Analyzing Process of Friction Stir Spot Weld Joint

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Abstract

Friction stir spot welding (FSSW) is a well-known novel variant of the conventional friction stir welding (FSW). FSSW shows great potential to be a replacement of single-point joining processes like riveting and resistance spot welding. In this review work the testing method on weld joints produced from Friction Stir Spot welding are studied. Different tool pin geometries, pin angles, pin lengths, shoulder diameters and shoulder angles were used for FSSW. Lap-shear tensile and thermal distribution, macrostructure and flexural tests were conducted by varying the welding parameter and finding out the weld static effect. Optimize testing tool geometry and welding parameter was varied to carry out weld formation on HDPE sheet. Based on the open literatures, the process features and variants, optimization of the testing method of the Friction stir spot welding process were summarized.

Keywords: FSSW, Flexural behavior, Lap-shear tensile, Taguchi method and tool profile

I. INTRODUCTION

Friction stir welding (FSW) process was well known invented by TWI in 1991 for aluminium alloys. Friction stir welding process is very basic of solid-state weld process. Its various offers an advantage such as fine and uniform weld microstructure, high welding efficiency, small thermal deformation, mechanical properties, and green welding process, very small infrastructure, less maintains which has received considerable attention in welding aluminium alloys and other advanced materials. As FSW is applied and studies for advanced materials, such as aluminium alloys, magnesium alloys, copper alloys, titanium alloys, steels, and super alloys, have been reported. With developments in FSW process, studies were carried out to include advanced material such as copper alloy, magnesium alloys, titanium alloys, and steels. Friction stir spot welding (FSSW) is a variant process of the FSW. FSSW process was invented by Mazda Auto Corporation an automotive industry in 2001. It was applied of aluminium sheets a replacement for resistance spot welding process. It was getting worldwide attention due to infra-structure, potentially large energy savings, as compared to other types of welding techniques. FSSW process essentially consists of three phases such as plunging, stirring and retracting.

FSSW is a welding process, in which a specially designed for rotating tool is first phases plunged into the upper sheet. When the rotating tool contacts the upper sheet, second phases of 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 means a third phase of the tool is drawn out of the sheets and protruded pin leaves a characteristic exit hole in the middle of the joint.

Till the date a lots of research has been done testing on FSSW, while in this paper mainly focuses on the process, testing, and mechanical properties.

II. FRICTION STIR SPOT WELD PROCESS

FSSW is Conventional of solid state welding process, which is similar in concept and appearance to its replaced Resistance Spot welding. FSSW process kind of three stages: plunging, stirring, and retracting. The process initiates with the rotation of the tool at a high angular speed (N). Then the tool is forced (F) into work pieces until the shoulder of the tool touches the top surface of the upper plate. The plunging movement (P) of the tool causes the base material to expel out. After plunging, the stirring stage starts when the tool reaches a predetermined depth. In this stage, the tool keeps rotating without any further travel. Frictional heat is generated in the plunging and stirring stages, and thus the materials adjacent to the tool are heated, softened, and mixed in the stirring stage where a solid-state joint will be formed. When an acceptable bonding is obtained, the tool is retracted from the work pieces [11].

A. Pin less.

The pin less tool profile in FSSW was invented by Tazokai. In this process, the tool without a probe but with a scroll groove on its shoulder surface has been proposed in 2009 [16] shown fig.1. This kind of pin less tool has many advantages, a simpler
process, together with a better appearance with a shallow or no keyhole retained. Recently, preliminary data approach can be used to produce high-strength welds with a short dwell time [9].

![Pin less and Pin Refill Tool](image)

**B. Pin Refill.**

The refill FSSW was developed and patented by Helmholtz-Zentrum Geesthacht, in Germany [15]. The refill FSSW process consists of four phases: friction, first extrusion, second extrusion, and pullout. In this process, the tool has three parts: pin, sleeve, and clamp. The clamp holds the plates firmly against the anvil and also constrains the flow of material during the process. While the pin and sleeve begin to rotate in the same direction, they can also translate independently in the axial direction. The pin and sleeve move in the opposite direction, creating a space where the material is accommodated. After reaching the preset plunge depth, the pin and sleeve move reversely to the surface of the work piece, forcing the displaced material to completely refill the keyhole. Finally, the tool is withdrawn from the joint leaving a flat surface with minimum material loss [2].

**III. OPTIMIZATIONS PROCESS (TESTING METHOD)**

**A. Modeling of the FSSW process**

To optimize the welding process parameter and developing FSSW, it is very important to understand the physics of this complex process that involves tool geometry, tool and work pieces material, and friction, temperature gradient, and fatigue life, macrostructure and weld strength by numerical solution. With the help of design analyses and modeling on Ansys and Catia or other design software.

