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Word Analysis of Friction Stir Spot Weldments Characteristics Using Different Tools Materials and Shape for Similar and Dissimilar Metals

Asst. Prof. Attalique Rabbani, Mohd. Zeeshan, Mohammed Salahuddin, Shaik Amjad
Department of Mechanical Engineering,
ISL Engineering College,
Hyderabad,India

Abstract*- Efforts to reduce vehicle weight and improve safety performance have resulted in increased application of light-weight aluminium alloys and a recent focus on the weldability of these alloys. Friction stir spot welding (FSSW) is a solid state welding technique (derivative from friction stir welding (FSW), which was developed as a novel method for joining aluminium alloys). During FSSW, the frictional heat generated at the tool-workpiece interface softens the surrounding material, and the rotating and moving pin causes material flow. The forging pressure and mixing of the plasticized material result in the formation of a solid bond region. The present work investigated the effect Aluminium, Brass and Copper alloy plates are joined by friction stir Spot welding (FSSW) by using EN31 and EN19 Tool material with Circular, Taper thread, Square and Diamond Profile Tools. Profiles with varying welding parameters like with a Rotational speed of RPM, Feed and depth of cut, inclinational angle of the tool.All welded samples are observed by followed by their tensile tests. Mechanical strength of the base material with comparable elongation is achieved in FSSW sample rotation speed and welding speed. Material flow during FSSW using a step spiral pin was studied by decomposing the welding process and examining dissimilar alloys spot welds which allowed a visualization of material flow based on their differing etching characteristics. The movement of upper and bottom sheet material, and their mixing during FSSW were observed.

***Keywords*- Friction Stir Spot Welding; tool design; Al, Brass and Cu alloy; process parameter; failure mode.**

I. INTRODUCTION

Weight reduction without affecting the safety performance is a great challenge in the automotive industry in order to improve fuel economy and reduce emissions. It has been reported that fuel consumption can be reduced by 5.5% for each 10% reduction in vehicle weight and a one-pound reduction in the weight of a car would reduce carbon dioxide emissions by 20 pounds over the life of the vehicle. An automobile consists of outer panels and a platform, which is typically made of steel and contains the drive system, engine system and exhaust system. The weight of the platform is around 70 % of the total weight of an automobile.

Steel has been applied widely in the automotive industry because of its wide range of desirable properties, ease of processing, availability, and recyclability. However, lightweight materials like aluminum have obvious advantages over steel with comparable properties but an almost three times lower density, a high corrosion resistance, and high degree of utilization reaching 85-95%. Aluminum alloys are promising candidates for replacing equivalent steel assemblies and the use of them in the automotive industry is increasing recently.

For replacing steel with aluminum in the structure of automobiles, it is necessary to explore joining methods that can be used efficiently.

Current panel welding techniques used to join steels include resistance spot welding (RSW) and self-piercing rivets (SPR). However, these welding techniques cannot be applied easily to aluminum alloy, because of its physical properties, particularly surface oxide film. Friction stir spot welding (FSSW) is a derivative of friction stir welding, which was developed by TWI (Abington, United Kingdom) in 1991 as a solid-state method for aluminum alloy joining.

This 2 novel joining mechanism is advantageous for producing aluminum joints without contamination, blowholes, porosity and cracks.

II. REVIEW OF LITERATURE

1. Aluminum and its 6XXX Series Alloys:
Aluminum and its alloys have been used extensively in modern life, from soda cans, household cookers to automotive and aircraft structures. Low density, high strength, high ductility, excellent formability and high corrosion resistance in the ambient environment make

them promising candidates for vehicles, particularly the closure panels such as hoods, decklids and lift-gates.

The weldability of aluminum alloys varies depending on the chemical composition of the alloy used. The 6XXX series aluminum alloys mainly used in this project, designating the Al-Mg-Si-(Cu) alloys, are most commonly used for extrusion purpose and are widely used as automobile body sheets.

This 6XXX series alloys are heat-treatable and have the following qualities:

- Good corrosion resistance
- Perfect surface finish
- Good formability
- Medium strength
- Hemming behavior
- Easy recyclability

All these advantages make them suitable for structural applications. Magnesium and silicon are the main additions and combine to form the stoichiometric compound, Mg2Si, which makes 6XXX series alloys heat treatable and capable of achieving medium strength after artificial ageing. An increase in the Mg2Si content results in improved tensile properties.

