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Effect of Welding Parameters on The Properties of Aluminium Alloys 6063 and 6101 Welded with Friction Stir Welding

Yadwinder Pal Sharma[1*] and Pardeep Kumar[2]

[1]Mechanical Engineering Department, Giani Zail Singh Punjab Technical University Campus, Bathinda, Punjab, India
[2]Mechanical Engineering, Yadavindra College of Engineering, Punjabi University G.K. Campus, Talwandi Sabo, Distt. Bathinda, Punjab, India
* corresponding author e-mail: er.yad_2007@yahoo.co.in

Abstract- Friction stir welding (FSW) has got wide attraction in aerospace and automobile industries, as conventional fusion welding techniques are susceptible to various welding defects like cracks and porosity, Welding of aluminum alloys were also a matter of concern because of the thin oxide layer formation on the surface of alloys as this oxide layer tends to thicken at higher temperatures. Friction stir welding process shows several advantages to weld aluminum alloys. In the present research the optimization of the mechanical properties of welded joint of aluminum alloy of 6000 series are considered. This aluminium alloy series is used for architectural fabrication due to good surface finish, high corrosion resistance and good mechanical properties. The aluminium alloys 6063 and 6101 are successfully welded with friction stir welding technique. Two different rotation speeds of tool 1600 rpm and 1200 rpm and two different pin profiles tools square & hexagonal are selected for this work. From the results it is observed that the joint welded with hexagonal pin profile at 1200 rpm tool rotation speed gives superior mechanical properties.

Keywords: Friction stir welding, aluminum alloys, mechanical properties, rotational speed, pin profile.

1. INTRODUCTION

In the recent years friction stir welding is very widely used in joining of lightweight materials such as aluminium and magnesium alloys. The light weight aluminium alloys are the most attractive materials in aerospace and automotive industrial fields. It is very difficult to obtain defect free welded joints of Aluminum Alloys with the help of fusion welding processes. Welding of aluminium alloys with Conventional fusion welding produces a weld which suffers from defects, such as porosity developed as a consequence of entrapped gas which is not able to escape from the weld pool during solidification. 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].

The aluminum alloys are now weld easily with friction stir welding. In friction stir welding, the materials or alloys are joined through visco-plastic deformation with the frictional heat, below the melting point of the materials / alloys. FSW was invented by The Welding Institute (TWI). Friction Stir Welding is a solid state welding process, which offers all such benefits as compare with fusion welding processes. In friction stir welding, the materials or alloys are joined through visco-plastic deformation with the frictional heat, below the melting point of the materials / alloys. Friction stir welding (FSW) as a solid state joining technology, is one of the environmental friendly fabrication techniques involving energy efficiency and versatility to provide satisfactory combination of microstructure and mechanical properties of the assemblies [2]. 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 [3]. FSW is an emerging solid state joining process in which the material that is being welded does not melt and recast [4].

In fact, the undesirable low mechanical properties resulting from melting and re-solidification are absent in FSW welds leading to improved mechanical properties, such as ductility and strength in some alloys [1, 5, 6]. The development of friction stir welding has provided an alternative improved way of satisfactory producing aluminium joints, in a faster and reliable manner.

FSW uses a rotating (non consumable) cylindrical tool that consists of a shoulder and a probe [7]. The probe is slightly shorter than the thickness of the work-piece and its diameter is typically equal to the work-piece thickness [8]. The shoulder is pressed against the surface of the materials being welded, while the probe 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. The softened material then easily moves behind the tool and forms a solid state weld as the stirred material is consolidated. FSW can be regarded as an autogenous keyhole joining technique [7]. FSW involves complex material flow and plastic deformation of material. The process and the terminology are schematically explained in Fig 1.

