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Experimental Investigations on Friction Stir Welding Process to Join Aluminum Alloys

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Abstract

Friction stir welding process is and advanced welding technique that is offering numerous advantages when compared with the conventional welding techniques reported in the literature. The advantages in brief are 1. Weld quality is good 2. Less power consumption 3. No flux and No filler material et. Keeping in view of its advantages and considering its growing increase in the usage of FSW process in various automobile and aerospace industries, this FSW process is taken as the research work. This paper reports the experimental investigations on the effects of process parameters i.e. tool rotational speed, weld speed and tilt angle on the responses i.e tensile strength, impact strength & elongation in dissimilar welding of Aluminum alloys of different grades using the solid state welding technique Friction Stir Welding process. In view of the costlier process, Taguchi L9 is used for carrying out the research. As it is a complex process, to identify the significant variables, initial trial experiments are done on the same parent materials. Based on them ranges are also found out for each input process parameter. A total of three input process parameters (tool rotational speed, weld speed & tilt angle) are chosen for study and the output responses measured are tensile strength, impact strength and elongation. ASTM standards are used in preparing the work pieces. After measuring its output responses, main effects are studied between the input process parameters vs output responses. This analysis can be further used in predicting the empirical equations with which the process can be automated based on the optimal values.

Keywords: Friction Stir Welding, Aluminum Alloys, Square Tool, Taguchi L9.

INTRODUCTION

Friction stir welding now a days is widely using in aircraft industries for welding wings, fuel tanks, aircraft structure and marine industries in structure work, automotive industries to weld wheel rims, chassis, fuel tanks, chemical industries for joining pipelines, heat exchanger, air conditioner, electronic industries for joining bus bar, aluminum to copper, connectors, electronic equipments fabrication industries etc. The advantage of friction stir welding is that it can be used to weld both similar and dissimilar metals having no flux and no filler metal [1]. Also, the entire process consumes less power consumption, can be made automated easily, less maintenance is required, process easy to operate and environmental pollution free.

The principle of operation is for without reaching melting point of material for soften tool pin and tool shoulder enable deformation of heat for low plasticized material. The work piece material and rotating tool generates friction and joining the work pieces non consumable tool is used shown in figure 1.

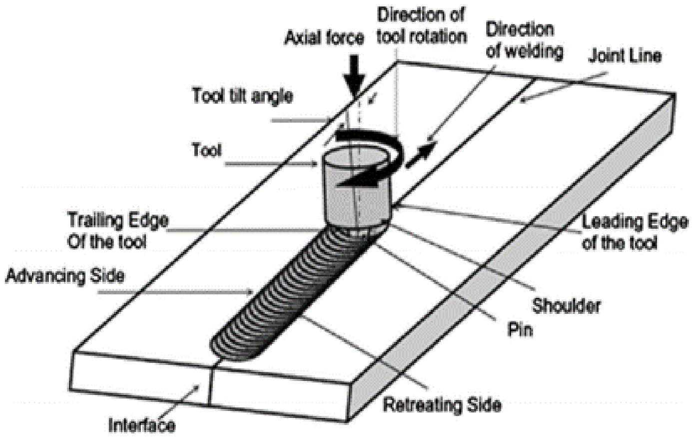

Figure 1. Schematic Diagram of Friction Stir Welding Process [1]

The base materials heating takes place because of plasticity by friction force, deformation of joining process with rotating tool takes place and the continuous weld is formed. The shoulder of weld direction is on advancing side. The shoulder which moves opposite direction is on retreating side and different parameters play a major role of input parameters on tool as rotational speed rpm, line at rotating tool on welding speed mm/min, tool tilt angle degree.

The place at which work piece on heating of tool as different zones such as thermos mechanically zone, nugget zone, stirred zone, heat affected zone on welding condition. The zones which will occur thermos mechanically affected zone involves on nugget zone and heat affected zone. The welding material mainly affected due to heat on mechanical deformation and welding un affected material zone with no deformation. The heat effects of different zones occur on heat affected zone involves unaffected zone and thermos mechanical affected zone.

LITERATURE SURVEY

Various related studies are present in this section and is as follows.