2. Conventional Welding Methods for Alumium Alloys:
A number of welding methods are available based on the variability associated with entities joined, corresponding joining mechanism and source of energy used. Conventional methods used for aluminum alloy welding in automotive industry are resistance spot welding (RSW) and self-piercing riveting (SPR).

3. Resistance Spot Welding:

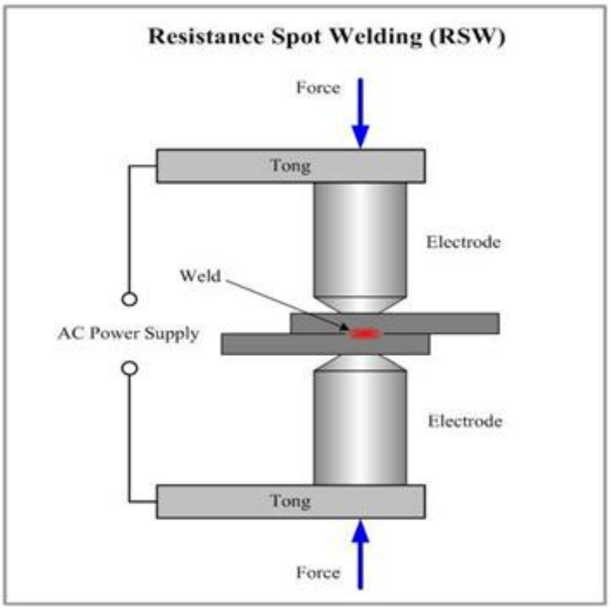

Fig 1. A schematic of resistance spot welding.

RSW is one of a group of resistance welding (RW) process, in which workpieces are welded due to a combination of pressure applied by electrodes and enormous amounts of heat, which is generated locally by a high electric current flowing through the contact area of the weld. A schematic of resistance spot welding is shown in Fig. 1 Two electrodes are simultaneously used to clamp workpieces together and to pass current through them.

The amount of heat delivered to the spot is determined by the resistance between the electrodes, the amplitude and duration of the current and the heat loss factor. The formula for heat generation during RSW is :

$$\mathbf{H = I^2RTK}$$

Where;
I = Current flowing through the weld in amps
R = Resistance in ohms from one electrode tip to the second tip.
T = Time of current flow in seconds
K = Heat loss factor

The amount of energy needed to produce a sound weld varies with the change of sheet material properties, thickness, and type of electrodes. Either too little or too much heat will not give a good joint. Too little heat will result in lack of melting and make a poor weld. Too much heat will melt too much material and make a hole rather than a weld.

4. Self-Piercing Riveting:
SPR is a high-speed mechanical cold joining process used to join two or more overlapping sheets by pushing a rivet through the stack from one side without pre-drilling holes to the sheets. A large-deformation process is involved during piercing

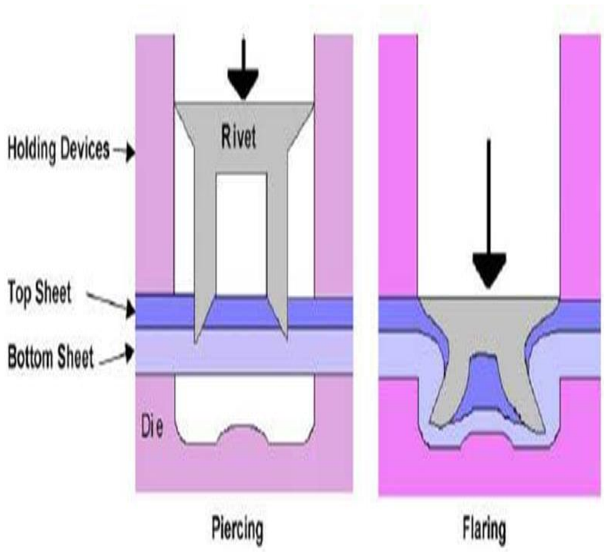

Fig 2. An illustration of a self-piercing riveting process in cross section view.

Fig 2 shows a schematic of SPR process. The self-piercing rivet, under the press applied by the punch, pierces the upper sheet and flare into the bottom sheet under the influence of an upset die. A mechanical interlock was formed between the rivet and the transformed sheets. The rivet stays in a position with its upper surface at the same level as the surface of the upper sheet. This joining process comprises many pairs of contacts between the punch, holder, rivet, upper sheet, bottom sheet, and die.

