VOL. 11, NO. 9, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

PROCESS PARAMETERS EFFECT ON THE STRENGTH OF FRICTION STIR SPOT WELDED AA6061

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ABSTRACT

Friction Stir Spot Welding (FSSW) is a recent welding technique used for spot welding of thin sheets. Response surface methodology (RSM) is used to develop a model for the tensile shear failure load of AA6061joined by FSSW. The experiments are conducted for different combinations of three parameters viz. tool rotational speed, dwell time and shoulder diameter as per Box -Behnken design and mathematical model is developed. The developed equation is used to find the optimum parameter combinations for obtaining joints with higher TSFL.

Keywords: friction stirs spot welding, optimization, response surface technique, box-behnken, design of experiment.

1. INTRODUCTION

Friction stir spot welding (FSSW) is a new welding process that can be used to spot weld thin sheets of metals. A variant of friction stir welding process and being solid state nature the process eliminates problems of porosity and solidification cracks in this welding process [1].The process is gaining interest in wide range of engineering applications like aerospace, marine and automotive industries due to its ability to weld conventionally non weldable Aluminium, and Magnesium alloys.

The weld quality and mechanical properties are determined by the FSW process parameters such as Tool Rotation Speed (TRS), Welding Speed (WS), Tool Shape and Size. The process parameters of the FSW have direct control over the grain size, microstructure and strength of the welds. Added to these process parameters, initial temperature of the work piece, heat transfer through convection mode and conduction mode via the backing plate, axial force applied over the work piece also affects the FSW process.

A review on FSSW of aluminium alloys is presented by Ojo *et al.*, [2]. Bilici [3] investigates the effects of the welding parameters on static strength of friction stir spot welds of high density polyethylene sheets. Babu *et al.*, [4] joined A 2014 by FSSW and investigates the effects of tool profile and FSSW parameters on joint formation. Karthikeyan *et al.*, [5] presents empirical relations incorporating process parameters to predict joint strength obtained by FSSW. Numerical simulation studies have also been carried out to investigate the effect of process parameters. Lacki *et al.*, [6] numerically simulates FSSW and explores influence of tool stem radius, height and angles of the abutment on heat transfer during FSSW. Buffa *et al.*, [7] presents process temperature fields, the micro and macro mechanical properties of the joint, the effect of the joint geometry on the microstructure and local strength of the lap friction stir spot welded AA6082-T6 aluminium alloy. Baskoro *et al.*, [8] analyses the effect of high speed tool rotation on shear fracture load of micro friction stir spot welds using response surface methodology.

Guler *et al.*, [9] applies friction stir spot welding to an AA 5754-H111 alloy and compares the effect of different tool geometry and material on shear strength. The total thickness and weld nugget diameter were also investigated in this study. Jambhale [10] identifies the effect of different process parameters on mechanical properties of friction stir spot welded joints. Lakshminarayana *et al.*, [11] explores the interdependence of the FSSW process parameters. Paidar et al., [12]investigates the effects of nano sized silicon carbide (SiC) on the metallurgical characteristics and properties of friction stir spot welded (FSSW) 2024 aluminium alloy. Manickam *et al.*, [13] investigates effects of the four major parameters of FSSW process, namely Tool rotational speed, Plunge rate, Dwell time and Tool diameter ratio on joining aluminium alloy (AA6061) with copper alloy (commercial grade) by FSSW process.

Siddharth *et al.*, [14] analyses important FSSW parameters and their effect on the strength of the dissimilar materials joints. Paidar *et al.*, [15]explores the effect of FSSW parameters on the mode of failure and stir zone characteristics of aluminium alloy 2024-T3 joined by friction stir spot welding. Lambiase *et al.*, [16]aims at analysing the influence of the processing speeds and processing times on mechanical behaviour of Friction Stir Spot Welding (FSSW) joints produced on polycarbonate sheets. Cox, Gibson *et al.*[17] investigates the effect of the number of tool rotations on the quality of the friction stir spot welded aluminium alloy. Tozaki, Uematsu *et al.* [18] report that microstructure and static strength of AA6061sheets joined by FSSW of depends on probe length, tool rotational speed and tool holding time.

