

Influence of Tool Pin Profile on Mechanical Properties of Joint of Aluminium Alloys 2014 and 6082, Welded With Friction Stir Welding

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Abstract - It is challenging to obtain defect free welded joints of Aluminum Alloys with the help of fusion welding processes. In fusion welding, oxide layer of aluminum alloys penetrate inside, which has the tendency to thicken at higher temperatures, which in turn results in the defects like porosity and cracks in the weld joint. In contrast, Friction Stir Welding (FSW) is proved to be a very good solid state welding technique, which has got a worldwide attraction, especially in aerospace industry. FSW doesn't involve actual melting of the materials, rather the welding is done at visco-plastic state of the materials, which helps to reduce the heat affected zone in the weld joint and original characteristics of material are protected from getting changed, as far as possible. Combination of 2xxx series and 6xxx series of aluminum alloys are highly used in aerospace and automobile industry due to their good-strength to weight ratio, mechanical properties and anti-corrosion properties. The work has been done to improve the strength and quality of Friction Stir Welded joints by changing process parameters. Tool pin profile also has a great impact on the strength and quality of friction stir welded joints. The present paper investigates the influence of different pin profiles on the mechanical properties of dissimilar aluminum alloys, welded with FSW. Aluminum alloys 2014 and 6082 were successfully welded by using three (Square, Pentagon and Hexagon) different pin profiles. From the results, it was observed that that the joint fabricated by using pentagonal pin profiled tool given superior tensile and micro-hardness properties as compared to other joint.

Keywords: Friction Stir Welding (FSW), Mechanical Properties, Dissimilar Aluminum Alloys, Tool Pin Profile.

I. INTRODUCTION

In the recent year's aluminum alloys are widely used in engineering applications due to their wide range of properties. The use of lightweight material is most effective for reducing the weight of automobiles and a lot research has been going on to make a possible shift from steel to aluminum alloys for body work and structural components. Aluminum alloys now a day are highly used in aerospace and automobile industry due to their good-strength to weight ratio, mechanical properties and anti-corrosion properties. It is great challenge to obtain defect free welded joints of Aluminum Alloys with the help of fusion welding processes. In fusion welding, oxide layer of aluminum alloys penetrate inside, which has the tendency to thicken at higher temperatures, which in turn results in the defects like porosity and cracks in the weld joint.

The fusion welding of aluminum alloys leads to the melting and re-solidification of the fusion zone which results in the formation of brittle inter-dendritic structure and eutectic phases. The formation of brittle structure in the weld zone leads to the drastic decrease in the mechanical properties like lower in hardness, strength and ductility [1]. Therefore to solve these problems a solid state joining technique is greatly recommended.

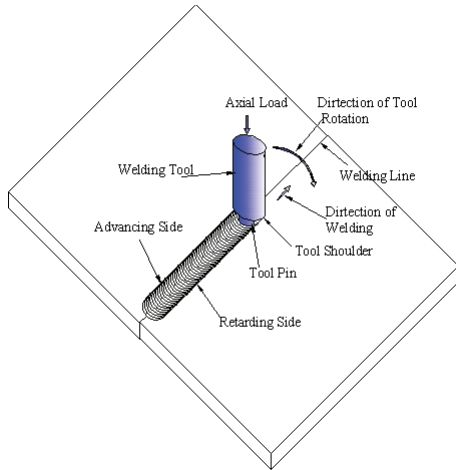


Fig.1 FSW Process

Compared to many of the fusion welding processes that are routinely used for joining aluminum alloy, FSW is an emerging solid state joining process in which the material that is being welded does not melt and recast [2]. FSW is used for applications where the original metal characteristics must remain unchanged as far as possible.

