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Parametric Optimization of Friction Stir Spot Welding Of AA6082 Using DFA and ANOVA

Dr. P. Hema[1] and U. Sainadh[2]
[1]Assistant Professor Dept. of Mechanical Engineering, SVUCE, Tirupati – 517 502
[2]Academic Consultant Dept. of Mechanical Engineering, SVUCE, Tirupati – 517 502
Corresponding Author: Dr. P. Hema

ABSTRACT:
Friction Stir Spot Welding (FSSW) is a process of pressure welding operating under the workpiece melting point. For AA6082 – T6 Sheets of aluminium alloy 3 mm thick, the mechanical behaviour (i.e. tensile shear tests, micro-hardness) of friction stir spot welded joints was studied in the present work. List of FSSW experiments with vertical CNC milling machine were conducted. FSSW is performed with different pin profiles (cylindrical, taper and threaded) with concave shoulder, Tool rotational speeds, i.e. 2000, 25000 and 3000 rpm, Dwell time 3 and 6 sec., feed rate 10, 15 and 20 mm / min. In this work, welding experiments are conducted on AA6082 with different process parameters combination of dwell time, tool geometry, tool rotational speed, feed rate and the output responses such as peak load, % of elongation, shear strength, and hardness. Impact of parameters of the process on welding output responses is studied. Desirability Functional Analysis (DFA) is used to identify the optimal process parameters for output responses in this Experimentation. Experimental conformation test was conducted with optimum process parameters and Conformation test values are compared with DFA values.

Keywords: *Friction Stir Spot Welding (FSSW), Resistance spot welding, AA6082 – T6 aluminium alloy, CNC milling machine, peak load, % elongation, shear strength, hardness, Desirability Functional Analysis (DFA);*

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I. INTRODUCTION

FSSW is a solid state welding process, there is no need for compressed air and coolant, and less power is needed than RSW. FSSW welds have higher strength, less residual stress, improved fatigue life, lower distortion, and better resistance to corrosion. Unlike FSW, after plunging a rotating non-consumable tool into the workpieces, there is no traverse movement. FSSW tools have two components, a shoulder and a pin. The pin has been designed to disrupt the workpieces faulty surface, Shear and carry the material around it and cause deformation and frictional heat in heavy workpieces. The shoulder of the tool produces most of the frictional heat on the workpieces surface and subsurface regions.

A rotation tool with a protruding pin is plunged into the workpieces from the top surface to a predetermined depth during plunging. The tool generates frictional heat – the working interface softens the surrounding material by stirring and the rotating and moving pin causes material flow in both axial and circumferential directions. After plunging, the forging pressure applied by the tool shoulder and the mixing of the plasticized material result is a solid bond region.

