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Friction Stir Welding of Polymer: A Review

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ABSTRACT

Friction stir welding (FSW) is a solid-state joining process, invented at TWI Cambridge, involves joining or welding of 2 materials without using any filler material. This process has developed remarkably during the last 2 decades. FSW benefits over conventional welding techniques, along with growing industrial demands due to the absence of bulky filler material leading to lightweight designs. FSW found its way into becoming one of the fascinating engineering subjects of today. This method is used for welding similar and dissimilar materials together. Due to increase in polymeric material's consumption in the industry, the possibility of increasing polymeric material welding received a considerable share of interest. There is very limited research done on po lymeric welding with FSW technique. This article reviews previous studies which were focused on welding parameters for different polymeric materials and are then analyzed. The main focus of this article is on welding polymers using FSW technique, welding strength, tool geometry and to observe and analyze the conditions under which optimum results of FSW process is obtained.

Keywords: Friction Stir Welding (FSW), Tool Geometry and Strength, Workpiece Material, Weld Defects, Polymer

I. INTRODUCTION

FSW was originally used to weld materials that are difficult to weld with traditional methods. Subsequently, the advantages of this method and the increase in industrial demand for lightweight design structures lead this method into welding polymeric materials. The FSW technique is generally based on heat due to friction between the welding tool, base material, and material deformation. The main advantage of thermoplastic composites may lie in their potential for rapid and low cost production. The surface properties of thermoplastic suddenly increase reinforcing fillers. FSW is the process in which conversion of mechanical energy into thermal energy is used to join materials. The joining takes place through the movement of a rotating shoulder tool with profile pin plunged into the joint line between 2 pieces of sheet or metal plate. In the FSW method, it is found by Paneerselvam that the majority of voids occur in the bulk of the weld, due to the lack of sufficient heat on the retracting side [2, 4].It is also noted that welding with low welding speed provides adequate time for stirring and homogenization of the parent material [19]. The rotational speeds outside of the "weldable condition" produced the lowest mechanical properties for 4 -mmHDPE in compared to the obtained results inside the "weldable condition" range, [4, 20].

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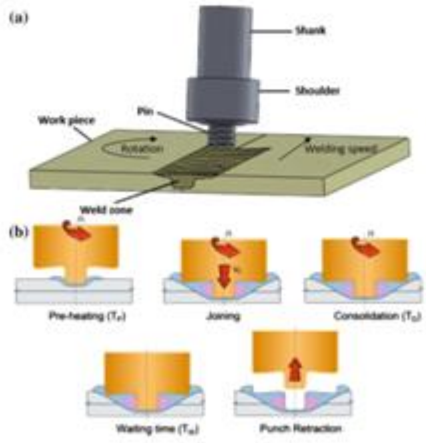

Fig 1: Schematic of a conventional FSW process [18]

This article reviews the various studies and research conducted on the topic of FSW on different polymeric materials such as Acrylonitrile Butadiene (ABS), High Density Polyethylene (HDPE), Nylon 6, P olymethyl methacrylate (PMMA), Polypropylene, Ultra High Molecular Weight Polyethylene (UHMWPE)and observes the effects of varying input parameters such as tool geometry, tool material, rotation speed, traversing speed, and using external and auxiliary heat sources such as a hot shoe in order to optimize various mechanical properties such as the hardness, tensile strength and relative tensile strength with respect to the base material.. This research paper consists of different headings like workpiece materials, tool profile, tool geometry and materials; covering the various parameters which affect the strength of weld. It further encapsulates the studies and research papers re viewed in a tabular form and ends with the summary along with the future scope of research and innovations in this particular field as seen by the limited view of the authors.