Z.Y. Maetal [2] studied the joining of aluminum alloy and magnesium alloy of metal working technique fabricating metallic materials and microstructural changes and mechanical properties used TEM test and cooling of joints of water dissolution isothermal of 7075and7050Al, joint strength of 2195Al,2014Al,2219Al thirst sensitive and microstructures kissing bond, parameters of welding has cohesive band and circular shape and path studied of tool intention.

D.A.Dragatogiannisetal [3] has high strength alloy and excellent corrosion resistance is structural alloy its commonly used for machining relate new alloy an added large amount of manganese controls in grain structure turns to stronger alloy. This Aluminum alloys has demand good fatigue resistance and is used for structural elements and complex structures and worldwide interest for development of Al6082T651 for good mechanical resistance behavior of extrusion and electric arc and high corrosion resistance it's also for civil constructions and its application

Anjali R. Patel et al [4] carried out studies on AA6061-T6 plates of thickness 3mm and base metal is below melt temperature welding speed and rotational speed, micro hardness is carried out.

UmasankarDas et al. [5] studied the dissimilar joining of Al6101T6 and Al6351T6 plates 12mm fluidity of rotational speed 900rpm,1100rpm and welding speed 16mm/min. The impact test is analyzed maximum increasing at 1100rpm rotational speed behavior of substantial change. Scanning Electron Microscope to examine fracture pattern to ductile fibrous fracture.

Chirag G et al [6] investigated the optimizing effect of different parameters tool rotational speed 500rpm to 1000rpm and welding speed 31.5mm/min to 50mm/min,higher tensile strength 7.076Mpa at rotational speed 100rpm and welding speed 40mm/min and lower tensile strength 1.034Mpa at 710rpm and 50mm/min micro hardness is high 112vh because of extent plastic deformation.

Angelos P et. Al. [7] studied the modeling process of taguchi method, composition factor method, grey relation analysis, response surface methodology observed and Design experiments are capable reliable tools.

A.A. Fallahi et al [8] studied the FSW process and examined the material flow direction tensile strength, SEM, elongation, micro hardness is reducing at stir zone.

Tara et al [9] examined the propagation behavior guided towards scattering velocities are guided waves propagate across distinct media elastic properties for material weld. Rajesh G et al. The joints of brass plates studied for fault of free weld zone and smooth crack weld zone rotational speed are visible and hardness is higher for different zones.

R Morgan et al [10] studied the Micro hardness and metallographic studies of welding done transverse speed 40mm/min during travel time values valuated during FSW process.

Kepi Gangway et al [11] suggested that the Aerospace industry depends on manufacture and improves of titanium alloys at high temperatures. The sheets and plates of different sizes welded to produce structure and optimal values. In this research direct focuses on titanium sheets for welding of similar and dissimilar titanium alloys of different thickness and selection of tool and position of sheets, material composition and cooling at weld nugget zone and current challenges of mechanical and microstructural properties of texture evolution.

Mohammad Mahdi et. Al. [12] examined The friction stir welding joint of AA2024 and AA6061 of investigated microstructure and crystallographic structure and technique electron back scattered diffraction used. The results of microstructures has grain refinement in stir zone. The thermo mechanically affected zone has continuous dynamic recrystallization of advancing side is lower than retreating side. The profile has three regions on retreating side. The advancing side of micro hardness profile is identical.

Hussein Karami et. Al. [13] studied The welding joint of Al2024-T6 and Al6061T6 plates of 4mm thickness and taper threaded tool was used, welding speed 100mm/min and rotational speed 1000rpm.The precipitation of heat treatment hardening effects on retreating side and advancing side. The micro and macro analysis done on optical and field emission scanning electron microscope. The analysis of microstructural has some grain coarse in weld zones and base metals.

Mojtaba Rezaee Hajideh et. Al. [14] Investigated dissimilar joints Polypropylene and Acrylonitrile Butadiene Styrene incorporated by copper powder to weld zone. The heat temperature 80ºC and rotational speed 1600rpm, welding speed 16mm/min. The reinforced weld joint of strength equal to 91.2% of polypropylene hardness equal to 94.1%. The tensile strength and hardness of joint is optimum welding condition of 36% and 30% by adding copper powder.

Fey X, Ye Y et. Al. [15] studied the friction stir butt welding of Al6061T6 and pure copper of laser power 700W, rotational speed 950rpm and welding speed 23.5mm/min. The tool pin offset distances 0.2mm to 2.1mm.SEM and EDS, microstructure of inter metallic compounds.

