Evaluation of Friction Stir Spot Welded of Single Joints

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Abstract-In Paper focused on welding lap joint of high density polyethylene sheet with a new invented tool and tool design, in order to evaluate the effects of the variable welding parameters on the lap weld strength. In this describe the details of the process of developing as FSSW tool for welding thin Specimen of high density polyethylene. The welds produced with this tool improved the welds surface quality and strength significantly. The use of the proposed tool showed to improve the stability in the axial force magnitude during the welding procedure in comparison with a conventional method. It was also concluded that the rotational and traversing speed have the most effective role regarding the overall specimen tensile strength.

Index Terms *-FSSW, Welding parameter, high density polyethylene.*

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1 INTRODUCTION

Friction stir spot welding (FSSW) is a variant of the FSW process. FSSW was developed by Mazda Auto Corporation an automotive industry as a replacement for resistance spot welding of aluminium sheets in 2001. It was gaining worldwide attention due to potentially large energy and infra-structure savings compared to other types of welding techniques, to fill the same materials is not required filler extra material or shielding gas, reduction in production costs in further processing and finishing is possible as the surface appearance of FSSW approaches to that of a rough machined surfaces, the process is eco- friendly, as no splatter, fumes or UV radiations are produced during FSSW process.

FSSW process essentially consists of three phases such as plunging, stirring and retracting. FSSW is welding process, in which especially a non-consumable rotating tool with designed pin and shoulder is inserted into the edges of the lap plates to join. When the rotating tool contacts the upper sheet, a downward force is applied whereas a backing anvil beneath the lower sheet supports this downward force. The downward force and the rotational speed are maintained for an appropriate time (dwell time) to generate frictional heat. Then, heated and softened material flows around the tool through extensive plastic deformation, and a solid-state bond is made between the upper and lower sheet. Finally, the tool is drawn out of the sheets and protruded pin leaves a characteristic exit hole in the middle of the join shown in figure 1.1.

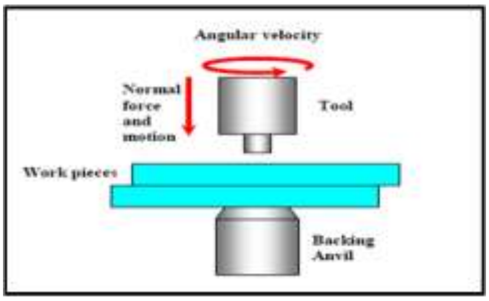


Figure 1.1 Principle of working (FSSW)

Good quality of welded joint between dissimilar materials is a very useful for many emerging application including the Ship building, Automobile, Aerospace, Transportation, Power generation, Chemical, Nuclear industries.

1.1 FSSW plays important role.

The following new spot welding process are investigated and compared with new conventional friction stir spot welding process

i. Friction spot welding (with same material filler rod)
ii. Friction spot welding (with steel filler rod)
iii. Friction spot welding (with copper filler rod)

II. EXPERIMENTAL SETUP

The experimental setup of Friction stir spot welding has developed on Universal Milling machine (UMM). UMM is converted into Friction Stir spot welding machine with certain required modification. For performing the FSSW process milling machine requires some extra attachments.

2.1Design and Development of Mechanical Fixture

The main purpose of a fixture for FSSW is to hold the work-pieces in position during welding. The main reason for having appropriate clamps or fixtures is to prevent the specimens from moving while being welded shown in below.

Figure 2.1 -Fixture and clamping plate

Obtaining good stability during the process is important since any deflection or major vibration would affect the quality of the weld.

- ***Clamping requirement***

The forces that act on the base plates as a result of transverse and rotational movement of the tool can be summarized and built into a clamping design. The initial plunge of the tool, before welding feed, transfers forces to the base material. Firstly the tool generates a moment while rotating against the frictional surface of the base material. This frictional moment or shearing force is assisted by the downward thrust of the tool increasing the linear force vector at every increment of rotation. The probe that is sunk into the joint line wants to push the two base plates apart. Movement of the tool through the joint line also produces translational forces that tend to push the plates in the x-axis direction. The magnitude of these forces will depend on the viscosity level reached as well as the feed rate that the process commences at. The other forces to be under attention are the transverse forces produced by the rotating tool due to the shearing action.

