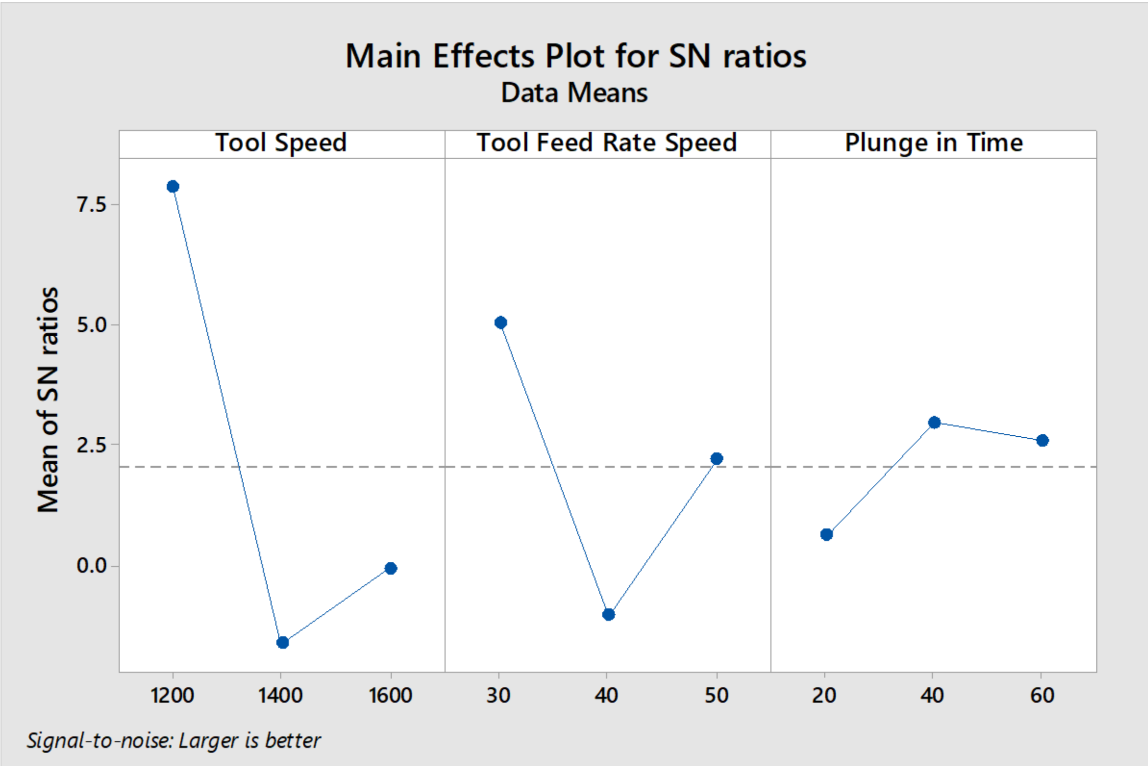


Fig 8.2 Main Effects plot for SN ratios

Chapter 11
Conclusion

11.1 Conclusion:

After performing the experimentation of FSW on dissimilar polymers. The following conclusions may be drawn:

- Welding of dissimilar materials (Nylon-6,6 – HDPE) using FSW is made successfully achieved.
- The tensile and bending tests performed on the welded joint gives the significant results for tensile test at optimum parameters is tool speed:1400, feed rate speed:30, Plunge in time: 40 and for bending strength is tool speed:1200, feed rate speed:50, plunge in time: 60.
- Variation in the input parameters such as tool speed, tool feed rate and plunge in time causes expelling of material from the joint region and also decreases joint efficiency.
- Joint strength at start and end point of the welded joint is less because due to plunge in time.
- The morphological characterization could be done to strengthen the mechanical findings.

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