STUDY THE PROCESS PARAMETRIC INFLUENCE ON IMPACT STRENGTH OF DISSIMILAR FSW JOINT OF AA6061 AND AA6082 BY USING TAGUCHI S/N RATIO AND ANOVA

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Abstract - **In this research study, Friction Stir Butt Welds made of dissimilar AA6061 and AA6082 Aluminium alloys are performed with various input welding parameter as welding speed, tool rotation speed and tool Pin Profile which plays a significant role in the assessment of mechanical properties such as impact strength. Using Taguchi, ANOVA and Signal to Noise ratio, influence of FSW process parameters are evaluated and optimum welding condition for maximizing impact strength of the weld joint is determined. The optimum values of process parameter on impact strength are found as welding speed of 115 mm/min, tool rotation speed 1450 rpm and tool Pin Profile of cylindrical threaded (tpi-22) by S/N ratio analysis. Using analysis of variance (ANOVA), the percentage of contribution for Rotational Speed, Welding Speed and Tool Pin Profile on Impact Strength is determined. But welding speed has great influence on Impact Strength of friction stir welded joints of dissimilar Al alloys of AA 6061 and AA 6082.**

Index Terms - **Dissimilar alloys as AA6061 and AA6082, Friction Stir Welding, S/N Ratio, tool Pin Profile, tool rotation speed, Two-Way ANOVA, welding speed.**

I. INTRODUCTION

Friction stir welding is the most important and innovative process in the field of similar or dissimilar metal joining. Friction stir welding tool, having an electro-mechanically or hydraulically auto-adjusting pin. The tool is having a major advancement in design of having a control system that forms a closed-loop feedback system to control the pin. The tool can be used to weld plates of different thickness [1-3]. The material flow was asymmetric about the weld centerline, the flow patterns on the advancing & retreating sides were different. Two tool motions, translation and rotation are responsible for the movement of material in a FSW weld. There is no major influence of welding speed ranges of 700 mm/min to 1400 mm/min on the mechanical and fatigue properties of the friction stir weld joints. The friction stir weld joints showed higher static and dynamic strength than MIG-pulse and TIG welds [4-5]. The tensile strength is inversely proportional to the thickness of the work pieces to be welded. The bending strength depends on the thickness of the work pieces to be welded. The mechanical properties such as tensile strength, bending strength and hardness increases by increasing the Tool RPM up to a certain limit and properties start to decrease thereafter. The weld joint could not be formed at too low welding speeds which results in achieving the poor mechanical properties and weld appearance [6-7, 18]. The heat-affected zone consists of relatively large austenite grains and smaller recrystallized grains presented at the grain boundaries and the thermal mechanical affected zone located between the nugget and heat-affected zone that shows a micro-structural transition from the completely refined structure very similar to base material. The screw pitched taper stir pin give the best bonding with good appearance of the weld. There is no defect find with the use of screw pitched taper stir pin with very fine grains at the weld nugget.The material's ductility achieved the more for 40 and 56 mm/min welding speed with the lowest rotating speed of 500 rpm but start to decrease strongly with increasing rotating speed and the welding speed. A significant grain refinement of the aluminium alloy matrix due to dynamic recrystallization induced by the plastic deformation and frictional heating during welding and a significant reduction

Manuscript received April , 2015.
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ISSN: 2278 – 7798

of the particles size due to the abrasive action of the tool are achieved [8-17]. The hardness in the weld zone obtained lower than that of the base metal and decreased with increasing rotation speed which resulting transverse tensile test indicated that all the joints exhibited lower tensile strength than the base metal and tensile strength of the joints decreased with increasing rotation speed [2]. The intermediate mechanical properties observed in friction stir dissimilar weld joints when compared with each base material. In the tensile tests, failures occurred near by the weld edge line where a minimum value of hardness achieved. The best mechanical properties like tensile strength and fatigue strength are achieved for the weld joints by increasing tool feed rate along with increasing the vertical force. The analysis of results concerning the contact conditions provides interesting data about the evolution of the relative sliding between the shoulder and the material to be welded. The sliding ratio increases with the tool rotational velocity and decreases with the temperature in the vicinity of the tool. The defects present in cast aluminum alloys are eliminated in the area of processing with the use of four-tool pin profiles such as straight cylindrical, tapered cylindrical, threaded cylindrical and square, from which threaded cylindrical pin profiled tool produced metallurgical defect free region [18-24].