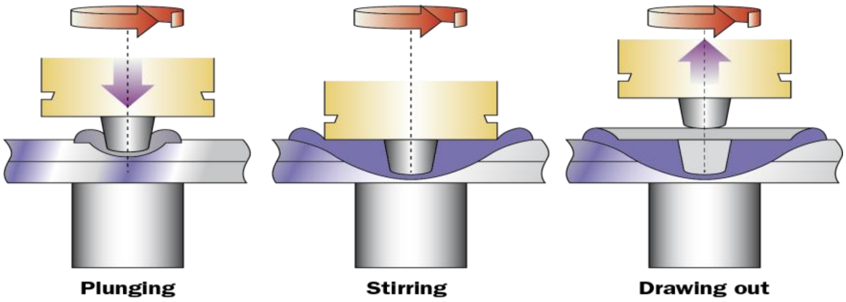

Figure 1 Rotation of the tool with protruding pin

II. LITERATURE REVIEW

Tran et al. [1] investigated the fatigue behaviour of aluminium 5754 – O and 6061 – T4 friction spot welds in lap – shear specimens. They stated that estimates of fatigue life based on growth of kinked fatigue crack model and the structural stress model appears to agree well with the experimental results for both types of welds. **Merzoug** et al. [2] conducted AA6060 – T5 experiments using a type X210 CR 12 tool steel and the rotational speed of the tools ranged between 1000 and 2000 rpm. The tensile tests enabled good welding quality to be established of the 1000 rpm and 16 mm / min sample with 5 KN to 16 mm / min and 1000 rpm compared to 1.98 KN for 25 mm / min and 2000 rpm. **Shen** et al. [3], joined 6061 – T4 2 mm thick aluminium alloy sheets using a high-speed steel tool (JIS, SKD61) 10 mm diameter of the shoulder and a concave profile. At higher rotational speed and longer duration, a preferable joint appearance was obtained. The microstructures of the weld were divided into four regions: BM, HAZ, TMAZ, and SZ. **P.Hema** et al. [4] investigated the impact of process parameters on AA2014 and AA6061 aluminum alloy of friction stir welded joints and its mechanical properties have been determined and optimization is carried out through RSM. SEM analysis carried out to investigate the behavior of the material flow in the weld zone. **Badarinarayan** et al. [5] joined AA 5083 annealed sheets with two different 1.64 and 1.24 mm thicknesses. The shoulder of the tool had a concave profile of 12 mm and a pin length of 1.6 mm. Conventional cylindrical and triangular pins are the two different pin geometries. They concluded that the geometry of the tool pin affects the hook significantly. **Wang and Lee** et al. [6] AA6061-T6 spot welded 1 mm thick. They found that the failure was initiated near the SZ in their experimental results in the middle of the nugget under lap-shear loading conditions and the failure propagates to the final fracture along the nugget's circumference. **Buffa** et al. [7] used aluminium alloy AA6082-T6 with a thickness of 1.5 mm. They used a 1020 OC quenched H13 tool steel, characterized by a hardness of 52 HRC. The shoulder had a diameter of 15 mm and a 40o conical pin with a 7 mm in large diameter and 2.2 mm in small diameter ; 2.6 mm in pin height. **Thoppul and Gibson** [8] made spot welds using AA6111-T4. It is clear from the micro – structural studies that the processing time increases the tool's penetration depth and bonding between the joints of the lap.

Aluminium 6082 is the most common heat treated alloy and in plate form it is commonly used for machining applications, High Stress applications are Aircraft Trusses, Bridges, Cranes and Transport applications are skips Beer barrels. This study can be extended to combinations of different alloys by applying the same technique to other aluminium alloys such as 5XXX and 7XXX, the alloys used in the automotive industry. Another area of interest is welding of materials such as copper, titanium and magnesium using friction stir spot welding. Better tool design and new tool materials should be tested to enhance weld quality study of the effects of parameters of welding on microstructure of the resulting weld and surface morphology.

III. METHODOLOGY

Taguchi's strategy is a good way to plan a brilliant framework. It provides both a productive and an orderly way of dealing with improved implementation and quality plans. In addition, Taguchi parameter configuration can reduce the change in the execution of the framework. The experiment follows the following steps:

- Choose the appropriate orthogonal array and assign to the orthogonal array these parameters.
- Execute experiments based on orthogonal array arrangements.
- Use ANOVA and Desirability Function Analysis to analyze the experimental results.
- Experimental Design
    - **Selection of process parameters**: Research work has determined the process parameters and their ranges. The parameters for experiments like Tool Geometry, Tool Rotational speed, Feed Rate and Dwell Time are identified.
    - **Selection of the orthogonal array**: Select a suitable orthogonal array for the experiments based on the selection of parameters and their levels. Here, we have three parameters in three levels and one parameter in two levels.
    - **Perform the experiment and record the responses**: 18 experimental runs under the L18 orthogonal array of Taguchi were conducted. The test runs were performed randomly to avoid a systematic error in the experimental procedure.
    - **Analysis by ANOVA**: Using variance analysis, performance parameter analysis can be obtained and the most critical factors can be found to obtain the optimum performance parameters.
    - **Optimization using DFA**: Analysis of desirability functions used to convert multi-response issues into single responses. As a result, it is possible to optimize the complicated multi-response problems into optimizing the composite desirability of a single response problem.