II. WORKPIECE MATERIAL

The FSW require very few process parameters (rotational speed, welding speed, Tool dimension, and plunge depth) and each parameter has vital roles in heat Generation and stirring. The optimization of parameters is significant to produce an Acceptable joint strength. Due to different rheological and physical differences among polymers, they were welded at diverse FSW parameters [21]; for this experiment nylon sheet having dimension 105 x 76 x 6 mm have been used. Nylon-6 is one of the most widely used engineering thermoplastics. This Polymer is an excellent replacement for a wide range of different materials like metals and rubber due to its toughness, lighter weight, low coefficient of friction and abrasive resistance properties. It has limitations in usage because of high water/moisture absorption characteristics and poor chemical resistance to strong acids and bases. Dashatan et al. [13] showed the Feasibility of dissimilar polymer joining by FSW of PMMA and ABS. Both of these materials have pattern of crystalline structure and approximate the same glass transition temperature [17]; The polycarbonate sheets were obtained from local market in the form of plates having 1000 mm length, 1000 mm width and a 10mm thickness. The plate is then cut into rectangular plates having 200 mm length and 100mm width. Polycarbonate is naturally

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transparent, with the ability to transmit light nearly that of glass. It has high strength, toughness, heat resistance, and excellent dimensional and color stability. Flame retardants can be added to polycarbonate without significant loss of properties [2]; The samples used in this work consisted of two polypropylene plates with dimensions of 220 x 100 x 10 mm was prepared to fabricate FSW joints [13]; Nylon is well known engineering material used in a wide range of applications due to its excellent combination of good mechanical properties and an easy processing ability, the work piece material is this experiment is taken of dimensions 220 x 95 x 10 mm. Sadeghian and Givi [6]; ABS is a triple copolymer thermoplastic that has a unique structure with polymerization point of 75°C and a highest glass transition temperature of about 80°C. ABS acts as an amorphous thermoplastic and has low moisture absorption content that prevents from growing up of micro bio-organs. Main applications of ABS sheet are in automobile industries due to its capabilities in impact energy absorption, and dimensional stability. In addition, good wear resistance in room temperature make ABS as a suitable choice for home appliances [8]; Butt welds were produced between ABS plates of 300x80x6(mm3). ABS is a light material with low glass transition temperature, which has a broad spectrum of applications, such as in the chemical and automobile industries [7]; Compression-molded ABS sheets chosen for this paper for several reasons. First, ABS is a very common commodity thermoplastic with a variety of applications. Second, it is readily joined by every common joining process. Third, although ABS is slightly hygroscopic, it does not need to dry prior to processing, thus eliminating the need for extra moisture consideration during testing shows some basic mechanical properties of these sheets [5]; Polycarbonate sheets having 3mm thickness, 20 mm width and 90 mm length have been cut from commercial plates. Polycarbonate is an amorphous thermoplastic polymer having tensile strength 58 – 62 MPa. A glass transition temperature 147 °C and melting temperature about 155 °C [14]; we are using two dissimilar working material having different thickness (1) Polyethylene (2) polypropylene.

III. TOOL MATERIAL DESIGN AND GEOMETRY

Since the tool plays a primordial role in this technique, a number of modifications to obtain appropriate FSW tool solutions for welding polymers were required. Given that polymers behave differently than metallic materials during FSW, new tool developments are needed to minimize the defects in order to achieve sound welds. In FSW, pin and shoulder geometry of the tool profoundly affect the weld quality. Considering the importance of tool geometry, wide research on tool design has also been performed. Different types of tool Geometry are shown in the fig. below

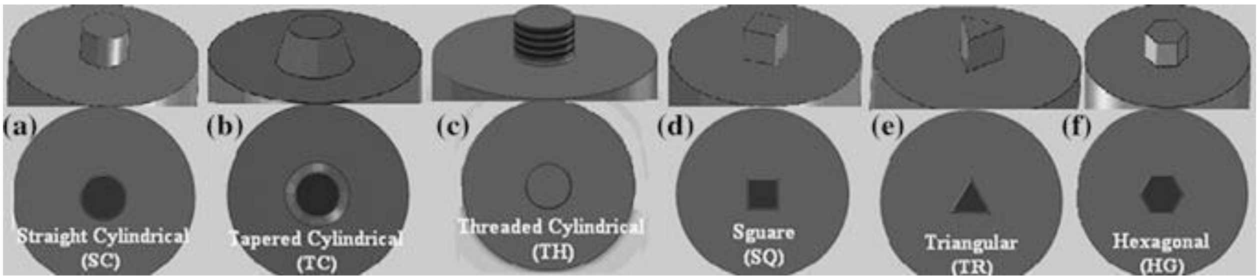

Fig. 2: Various types of Pin Geometry [18]

Sadeghian and Givi [6] They used a specially designed concave shoulder with straight cylindrical and conical pins. This particular design of shoulder was made to restrict the generated heat of friction within the weld area. A