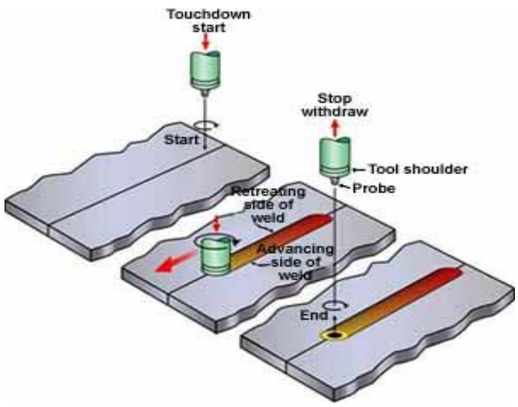


Figure1. Schematic diagram of Friction Stir Welding [2]

II. EXPERIMENTAL PROCEDURE

A. Experimental Material

The materials of Aluminium alloy as AA6061 & AA6082 graded plates are selected for the experimentation with dimensional configuration of 100mm x 50mm x 6mm. The Aluminium alloys of AA6061 & AA6082 graded materials are having nominal compositions and mechanical properties discussed below in the tables 1, 2, 3 and 4 as:

Table1. Nominal composition of the AA6061 plates

Al	Mg	Mn	Cr	Cu	Fe	Si	Ti	Zn
95.8-98.6	0.8-1.2	Max. 0.15	0.04-0.35	0.15-0.4	Max. 0.17	0.4-0.8	Max. 0.15	Max. 0.25

Table2. Mechanical properties of the AA6061 plates

Elasticity (E), GPa	Tensile strength, MPa	Yield strength, MPa	Hardness, HV	Elongation %
68.9	310	386	107	12

Table3. Nominal composition of the AA6082 plates

Al	Mg	Mn	Cr	Cu	Fe	Si	Ti	Zn
95.4 - 97.8	0.6-1.2	0.4-1.0	Max 0.25	Max 0.1	Max 0.5	0.7-1.3	Max 0.1	Max 0.2

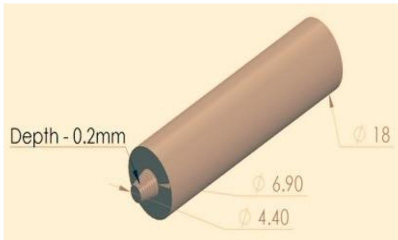
Table4. Mechanical properties of the AA6082 plates

Elasticity (E), GPa	Tensile strength, MPa	Yield strength, MPa	Hardness, HV	Elongation %
70	340	392	101	11

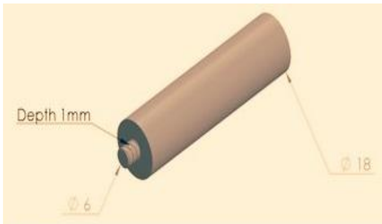
B. Welding Tool Geometry

The welding tools used in Friction Stir Welding are made of high speed steel discussed their dimensional parameters below in figures 2 as:

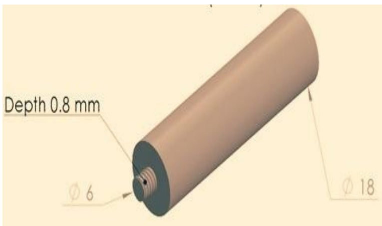
a.



(a) Taper Threaded Welding Tool



(b) Cylindrical Threaded Welding Tool (TPI-14)



(c) Cylindrical Threaded Welding Tool (TPI-22)

Figure2. Welding tools (a, b, c) used during friction stir welding

C. Equipment Used For Conducting The Experimental Work

The CNC vertical milling machine was used for making the weld joints which available at CTR Ludhiana with following specifications such as type of machine - CNC milling machine, Travel capability of x = 1600, y = 800, z = 750, Running speed limit of 30 – 7500 rev/min and load application of 1800 kg. A fixture is generally used to hold the work piece firmly during the welding process. The various forces acting on the work piece are the transverse force that acts parallel to the tool motion, downward and upward forces due to the plunging, torque due to the rotation of the tool and lifting of the tool during welding process respectively.