FSW was invented in December, 1991 at The Welding Institute (TWI) in UK. In FSW thermo-mechanical joining of the two materials takes place i.e. the materials are joined due mechanical deformation caused by the heat produced. The process and the terminology are schematically explained in Fig 1. In FSW a non-consumable rotating shouldered pin tool is plunged into interface between two plates being welded, until the shoulder touches the surface of the base material and is the transferred along the weld line [3]. The shoulder is pressed against the surface of the materials being welded, while the probe or pin is forced between the two components by a downward force. The rotation of the tool under this force generates a frictional heat that decreases the resistance to plastic deformation of the material [4]. The microstructure evolution and the resulting mechanical properties depend strongly on the variation of the processing parameters leading to a wide range of possible performances [5]. Benefits of FSW compared to fusion process are low distortion excellent mechanical properties in the weld zone execution without a shielding gas and suitability to weld all aluminum alloys [6]. In fact, the undesirable low mechanical properties resulting from melting and resolidification are absent in FSW welds leading to improved mechanical properties, such as ductility and strength in some alloys [1, 7, 8]

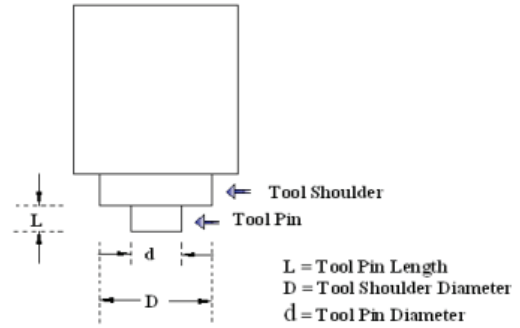


Fig. 2. Friction Stir Welding Tool Dimensions

The Welding Parameters such as Tool Rotation Speed, Transverse Speed, Tool Tilt Angle and Tool Geometry like Tool pin profile, Tool shoulder diameter, Tool pin length, Tool pin diameter plays a major role in deciding the quality of the weld. Tool parameters are shown in Fig. 2. Lot of work has already been done to improve the strength and quality of Friction Stir Welded joints by changing the welding process parameters. Tool pin profile also has a great impact on the strength and quality of friction stir welded joints. The present review paper investigates the influence of different pin profiles on the mechanical properties of dissimilar aluminum alloys 2014 and 6082, welded with FSW. The dissimilar aluminum alloys 2xxx series and 6xxx series exhibits poor weld ability by fusion process but were successfully welded by FSW [9] and gives superior tensile properties [10].

II. EXPERIMENTAL WORK

The rolled plates having 6 mm thickness of both the aluminum alloys 2014 and 6082 were cut in required sizes at slow speed, in order to avoid any temperature rise, so that the grain structure of the materials may not damage. The size of rectangular pieces was 100 mm x 70 mm x 6 mm. The chemical compositions of both the alloys are presented in Table 1. Square butt joint configuration (100 mm x 140 mm) was prepared by welding the samples. Single pass welding process was followed for FSW of samples. Direction of welding is normal to the rolling direction of the samples.

TABLE I CHEMICAL COMPOSITION OF WORK MATERIAL (%WT)

Al Alloy	Mn	Si	Mg	Cu	Zn	Fe	Al
2014	0.44	0.74	0.38	2.86	0.047	0.084	95.3
6082	0.57	1.23	0.48	0.028	0.030	0.13	97.3

TABLE II CHEMICAL COMPOSITION OF TOOL MATERIAL (% WT)

Tool	C	Mn	Si	Cr	P	S	Fe
HCHCr	2.1	0.45	0.51	11.2	0.02	0.03	Bal.

Non-consumable tools of high carbon high chromium steel were used in this welding process. The chemical composition of the tool material is presented in Table II. The tools used to fabricate the joints had three different tool pin profiles (Square, Pentagon and Hexagon).