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stainless steel blade was also placed on the upper surface of the ABS sheets to prevent the top of the weld from undercutting thus producing a good surface finish. The tensile strength of specimens showed effective results as the highest weld efficiency was pegged at 101 and 99% in the conical and the cylindrical pinned tools, respectively. Oliveira et al. joined thin PMMA sheets using refill friction stir spot welding. This process is efficient in a way that a key-hole will be filled by a non-consumable FSW tool. Mendes *et al*. [8]In this experiment the FSW tool consisting of a stationary shoulder and a conical threaded pin. A long stationary shoulder is design to allow heating In front of and behind the pin although in this set on test no external heating was applied. External shoulder dimensions are 177 x 25 mm.[17]from studied tool geometry using rotating shoulder FSW tool has resulted in spinning out of the polymeric material and building it around the shoulder [13] showed the effect of inertia force on shoulder, furthermore shoulder could easily insert molten area without applying enough forging pressure .to avoid the problem equipped with an additional plate was designed and employed [3]. this studied has four different FSW tool pin profile such as square pin, taper pin, triangular pin and threaded pin with cylindrical shank. From this investigation threaded tool pin profile created good welded region and more hardness without bothering of welding from investigation speed, speed rotation parameters were depend on pin profile [14]showed the tool material used for welding is hot shoe static shoulder with aluminum coated with polytetrafluoroethylene or Teflon on contacting surface area. In his second iteration he simply removed hot shoe and worked on static shoulder made by Teflon with a highly conductive sleeve around rotating pin. This prevents injection of the soft material inside the shoulder and due to its ability to preheat the areas around the pin in advance.

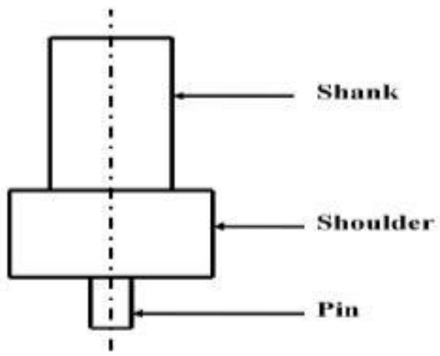

Fig. 3: Various nomenclatures of FSW tool and Pin Geometry [2]

IV. OPTIMIZATION PARAMETERS

Optimization is a general design techniques which is used in various disciplines of engineering in order to maximize a given constraint or parameter. Optimization is overwhelmingly used in engineering analysis of data points, for e.g. Taguchi method, ANOVA analysis & many more are generally used to improve the quality of manufactured goods & more recently applied to engineering biotechnology etc.

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Table 1 Optimization Parameters

Sr. No	Optimization method	Input Parameter	Output Parameter
1	Taguchi design method is the study the effect of processing parameter on yield strength of welded sheet. ANOVA Analysis determines the main effects contribution of factors on the response and defining an Empirical equation between the factors and the response mathematically calculated of the ANOVA is carried out by Minitab software version 16.	• Elastic modulus= 1108 – 1339 MPa • Tensile strength= 39.35 – 42.87 MPa • Ultimate Elongation= 2.92 – 3.14 % • Notched Izod impact strength at 23°C= 30 – 450 J/m	• We determine t factors to the tens the final weld f ANOVA Analy diameter ratio, rotational speed etc. • Maximum Tens different work-pi 23.84 to 41.95I
2	This experiment study Taguchi method defines the quality of products in terms of the loss imported by the product to the society form the time the product shipped to the customer. In the experimental work, orthogonal L'16 array was utilized to identify the optimized parameter.	• FSW tool pin profile – square, triangular, threaded & tapered. • Speed mm/min – 30,40,50& 60. • Rotation speed – 1500, 1750, 2000 & 2250.	• Based on inv welding spee speed both parameters w only the tool Difference oc welding & ro negligible.
3	In this experiment using ANOVA method in order to investigate friction stir welding parameters effect on the weld strength. Lap shear test were carried out to find the weld strength as the mechanical property of the welded specimens.	• Dwell Time (sec) – 10, 20 & 30. • Plunge Rate (mm/min) - 8, 16 & 24. • Rotational speed (rpm) – 500, 800 & 1250.	• As illustrated rate, dwell ti rotational speed are im parameters b values as calculated experimental are larger tha the F values statistical cal plunge rate is found effective fact strength. Then dwell t rotational spe be effective in w respectively. • From statistica illustrate that wel increased by dwell time w the tool plunge r weld strength
4	DSC tests (Differential Scanning	Tensile test were performed on a	The tensile streng

