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Effect of Process Parameters on Mechanical Properties of Friction Stir Lap Welds of AA6082

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***Abstract:*— In this study experiments were performed to investigate the effects of FSLW process parameters including Tool Rotational Speed, Welding Speed and Tool Tilt Angle on Mechanical properties of Aluminum 6082 alloy in lap joint welding. Using ANOVA, significance and influence of FSLW process parameters were predicted, and Harmony Search Algorithm (HSA) is developed for optimum welding conditions for measuring mechanical properties of the joint.**

***Keywords:*-- Friction Stir Lap Welding (FSLW), Friction Stir Welding of lap joint, ANOVA, Al-Alloys, Tool Rotation Speed (N), Welding Speed(S), Tool Tilt Angle(TA).**

I. INTRODUCTION

Friction Stir Lap Welding (FSLW) was invented as solid state joining technique at The Welding Institute (TWI), Cambridge in 1991 and it was initially applied to aluminum alloys. The basic principle of Friction Stir Welding is to enable joining of metals by heating the base metal to temperature below the re-crystallization temperature. The majority of FSW studies have been based on butt joint geometry. Lap joint configuration is also widely used in conventional welding and Friction Stir Lap Welding (FSLW) should potentially be applied widely, particularly in automotive and aerospace industries [1]. Conventionally, these joints are produced using riveting, given limited fusion weldability of many high-strength AL alloys in lap configuration can help to realize significant weight and cost savings with improved mechanical performance and reduced manufacturing complexity [1, 2].

The FSW lap joint has been conducted on AA 6082 and determined their mechanical properties with design of experiments using Taguchi method [3]. The welding parameters were optimal in order to achieve non-defectivewelding. The welding done by combination of in-situ extrusion with forging due to tool rotation, friction stir welds are not symmetric about weld centerline the side of the weld on which the rotational velocity of the tool has the same direction as the welding velocity is designated the advancing side of the weld. The side of the weld on which the two velocities have opposite direction is designated the retreating side of the weld [1-3].
The Friction Stir Weld tool plays a major role on deciding the strength of the weld joint. Among the various tool profiles the threaded taper cylindrical tools withstand significantly higher loads compared to those made with triangular profile [4, 5].

The FSW lap joint was applied in this research to join and the effect of Tool Rotational Speed, Welding Speed and Tool Tilt Angle on mechanical properties were studied, thus after conducting experiments and testing is doneand the optimization is done through ANOVA and Harmony Search Algorithm.

II.EXPERIMENTAL DESIGN

The experiment is designed by using MINITAB 17 software tool in which the Taguchi design is used for it. Based on the number of input factors 9 number of experiments is carried out. The main objective of Taguchi is to optimize that response variable which is influenced by other variable using a developed model of designed experiments [3].
Central composite design (CCD) can be implemented to estimate a second-degree polynomial model. Depending on my work 3 factors is necessary so nine experiments is conducted on a Vertical Milling Machine shown in figure 1 below. The work pieces used are AA6082 and the size of the work piece is 150*100*3 for lap welding and the tool used is H13 tool with THREADED TAPER PIN CYLINDRICAL Profile [4].

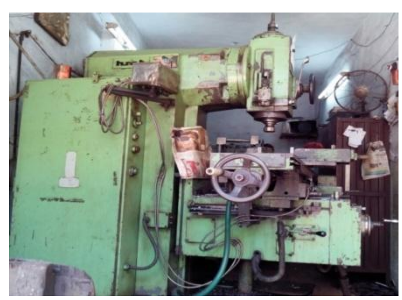

Figure 1: Vertical Milling Machine

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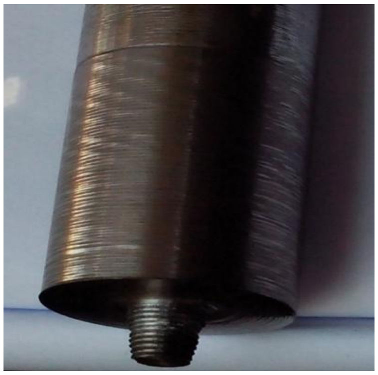

Figure 2: Threaded Tapered Pin Profile

Experimental details:
Machine Tool : Vertical Milling Machine
Work material :Aluminum Alloys 6082
Cutting tool :H13

Table 1: Experimental Details

S. No	**Tool Rotational Speed(N) (rpm)**	**Welding Speed(S) (mm/min)**	**Tool Tilt Angle (TA) (Degrees)**
1	710	31.5	0.5
2	710	40	1
3	710	50	1.5
4	900	31.5	1
5	900	40	1.5
6	900	50	0.5
7	1120	31.5	1.5
8	1120	40	0.5
9	1120	50	1

Table 2: Specified chemical composition of alloy AA 6082 (wt.%)

Alloy(6082)	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Composi-tion	0.7-1.3	0.5	0.1	0.4-1.0	0.6-1.2	0.25	0.2	0.1	Bal