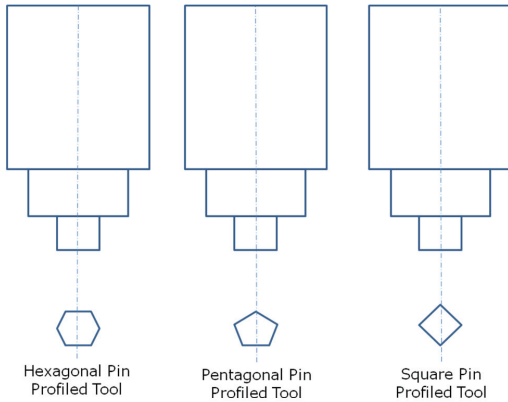


Fig. 3 Different tool pin profiles

Drawings of different types of tool pin profiles are shown in Fig. 3. The tool specifications are presented in Table III.

TABLE III FSW TOOL SPECIFICATIONS

Tool Length	80 mm
Tool Shoulder Diameter (D)	18 mm
Tool Pin Profile	Square, Pentagon and Hexagon
Tool Pin Diameter (d)	6 mm
Tool Pin Length (L)	5.7 mm
Tool Tilt Angle	0 Degrees

CNC vertical milling machine was used for fabricating the friction stir welded joints. A specially designed fixture was used to hold the samples in position on the table of CNC milling machine. The fixture was made of mild steel plate of 20 mm thickness, had dimensions 200 mm X 200 mm. The welded samples were sliced at slow speed cutting to the required dimensions to prepare tensile specimens as shown in Fig. 4. American Society for Testing of Materials (ASTM) guidelines were followed for preparing testing specimens. Tensile tests were performed in order to evaluate the mechanical properties of the joints. Ultimate Tensile Strength of the specimens was recorded by using Universal Testing

Machine of 25 KN load. X-ray Radiography had been done to reveal the internal defects like porosity, voids and cracks etc. that were produced during FSW in the weld.

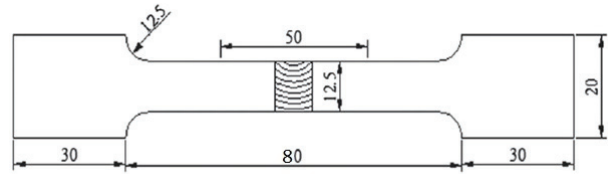


Fig. 4 Dimensions of tensile test specimen (in mm)

Micro-structural analysis have been performed by using an inverted optical microscope (Make: Leco, USA) at a magnification of 200x. The specimens for metallographic test were cut to the required sizes at slow speed. The metallographic sample comprises FSP zone, TMAZ, HAZ and base metal region. Samples were polished by using different grades of emery papers (200, 400, 600, 800, 1000, and 1500). Final polishing of the samples was done on the double disc polishing machine by using diamond paste on velvet cloths. Specimens were etched with Hydrofluoric (HF) acid to reveal the microstructures. Vicker’s microhardness testing had been done to analyze the hardness of the weld zone (stirred zone). Vickers microhardness tester VHS 1000 A (Make: Banbros, India) was used for this test. The microhardnes testing was performed at a load of 100 gms for a dwell time of 10 s.

III. RESULTS

A. Visual Inspection

The samples welded by FSW were visually inspected. Most of the fusion welded joints results in the defects like porosity, slag, cracks etc. which affects the quality of the weld. Friction Stir Welded joints are free from these type of defects as the solidification takes place in solid state. Almost, all the joints were produced with a smooth surface finish except the visual defect may be infilling of material was produced on the top of the joints welded with square pin profiled tool. This was also clear from the X-ray radiography of the weld samples that there is a little bit porosity in the sample welded with square pin profiled tool. The defect was on the advancing side of the weld. When unusual welding parameters were used the material cannot flow properly from retarding side to the advancing side of the weld. From visual inspection it was found that the formation of welding defect is a function of welding tool parameters.

When welding tool was removed from the welded zone, it leaves a hole in the weld, which is called pin hole defect. This defect was produced at the end of all the joints, fabricated at various combinations of parameters.

