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Effect of Process Parameter on Mechanical Properties of Friction Stir Welded Aluminium Alloy Joints Using Factorial Design

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***Abstract**: In this paper effect of process parameter on mechanical properties of friction stir welded aluminum alloy joints using factorial design is calculated. In experimentation, Two Level of Factorial Design is found to be a more effective tool to investigate the interaction effects of parameters on the required response. Various models have been proposed in this context out of that 95% are at an adequate confidence level. In an analysis of stir welding, tensile strength is found to get an increase with a decrease in rotational speed of tool while decreases with increase in the welding speed.At the low rotational speed of tool high welding speed, there is a small increasing response to Tensile Strength. But at high rpm, and high welding speed, there is a significant increase in Tensile Strength. At a low value of welding speed and high rotational speed, there is a sharp decrease in Tensile Strength. At high welding speed, an increase in rpm, there is a little decrease in Tensile Strength. Prediction of the Tensile Strength at any combination of the two parameters welding speed and rotational speed can be done. With increase shoulder diameter, there is a decrease in Impact Strength. Impact Strength increases with the increase in tool rotational speed.*

***Keywords**: Friction-stir Welding, Polynomials, Milling, Tensile Strength, Rotational Speed, Hardness.*

I. INTRODUCTION

Friction-stir welding (FSW) is a solid-state joining process (the metal is not melted) that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool. It then mechanically intermixes the two pieces of metal at the place of the join, then the softened metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool), much like joining clay, or dough. It is primarily used on aluminium, and most often on extruded aluminum (non-heat treatable alloys), and on structures which need superior weld strength without a post weld heat treatment. A constantly rotated non consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, causes the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticised material to the rear where clamping force assists in a forged consolidation of the weld. This process of the tool traversing along the weld line in a plasticised tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material. The solid-state nature of the FSW process, combined with its unusual tool and asymmetric nature, results in a highly characteristic microstructure. There are two tool speeds to be considered in friction-stir welding; how fast the tool rotates and how quickly it traverses the interface. These two parameters have considerable importance and must be chosen with care to ensure a successful and efficient welding cycle. The relationship between the welding speeds and the heat input during welding is complex but, in general, it can be said that increasing the rotation speed or decreasing the traverse speed will result in a hotter weld.

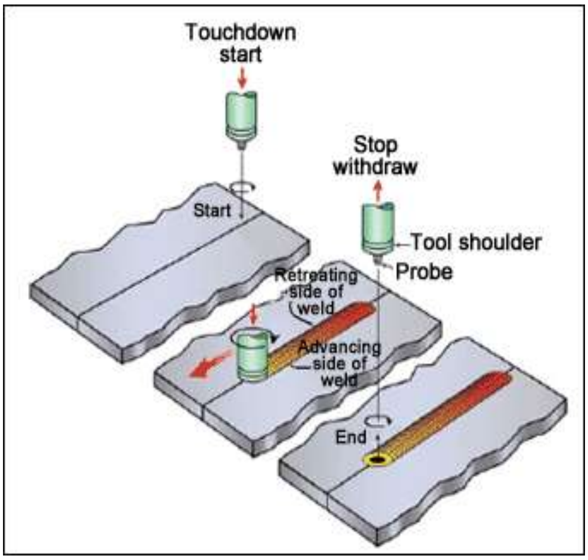
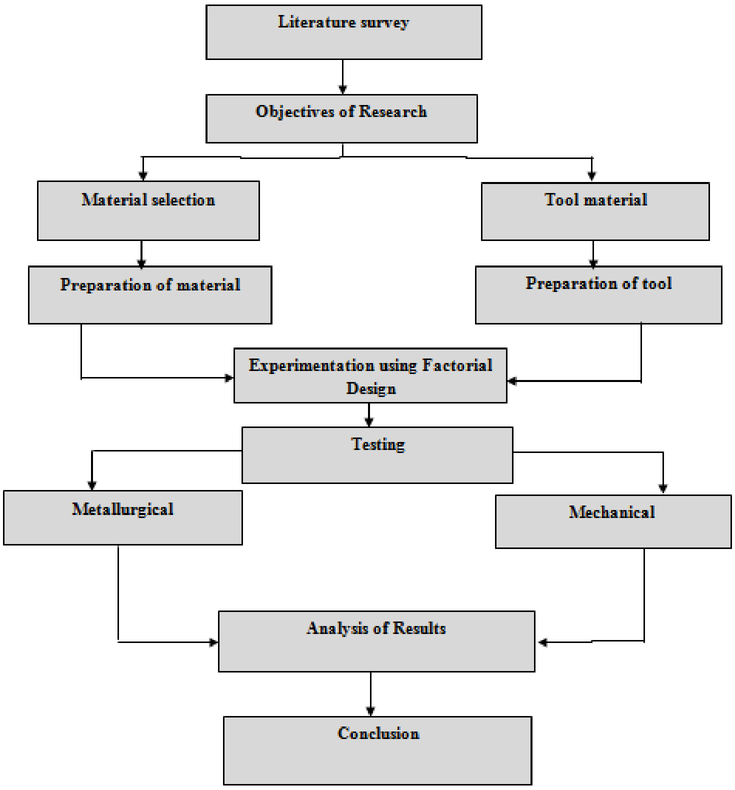