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	Calorimetry) was performed in order to determine the crystallinity were performed on a Perkin-Elmer differential scanning calorimeter at a heating rate 10K/min in temperature range 350-500K.	ZWICK Z020 universal tensile tester using 20*15mm specimen at tensile rate of 10mm/min. Heat rate 10K/min temperature range of 350-500K.	11.5MPa, which to about 50% of ori The molten mater largest distance f can be found at t the seam border.

Table 2Literature Review

Sr. No.	Aim	Methodology	Fixed parameter	Observation
1	Study of mechanical and microstructure properties on nylon 6	• Take nylon 6 sheet for experimentation dimension (105* 75*6mm) • Was carried out in CNC machine with change in rotational speed and feed rate	• Type of tool- Cylindrical with threaded pin • Hardness - 62HRC • Shoulder dia - 16mm • Pin dia -8mm • Pin length - 5.8mm • Rotational speed- 600,800,1000,1200 • Feed rate- 18,21,24,23mm/ min • Angle-0^0	• Lower rotational spe rate- generate less friction insufficient to plastic • Mechanical propertie a. Different transvers i. Min yield strength- ii. Min UTS 4.5-13% iii. % of elongation- 1 b. At different rotatio i. Min yield strength ii. Min UTS 7.2%-18%. • C. % of elongation- 2
2	FSW of dissimilar of PMMA and ABS sheet	• PMMA and ABS sheet (5*25.4*100mm) to produced welding using vertical milling machine. • ANOVA analysis	• Type of tool Cylindrical with threaded pin • Shoulder dia - 20mm • Pin dia -6mm • Rotational speed- 500,800,1250 • Plunge rate- 8, 16, 24. • Dwell time- 10, 20, 30.	• 1.Plunge rate affecte of weld • 2. Extreme rotational extra heating of tool and fo reduced strength of weld
3	Study of polycarbonet sheet for tensile properties and microstructure	• Using polycarbonet sheet (1000*1000*10mm) Using vertical milling machine for operation • Hardness test- Vickers hardness test • Surface hardness-emery	• Type of tool Cylindrical with threaded pin • Shoulder dia - 20mm • Pin dia -7mm • Pin length -9mm • Pitch thread-1mm	• Joint efficiency-30.7 Maximum strength- speed- 1220rpm. • Feed rate- 40. • Angle- 1^0. • Tilt angle affect the

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		paper	• Pin material- H13steel • Rotational speed- 1000,1220, 1850rpm • Feed rate- 20,40mm/min • Angle-1^{0}, 3^{0}.	
4	Effect and defects of PP Plate for different parameter of FSW	• Sample are hold on CNC vertical machine of centre for welding (220*110*10mm) • Hardness test- Rockwell test	• Type of tool Cylindrical with threaded pin • Shoulder dia - 24mm • Pin dia -6mm • Pin length -10mm • Pin material- Mild steel • Rotational speed- 1500-2250.	1) Investigation on hard microstructure a) Threaded pin tool- g region b) Square pin- good nu affect to strength c) Triangular pin- good convex profile d) Taper pin- do not crea
5	Microscopic analysis of morphology of seams in FSW of PP	• Using vertical milling machine PP sheet (10mm thickness) • Strenght-25.6mpa • Using optical and electron microscopic technique	• Cutting depth 6mm • Feed rate 60mm/min • Rotational speed- 2000 • 4. Type of tool- Cylindrical with threaded pin	• Super molecular stru Transition zone (outer perimeter of to • Cylindric or distorted PP softer in HAZ reg • better joint efficiency
6	To study the effect of joint formation by rotation of the pin pro file.	• To take a Nylon 6 base workpeice at predetermined conditions, select a non-consumable left handed tool (threaded) made of steel and provide it with a fixed feed rate and rpm and thus carry out the welding of the workpeice. We then study the joint formation and compare the results for Clockwise and Anti Clockwise Rotations from using ASTM standards.	• Nylon 6 Properties: a) UTS= 73.44 MPa b) Shore D Hardness= 70 c) Izod Impact strength= 180 kN/m d) Charpy Impact Strength= 296.296kN/m • Dimension of Workpiece= 220*95*10 mm • Temperature= 30 degree Celsius • Rotation speed=1000rpm • Feed Rate= 10mm/min	• Clockwise a) UTS= 14.4 MP b) Shore D Hardness c) Izod Impact stre kN/m d) Charpy Impact 148.148kN/m • Anti-Clockwise a) UTS= 34.8 MP b) Shore D Hardness c) Izod Impact stre kN/m d) Charpy Impact 168.494kN/m • Thus we observe that Clockwise

