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An effect of Pin less Mild Steel Tool on Friction Stir Welding for Joining Aluminium 6082 Plates

S. G. Khobragade[1], Dr. P. M. Khodke[2],

[1,] *P.G.Student, Mechanical Engineering, Government College of Engineering, Karad, Maharashtra, India*
[2,] *Professor, Department of Mechanical Engineering, Government College of Engineering,Karad, Maharashtra,India*

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Abstract - *In this paper, research has been carried out experimentally to compare the effect of pin less Mild Steel tool of 10 mm diameter for Friction Stir Welding to join Aluminium 6082 plates of 3mm thickness with the Mild Steel tool of 3 mm diameter and 1 mm length. The effect of FSW is studied on hardness, strength and microstructure with different tool rotational speeds ranging from 800 rpm to 1600 rpm, at feed rate 55 mm/min, for making comparison between the newly developed pin less tool and the pin tool of Mild steel. The comparative research indicates that, the pin less mild steel tool produces the better tensile strength than the pin tool in the entire range of the tool rotational speeds and feed rates. The maximum strength of the FSW joints is 82.41% of that of its base metal at 1200 rpm and feed of 55 mm/min using the pin less tool. It is further observed that, for both the tools, the hardness of weld zone is increased at lower tool rotational speed, while refined microstructure can be noticed on surface of the weld zone at higher tool rotational speed.*

Key Words: *Friction Stir Welding; Mild Steel pin less tool; Hardness; Strength; Microstructure.*

1. INTRODUCTION

One of the most common and effective method for joining metal structures is conventional welding. In conventional welding process such as TIG/MIG, the weight of workpiece increases due to deposition of filler material. Aluminium alloys are extensively used as a main engineering material in various industries such as automotive industries, the mould and die components manufacture and the industry in which weight is the most important factor. These materials help machining and possess superior machinability index. Additionally, due to high thermal and electrical conduction, conventional fusion or resistance welding of aluminium alloys encounters many problems and some aluminium alloys are even regarded as non-weldable due to a risk of hot cracking. For critical applications, aluminium alloys are fusion welded with extreme precautions to avoid possible weld defects such as formation of deleterious oxides, porosity, hot cracking and hydrogen entrapment related delayed cracking.
Friction stir welding (FSW) is a solid-state joining technique that has expanded rapidly since its development in 1991 and has found applications in a wide variety of industries, including aerospace, automotive, railway, and marine. Fig.1 displays a conventional FSW square butt joint. A rotating tool consisting of a probe and shoulder 2 plunges into the work piece, generating heat through both friction and plastic deformation, and traverses the joint line.

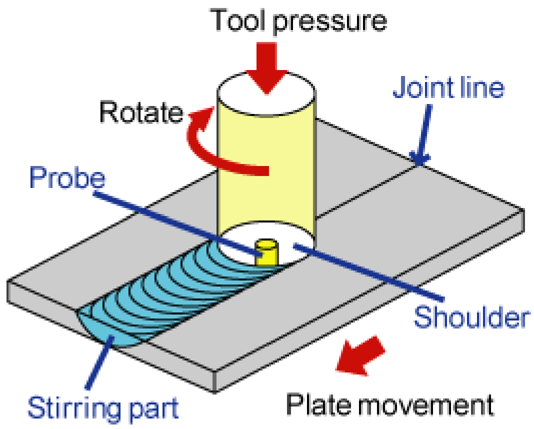


Fig. 1. Principle of FSW process

Frictional heat is generated between the wear-resistant welding tool shoulder and pin, and the material of the work-pieces. The frictional heat and surrounding temperature, causes the stirred materials to be softened and mixed. The bonding is considered a solid state process, since the materials are not melted. However the grains are transformed and relocated. Material flows under the shoulder are similar to the forging process, while the material flows around the tool pin are like an extrusion process. The FSW process exhibits a number of attractive advantages when compared to other welding processes, perhaps the most significant of which is the ability to weld alloys that are difficult or impossible to weld using fusion welding techniques. The FSW process takes place in the solid-phase, at temperatures below the melting point of the material, and as a result does not experience problems related to resolidification, such as the formation of second phases, porosity, embrittlement, and cracking. In addition, the lower temperature of the process enables joining with lower distortion and lower residual stresses. FSW is also an energy efficient process that requires no filler material and, in most cases, does not require the use of a shielding gas. Furthermore, the process lacks the fumes, arc flash, spatter, and pollution associated with most fusion welding techniques. For these and many other reasons, FSW has become an attractive joining process for many manufacturers.

