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OPTIMIZATION OF FRICTION STIR WELDING (FSW) PARAMETERS FOR JOINING ALUMINUM ALLOYS: A REVIEW

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ABSTRACT

Friction stir welding is a recent technique deployed for welding of metals otherwise having low weldability such as most of the Aeronautic Aluminium alloys. In this paper various research papers dealing with optimizing the FSW parameters have been reviewed and a tabular comparison of relevant parameters studied has been done to identify the parameter that has given less weightage to, so far.

Keywords: Friction Stir Welding (Fsw), Mechanical Properties, Parameters, Rotational Speed, Traverse Speed

I. INTRODUCTION

Demand for Aluminium alloys have steadily increased in aerospace, aircraft and automobile applications because of their excellent strength to weight ratio, good ductility, corrosive resistance and cracking resistance in adverse environment. Welding of these alloys, however, still remains a challenge. Apart from softening in the weld fusion zone and HAZ, hot cracking in the weld can be serious problem [1]. Thus, solid state bonding processes such as FSW are highly recommended to solve these problems as this process is carried out in solid state. Avoiding melting prevents the production of defects, for instance due to the presence of oxygen in the melting bath, and limits the negative effects of material metallurgical transformations and changes strictly connected with changes of phase [2].

In FSW a rotating cylindrical, shouldered tool with a profiled probe penetrates into the material, which are butted together as shown in Fig. 1. Frictional heat is generated between the wear resistant welding tool and the material of the work pieces. This heat causes the later to soften without reaching the melting point and allows traversing of the tool along the weld line [1]

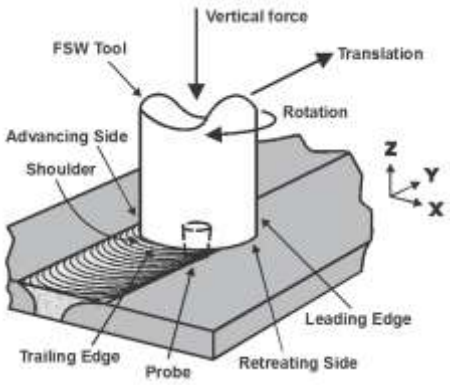

Fig.1: Schematic of FSW Process Courtesy University Of Wisconsin-Madison

II. LITERATURE REVIEW

Many investigators have observed and analyzed the effect of variations of various parameters like rotational speed, axial force, traverse speed, pin length, profile etc. on objective functions such as hardness, tensile strength, yield strength etc. of the weldments of different Aluminium alloys. The gist of these reviews have been presented in the table 1.

S.No	Jounal Name, Year,Volume	Process Parameter	Results
1.	IJEAT(2014) 2249 – 8958, Volume-3	Pin Profile 1-5 RotationalSpeed(rpm) 900,1400,1800 Traverse speed(mm/min) 16	Of the five tool pin profiles used to fabricate the joints, cylindrical pin profiled tool produced defect free FSP region, irrespective of welding speeds. Of the three rotational speeds used to fabricate the joints, the joints fabricated at a rotational speed of 1400 rpm showed superior tensile properties, irrespective of tool pin profiles except triangular pin profiled tool. At high rotational speed (1800 rpm) cylindrical tool is the best; at the middle rotational speed (1400 rpm) cylindrical and square tool are the best; while for low rotational speed (900 rpm) triangular and square tool are the best. Of the 15 joints, the joint fabricated using cylindrical pin profiled tool at a rotational speed 1400 rpm exhibited maximum tensile strength and defect free

			FSP region.
2.	IJRAME(2013)Vol.1 Issue.7	Axial force(KN) 4,5,6 Rot speed(rpm) 1000,1100,1200 Welding speed(mm/min) 45,60,75	AA6061 was found to exhibit better mechanical properties and this alloy is found to be amenable for friction stir welding by different tool profiles. Increase in tool rotational speed causes more heat input and the tensile strength is low for increase in TRS as the TMAZ and HAZ is more. The Square profiled tool facilitates the stirring action from tip to the collar, and due to this the turbulence is avoided(defect free welds) The tool rotational speed of 1000 rpm, weld speed of 60mm/min and axial force of 6kN generated good welded joints when Square profiled tool is used. A threaded cylindrical profile is also found to pulsating stirring action. and this, in turn, yielded higher strength and hardness
3.	NUCEJ(2012)Vol.15 No.2	Rotating speed(rpm) 1000, 1250, 1500, 2000 welding speed(mm/min) 20, 40, 60, 80	Because of the plunging depth of the tool flash can be avoided by controlling it which must be little more than the plate thickness . Tunnel defect was found at the intersection of weld nugget and thermo-mechanically affected zone due to high rotational speed and travel speed. By optimizing rotational speed 1500 rpm and travel speed 80 mm/min this defects was avoided. Others show presence of pin hole this easily removed using filler and getting

