An Investigation of Process Parameters of Acrylic polymer using Friction Stir Welding

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ABSTRACT

The light weight alloys usage in automotive and aircraft industries are booming up day to day. Friction stir welding is one of the modern techniques for joining of polymers. The Acrylic polymer were used in this investigation for conducting the experiments based on different combinations inputs such as Spindle Speed, Transverse Speed and Axial Load at three level using Taguchi's Orthogonal Array. The strength of the joint was analyzed by Tensile test and the Yield Strength and Percentage of Elongation. It is found that the improvement on tensile strength and yield strength were achieved from 1800 rpm spindle Speed; 0.05 mm/min transverse Feed (weld speed) with 0.428 KN axial load.

***Keywords**: Acrylic, Polymer, Tensile Strength, Yield Strength, Percentage of Elongation.*

1 Introduction

Friction stir welding is a type of solid state innovative welding technique developed and invented by The Welding Institute (TWI) [1]. The research made by Yuh J. et al. [2] on heat transfer of AA 2195-T8 alloy gives a clear explanation that nearly 95% of total heat generated is taken by work piece and only 5% is with the working tool. Aleksandar Živkovićet et al. [3] investigated that joining of materials by using FSW reduces the chance of Porosity, hot cracks and distortion. Maruthu et al. [4] found that FSW is predominantly used to keep original state or to increase the tensile strength of the material which is welded, and also they said importance of FSW such as obtaining best mechanical properties in the welded region, ease of automation, less residual stress. G.Selvaraj et al. [5] presented that FSW is highly important and developing technology which produces a solid state bond in which the material is being welded without being melted or recast. V.Jaiganesh et al. [6] presented that Friction stir welding is an eco-friendly welding technique which is especially used to join aluminium alloys since they are difficult to join by conventional machining processes. Maruthu et al. [4] investigated that plastic materials are easily joined by friction stir welding. The FSW machine parameters are spindle or tool rotation speed, welding speed and axial force. FSW tool geometry are probe or pin diameter, shoulder to probe diameter ratio, probe length and probe profile. The main objective of the work is to perform tensile test on friction stir welded acrylic plastic. An attempt has been made to optimize the parameters to maximize the tensile strength of FSW joint. The

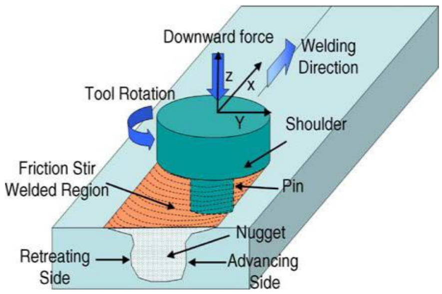

Figure 1: FSW process principle

Figure 1 shows that the welding process in FSW machine, where the tool is penetrated into the acrylic plastic with high rotational speed and transverse speed. When the tool is penetrated into the specimen its shoulder is made to place on the specimen. The gap between the tip of the tool and the back plate of the machine should be of minimum distance (0.05 mm). The machine moves with three degrees of freedom. X direction shows the welding direction, Y direction shows the To and fro of the table and Z direction shows the downward force of the tool. The Figure 2 shows the photographic View of the Friction stir welding machine.

Fig 2: Photographic View of the FSWmachine

2 Literature review

One of the important parameter is tool geometry. It restricts the heat input, material flow and it also changes the grain size, hardness and quality of weld in the weld nugget of friction-stir-welded on acrylic plastic, defect formation in friction stir weld reported excessive groove like defects, lash formation and cavity tunnel defect. Rajib Kumar Mandal, et al. [7] reported at varying clamping pressure, scanning speed (feed rate) and rotating speed is recommended to apply properly. Maruthu et al. [4] investigated that the yield strength of the high density polypropylene plate was found to be 10 MPa which was 45% increase that of parent material, this was obtained with optimum spindle speed of feed rate of 9 to 12 mm/min, tilt angle of 1^0 and 950 to 1000 RPM.

