Review on Multispot Friction stir spot welding of AA6061 and its Investigation

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Abstract: Friction stir spot welding is a spot welding process and an alternative joining method of friction stir welding technique. The application of FSSW alloys in aerospace, high-speed train manufacturing, and automotive industries is increasing gradually. In the present paper, a detailed description provided on the base of past research work that has been done. Based on the past work there is no data for Multispot FSSW so that in the present work there is an attempt will be taken on the same. And based on that further Mechanical and different properties of the metal after the welding process will be evaluated.

***Keywords*– Friction Stir Spot Welding (FSSW), Microstructure, Macrostructure, Tensile strength, Resistance Spot Welding(RSW), Friction Stir Welding(FSW).**

I INTRODUCTION

1.1 What is Welding?

Welding can be defined as a fabrication process used to join materials, including metals and thermoplastics.

1.2 What is Friction Stir Spot Welding?

Recently, a new solid-state welding technique, friction stir spot welding (FSSW) has been developed by Mazda Motor Corporation and Kawasaki Heavy Industry, as an extension of friction stir welding (FSW) for joining aluminum alloys. Mazda reported a great reduction in energy consumption and equipment investment to compare to RSW for aluminum. Since FSSW is a solid state welding process, no compressed air and coolant are the need, and less electricity is required than RSW. Friction stir spot welds have higher strength, better fatigue life, lower distortion, less residual stress, and better corrosion resistance.

Unlike FSW, there is no traverse movement after plunging a rotating non-consumable tool into the workpieces. Tools used for FSSW have two parts, a pin, and a shoulder. The pin is designed to disrupt the faying surface of the workpieces, shear and transport the material around it and produce deformational and frictional heat in the thick workpieces. The tool shoulder produces a majority of frictional heat to the surface and subsurface regions of the workpieces. Also, the shoulder constrains the flow of plasticized material and produces downward forging action.

1.3 Types of Friction stir spot welding process

FSSW mainly consists of four types of processes

[1] Plunge type FSSW

[2] Refill type FSSW

[3] Stitch FSSW

[4] Swing FSSW

1.3.1 Plunge Type FSSW

Plunge type FSSW is most commonly used in current industries. During plunge type FSSW, a rotation tool with a protruded pin is plunged into the workpieces from the top surface to a predetermined depth, and after a certain dwell time, it is retracted and a keyhole is left. The frictional heat generated at the tool-workpiece interface softens the surrounding material, and the rotating and moving pin causes the material flow in both the circumferential and axial directions. The forging pressure applied by tool shoulder and mixing of the plasticized material results in the formation of a solid bond region. A schematic of the plunge type FSSW method is indicated in Fig. 1.3.1.

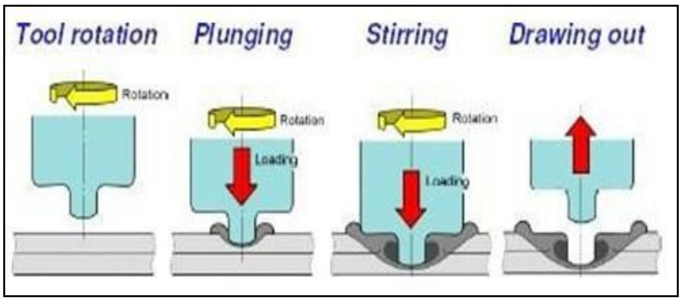


Figure 1.3.1 – Schematic diagram of plunge type FSSW

1.3.2 Refill Type FSSW

Refill FSSW, which is a patented process of GKSS that joins two or more sheets of material together by utilizing delicate relative motions of the pin and the shoulder to fill the pinhole. As indicated in Fig. 1.3.2, it consists of three stages: initiation, full plunge and full retract. In the initiation stage both the pin and shoulder are placed on the surface of the upper sheet and rotate to generate sufficient frictional heat for plunging. The full plunge stage consists of plunging the shoulder into the sheet material and retracting the pin. In the full retract stage, the shoulder is retracted and a pin is plunged to push the displaced material back into the void formed by the shoulder.