			finer shape, The best result obtained at 1500 rpm and 80 mm/min and the efficiency 89 % of the base metal Al 3003 H14
4.	JOCIE(2011) Vol. 34, No. 1	Rot speed(rpm) 550,1100,1250,1800 Traversespeed(mm/min) 53,90,143,180 Tool tilt angle(degree) 1,2,3,4 Pin length(mm) 2.5,2.7,2.9,3.1	The optimum operating conditions of FSW have been obtained for two plates of aluminum alloy AA5083 welded in butt joint. The optimal FSW process parameter combinations are rotation speed at 1800 rpm, transverse speed at 180 mm/min, tool tilt angle at 1, and pin tool length at 2.9mm for the best multiple performance characteristics and cost.
5.	JSIR(2009) Vol-68	Rotation speed(rpm) 1000,1200,1400 Traverse speed(mm/min) 22,40,75 Axial force(KN) 2,3,4	For best values of Tensile strength rotational speed of 1200rpm, welding speed of 40mm/min and Axial force of 4KN
6.	ARPN(2011) Vol-6, No.-2	Rotation speed(rpm) 800,1000 Traverse speed(mm/min) 10,15	The optimized parameters are tool rotation speed 800 rpm and welding speed 10 mm/min
7.	Journal of Engineering (2011) Volume 17 No 6	Shoulder diameter D (mm) 10-19 Preheat dwell time (sec) 20 sec Plunging time (sec) 60 sec	As shoulder diameters increase from 10 to 19 mm for a given preheating and plunging time causing increase in shear force (weld force). The highest shear weld failure force 2200 N was obtained at tool shoulder diameter 19 mm. The weld joint fabricate with tool of 19 mm diameter showed better mechanical properties than the others.
8.	International Journal of Machine Tools & Manufacture 47 (2007) 2230–2236	probe length(mm) 2.4-3.7 tool rotational speed(rpm) 2000,3000 tool holding time(sec) 0.2-3.0	The tensile shear strength increased with increasing probe length, while the cross-tension strength was not affected significantly by probe length. With increasing tool rotational speed and tool holding time, the tensile shear strength increased, while the cross-

			tension strength decreased.
9.	Materials and Design 37 (2012) 384–392	Applied Load(kg) 1000-2000, Rotation speed(rpm) 600-1000 Dwell time (s) 2	The flat spot FSW technique was applied to mild steel sheets in this study, which has a much higher melting point than that of aluminum alloys. It was revealed that sound welds with high mechanical properties can be obtained and the technique show high feasibility for the joining of mild steel.
10.	IJAME(2014) Vol 4, No.5	Rotationalspeed(rpm) 760,800,900,1040 Traverse speed(mm/min) 26,30,40,50	Rotational speed and welding speed both have their significant effect on the mechanical properties of the weld joint. From which greater impact is been produced by the rotational speed.. The weld produces at low speed have good mechanical properties than the weld produces at higher speed.
11.	IJEST(2013) Vol.5 No.3	Rotationalspeed(rpm) 900,1120,1400 Tool tilt angle(degrees) 0,1,2 Traverse speed(mm/min) 8,15.75,20	The optimum combination of parameters obtained from the main effect plot for the S/N ratio and mean is 1120rpm rotational speed, 1° tool tilt angle and 8mm/min traverse speed, and the tensile strength has been predicted as 472 MPa. The confirmation test performed with the optimum process parameter is found to have an average tensile strength of 474 MPa, and hence, the optimization is useful
12.	Elsevier(2015) 2214-9147	Rotationalspeed(rpm) 1000,1100,1200,1300,1400 Traverse speed(mm/min) 600,700,800,900,1000 Axial force(KN) 8,10,12,14,16 Toolprofiles-triangle, square, conical, hexagonal, Pentagonal	The results indicate that the shape of the pin has a significant effect on the joint structure and the corrosion properties. The best quality weld was acquired using hexagon tool profile with 1307rpm rotational speed, 880.5 traversing speed and 12.2 Kn axial force