B. Tensile Properties

All the specimens welded with FSW were tested for finding out their ultimate tensile strength. For each combination of parameters, three specimens were tested and the average value was considered, as given in Table 4 and the results were plotted in the form of bar chart Ultimate tensile strength v/s Tool pin profile as shown in Fig. 5. From the results, it can be clearly studied that the ultimate tensile strength of the friction stir welded joint has been influenced by the tool pin profile of the welding tool. The joint produced by pentagonal pin profiled tool have given superior tensile properties as compared to other joints.

TABLE IV RESULTS OF TENSILE TEST

S. No.	Tool Pin Profile	Ultimate Tensile Strength in MPa			
		1 st Value	2 nd Value	3 rd Value	Avg. value
1	Square	56.5	58.8	58.4	57.9
2	Pentagon	65.4	66.9	65.7	66.0
3	Hexagon	61.2	63.4	63.8	62.8

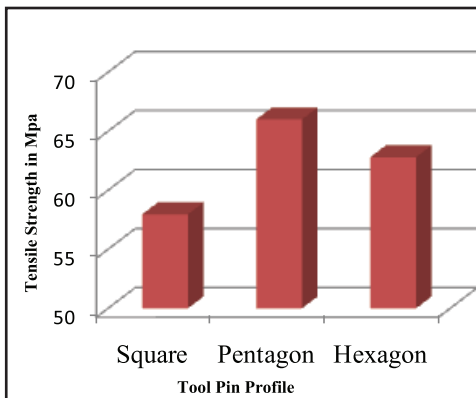


Fig. 5 Effect of Tool Pin Profile on Uts of Fsw Joints

Almost matching results are produced by hexagonal pin profiled tool. But the joints fabricated by using square pin profiled tool exhibited inferior tensile properties as compared to other joints.

C. Microhardness

While performing the tensile test, almost all the specimens were failed in the FSW zone but the accurate location of the

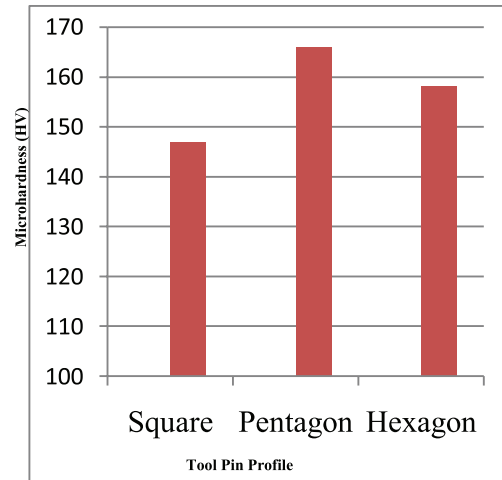


Fig. 6 Effect of tool pin profile on the microhardness of SZ

failure was either on the advancing side or on the retarding side of the weld zone. Hence, microhardness analysis of the joints was carried out in the FS weld zone. The values are presented in Fig. 6.

From the results, it can be clearly observed that the highest hardness value of 166 HV was recorded for the joint, produced by using pentagonal pin profiled tool. The second highest hardness value of 158 HV was recorded for the joint, produced by using hexagonal pin profiled tool. The lowest hardness value of 147 HV was recorded for the joint, produced by using square pin profiled tool. The hardness of the stirred zone was considerably higher than both of the base metals irrespective of the tool pin profile used. Two main reasons are responsible for the hardness improvement in the stirred zone. (i) The size of the grains present in the welding zone, if the grains in the welding zone are finer than the base metal that plays an important role to provide strength in the material. According to the Hall-Petch equation, hardness increases as the grain size decreases. (ii) The small particles of inter-metallic compounds are also a benefit to hardness improvement [11].

IV. DISCUSSION

The factors which determine the tensile strength of dissimilar aluminium alloy joints are: (i) presence of macroscopic defects in weld zone (ii) degree of plastic flow and amount of mixing of both the materials [12].