2. LITERATURE REVIEW

K. Elangovan et al. (2009) [3] compared FSW to the fusion welding processes that are routinely used for joining structural aluminium alloys. The welding parameters such as tool rotational speed, welding speed, axial force etc., and tool pin profile is found to play a major role in deciding the joint strength. An attempt had been made to develop a mathematical model to predict tensile strength of the friction stir welded AA6061 aluminium alloy by incorporating FSW process parameters. Response surface method (RSM) had been used to develop the model. Statistical tools such as analysis of variance (ANOVA), student's t-test, correlation co-efficient etc. had been used to validate the developed model.
R. Palanivel et al. (2012) [7]used FSW to join 6 mm thick dissimilar aluminium alloys AA5083-H111 and AA6351-T6 and studied the effect of tool rotational speed and pin profile on the microstructure and tensile strength of the joints. Dissimilar joints were made using three different tool rotational speeds of 600 rpm, 950 rpm and 1300 rpm and five different tool pin profiles of straight square (SS), straight hexagon (SH), straight octagon (SO), tapered square (TS), and tapered octagon (TO). The tool rotational speed and pin profile considerably influenced the microstructure and tensile strength of the joints. The joint which was fabricated using tool rotational speed of 950 rpm and straight square pin profile yielded highest tensile strength of 273 Mpa.
K. Krasnowski et al. (2014) [8]investigated the influence of tool shape and weld configuration on the microstructure and mechanical properties of Al 6082 alloy FSW joints. Three types of tool with different probe shapes and shoulder surfaces and two weld configurations (one sided and two-sided) were used in experiments. It showed that all tool types produce high quality butt joints free from defects or imperfections. The best tensile strength was obtained by a conventional and triflute tool. The joint configuration influenced mechanical properties, the twosided welds exhibited lower mechanical properties due to greater heat transference into the material during the second pass. However the optimum process conditions have not been evolved.
Atul Suri (2014) developed improved flat pin tool with side radius and compare it with standard straight threaded pin tool with flat collar made of hardened steel. The effect of FSW was studied on hardness, strength, toughness and microstructure with different tool rotational speeds ranging from 400 rpm to 1400 rpm, at a constant feed rate i.e., at 30 mm/min for making comparison between the newly developed flat pin tool and the standard straight threaded pin tool. The comparative study indicated that, the newly developed tool produces the better tensile strength than the standard straight threaded tool in the entire range of the tool rotational speeds. The maximum strength of the FSW joints was 78% of that of its base metal at 400rpm using the new tool. It was further observed that, for both the tools, the hardness of weld zone is increased at lower tool rotational speed, while refined microstructure can be noticed on surface of the weld zone at higher tool rotational speed.

3. EXPERIMENTAL METHODS AND MATERIALS

FSW process is considered for this experimental study and comparison of a Pin less tool and pin mild steel tool. Single sided welding is performed to make a butt joint of aluminium plates. Mechanical properties and microstructure of the weld specimen is compared for both the tools. In this study the specimen are made by using commercial Al plates. The dimensions of the specimen are 150 mm x 50 mm x 3 mm. The chemical composition of Al plates is shown in table 1.