Based on the literature survey, it is found that FSW is the suitable process for getting welds with high quality. But the difficulty is that, as it involves more number of process parameters to be controlled it is always difficult to set the process parameters at the right value in order to get the optimal output. In order to get the optimal values of output, there is a need to find the method which gives the information about the values of input process parameters to be set to get the desired accuracy and output. Hence the present work focused mainly on finding the relationship between the input and output variables, so that the entire process can be further optimized based on this experimental data.

EXPERIMENTAL WORK

The experiments are carried out on the Friction Welding Setup having the following specifications as shown in table given below. The maximum load capacity of the machine is 5 Tonnes.

Table 1. Machine Specifications

Table Size	2m Length x 1m Width
Drive Motor	1RPM to 3000RPM
Motor Capacity	13KW(Servo)
X-Axis Motor - 3KW(Servo)	Range-1mm/min to 1000mm/min
Y-Axis Motor-3KW(Servo)	Range-1mm/min to 1000mm/min
Total Area-Cross Rail(Vertical Moment)	3HP Motor Movement-Induction Motor
Range of Tilt Angle	$0^0$to 7^0Angle
Max Diameter	20mm Thickness
Loads Capacity	5 Ton (Maximum)

The dissimilar butt welding samples are prepared on the two base materials i.e. AL7075-T651 and AL6082-T651 using the FSW setup shown in figure which is controlled with the help of a computer unit.

Figure 2. Friction Stir Welding Setup

The experiments are carried out over the FSW unit as per the experimental design prepared using Taguchi method. A total of 9 experiments are carried out based on L9 orthogonal array method. The figure gives the ready to weld position after fixing and aligning the two parent materials using the special made fixtures which helps to hold the work pieces in positions.

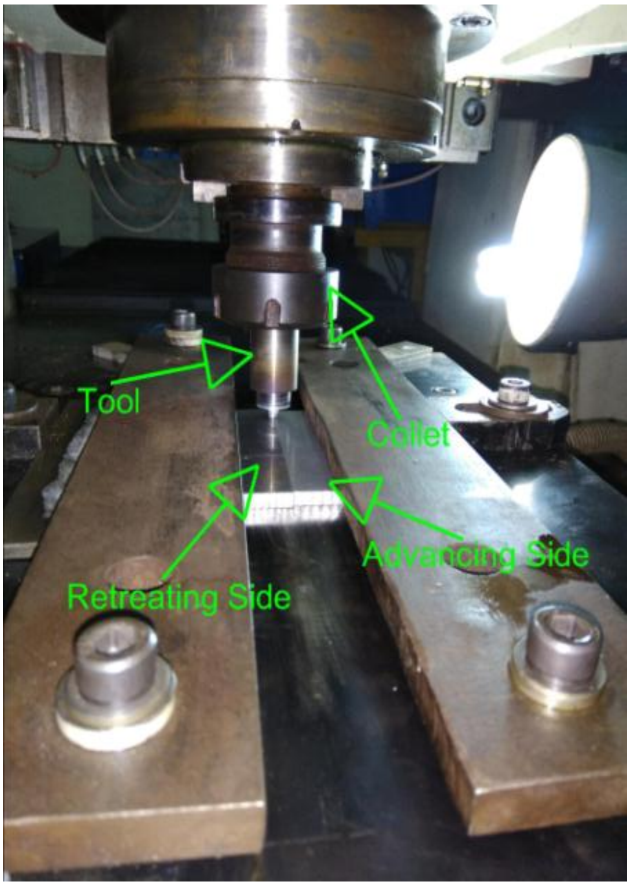

Figure 3. Ready to weld position

AL7075-T651 and AL6082-T651 are chosen as the work piece materials because of the growing importance in terms of its usage in many aerospace & automobile industries. The figure shows the butt welded samples.