III. FINAL EXPERIMENTATION

Friction Stir welding method is adopted to carry out the experimental trials by which dissimilar materials of AA6061 and AA6082 welded at three different levels listed in tables 5 shown below as:

Table5. Levels of input welding parameters

Welding levels	Tool rotational speed in RPM	Welding speed in mm/min	Tool pin profiles types
1	750	115	Taper threaded
2	1100	145	Cylindrical threaded (tpi-22)
3	1450	175	Cylindrical threaded (tpi-14)

After conducting the experimental trials, it has been observed that input parameters like tool rotational speed, welding speed and tool pin profiles have some significant effect on the impact strength of dissimilar materials of AA6061 and AA6082 weld joint.

The Taguchi Method is a multi-stage process, namely, systems design, parameter design, and tolerance design which used to improve the quality of products and processes. In Taguchi's approach, optimum design is determined by using design of experiment principles, and consistency of performance is achieved by carrying out the trial conditions under the influence of the noise factors. Taguchi defines three categories of quality characteristics in the analysis of Signal/Noise ratio, i.e. the lower-the-better, the larger-the-better and the nominal-the-better [2]. That’s why designs of final experiments made for the optimization of process, according to Taguchi’s L9 orthogonal array shown in table 6.

Table6. Taguchi’s L9 orthogonal array for experimental trials

Experimental Trials	Tool rotational speed (T)	Welding speed (S)	Tool pin profiles (P)
1	750	115	Taper threaded
2	750	145	Cylindrical threaded (tpi-14)
3	750	175	Cylindrical threaded (tpi-22)
4	1100	145	Cylindrical threaded (tpi-22)
5	1100	175	Taper threaded
6	1100	115	Cylindrical threaded (tpi-14)
7	1450	175	Cylindrical threaded (tpi-14)
8	1450	115	Cylindrical threaded (tpi-22)
9	1450	145	Taper threaded

IV. RESULTS AND DISCUSSIONS

The welding input parameter ranges taken into account for welding the specimens in experimental trial as tool rotational speed ranges of 750 – 1450 rpm and welding speed ranges of 115 - 175 mm/min. Friction stir welding have been performed on AA6061 and AA6082 dissimilar aluminium alloy metals by using CNC Vertical Machine according to TAGUCHI L-9 orthogonal array method. After welding, prepare the samples for performing impact strength test over IZOD/CHARPY testing machine in order to observe some significant effect of input parameters on the impact strength of dissimilar materials of AA6061 and AA6082 weld joints shown in table 7.

Table7. Observation table of impact strength

Specimen. No	Tool rotation speed (T) in RPM	Welding speed (S) in mm/min	Tool pin profile (P)	Impact Strength In KN/mm^2
A	800	120	Taper threaded	234
B	800	150	Cylindrical threaded(tpi-22)	262
C	800	180	Cylindrical threaded(tpi-14)	302.16
D	1100	120	Cylindrical threaded(tpi-22	410

ISSN: 2278 – 7798

			)	
E	1100	150	Cylindrical threaded(tpi-14)	289.40
F	1100	180	Taper threaded	263.1
G	1400	120	Cylindrical threaded(tpi-14)	381.51
H	1400	150	Taper threaded	364.90
I	1400	180	Cylindrical threaded(tpi-22)	336.50

A. S/N Ratio Analysis

Observed Impact Strength values are analysed with Taguchi S/N ratio and mean value analysis by applying larger is better as quality character.

The Signal-To-Noise ratio for the bigger-the-better is:

S/N = -10*log (mean square of the inverse of the response).

$$S/N = -10 \log_{10} (1/n \sum 1/y^2) \qquad [2]$$

Where n = number of repetitions, y = response of impact strength.

The experimental results were transformed into signal-to-noise (S/N) ratio. In this work, S/N ratios and mean values are calculated for each process parameter in three levels, shown in Table-8 and 9, and figure 3 and 4.

Table8. Response table for S/N ratio

SR NO	WELD SPEED	TOOL SPEED	TOOL PIN PROFILE
1	50.42	48.45	49.01
2	49.61	49.96	50.39
3	49.52	51.14	50.15
Delta	.91	2.69	1.38
Rank	3	1	2

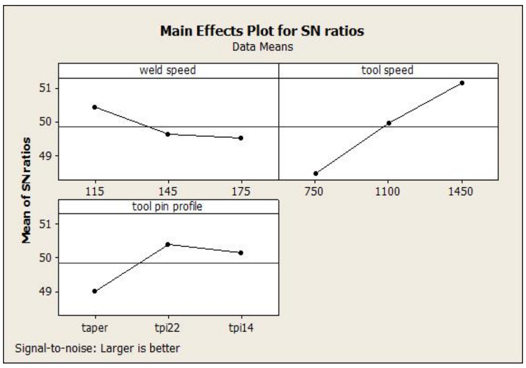


Figure3. Main effects plot for S/N ratios

Table9. Response table for mean

SR NO	WELD SPEED	TOOL SPEED	TOOL PIN PROFILE
1	341.8	266.1	287.3
2	305.4	320.8	336.2
3	300.6	361.0	324.0
Delta	41.3	94.9	48.8
Rank	3	1	2