Table 1. Chemical composition of base metal

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Weight %	0.7 - 1.3	0.5	0.1	0.4 - 1.0	0.6 - 1.2	1.2	0.2	0.1	rest

The welds are developed in square butt joint configuration. The Mild steel Tool used for FSW is shown in fig. 2a and 2b.
A pin less tool is compared with pin tool. Tools specifications are shown in table 2. The welds are developed at different tool rotational speeds i.e. 800, 1000, 1200, 1400 and 1600 rpm and different feed rates i.e. 25, 40, 55, 65, 80 mm/min.

a. Pin less tool b. pin tool

c. FSW machine setup

Fig. 2. FSW tools and machine setup

A pin less tool is compared with pin tool. Tools specifications are shown in table 2. The welds are developed at different tool rotational speeds i.e. 800, 1000, 1200, 1400 and 1600 rpm and different feed rates i.e. 25, 40, 55, 65, 80 mm/min.

Table 2. FSW Tool Specifications

Sr. no.	Variable description	Specification of pin less tool	Specification of pin tool
1.	Tool diameter	Mild steel	Mild steel
2.	Shoulder diameter	10 mm	10 mm
3.	Pin diameter	0 mm	3 mm
4.	Pin length	0 mm	1 mm

Tool is positioned perpendicular to the welding surface during the joining process as shown in fig. 2c. A standard specimen drawing is shown in fig. 3

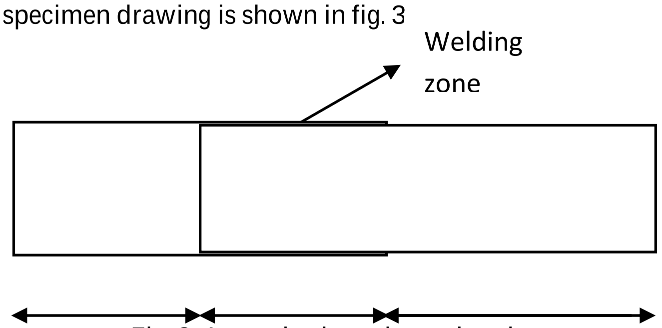


Fig. 3. A standard specimen drawing

Rockwell Hardness Test shown in fig 4.a is used to find hardness for FSW welded specimen. Microstructure is observed using optical microscope and the effect of tool rotational speed on grain size of FSW specimen is observed for pinless tool. All specimens are subjected to shear tests on a computerized Universal Testing Machine (UTM) shown in fig 4.b to observe the mechanical behaviour. Shear tests are performed at a constant cross head speed of 5 mm/min.

a. Rockwell Hardness Test Machine b. UTM

Fig. 4. a. Rockwell Hardness Test Machine Fig 4. b. UTM

4. RESULTS AND DISCUSSIONS

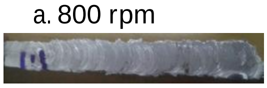
All welded specimen are studied for their mechanical properties such as surface appearance, microstructure, shear strength and hardness by employing appropriate tools and techniques.

4.1 Surface Appearance of weld zone

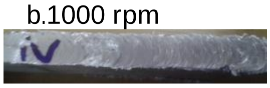
Surface appearance of FS welded plates at tool rotation speeds of 800, 1000, 1200, 1400 and 1600 rpm at feed rate of 55mm/min using improved pin less tool is presented in figure 5. This tool produces larger defects like excessive burrs and valleys on 800 rpm which keep reducing at increasing rpm. Pin less tool produces better surface finish on high tool rpm of 1200 rpm and 1400 rpm due to minimal surface contact of the tool pin in the weld zone. In case of pinned tool welding is not possible because of soft properties of MS or low thickness of aluminium.

a. 800 rpm

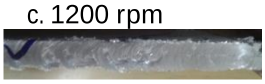
b.1000 rpm



c. 1200 rpm



d. 1400 rpm

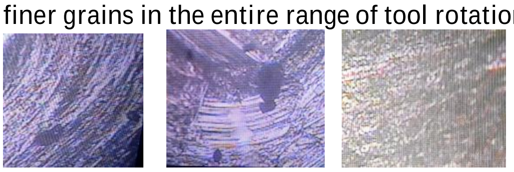


e. 1600 rpm

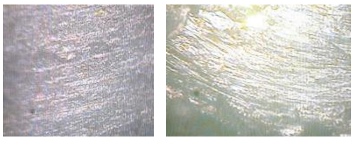
Fig.5. Surface appearance of weld zone obtained using pin less MS tool.