3 Tool material and nomenclature

Friction stir welding tool plays important role on the friction stir welding process. Hot die steel is commonly used in cutting tools and tool bits . It is also used in drill bits and power saw blades. HDS has superior properties when compared to high carbon tool steel which was extensively used through early 1940s it can withstand higher temperatures without losing its temper hardness. So it allows HDS to cut faster than high carbon tool steel, hence the name high speed steel. The tool was hardened 900^oc. It is compared to the HSS & HCHCr the HDS withstand the high temperature and better heat resistance. V.Jaiganesh et al. [8] found that the tapered cylindrical tool profile produced fine grain structure having uniform orientation. Better wear resistance and the low dimensional distortion.

Where,

D =Shoulder diameter

d_1 = Top diameter of pin

d_2 =Bottom diameter of pin

Shoulder diameter = 15

Pin diameters

$d_1 = 5$

$d_2 = 3$

Pin Length= 4.8

All dimensions are in mm

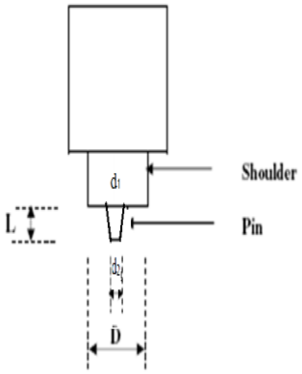

Figure 3: Tapered cylindrical tool pin profile nomenclature

4 Acrylic chemical composition and mechanical properties

Esters of acrylic acids are Acrylics. They are the products brought into existence by the reaction of alcohol and acrylic acid. The esters of acrylic acid polymerize quickly to form especially luminous plastics.Acrylic plastic starts out as a powder or liquid and then it is moulded into a functional plastic. Polymethyl methacrylate (PMMA) is the technical name for Acrylic plastic also have a.It also have wide range of applications in requiring clear durable surfaces, e.g. in the automobile industries and aircraft. The physical properties of the acrylics (such as hardness, gloss, flexibility and adhesion) the properties can also be altered by changing the composition of the monomer mixture used in the polymerization process.

The chemical formula for one unit of methyl methacrylate is $C_5H_8O_2$.

No of carbon atoms	=	5
No of Hydrogen atoms	=	8
No of Oxygen atoms	=	2

The mechanical properties of acrylic

Density	=	1170 – 1200 kg/m^3
Melting Point	=	460 °C (860 °F)
Specific gravity	=	1.19
Modulus of Elasticity	=	3300 MPa
Tensile Strength	=	69 MPa (10,000 psi)
Thermal Conductivity	=	0.19 w/mK
Light transmission	=	92%

5 Experimental Procedure

In this present investigation a Hot die steel (HDS) tool was introduced, it has the toughness, wear resistance and better higher temperature resistance when contemplate with normally used FSW tools such as high carbon high chromium tools and high speed steel. The effect of process parameters such as shoulder penetration, welding speed and rotational speed on yield strength, percentage elongation and tensile strength of acrylic plastic are optimized and evaluated by using Taguchi DOE approach. The acrylic plate of 100x50x5 mm was used in this experiment. The process parameters used in this investigation are Speed, Feed, Axial load. Speed ranges from 1600- 1800 RPM. Feed ranges from 0.05 – 0.2 mm/min. Axial load ranges from 0.365 – 1.245 KN. Figure 6 shows the actual image of acrylic material.