13.	JMEA(2015) Vol.2 No-6	Tool tilt angle(degrees) 0,1,2 Rotational speed(rpm) 355,560,900 Traverse speed(mm/min) 12.5,16,20	The FSP process parameters were optimized to maximize the tensile strength and hardness. The optimum condition of the rotational speed, transverse speed and tool tilt angle were found to be 560 r/min, 20 mm/min and 1 degree respectively.
14.	ARPN(2015) Vol.10 No.12	Rotational speed(rpm) 700,800,900 Traverse speed(mm/min) 40,60,80 Axial force(KN) 10 Tool tilt angle(degrees) 0	The transverse feed increases lack of heat input affects the joints and its tensile properties gets affected. From the experiment conducted the tool rotational speed of 700 rpm with 40mm/min transverse feed gives excellent mechanical property both tensile as well as hardness.
15.	IJER(2014) Vol.3 No.1	Rotationalspeed(rpm) 1200,1600,2000 Traverse speed(mm/min) 50,62,74 Axial force(KN) 2,2.5,3	The optimum combination of parameters obtained from the main effect plot for mean is process parameters of 1200 rpm tool Rotation rate (rpm), 62 mm/min welding speed and 2.0 KN Axial force has been predicted to give the Impact Strength of 43.89.
16.	IJEST(2015) Vol.7 No.4	Rotationalseepd(rpm) 800,950,1100,1250,1400 Traversespeed(mm/min) 30,36.25,42.5,48.7,55 Pin diameter(mm) 4,5,6,7,8	The optimum conditions identified from the response surface plots are 4 mm tool diameter, 800 rpm rotational speed and 50 mm/min welding speed
17.	IJIRSET(2013) Vol.2 Issue-6	Rotational speed(rpm) 1120,1400 Traverse speed(mm/min) 20,25 Pin length(mm) 5.2,5.7	Tool rotation speed 1400 rpm, Welding speed 25 mm/min and Pin length of the tool 5.7mm are the optimized parameters for optimum Tensile strength obtained which is 182Mpa. We know that tensile strength of base material is 320Mpa; it means the joint efficiency is 60%.
18.	IRJET(2016) Vol.3 Issue-03	Rotationalspeed(rpm) 1000,1500,2000 Traverse speed(mm/min)	The optimized conditions for weld is obtained at 2000rpm rotational speed, 30 mm/min traverse speed and 2^0 tilt angle

		30,35,40 Tool tilt angle(degrees) 0,1,2	
19.	JMIE(2014) Vol-1 Issue-2	Rotationalspeed(rpm) 900,1150,1400 Traverse speed(mm/min) 32,34,40 Tool tilt angle(degrees) o,1,2	Multi objective optimization of the FSP process parameters was done and maximum mechanical properties were obtained at a rotational speed of 1126 rpm, at a traverse speed of 35 mm/min and at a tool angle of 10.
20.	Elsevier(2015) 209-219	Rotationalspeed(rpm) 600,800,1000,1200,1400 Traversespeed(mm/min) 200,400,600,800,1000 Tootilt angle(degrees) 1.5,2,2.5,3,3.5 Pin profiles- Triangle, conical, hexagonal, pentagon, square	The optimum mechanical properties obtained from the response surface model are predicted by using a rotational speed of 1000 rpm, traverse speed of 800 mm/min, tilt angle of 3.5 degrees and hexagon tool profile.
21.	IJDMT(2013) Vol.2, Issue-2	Rotational speed(rpm) 1000,1400 Traverse speed(mm/min) 1.2,1.8 Axial force(KN) 7,8	The optimal FSW process parameter combinations for optimized tensile strength are spindle speed at 1400 rpm, traverse feed at 1.2 mm/ sec and axial load at 7 KN with 70% joint efficiency.
22.	IOSR-JMCE e-IISN:2278-1684	Rotationalspeed(rpm) 1200,1400,1600 Traverse seep(mm/min) 25,35,50 Axial force(KN) 5	At 35mm/min traverse speed and 1400rpm rotational speed best tensile strength and hardness is obtained
23.	JEST(2015) Vol.10 No.6	Rotationalspeed(rpm) 900,1050,1200 Traverse speed(mm/min) 10,15,20	Surface and contour plots reveal that the tensile strength would be very near to maximum when the TRS and WS are within 1075 rpm to 1125 rpm and 13 mm/min to 15 mm/min respectively
24.	JOE(2012) Vol.18, No.6	Rotational speed(rpm) 900,710 Traverse speed(mm/min) 20,30,40	710rpm rotational speed and 40mm/,min traversing speed has the best tensile properties of the weldments
25.	IJESRT(2014) Vol.3 No.4	Rotationalspeed(rpm) 1200,1600,2000 Traverse speed(mm/min) 48,60,72 Axial force(KN) 1.5,2,2.5	The optimum parameter values are found at 1200rpm, 60 mm/min, 2.0 KN for Hardness. The optimum parameter values are) 1600

