



THERMAL EFFECTS ON FRICTION STIR SPOT WELDING OF HIGH DENSITY POLYETHYLENE SHEET USING FINITE ELEMENT METHOD

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ABSTRACT

Friction stir spot welding process is a solid state joining process which utilizes frictional heat of a rotating tool and the stirring effect of tool probe for solid state joining. The use of High Density Polyethylene (HDPE) and its welded sheets is the latest trend in various industrial application especially in the area of aerospace & automobile to have a light weight components. With adequate strength to sustain various load and stress conditions. FSSW are employed for the automation with aluminum sheet to reduce the weight of weld. The high density polyethylene sheets are implemented for welding. FSSW is an environmentally cleaner process due to absence of need for various gases that normally accompany fusion welding. Rotational speed, applied force and dwell time were considered for experimentation. The temperature history & process parameters related in the welding of HDPE, as these are the factors govern the weld strength microstructure as well as macrostructure. In finite element method, the thermal finite element model of spot lap weld of HDPE sheet made by friction stir spot welding were developed and simulated. The results generated by experimental method and finite element method were compared and validated. The friction stir spot welding is stimulated by using finite element software LS-DYNA. Even if process optimization is required, the final performance of the joints are sufficient to access that friction stir welding of high density polyethylene may be valid alternative to conventional joining technologies.

Key words: *friction stir welding process, fusion welding, HDPE, LS-DYNA, FSSW*

I. INTRODUCTION

In the industries like automobile & aerospace, Spot welding is very common joining technique. It is widely used in the joining of metal parts due to its advantageous on welding efficiency & suitability for automation. The latest trend in automobile & aviation sector requires to manufacture lighter, safer, cheaper & ecofriendly vehicles. For the light weight vehicle, there should be replacement of metals like cast iron & steel by lightweight materials like thermoplastics, composites, aluminum etc. The materials like High Density Polyethylene (HDPE),



being very light weight, setting up the trend to be used in the automobile assembly, however, require improvement in its welding techniques.

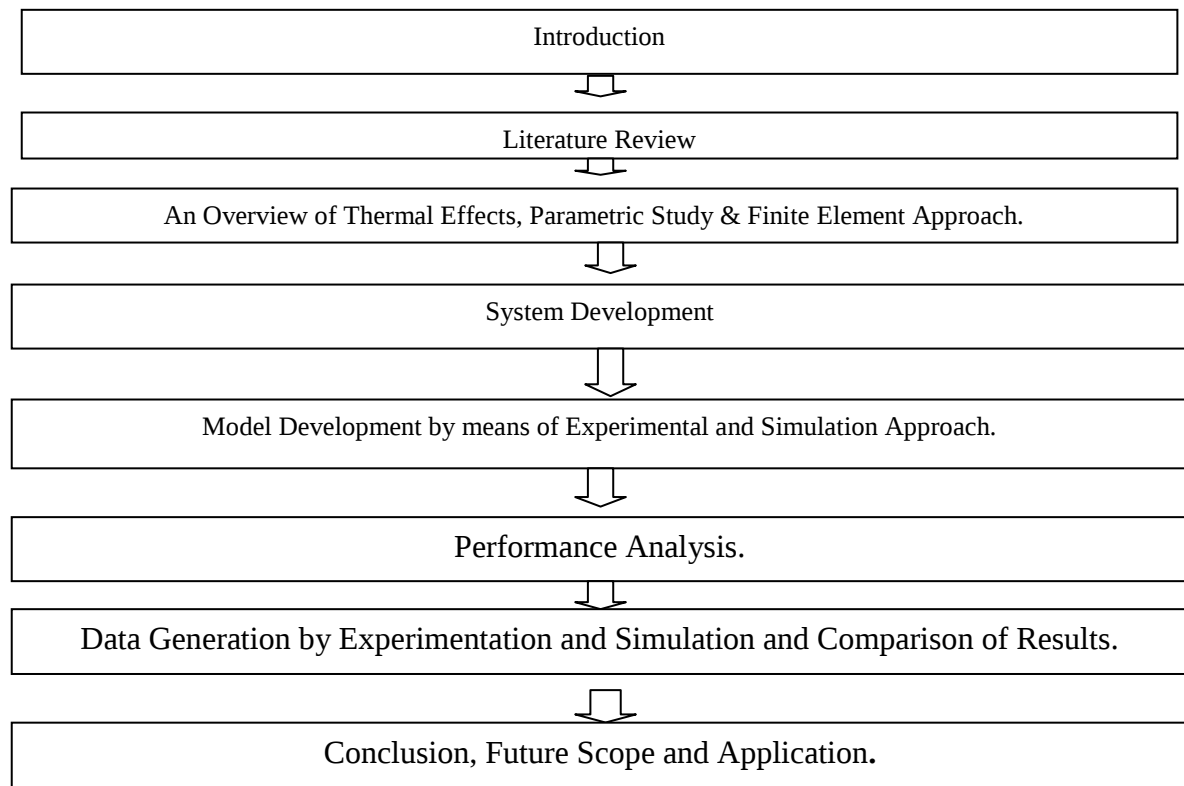
High Density Polyethylene (HDPE) is one of the most popular polymers due to its availability and competitive cost. Furthermore, it is a thermoplastic with noticeable mechanical properties. However, the need to produce larger and more complex parts from polymers such as HDPE has created an increased demand for joining. Furthermore, 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.