Unlike RSW, no metallurgical process is involved in SPR joining, a wide range of materials can be joined, including combinations of similar or dissimilar materials, such as aluminum to aluminum, steel to steel and aluminum to steel. SPR shows better performance in joining aluminum alloys than RSW, it is environmentally friendly due to the low energy requirement, no fumes and low-noise emissions. SPR of aluminum alloys also gives superior fatigue behavior than RSW of aluminum alloys.

III. RESEARCH METHODOLOGY

1. 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 . Since FSSW is a solid state welding process, no compressed air and coolant are 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.

2. 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 key hole is left.

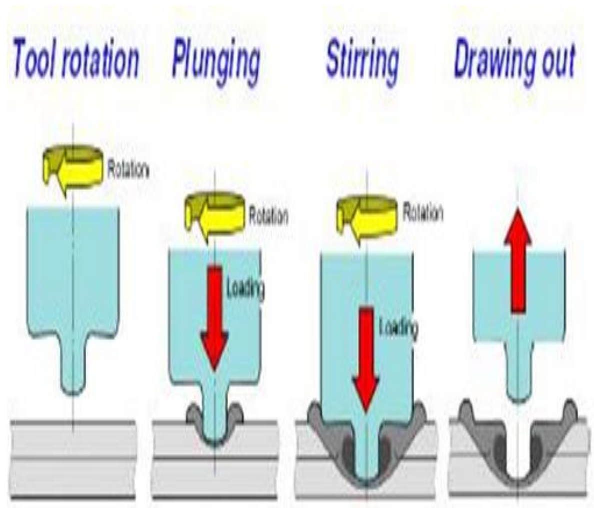

Fig 3. A schematic of a plunge type FSSW.

3. 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.4 After plunging, the tool goes up a little but this is negligible since it moves in a swing-like motion with large radius and small angle. This movement results in 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.

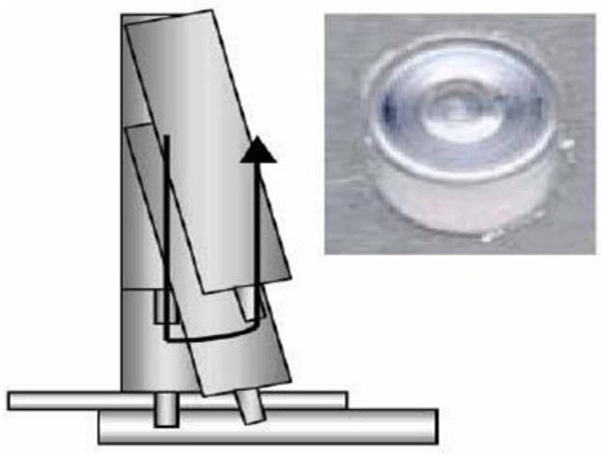

Fig 4. Schematic of swing FSSW.

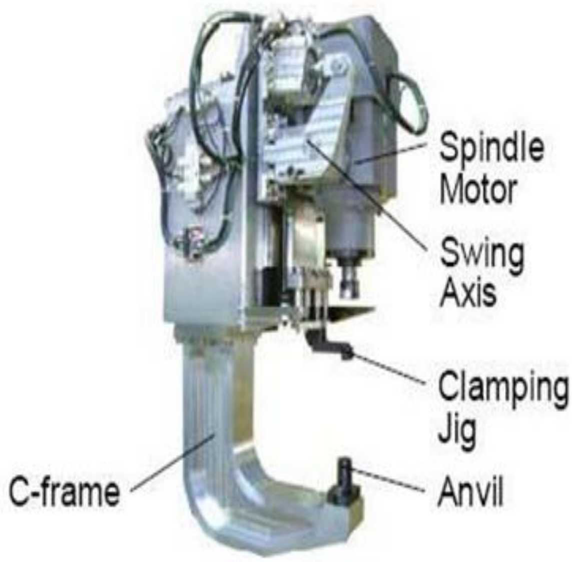

Fig 5. Prototype swing FSSW gun “Swing-Stir”.

4. FSSW vs. Conventional Welding:
FSSW is a derivative of the FSW process. It has been used in the production of aluminum doors, engine hoods, and decklids in the automotive industry. Mazda has claimed the benefits of using FSSW of aluminum for RX-8 production.