Fig: Schematic Diagram of FSW Process

II. METHODOLOGY

Following flow chart will be followed for the completion of research problem:



III. DESIGN OF EXPERIMENT

The design of the experiment is a procedure of selecting the number of trials and conditions running them, essential and sufficient for solving a problem that has been set with the required precision. The use of design of experiment makes the behaviour of investigator purposeful, organized and appreciably facilitates an increase in productivity of his work and reliability of results obtained.

A two level factorial design of ($2^3 = 8$) eight trials, which is a standard statistical tool to investigate the effects of a number of parameters on the required response, was selected for determining the effect of three independent direct welding parameters. The commonly employed method of varying one parameter at a time, though popular, does not give any information about interaction among parameters. The selecting of two level factorial design also helped in reducing experimental runs to the minimum possible.

The design of the experiment is a procedure of selecting the number of trials and conditions running them, essential and sufficient for solving a problem that has been set with the required precision. The use of design of experiment makes the behavior of investigator purposeful, organized and appreciably facilitates an increase in productivity of his work and reliability of results obtained.

A two level factorial design of ($2^3 = 8$) eight trials, which is a standard statistical tool to investigate the effects of a number of parameters on the required response, was selected for determining the effect of three independent direct welding parameters. Tool rotation speed, welding speed, and shoulder diameter were identified as critical welding variables for carrying out the experiment. The working range covering the lowest and the highest level of the direct welding parameters were carefully selected by carrying out the trial runs so as to maintain defect free friction stir welding. The direct and indirect parameters except under consideration were kept constant. The upper level was coded as (+1) and lower level as (-1) or simply (+) and (-) for the factors with a continuous determination region, this can always be done with the aid of transformation with in the variation interval.

$$X_j = (X_{jn} - X_{jo})/ J_j \text{...} (1)$$

Where X_j, X_{jn}, and X_{jo} are the coded, natural and basic value of the parameter respectively. J_j and j are the variation and number of parameters respectively.

Table: Showing the Units, Symbols used and Limits of Welding Parameters

Parameters	**Units**	**Symbols**	**Lower limit**	**Upper limit**
Tool Rotational Speed	**RPM**	**N**	**1200**	**1500**
Welding Speed	**Mm/min**	**S**	**40**	**60**
Shoulder Diameter	**Mm**	**D**	**18**	**21**

The design matrix developed to conduct the eight trials runs of 2^3 fractional factorial designs as given in Table. The signs under the columns 1, 2, 3 were arranged in standard Yate's order.