Plastic welding processes can be divided into two main groups: processes involving mechanical movement to produce heat (Ultrasonic welding, friction welding & vibration welding) and processes involving external heating (Hot plate welding, hot gas welding and restive and implant welding). All plastic welding techniques consists of three common stages:- Formation of a layer of molten material on the surfaces to be joined; Bond formation by application of pressure; The melt is allowed to cool and in this stage pressure should be maintained in order to prevent forming voids inside the weld zone. The last stage is the most significant one and an additional care should be taken to achieve a high quality weld. In this context, Friction stir welding (FSW) is emerging as an appropriate technology that produces welds that are high in quality, strength & also inexpensive to make. The other main advantage is that it produces no fumes during process & is energy efficient. FSW does not need any filer material as required in conventional welding processes & is relatively easy to perform. However, the work-piece should be rigidly clamped & welding speeds are low in order to avoid defects like porosity. Since the joint can be obtained below the melting temperature, this method is suitable for joining a number of materials which are extremely difficult to be welded by conventional fusion techniques.

II. NEED OF THERMAL ANALYSIS OF FSSW OF HDPE

The weld strength of the lap joint produced by FSSW is ultimately the function of temperature generation and temperature generated itself relies on the process parameters like tool rotational speed, tool plunge depth, dwell time and tool geometry. The finite element method predicts the transient temperature distribution along the weld area with respect to boundary conditions and thus, helps to lay down the optimum weld layout and related process parameters. Therefore, thermal interaction is a very important aspect in FSSW since the process is dependent on the heat generated from the frictional force between tool and workpiece to soften and join the workpieces. Although this welding technique has been successfully developed and applied in various cases in industries, the phenomena of thermal interaction between the HDPE and the tool should be fully understood. Therefore, this report addresses the study of thermal aspects between the tool and the workpiece interface using finite element analysis.

III. FLOW CHART



IV. OBJECTIVE

- 1) To develop experimentally the models of Lap joint of HDPE sheets using FSSW process and verify the effect of the different process parameters on the temperature generation and weld strength as well.
- 2) Finite element analysis of a 3 dimensional weld model by imposing the boundary conditions, comparison and validation of the FE model by comparing it with the experimental data generated.