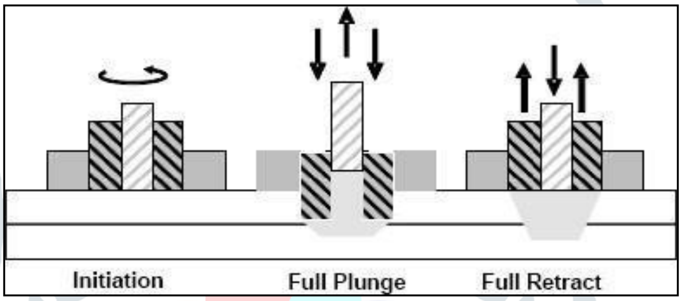


Figure 1.3.2 - Schematic diagram of refill type FSSW

1.3.3 Stitch FSSW

Another variation of the FSSW is "Stitch FSSW" from GKSS, as illustrated in Figure1.3.3. During stitch FSSW the tool, after plunging, traverses a short linear distance before retracting. The purpose of this method is to produce joints with the larger joining area for higher strength.

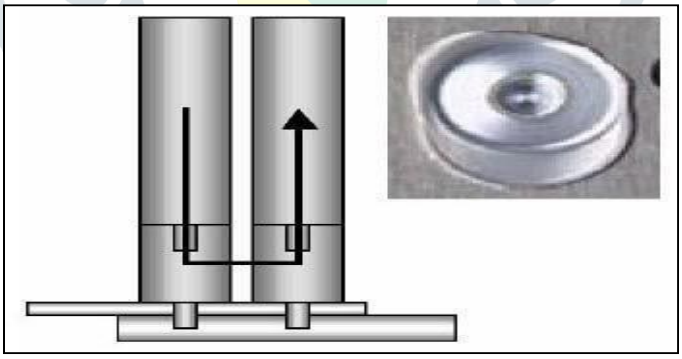


Figure 1.3.3 – Schematic diagram of stitch type FSSW

1.3.4 Swing FSSW

Swing FSSW was developed out of stitch FSW by Hitachi with the idea to give a large enough radius. As shown in Fig. 1.3.4, after plunging, the tool goes up a little but this is negligible since it moves in a swing-like motion with a large radius and small angle. This movement results in a squeezed material located at the end of the welding. The plunge type FSSW requires the simplest gun or assembly with spindle motor and tool plunge motor. An additional motor is needed to give a linear movement for stitch FSSW, which leads to complex and heavy C-frame gun design. A prototype C-frame "swing stir" gun has been designed by Hitachi. As shown in Fig.1.3.4, it consists of three motors: the spindle motor for tool rotation, a tool plunge motor and a swing motor for the sliding cam used to swing the rotating tool in an arc giving a swing motion.

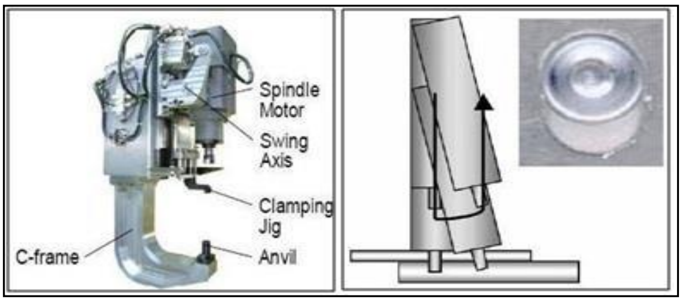


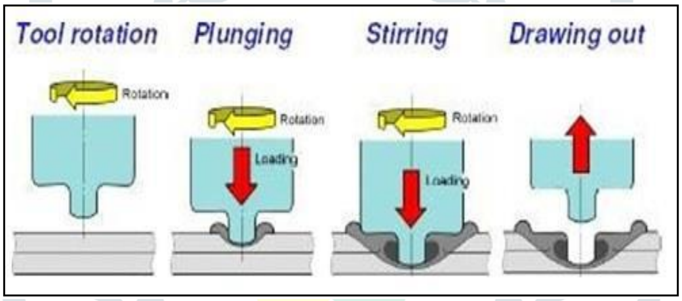
Fig. 1.3.4 – schematic diagram of swing FSSW