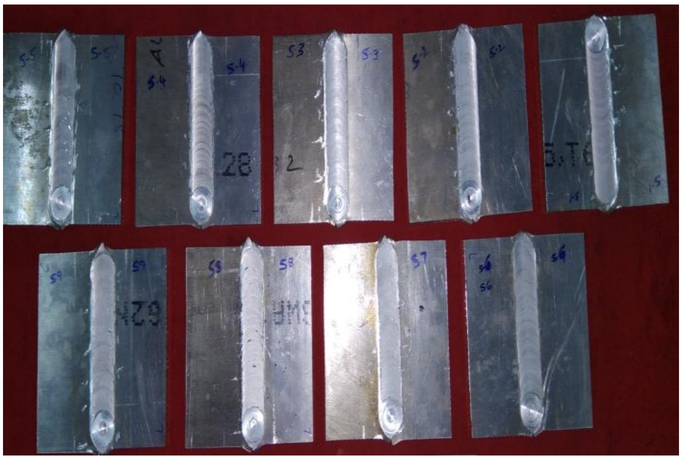

Figure 4. Butt Welded Samples

The chemical compositions of base materials are given in table 2 and its mechanical properties are listed in table 3.

Table 2. Chemical composition of 7075-T651 and 6082-T651 Al alloys (wt.%)

Al alloy		
Elements	7075-T651	6082-
Si	0.12	1.05
Fe	0.2	0.26
Cu	1.4	0.04
Mn	0.63	0.68
Mg	2.53	0.8
Cr	0.2	0.1
Ni	0.004	0.005
Zn	5.62	0.02
Ti	0.03	0.01
Al	bal	bal

Table 3. Mechanical properties of Aluminum Alloys

Al alloy	Tensile Strength Mpa	Elongation %	Impact Strength J
7075-T651	220	10	17
6082-T651	330	15	10

The plates were finished to a dimension of 100mm × 50mm×6mm. A butt weld is been made by clamping the materials using fixtures by placing AA7075 and AA6082 on Advancing Side and Retreating Side respectively by opting the parametric values as mentioned in central composite design matrix. The M2Grade SHSS tool is used for experimentation having shoulder dia 18 mm and probe length 6 mm. The specimens used are prepared as per the ASTM Standards. The side where the spindle rotation direction is in the same direction with the tool traversing is called the advancing side and the opposite side is called the retreating side. Out of two base materials used, Al7075-T651 placed in the advancing side and Al6082-T651 placed in the retreating side in order to improve mechanical properties of Joint. The butt joints in total of 9 are prepared as per the taguchi L9 design experiment. For conducting the experiments only the major influencing parameters are taken into consideration, as the minor influencing parameters account to the less variations in output responses. Major influencing parameters are identified based on the literature survey and also based on the trail experiments. The parameters chosen and its ranges and various other notations are given in table 4.

Table 4. The coded and actual values of input variables

S.No.	Parameters	Notation	Unit	Levels		
				1	**2**	**3**
1	Rotational speed	*RS*	rpm	1150	1250	1350
2	Welding speed	*WS*	mm/min	40	50	60
3	Tilt angle	*TA*	Degree	1	2	3

In this research, Tool rotational speed, Welding speed & Tilt angle are the three significant process parameters chosen to vary. After completion of experiments, the output responses are measured and recorded and is shown in table 5. In order to measure the output responses, the welded specimens are prepared using metallographic techniques. Hydro Fluoric Solution is used as the etching agent. Each output is measured at three different points along the weld zone and the averages of three values are calculated and is taken as the final value which is recorded. Microstructural examination and material mixing observation were carried out using optical microscope.

Table 5: Experimental Design of Taguchi Model

S.No	Input Process Parameters			Output Responses		
	Rotational Speed	**Weld Speed**	**Tilt Angle**	**Tensile Strength**	**Impact Strength**	**Elongation**
1	1150	40	1	142.00	7.80	8.90
2	1250	50	1	181.20	9.45	11.60
3	1350	60	1	175.00	10.40	8.24
4	1150	40	2	153.00	7.40	8.50
5	1250	50	2	165.10	9.50	7.12
6	1350	60	2	160.20	8.10	7.50
7	1150	40	3	155.00	9.00	6.19
8	1250	50	3	160.00	7.40	7.60
9	1350	60	3	158.00	8.00	8.15

ANALYSIS OF INPUT PROCESS PARAMETERS OVER OUTPUT RESPONSES

The plots were drawn between the selected inputs (i.e. Tool rotational speed, Weld traverse speed and tilt angle) and the chosen output responses i.e. Tensile strength, Impact strength and elongation. The experimental data is used for plotting the graphs and are shown below. Only the main effects are studied.