The primary function of the non-consumable rotating tool pin is to stir the plasticized metal and move the same behind it

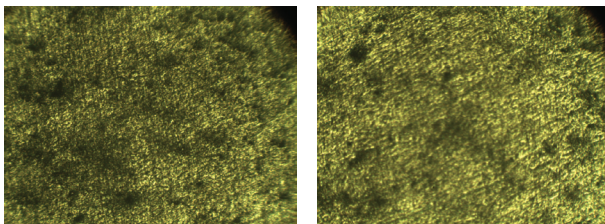
to have good joint. Pin profile plays a crucial role in material flow of the FSW process. Pin profiles with flat faces (square, pentagon and hexagon) are associated with eccentricity. This eccentricity allows incompressible material to pass around the pin profile [13].

Moreover square, pentagon and hexagon pin profiles produce a pulsating stirring action in the flowing material due to flat faces as shown in Fig. 7 [14].

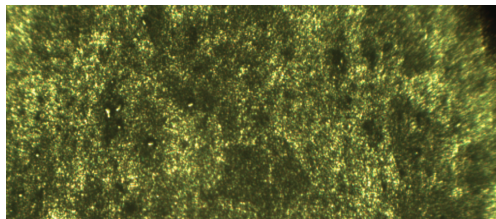


Fig.7 Pulsating action of flat faced tools [14]

The square pin profile produces 107pulses/sec, pentagon pin profile produces 134pulses/sec and hexagon pin profile produces 160pulses/sec, when the tool rotates at a speed of 1600 rpm. There is no such pulsating action in the case of cylindrical pin profile tools. This may be the reason of superior tensile properties produced by pentagon and hexagon pin profile tools. Due to large number of pulses a good pulsating stirring action was produced that properly mixes the two materials and proper plasticized flow of material happens. Hexagon pin profile tool produced a little lower tensile properties may be due to the reason that hexagon pin profile tool approaches towards cylindrical shape and hence has a weak stirring action. Square pin profile produces inferior tensile properties due bad stirring action or less number of pulses/sec. Due to bad stirring action proper



(a) (b)



(c)

Fig.8 Micrographs of Stirred Zone (a) Pentagon pin profile tool (b) Hexagon pin profile tool (c) Square pin profile tool

mixing of both the materials does not take place also causes poor plasticized material flow around the tool which resulted in poor mechanical properties. It was also clear from the X-ray radiography which shows a little bit porosity in the joint fabricated with square pin profile tool.

As the pentagonal and hexagonal pin profile tools produce good stirring action i.e. large number of pulses/sec and produce sufficient amount of frictional heat due to large number of pulses, which resulted in grain refinement in the stirred zone. It can also be clearly observed from the micrographs that the grain structure of the stirred zone varies with the change in tool pin profile. Grain structure produced by pentagonal and hexagonal pin profile tools contains very fine equiaxed grains as observed from Fig. 8 (a) & Fig. (8) b. This may be the reason for the higher values of micro-hardness at these parameters. On the other hand, square pin profile tool produce insufficient amount of frictional heat due to less number of pulses/sec. Due to poor stirring action and less amount of frictional heat the grains in the stirred zone may become coarse, which was clearly observed from Fig. 8 (c). Figure shows a little bit of coarse grain structure in the micrograph of friction stir welded joints by using square pin profile tool. Due to this coarse grain structure lower value of hardness was obtained at this parameter.

V. CONCLUSION

In the above investigation an attempt has been made to study the influence of tool pin profile on the mechanical properties of joint of aluminium alloys 2014 and 6082, welded with friction stir welding.

It has been found that the tool pin profile has a great impact on the strength and quality of friction stir welded joints.

- a. Out of all the joints, the joint fabricated by using pentagonal pin profile tool had given superior mechanical properties.
- b. Good stirring action and sufficient amount of frictional heat in the stirred zone is required for the proper plasticized flow of the material and in turn to produce defect free welds.

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