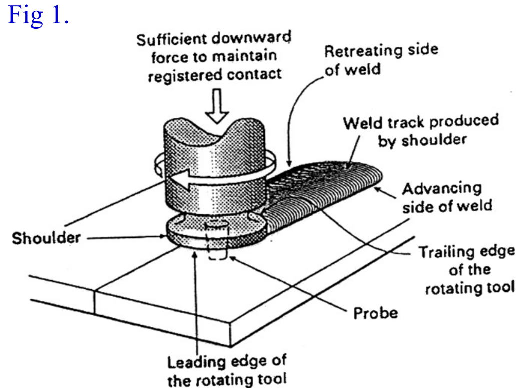

Fig. 1 Schematic representation of FSW principle [9]

The FS Welded material produces three different areas: the weld nugget, the thermo-mechanically affected zone and the external heat affected zone. The microstructural grain structure in the weld nugget is usually very fine and equiaxed, ensuring elevated mechanical strength and ductility [10, 11]. 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 [12].
The welding parameters are greatly affected the mechanical and metallurgical properties of weld. The tool is used for friction stir welding is shown in Fig. 2. Tool pin profile has a great effect on the strength and quality of friction stir welded joints.

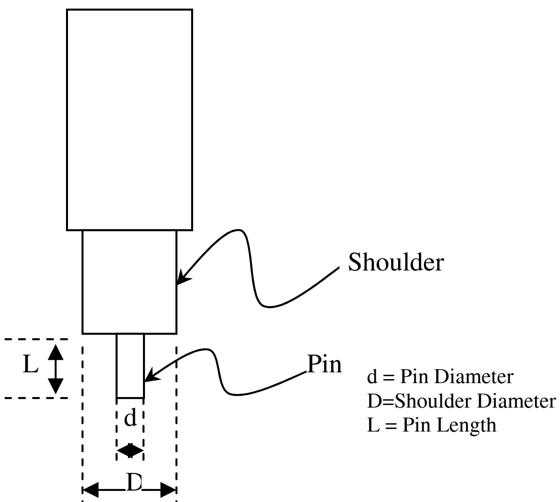

Fig. 2 Tool geometry

Some authors analysed the influence of the tool rotation speed, welding speed and both parameters simultaneously on the microstructure and mechanical properties of 6XXX welds [13]. The material flow behaviour is predominantly influenced by the FSW tool profiles, FSW tool dimensions and FSW process parameters [14, 15]. In the present investigation the effect of tool rotational speed and different tool pin profile on mechanical and metallurgical properties of joint is observed wit FSW. The investigation is done to find the optimize parameters of FSW for joining aluminium 6xx series. The dissimilar aluminium alloy 6xxx series are successfully welded with Friction stir welding.

II. EXPERIMENTAL WORK

The plates of aluminium alloys 6061 and 6063 having 6mm thickness were cut into rectangular shape with the help of power hacksaw. The size of rectangular pieces was 100 mm x 70 mm. The pieces were welded with Friction stir welding to obtain butt joint configuration. The size of the samples after welding was 140 mm x 100 mm. Non consumable high chromium steel tools with two different pin profiles (square and hexagon) were used in this study. The tool pin length and pin diameter was made on conventional lathe machine by turning process and then hexagonal and square pin profile was made by using vertical milling machine. The tool dimensions and other welding parameters are shown in Table 1. Two different tool rotation speeds were used to fabricate the joints. Other parameters such as tool tilt angle 0°, and welding speed 80 mm/min were constant.

TABLE 1 FRICTION STIR WELDING PROCESS PARAMETERS.

Tool Length	90 mm
Tool Shoulder Diameter (D)	18 mm
Tool Pin Diameter (d)	6 mm
Tool Pin Length (L)	5.7 mm
Tool Rotation Speed	1200 rpm, 1600 rpm

The friction stir welded joint was fabricated on vertical milling machine. Work pieces were hold in specially designed mild steel fixture on the table of CNC vertical milling machine. The prepared Fixture was clamped with the help of four clamps. Tool moved along the weld line and at the end the tool was taken out with its upward motion leaving a key hole at the end of the weld joint. The Tool holder and movement of table were controlled pneumatically. The mechanical properties were evaluated with the help of tensile tests. The welded samples were cut as per American Society for Testing of Materials (ASTM) guidelines as shown in Fig. 3. Universal Testing Machine of 25 KN load was used to test Ultimate Tensile Strength of the specimens. X-ray Radiography had been done to reveal the internal defects like porosity, voids and cracks etc. The hardness of the weld zone was analyzed by Vicker's microhardness testing. The microhardnes testing had been done at a load of 100 gms for a dwell time of 10s.

