Optimization of Input Parameters in Friction Stir Welding of High Density Polyethylene Sheets

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Abstract—Friction stir welding (FSW) process is a solid state joining process which uses anon consumable tool to form joint between to plates. In FSW the material that is being welded does not melt completely and recast. To obtain maximum strength, it is essential to have a complete control the relevant process parameters to maximize the Lap shear fracture force on which the quality of welded joint is based. In the present investigation an optimization of Friction stir welding parameters has been carried out using Response surface methodology. The parameters Tool rotation speed, Dwell time and Tool pin profile were chosen for study. Lap shear fracture force is taken as response criteria for spot welding.The effect of various parameters on the strength of joint were studied. In FSSW of HDPE sheets Empirical relationships were established between input parameters and responses to predict LSFF.

Keywords*-Friction stir welding (FSW), Optimization, Response surface Methodology, High Density Polyethylene sheets*

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I. INTRODUCTION

Friction stir welding (FSW) is a solid state welding process and it considered the most significant development developed by the welding Institute (UK) in 1991. [1] Now being used increasingly for joining High Density Polyethylene sheet for which fusion welding is often difficult.FSW uses a non-consumable tool to generate frictional heat at the point of welding, inducing gross plastic deformation of the work piece. The plates to be joined are placed on a rigid backing plate and clamped in a manner that prevents the abutting joint faces from separating. A cylindrical-shouldered tool, with a specially projecting pin (probe) is rotated and slowly plunged into the joint line. The pin length is similar to the required weld depth. The shoulder of the tool is forced against the plates. The rotating tool causes friction heating of the plates which in turn lowers their mechanical strength. The rotating tool at a high angular speed is plunged into workpiece until the tool shoulder contacts the top surface of the upper workpiece to form a weld spot. After plunging, the stirring of material starts when the tool reaches a predetermined depth. In this stage, the tool keeps rotating in the workpieces. Due to high rotation speed of tool heat is generated and thus the materials adjacent to the tool are heated, softened, and mixed in the stirring where a solid-state joint will be formed. Generally, the quality of a weld joint is directly influenced by the welding input parameters during the welding process; therefore, welding can be considered as a multi-input multi-output process.[3] It is required to control the welding input parameters which play an important role in determining the mechanical properties of welded joints. Therefore proper selection of process parameter is necessary to achieve good quality of welded joint.In order to overcome this problem various optimization technique can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameter and output variables. In this study the optimization of process parameter is done by using Response Surface Methodology. High-density polyethylene is one of the most popular polymers due to its availability competitive cost. HDPE is a thermoplastic with noticeable mechanical properties. With the increasing development of engineering plastics, the demand for reliable, rapid, high productivity and cost effective joining methods, similar to those used in the case of metals, also increases.

Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response.[2] The RSM is important in designing, formulating, developing, and analyzing new scientific studies and products.[12] It is also efficient in the improvement of existing studies and products. RSM will be used to reduce the number of experiments, in addition to build a numerical relation between the quality of welding and the welding parametersRecently some reports have been available on the FSW polyethylene sheets and their optimization by Response surface methodology but no study has been reported on optimization of FSSW of HDPE sheets by using RSM so that this material is select for further study.

II.Experimental Work

The plates of HDPE sheets 5 mm thickness cut into required size 400×75×5 (mm). Lap joint configuration was prepared to fabricate FSSW joint non-consumable tools made of Mild Steel were used to weld the joint.Welded joint was shown in Fig 1. From the initial experiments the working rage of parameters were decided as shown in Table 1.The experiments

ISSN: 2321-8169
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are performed according to the three level three factors Central composite design matrix to prescribe the required number of experimental condition. Table 2 shows the 20 set of coded condition used to form the design matrix

Sr. No	Factors	Notation	Levels		
			-1	0	1
1	Tool rotation speed	R	560	900	1400
2	Dwell Time	D	30	60	90
3	Tool Pin Profile	T	S.C.	T.C	TC Threaded

Table 1: Level of Parameters

SC-Straight Cylindrical
TC-Taper Cylindrical

	Coded Value			
Run Order	Rotational speed (R)	Dwell Time (D)	Tool Pin Profile(T)	LSFF (KN)
1	-1	-1	-1	2.738
2	1	-1	-1	3.167
3	-1	1	-1	2.711
4	1	1	-1	2.828
5	-1	-1	1	2.887
6	1	-1	1	3.193
7	-1	1	1	2.805
8	1	1	1	2.761
9	-1	0	0	3.567
10	1	0	0	3.749
11	0	-1	0	3.405
12	0	1	0	3.517
13	0	0	-1	4.080
14	0	0	1	3.910
15	0	0	0	4.042
16	0	0	0	4.017
17	0	0	0	4.042
18	0	0	0	4.087
19	0	0	0	4.082
20	0	0	0	4.112