Table: Showing Design Matrix

Sl. No	**N 1**	**S 2**	**D 3**
1	+	+	+
2	-	+	+
3	+	-	+
4	-	-	+
5	+	+	-
6	-	+	-
7	+	-	-
8	-	-	-

IV. EXPERIMENTATION

Vertical Milling Machine was used to carry out the experiments. The material of the tool was High Carbon High Chrome steel. The metal plates taken for investigation was aluminium having dimensions of 150 x 100 x 6mm. Two friction stir welding tools with shoulder diameters (D) 18 mm and 21 mm, 5.8 mm long (h) and pin diameter were 6 mm were used. The welding was carried out by using a properly designed clamping fixture that allows fixing the two plates. The iron plates composing the fixture were finished at the grinding machine in order to assure a uniform pressure distribution on the two fixed specimens. The complete set of eight trials was repeated twice for the sake of determining the 'variance of optimization parameter' and once for 'variance of adequacy' for this model. The experiments were performed in a random order in order to avoid any systematic error. The responses for the three set of experiments are given in Table. The Design of experiment software Design Expert was used to develop to Design of Experiment.

Table: Showing Experimental Results

S. No.	Run No.	Tool Rotational speed	Welding speed mm/mim	Shoulder diameter (mm)	Tensile strength (MPa)	Micro hardness Hv	Impact toughness (J)
1	5	-1	-1	-1	209	70	17
2	14	-1	-1	-1	210	71	17.5
3	20	-1	-1	-1	209	70	17
4	19	1	-1	-1	217	78	20
5	22	1	-1	-1	217	79	21
6	4	1	-1	-1	215	78	21
7	10	-1	1	-1	190	60	15
8	21	-1	1	-1	192	61	15
9	2	-1	1	-1	195	62	16
10	18	1	1	-1	215	75	17
11	6	1	1	-1	212	74	18
12	8	1	1	-1	216	75	18
13	15	-1	-1	1	212	70	14
14	7	-1	-1	1	214	69	15
15	1	-1	-1	1	213	69	14
16	16	1	-1	1	220	80	18
17	24	1	-1	1	221	79	18
18	12	1	-1	1	219	80	19
19	9	-1	1	1	186	60	13
20	23	-1	1	1	183	59	14
21	11	-1	1	1	188	61	13
22	3	1	1	1	215	68	15
23	13	1	1	1	217	68	15.5
24	17	1	1	1	217	69	15

The models of the type Y = f (N, S, D) could be developed to facilitate the prediction of a response within the specified dimensional tolerance for a particular set of direct process parameters. Assuming a linear relationship in the first instance and taking into account all the possible two factor interaction and confounded interactions, it could be written as:

$$Y=b_0+b_1N+b_2S+b_3D+ b_{12}NS+b_{13}ND+b_{23}SD \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... (2)$$

Models were developed by the method of regression. Adequacy of the model and significance was tested by the analysis of variance technique and student's't'-test respectively.

The regression coefficients of the selected model were calculated using Equation -3. This is based on the method of least squares.

$$b_j = \sum N_i X_{ji} Y_i / N, \qquad j = 0,1,\ldots..,k \quad \ldots\ldots\ldots\ldots(3)$$

Where,
X_{ji} = value of a factor or interaction in coded form
Y_i =Average value of response parameter
N= No.of observations
k= Number of coefficients of the model

Table: Coefficients of Model

Sl. No	Coefficient of Regression	Due to
1	b_0	Combined Effect of all Parameters
2	b_1	Tool Rotational Speed
3	b_2	Welding Speed
4	b_3	Shoulder Diameter
5	b_{12}	Interaction of N & S
6	b_{13}	Interaction of N & D
7	b_{23}	Interaction of S & D

Table: Design Matrix for Calculating the Value of Coefficients

b_0	b_1 N	b_2 S	b_3 D	b_{12} NS	b_{13} ND	b_{23} SD
+1	+1	+1	+1	+1	+1	+1
+1	-1	+1	+1	-1	-1	+1
+1	+1	-1	+1	-1	+1	-1
+1	-1	-1	+1	+1	-1	-1
+1	+1	+1	-1	+1	-1	-1
+1	-1	+1	-1	-1	+1	-1
+1	+1	-1	-1	-1	-1	+1
+1	-1	-1	-1	+1	+1	+1