III. RESULTS AND DISCUSSIONS

FSW of lap joint technique is employed on 6082 Aluminum alloys and tested using different parameters Tool Rotation Speed (N), Welding Speed(S), Tool Tilt Angle (TA).
Harmony Search Algorithm (HSA) is employed to optimize the Peak Load, Elongation at Peak Load, Shear strength and Hardness of the AA 6082 material for Friction Stir Welding of lap joint for getting the compromised solution among the responses [13]. Tables are presented for responses using ANOVA calculations and HSA results

Statistical Analysis

ANOVA is a particular form of statistically hypothesis testing heavily used in the analysis of experimental data. A statistical hypothesis test is a method of making decisions using data. Analysis of variance (ANOVA) technique is applied to find out the significance of the parameters for validation [8-11]. The percentage of contribution of Tool Rotational Speed (N), Welding Speed (S), and Tool Tilt Angle (TA) on Peak Load, Elongation at Peak Load, Shear strength and hardness were studied and analyzed by using ANOVA technique.

Process Parameters (Factors) and their Levels

Below tables shows the process parameters and their design levels. These values are considered for carrying the project work, such as Tool Rotational Speed (N), Welding Speed(S) and Tool Tilt Angle (TA).

Table 3: Process Parameters and their design levels using in FSW of lap joint technique

Process parameters	**Range**	**Level 1**	**Level 2**	**Level 3**
Tool Rotational Speed (N), rpm	710- 1120	710	900	1120
Welding Speed(S), mm/min	31.5 – 50	31.5	40	50
Tool Tilt Angle (TA),Degrees	0.5-1.5	0.5	1	1.5

Table 4: Experimental Values for Shear Strength &Hardness for AA6082

S. No	**Tool Rotational Speed (N) (rpm)**	**Welding Speed (S) (mm/min)**	**Tool Tilt Angle (TA) (Degrees)**	**Peak Load (LP) (KN)**	**Elongation at Peak Load (EP) (mm)**	**Shear Strength (SS) (MPa)**	**Hardness (H_v)**

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1	710	31.5	0.5	07.84	2.88	42.026	63.6
2	710	40	1	13.10	3.82	64.274	64.9
3	710	50	1.5	10.53	2.82	49.822	63.4
4	900	31.5	1	13.81	5.43	66.057	62
5	900	40	1.5	10.95	2.91	51.765	65.6
6	900	50	0.5	07.46	2.36	34.961	53.3
7	1120	31.5	1.5	11.04	5.53	51.147	68.9
8	1120	40	0.5	13.90	5.92	62.677	67.9
9	1120	50	1	08.47	3.37	39.957	61.4

Table 5: ANOVA Results for Peak Load using Threaded Taper Pin Profile for AA6082

Factor	**Degrees of Freedom DOF**	**Sum of Squares SS**	**Mean Squares MS**	**Percentage of Contribution**
N	2	0.6380	0.3190	**1.28**
S	2	22.055	11.027	**44.59**
TA	2	6.3772	3.1886	**12.89**
RES	8	20.387	10.193	41.24
TOTAL	14	49.458		100

Table 6: ANOVA Results for Elongation at Peak Load using Threaded Taper Pin Profile for AA 6082

Factor	**Degrees of Freedom DOF**	**Sum of Squares SS**	**Mean Squares MS**	**Percentage of Contribution**
N	2	5.1619	2.5809	**34.58**
S	2	5.1345	2.5672	**34.40**
TA	2	0.4435	0.2217	**2.97**
RES	8	4.1838	2.0919	28.05
TOTAL	14	14.9236		100

Table 7: ANOVA Results for Shear Strength using Threaded Taper Pin Profile for AA6082

Factor	**Degrees of Freedom DOF**	**Sum of Squares SS**	**Mean Squares MS**	**Percentage of Contribution**
N	2	1.958	0.979	**0.195**
S	2	498.075	249.037	**49.83**
TA	2	157.422	78.711	**15.75**
RES	8	342.025	171.012	34.225
TOTAL	14	999.48		100

Table 8: ANOVA Results for Hardness using Threaded Taper Pin Profile for AA6082:

Factor	**Degrees of Freedom DOF**	**Sum of Squares SS**	**Mean Squares MS**	**Percentage of Contribution**
N	2	51.109	25.554	**30.86**
S	2	77.362	36.681	**46.72**
TA	2	30.669	15.334	**18.52**
RES	8	6.442	3.221	3.9
TOTAL	14	165.582		100

From the Tables shown above Welding Speed (S) is the influential parameter compared to Tool Rotational Speed and Tool Tilt Angle, so by changing the Welding Speed there will be more considerable change in Peak Load, Shear Strength and Hardness values. For Elongation at Peak Load the Tool Rotational Speed is the influential parameter, also the Welding Speedhas considerable impact. It is also observed that the residual factors also plays important role in maximizing responses of Peak Load, Elongation at Peak Load and Shear Strength those factors may be Tool Plunge Depth and Axial Force upon the work piece during welding [6].