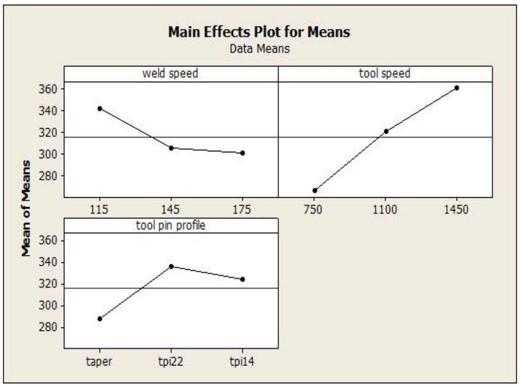


Figure4. Main effects plot for Means

Figure 3 and 4 both predicts the optimum process parameter values of Welding speed (S) 115 mm/min, Tool Rotation speed (N) 1450 rpm, Tool Pin Profile of Cylindrical threaded (tpi-22) to obtained efficient Impact Strength.

B. ANOVA Results

The results of Two Way ANOVA Method on the Welding speed (S), Tool rotation speed (N), Tool Pin Profile and their influence on Impact Strength of weld joint of dissimilar AA6061 and AA6082 are determined by using MINITAB software and its values are shown in table 10.

Table10. Two-way ANOVA: Impact strength versus tool rotational speed, welding speed and tool pin profile

Source	Degree of Freedom (DF)	Sum of Square (SS)	Mean Square (MS)	F-ratio	Percentage (P)
Tool Rotational Speed	2	13621.0	6810.49	2.16	0.23
Welding Speed	2	3050.3	1525.13	0.48	0.72
Tool Pin Profile	2	3895	1947	0.46	0.65
Error	20	8710.7	435.54		
Total	26	29277			

1. ANOVA Results for Impact Strength

The Percentage Contribution of process parameter values as Tool Rotational Speed of 0.23 %, Welding Speed of 0.72 % and Tool Pin Profile of 0.65 % are determined by using two way ANOVA shown in table 10. It is observed that the

Welding Speed have great influence on Impact Strength of weld joint of dissimilar metals as AA6061 and AA6082.

V. CONCLUSION

All the experimental trials are analyzed under precautionary measures in order to keep the error factors low and optimize the reliable results to produce the efficient weld joint of dissimilar aluminium alloys with friction stir welding technique. Thus, the results obtained in this research study lead to conclusions for friction stir welding of AA6061 and AA6082 dissimilar aluminium alloy materials after analyzing the collected data.

i. The optimal process parameters of Friction Stir Welded joints of dissimilar Aluminium Alloys for Impact Strength are determined by Using Taguchi method and optimum values of the most Influence of process parameter on impact strength of friction stir welded joints of dissimilar Al alloys of AA 6061 and AA 6082 are found as Welding speed (S) of 115 mm/min, Tool Rotation speed (N) 1450 rpm and Tool Pin Profile of Cylindrical threaded (tpi-22).

ii. Using analysis of variance (ANOVA), the percentage of contribution for Rotational Speed, Welding Speed and Tool Pin Profile on Impact Strength is determined. But welding speed has great influence on Impact Strength of friction stir welded joints of dissimilar Al alloys of AA 6061 and AA 6082.

The future scope of the study is discussed as:

Rotational Speed, Welding Speed and Tool Pin Profile variations are taken into account as input parameters in this research study. The other input welding parameters such as heat input and any other type of tool pin profile can be investigated on same as well as on different alloys of aluminium and magnesium. Further Researcher can apply post weld heat treatment on same or different materials to achieve better strength.

VI. ACKNOWLEDGMENT

This whole research work has done under the guidance of Er. Lakshman Singh and Er. Simranjeet Singh as a Assistant Professor, Mechanical Department, Chandigarh University, Gharuan, Mohali who has provided all necessary resources like data book for getting necessary and valuable information for the completion of this work and learned about the Taguchi as well as ANOVA methods and above all, utmost appreciation to the almighty God for the divine intervention in this endeavor.

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