Developed models could be obtained by putting the values of the regression coefficients obtained from equation (4) in the selected model,

$$Y = b_0 + b_1N + b_2S + b_3D + b_{12}NS + b_{13}ND + b_{23}SD \text{ ………………….... } (4)$$

The regression coefficients of the selected model were calculated using Equation -3. This is based on the method of least squares.

$$b_j = \sum N_i X_{ji} Y_i / N, \qquad j = 0,1,\ldots,k \quad \text{…………}(3)$$

Where,

X_{ji} = value of a factor or interaction in coded form

Y_i =Average value of response parameter

N= No.of observations

k= Number of coefficients of the model

The adequacy of the model was determined by the analysis of variance technique. The regression coefficients were determined by the method of least square, from which the F-ratio for the polynomial was found. The variance of the response and the adequacies were calculated. The 'F'- the ratio of the model were compared with the corresponding 'F'- ratio from the standard table and it was found that the model is adequate within 95% level of confidence, thus justifying the use of assumed polynomials.

After calculating the coefficients of the model, it must be tested for its fitness. Thus adequacy of the model was tested using analysis of variance technique. For this, the variance of optimization parameter (S^2y) was determined. For two repetitions of each trial the formula is:

$$S^2y = 2\sum_{i=1}^{N}(\Delta Y^2)/N \text{ ……………………………. } (5)$$

Where $\Delta Y^2 = (Y_{iq} - Y_m)^2$

Y_m = Arithmetical mean of repetitions (response in the repetitions)

Y_{iq} = Value of response in a repetition trial

N = Number of observations

i= No. of trials

q=No. of repetitions

Further, the variance of adequacy, also called residual variance was determined by using following formula:

$$S^2ad = \sum_{i=1}^{N} \Delta (Yp - Ym)^2/f \ldots\ldots\ldots\ldots (6)$$

Where
S^2_{ad} = Variance of adequacy
Y_m = Observed or Measured response
Y_p = Estimated/Predicated value of response (obtained from model)
f = N-(K+1) (Degree of freedom)
$\sum_{i=1}^{N}$ = residual sum of square
k = Number of independently controllable variables.

The ratio of the variance of adequacy to the variance of optimization parameter gave Fisher ratio:

$$F = S^2ad/ S^2y \ldots\ldots\ldots\ldots (7)$$

F-values, thus, obtained and denoted as (F_m) were compared from the table value as (F_t). It was found that the model was adequate at 95% level of significance thus justifying the use of the assumed polynomial.
The final model could be obtained by dropping statistically in-significant terms from the developed models.
The vertical milling machine selected to install in Mechanical Workshop, Department of Mechanical Engineering, Gita College of Engineering and Technology, Kurukshetra. The specifications of the vertical milling machine in presented in Table.

Table: Showing Milling Machine Specifications

S. No	Specifications	Units
1	Size of the Table	1500×400mm
2	No. of Speeds	10
3	Spindle Speed range	Low(140,250,360 and 500) High(1200,1950,2500 and 2800)
4	Motor	5 HP

Table 7: Tool Specifications

Shoulder Diameter:	18 mm and 21 mm
Shoulder Height:	30 mm
The height of Pin:	5.8 mm.
Pin Diameter:	6 mm

Table 8: Chemical Composition of Base Material

Si	Fe	Cu	Mn	Mg	Al
0.57	0.35	022	0.12	1.1	Bal

Table 9: Mechanical Properties of Base Material

Ultimate Tensile Strength (MPa)	Elongation	Hardness Hv
280	20	100

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V. RESULTS

The design expert software 6.0 was used to analyze the results. The final mathematical models for tensile strength after dropping insignificant co-efficient is given below:

$$T= 208+8.33N -6.25S +0.33D+ 4.83NS+1.08ND-1.50SD$$

This mathematical model can be used to predict the effects of the parameters on the tensile strength by substituting the values of respective factors in coded form. In the mathematical model for tensile strength, the effects of interaction of two parameters can be explained well.