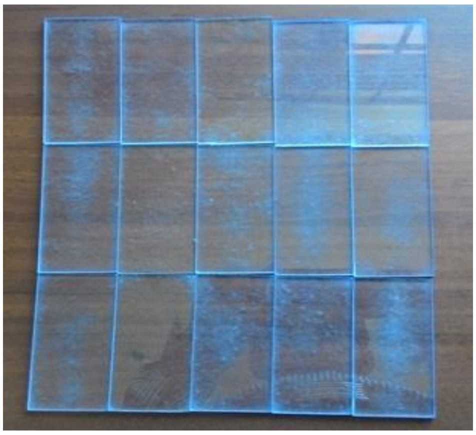

Figure 4: Photographic view of Acrylic plastic specimen before welding process

6 Process parameters

The welding parameters were recorded the table can be formed with the help of Minitab software version 17.Orthogonal array was formed and the values were arranged as per the rank. According to the principle of Taguchi the design is to be more important than the manufacturing process in quality control and tries to eliminate variances in production before they can occur. So, the design calculation is performed for nine samples which gives the optimum result as compared to Taguchi's principle.Table 1 shows the experimental output results according to the L_9 orthogonal array.

Table 1: L9 Experimental out put results

S.No	Speed (RPM)	Feed (mm/min)	Axial load (KN)	Tensile strength (MPa)	Yield strength (MPa)	% elongation
1	1800	0.05	1.245	1.8	2.1	4.098
2	1800	0.1	0.428	2.4	1.8	2.949
3	1800	0.2	0.365	1.4	1.6	3.125
4	1700	0.05	0.428	1.2	2.0	2.652
5	1700	0.1	0.365	2.0	1.8	3.245
6	1700	0.2	1.245	1.5	1.7	4.124
7	1600	0.05	0.365	2.2	2.0	3.965
8	1600	0.1	1.245	1.5	1.2	2.354
9	1600	0.2	0.428	1.6	1.5	3.014

7 Cutting of acrylic material

The welded work piece is cut using the water jet cutting machine. The cutting process begins with the help of design profile that is how the work piece has to be cut into the required shape. Then the profile is programed to the machine and is started to cut the material.The welded acrylic plate is subjected to Water Jet Cutting and it is cut into the shape of "I". The machine is programed once but the time taken to change the work piece is more and finally the work piece is cut into the required shape.

8 Tensile testing

The cut portion of the specimen is subjected to Universal Testing Machine (UTM). Here the machine is connected to the digital load indicator and a software installed computer. The specimen is locked in the UTM tool holder on both ends and the load value is gradually increased. At a point the specimen will get break into two pieces. That load is recorded in the computer and from that the graph will be generated to show how the specimen is broken and the values are shown in the graph. These values can be calculated and also draw the graph manually. The specifications of the machine are the machine can withstand maximum load of 5 tons, gear rotational speed varies gradually like 1.25. 1.5 & 2.5 mm /min and software installed is FIE made in India. Figure 5 shows the I section specimen as per the ASTM standard.

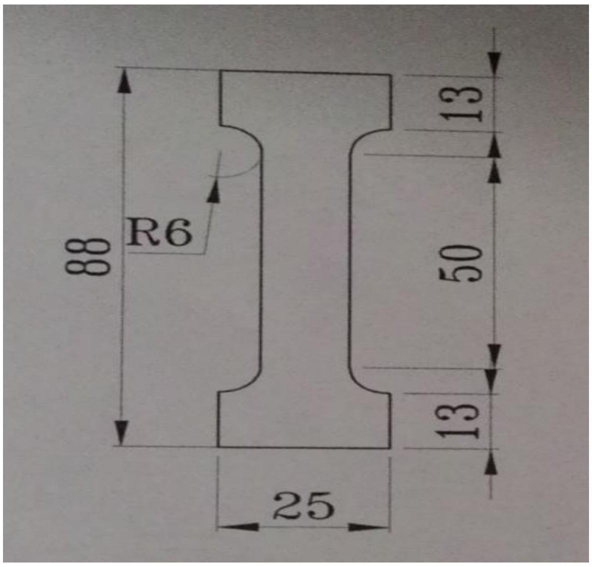

Figure 5: I section profile

9 Results and discussion

The Welded specimens are fabricated as per the American Society for Testing of materials (ASTM E8) standards to evaluate the tensile strength of the joints. Tensile strength of the FSW joints is evaluated by conducting test in UTM (Universal Testing Machine). Acrylic plastic is cut to dimension 100 mm x 50 mm x 5 mm. Butt joint configuration is prepared to fabricate FSW joints with the non-consumable HDS tool. Taguchi's orthogonal array is used to design experiments with three factors at three levels. The material is welded according to specification of welding parameters respectively. Figure 6 shows the specimen after the tensile test.