IV. EXPERIMENTATION

For experimental work following equipment and material are needed CNC Milling Machine, Fixtures, Aluminium plates, Tool bits. In the wrought aluminium – magnesium – silicon family 6000 or 6xxx, 6082 aluminium alloy is an alloy. H13 Tool Steel is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling applications. The hot hardness (hot strength) of H13 resists thermal fatigue cracking which occurs as a result of cyclic heating and cooling cycles in hot work tooling applications. For experimental work aluminium plates are used, their dimensions are length = 20 cm, width = 5 cm, thickness = 3 mm. All the tools had concave shoulder and different pin geometry viz., straight cylindrical pin, cylindrical taper pin and cylindrical threaded pin shown in Figure 2 (a), Figure 2 (b), Figure 2 (c). The tool penetration depth was kept constant at 4.5 mm and 15 mm / min respectively in all experiments.

Figure 2 (a)
Straight Cylindrical tool

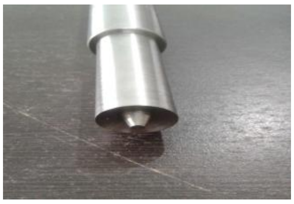

Figure 2 (b)
Taper cylindrical tool

Figure 2 (c)
Threaded cylindrical tool

Design of tool and Dimensions:

Table 1 Dimensions of the Tool

Tool No.	Pin Shape and Dimensions			
	Shape of pin	**Details of pin**	**Length of the pin**	**Concave Shoulder Diameter**
Tool 1	Straight Cylindrical (SC)	4 mm Diameter	3.5 mm	12 mm
Tool 2	Tapered Cylindrical (TC)	4 mm dia. (at shoulder) 2 mm dia. (at pin's tip)	3.5 mm	12 mm
Tool 3	Threaded Cylindrical (THC)	4 mm Diameter 1 mm Pitch	3.5 mm	12 mm

Table 2 Process Parameters and Their Levels

Symbol	Process parameters	Level – 1	Level – 2	Level – 3
A	Dwell time (Sec)	3	6	
B	Tool geometry	Straight Cylindrical (SC)	Tapered Cylindrical (TC)	Threaded Cylindrical (THC)
C	Rotational speed (Rpm)	2000	2500	3000
D	Feed rate (mm / min)	10	15	20

Table 3 Experimental Results for Output Response

S. No.	Dwell Time (Sec)	Tool Geometry	Rotational Speed (Rpm)	Feed Rate	Peak Load (KN)	% Elongation (mm)	Shear Strength (N/mm^2)	Hardness HV0.5
1	3	SC	2000	10	8.56	17.38	16.07	77.09
2	3	SC	2500	15	9.85	14.54	18.50	82.01
3	3	SC	3000	20	9.53	15.96	17.90	75.83
4	3	TC	2000	10	1.25	6.44	2.35	72.30
5	3	TC	2500	15	0.74	3.04	1.39	71.30
6	3	TC	3000	20	0.22	1.06	0.41	72.71
7	3	THC	2000	15	8.30	13.48	15.62	71.60
8	3	THC	2500	20	4.40	10.14	8.26	72.04
9	3	THC	3000	10	8.27	13.74	15.53	79.98
10	6	SC	2000	20	7.85	16.18	14.74	73.84
11	6	SC	2500	10	11.17	14.48	20.98	81.77
12	6	SC	3000	15	9.10	13.8	17.09	81.15
13	6	TC	2000	15	1.02	4.21	1.39	77.30
14	6	TC	2500	20	0.62	2.54	0.62	75.20
15	6	TC	3000	10	6.26	14.56	3.75	80.88
16	6	THC	2000	20	3.49	9.06	6.55	72.28
17	6	THC	2500	10	3.94	8.66	7.40	80.22
18	6	THC	3000	15	3.61	11.56	6.78	79.59

V. RESULTS AND DISCUSSION

Analysis of Variance for Peak Load:

ANOVA aims to investigate which process parameters affect the performance characteristics significantly. The ANOVA procedure performs variance analysis (ANOVA) for peak load to determine the meaningful process parameter affecting the output response.