Compared to the conventional welding process, such as RSW and SPR, it has following benefits:

- High joint strength without porosity, cracks and contamination. There is no Material melting during FSSW.
- Lower energy consumption. The only energy consumed in FSSW is the Electricity needed to rotate and drive the tool. Compared to RSW, the energy Consumption has reduced by 99% for FSSW of aluminum and 80% for steel.
- Lower equipment investment. About 40% reduction in equipment investment compared to RSW for aluminum is reported . No large-scale electricity supply is required and tools for FSSW are no-consumable.
- No hazardous emissions and environment friendly. No weld spatter, noise and reduced vapor emissions during FSSW.
- Little welding deformation. FSSW is a solid state welding process without melting of materials, so distortions are smaller than for RSW and SPR.
- High repeatability and consistence due to its simple joining mechanism with few
- process parameters.
- Lower maintenance. Since equipment usedis less than that used for RSW and SPR.
- No preparation and consumables are needed. Such as surface clean, drilling, and rivets or bolts.

5. Tool Design For FSSW:

Friction stir spot welding tool consists of a tool shoulder and a pin. Shoulder produces a majority of the deformational and frictional heat to the surface and subsurface regions and applies a forging pressure to welds, while the pin produces a majority of the heat in the thick workpieces and transports the material around it. Different tool designs will modify their effects on weld properties.
compared effects of concave and flat shoulder on lap-shear strength and fatigue life of welds and indicated that welds made using concave shoulder had higher shear strength and fatigue life. Studied three different tool designs: a tool with threaded pin and shoulder, a tool with smooth pin and shoulder, and a tool with only smooth pin.

6. Mechanical Properties of Friction Stir Spot Welds

The most commonly used testing methods to determine the properties of spot welds are lap-shear tension test, cross-tension test, fatigue test and microhardness. Lap-shear test is a fast, convenient and practical method for evaluating weld property. This test was used in almost all current literature when considering the mechanical properties.

7. Tool Material Characteristics & Selection:

Tool material characteristics can be critical for FSW. The candidate tool material depends on the work-piece material and the desired tool life as well as the users own experiences and preferences.

Ideally, the tool material should have the following properties;

- Higher compressive yield strength at elevated temperature than the expected forge forces onto the tool.
- Good strength, dimensional stability and creep resistance.
- Good thermal fatigue strength to resist repeated heating and cooling cycles.
- No harmful reaction with the work-piece material.

8. EN19 Tool Specification:

EN19 also known as 709M40 is a high quality alloy steel, renowned for its good ductility and shock resistant and its resistance to wear properties. It is suitable for gears, pinions, shafts, spindles. it is now also widely used in the industries of FSW tool including other uses.

EN19 is normally supplied as high tensile grades EN19T (709M40T) OR EN19U. EN19T has a tensile strength of 850-1000 N/mm². For additional wear resistance EN19T can be nitride. A closely related grade to EN19 is 708M40. High peak steels can supply EN19 in bright and black bar form.

Fig 6. En19 tool Materials.

Fig 7. EN19 tool.

Table 1. En 19 composition.

C	Si	MN	S	P	Cr	Md
0.36-0.44%	0.10-0.40%	0.70-1.00%	0.040 Max	0.035 Max	0.90-1.20%	0.25-0.35%

9. EN 31 Tool Specification:
EN 31 is a excellent high carbon steel which offers a high measure of hardness with compressive strength and abrasion resistance. This grade is quite often used for wear resisting machine constituents and for press instruments which don't advantage a extra complex satisfactory. Standard high-speed steel grade, it's well-balanced alloy composition forms the basis of its high toughness and good cutting edge retention, rendering it suitable for a large variety of applications.

Fig 8. EN 31 TOOL Materials.

Fig 9. EN 31 TOOL.

Table 2. En 31 composition.

C	Si	MN	S	P	Cr
0.90-1.20%	0.10-0.35%	0.30-0.75%	0.050% max	0.050% max	1.00-1.60%

10. Hardening of Tool:
To prolong the operation life of tool steel, heat treatment is often a necessary requirement. These treatments improve on hardness, wear resistance and improve the frictional properties through reducing the coefficient of friction

11. Tool Wear:
Excessive tool wear changes the tool shape, thereby increasing the probability of defect generation, and possibly degrading the weld quality. The exact wear mechanism depends on the interaction between the work-piece and the tool materials, the selected tool geometry and the welding parameters. The wear at low tool rotation rate is mainly caused by adhesive wear known as seizing, while the wear at high tool rotation rate is due to abrasive wear.