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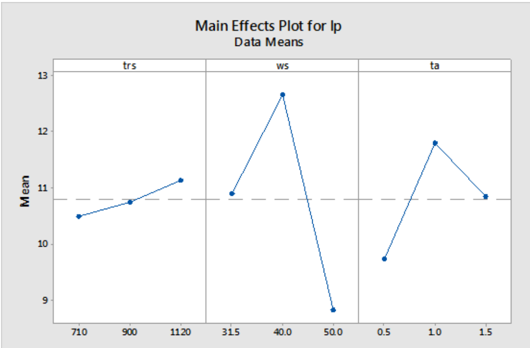

Figure 3: Graph for Peak Load

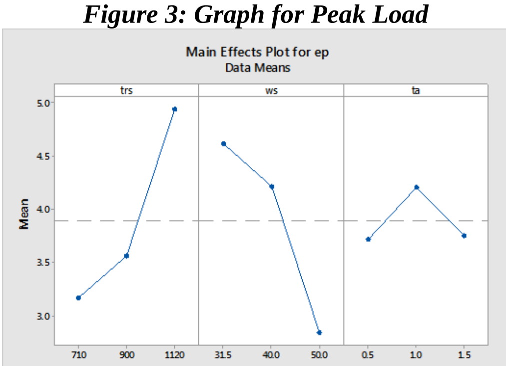

Figure 4: Graph for Elongation at Peak Load

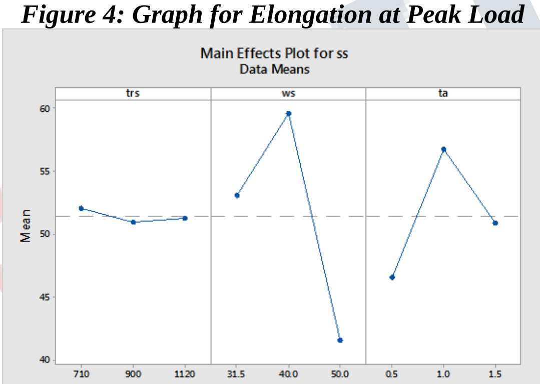

Figure 5: Graph of Shear Strength

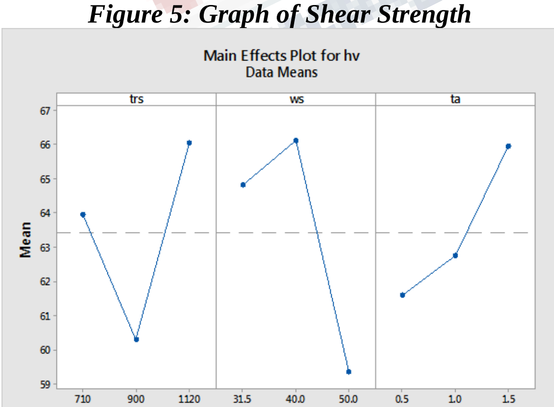

Figure 6: Graph of Hardness

From the graphs shown above for getting max peak load value welding is to be done at the tool rotational speed of 1120 rpm, welding speed of 40 mm/min, and tool tilt angle of 1^0. For maximizing the Elongation at Peak Load the welding should done at the Tool Rotational Speed of 1120 rpm, Welding Speed of 31.5 mm/min and Tool Tilt Angle of 1^0. For maximum Shear Strength the Welding should be done at the Tool Rotational Speed of 710 rpm, Welding Speed of 40 mm/min and Tool Tilt Angle of 1^0.Similarly for getting max Hardness welding should done at 1120 rpm, Welding Speed of 40 mm/min and Tool Tilt Angle of 1.5^0.

Harmony Search Algorithm

Harmony Search (HS) is a relatively new meta-heuristic optimization algorithm that imitates the improvisation process of Jazz musicians [12]. Each musician is analogous to each decision variable: the audience's aesthetics are analogous to the objective function: the pitch range of a musical instrument corresponds to the value range of the decision variables; the musicians' improvisations correspond to local and global search schemes; musical harmony at certain time to a solution vector at certain iteration [15].

For Harmony search Algorithm, the input parameters (N, S, TA) are decision variables and the lower and upper limits are provided for each decision variable in the algorithm. Based on the objective function value obtained by random selection of variable values the maximum value for objective function is finalized, the corresponding values of decision variables are best parameters [12-15].

From Harmony Search Algorithm a compromised solution for the given objective function is obtained for machining variables of Tool rotational speed, Welding Speed and Tool tilt angle. The Harmony Search Algorithm is processed to find the best result for the objective using Regression equations and its boundaries and the optimum value of compromised solution of all responses is obtained at Tool rotational speed 1120 rpm, Welding peed 31.5 mm/min and Tool Tilt Angle 1.5^0 which are most significant and applicable value amongst all other experimental values.

IV. CONCLUSIONS

In this study, the Taguchi method was used to obtain optimal condition for friction stir welding of AA 6082 aluminum alloy. Experimental results were evaluated using ANOVA and Harmony Search algorithm. The results can be drawn as follows:

1. Welding speed is the major factor affecting the peak load, shear strength and hardness.
2. Tool rotation speed and welding speed are the most influencing parameter to get good elongation at peak

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load.

3. Tool tilt angle has the minimum effect on all responses.
4. Tool rotation speed of 1120 rpm welding speed of 31.5 mm/min and 1.5 degree tilt angle is the optimum machining condition to get a compromised solution of all responses.

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