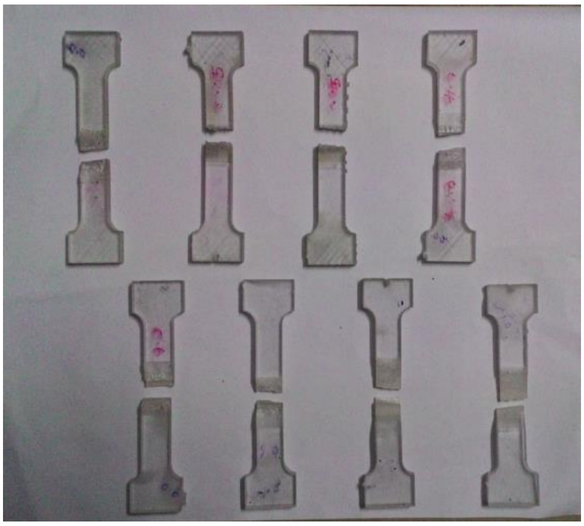

Figure 6: Specimen after tensile test

Results

Ult./Break Load	1.025 kN
Disp. at FMAX	1.900 mm
Max. Disp.	2.400 mm
Area	43.575 mm²
Ult. Stress	0.024 kN/mm²
Elongation	3.852 %
Yield Stress	0.021 kN/mm²
YS/UTS Ratio	0.898

Figure 7: Results of tensile test

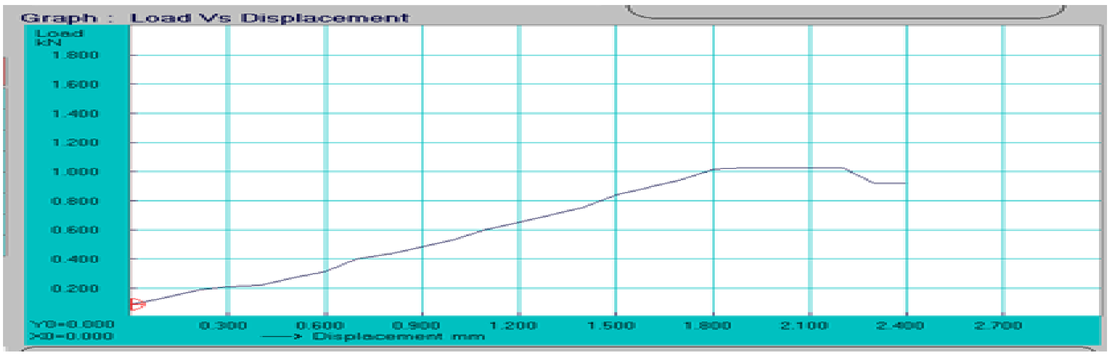

Figure8: Load vs Displacement graph

Figure 8 graph shows the breaking load at which the welded specimen is separated, ultimate stress, % of elongation, yield stress and yield strength vs. ultimate tensile strength ratio. Maximum tensile stress of 2.4 M Pa, breaking load of1.025 K and % of elongation of 3.852 is obtained. Figure 7 shows the results obtained aftertensile test. V.Jaiganesh et al. [9] found the main reason for superior mechanical properties and flawless joints is uniformed flow of plasticized material, ideal level of heat generation and the formation of fine grain structure with uniform distribution in the weld zone.

