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Study of Friction Stir Spot Welding (FSSW) of 4mm thick Aluminium Alloy 6061 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 a FSSW alloys in aerospace, high speed train manufacturing, ship building and automotive industries is increasing gradually. The similar joining of aluminum alloy Al6061 with the plates of 4 mm thickness is going to carried out by friction stir spot welding. The objective of this research is to enhance the mechanical properties by changing the joint pattern of the welding joints and also optimizing the various process parameters such as tool rotation speed and dwell time for higher joining strength. In present topic an attempt on the different configuration of FSSW lap joints is going to achieve like in normal pattern in single spot and double spot, chain spot pattern etc and simultaneously the different strength, tensile load values and stresses developed in the joints will be discovered. And to check the possible properties change in the plates after welding process.
Keywords: Friction Stir Spot Welding (FSSW), Microstructure, Macrostructure, Tensile strength, Resistance Spot Welding (RSW), Friction Stir Welding (FSW), Single spot, Multi spot, AA6061 Alloy.

I. INTRODUCTION

A. What is Welding?

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

B. 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.

C. 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

D. 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.

E. In FSSW there are Three sub Processes

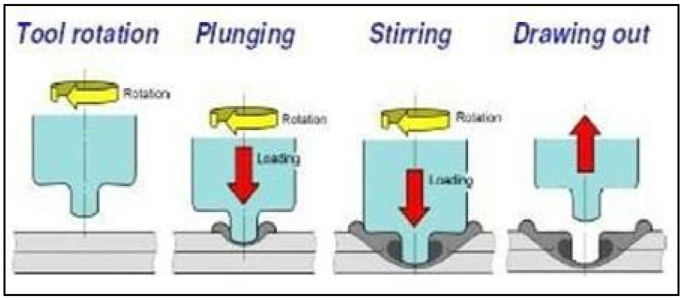

Fig.1 Working principle of FSSW

1) *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.
2) *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.
3) *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.

F. 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.

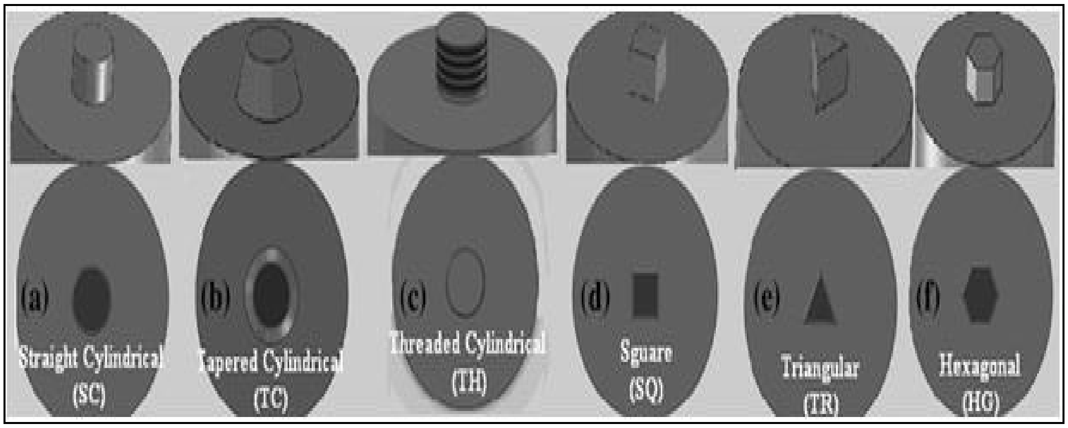

Fig.2 Different types of tool pin

G. FSSW Affecting Parameters

1) Tool penetration depth in mm
2) Tool shoulder plunge depth in mm
3) Dwell time – Duration of Plunge in seconds
4) Tool plunge speed in mm/min
5) Axial force in N

H. Advantages of FSSW process

1) Metallurgical benefits Environmental benefits
2) Solid-phase welding process Shielding gas not required
3) Acceptable distortion Requires minimal surface cleaning
4) Good dimensional stability and repeatability
5) Eliminates grinding wastes

I. Applications of FSSW Process

1) Automotive industry
2) Rail vehicle construction
3) Aerospace industry
4) 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).

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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.EXPERIMENTAL WORK

In this work AA6061 was used. For the Welding process Universal milling machine was used to perform the experiments. Special type of Fixtures was made by the use general mechanical processes like machining, cutting, notching etc to rigidly hold the work pieces at the time of welding process.

