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OPTIMIZING THE WELDING PARAMETERS OF FRICTION STIR WELDING BY USING RESULTANT FORCE AND DEFECTS FOR NYLON 6 MATERIAL

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ABSTRACT

Nylon 6 is one of the thermoplastic materials that have a lot of engineering applications. Friction Stir Welding (FSW) is a solid-state method for joining metals. In this paper presents a successful FSW process to join non metals. Taguchi optimization methodology and analysis of variance (ANOVA) were used to study the effect of process parameters by this welding process.

In this investigation, an attempt was made to join the nylon 6 plate of 10 mm thickness with different FSW tool pin profiles (square, triangular, threaded and grooved with square pin profile) and different feeds such as 0.167, 0.333, 0.5 and, 0.667 mm/sec at a constant spindle speed of 1000 rpm.

During FSW, Forces acting on the tool along the three axes were measured and defects occurred in the joints were observed and analyzed for the process parameters optimization.

The main objective was to find the important factors which influence the welding process to achieve defect-free joint with minimum force acting on the tool. From this investigation, it is found that the joint fabricated using threaded pin profile tool at 0.167mm/sec needed minimum amount of resultant force and produced defect free welds.

KEYWORDS: ANOVA, Feed Rate, Nylon 6, Pin Profile, Taguchi

INTRODUCTION

FSW is a novel solid-state welding process for joining metallic alloys and composites; it has numerous applications in manufacturing situations [1, 2]. FSW is considered to be one of the most significant welding processes; FSW has the advantage of non-consuming tool for fabrication of continuous linear welds, the most common form of weld joint configuration.

This joining technique is energy efficient, environmental friendly and versatile [3]. In general, the process is carried out by slowly plunging a rotating FSW tool into the interface of two rigidly clamped sheets, until the shoulder touches the surface of the material being welded, and transverse along the weld line. The frictional heat and deformation heat are utilized for the bonding under the applied normal force [4].

The primary heat source is the frictional heat from tool shoulder and secondary heat source is the deformation heat from the tool pin [5]. The secondary heat was only utilized in this experiment because so as to prevent the over heat on the weld nugget. This process is illustrated in Figure 1.

Most of the literature on FSW focuses on aluminum alloys; however, recently interest has grown in applying this technique to the joining of thermoplastic materials. Currently, there are few reports on the study of the tool pin profile on polymers with FSW and they only explained about polyethylene and polypropylene for friction stir spot welding [6-11].

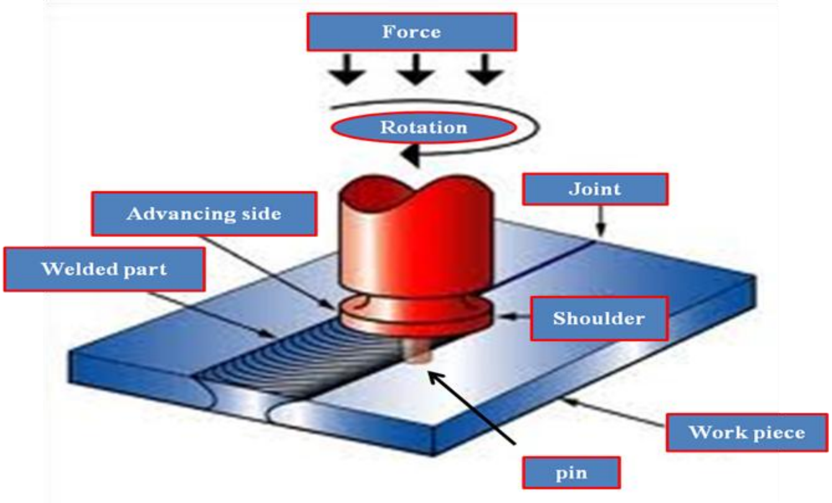

Figure 1: The FSW Process

This paper addresses this gap in the study on the effects of process parameters such as welding speed and tool pin profile. In this research, the effect of tool pin profiles and feeds are analyzed using ANOVA over the tool forces and joint defects.