V. METHODOLOGY ADOPTED

Two types of methodologies were adopted in the study. The first one was the Experimental Method and second one was the FEM. Experimental study on the temperature distribution and the heat generation during FSSW process has been reported by many researchers. Based on these researches, the experimental method was used to develop an actual spot weld joint model of HDPE sheets using FSSW technique. The welded model was then assessed in terms of temperature generation during the process and the weld strength, experimentally. Also, on the basis of previous literatures, the data regarding the process parameters from different literatures was collected, studied, analyzed and imposed in the experimentation as the FSSW of HDPE involves various process parameters which govern the heat generation, temperature distribution during the process and the weld strength.

The FEM technique was used to develop a thermal model for the lap (spot) welds based on the data generated by experimentations. The generated model was used to perform further parametric study involving process conditions. The focus of the study was to investigate the thermal effects on the spot weld lap joint of HDPE by FSSW. For the purpose, the commercial code LS-DYNA from Livermore Software Technology Corporation (LSTC) was FEA code used in the study. The geometric model was developed using a pre-processor CREO. The generated output from LS-DYNA code was then correlated with the results obtained experimental model.

VI. LITERATURE REVIEW ON FINITE ELEMENT ANALYSIS APPROCH ON FSSW

Erica Squeo et al., [2] presented a technical report in which they studied the effect of temperature change in the weld zone during their experimentation on High Density Polyethylene. The sheet and pin temperature was changed in two different ways: By means of a hot air gun and by heating plate. The temperature changed between the room value and 150°C. Thermal tests were carried out with a differential scanning calorimeter (DSC, Netzsch DSC200 PC). At high rotational speeds, a higher amount of heat is transferred to the material due to friction. However, if the rotational speed is excessive, the material gets parted by the pin and a poor joining is observed. Finally they concluded that welding strength is depends on the optimized temperature value in the range of 132-140°C.

Memduh Kurtulmus [4] presented a technical report in which he found that effect of dwell time on the temperature of the weld zone. The temperature in the weld zone increased with the duration of dwell time. The temperature of the material reached the melting temperature (171°C) with a 50s dwell time. The temperature rose up to 190°C with 60s dwell time and it did not change with extended dwell time. Similar over melting temperature were calculated in friction stir welding of High Density Polyethylene (HDPE) Sheets. So finally he concluded that Melting of polypropylene occurred in the vicinity of the tool pin.

Rajesh Naidu [6] presented a report to developed and validate finite element models of the FSW process for butt and lap welds for specific experimental cases that in effect enhances the predictability of temperature evolution in the joined workpiece. The effect of varying tool rotational speed on workpiece temperature was observed that for given increase in the tool rotational speed there has to be a proportional increases in the tool linear speed to achieve the required peak temperature. This probably due to amount of dwell time of tool needed to generate necessary amount of heat. The faster the linear speed for a given tool rpm less is the time to heat the workpiece.

M. G. Cooper et al., presented a report in which the consideration about the resistance to the flow of heat between two thick solid bodies in contact in a vacuum. Existing analysis of single idealized contacts are summarized and compared, and then applied, together with results of recent electrolytic analog tests, to predict the conducts of multiple contacts. This study shows that the thermal contact conductance is dependent upon the characteristics of the surfaces, the mechanical pressure between them, and whether there is any conducting fluid (gas or liquid) in the interstices of the interface.

Gould Jerry E. et al., [9] performed a 3D analytical study to predict the workpiece temperature for FSW butt weld using the Rosenthal equation describing a moving heat source. The heat Input was function of process parameters including tool rpm and the force on the tool and was directly applied on top of the workpiece with radius equal to that of the tool shoulder.

VII. TOOL GEOMETRY AND THEIR SPECIFICATIONS AND RESULTS

For 3 mm Tool

Sr. No.	Tool Geometry	Tool Material	Shoulder Diameter (SD)	Shoulder Length (SL)	Pin Size (PD)	Pin Length (PL)	Shoulder Concavity Angle (SCA)	Pin Angle (PA)
01		MILD STEEL	30mm	70mm	7.5mm	4mm	---	---
02		MILD STEEL	30mm	70mm	7.5mm	4mm	4°	----