Table 2: Experimental run

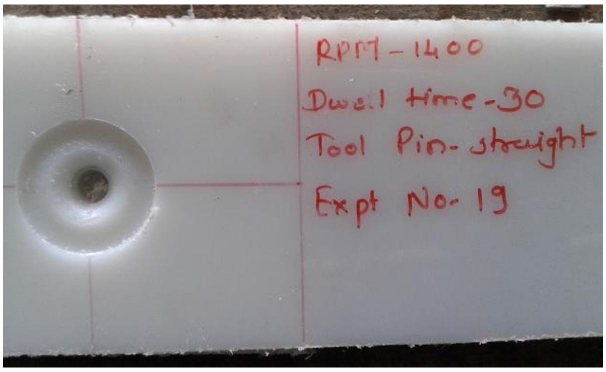

Figure1: Welded specimen of HDPE

III. Result and Discussion

A.Analysis of experiments

Analysis of the experimental data obtained from CCD design runs is done on MINITAB R14 software using full quadratic response surface model as given by

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j\ x_j + \sum_{j=1}^{k} \beta_{j\,j}\, x_j^{\,2} + \sum_{j=2}^{k} \beta_{ij}\ x_i x_j$$

Where *y* is the response, *i x* is i^{th} factor

For significance check F value given in ANOVA table is used. Probability of F value greater than calculated F value due to noise is indicated by p value. If p value is less than 0.05, significance of corresponding term is established. For lack of fit p value must be greater the 0.05. An insignificant lack of fit is desirable as it indicates anything left out of model is not significant and develop model fits. Based on analysis of variance (ANOVA) test full quadratic model was found to be suitable for LSSF with regression p-value less than 0.05 and lack of fit more than 0.05

Term	Coeff.	SE Coeff	T	P
Constatnt	4078.56	27.31	3.623	0.005
A	98.95	27.31	3.623	0.005
B	-76.65	27.31	-2.806	0.019
C	3.20	27.31	0.117	0.909
A*A	-442.16	52.09	-8.489	0.000
B*B	-639.16	52.09	-12.271	0.000
C*C	-105.41	52.09	-2.024	0.071
A*B	-82.75	30.54	-2.710	0.022
A*C	-35.63	30.54	-1.167	0.270
B*C	-18.50	30.54	-0.606	0.558

R^2=98.2% R^2(adj)=97.5

Table 3 :Estimated regression coefficients for LSSF

In Lap share fracture force analysis factors A, B and interaction A*A, B*B, C*C, A*B are important because their P value is less than 0.05. The coefficient of determination (R2) which indicates the goodness of fit for the model so the value of R2 =98.2% which indicate the high significance of the model.

$$LSFF\ (N) = 4078.56 + 98.95(A) - 76.65(B) - 442.16\ (A)^2 - 639.16\ (B)^2 - 105.41\ (C)^2 - 82.75(AB)$$

Sr No	Expt	Predicted	Percentage error
1	2738	2786.78	-1.75041
2	3167	3150.18	0.533938
3	2711	2798.98	-3.14329
4	2828.5	2831.38	-0.10172
5	2887	2786.78	3.596265
6	3193	3150.18	1.359287
7	2805.5	2798.98	0.232942
8	2761	2831.38	-2.48571
9	3567.5	3537.45	0.849482
10	3749	3735.35	0.365428
11	3405	3516.05	-3.15837
12	3517.5	3362.75	4.601888
13	4080	3973.15	2.689302
14	3910	3973.15	-1.58942
15	4042.5	4078.56	-0.88414
16	4017.5	4078.56	-1.4971

 ISSN: 2321-8169
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17	4042.5	4078.56	-0.88414
18	4087.5	4078.56	0.219195
19	4082	4078.56	0.084343
20	4112	4078.56	0.819897

Table 4: Experimental value with predicted

Source	DF	SS	MS	F	P
Regression	9	56796.82	6310.76	84.59	0.000
Linear	3	1567.66	522.55	7.00	0.008
Square	3	54552.45	18184.15	243.74	0.000
Interaction	3	676.72	225.57	3.02	0.080
Residual	10	746.04	74.60		
Lack of Fit	5	683.37	136.67	10.90	0.010
Pure error	5	62.67	112.53		
Total	19	57542.86			