Influence of Rotational Speed on Tensile strength

It is shown that as the tool rotational speed increases, the tensile strength increases and it reaches a maximum of 168.76 Mpa at the tool rotational speed of 1250 Rpm. Afterwards it decreases. The lower rotational speed produce insufficient heat input and also affects the tensile properties. As the rotational speed increases, more heat supplied to the materials thereby the material softens hence the tensile strength increases. The average values are calculated and are shown in table 6. The influence of rotational speed over the tensile strength is shown in figure 5. Higher and lower tool rotational speeds lead to poor bonding due to high frictional heat generation and low frictional heat generation, respectively. The optimum heat generation leads to plasticized flow, and the materials in the weld diffuse and recrystallize, thereby creating a qualified joint. The lower rotational speed produce insufficient heat input and also affects the tensile properties.

Table 6. Average values of Rotational speed and Tensile strength

S.No	Rotational Speed	Tensile Strength
1	1150	150
2	1250	168.767
3	1350	164.4

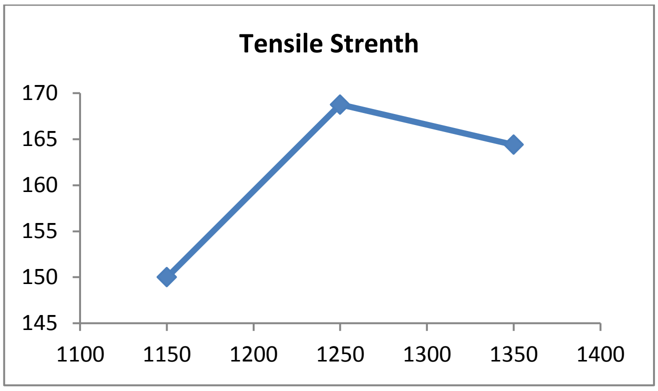

Figure 5. Effect of Tool Rotational Speed on Tensile Strength

Influence of Weld Speed on Tensile strength

The average values of Weld speed and tensile strength are calculated and are shown in table 7. The influence of weld speed over the tensile strength is shown in figure 6.

Table 7. Average values of Weld speed and Tensile strength

S.No	Weld Speed	Tensile Strength
1	40	150
2	50	168.767
3	60	164.4

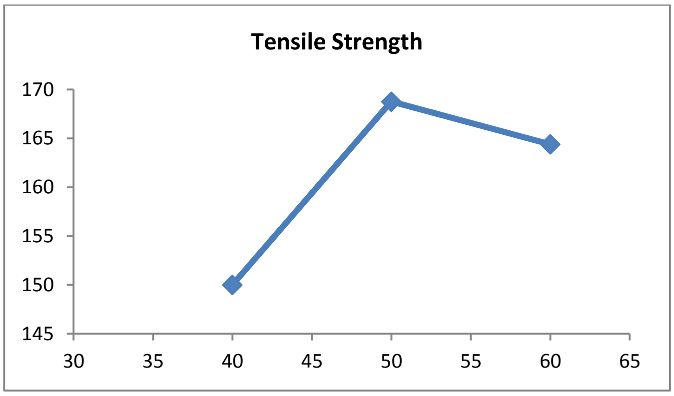

Figure 6. Effect of Weld speed on Tensile Strength

The variation of ultimate tensile strength with welding speed at different constant rotary speed is presented in Figure 6. It is evident from the plotted graph that, with the increase in welding speed the tensile strength increases and then decreases at all rotary speeds. On the other hand, the trend of variation of ultimate tensile strength with different constant welding speeds is opposite to that of the welding speed. And the higher and lower welding speeds always lead to poor bonding due to very low frictional heat generation and high frictional heat generation, respectively. The Heat input plays an important role on mechanical properties of the welded joints. In the test range, the tensile strength increases with an increase in welding speeds. The increasing weld speed and decreasing rotational speed reduce heat input required for joining leading to a reduction in thickness of thermo mechanically affected zone and heat affected zone, softened region has been form in welded region of parent metal due to frictional heat joints of heat treatable aluminum alloys. when a joint is free from defects, tensile joint is dependent on microstructure of joint.