EXPERIMENTAL PROCEDURE

FSW was performed on a CNC vertical machining centre for welding. The samples used in this work consisted of two 220 x 100 x 10 mm (length, width, depth) nylon 6 plates with density 1.15 g/cm^3, thermal conductivity 0.25 w/(m.K), specific gravity 1.13, tensile strength 5,800 Psi and, Rockwell hardness R104. Square butt joint configuration was prepared to fabricate the FSW joints. The initial joint configuration was obtained by securing the plates in position using clamps. Single pass welding procedure was used to fabricate the joints. The non-consumable rotating tools used in this study had four different tool pin profiles such as Square pin, Grooved with square pin, Triangular pin, and Threaded pin with a cylindrical shank. The fixed pin type tool was made of mild steel with a nominal pin diameter 6mm and shoulder diameter of 24mm and pin length of 9.5mm was used in the present investigation.

DESIGN OF EXPERIMENT, TAGUCHI METHOD AND EXPERIMENTAL DETAILS

Design of Experiment

Design of experiments (DOE) is a powerful analysis tool for modeling and analyzing the influence of process variables over some specific variables, which is an unknown function of these process variables. The most important stage in the DOE lies in the selection of the control factors. As many factors as possible should be included, so that it would be possible to identify the non-significant variables at the earliest opportunity. The feed rate and pin profile are the main parameters in friction stir welding. Table 1 shows the details of the variables used in this experiment

Table 1: Levels of the Variables Used in the Experiment

Variables	Lowest	Low	Medium	High
Pin profile	Square	Grooved	Threaded	Triangular
Feed rate in mm/sec	0.167	0.333	0.500	0.667

Taguchi Method

Taguchi defines the quality of a product, in terms of the loss imparted by the product to the society from the time the product is shipped to the customer. Some of these losses are due to the deviation of the product's functional characteristic from its desired value, and these are called losses due to functional variation. The uncontrollable factors which cause the functional characteristics of a product to deviate from their target values are called noise factors, which can be classified as external factors such as temperature and human factors, manufacturing imperfections due to variation of product parameter from unit to unit and product deterioration, etc. The overall aim of quality engineering is to make products that are robust with respect to all noise factors. Taguchi created a standard orthogonal array to accommodate this requirement. Depending on the number of factors and their level, an orthogonal array is selected by the investigator. In this experimental work, L'16 orthogonal array is utilized to identify the optimized parameters as shown in Table 2.

Table 2: Machining Parameters

Factors	Level 1	Level 2	Level 3	Level 4
A (Tool pin profile)	Triangular	Square	Grooved	Thread
B (Feed rate in mm/sec)	0.167	0.333	0.5	0.667

RESULTS AND DISCUSSIONS

Table 3 shows the different resultant force values for corresponding feed rate and pin profile. Normally, the vertical movement (Z-Axis) and the transverse movement (Y-Axis) produced very less amount of force and also maintained the small changes at the entire length of weld. Linear force was the X-Axis force and this value varied randomly. In this investigation, all the forces combined as resultant force and this force was calculated from the equation 1. These calculated values are presented in Table 3. All the tool pin profiles took less amount of resultant force at low feed rate. When the feed rate was increasing, the resultant force also increased gradually and randomly depending upon the tool pin profile. The grooved pin, square pin and triangular pin produced gradual changes of resultant force for different feed rates. But, in the threaded pin profile, the resultant force's variation was abnormal and at a high level. The threaded pin profile at 0.167mm/sec feed rate produced less amount of resultant force and created good welded region apart from all other parameters for welding. The material was distributed evenly at the entire length of the weld line and interior section is shown in Figure 3.

$$\text{Resultant force} = \sqrt[2]{(\text{X axis force}^2 + \text{Y axis force}^2 + \text{Z axis force}^2)} \quad (1)$$

Table 3: Resultant Force acting on the work Piece for Different Feed Rate at Constant Speed (1000 rpm)