9.1 Stress vs strain graph:

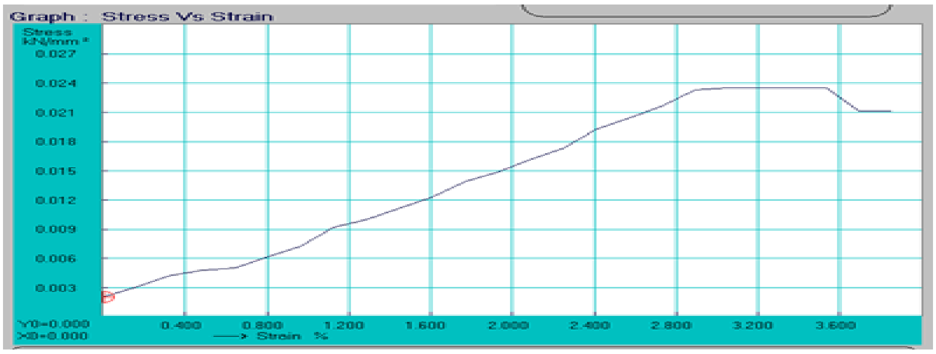

Figure 9: stress vs. strain graph

Figure 9 shows the Stress vs. Strain graph. The curve indicates the ultimate tensile stress and strain at which the specimen is separated. Many welded specimens were tested by UTM to form a table and evaluate the optimum welding process parameters. Nine samples were subjected to testing.

9.2 Analysis of signal to noise ratio (s/n) as a response

This SN ratio graph shows the main effects plot for SN ratios. Speed, Feed and Axial load are three parameters whose nominal values are shown in the figure. This graph is set to the mode of Larger is better and graph indicates the larger value of Speed, lower value of Feed and lower value of Axial load is better for Friction Stir Welding of the Acrylic plastic. The S/N ratio graph for mean of means shows the mean value of the three parameters Speed, Feed and Axial load.V.Jaiganesh et al. [10] presented that the present day approach to find the optimum output value over input value can be easily made out by the use of Taguchi's method than using any other traditional methods.

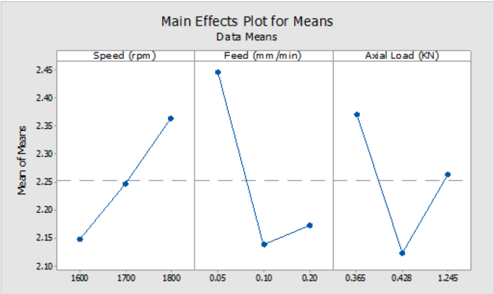

Figure 10: Main effect plot for Means

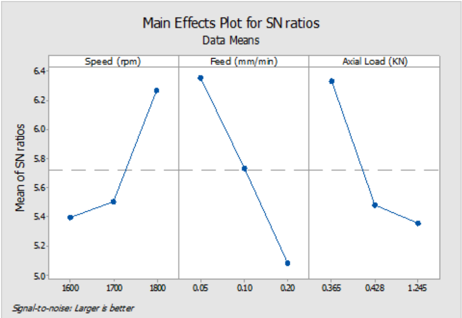

Figure 11: Main effects plot for SN ratios

Figure 10 shows that the mean value of Speed, Feed and Axial load for Friction Stir Welding. The mean value of Speed is 1800 rpm, the mean value of Feed is 0.05 mm/min and the mean value of axial load is 0.365 KN. Figure 11 shows the main effects plot for SN ratios. This SN ratio graph shows that the larger value of Speed, Feed and Axial load is best for Friction Stir Welding. From the graph the largest value of speed is 1800 rpm, the largest value of feed is 0.05 mm/min and the largest value of axial load is 0.365 KN.

10 Conclusions

For various combinations experiments were conducted based on speed, feed, axial load in Taguchi's Orthogonal Array at three levels. The joint strength is investigated by percentage elongation, yield strength and tensile strength.

The main observations of this investigation are:

1) Acrylic plates were welded successfully by FSW machine, optimized values were found by Taguchi's Orthogonal Array.

2) As a result the least influencing parameter is feed and speed is most influencing parameter.

3) The optimized process parameter are 1800 RPM Speed; 0.05 mm/min Feed and 0.428 KN Axial Load.

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