Influence of Tilt angle on Tensile strength

The average values of tilt angle and tensile strength are calculated and are shown in table 8. The influence of tilt angle over the tensile strength is shown in figure 7.

Table 8. Average values of Tilt angle and Tensile strength

S.No	Tilt angle	Tensile Strength
1	1	166.067
2	2	159.433
3	3	157.667

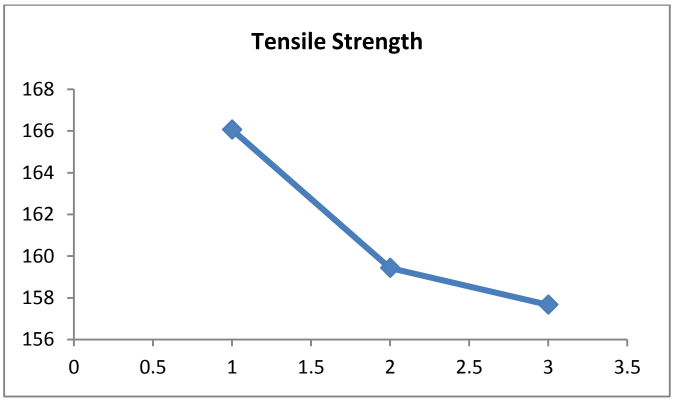

Figure 7. Effect of Tilt Angle on Tensile Strength

The tilt angle of the tool plays a significant role in finding the tensile strength of the joints. The decrease of tool tilt angle leads to poor bonding due to high frictional heat generation and the increase in tilt angle leads to poor bonding due to very low frictional heat generation. The results of tensile test reveals that the tool tilt angle is vital in determining the tensile strength of the welded joint. An increase in the tilt angle leads to the better consolidation of the material under shoulder thereby increasing the mechanical properties of the joint.

Influence of Rotational Speed on Impact strength

The average values of rotational speed and impact strength are calculated and are shown in table 9. The influence of rotational speed over the impact strength is shown in figure 8.

Table 9. Average values of Rotational Speed and Impact Strength

S.No	Rotational Speed	Impact Strength
1	1150	8.066
2	1250	8.783
3	1350	8.833

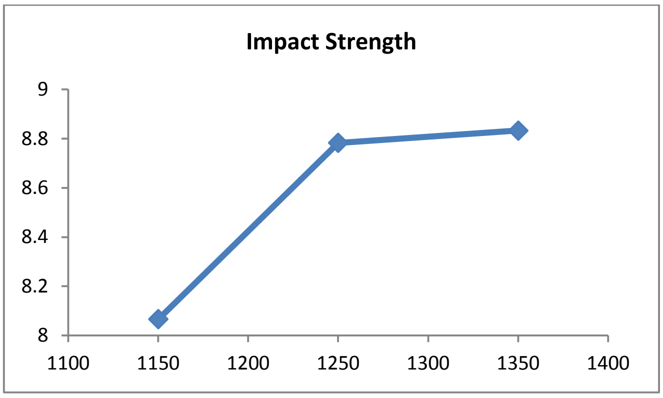

Figure 8. Effect of Rotational Speed on Impact Strength

During low rotation speeds of the tool, the desired amount of heat to make the proper welds is not generated and therefore the obtained welds have lower mechanical properties, in contrast, higher rotational speed leads to higher friction between the tool and sample, therefore, more heat is generated and the softening of materials is enhanced. On the other hand, higher rotational speed makes the mixing process easier and better, subsequently, welds with higher mechanical properties are achieved.

Influence of Weld Speed on Impact strength

The average values of weld speed and impact strength are calculated and are shown in table 10. The influence of weld speed over the impact strength is shown in figure 9.