4.2. Microstructure of Weld Zone

Figure 6 shows the microscopic images of the weld zone top surface obtained by an improved flat pin tool and standard straight threaded pin tool at 800 rpm to 1600 rpm. It is clearly visible that the pin less tool produces finer grains in the entire range of tool rotation.



a. 800 rpm b. 1000 rpm c. 1200 rpm

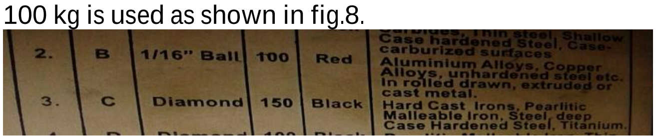


d. 1400 rpm e. 1600 rpm

Shear strength =
(Breaking force)/(Length of Weld * Depth of Weld)
And
Tensile strength = 2*shear strength
Length = 120 mm and depth of weld = 1 mm

4.3. Hardness

Hardness is measured on Rockwell Hardness Tester shown in fig 4a. Scale 2 No. B Indentor of 1/16" and load of 100 kg is used as shown in fig.8.



					Case hardened Steel, Case-carburized surfaces
2.	B	1/16" Ball	100	Red	Aluminium Alloys, Copper Alloys, unhardened steel etc. In rolled drawn, extruded or cast metal.
3.	C	Diamond	150	Black	Hard Cast Irons, Pearlitic Malleable Iron, Steel, deep Case Hardened Steel, Titanium.

Fig. 8. Indentor size should be taken as specimen

Table 3. Effect of speed variation on Tensile Strength of Weld

At constant 55 mm/min feed			
Sr. no.	SPEED rpm	Utm readings KN	Tensile strength Mpa
1	800	7.05	117.5
2	1000	8.04	134
3	1200	8.97	149.5
4	1400	8.7	145
5	1600	7.92	132

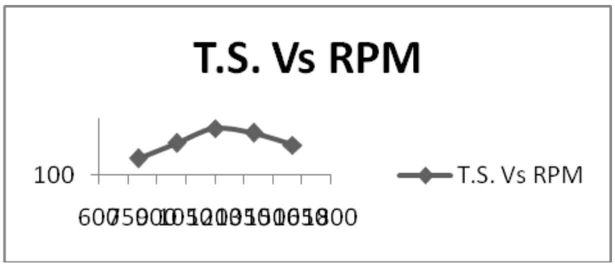


Fig.9. Graph of TS against Speed

5. CONCLUSION

This experimental studied the effect of an pin less MS tool to the Lap joint of Aluminium 6082 that are produced by FSW process using at different tool rotational speeds to ascertain the effect of rotational speed of FSW tool on surface appearance, microstructure, tensile properties and hardness. The following conclusions are drawn.

1. It is observed that surface appearance and the accumulation of material on the advancing side increases with the decrease of tool rotational speed at a constant feed rate i.e., 55mm/min. At higher tool rotational speeds i.e., at 1600 rpm the surface finish starts deteriorating due to excessive melting of the base metal in the weld nugget using standard tool where as improved tool produces better surface at 1200rpm.
2. Increased Rockwelll hardness, of 77 BHN is obtained at weld zone 800rpm, which is 10 % more than the base metal. The hardness reduces with the increase of tool speed.
3. An increased strength is observed for the specimen produced from 800rpm to 1600rpm a marginal improvement in the toughness of about 9% is observed. At increased tool speed of 1200rpm and 1400rpm the improved tool produces 18% to 15% higher toughness in FS welded specimen.
4. The tensile strength using newly developed FSW tool at tool rotational speed of 800 rpm is observed to be as 117.5 MPa, which is 64.91 % of the base metal.

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BIOGRAPHIES

P.G.Student, Mechanical Engineering, Government College of Engineering, Karad, Maharashtra, India

Principal, Department of Mechanical Engineering, Government College of Engineering, Karad, Maharashtra, India