Table 4 ANOVA for Peak Load

Source	DF	Sum of Square	Mean Square	F-Value	P-Value	% Contribution
DT	1	1.617	1.671	0.74	0.439	2.17
TGY	1	44.548	44.548	19.63	0.011	18.59
TRS	1	0.800	0.800	0.35	0.585	0.01
FR	1	0.004	0.004	0.00	0.968	1.73
TGY x TGY	1	167.053	167.053	73.61	0.001	68.31
TRS x TRS	1	0.174	0.174	0.08	0.796	0.00
FR x FR	1	1.162	1.162	0.51	0.514	0.35
DT x TGY	1	7.806	7.806	3.44	0.137	3.29
DT x TRS	1	2.145	2.145	0.95	0.386	0.74
DT x FR	1	1.030	1.030	0.45	0.537	0.03
TGY x TRS	1	3.198	3.198	1.41	0.301	1.22
TGY x FR	1	0.037	0.037	0.02	0.905	0.01
TRS x FR	1	0.142	0.142	0.06	0.815	0.05
Error	4	9.077	2.269			3.50
Total	17					100.00

From the Table 4, it is clear that Tool Geometry individually is having great influence on peak load and with interaction peak load is highly influenced by Dwell Time with Tool Geometry.

Regression Equation for Peak Load:

To predict the optimal peak load and to estimate the significant coefficients without losing the accuracy and to avoid complex mathematical calculations, second ordered polynomial regression equation is used. After determining the coefficients, the final model equation is given below:

$$\text{Peak Load} = 9.0 + 2.05\ DT - 22.12\ TGY + 0.0104\ TRS + 0.06\ FR + 6.706\ TGY*TGY - 0.000001 TRS*TRS - 0.00236\ FR*FR - 0.596\ DT*TGY\ 0.000807\ DT*TRS + 0.0559\ DT*FR - 0.00149\ TGY*TRS - 0.016\ TGY*FR + 0.000084 TRS*FR$$

Where DT = Dwell Time, TGY = Tool Geometry, TRS = Tool Rotational Speed, FR = Feed Rate from regression analysis the optimum process parameters for peak load is Dwell Time = 3 Sec, Tool Geometry = Straight Cylindrical, Tool Rotational Speed = 3000 Rpm and Feed Rate = 10 mm/min.

By substituting the optimum process parameters in the regression equation the required obtained optimal peak load is 12.816 KN.

Analysis of Variance for Elongation:

The ANOVA procedure performs variance analysis (ANOVA) percentage elongation to determine the significant process parameter that affects the response to the output.

Table 5 ANOVA for Elongation

Source	DF	Sum of Square	Mean Square	F – Value	P – Value	% Contribution
DT	1	0.563	0.563	0.22	0.663	2.03
TGY	1	160.395	160.395	62.69	0.001	10.67
TRS	1	5.450	5.450	2.13	0.218	1.33
FR	1	0.221	0.221	0.09	0.783	0.87
TGY x TGY	1	391.933	391.933	153.19	0.000	79.23
TRS x TRS	1	3.276	3.276	1.28	0.321	1.67
FR x FR	1	0.591	0.591	0.23	0.656	0.09
DT x TGY	1	2.992	2.992	1.17	0.340	0.35
DT x TRS	1	0.025	0.0255	0.01	0.926	0.00
DT x FR	1	2.655	2.655	1.04	0.366	0.87
TGY x TRS	1	1.202	1.202	0.47	0.531	0.26
TGY x FR	1	1.880	1.880	0.73	0.440	0.36
TRS x FR	1	1.427	1.427	0.56	0.497	0.28
Error	4	10.234	2.558			1.98
Total	17					100.00

From the Table 5, it is clear that Tool Geometry individually is having great influence on elongation and with interaction elongation is highly influenced by Dwell Time with Feed Rate.

Regression Equation for Elongation:

To predict the optimal Elongation and to estimate the significant coefficients without losing the accuracy and to avoid complex mathematical calculations, second ordered polynomial regression equation is used. After determining the coefficients, the final model equation is given below:

$$\begin{aligned}\text{Elongation} = {} & 89.3 - 1.19\,DT - 41.98\,TGY - 0.0271\,TRS - 0.43\,FR + 10.272\,TGY*TGY + 0.000004\\ & TRS*TRS - 0.0168\,FR*FR - 0.369\,DT*TGY + 0.000087\,DT*TRS + 0.0898\,DT*FR\\ & + 0.00092\,TGY*TRS - 0.114\,TGY*FR + 0.000265\,TRS*FR\end{aligned}$$

Where DT = Dwell Time, TGY = Tool Geometry, TRS = Tool Rotational Speed, FR = Feed Rate

From regression analysis the optimum process parameters for Elongation is DT=3 Sec, TGY = Straight Cylindrical, TRS = 2000 Rpm, FR= 10 mm/min by substituting the optimum process parameters in the regression equation the required obtained optimal Elongation is 17.95 mm.