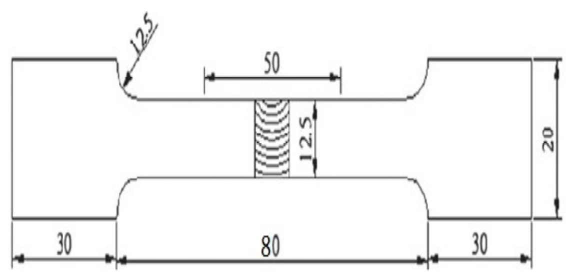

Fig. 3 Tensile test specimen dimensions in mm.

The specimens for metallographic test were prepared by polishing them by using different grades of emery papers (200, 400, 600, 800, 1000, and velvet cloth. To reveal the microstructures Specimens were etched with Hydrofluoric (HF) acid.

III. RESULTS

All the samples welded with FSW process were visually inspected. No defect was observed on visually inspecting the welded specimens. At the end point of the weld line, pin-hole was observed on the surface of each specimen, which is the common drawback of FSW process. This defect can be removed by refilling the hole with help of TIG welding, however it was not done in the present work, as this portion of the welding was not considered for testing purpose.

Higher heat input needs higher interaction time between tool and work piece to obtain proper consolidation [16].

The effects of friction stir welding process parameters i.e. tool rotational speed and tool pin profile on the ultimate tensile strength is evaluated with the help of tensile testing. All the specimens were failed from the weld zone, which indicates that the strength of the weld region is weaker than that of the original parent materials. The average values of tensile strength were calculated from three different test readings for each type of specimen. The results are plotted in the form of bar chart Ultimate tensile strength v/s Tool pin profile and rotational speed as shown in Fig. 4. From the results, it is observed that the ultimate tensile strength of the friction stir welded joint has been influenced by the tool pin profile and tool rotational speed. The joint produced by hexagonal pin profiled tool and at rotational speed 1200 rpm have given superior tensile properties as compared to other joints. The primary function of the non-consumable rotating tool pin profile 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 and in turn regulates the welding speed of the FSW process [17]. The tool pin profile with flat faces produces pulsating effect and better plastic flow of material [18]. Tools with hexagon pin profile were produces high pulsating action which gives superior tensile properties.

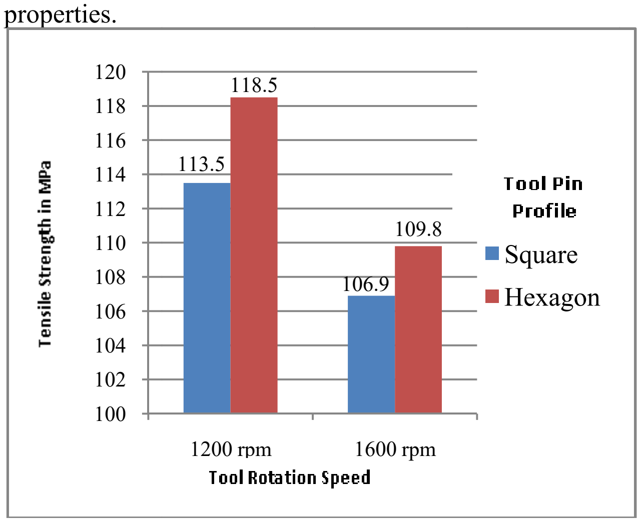

Fig. 4: Effect of rotation speed tool and pin profile on UTS of FSW Joints.

The tool rotational speed 1200 rpm provides sufficient interaction time between the tool and the work piece, which may result in sufficient frictional heat generation and proper mixing of materials.

These results are consistent with that of [17]. At high rotational speed of 1600 rpm, large amount of frictional heat was generated, which interrupted the flow of material and results in coarse grain structure, which resulted in poor tensile properties.

The increase in tool rotational speed results in the increase in tensile strength of the FS welded joints. The tensile strength reaches a maximum value and further increase in tool rotational speed leads to the decrease in tensile strength [19].

X-ray radiography, a non-destructive test, was performed to analyze the internal defect in weld zone. FSW joints are prone to other defects like pin hole, tunnel defect, piping defect, kissing bond, zig-zag line and cracks etc., due to improper flow of metal and insufficient consolidation of metal in the FSP (weld nugget) region [20].