Table 5:Analysis of Variance for LSFF

B.Response surface analysis for LSFF

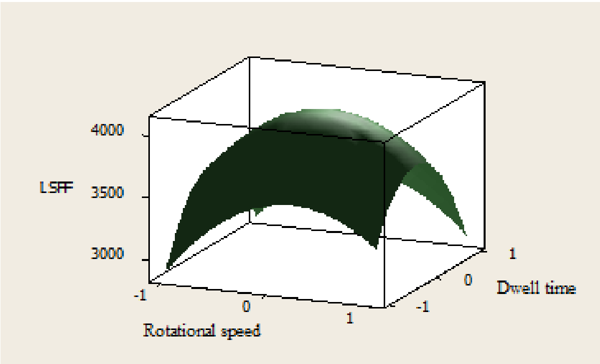

Fig 2: Surface Plot of LSFF vs Dwell Time, Rotatinal speed

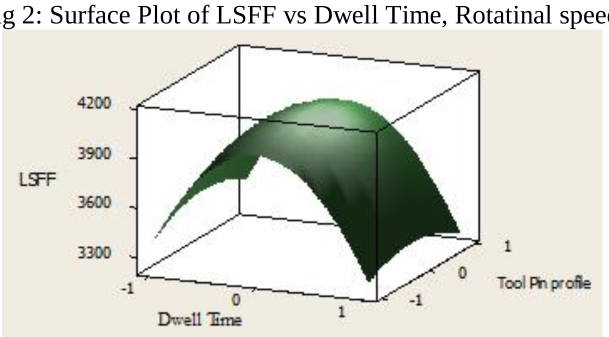

Fig 3: Surface Plot of LSFF vs Tool Pin profile, Dwell Time

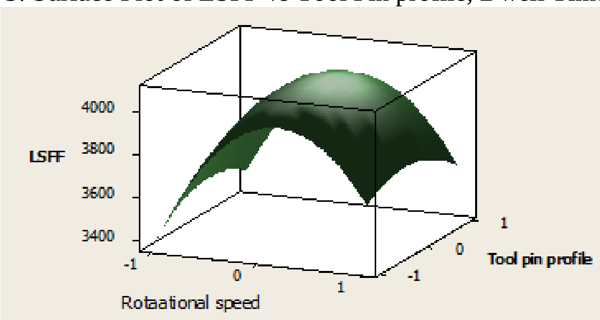

Fig.4: Surface Plot of LSFF vs Tool pin profile, Rotational speed

Contour plots show distinctive circular shape indicative of possible independence of factors with response. A contour plot is produced to visually display the region of optimal factor settings. For second order response surfaces, such a plot can be more complex than the simple series of parallel lines that can occur with first order models. Once the stationary point is found, it is usually necessary to characterize the response surface in the immediate vicinity of the point by identifying whether the stationary point found is a maximum response or minimum response or a saddle point. To classify this, the most straightforward way is to examine through a contour plot. Contour plots play a very important role in the study of the response surface. By generating contour plots using software for response surface analysis, the optimum is located with reasonable accuracy by characterizing the shape of the surface. If a contour patterning of circular shaped contours occurs, it tends to suggest independence of factor effects while elliptical contours as may indicate factor interactions. Response surfaces have been developed for both the models, taking two parameters in the middle level and two parameters in the *X* and *Y* axis and response in *Z* axis. The response surfaces clearly reveal the optimal response point. RSM is used to find the optimal set of process parameters that produce a maximum or minimum value of the response. In the present investigation the process parameters corresponding to the maximum Lap shear fracture force are considered as optimum. Hence, when these optimized process parameters are used, then it will be possible to attain the maximum Lap shear fracture force.

From response surface of Fig.2 it is observed that fracture force first increase and then decrease with rotational speed. The reason may be that at highest rotational speed temperature is also increased which decrease the strength of the joint. The same thing is happened in case of variation in dwell time the fracture force increase and after that decrease. But the effect of variation of dwell time on LSSF is more as compared to the effect of the Rotational speed.

Response surface graph shown in Fig.3 is drawn between LSFF, Tool Pin profile and Dwell Time. Variation of dwell time and tool pin profile against fracture force is studied. In which it is observed that change in tool pin profile has less effect on variation of Lap shear fracture force. Effect of dwell is similar to previous response surface graph. Increase in dwell time gives more force up to the 60 s after this it get decreased. Lap shear fracture force is increased up to a certain level and then decrease in both the cases i.e. dwell time and tool pin profile.

Combination of the tool pin profile and rotational speed increase the tensile strength observed in fig 4. In this response surface graph Lap shear fracture force first increase up to certain level and then decrease. Same thing is repeated in cases of dwell time.

III. CONCLUSION

In this work the Design of Experiment is used for conducting the experiments. Response surface methodology gives the mathematical model to predict the responses. The joints fabricated using Taper cylindrical profile tool with rotational speed of 900 rpm and 60 sec dwell time exhibited superior Lap shear fracture force compared to other joint. The results obtain by Response Surface Methodology are summarize as follows.

- In FSSW of HDPE sheets the effect three process parameters rotational speed, dwell time and tool pin profile studied on LSFF of HDPE welded joint is studied through response surface analysis.
- A mathematical relationship has been developed to predict the LSFF of friction stir welded HDPE sheets

by incorporating FSW process parameters using statistical tools such as design of experiment, ANOVA and regression analysis

- Based on the regression models the effects of FSW parameters on Lap shear fracture force of friction stir welded joints were presented and interpreted in detail

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