FSSW of Polycarbonate Sheets using Conventional Drilling Machine

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Abstract— Friction stir spot welds are made by applying pressure using a rotating tool onto the top surface of two sheets that overlap each other to create a lap joint. Due to the frictional heat and the high pressure created by the rotating tool, it plasticize the workpiece material. This paper discuss on the friction stir spot welding of polycarbonate sheets of 3mm thickness, using a conventional drilling machine with process parameters as dwell time, waiting time and tool rotational speed. A stainless steel tool of shoulder diameter 20mm, pin diameter 5mm and pin length 4mm is used to make these FSSW joints. By varying these parameters using a 3x3 full factorial design, a total of 27 lap joints by FSSW of polycarbonate sheets have been made. Studies have been conducted to evaluate the influence of process parameters on the shear strength of FSSW lap joints. Optimal process parameters for maximum shear strength are found out from shear strength test. Optimization of process parameters using Taguchi method and grey relational analysis are also done. It is seen that the shear strength of the FSSW joint obtained with the optimal process parameters are found to near the tensile strength of the polycarbonate sheet.

Keywords: FSSW, Conventional Drilling Machine, UTM

I. Introduction

The polycarbonate material does not melt during welding as the FSSW is a solid state welding method. It does not require any filler metal, flux or shielding gas. The process is carried out by applying pressure using a rotating cylindrical tool to the metal sheets. At the tip of the tool there is a projected portion, known as the pin. The configuration and dimensions of the tool, especially the pin, vary depending on the material, the thickness of the sheets, and the strength requirements of the joint.

FSSW is like friction stir welding. Both the methods utilize a rotating tool with a pin. But in friction stir welding, the tool travels along a path between two metal plates, while in friction spot joining, the tool is kept stationary.

Resistance spot welding is a typical joining method in the automotive industry. Polycarbonate sheets are conventionally welded by Resistance spot welding technique. But it has some issues like wear, overheating, flush and melting. Because of these problems, FSSW method has been developed as an alternative method.

A Paoletti Et al. [1] (2015) optimized the mechanical strength of friction stir weld of thermoplastics by using artificial neuron network technique. By using Artificial Neural Network the influence of FSSW process parameters on the maximum plunging force, joint strength and, maximum torque of polycarbonate sheet welds has been modelled. M K Bilici [2] (2012) optimized friction stir spot welding parameters of polypropylene for maximum weld strength using Taguchi approach. There was an improvement in the weld strength of about 47.7% by using the optimal welding parameters. A Bagheri Et al. [3] (2013) optimized the mechanical properties of friction stir welded ABS sheets by experimental analysis. Analysis is done in this study on the tensile strength of friction stir welded ABS sheets. The structure and weld quality of the lowest and the highest tensile strength samples were compared. It has been inferred that better weld quality and better weld strength was attained by the usage of high level of shoe temperature and rotational speed and a low level of tool travel speed. F Lambiase Et al. [4] (2016) examined the impact of tool geometry on the mechanical strength of friction stir spot welded joints of polycarbonate sheets. From the results, when the pin diameter and taper angle are increased the strength of the welds are reduced. Mechanical strength showed an increase upon increasing the tool shoulder diameter.

II. Experiments

A. *Characterization of Parent Material*

The polycarbonate sheet is cut into a tensile specimen based on the standard ASTM D638 as shown in Fig 5. The polycarbonate sheets are cut using a laser cutting machine [5]. After the tensile specimen is made, they are subjected to tensile test. The tensile specimen is fixed between the jaws of a computer controlled UTM.

B. *Experimental Setup*

The friction stir spot welding process is done with the help of a conventional pillar drilling machine shown in Fig 1. The tool material used in this experiment is stainless steel of grade 304 [6]. A tool with shoulder diameter 20 mm, pin diameter 5mm and pin length 4 mm (T1 tool) and also same tool with shoulder diameter 10 mm (T2 tool) is also used here.

The FSSW process consists mainly of three steps [7]. FSSW setup on pillar drilling machine is shown in Fig 2. The dimension of the polycarbonate sheets in lap joint position is shown in Fig 3. First step is plunging, then stirring and finally retracting. The tool is rotated at a high rotational speed. The tool is then moved to the weld spot until the pin of the tool comes in contact with the top surface of the polycarbonate sheet.