			rpm, 60 mm/min, 2.5 KN for Tensile Strength.

Table1: Gist of literatures on optimization of parameters in FSW

III. RESULT

A comparative study of the parameters studied by researchers for optimization of various mechanical properties of Aluminium alloys is presented in table 2.

S.No	Jounal Name, Year,Volume	Parameters								
		Axial force	Rotational Speed	Traverse speed	Pin Profile	Pin Length	Pitch	Tool Diameter	Tool Tilt Angle	Dwell time
1.	IJEAT(2014) 2249 – 8958, Volume-3		✓	✓	✓					
2.	IJRAME(2013)Vol.1 Issue.7	✓	✓	✓						
3.	NUCEJ(2012)Vol. 15 No.2		✓	✓						
4.	JOCIE(2011) Vol. 34, No. 1		✓	✓		✓			✓	
5.	JSIR(2009) Vol-68	✓	✓	✓						
6.	ARPN(2011) Vol-6, No.-2		✓	✓						
7.	Journal of Engineering (2011) Volume 17 No 6							✓		
8.	International Journal of Machine Tools & Manufacture 47 (2007) 2230–2236		✓			✓				

9.	Materials and Design 37 (2012) 384–392	✓	✓							
10.	IJAME(2014) Vol 4, No.5		✓	✓						
11.	IJEST(2013) Vol.5 No.3		✓	✓					✓	
12.	Elsevier(2015) 2214-9147	✓	✓	✓	✓					
13.	JMEA(2015) Vol.2 No-6		✓	✓					✓	
14.	ARPN(2015) Vol.10 No.12	✓	✓	✓						
15.	IJER(2014) Vol.3 No.1	✓	✓	✓						
16.	IJEST(2015) Vol.7 No.4		✓	✓				✓		
17.	IJIRSET(2013) Vol.2 Issue-6		✓	✓		✓				
18.	IRJET(2016) Vol.3 Issue-03		✓	✓					✓	
19.	JMIE(2014) Vol-1 Issue-2		✓	✓					✓	
20.	Elsevier(2015) 209-219		✓	✓	✓				✓	
21.	IJDMT(2013) Vol.2, Issue-2	✓	✓	✓						
22.	IOSR-JMCE e-IISN:2278-1684	✓	✓	✓						
23.	JEST(2015) Vol.10 No.6		✓	✓						
24.	JOE(2012) Vol.18, No.6		✓	✓						
25.	IJESRT(2014) Vol.3 No.4	✓	✓	✓						

Table 2: Tabular comparison of FSW parameters studied by researchers

IV. CONCLUSION

Aluminium alloys are having very less weldability and FSW provides a viable solution to overcome this problem. Various parameters affecting the quality of Aluminium weldments obtained by the process have been studied by many researchers for the optimization of an objective function. It has been observed that literatures dealing with pitch of the pin as parameter are very scarce, while pitch may play a prominent role in attaining sound quality of weldments in terms of mechanical properties like hardness. It also has been observed that effect of pitch on the hardness of the weldments has not been studied so far and can be studied with the help of Taguchi's Method of Optimization or any other relevant method.

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