Optimum process parameters setting will result in efficient and defect free welds with superior mechanical, micro structural, corrosion and tribological properties. In this study the effect of FSSW parameters (TRS, SD and WS) on tensile shear failure Load (TSFL) of AA6061 sheets joined by FSSW is investigated using response surface methodology (RSM). The RSM is one of the empirical methods to integrate scientific approach in FSSW procedure. Friction stir spot welding trials are carried out for different combinations of the above process parameters and TSFL for the corresponding joints are obtained. A mathematical model between the independent variables (process parameters) and the output variable (TSFL) is established in RSM. The model helps in studying the variation of TSFL corresponding to the different FSSW parameter combinations and in predicting optimum parameters.

2. EXPERIMENTAL PROCEDURE

Aluminium alloy 6061 plates, 3 mm thick measuring 100 mm × 25 mm were joined by FSSW using the vertical milling center (CNC Controlled) shown in Figure-1.

Figure-1. Setup for FSSW.

A cylindrical tool with tapered threaded pin profile made of tool steel was used for performing the welding trials. The FSSW trials were made as per Box - Behnken design for three FSSW parameters namely TRS, SD and DT. Trial runs performed and the corresponding TSFL are given in the Table-1.

Table-1. Experimental design matrix and corresponding results.

Trial No.	**Shoulder diameter** (mm)	**Tool rotational speed** (rpm)	**Dwell time** (s)	**TSFL** (N)
1	15	750	45	3128.00
2	15	1500	45	3327.00
3	21	750	45	3481.00
4	21	1500	45	3213.00
5	15	1125	30	3876.00
6	15	1125	60	3287.00
7	21	1125	30	3631.00
8	21	1125	60	3958.00
9	18	750	30	2584.20
10	18	750	60	2896.00
11	18	1500	30	3025.00
12	18	1500	60	2935.90
13	18	1125	45	2923.00
14	18	1125	45	2921.00
15	18	1125	45	2927.00

3. MODEL DEVELOPMENT

A number of experimental design techniques are available to obtain the regression coefficients. In this work, Box-Behnken experimental design was used to obtain the second order regression coefficients. The RSM procedure and determination of model coefficients can be found in Myers *et al.* [19]. The significant regression coefficients were determined at 95% confidence level and then the final mathematical model was developed to estimate TSFL as given in Eq.(1). The quadratic equationobtained after elimination of inconsequential coefficients (terms with $P > 0.05$) is

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$$\text{TSFL} = 43028 - 16.2751\ \text{TRS} - 4683.65\ \text{SD} - 187.583\ \text{DT} - 0.00523515\ \text{TRS}^2 + 126.368\ \text{SD}^2 - 0.199556\ \text{TRS.SD}9.24444\ \text{SD.DT} \quad (1)$$

3.1 Adequacy of the model developed

The developed model was tested using analysis of variance (ANOVA) and the results is given in the Table-2. The value of determination coefficient $\mathrm{R}^2 = 0.9898$ indicates that less than 2 % of the total variances are not explained by it. The high value of adjusted coefficient $\mathrm{R}^2 = 0.9716$ indicates the high significance of the developed model. The predicted R^2 is in agreement with the adjusted R^2.

The probability value (p – value) for the developed model is less than 0.005 indicating that the model is significant. Added to this, tool rotation speed (TRS), shoulder diameter(SD), dwell time (DT) and interaction effect of tool rotation speed and shoulder diameter (TRS. SD), interaction effect of shoulder diameter and dwell time (SD. DT) and second order term of tool rotation speed (TRS^2), shoulder diameter (SD^2) have significant effect. The Lack of fit is non-significant indicating the fitness of the model.

The plot of residuals as shown in the Figure-2 is a straight line indicating the normal distribution of errors. The above all considerations indicate that the regression model is adequate.

Table-2. ANOVA results for TSFL (only significant terms).