1.4 Working principle of FSSW

Friction stir spot welding (FSSW) is a pressure welding process that operates below the melting point of the workpieces. In friction stir spot welding, individual spot welds are created by pressing a rotating tool with high force onto the top surface of two sheets that overlap each other in the lap joint. The frictional heat and the high pressure plastify the workpiece material so that the tip of the pin plunges into the joint area between the two sheets and stirs-up the oxides. The pin of the tool is plunged into the sheets until the shoulder is in contact with the surface of the top sheet. The shoulder applies a high forging pressure, which bonds the components metallurgically without melting. After a short dwell time, the tool is pulled out of the workpieces again so that a spot weld can be made as fast as possible.

1.4.1 In FSSW there are three subprocesses

[1] Plunging
[2] Stirring
[3] Retracting / Drawing out.



The fig.1.4.1 working principle of FSSW

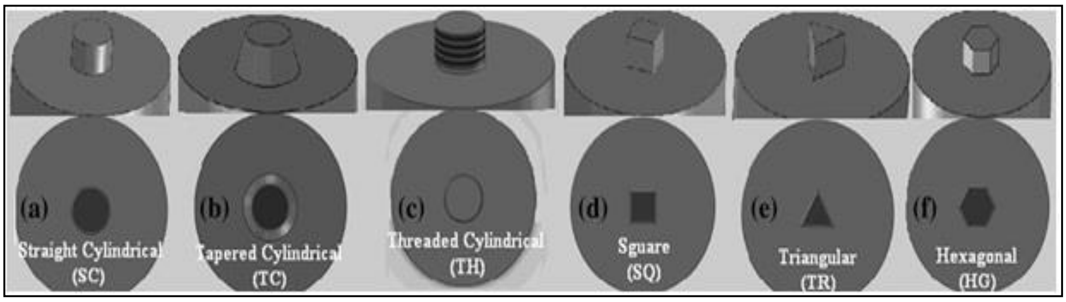
Plunging- During this process, a rotating tool with a probe is plunged into the material from the top surface for a certain period of time to generate frictional heat. At the same time, a backing plate contacts the lower sheet from the bottom side to support the downward force.

Stirring- In this stage for a particular duration of time frictional heat is generated between the wear resistant welding components and workpieces. This heat, along with that generated by the mechanical mixing process softens the materials without melting. Heated and softened material adjacent to the tool causes plastic flow. In addition, the tool shoulder gives a strong compressive force to the material.

Retracting/Drawing Out- After the dwell period, the tool is withdrawn from the plunged zone and drawn away from the material, a solid-phase weld is produced between the upper and the lower sheets. The material hardens on cooling thereby welding the two pieces together.

1.5 Tool for FSSW process

We can use different materials for the tool. Ex. (1) Mild steel, (2)High carbon steel, (3) High-speed steel, (4)Armour steel, (5)Tool steel, (6)Stainless steel etc.