L'16 OA Layout			Input Data		Output Data
Treatment Conditions	A	B	Pin Profile (A)	Feed Rate (B) in mm/sec	Resultant Force in kN
1	1	1	Square pin	0.167	1.093
2	1	2		0.333	1.244
3	1	3		0.5	1.359
4	1	4		0.667	1.532
5	2	1	Grooved pin	0.167	1.414
6	2	2		0.333	1.583
7	2	3		0.5	1.736
8	2	4		0.667	1.846
9	3	1	Thread pin	0.167	0.866
10	3	2		0.333	1.811
11	3	3		0.5	2.783
12	3	4		0.667	3.240
13	4	1	Triangular pin	0.167	1.096
14	4	2		0.333	1.234
15	4	3		0.5	1.280
16	4	4		0.667	1.393

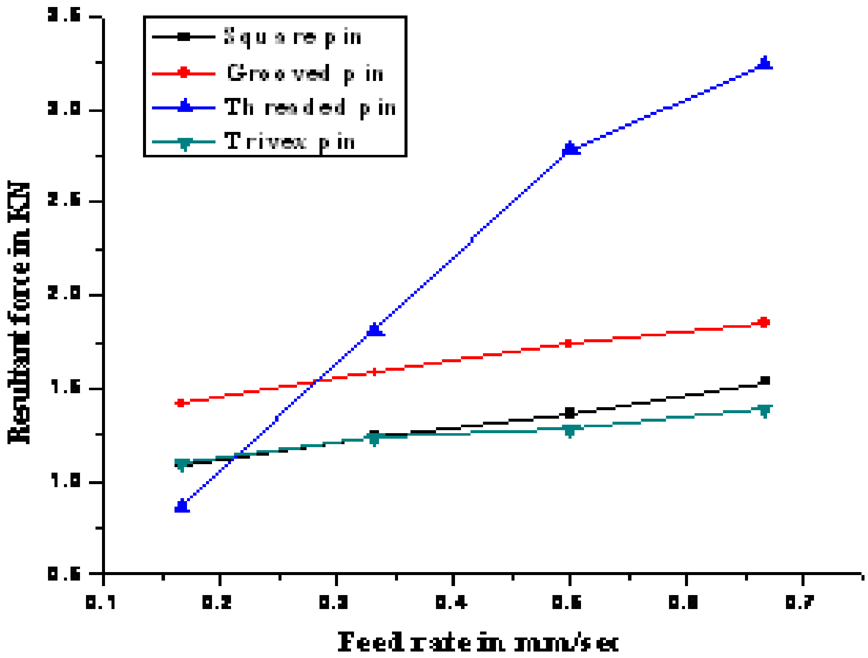

Figure 2: Feed Rate Verses Resultant Force Curve

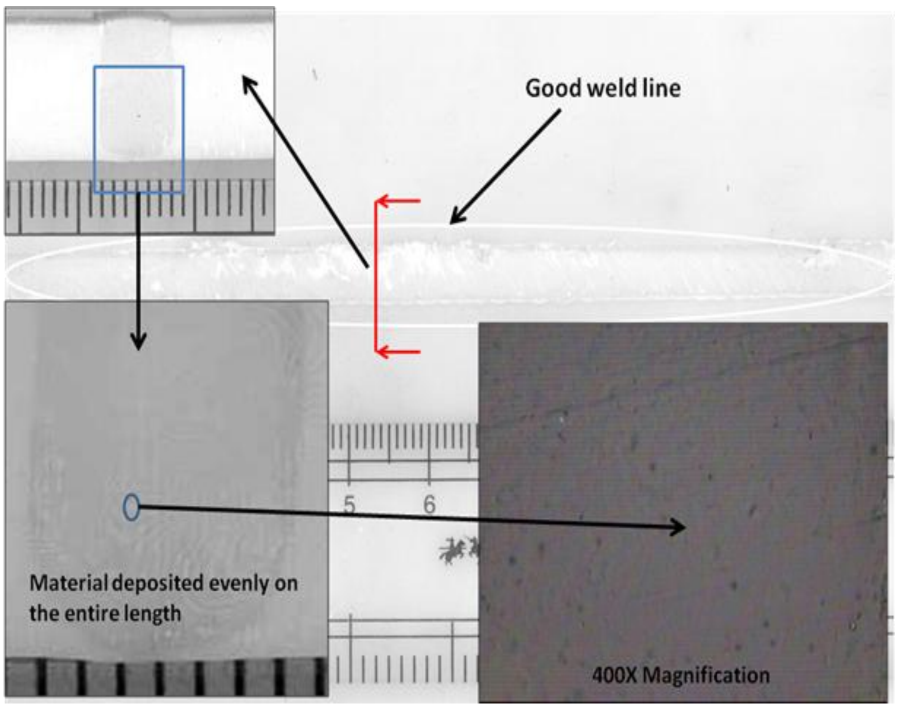

Figure 3: Good Welded Butt Line

At a high feed rate of 0.5 mm/sec with grooved pin profile, the material deposition was large on the advancing side and the tool profile produced partially molded interior region as shown in Figure 4. Due to this deposition, a small gap was created by the pin in the retreating side and this deposition spoiled the strength of the welding.