- ***Clamp Design***

A recommended advantage on the engineering design side was a universal clamp that would characterize easy manufacturing; good stability and quick disassembling characteristics. The clamp was only bolted down with one T-nut it could not prevent any rotational (moments) movement of the clamp base.

- ***Backing Plate***

The design of the fixtures had to be based around a backing plate size. This backing plate is a piece of material, normally made out of a medium carbon steel, placed at the bottom (back) of the plates to be welded. The main purpose of this backing plate is to prevent the welded material being forced out of the joint line during a weld run. Since the tool shoulder applies a downward force on the plasticized material the backing plate must support the welded plate and resist any thermal deflection.

III WELDING PARAMETERS

The welding parameters are the key art of FSSW process. They decide what materials that can be welded by this new technology and determine the thickness of work piece with the help of literature. The important input process parameters in FSSW are listed below.

1 . Tool rotational speed (N)

Tool rotation speed is one of the most important parameter using FSSW process. In this process Tools speed are used 225, 560, 900 and 1400 rpm. The motion of the tool is generate frictional heat on the work pieces such a HDPE Sheet, to extruding the softened plasticized material around it and forging the same in place so as to form a solid-state seamless joint. As the tool rotates and moves deep along on Z axis of the lap surfaces and heat is being generated at the shoulder work piece and to lesser extend at the pin work-piece contact surfaces, as a result of the frictional-energy dissipation.

2. Plunge rate (f)

The Plunge rate depends on several factors, such as polymers and alloy type, rotational speed, penetration depth, and joint type Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material. Plunge rate are define from when wheel is one rotation into convert reciprocating moves 2 mm at z-axis of machine.

3. Dwell Time (Td)

Dwell time is the time for which the tool is continue to rotate on the spot of the joint with no movement or no further plunge of the tool. Actually, the dwell time is the parameter responsible for the melting of the HDPE. During this time, stirring of the material occurs. The temperature of the weld increases with the dwell time. This is due to fact that the friction heat produced in the vicinity of the tool increases with the dwell time, so the temperature of the material increases. The temperature of the material reaches to the melting temperature but it does not change with extended dwell time. The values of the dwell time taken in this study are in the range of 30 to 90 seconds.

4. Axial force (F)

During traversing, softened material from the leading edge moves to the trailing edge due to the tool rotation and the traverse movement of the tool, and this transferred material, are consolidated in the trailing edge of the tool by the application of an axial force.

5. Tool Plunge Depth (Z)

The tool plunge depth is the depth to which the tool penetrates into the weld joint. In this study, the tool plunge depth is kept constant to a value of 9mm which is equal to the value of pin length of the tool.

6. Tool Delay

Tool delay is also a parameter which mainly decides the macrostructure of the weld nugget. It is the delay made in the withdrawal of the tool as soon as the dwell time is over. The cross section of the weld nugget depends upon the waiting time of the tool after the end of the dwell time. The values of the tool delay have been taken for the studies are in the range of 5 to 9 seconds.

7. Nugget Formation

Nugget Formation is the thickness of solid molten material which takes place around the tool pin. The nugget thickness increased with the dwell time. There is a direct relationship between the nugget thickness and weld bond area. The weld bond determines the strength of a weld in metals. The high friction heat affects the nugget formation. The nugget gets thicker with tool rotational speed. The friction heat produced in the weld area increases with the tool pressure and obtaining thicker weld nuggets.