1.5-Different types of tool pin

1.6 FSSW affecting parameters

- Tool penetration depth in mm
- Tool shoulder plunge depth in mm
- Dwell time – Duration of Plunge in seconds
- Tool plunge speed in mm/min
- Axial force in N

1.7 Advantages of FSSW process

- ✓ Metallurgical benefits Environmental benefits
- ✓ Solid-phase welding process Shielding gas not required
- ✓ Acceptable distortion Requires minimal surface cleaning
- ✓ Good dimensional stability and repeatability
- ✓ Eliminates grinding wastes
- ✓ No loss of alloying elements Eliminates solvents required for degreasing
- ✓ Improved mechanical properties in the joint
- ✓ Consumable materials saving include rugs, wire, or any other gases
- ✓ Fine recrystallized microstructure No harmful emissions
- ✓ Solidification cracking is non-existent
- ✓ Replaces multiple parts joined by fasteners

1.8 Applications of FSSW process

- ➢ Automotive industry
- ➢ Rail vehicle construction
- ➢ Aerospace industry
- ➢ Robotics

II LITERATURE REVIEW

Dhruvil Trivedi et. al.[1] focused on the dissimilar joining of aluminum alloy Al6061 and Al5083 with the plates of 6 mm thickness by friction stir welding. The objective of this research is to enhance the mechanical properties by changing the advancing side material during welding and also optimizing the various process parameters such as tool rotation speed and traverse feed for higher joining strength. The influence of welding process parameters on strength of joint has been evaluated by means of a tensile test. The tool rotational speeds were taken between 500 to 1000 rpm and tool traverse speeds were taken between 40 to 125 mm/min. The maximum tensile strength yielded 98.90 MPa when the Al6061 keep in an advancing side and 32 MPa when Al5083 keep in advancing side during the weld joint at 1000 rpm and 50 mm/min. It was observed that the advancing sides of materials also play a key role in joint strength while keeping remaining process parameters constant during FSW.

Necdet Capar et. al.[2] focused on the importance of the use of FSSW in the automotive industry and overviews advantages of FSSW on lightweight applications. Also stated that different alloys like Al-Mg, Al-Steel, Mg-Steel can be welded by this process easily and mechanical properties of the welded alloy are optimum. For the Mg-Steel joint, they used AM60 Mg and DP600 steel and tool rpm was 3000 and 1mm/s plunge speed and 0.55mm pin penetration.

S.Siddharth et. al.[3] stated that the depth of penetration the tool in the top plate is responsible for determining the overall quality of the joints. During the FSSW process as the materials soften due to the frictional heat, the axial force of the plunging tool plays a pivotal role in holding the two workpieces together. Dwell time is found to have a great influence on tensile shear fracture load(TSFL) followed by tool rotation speed & plunge depth.

M.K. Kulekci et. al.[4] focused on Aluminium alloy 5005 and took experiments for plates of the same alloy which have a thickness of 1.5mm. sample dimensions are100×25×1.5 mm. and used an overlap area of 25×25 mm. and used pin height of 2.2mm, 2.4mm, and 2.6mm for the tool rotation speed of 1500rpm and 2000rpm. In which he found that an increase in tool rotation speed increases the tensile shear strength in a limited range. And an increase in tool pin height also increases the tensile shear strength. And the increase in dwell time reduces the tensile shear strength.

S.Ravi Sekhar et. al.[5] stated that the FSSW process offers an ability to join Aluminium sheets from 0.5 mm to 50 mm thickness. In his investigation, he used 2mm thick rolled Aluminium sheets. Using the lap joint configuration and the size of the plate is 25×75 mm. where the lap joint area is about 25×25mm. a tool used was of high-carbon steel. tool rpm of about 500-1300 RPM. While the other factors were constant. Different parameters used by him are tool rotation speed is 500, 700, 900, 1100, 1300 RPM, Plunge rate 10mm/min, Plunge depth 3.3mm, and Dwell time is 3 sec. He found that the tensile shear fracture load increases with an increase in RPM of 500 to 900 RPM and then further increase in RPM, tensile shear fracture load decreases.

S.Siddharth et. al.[6] find that optimum FSSW process parameters were tool rotation speed of 1100 RPM, plunge depth of 2.05mm and dwell time of 11.5seconds by using response surface methodology. A maximum tensile shear failure load value of 2.234kN and minimum interface hardness of 90.9HV was predicted and validated. He used Aluminium Al5086(H 32) of 1.5mm thickness and Copper C10100 plate of 1.5mm thickness and the size of both plates was 100×30mm. Using lap joint formation and BH13 tool with straight cylindrical profile and 0˚ degree tilt and pin of 6mm diameter and having a height of 1.5mm.