Table: 10 ANOVA for Selected Factorial Model for Tensile Strength

Source	Sum of Squares	DF	Mean Square	F Value	p-value Prob > F	Significant
Model	3249.67	6	541.61	127.59	< 0.0001	Yes
N-tool rotational speed	1666.67	1	1666.7	392.61	< 0.0001	Yes
S-Welding speed	937.50	1	937.0	220.84	< 0.0001	Yes
D-shoulder Diameter	2.67	1	267	0.63	0.0809	No
NS	560.67	1	560.67	132.07	< 0.0001	Yes
ND	28.17	1	28.17	6.64	0.0196	Yes
SD	54.00	1	54.00	12.72	0.0024	Yes
Residual	72.17	17	4.25			
Lack of Fit	28.17	1	28.17	10.24	0.56	No
Pure Error	44.00	16	2.75			
Cor Total	3321.3	23				

The "Pred R-Squared" of 0.9567 is in reasonable agreement with the "Adj R-Squared" of 0.9706; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 30.855 indicates an adequate signal. This model can be used to navigate the design space. Scatter diagrams, which show the predicted and the observed values of responses, were also drawn so as to test the validity of these models. A good agreement was found to exist between the actual and the predicted responses of percentage elongation as shown in Fig. 4.1 and Fig 4.2 respectively. The Model F-value of 127.59 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case, N, S, D, NS, ND are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), the model reduction may improve your model. The "Lack of Fit F-value" of 10.24 implies the Lack of Fit is not significant. There is only a 0.56% chance that a "Lack of Fit F-value" this large could occur due to noise. Significant lack of fit is bad. The design expert software 6.0 was used to analyse the results. The final mathematical models for tensile strength after dropping insignificant co-efficient is given below:

$$T= 208+8.33N -6.25S +0.33D+ 4.83NS+1.08ND-1.50SD$$

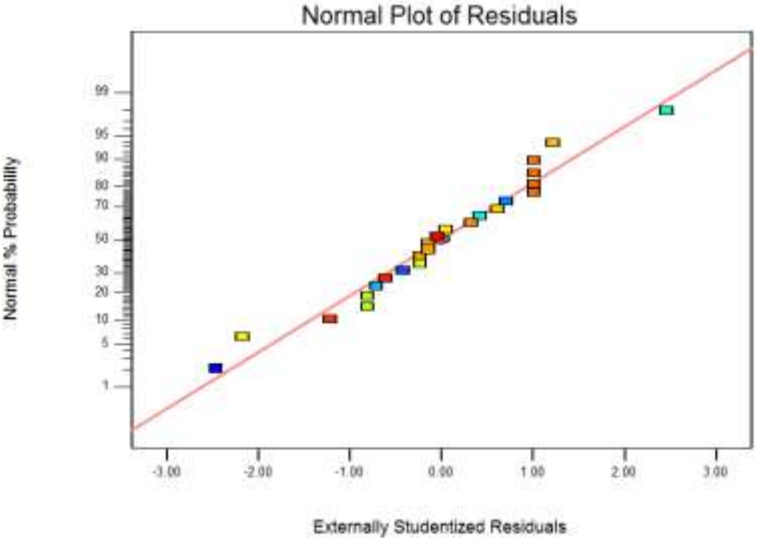

Fig 4.1 Normal plot of Residuals for Tensile Strength (MPa)