Analysis of Variance for Shear Strength:

The ANOVA procedure performs variance analysis (ANOVA) to determine the significant process parameter affecting the output response.

Table 6 ANOVA for Shear strength

Source	**DF**	**Sum of Square**	**Mean Square**	**F – Value**	**P – Value**	**% Contribution**
DT	1	5.491	5.491	0.74	0.437	2.41
TGY	1	163.031	163.031	22.10	0.009	18.16
TRS	1	2.496	2.496	0.34	0.592	0.02
FR	1	0.024	0.024	0.00	0.957	1.80
TGY x TGY	1	606.940	606.940	82.29	0.001	68.98
TRS x TRS	1	0.448	0.448	0.06	0.818	0.00
FR x FR	1	3.741	3.741	0.51	0.516	0.32
DT x TGY	1	27.129	27.129	3.68	0.128	3.22
DT x TRS	1	6.925	6.925	0.94	0.387	0.67
DT x FR	1	3.161	3.161	0.43	0.548	0.02
TGY x TRS	1	11.335	11.335	1.54	0.283	1.20
TGY x FR	1	0.136	0.136	0.02	0.899	0.01
TRS x FR	1	0.359	0.359	0.05	0.836	0.04
Error	4	7.376	7.376			3.15
Total	17					100.00

From the Table 6, it is clear that Tool Geometry individually is having great influence on shear strength and with interaction shear strength is highly influenced by Dwell Time with Tool Geometry.

Regression Equation for Shear strength:

To predict the optimal Elongation and to estimate the significant coefficients without losing the accuracy and to avoid complex mathematical calculations, second ordered polynomial regression equation is used. After determining the coefficients, the final model equation is given below:

$$\begin{aligned}\text{Shear Strength} = {} & 19.2 + 3.71\,DT - 42.32\,TGY + 0.0183\,TRS + 0.14\,FR + 12.78\,TGY*TGY -\\ & 0.000001\,TRS*TRS - 0.0423\,FR*FR - 1.112\,DT*TGY - 0.00145\,DT*TRS\\ & + 0.098\,DT*FR - 0.00281\,TGY*TRS - 0.031\,TGY*FR + 0.000133\,TRS*FR\end{aligned}$$

Where DT = Dwell Time TGY = Tool Geometry TRS = Tool Rotational Speed and FR = Feed Rate

From regression analysis the optimum process parameters for Shear strength is DT = 3 Sec, TGY = Straight Cylindrical, TRS= 3000 Rpm, FR = 10 mm/min by substituting the optimum process parameters in the regression equation the required obtained optimal Shear strength is 25.6640 N/mm^2.

Analysis Of Variance for Hardness:
The ANOVA procedure performs Hardness Variance Analysis (ANOVA) to determine the significant process parameter affecting the output response.

Table 7 ANOVA for Hardness

Source	DF	Sum of Square	Mean Square	F – Value	P – Value	% Contribution
DT	1	2.6028	2.6028	0.33	0.595	15.68
TGY	1	19.2762	19.2762	2.46	0.192	8.02
TRS	1	5.4688	5.4688	0.70	0.450	20.79
FR	1	2.2720	2.2720	0.29	0.619	28.90
TGY x TGY	1	18.7244	18.7244	2.39	0.197	8.22
TRS x TRS	1	2.3887	2.3887	0.31	0.610	1.16
FR x FR	1	6.9663	6.9663	0.89	0.399	1.45
DT x TGY	1	4.0321	4.0321	0.52	0.513	1.38
DT x TRS	1	3.6243	3.6243	0.46	0.533	1.97
DT x FR	1	0.0312	0.0312	0.00	0.953	0.16
TGY x TRS	1	0.4439	0.4439	0.06	0.823	0.15
TGY x FR	1	0.4386	0.4386	0.06	0.824	0.17
TRS x FR	1	0.4188	0.4188	0.05	0.828	0.16
Error	4	31.2983	7.8246			11.79
Total	17					100.00

From the Table 7, it is clear that Feed Rate individually is having great influence on Hardness and with interaction hardness is highly influenced by Dwell Time with Tool Rotational Speed.