Now the feed of the tool is stopped. As the rotation continues, it produces a material heating and this time period is called preheating time.


Fig. 1: Pillar drilling machine


Fig. 2: FSSW setup on pillar drilling machine

The tool is plunged into the polycarbonate sheet till the bottom of the shoulder part of tool touches the top surface of the polycarbonate sheet, after the preheating time is over [8]. The plunging motion of the tool causes ejection of the polycarbonate material. When the tool attains the required depth (4mm), the plunging motion of the tool is stopped. Then the stirring phase starts. In this phase, the tool is made to rotate inside the polycarbonate sheet without any plunging of the tool. This time period is called the dwell time [9].

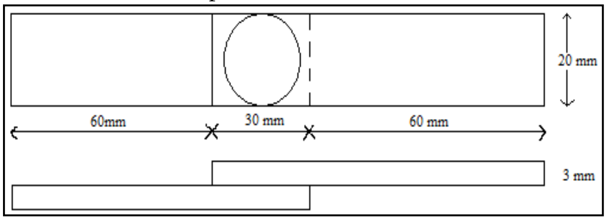

Fig. 3: Dimensions of the workpiece for FSSW

The material near the tool gets heated and softened as frictional heat is produced during the plunging and stirring steps [10]. Upper and lower polycarbonate material gets mixed in the stirring phase.

Rotation of the tool is stopped when the predefined dwell time is reached. Now the tool remains stationary in the polycarbonate sheet for a time period known as the waiting time. FSSW joint is formed because of the pressure exerted by the shoulder of the tool on the softened polycarbonate material. After the waiting time is over, the process is stopped. Now the tool is taken out from the polycarbonate sheets [11].

C. Experimental Procedure and Plans

The tool used for the FSSW process is shown in Fig 4. The variable process parameters used for making the FSSW joints are dwell time, waiting time and tool rotational speed, as shown in Table 1. The constant process parameters are preheating time (20 sec) and load.

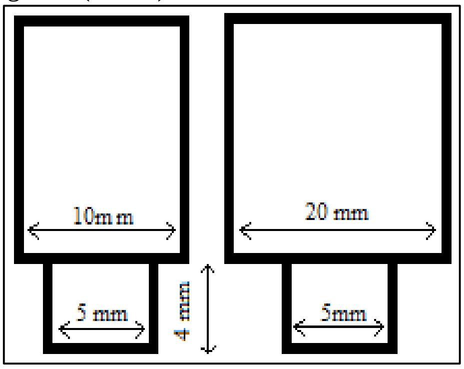

Fig. 4: Schematic of tools (T2 and T1 respectively)

Welding parameters	Level 1	Level 2	Level 3
Dwell time (sec)	10	20	30
Waiting time (sec)	10	20	30
Tool speed (rpm)	500	650	1000

Table 1: Process parameters

Preheating time of 20 sec is kept constant throughout the process. Using a 3X3 full factorial design of experiments, 27 FSSW joints were made using a stainless steel tool of shoulder diameter 20mm (T1 tool). The tool (stainless steel rod) and polycarbonate sheets are fixed onto the vertical milling machine and the experiment is started. The first FSSW weld (specimen 1) is made by selecting a dwell time of 10 sec, waiting time of 10 sec and tool rotation speed of 500 rpm. Likewise, 26 more specimens are made [12].

D. Characterization Tests of FSSW Welds

Shear test of the 27 FSSW joints made by T1 tool were done using a computerized UTM machine. Optimal process parameters were found out by analysing the shear test results [13]. Tensile strength of the polycarbonate sheet is compared with the shear strength of the FSSW joints made by T1 tool.

III. Results and Discussions

A. Mechanical behaviour of parent material

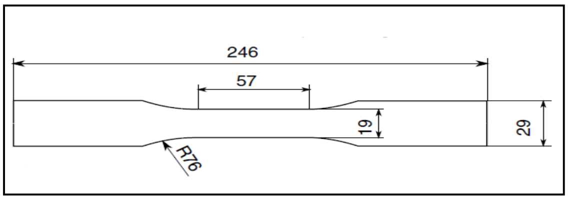

Fig. 5: Tensile test specimen as per ASTM D638

Tensile strength obtained from the tensile test conducted on the polycarbonate sheet is 45.40 MPa. Image of the tensile specimen after tensile test is shown in Fig 6.