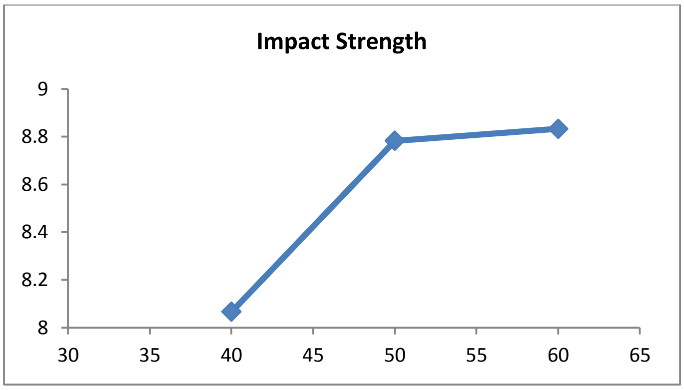

Figure 9. Effect of Weld Speed on Impact Strength

The higher transverse speed means a shorter welding duration, in this type of situation, there will not be enough time for mixing and joining the process of materials therefore by minimizing the transverse speed more time is given to materials to soften and mixed. This is the reason why welds with lower transverse speed will have the better impact strength.

Table 10. Average values of Weld Speed and Impact Strength

S.No	Weld Speed	Impact Strength
1	40	8.066
2	50	8.783
3	60	8.833

On the other hand, around weld lines of samples that were welded with high transverse speed, some cracks were observed these cracks can have a negative effect on mechanical properties of the sample.

Influence of Tilt angle on Impact strength

The average values of tilt angle and impact strength are calculated and are shown in table 11. The influence of tilt angle over the impact strength is shown in figure 10.

Table 11. Average values of Tilt angle and Impact Strength

S.No	Tilt Angle	Impact Strength
1	1	9.2166
2	2	8.333
3	3	8.1333

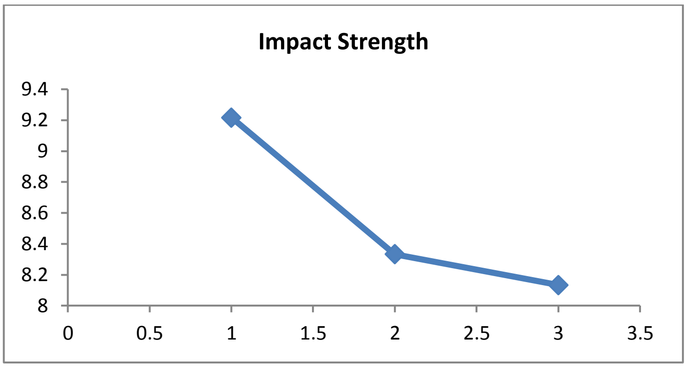

Figure 10. Effect of Tilt Angle on Impact Strength

The impact strength reduces with the increase in tilt angle. At lower tilt angles, the impact strength is more and it gradually reduces with a gradual increase of tool tilt angle, while keeping the other rotational speed and weld speed constant. The graph gives an indication that the tool tilt angle is influencing more on impact strength.

Influence of Rotational Speed on Elongation

The average values of rotational speed and elongation are calculated and are shown in table 12. The influence of rotational speed over the impact strength is shown in figure 11.

Table 12. Average values of Rotational Speed and Elongation

S.No	Rotational Speed	Elongation
1	1150	7.8633
2	1250	8.7733
3	1350	7.9633

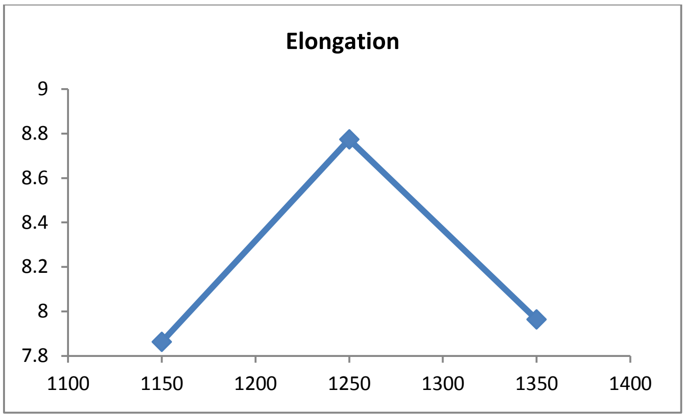

Figure 11. Effect of Rotational Speed on Elongation

The strength and the elongation increases to a maximum value with the increase in spindle speed. Again it falls even the rotational speed increases also. The heat input increases with the rotational speed. The tool rotational speed must be optimized to get FSP region with fine particles uniformly distributed in the joint. To get the superior weld properties, the combined effect of higher number of pulsating stirring action during metal flow and an optimum tool rotational speed is the requirement.