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			• FSW tool properties: Pitch = 1mm&Pin • length= 10mm • Nominal dia= 6mm • Shoulder dia= 24mm	Rotation gives better quality for left handed tool.
7	Experimental Optimization of the Mechanical Properties of Friction Stir Welded Acrylonitrile Butadiene Styrene Sheets by varying several input parameters such like tool geometry, diameter ratio etc.	In this research, the core of weldment free from top and root of weld defects is used. Based on the experiences, two types of FSW tools are selected: • Cylindrical shoulder with a cylindrical pin and a conical pin. FSW tool is inserted in a universal FRITZ WERNER milling machine where welding is to be carried out. We thus conduct the experiment and study the effect of various parameters like tool geometry, tilt angle, diameter ratio on the Mechanical Properties and find the optimum value to maximize the weld strength.	• Elastic modulus= 1108 – 1339 MPa • Tensile strength= 39.35 – 42.87 MPa • Ultimate Elongation= 2.92 – 3.14 % • Notched Izod impact strength at 23°C= 30 – 450 J/m • Coefficient of friction (with Steel)=0.21 – 0.28 • Coefficient of friction (with Aluminum)= 0.4 • Coefficient of friction (with Aluminum)=102 – 124 R • Rotational speed= 900 – 1800 rpm • Linear speed= 6 – 25mm/min • Tilt angle= 0 – 2 degree • Shoulder diameter= 10 – 20 mm • Pin diameter= 5 – 8mm • Diameters ratio= 2 - 3.34	• Maximum Tensile S different work-pieces varie 23.84 to 41.95MP • We determine the co factors to the tensile strength of weld from the ANOVA Analysis diameter ratio, rotational sp speed etc.
8	experimental on mechanical properties of friction welded ABS sheets. In this research paper the	In the experiment Compression-molded ABS sheets produced by ‘‘Aida Plastic’’ are used as the base material for the welding. The welding is carried out by a rotating pin made of CK45 steel	• Tensile strength=54MPa • Tensile elongation= 25% • Flexural strength= 72MPa • Rockwell hardness= 112 R scale • Heat distortion temperature = 91 Celsius	• From the above expe conclude that the Tensile Stren from 1.99 – 32.62 MPa with Rela Strength varying from 5.4 – 8 the Base Tensile Strength of 3

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	Rotational of the pin, traveling speed and temperature at the beginning of the welding procedure considered as varying parameters.	having a hot shoe is made from common structural steel and an electric Heater placed on it. Then the cross section of the welded is cut and observed and tested to study the relation between the various physical processes.	• Density= 1.04 g/cc • Rotational speed (rpm)= 800 - 1600 • Travel speed (mm/min)= 20 - 80 • Temperature (C)= 50 – 100 Celsius