B. Shear Test Results

Shear strength test of the 27 FSSW joints made by T1 tool are done. A close-up view of the FSSW joint gripped in the UTM machine is shown in Fig 7. Shear test results obtained by welds made by T1tool are tabulated in Table 3. From the shear strength results it has been identified that a maximum shear strength value of 42.96 MPa has been obtained.

Fig. 6: Tensile specimen after tensile test

This shear strength value corresponds to process parameters of dwell time 30 sec, 20 sec and tool speed 1000 rpm [14]. Thus these process parameters are considered to be experimentally optimum parameters for maximum shear strength of the FSSW of polycarbonate sheets. At this optimal process parameters, 2 FSSW joints are made using T2 tool and the shear strength test is done. Shear test results obtained by welds made by T2 tool are tabulated in Table 4. From the shear test results using T2 tool, average shear strength of 33.25 MPa is obtained. On the other hand the shear strength obtained using T1 tool is 42.96 MPa at the same optimal process parameters. A comparison of the strengths obtained by T1 tool, T2 tool and the parent material is shown in Fig 10.

Fig. 7: Close-up view of specimen in UTM

C. Influence of Process Parameters

The optimization of shear strength, for weld done by T1 tool, was done by Taguchi analysis using Minitab software. The tool rotational speed was found to be the most influencing parameter on the shear strength of weld; then followed by waiting time and dwell time.

Sl No.	Dwell time (sec)	Waiting time (sec)	Tool speed (rpm)	Peak Load (N)	Shear Strength (MPa)
1	10	10	500	340	11.33
2	10	10	650	527	17.56
3	10	10	1000	1000	33.33
4	10	20	500	149	4.96
5	10	20	650	390	13
6	10	20	1000	192	6.4
7	10	30	500	746	24.86
8	10	30	650	584	19.46
9	10	30	1000	610	20.33
10	20	10	500	829	27.63
11	20	10	650	847	28.23
12	20	10	1000	1138	37.93
13	20	20	500	168	5.6
14	20	20	650	1004	33.46
15	20	20	1000	1289	42.96
16	20	30	500	116	3.86
17	20	30	650	652	21.73
18	20	30	1000	472	15.73
19	30	10	500	196	6.53
20	30	10	650	1171	39.03
21	30	10	1000	1363	45.43
22	30	20	500	689	22.96
23	30	20	650	825	27.5
24	30	20	1000	1425	47.5
25	30	30	500	218	7.26
26	30	30	650	261	8.7
27	30	30	1000	627	20.9

Table 2: Shear test results using T1 tool

The optimized process parameters based on Taguchi analysis are: dwell time 30 sec, waiting time 10 sec and tool rotational speed 1000 rpm. Main effects plot for means is shown in Fig 8. Main effects plot for SN ratios is shown in Fig 9. From these two plots it can be inferred that as the dwell time increases, shear strength also increases.

Sl no	Dwell time (sec)	Waiting time (sec)	Tool speed (rpm)	Peak load (N)	Shear strength (MPa)
A	30	20	1000	704	35.2
B	30	20	1000	626	31.3

Table 3: Shear test results using T2 tool

As the waiting time increases, shear strength decreases. As the tool rotational speed increases shear strength increases.

A response table for means and SN ratios are also tabulated using Minitab software as shown in Table 5 and Table 6 respectively. From this it has been found out that the most influencing parameter is tool rotational speed followed by waiting time and dwell time.

Grey relational analysis was done to verify the results obtained from Taguchi analysis methods. It is shown in Table 7.