Fig.3 Universal milling machine

The Chemical Composition of AA6061 is as below:

Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Weight%	0.6	0.35	0.25	0.10	0.9	0.21	0.13	0.11	97.35

Table.1 Chemical composition of AA6061

Mechanical and Physical properties of AA 6061 are as below:

UTS (Mpa)	Tensile yield strength (Mpa)	Elongation (%)	Hardness (Brinell number)	Melting temperature (˚C)	Modulus of Elasticity (Gpa)	Thermal conductivity (W/m×K)	Density (gm/cm3)
310	276	12-25	95	585	68.9	151-202	2.70

Table.2 Mechanical and Physical properties of AA6061

To develop friction stir spot welded region on AA 6061 surfaces, its foremost requirement is to design FSSW tool which have pin profile, shoulder and tool holder. The design tool is capable to produce any defect free weld joint.

The tool material used was H13 hot work tool steel because it contains enough strength and other required properties for the FSSW. According to the dimensions of plates tool was designed, it have a conical cylindrical tip with diameter of upper diameter of 6mm and lower diameter of 2mm. and having tip length of 6.2mm with shoulder diameter of 20mm.

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Fig.4 Tool for FSSW

The chemical composition (in weight %) of H13 Tool steel is as below

Carbon	Chromium	Molybdenum	Copper	Phosphorus	Silicon	Sulphur
0.32-0.45	4.75-5.5	0.2-0.5	1.1-1.75	0.00-0.03	0.8-1.2	0.00-0.03

Table.3 Chemical composition of H13 tool steel

Fixture used for holding the plates rigidly was made of Die steel, which is very popular grade of through-hardening medium carbon steel, which is readily machinable in any condition.

A sample of experiments was taken and here the main aim of the study was to find the different tensile load value and to check effect of the same.

Basic size of welding plates is 20×70×4mm. While the lap joint area is 20×20 mm^2.

Experiment no.	RPM	Pattern
1	710	Single spot
2	710	Double spot
3	710	Chain spot(Triple spot)
4	1000	Single spot
5	1000	Double spot
6	1000	Chain spot(Triple spot)
7	1400	Single spot
8	1400	Double spot
9	1400	Chain spot(Triple spot)

Table.4 Samples of Experiments

IV. RESULT AND DISCUSSION

Here at the same RPM of the tool different experiments taken for the FSSW process.

Fig.5 FSSW plates at 710RPM, 1000RPM and 1400RPM

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A. Results of Tensile Load

Experiment no.	RPM	Pattern	Tensile Load(KN)
1	710	Single spot	1.620
2	710	Double spot	1.620
3	710	Chain spot(Triple spot)	2.740
4	1000	Single spot	1.940
5	1000	Double spot	4.340
6	1000	Chain spot(Triple spot)	1.140
7	1400	Single spot	2.920
8	1400	Double spot	4.240
9	1400	Chain spot(Triple spot)	4.140

Table.5 Results of experiments

From the experiments it have been found that as the welding pattern is the also the predominant factor for the Tensile load value. The maximum tensile load was obtained in the Double spot pattern at 1000RPM. And highest elongation was obtained was 40.8% it's too much for the any joining process like this. As the different factors like Pitch, margin, Tool pin height and material thickness are also the major factors that affect the welding strength.

Blank development occurs at the time of failure in the upper plate while in the lower plate "Dipping profile" is generated and shearing action found in the mating of two surfaces at TMAZ as the stir zone is not available. As value of slope increases, deformation decreases and material defines early stage failure and not able to carry further load. In the experiments it was also derived that this kind of process can be used for the general load carrying applications as it can carry the high tensile load.

From the microstructures of the plates it is shown that the grain distribution is uniform after the welding process of the plates.

Fig.5 microstructures of plates

B. Broken Plates

Fig.6 Plates after testing

V. CONCLUSION

In this work, Friction stir spot welding of AA6061 alloy with various welding parameters were carried out successfully.
The following conclusions are drawn from the experiments.

A. As the pattern is changing the load carrying capacity of the joints also varies.
B. Highest load carrying capacity was at intermediate RPM and the elongation of the joint is also 40.8% achieved which is 2 times than normal plate failure.
C. All the experiments got break through the TMAZ of the welding region and generate dipping profile in the bottom plate.
D. At Low RPM it shows higher failure rate.
E. At high RPM for the consecutive welding region also it shows lower load carrying capacity.
F. Best result was achieved in the Double spot at medium range RPM.