12. Specimen Material Selection

Table 3. Chemical Composition of Aluminium 6061.

component	Amount(wt%)
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4-0.8
Iron	Max.0.7
Copper	0.15-0.40
Zinc	Max.025
Titanium	Max.0.15
Manganesese	Max.0.15
Chromium	0.04-0.35
Other	0.05

Table 4. Chemical Composition of Aluminium 6082.

component	Amount (wt%)
Aluminium	95.2 to 98.3%
Magnesium	0.6 to 1.2%
Silicon	0.7 to 1.3%
Iron	0.5% max
Copper	0.1% max
Zinc	0.2% max
Titanium	0.1% max
Manganesese	0.4% to1.0%
Chromium	0.25% max
Other	0.15% max

Table 5. Chemical Composition of Aluminium 4100.

Silicon	9.0-10.5
Iron	0.8
Copper	0.25
Manganesese	0.10
Magnesium	1.0-2.0
Zinc	0.20
OTHERS	0.05
OTHERS	0.15
Aluminium	Rem.

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IV. OBJECTIVES

1. Main Fssw Process Variables:

Table 6. Main Fssw Process Variables.

Tool design variables	Machine variables	Other variables
Shoulder and pin materials	Welding speed	Anvil material
Shoulder diameter	Spindle speed	Anvil size
Pin diameter	Plunge force or depth	Work-piece size
Pin length	Tool tilt angle	Work-piece properties
Thread pitch		
Feature geometry		

2. Friction Stir Spot Welding on Vertical Milling Machine Experimentation:

On vertical milling machine friction stir spot welding is performed. The input parameters as mentioned before were taken for machine process parameters. The tools of different profiles were mounted on turret of machine.
We have machined our Al-6061,6082 plates in the size of 100*55mm* 4mm and also Al-6082 and 4100 plates in the size of 160*80*2mm thickness by automatic showing cutter. After cutting of plates we have finished the edges of plates by rough and smooth files.

Then two plates were clamped on machine bed tightly such that it can withstand the force of tool motion without dislocating from its size.First we have taken circular tool profile and speed of 1120 rpm and feed of 25mm per minute. The process of operation is started and the tool penetrated between two plates. At the time of penetration some chips came out, after that the shoulder of tool made the material to stay inside and to form the good weld.

Fig 10. Vertical Milling Machine.

We have taken the following input parameters for our project:

Table 7. Parameters of vertical milling machine for FSSW.

Parameters	1	2
Rotational speed (rpm)	1120	1120
Feed (mm/min)	25	25
Depth (mm)	3.5	3.5
Inclination angle	0.5	0.5
Tool profile	circular	Taper threaded

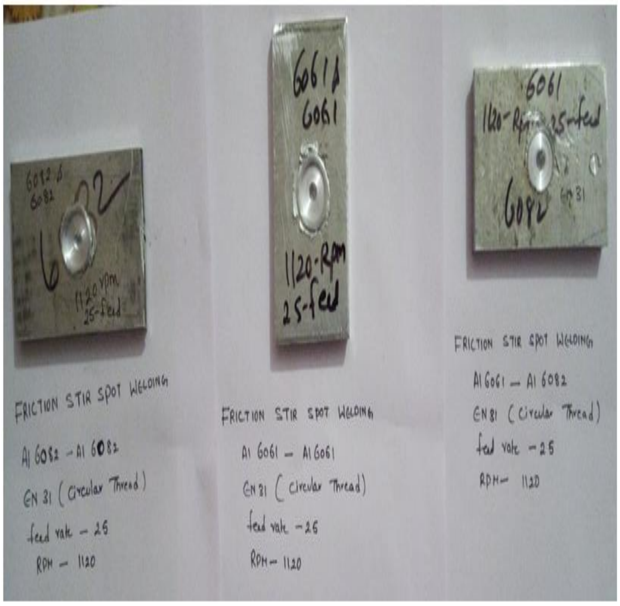

Fig 11. Friction stir spot welding.

Fig 12. Tensile test.