8. Tool Design

Tool design influences heat generation, plastic flow, the power required, and the uniformity of the welded joint. Tool geometry such as probe length, probe shape and shoulder size are the key parameters because it would affect the heat generation and the plastic material flow.Friction stir welds are characterized by well-defined weld nugget and flow contours, almost spherical in shape, these contours are dependent on the tool design and welding parameters and process conditions used. Finally tool geometry and design standard size given by the probe diameter is 0.8 times the sample thickness plus a constant of 2.2 mm, shoulder diameter is 2.1 times the probe diameter plus 4.8 mm.

IV. EXPERIMENTAL MATERIALS

1. Material of Tool

Tools for FSSW process using for AISI-1045 steel, a high wear resistant material and its heat treated forms possesses good homogenous metallurgical structures, giving consistent machining properties. En-43B is a very popular grade of through hardening medium carbon steel, which is readily machinable in any condition. The chemical composition of the tool material En-43B steel for AISI-1045 is given in following table.

		
T01	T02	T03

2. FSW of High Density Polyethylene sheets

HDPE is use in an expanding range of engineering applications, such as in the automotive industry due to their enhance stress to weight ratio, toughness, a very short time of solidification and a low thermal conductivity. It is used for electrical insulation, packaging where strength and aesthetic are important. It is light in weight, ease of handling, water proof. It cannot weld by Fusion welding process.M60075-grade for high density polyethylene sheet are used FSSW such properties are shown in below.

V MATHEMATICAL MODEL

In this study the methods are used for optimization and development of mathematical model namely Artificial Neural Network and Taguchi method.

1. Taguchi Method

Taguchi Method is developed by Dr. Genichi Taguchi, a Japanese quality management consultant. The method explores the concept of quadratic quality loss function and uses a statistical measure of performance called Signal to Noise (S/N) ratio. The S/N ration takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality 40 characteristic of the product/process to be optimized.

The following steps briefly describe the Taguchi method for finding the optimum setting of the design variables to make the response insensitive to noise factors, which may be regarded as the design and manufacturing tolerances in a numerical structural analysis.

1. To determine the response characteristic to be optimized, the design parameters and their noise factors (uncertainty of design parameters).
2. To design the experiment matrix to determine the effect of the design parameters and conduct the data analysis procedure. After selecting the appropriate orthogonal array for the noise and parameters to fit a specific study, variation in the response characteristic due to the noise factors are simulated.
3. To analyze the data and determine the optimum levels. After the experiments have been conducted, the optimal parameter configuration within the experiment design must be determined.

2. Designing an experiment The design of an experiment involves the followingsteps

1. ***S***election of independent variables
2. Selection of number of level settings for each independent variable
3. Selection of orthogonal array
4. Assigning the independent variables to each column
5. Conducting the experiments
6. Analyzing the data
7. Inference

3. Experimental Procedure

HDPE sheets of 4mm thickness are welded by FSSW. The different welding specimen having dimensions 400×75×4, 400x80x4 and 400x90x4 mm is prepared. Welding was carried out in single and multi spot joint configuration using universal milling machine. Fig shows the Friction stir spot welded specimen of HDPE-Sheet. From the previous literature important process parameters are identified that influence the quality of welded joint which is Rotational speed, plunge depth, Dwell time, Delay time and Tool pin profile. After identifying the important process parameters their levels are decided by performing the design of experiment of initial experiments. The feasible working limit of the parameters is mentioned below.

Table:-L09 Ortho used parameter

S.No	Process parameters	Level 1	Level 2	Level 3
1	Rotational speed (Rpm)	560	900	1400
2	Plunge depth(mm)	6.4	6.8	7.1
3	Dwell Time (Sec)	30	60	90

4. Orthogonal array for Single spot weld joint

Optimization of welding input parameters is done by using Taguchi Method so that orthogonal array is selected for DOE.In this study three factors are varied to three levels each thus an L9 orthogonal array with four columns and nine rows was used for single spot weld joints show in below figure.

No of factors to be studied=03

No of levels for each factor=03

By calculating the degree of freedom we can decide the standard orthogonal.