Regression Equation for Hardness:
To predict the optimal Elongation and to estimate the significant coefficients without losing the accuracy and to avoid complex mathematical calculations, second ordered polynomial regression equation is used. After determining the coefficients, the final model equation is given below:

$$\text{Hardness} = 39.1 + 2.55\ DT - 14.55\ TGY + 0.0272\ TRS + 1.37\ FR + 2.25\ TGY*TGY - 0.000003\ TRS*TRS - 0.0577\ FR*FR + 0.429\ DT*TGY - 0.00105\ DT*TRS + 0.010\ DT*FR + 0.00056\ TGY*TRS + 0.055\ TGY*FR - 0.000144\ TRS*FR$$

Where DT = Dwell Time, TGY = Tool Geometry, TRS = Tool Rotational Speed, FR = Feed Rate

From regression analysis the optimum process parameters for Hardness is DT = 6 Sec, TGY = Straight Cylindrical, TRS = 3000 Rpm and FR = 10 mm/min by substituting the optimum process parameters in the regression equation the required obtained optimal Hardness is 86.8140 HV 0.5.

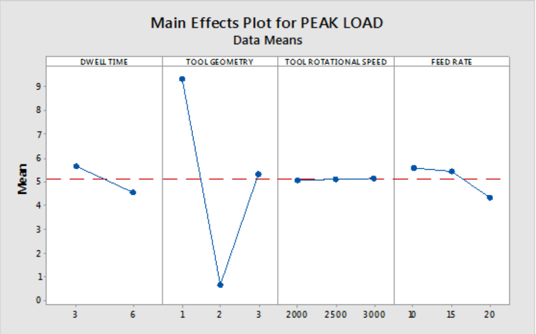

Figure 3 Main Effect Plot for Peak Load

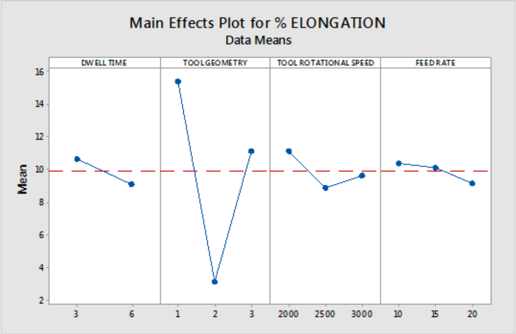

Figure 4 Main Effect Plot for Elongation

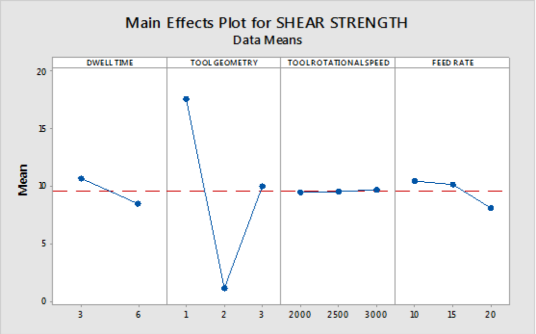

Figure 5 Main Effect Plot for Shear strength

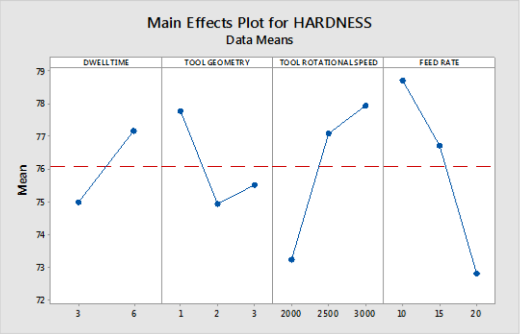

Figure 6 Main Effect Plot for Hardness

Desirability Function Analysis:

Desirability function analysis (DFA) is one of the most widely used methods of multi-response problem optimization in industry (Derringer and Suich, 1980). Analysis of desirability functions is used to convert multi-response problems into single answers. As a result, optimizing the complex multi-response problems can be converted into optimizing a single response problem known as composite desirability. Welding experiments are carried out on AA 6082 alloy based on the Taguchi L18 Orthogonal array. In this study, multi-response considerations optimize parameters such as Dwell time, Tool geometry, Tool rotational speed and feed rate. For the DFA multiple responses, a composite desirability value is obtained. The optimum parameter levels were identified using the composite desirability value and ANOVA determines a significant contribution of the parameters. DFA combines multiple responses such as peak load, percent elongation, shear strength and hardness as a composite desirability. This method makes it easier to identify operating conditions that provide the 'most desirable' responses. In short, there is ample scope in the Taguchi method for the optimization of welding parameters to apply the proposed methodology of desirability function analysis.

Methodology of DFA:

- **Step 1**: Use the formula proposed by Derringer and Suich (1980) to calculate the individual desirability index (di) for the corresponding responses. Depending on the response characteristics, there are three forms of desirability functions.
    - **Nominal the Better**: The nominal's desirable function the better can be written in eq. (5.1).

$$d_i = \begin{cases} \left(\frac{\hat{y}-y_{min}}{T-y_{min}}\right)^s & y_{min} \leq \hat{y} \leq T \quad s \geq 0 \\ \left(\frac{\hat{y}-y_{min}}{T-y_{min}}\right)^t & T \leq \hat{y} \leq y_{min} \quad t \geq 0 \\ 0 & \end{cases} \tag{5.1}$$

Where the y_{min} represents the minimum value of particular column of $\hat{y}$, the y_{max} represents the maximum value of particular column of $\hat{y}$ and s and t represents the weight.

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    - **Larger the Better**: The desirability function of larger the better can be written in eq. (5. 2).

$$d_i = \begin{cases} 0 & \hat{y} \leq y_{min} \\ \left(\frac{\hat{y}-y_{min}}{y_{max}-y_{min}}\right)^r & y_{min} \leq \hat{y} \leq y_{max} \quad r \geq 0 \\ 1 & \hat{y} \geq y_{max} \end{cases} \tag{5.2}$$

Where the y_{min} represents the minimum value of particular column of $\hat{y}$, the y_{max} represents the maximum value of particular column of $\hat{y}$ and s and t represents the weight.

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    - **Smaller the Better**: The desirability function of smaller the better can be written in eq. (5. 3).

$$d_i = \begin{cases} 1 & \hat{y} \leq y_{min} \\ \left(\frac{\hat{y}-y_{max}}{y_{min}-y_{max}}\right)^r & y_{min} \leq \hat{y} \leq y_{max} \quad r \geq 0 \\ 0 & \hat{y} \geq y_{max} \end{cases} \tag{5.3}$$

Where the y_{min} represents the minimum value of particular column of y^, the y_{max} represents the maximum value of particular column of y^ and r represents the weight . The s, t and r indicate the weights in the term (5.1) to the term (5.3) and they are defined by the user's requirement. If the corresponding response is expected to be closer to the target, the weight may be set to the greater value; otherwise the weight may be set to the lower value.

- **Compute the composite desirability (dG):** The following equation can combine the individual desirability index of all responses to form a single value called composite desirability (dG).

$$d_G = (d_1^{w_1} x\, d_2^{w_2} x \ldots\ldots\ldots\ldots d_n^{w_n})^{\frac{1}{W}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{5.4}$$

Where d_i is the individual desirability of the property y_i
w_i is the weight of the property “ y_i ” in the composite desirability, and w is the sum of the individual weights.

- **Determine the optimum parameter and combine the level:** The higher the desirability value of the composite implies improved product quality. Therefore, the parameter effect and the optimum level for each controllable parameter are estimated based on the composite desirability (dG).
- **Perform ANOVA to determine the relevant parameters:** In terms of their percentage contribution, ANOVA sets the relative significance of the parameters. To measure the relative influence of parameters, the calculated total sum of square values is used.
- **Calculate the optimal condition foreseen:** After selecting the optimum level of the design parameters, the final step is to predict and verify the quality characteristics using the optimum level of the design parameters.