VI. FUTURE SCOPE

A. Various attempts can be made for different configuration in diamond shape, zig-zag formation and variation in the dimensions of plates for similar and dissimilar materials

B. The novelty in the future research can also include Bi-directional welding joint formation of Friction stir spot welding joints.

C. The mechanical design joints can also be proposed as comparative study of the rivets & other fusion welding techniques like FSSW joint method.

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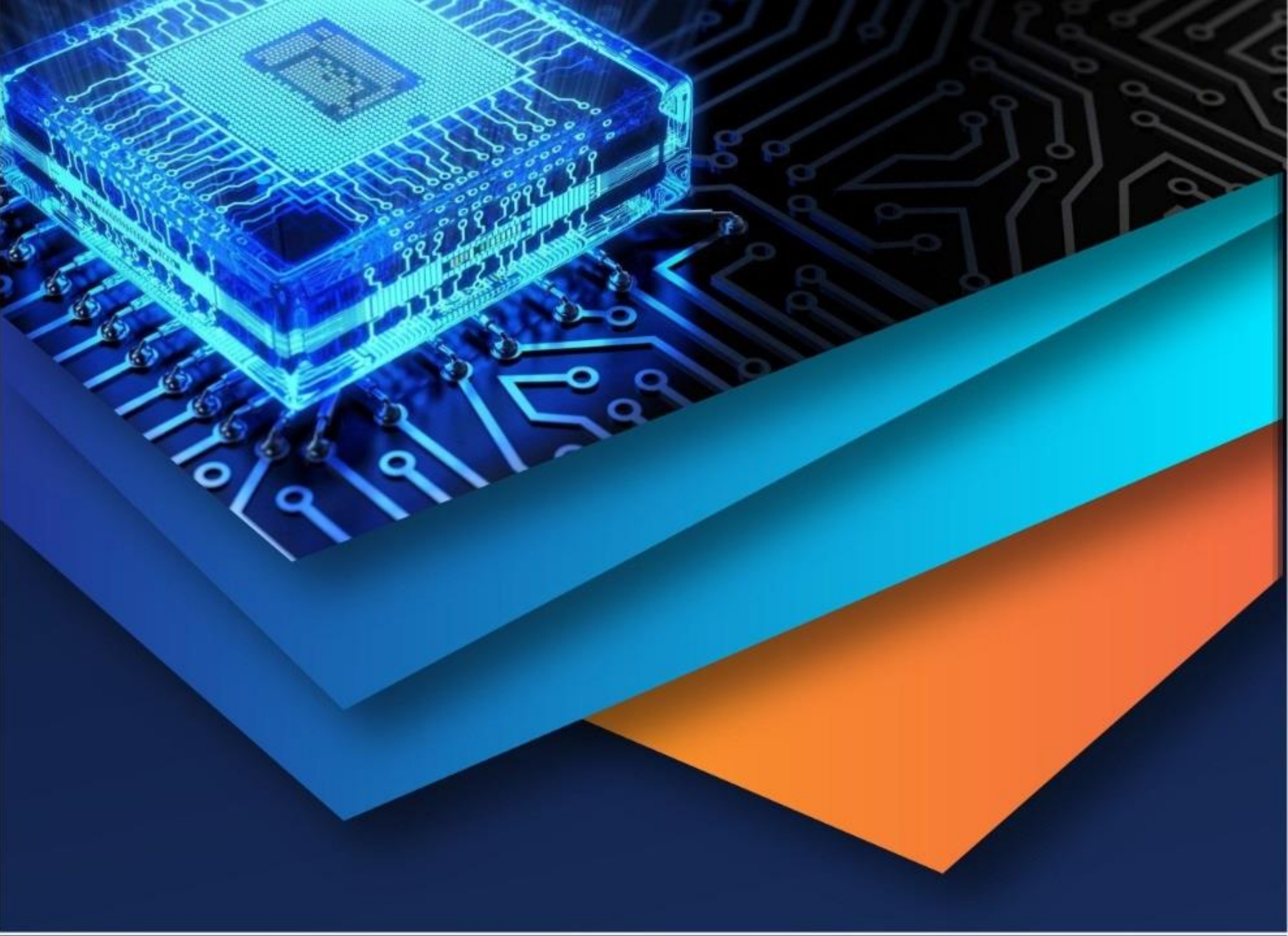

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