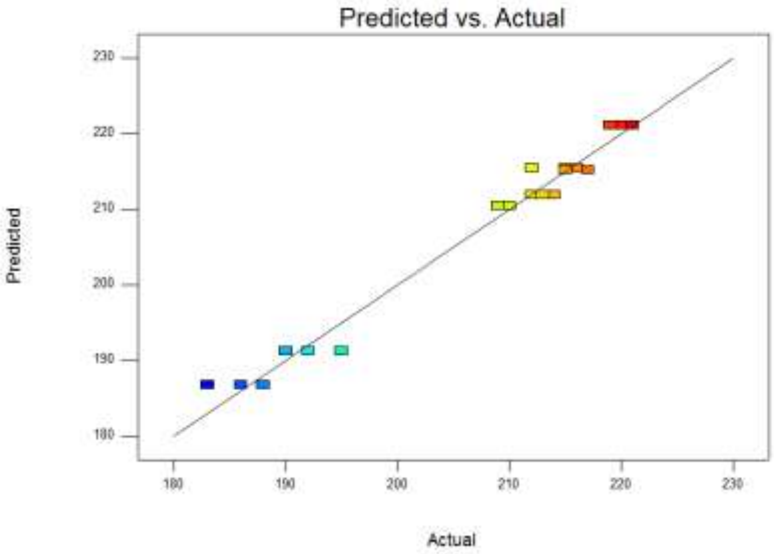

Fig.4.2 Predicted v/s Actual Plot for Tensile Strength (MPa)