The underside area became good weld region and when gradually moved upward, the unmolded particle mixed with the molded particle and some porous were also visible in this condition. When the tool pin moved at a high feed rate, the developed heat was not enough to soften the material in the welded region.

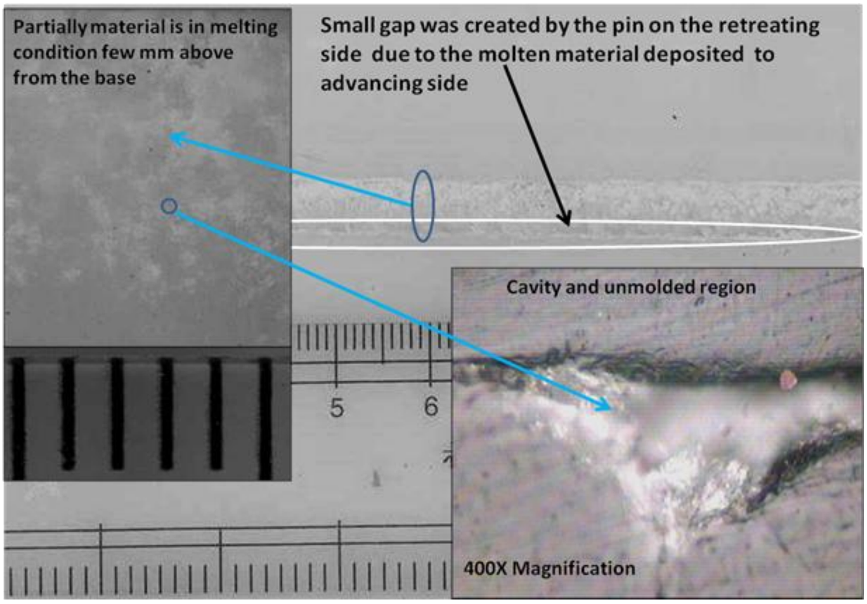

Figure 4: Small Gap Creation on the Retreating Side

In few welding condition, some very minute built up layer formed in the initial condition on the welded line due to the over heat of the welded region. The threaded pin profile with high feed rate produced good welded region with small built up layer of unmolded material deposition as shown in Figure 5. In this condition, the material deposited as a convex shape in the starting condition. This convex shape did not continue to the entire length due to the unmolded material deposition and also the small gap presented on both sides.