Influence of Weld Speed on Elongation

The average values of weld speed and elongation are calculated and are shown in table 13. The influence of rotational speed over the impact strength is shown in figure 12.

Table 13. Average values of Weld speed and Elongation

S.No	Weld Speed	Elongation
1	40	7.8633
2	50	8.7733
3	60	7.9633

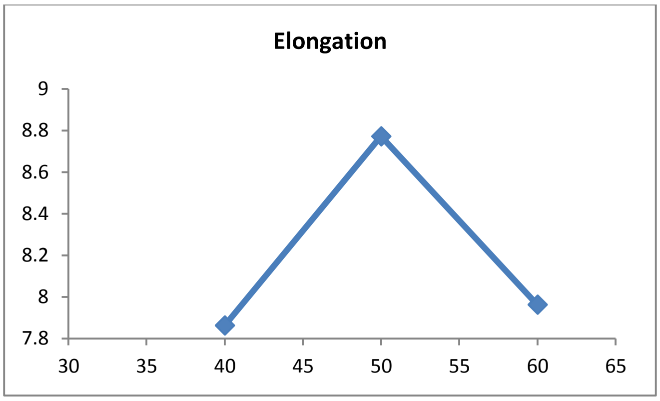

Figure 12. Effect of Weld Speed on Elongation

It is evident from the graph that the elongation increase with increase in weld speed initially and later reduces with increase in welding speed. whereas it improves with increase in rotary speed. The effect of change in welding speed from 40 to 60mm/min on elongation. During constant welding speeds, the elongation increases with increase in rotational speeds. The extent of increase in elongation with increase in rotary speed is more at lower welding speed than at higher welding speed.

Influence of Tilt angle on Elongation

The average values of tilt angle and elongation are calculated and are shown in table 14. The influence of tilt angle over the impact strength is shown in figure 13.

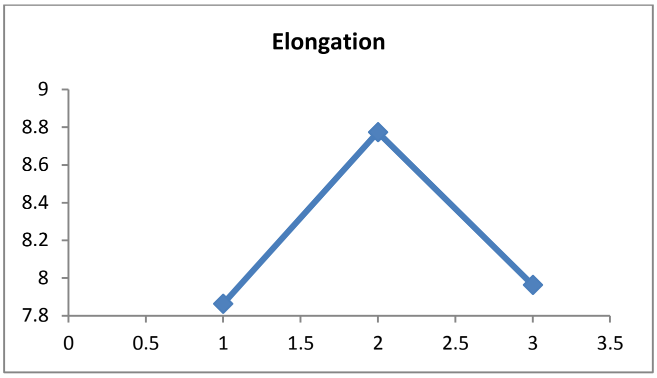

Figure 13. Effect of Tilt Angle on Elongation

When the tilt angle is low, that is 1◦, lower part of the nugget appeared bell-shape, and channel type defect occurs on the upper nugget zone. The generation of the channel or other defections can be considered that because of small tool tilt angle, and the plastic material cannot flow sufficiently during welding.

Table 14. Average values of Tilt angle and Elongation

S.No	Tilt Angle	Elongation
1	1	7.8633
2	2	8.7733
3	3	7.9633

In a summary, on one hand, large tool tilt angle will be beneficial to the heat generation under the same welding speed, with the increase of the tilt angle, the heat generation is increased during friction stir welding. More heat input can improve the flow of the plastic material; on the other hand, the plastic material near the end of the pin was extruded and driven down due to small tool tilt angle.

CONCLUSIONS

In this work, the important weld strength characteristics i.e. tensile strength, impact strength & elongation are analysed after conducting experiments using the Friction Stir welding setup. The experiments are based on Taguchi L9 orthogonal array design. In order to understand the influence of input process parameters on the output responses, 2d plots are plotted for the average values. The 2d plots are analyzed and found that the selected input process parameters are influencing over the output responses. The individual graphs presented give the exact trend between the inputs and the outputs. The results presented in the work can be used for further analysis. That is using the experimental data empirical models can be developed and then these models can be used for finding the optimal process parameters to get the best output characteristics of welded joints. Then the problem can be solved by using any optimization algorithm after formulating the objective function. Later the entire process can be automated which helps to increase the product rate without increasing the unit cost of the welded joints.

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