Source	DF	SS	Adj. SS	MS	F – value	p – value
Model	7	10154413	10154413	1450630	97.10	0.000
Linear	3	1961701	1961701	653900	43.77	0.000
TRS	1	919368	919368	919368	61.54	0.000
SD	1	234162	234162	234162	15.70	0.005
DT	1	807720	807720	807720	54.01	0.000
Square	2	7298887	7298887	7298887	244.28	0.000
TRS^2	1	2494574	2013065	2013065	134.75	0.000
SD^2	1	4804313	4804313	4804313	321.59	0.000
2-Way Interaction	2	893825	893825	446912	29.92	0.000
$\mathrm{TRS} \times \mathrm{SD}$	1	201601	201601	201601	13.49	0.008
$\mathrm{SD} \times \mathrm{DT}$	1	692224	692224	692224	46.34	0.000
Residual Error	7	104575	104575	14939		
Lack of Fit	5	80252	80252	16050	1.32	0.484
Pure Error	2	24323	24323	12161		
Total	14	10258988				
R^2 = 98.98% R^2(pred) = 95.95%			R^2(adj) = 97.96%			

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

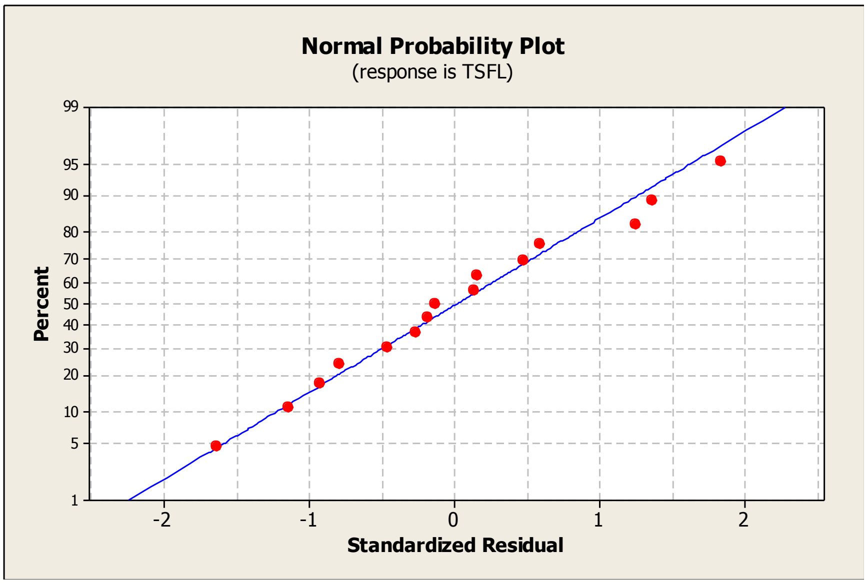
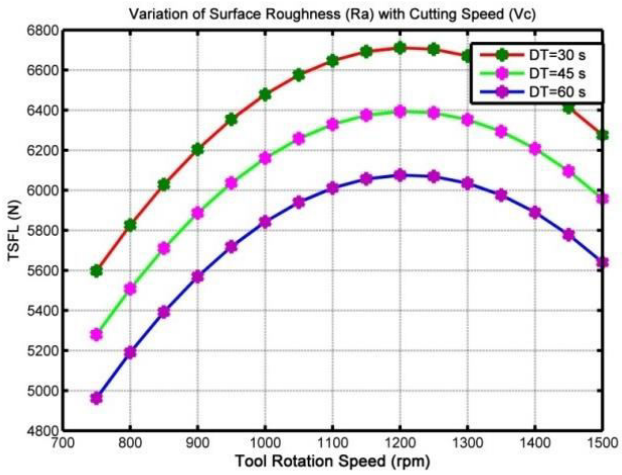


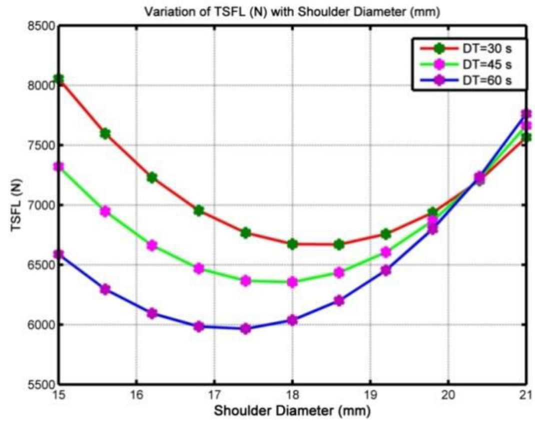
Figure-2. Residual plots for the response (TSFL).