(a) single Spot welding specimen

Depending upon the parameters to be studied and the number of levels for each factor an orthogonal array is suggested by Taguchi using MINITAB 14 statistical software.

5. Percentage of Contribution

Percentage contribution is a function sum of squares for each significant item, indicates relative power of a factor to reduce the variation. If factor levels were controlled precisely, then total variation could be reduced by the amount indicated by percentage contribution. In this study the Rotating Tool speed has the highest contribution i.e. 40.92 %, Dwell time is 35.77 %, Plunge depth of 17.69 % and 5.64 % residual error is present.Shows the result the weld strength mean lap shear force. The F value of a welding parameter shows the electiveness' of the parameter.

6. SAMPLE CALCULATION: TENSILE FILE NAME : 00001.utm

Tensile Strength at Peak Load = (Peak Load/(Thickness x Width))
= (510.4 x 100)/(4.0 x 73.0)
= 174.7945 Kg/Sq.Cm

Tensile Strength at Break Load
= (Break Load/(Thick. x Width))
= (0.1 x 100)/(4.0 x 73.0)
= 0.0342 Kg/Sq.Cm

% Elong. at Peak Load = (Elong. at Peak Load/Specimen Length) x 100
= (22.9/250.00) x 100
= 9.16 %

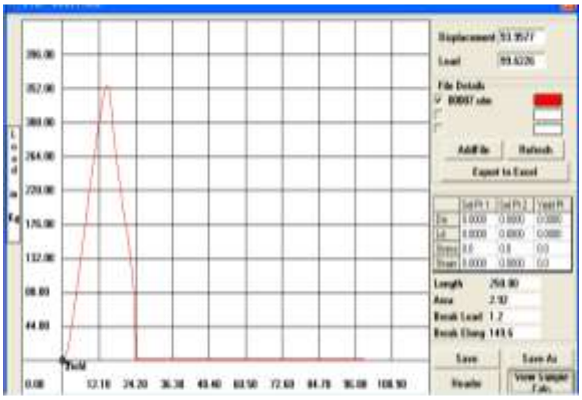
% Elong. at Break Load = (Elong. at Break Load/Specimen Length) x 100
= (699.8/250.00) x 100
= 279.92 %

Yield Stress = (Load at Yield Pt./(Thick.*width)
= (0.0/ (4.0 x 73.0)) x 100
= 0 Kg/Sq.Cm

Youngs Modulus = (Y2-Y1/X2-X1)
= (0.0 - 0.0)/(0.0 - 0.0)
= Indeterminate Kg/Sq.Cm

Coeff Of Friction = Log(Peak Load/T2) / Radian
= Log(510.4/37.0) / 17.322
= 0.013

The welding parameter which has the highest degree is the most important parameter and value of the highest represent in graph.



7. Justification of Error

There are some errors emerged in Experimental Results and Mathematical Results which are slightly diff erent.The reason behind the errors may be human error, Machine er-ror,Tool Geometry error,Clamping error and error due to environmental condition.But in this according to error occurred mostly due to the machine condition and clamping of the Specimens.

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CONCLUSIONS

In this work the Design of Experiment is used for conducting the experiments byTaguchi method. Taguchi method gives the optimize process parameter combination while gives the mathematical model to predict the responses. The results obtain by Taguchi method summarize as follows.

1. Friction stir spot welding process having many numbers of factors affecting current main factors considered are: Tool rotational speed, Plunge depth and Dwell Time.
2. Taguchi method through Optimization of Percentage contribution of Rotational speed, Plunge depth and Dwell Time is 41 %, 18 % and 36 % respectively and also the error is present which is 5 %. The effect of these parameters on Lap shear strength of welded joint has been studied.
3. Optimum parameter settings obtain from S/N ratio plot are Tool rotational speed 900 rpm , plunge depth 6.8 mm and dwell time 60 sec for Straight Hexagonal pin profile.

Confirmatory experiment has been performed and found a good agreement between predicted and experimental value.

4. 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.

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