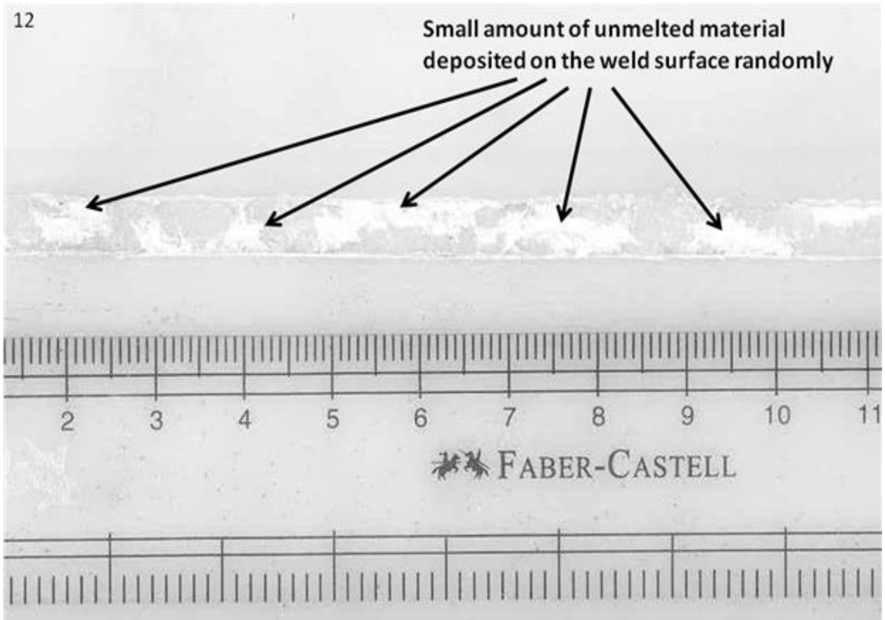

Figure 5: Unmolded Material Deposited Randomly on the Surface

The triangular pin profile created a small crystal form of material deposition on the welded region for the 0.5mm/sec feed rate because when the pin moved with high feed rate, the tool pin profile lost its ability to bring the material as colloidal form. These defects continued in the high feed rate condition also. But, in the 0.5 and 0.667 mm/sec feed rate, the material formed as a larger crystal in the butt line as well as interior area of the welded region. The material did not mingle with the retreating side material and developed a gap in between the butt line and the retreating side material as shown in Figure 6. A small amount of soften material consolidated in this side compared with the advancing side and also the major amount of joint developed only on the advancing side.

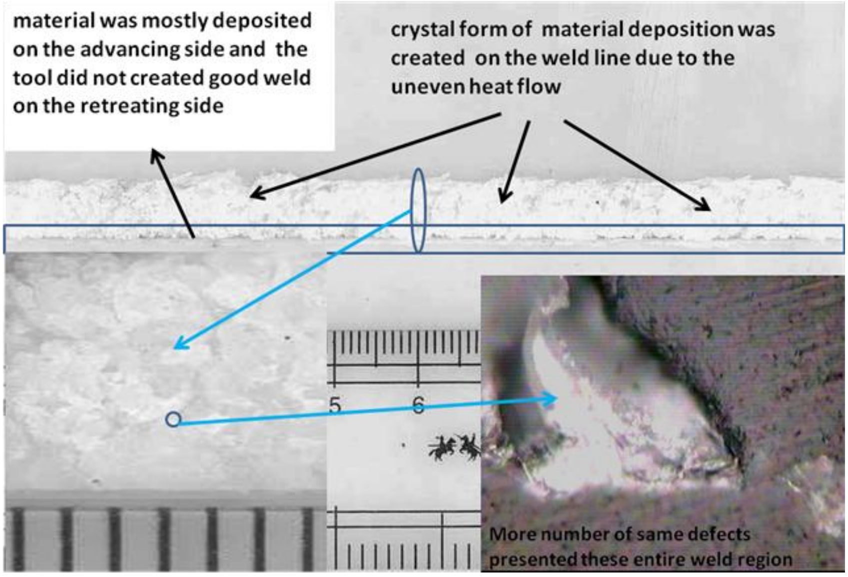

Figure 6: Crystal form of Material Deposition and Defective Welding on Retreating Side

The factors signification is a very important one in the investigation of any experimental oriented work. In this experimental work, the significant factors were identified by using the analysis of variance (ANOVA). The response table for actual values was prepared as shown in Table 4. In the responsible table, the changes of the parameters with respect to different level are mentioned in graph (see Figure 7). In this graph, the average values of resultant force for different feed rate increased gradually compared with the resultant force of the pin profile. But, the resultant force of the tool pin profile increased gradually and came down at the final condition.