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9	In this paper, a newly designed tool with two shoulders, touches upper and beneath surface of the workpiece has been used in order to weld acrylonitrile butadiene styrene (ABS) sheets.	In this investigation, 100 × 80 × 5 mm Compression-molded ABS sheets were used in order to create a Butt-joint welding. The FSW tool was manufactured by T300 series. Two polytetrafluoroethylene (PTFE) washers were used between the ball bearing and each shoulder for simple positioning the bearing in the shoulder and to prevent penetration of outpouring melted material into the bearing. In present research the pin geometry was chosen in two different shapes; convex and simple and the welding of the workpiece is conducted and the correlations between effect of rotational, translational speed, fracture mechanics on the tensile strength of the weld.	• Rotational speed of tool= 400 -800 rpm • Translational speed of tool=20 - 60mm/min • Shape of pin- Simple and Convex	• For Simple Geometry, Tensile Str 15.58 MPa is 45.636% Strength of base. • For Conve Geometry, Tensile Str MPa which 60.63% of Strength of material.
10	Effect of friction stir welding parameters on morphology and strength of acrylonitrile butadiene styrene plate welds. The aim of this study is to examine the effect of main friction	• In this Study, the welds were carried out in a FSW machine, • Using a tool with a stationary shoulder and no external heating system. The welding parameters studied were and the. The major novelty is to study the influence of the parameter axial force on FSW of polymers. Butt welds were produced	• Density (g/cc)= 1.04 • Tensile strength(MPa)= 40.5 • Strain at break(%)= 50 • Glass transition • Temperature(C)= 105 • Tool rotational speed varies between 1000 and 1500rpm • Feed speed which varied between 50 and 200 mm/min	The Tensile St Efficiency is r of 67% at the speed of 1500 • It is feas produce welds w external • Tool rot and axia values a • Thresho speed hi 1250 (rp force hi

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	stir welding (FSW) parameters on the quality of acrylonitrile butadiene styrene (ABS) plate welds.	between ABS plates. A FSW tool consisting of a stationary shoulder and a conical threaded pin and a long stationary shoulder was designed in order to allow heating in front of and behind the pin. Optical transmission microscopic analyses were conducted using an Olympus BH transmittance microscope. • For mechanical tests a minimum of five tensile specimens were removed from each weld, transversely to the welding direction, and tested in a 10 (KN) universal testing machine, SHIMADZU • AG-X, at room temperature, according to the ASTM.	• Axial force ranging from 0.75 to 4 kN. • Dimensions of ABS plates of 300*80*6 mm	1.5 (KN to produ free of c Tool rot • generate for plast polymer adequat mixing. The axia • contribu mixing a the form cavities retreatin zone. The tens • and stra welds is that of t material Welds c • efficien strain at achieved high rot and high are used

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11	Preliminary study on the feasibility of friction spot welding in PMMA. In this work the feasibility of friction spot welding of thermoplastics was investigated on Polymethyl Methacrylate plates. Preliminary results have shown that the weld strength is comparable to other available welding, techniques, while joining times are equal or shorter.	• In this preliminary study, Three-millimeter PMMA cast plaques (Plexiglas GS-Evonik) were cut to produce 25×100 mm length welding specimens. When welding thermoplastics by FSW, a higher amount of thermal energy is required to achieve the desired plasticizing volume, due to the low thermal conductivity of polymers. For this reason heat losses should be reduced. TiAl6V4 titanium alloy was selected as the tool material due its low thermal conductivity. The dimensions and geometries of the tool comprised a threaded sleeve, pin and a clamping ring of ϕ 9, 6 and 14.5 mm, respectively.	In this preliminary work, selected results of PMMA FSW joints are presented. It is possible to observe the presence of few voids along the weld seam. Although the mechanisms of void formation in FSW of thermoplastics are still under investigation, it is believed that these defects can be related to thermal shrinkage, entrapped air or some physical–chemical structural changes, such as structural water evolution.	Joint succe produ the follo Rota of 50 weld times joini press and p of 3. 4mm resul PMM cast i show curre spot stren comp other weld techn avail
12	To analyze the effect of the welding parameters on the weld strength with the new developed stationary FSW tool	Take new developed tool consisted of static shoulder made by Teflon with highly conductive bronze sleeve around the 6mm rotating pin. A position control method was	Type of tool: Static shoulder with rotating pin 1. Pin geometry: flat surface 2. Pin diameter: 6mm 3. Pin length: 2.4-2.8mm 4. Rotational speed: 1500rpm	• •