VIII. EXPERIMENTAL SETUP DEVELOPMENT

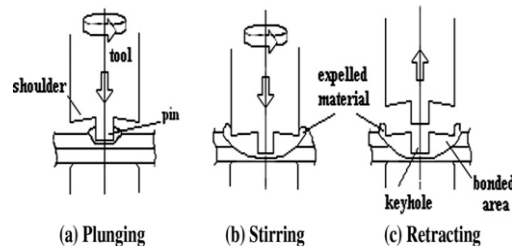
Friction stir weld were made on sheet sample EN52009 HDPE with 6mm thickness was cut out of raw material. The dimensions of HDPE sheets were used 450mm×75mm and lap shear specimen were cut from the sheets. Friction stir spot weld were made using FSSW tool was fabricated from mild steel. Tool had a concave shoulder (4°,6°,8°) while the tool no is made straight cylindrical with right hand thread of (1mm)pitch and taper threaded of (1mm)pitch.

The overall height of pin is 9mm making slightly shorter than the sheet thickness of 6mm and 5mm for sheet thickness 3mm.

In order to develop FSSW test properly design clamping fixtures was utilized to fix the specimen. The sheet plates comprising the fixture ensure a uniform pressure distribution on the fix specimens. The specimen had 110mm×75mm overlap area. The specimens were welded in bench drilling machine.

In this experiment, the process essentially consists of three phases, plunging, stirring, retracting as shown in fig no.3. When applying the force to plunge the pin the stirring phase of FSSW started with completion of tool plunging. Upon reaching predetermined dwell time the rotation of tool was intermediately stopped. All welding operations were done at room temperature. At beginning of each welding operation the pin and shoulder of tool

were the room temperature. In temperature determining, the temperature of weld joint was measured with an infrared thermometer. The temperature is obtained, when tool was retracted immediately with end of dwell time.



FigNo.3.1:-Three phases of friction stir spot welding process:

(a) plunging, (b) stirring and(c) retracting

The axial forces were measured by spring balance setup. After completion of weld, the welded lap shear specimens were tested on UTM of 100 tone capacity. The load and displacement were simultaneously recorded during test. The ultimate tensile strength of lap shear of the specimens were obtained, which were welded with identical welding parameters.



Fig No. 3.2:Experimental Setup

9. CONCLUSION

By utilizing friction stir welding, high density polyethylene sheets could be joined with ultimate tensile strength. Considering the aforementioned discussion, the following conclusions can be drawn about the effect of process parameters on mechanical properties and microstructure of friction stir welded high density polyethylene sheets. In general, higher rotational speed resulted in higher tensile, with increasing rotational speed of pin, the local temperature of material would rise up ,which leads to heat concentration in weld nugget. In this study, the dwell time, tool rotational speed and plunge depth affect the FSSW nugget formation and strength of the joint. Optimum parameter must be used to obtain high quality weld are 2970 rpm rotational speed, dwell time at 40 sec, tool delay time 8 sec.

Working with straight pin cylindrical tool of 9mm pin length (tool no.1) with rotational speed of 1760 rpm, the weld strength obtain is 3KN i.e.324 Kg, where as with speed of 2970rpm, the maximum weld strength is obtain i.e.13 KN

Dwell time and tool delay also play an important role in weld strength.

From experimental data, the force required for welding by using the tapered tool is more as compared to straight tool. From observation, the penetration of pin of a tool is depending upon the force. Also the force required for welding by using the concavity tool is more than plain cylindrical tool.

As a result, more molten material presented in joint, when uses straight cylindrical tool. The more molten material would be presented in joint line that leads to improved stirring Conditions as well as weld performance. The weld strength is minimum for the straight cylindrical threaded tool of(1mm) pitch and tapered cylindrical threaded tool of(1mm) pitch. In this type, time for penetration of the pin is less after that tool is moving with constant travel speed. Also observed that it cuts the maximum material when tool plunge in the specimen (HDPE Sheets).

Heat generation rate and plastic flow in work piece are affected by the shape and size of tool shoulder and pin.

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