4. RESULTS AND DISCUSSION

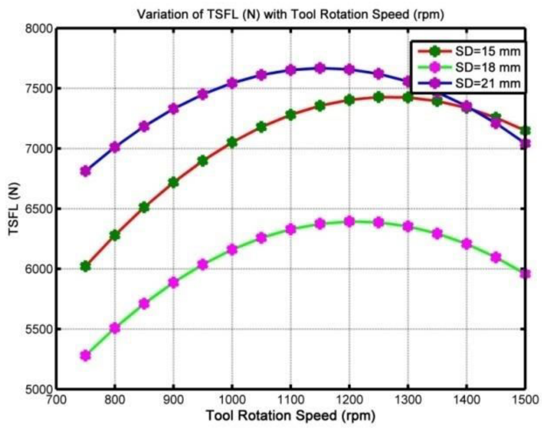
The effect of FSSW parameters on the TSFL of the welded joints is depicted in Figure-3. From Figure-3(a), it can be interpreted that TSFL increases with increase in TRS and then TSFL decreases with increase in TRS. The same trend is obtained at different DT. The optimum value of TRS is 1200 rpm (approx.) as there is decrease in TSFL with the lower and upper limit of TRS.



(a)



(b)



(c)

Figure-3. Effect of parameters on TSFL (a) TRS (b) SD (c) DT.

Increase in dwell time increases the heat generated at the stir spot creating a good plasticised flow of alloy. This increases the TSFL at high dwell period as shown in Figure-3(b). Maximum TSFL is obtained at SD of 21 mm and at DT of 60 s. Figure-3(c) depicts that maximum TSFL is obtained at TRS of 1100 rpm. As seen in Figure-4, the TSFL initially increases with increase in TRS and then increases to a maximum value of 1265 rpm. TSFL decreases with increase in SD and there is an increase after a SD of 17 mm. But the maximum TSFL is obtained only at SD of 15 mm. The dwell time is inversely proportional to TSFL. With increase in DT, TSFL decreases. The predicted optimum TSFL obtained from the plot is TRS of 1265 rpm; DT of 30 s and SD of 15 mm is 8163 N.

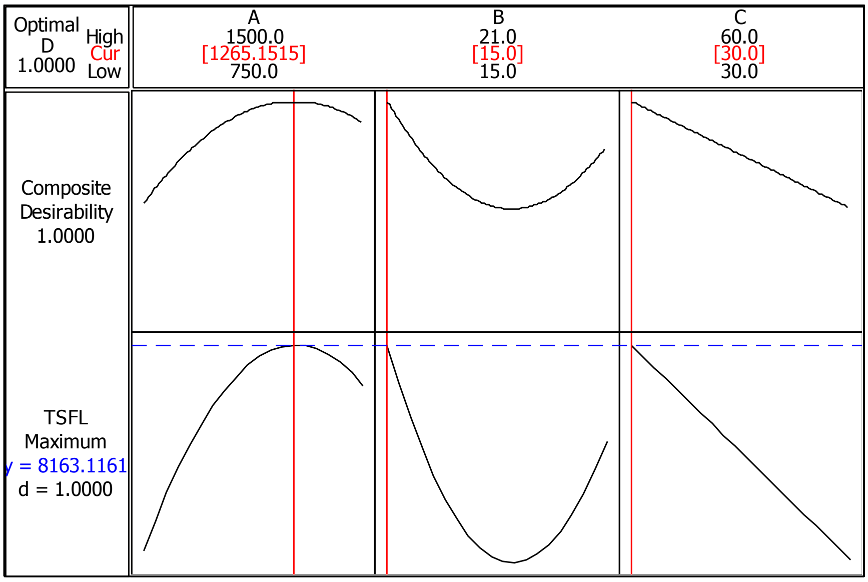


Figure-4. Optimization plot.

5. CONCLUSION

Aluminum alloy AA6061 plates are joined by FSSW under varying rotation speeds, tool shoulder diameter and dwell time combinations. The TSFL of the welded joints are measured and response surface technique is used to build a model for the TSFL of the welds. The developed equation is used to find the optimum parameter combinations for obtaining joints with higher TSFL. The FSSW parameters affect the strength of the joints, with TRS having major influence on TSFL followed by shoulder diameter and dwell time.The FSSW parameter for achieving stronger joints are predicted as: TRS of 1265 rpm, DT of 30 s and SD of 15 mm for maximum TSFL of 8163 N for the experimental conditions used.