G.pieta et. al.[7] used the Taguchi method for the finding of best results of mechanical properties for Friction spot welding of 3.2mm thick AA2198-t8 Alloy for the best lap shear test. The best result was obtained at the 2000RPM, 4.7mm of plunge depth at the time of 10s. He showed the welding conditions based on the L9 orthogonal array provided by the Taguchi method. He performed the different experiments using RPM of 1500, 2000, and 2500, plunge depth of 3.7, 4.2, 4.7 and 5.2 mm. and find the different values for the Mean lap shear strength (kN).

Mustafa Kemal et. al.[8] have reported that Friction-stir spot welding (FSSW) is a solid-state welding process suitable for the spot joining of lightweight low-melting-point materials. The process is performed by plunging a rotating pin that creates a connection between sheets in an overlap configuration by means of frictional heat and mechanical work. In this study, the tensile shear- strength and hardness variations in the weld regions are discussed. The results obtained are compared with those derived from the application of traditional resistance spot welding (RSW). The experimental results of the study show that FSSW can be an efficient alternate process to electrical resistance spot welding.

A.K. Lakshminarayanan et. al.[9] published a paper and said that Friction stir spot welding is a novel solid-state process that has recently received considerable attention from various industries including automotive sectors due to many advantages over the resistance spot welding. However, to apply this technique, the process parameters must be optimized to obtain improved mechanical properties compared to resistance spot welding. To achieve this, in this investigation, the design of experiments was used to conduct experiments for exploring the interdependence of the process parameters. A second order quadratic model for predicting the lap shear tensile strength of friction stir spot welded low carbon automotive steel joints was developed from the experimentally obtained data. It is found that dwell time plays a major role in deciding the joint properties, which is followed by rotational speed and plunge depth. Further optimum process parameters were identified for maximum lap shear tensile strength using numerical and graphical optimization techniques.

III SUMMARY OF LITERATURE REVIEW

- As the research papers are analyzed and it is shown that the different parameters affecting the FSSW process are different. In which the Tool penetration depth and tool rotation speed are the predominant parameters and these are giving the quality welds at an optimum limit.
- The tensile shear strength of FSSW significantly affected by tool rotation speed, dwell time and the tool pin height. Still the date no one has done in the chain spot joints and there is no data available for the same.

IV CONCLUSION

Friction stir spot welding (FSSW) is a very innovative and interesting welding process for any research scholar as well as for any academic person. Till the date, very few attempts have been carried out for the FSSW and all were in a different direction.

- From the literature review, different parameters are derived from the past research work and it is given in the table below.

Material	Thickness of Plate	Process parameters
For the FSSW process, there is a wide range of material are used EX. Aluminium (AA2xxx to AA8xxx) Steel, Magnesium, Titanium etc.	According to the past research work and Literature reviews, thickness used for FSSW varies between 0.5mm to 6mm.	Tool rotation speed(RPM) – 700 to 5000 Plunge Speed(mm/min) – 1.5 to 6 Axial load (N) – 1000 to 6500 Dwell time (second) – 2 to 7 Pin height of the shoulder of a tool (mm) – 1 to 10.

V FUTURE SCOPE

- Friction stir spot welding (FSSW) is very broad welding process in which we can use multiple spot patterns for the joining of the plates and can optimize different process parameters to achieve the best result and by comparing it with the different joining processes like riveting also, There is a possibility to use different riveting design criteria for the Friction Stir Spot Welding (FSSW) and from the comparison we can get the result.
- By using the different Mechanical and Chemical tests we can get the different properties of the FSSW and can set these parameters as a benchmark for the new researchers.

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