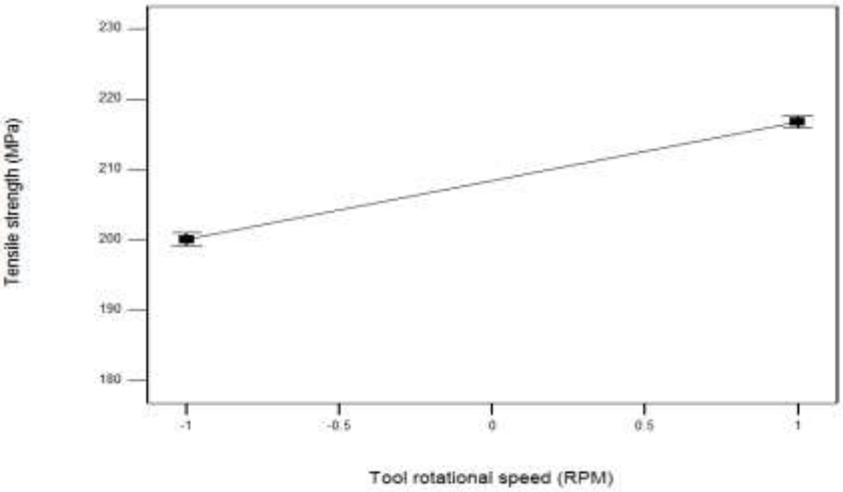

Figure 4.3 Effect of Tool Rotational Speed on Tensile Strength

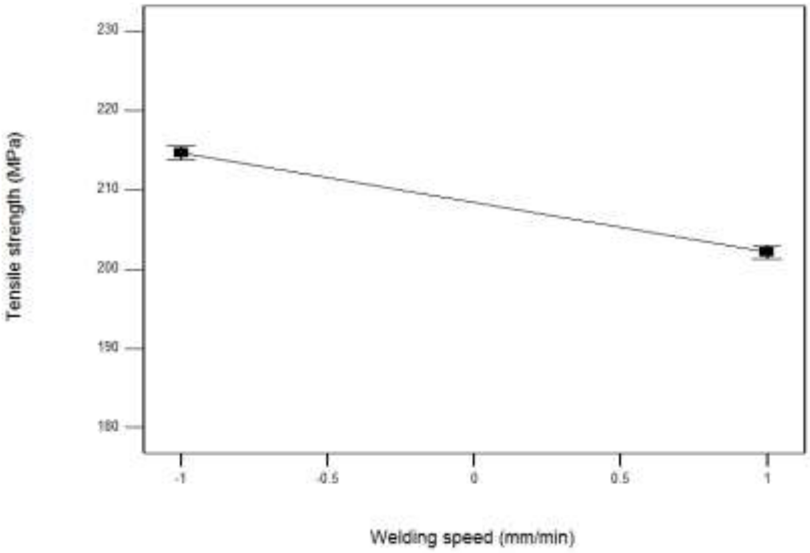

Fig.4.4 Effect of Welding Speed on Tensile Strength

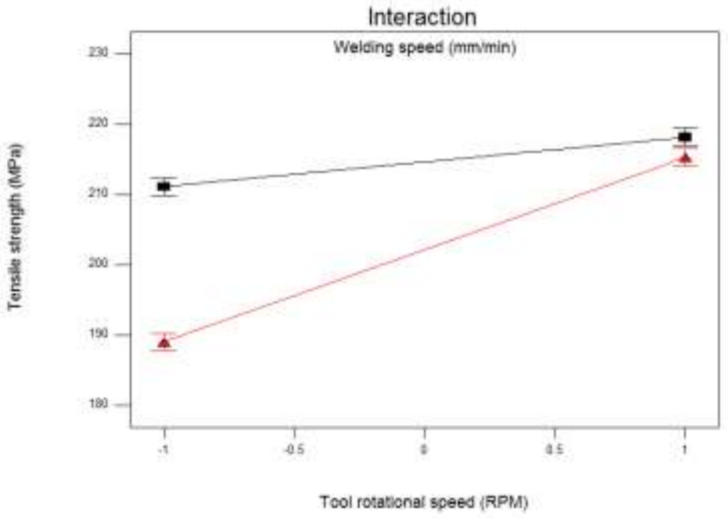

Fig.4.5 Interaction effect of Rotational Speed and Welding Speed on Tensile Strength

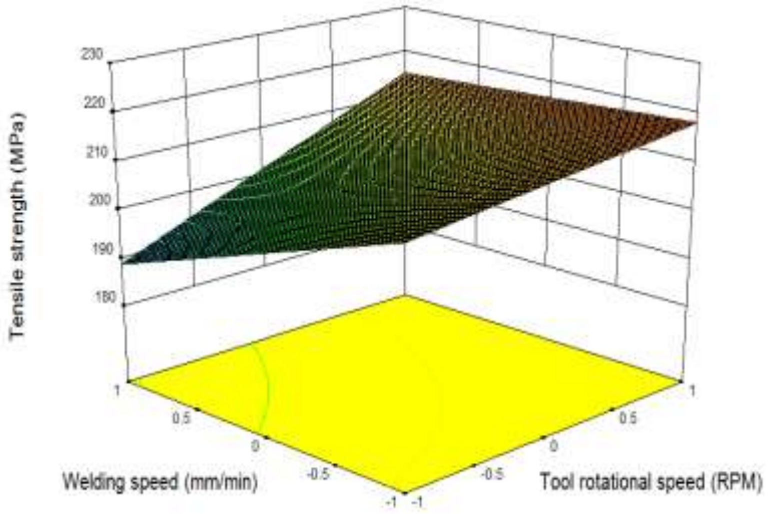

Fig.4.6 3D Surface Plot for Influence of Interaction of rotational Speed and Welding Speed on Tensile Strength

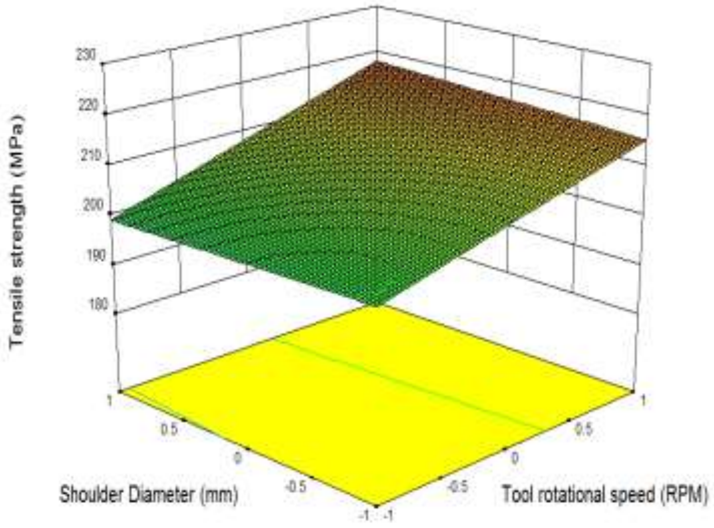

Fig.4.7 3D Surface Plot for Influence of Interaction of Rotational Speed and Shoulder Diameter on Tensile Strength