Table 4: Responsible Table

Symbol	Parameter	Responsible Values				Difference	Rank	Level
		Level 1	Level 2	Level 3	Level 4			
A	Tool pin profile	1.307	1.645	2.175	1.251	0.924	2	4
B	Feed rate in mm/min	1.117	1.468	1.790	2.003	0.886	1	1

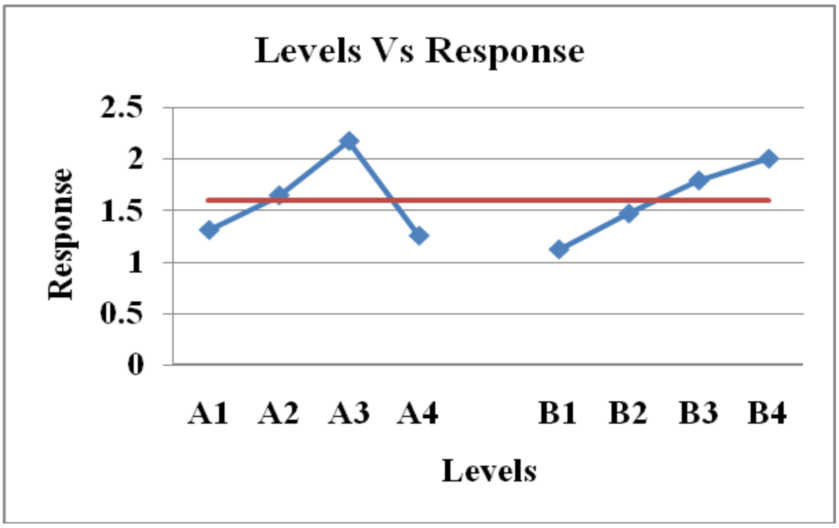

Figure 7: Responsible Graph for Resultant Force

Table 5 shows the result of ANOVA analysis and clearly depicts that both the tool pin profile and feed rate significantly contributes (95%) to the friction stir welding process and their F test values satisfy in F0.05. The feed rate contributed more percentage apart from tool pin profile. Also choosing the lowest feed rate with threaded pin profile produced the best result with low resultant force. Based on this analysis, feed rate was finalized for welding effect. At low feed rate, the parent material got good welded region for all tool pin profile and no tool pin profile produced good welded region at high feed rate.

Table 5: ANOVA Analysis

Factor	Sum of Square	DOF	Mean Square	Fcal	F table (0.05)	Contribution
Tool pin profile	2.0671	3	0.689	6.097	3.8625	**37.47**
Feed rate	2.4328	3	0.811	7.177	3.8625	**44.1**
error	1.0166	9	0.113			
Total	**5.5165**	**15**				

So, in this investigation, square pin, grooved with square pin and threaded pin profiles produced better results based on resultant force as well as visible failures. But, compared in between these pin profiles, threaded pin profile with low feed rate was the best one among the other pin profile because grooved pin profile at high feed rate , triangular pin at 0.5 mm/sec and 0.667 mm/sec feed rate produced defects. The entire pin profile created good weld region at low feed rate (0.167 and 0.333 mm/sec). Square pin, threaded pin and Grooved with square pin profile produced good welding at 0.5 mm/sec feed rate.

CONCLUSIONS

From this investigation, the following important conclusions are derived:

- Both feed rate and tool pin profile are significant factors. The percentage of contribution of feed rate is somewhat higher compared with the tool pin profile.
- Threaded pin profile with 0.167 mm/sec feed rate produces good welded region with minimum resultant force.
- In all the pin profiles, the threaded pin profile produces much amount of resultant force at high feed rate and the material attains maximum colloidal form. Due to this reason, the softened material deposition is in irregular convex shape and also some gap is created in between parent material in the retreating side and butt line.
- The grooved with square pin profile and square pin profile and threaded pin profile produces good weld region at the first three levels of the feed rate. But, high feed rate produces some defects in the joint interface.
- Triangular pin profile produces good joint interface at 0.167 mm/sec and 0.333 mm/sec and produces poor weld region to other two feed rates.
- Most of the defects occur in the welded region at high feed rate (0.5 and 0.667 mm/sec).

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