REFERENCES

[1] Mishra, R.S. and Z.Y. Ma, Friction stir welding and processing. Materials Science and Engineering: R: Reports, 2005. 50(1-2): p. 1-78.

[2] Ojo, O.O., E. Taban and E. Kaluc, Friction stir spot welding of aluminium alloys: A recent review. Materials Testing, 2015. 57(7-8): p. 609-627.

[3] Bilici, M.K. and A.I. Yukler, Effects of welding parameters on friction stir spot welding of high density polyethylene sheets. Materials & Design, 2012. 33: p. 545-550.

[4] Babu, S., *et al.*, Microstructures and mechanical properties of friction stir spot welded aluminium alloy AA2014. Journal of Materials Engineering and Performance, 2013. 22(1): p. 71-84.

[5] Karthikeyan, R. and V. Balasubramanian, Statistical Optimization and Sensitivity Analysis of Friction Stir Spot Welding Process Parameters for Joining AA 7075 Aluminium Alloy. Experimental Techniques, 2013. 37(2): p. 6-15.

[6] Lacki, P., *et al.*, Effect of Tool Shape on Temperature Field in Friction Stir Spot Welding, in Archives of Metallurgy and Materials. 2013. p. 595.

[7] Buffa, G., *et al.*, Influence of joint geometry on micro and macro mechanical properties of friction stir spot welded joints. Procedia Engineering, 2014. 81: pp. 2086-2091.

[8] Baskoro, A.S., *et al.*, Effects of Dwell-Time and Plunge Speed during Micro Friction Stir Spot Welding on Mechanical Properties of Thin Aluminium A1100 Welds. Applied Mechanics and Materials, 2015. 758.

[9] Güler, H., Investigation of the tool effect on the strength of friction stir spot welded aluminium

specimens: A comparative study. Materials Testing, 2015. 57(3): p. 239-244.

[10] Jambhale, S., S. Kumar, and S. Kumar, Effect of Process Parameters and Tool Geometries on Properties of Friction Stir Spot Welds: A Review. Universal Journal of Engineering Science, 2015. 3(1): p. 6-11.

[11] Lakshminarayanan, A., V. Annamalai, and K. Elangovan, Identification of optimum friction stir spot welding process parameters controlling the properties of low carbon automotive steel joints. Journal of Materials Research and Technology, 2015. 4(3): p. 262-272.

[12] Krishnaraj, C., Mohanasundram, K. M., & S. Navaneethasanthakumar. (2012). Implementation Study Analysis of Ftfmea Model in Indian Foundry Industry. Journal of Applied Sciences Research, 8(2), 1009-1017.

[13] Paidar, M. and M.L. Sarab, Friction stir spot welding of 2024-T3 aluminium alloy with SiC nanoparticles. Journal of Mechanical Science and Technology, 2016. 30(1): p. 365-370.

[14] Manickam, S. and V. Balasubramanian, Maximizing Strength of Friction Stir Spot Welded Bimetallic Joints of AA6061 Aluminium Alloy and Copper Alloy by Response Surface Methodology.

[15] Siddharth, S. and T. Senthilkumar, Study of Friction Stir Spot Welding Process and its Parameters for Increasing Strength of Dissimilar Joints.

[16] Paidar, M., et al., Effect of welding parameters (plunge depths of shoulder, pin geometry, and tool rotational speed) on the failure mode and stir zone characteristics of friction stir spot welded aluminium 2024-T3 sheets. Journal of Mechanical Science and Technology, 2015. 29(11): p. 4639-4644.

[17] Lambiase, F., A. Paoletti, and A. Di Ilio, Mechanical behaviour of friction stir spot welds of polycarbonate sheets. The International Journal of Advanced Manufacturing Technology, 2015. 80(1-4): p. 301-314.

[18] Cox, C.D., *et al.*, Energy input during friction stir spot welding. Journal of Manufacturing Processes, 2014. 16(4): p. 479-484.

[19] Tozaki, Y., Y. Uematsu, and K. Tokaji, Effect of tool geometry on microstructure and static strength in friction stir spot welded aluminium alloys. International Journal of Machine Tools and Manufacture, 2007. 47(15): p. 2230-2236.

[20] Myers, R.H. and D.C. Montgomery, Response Surface Methodology Process and product optimization using Designed Experiments. Second ed. Wiley Series in Probability and Statistics. 2001: John Wiley and Sons, Inc.