Harsha Badarinarayan et all- was present the effect of tool geometry on plastic flow and mixing of materials during process FSSW is investigated numerically using the particle method. Firstly Temperature distribution is axisymmetric and the temperature below the rotating tool is 340°C at dwell time is 0.44 s for the standard tool with a cylindrical pin of $\phi$ 5*1.25 mm length and rotating speed at 1500 rpm. For a cylindrical pin tool, the material flow at the pin periphery is in the upward direction. Near the shoulder, there are two flow patterns observed – beneath the shoulder, the material is pushed downward due to the force acting from the shoulder face, whereas on the shoulder periphery the material flows upward and outward due to extrusion of the material that is caused by the shoulder plunge. This material flow attributes to the formation of the ‘hook’ geometry. Numerical results showing the prediction on the hook formation agree well with the experimental data. The friction stir welding tool geometry has a significant influence on the material mixing and hence eventually influences the static strength of resultant spot welds.

S. Joy-A-Ka. et all – was presented on the crack initiation occurred as a boundary between the welding interface zone and non-interface zone or slit tip regardless of amplitude level which located in the HAZ. 3D observation clarified the fatigue fracture in FSSW joints. The fatigue fracture modes were independent on force amplitude level.

Furthermore, the results of the 3-D observation near the welded joint showed that the fatigue crack initiation of low force amplitude level was approximately 56% N/Nf of the whole fatigue life. As well as contrast with high force amplitude level was approximately 16% N/Nf of the whole fatigue life, which FSSW joints had a fatigue crack initiation life that accounted comparatively less proportion of the whole fatigue life. Therefore, it is important to consider the effect of force amplitude below the fatigue limit.

J.T. Chen et all- was present FEM can be successfully applied to model the 3D material flow [21]. The acquired results of There exists a good correlation between the equivalent plastic strain distribution and the distribution of the microstructure zones in the weld. The distribution of equivalent plastic strain is not strictly symmetric. On the advancing side, the gradient of the equivalent plastic strain is higher. The maximum of the equivalent plastic strain occurs on the advancing side. The equivalent plastic strain distribution in the nugget zone can be affected by the variations of the axial load on the shoulder, but the ones in HAZ and TMZ are not affected. With the increase of the axial load, the equivalent plastic strain in the nugget zone can be increased. There is a quasi-linear relation between the change of the axial load on the shoulder and the variation of the equivalent plastic strain in the nugget zone. The flow of the material in front of the pin on the retreating side is faster, but the flow behind the pin on the retreating side is slower.
IV. PROPERTIES TEST

A. Axial forces

Measuring of forces is performed FSSW by using precise analogue digital measuring equipment as well as load cell, related to information measuring system acting on Milling Machine. For a vertical acting force measuring system an analog signal from the sensor units (strain gauge) through the digital six-channel intensifier - the bridge and transferable units is transferred to the AD/DA card. Where it is converted to digital signal and saved to the PC with the installed software package for data acquisition system. Diagrams obtained in this way in the current voltage (V) and time (s), based on the known relationships and values of the calibration of measurement equipment providing diagrams of forces (N) in function of time (s).

B. Tensile-Shear Strength of FSSW Joints.

The quality of a FSSW was usually determined with a lap shear test. In lap shear tests, shims of the same material and thickness as the sample were used when clamping the samples to induce pure shear. There were usually two samples: tensile-shear and cross tension specimens. It was two sets of lap sheet specimens welded by FSSW, named sheet A and sheet B were fabricated and evaluated weld strength and weld quality shown in figure.

Ahmet Irfan Yukler et.al was investigates to use tapered cylindrical (TC) pin produced good quality (statics strength) of the weld joint through FSSW on HDPE sheet. It was result comparing different tool pin profiles, welds made with TC tool yielded higher weld strength than other tools at similar plunge depth. Finally obtained best weld statics strength on M7.25 size tool [01].

Mustafa et.al was presented lap-shear tensile force of FSSW joints affected result on welding parameter. In these studies to vary welding parameter such as the dwell time and plunge depth, to get find the dwell 30 sec and plunge depth up to 5.7mm on maximum strength and linear progress weld quality. In lap-shear tests, there were usually three different separation modes: interfacial shear separation, nugget pullout separation, and upper or lower sheet fracture separation. The joint with nugget fracture separation has higher strength. For tensile-shear sample, cracks of interfacial shear separation initiated preferentially at the crack tip in a weld and propagated along the bonded interface. The weld which has a low strength broke with the cross nugget failure morphology and Pull out nugget fracture morphology was high strength joint. Weld strength effect on weld parameter and tool pin profile [02].

Anup Chavan et al- his conducted the experiments and optimization of FSSW by Artificial Neural Network (ANN). The successful used of ANN to in predicting lap shear strength of FSSW welded joints on HDPE-sheet and his report was in good with other researchers. Predicted results define and show a mean squared error of 34.2 for overall performance. His also defined the maximum lap shear strength 3.749 N/mm² [01].

Memduh Kurtulmus et.al – result was investigated friction stir spot welding parameters effect of HDPE sheet. It was optimize weld strength with the help of the Taguchi method. The dwell time and speed was the most dominant welding parameter for maximum weld strength. Finally optimize welding parameter such as rotation speed of 700 rpm, plunge depth of 6.2mm and dwell time of 60s and improvement weld strength about 40% as compare to initial weld parameter [03].