Table 8 Individual Desirability (d_i) and Composite Desirability (d_G)

S. No.	Peak Load	% Elongation	Shear Strength	Hardness	Composite Desirability	Rank
1	0.7616	1	0.7620	0.5361	0.7468	5
2	0.8795	0.8260	0.8798	1	0.8941	2
3	0.8502	0.9130	0.8507	0.4194	0.7254	6
4	0.0941	3297	0.0969	0.0926	0.1292	14
5	0.0475	0.1213	0.0504	0	0	16
6	0	0	0.0029	0.1366	0	18
7	0.7379	0.7610	0.7402	0.0278	0.3279	10
8	0.3817	0.5564	0.3834	0.0685	0.2733	11
9	0.7352	0.7770	0.7388	0.8037	0.7624	4
10	0.6968	0.9265	0.6975	0.2352	0.5705	7
11	1	0.8223	1	0.9694	0.9449	1
12	0.8110	0.7806	0.8114	0.9120	0.8273	3
13	0.0731	0.1930	0.0504	0.5556	0.1410	13
14	0.0365	0.0907	0.0131	0.3621	0.0630	15
15	0.0037	0.0306	0	0.8870	0	17
16	0.2986	0.4902	0.3005	0.0907	0.2513	11
17	0.3397	0.4657	0.3417	0.8259	0.4597	9
18	0.3096	0.6434	0.3117	0.7676	0.4672	8

Table 9 Parameters Effect for Composite Desirability (d_G)

Process Parameters	Average composite desirability			Max – Min	Rank
	Level – 1	**Level – 2**	**Level – 3**		
Dwell Time	0.4288*	0.4139		0.0149	4
Tool Geometry	0.7848*	0.0555	0.4236	0.7293	1
Tool Rotational Speed	0.3611	0.4392	0.4637*	0.1026	3
Feed Rate	0.5072*	0.4429	0.3139	0.1933	2
Total mean value of composite desirability = 0.4213 (“*” denotes optimum values)					

Table 10 Analysis of Variance Results

Source	DF	SS	MS	F-Value	P-Value	% Contribution
Dwell Time	1	0.00100	0.001001	0.07	0.795	0.05
Tool Geometry	2	1.59568	0.797842	56.96	0.000	84.54
Tool Rotational Speed	2	0.03444	0.017221	1.23	0.333	1.82
Feed Rate	2	0.11623	0.058115	4.15	0.049	6.16
Error	10	0.14007	0.014007			7.42
Total	17					100

Confirmation Test:

After selecting the optimum level of FSSW process parameters, the final step is to predict and Check performance improvements using the optimum process parameters. The estimated total desirability value can be calculated using the optimum level of process parameters

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{q} (\overline{\gamma_j} - \gamma_m)$$

Where γ_m is the total mean of the overall desirability value,
$\overline{\gamma_j}$ is the largest overall desirability value for the i^{th} factor, and
q is the number of process parameters that significantly affects the multi performance characteristics.

The response mean of overall desirability for each level is summarized in the Table 8. In addition to that the total mean of overall desirability for the 18 experiments is also calculated i.e., **0.4213.**

Table 11 Confirmation test results

Parameters	**Initial Process Parameters**	**Optimal Process Parameters**	
		Prediction	**Experiment**
Setting level	DT2TGY1TRS2FR1	DT1TGY1TRS3FR1	DT1TGY1TRS3FR1
Peak load (KN)	11.17		12.09
Elongation (%)	14.48		16.65
Shear Strength (N/mm^2)	20.98		22.60
Hardness (HV 0.5)	81.77		82.83
ODV	0.9481	0.9231	0.9553

VI. CONCLUSIONS

The following conclusions are drawn from the present work:

The friction stir spot welding of similar AA6082 T-6 sheet metals was performed successfully and provided good lap welded joints. The FSSW joints created with utilizing the straight cylindrical pin profile demonstrated the most noteworthy qualities as contrasted and other pin profiles utilized in this investigation. Experimental work has shown that output response increases with increased tool rotation speed to a specific limit and decreased dwelling time and reduced feed rate with straight cylindrical tool. In the present work, parameters of FSSW have been optimized for obtaining higher Peak Load, % Elongation, Shear strength, and Hardness values.

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