Table: Showing ANOVA for Selected Factorial Model Micro Hardness

Source	Sum of Squares	DF	Mean Square	F Value	p-value Prob > F	Significant
Model	1083.92	6	180.65	102.23	< 0.0001	
N-tool rotational speed	610.04	1	610.04	345.21	< 0.0001	Yes
S-Welding speed	425.04	1	425.04	240.52	< 0.0001	Yes
D-Shoulder diameter	18.38	1	18.38	10.40	0.0050	Yes
NS	5.04	1	5.04	2.85	0.1095	No
ND	3.38	1	3.38	1.91	0.1849	No
SD	22.04	1	22.04	12.47	0.0026	Yes
Residual	30.04	17	1.77			
Lack of Fit	22.04	1	22.04	44.08	< 0.0001	Yes
Pure Error	8.00	16	0.50			
Core Total	1113.96	23				

VI. CONCLUSIONS

1. Two Level Factorial Design is found to be an effective tool to investigate the interaction effects of parameters on the required response.
2. Proposed models are adequate at 95% confidence level, thus justifying the use of assumed polynomials.
3. Tensile Strength increase with a decrease in rotational speed of the tool.
4. Tensile Strength decrease with increase in welding speed.
5. At the low rotational speed of tool high welding speed, there is the small increasing effect on Tensile Strength. But at high rpm, and high welding speed, there is a significant increase in Tensile Strength.
6. At low welding speed and high rotational speed, there is a sharp decrease in Tensile Strength. At high welding speed, as increase the rpm, there is a little decrease in Tensile Strength.
7. Prediction of the Tensile Strength at any combination of the two parameters welding speed and rotational speed can be done.
8. With increase shoulder diameter, there is a decrease in Impact Strength.
9. Impact Strength increases with the increase in tool rotational speed.

REFERENCES

1. Muthukumaran S. and Mukherjee s. K. (2007), " First mode offers compactness in friction stir welding process", welding –productivity and quality (WPQ-2007), pp. 481-487
2. R. Nandan, T. DebRoy, H.K.D.H. Bhadeshia Recent advances in friction-stir welding – Process, weldment structure and properties Progress in Materials Science 53 (2008) 980–1023
3. Schmidt H. N. Dickerson T. L. and Hattel J. H. (2006) "Material flow in butt friction stir welds in AA2024-T3" acta Materialia, 54, pp. 1199-1209.
4. Schmidt H. N. Dickerson T. L. and Hattel J. H. (2006) "Material flow in butt friction stir welds in AA2024-T3", Acta Materialia, vol. 54, 2006, pp. 1199-1209.
5. Tomotake Hirata, Taizo Oguri, Hideki Hagino, Tsutomu Tanaka, (2007) "Influence of friction stir welding parameters on grain size and formability in 5083 aluminum alloy" Materials Science and Engineering A 456, pp 344–349.

6. William D. Lockwood, Borislav Tomaz, A.P. Reynolds," Mechanical response of friction stir welded AA2024: experiment and modeling", Materials Science and Engineering A323 (2002) 348–353
7. Yingchun Chena, Huijie Liu, Jicai Feng (2006) "Friction stir welding characteristics of different heat-treated-state 2219 aluminum alloy plates" Materials Science and Engineering A420, pp 21–25
8. Z. Zhang, H.W. Zhang Numerical studies on the effect of transverse speed in friction stir welding Materials and Design 30 (2009) 900–907
9. A. K. Lakshminarayanan, V. Balasubramanian "Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique", Trans. Tech Non-ferrous Soc. Of china, 18, pp. 548-554
10. A. K. Lakshminarayanan, V. Balasubramanian 2009 "Comparison of RSM with ANN in predicting the tensile strength of friction stir welded AA7039 aluminium alloy joints", Trans. Tech Non-ferrous Soc. Of china Journal of Material Science Technology, 19 p. 9-18
11. A. Scialpi, L.A.C. De Filippis, P. Cavaliere, (2007) "Influence of shoulder geometry on microstructure and mechanical properties of friction stir welded 6082 aluminium alloy" Materials and Design 28 pp. 1124–1129
12. A. Simar, Y. Br´echet, B. De Meester , A. Denquin, T. Pardoen, "Microstructure, local and global mechanical properties of friction stir welds in aluminium alloy 6005A-T6", Materials Science and Engineering A 486 (2008) 85–95