Mustafa Kemal Bilici – was presented to the experimental and numerical affected of friction stir spot welding on HDPE sheet. Its optimize weld lap shear strength and evaluated with the help of the Taguchi method. The optimize welding parameters such as dwell time of 100 s, tool plunge depth of 5.7 mm and the tool rotation speed of 900 rpm and improvement in the weld strength from the initial welding parameters to the optimal welding parameters was about 47.7% [7, 8].

Yahya Bozkurt- In this investigation the applicability lap shear strength of the friction stir welding on HDPE sheet was studied by using the Taguchi method. To use L9 Taguchi orthogonal designed and the optimum welding parameters for the tool rotation
speed and tilt angle. Finally presented the lap shear strength improved approximately 112% and 105% respectively from initial welding parameters [13]. Wiebke S. Junior—to present the ultimate lap shear strength on dissimilar of commercial polymer [18]. The demonstrated equal or even higher shear strength when compared with thermal bonded joints. Considering that the work remains in its initial phase of welding conditions and that the optimization phase remains in progress, an improvement of the weld (shear strength) performance can be expected.

C. Macrostructure Modes

The first macrostructure was investigated by Wang and Lee on aluminum 6061-T6 lap shear specimens [20]. In reviews, keyhole was observed on the top surface of the weld. The thickness of the upper sheet material under the shoulder indentation decreased at the squeezing action of tool, consequently, resulting in an expansion of the upper sheet.

Based on the observation of the FSSW macro structure the weld zone on FSSW joint on HDPE sheet is shown in Fig.1. From the appearance of weld cross section a particular point can be which is the thickness of weld nugget which is an indicator of the weld bond area. The shape and size of the weld nugget determines the strength of the FSSW joint [1, 2].

It is known that macrostructure appearance of FSSW joint. The static strength and material deformation depends on welding parameters include tool rotational speed, plunge rate, plunge depth and dwell time. Hence macrostructure appearance changes with the change of welding parameters. Memduh Kurtulmus et al. and Saeid Dashatan et al. demonstrated that bonded region on HDPE sheet and other polymers.

D. Temperature Distribution

Temperature distribution of the measurement in the process of friction stir spot welding on lap plate of the HDPE materials is performed with precise data acquisition system mean analog-to-digital measuring device connected with information measurement system. Temperature distribution are measuring system is consisted of: sensors - thermal couple, measuring module and the PC with software Measurement & Automation Explorer shown in fig. and Lab VIEW where the processing of measuring signals is performed, and data are obtained in graphical and data form.

During the friction stir spot welding process, heat is generated basically due to two reasons: (a) friction between the tool and work piece, and (b) plastic deformation of the welded material due to heat generated and compressive loads exerted by the tool. Heat and plastic flow resulting from the tool rotation determines remarkable modification in microstructure resulting in local modification of material characteristics around the joint. In order to represent the material close to junction in the zones with different mechanical properties, a mapped mesh has been presented for the weld section as shown in fig.2. As we move from the periphery of the obtained joint towards the tool pin axis (also the axis of generated nugget), the first encountered zone is the BM (Base material) in which no metallurgical modification is found due to welding process. The second zone is the HAZ (Heat Affected Zone) where the material has experienced a thermal load that modified the microstructure and mechanical properties.

E. Flexural Strength of FSSW Joints:

Flexural strength (Bending strength) is one of the main criteria in evaluation of the mechanical properties of FSSW joints. The flexural strength of thermoplastics, such as high density polyethylene sheets, is influenced by welding parameters shown in Fig.5. Three point bent tests were done with manufactured by Gotech Company according to ASTM D790 standard. This standard uses maximum strain and fiber stress to assess the strength of the sheet. For making judgment about FSSW effects on macrostructure of HDPE sheets in various operating conditions, a LEICA DMRX polarized microscope was utilized.
The standard requires the testing of six specimens from each weld such that three put it in compression and three place the weld root in tension. Since those specimens tested root-up outperformed those tested root-down, three root-down specimens was selected to evaluated flexural strength. In other words, in friction stir welding, if the specimens are subjected to the flexural tests, all of specimens tested root-up can outperform those tested root-down. The reason is that, in root up specimens, root defect was subjected to a compressing force, however in root-down specimens; root defect was subjected to a tensile force which can remarkably reduce the flexural strength. These three specimens were cut perpendicular to the welding direction and from the middle of the welded plates to eliminate the start and end effects of the welding process.

## V. CONCLUSIONS

FSSW is a robust process, with capability to generate welds of good result of the strength over a wide range of welding parameters. In the above studies the testing process of friction stir spot welding on high-density polyethylene sheet has been carried out. Friction stir spot weld joint on high-density polyethylene sheets and specimen was evaluated to optimize weld strength. Results indicate that effective parameters of process are tool geometry. Optimum weld strength was evaluated with the help of the testing method. From the review, it is observed that work was not done on multi point of friction spot weld joint on HDPE sheet.

## REFERENCES