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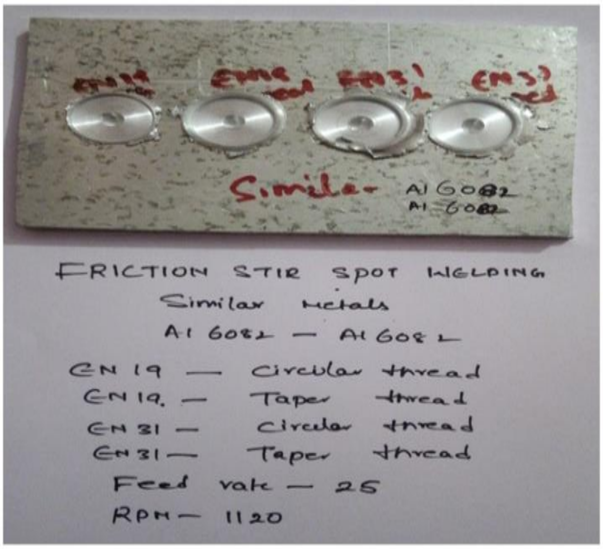

Fig 13. Friction stir spot welding with similar metals and its different tool and thread.

Fig 14. Tensile test machine.

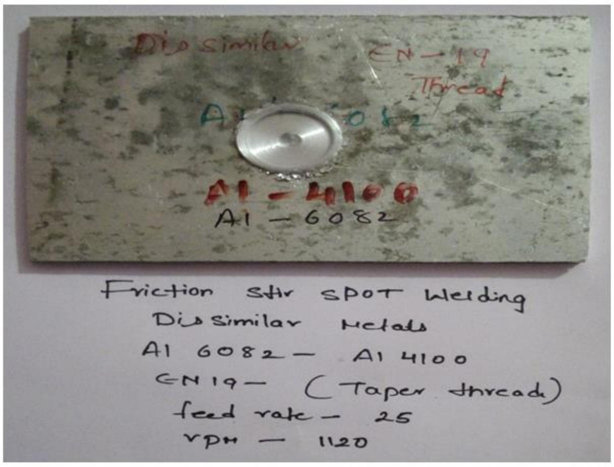

Fig 15. Friction stir spot welding.

Fig 16. Tensile test.

- 6061-6061 by using circular tip of EN31 tool.
- 6082-6082 by using circular tip of EN31 tool.
- 6061-6082 by using circular tip of EN31 tool.
- 6082-4100 by using taper thread tip of EN31 tool.
- 6082-4100 by using taper thread tip of EN19 tool.

Table 8. The following table gives the final results obtained from Universal Testing machine.

S. No	Material Combination	Tool Material	Ultimate Tensile Strength N/mm2	Yield Strength N/mm2
1.	6061-6061 - Circular Tip	EN31 tool	90.10	73.7
2.	6082-6082- Circular Tip	EN31 tool	61.4	42.97
3.	6061-6082- Circular tip	EN31 tool	120.01	90.4
4.	6082-4100- Circular tip	EN31 tool	133.33	131.08
5.	6082-4100- taper thread tip	EN19 tool	129.76	95.10

V. CONCLUSION

The experiments have been conducted On a Vertical Milling machine by using EN31 Tool with Various tool profiles for Friction Stir Spot Welding of T6061-6082, 6061-6061,6082-6082 and 6082-4100. With Circular profile.T6082-4100 with taper thread

The samples are tested on a Universal Testing machine for Ultimate Tensile Strength, Yield Strength T6061-6061 with circular tool(EN31) has got the values of Tensile strength 90.10 N/mm², Yield strength 73.7N/mm².

T6082-6082 with circular tool(EN31) has got the values of Tensile strength 61.4 N/mm², Yield strength 42.97/mm².

T6061-6082 with circular tool(EN31) has got the values of Tensile strength 120.01 N/mm², Yield strength 90.4/mm².

The biggest tensile strength and yield strength were obtained with Circular tool (EN31) with Rotational speed (rpm) 1120, Feed (mm/min) 25 and Inclination angle 0.5 degree is T6061-6082 with circular tool (EN31) compare with above three test.

Al4100-6082 with circular tool (EN31) has got the values of Tensile strength 133.33N/mm², Yield strength 131.08/mm².

Al4100-6082 with taper thread (EN19) has got the values of Tensile strength 129.76 N/mm², Yield strength 95.10/mm².

The biggest tensile strength and yield strength were obtained with Circular tool (EN31) with Rotational speed (rpm) 1120 , Feed (mm/min) 25 and Inclination angle 0.5 degree is Al4100-6082 with circular tool (EN31) compare with above two test.

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