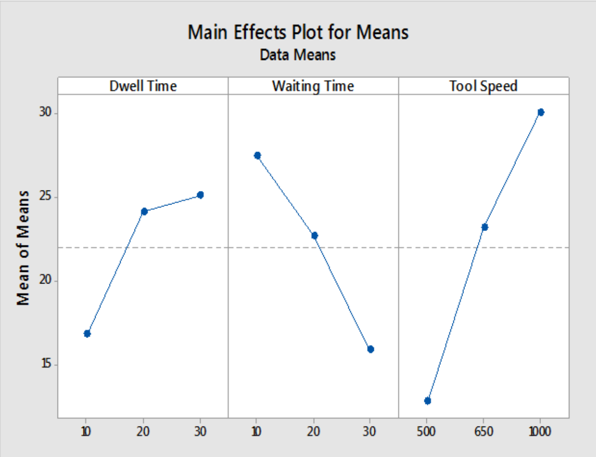

Fig. 8: Main effects plot for means

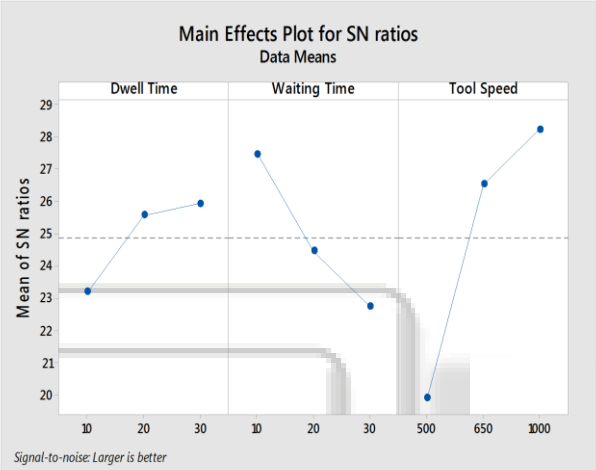

Fig. 9: Main effects plot for SN ratios

Level	Dwell time	Waiting time	Tool speed
1	16.80	27.44	12.78
2	24.13	22.70	23.19
3	25.09	15.87	30.06
Delta	8.29	11.57	17.28
Rank	3	2	1

Table 4: Response table for means from taguchi analysis

Level	Dwell time	Waiting time	Tool speed
1	23.18	27.46	19.91
2	25.55	24.44	26.51
3	25.91	22.74	28.22
Delta	2.74	4.72	8.32
Rank	3	2	1

Table 5: Response table for SN ratios from taguchi analysis

Level	Avg. GRG	Avg GRG	Avg GRG
Level 1	0.427906883	0.570542747	0.39722261
Level 2	0.525247015	0.538261746	0.49407765
Level 3	0.570648573	0.406831514	0.632502213
Optimal value	Dwell time	Waiting time	Tool speed
	30	10	1000

Table 6: Grey relational analysis results

The results obtained from grey relational analysis were same as that of Taguchi analysis.

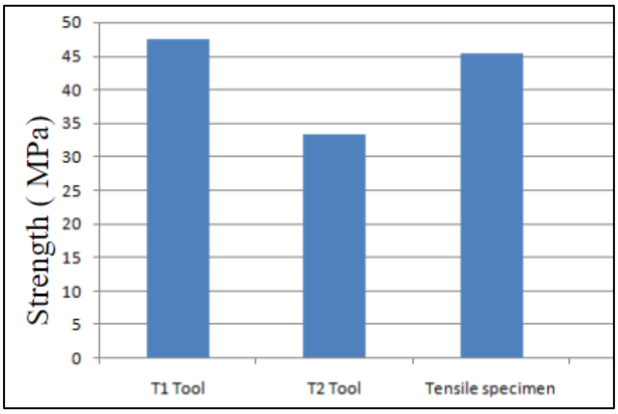

Fig. 10: Strength comparison graph

IV. CONCLUSIONS

Friction stir spot welding of polycarbonate material is a promising method of welding due to its advantages over other joining technologies. The effect of friction stir spot welding on the preheating time, dwell time and waiting time of polycarbonate sheets weld has been analysed experimentally and also using Taguchi analysis. The following points have been concluded from this project:

The effect of friction stir spot welding parameters on the shear strength of the welded joints are analysed and compared. It can be inferred from those comparisons that the parameters selected directly influence the strength of the FSSW joints.

- Increasing the dwell time makes it possible to increase the maximum weld area temperature. As a result, weld strength increases with the dwell time almost linearly.
- Before proceeding with the removal of the tool from the polycarbonate sheets, a certain amount of waiting time must be elapsed to prevent the removal of the welded joint.
- Increased rotational speed of the tool produces higher frictional heat and higher softening of the polycarbonate sheet. Thus the maximum tool speed resulted in maximum FSSW joint strength.
- The shear strength of the welded area came close to the parent material's tensile strength under optimal conditions. The FSSW technique can therefore be implemented using a conventional drilling machine at optimal conditions.

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