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		used to weld the plates together in a lap joint configuration. • Tensile test were performed for the specimen with different welding parameter in order to qualify the new tool effect on the weld strength.	5. Traverse speed: 100 mm/min	•
13	To study microstructure & tensile properties of dissimilar submerged friction stir welds between HDPE& ABS sheets	Multiwalled carbon Nano tubes (MWCNTs) • Were introduced in joints of HDPE joints. Non consuming rotating tool including a special shoulder & pin slowly pumped into the work piece until the shoulder touches the upper surface of the work piece, then pin moved along weld line & the shoulder always contacts with the work piece upper surface. The softened materials moved with the rotation & translation of the tool from the front to the back of pin.	HDPE: Density:0.96 g/cm^3 Melting point 130-137 ° C Tensile strength: 22.5MPa ABS: Density:1.05 g/cm^3 Melting point: 217-237 ° C Tensile strength: 39.6MPa Parent HDPE strength:65.3%	Micr evolu joints at di proce param been obser field scann elect micro (FES In mi analy obser new geom preve contr form inter comp

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14	To study the optimization of friction stir welding of thermoplastics	• Main component of tool is shoulder and pin. • During welding the pin travels in the material, while shoulders rub along the surface. • Heat is generated by the tool shoulder rubbing on the surface and by the pin mixing the material below the shoulder. • The mixing action permits the material to be made without any melting of the material.	Tool specification: Shoulder diameter: 11mm Pin diameter: 5mm Pin length: 3-4mm Dimensions of Polycarbonate sheet: 3×20×90mm Tensile strength : 58-62 MPa Glass transition temperature: 147° C. Melting temperature: 155° C	The mechanical strength of friction stir welding spot connections is mainly influenced by the plunge rate, Rotational speed and waiting time. Particularly the maximum lap shear strength was obtained for the friction stir welding. The joint with the highest strength exhibits a larger welded area, whose width r=1.5mm	[12]
15	To investigate the weld ability of UHMW-polyethylene via friction stir welding method	• Samples have to join with single pass under rotational speed and transverse speeds. • This method is carried out at room temperature by pre heating the bottom of plastic sample with metal molding. • It enables a homogeneous heat distribution by approximating the plastic material to fusing point in short time Hence, result will be supreme characteristic of welded join.	Rotational speed: 960-1960rpm Transverse speed: 10-20mm/min Tensile test, durometer hardness test, an optical microstructure analysis.	A tensile strength of 72% was achieved in non-preheated welds. A tensile strength of parent material was achieved approximately at an optimum value of 89% by preheating at 50° C	[17]

V. SUMMARY

From the above review of the following research papers on investigating the effects of various parameters on the strength of FSW proce ss performed on a wide variety of thermoplastics, it is observed that:

1. Welding with low welding speed provides an adequate time for stirring and homogenization of the parent materials which results in stronger welds.
2. One of the most important properties required for a proper weld is good surface quality, i.e. the more similar the weld is to the parent material, more closely it retains the characteristics of the parent material.

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3. In the FSW process, it was found that the majority of the voids that occur in the bulk of the weld are caused due to the lack of sufficient heat on the retracting side. As a result, an effective tool for FSW polymeric material, denominated as a 'hot shoe' has been developed, which consists of a static shoulder to keep the mixing mater ial during the welding process contained and an inbuilt heating system which maintains the appropriate temperature at the instantaneous site of weld.
4. High travel speeds of FSW tool or the high feed rate decreases of tensile strength of the bulk of the welded portion and also leads to a poor mixing of the base materials which were meant to be welded together. Also, the high travel speed or feed rate prevents the hot shoe and rotating pin to heat the weld area for a longer period of time thus reducing its weld strength.

VI. FUTURE SCOPE

The technology of Friction Stir Welding is still in its nascent stage, there's a lot more to be explored and there is enormous scope for improvement regarding the efficiency of the process, to try out various different polymer materials, subjected to different environmental conditions. Regarding the current review paper, it can be concluded that Friction Stir Welding has the ability to outperform and replace the conventional welding methods due to the ability of FSW to carry out welding without using any high density filler material, hence resulting in lightweight welds, also the ease by which FSW process is capable of welding a wide variety of metals and thermoplastics together. This versatile nature of the FSW process is what gives it a cutting edge against the conventional welding and joining techniques which are often more bulky and expensive.

Various parameters such as rotational speed of the tool, configuration of tool geometry, analysis of tensile strength of the weld as a function of various input parameters and its optimizations need to be studied and several constraints in order to increase the productivity and efficiency of the weld need to be identified. There need to be more studies focused on carrying out FSW processes on various polymers under different set of environmental conditions to find out the mechanical properties and behavior of the welds relative to the base materials.

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