But in this study no porosity and voids were observed in x-ray radiography analysis of all the weld joints Friction Stir Welded joints are free from these type of defects as the solidification takes place in solid state. All the joints were produced with a smooth surface finish. This is due to sufficient heat produced and metarial flow properly during welding process.

On the otherhand the joint febricated with Sequare pin profile tool at 1200 rpm produces poor stirring action due to this less amount of heat frictional heat was generated and the grains become coarse as shown in Fig 5 (b). The lower value of hardness was obtained at this parameter due to this coarse grain structure

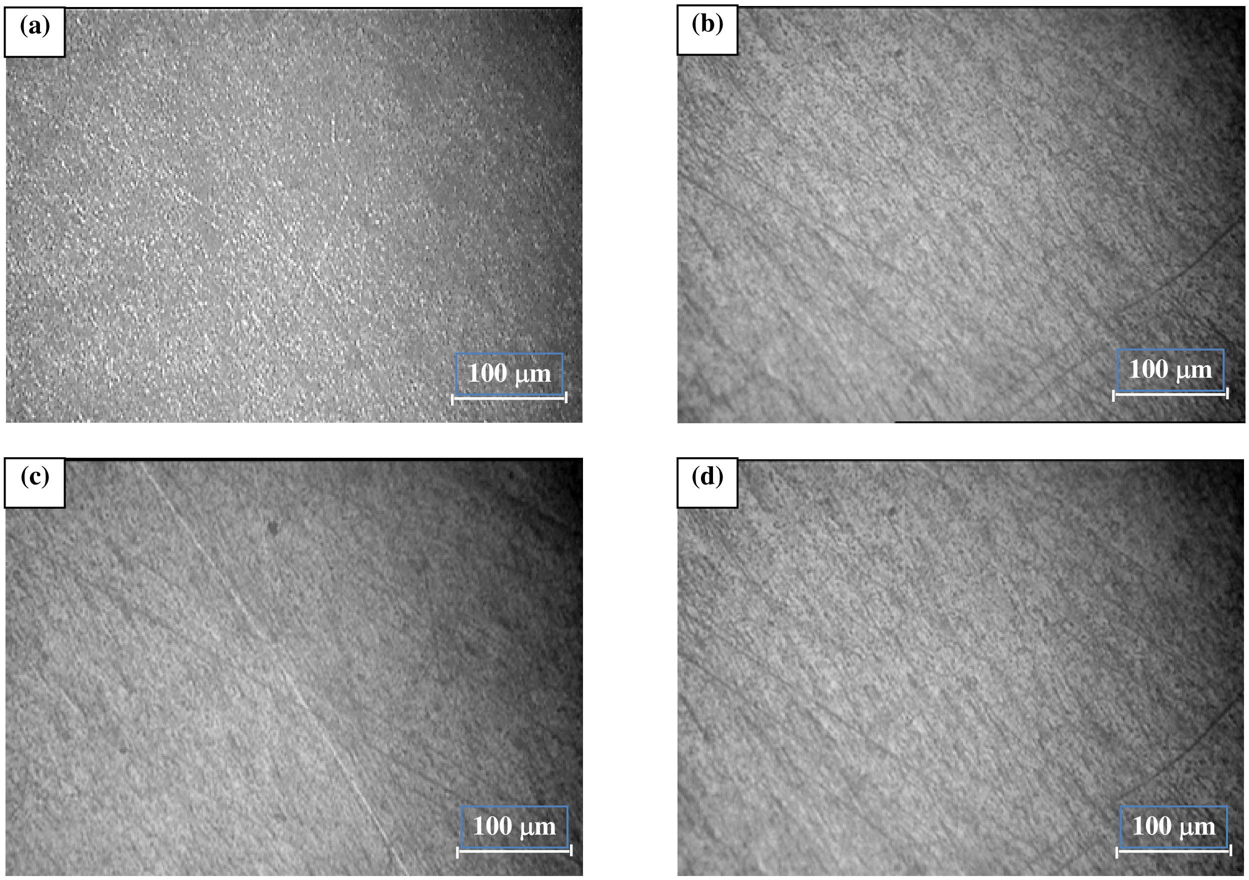

Fig. 5 Micrographs of stirred zone, (a) hexagonal tool with rotational speed 1200 rpm, (b) square tool with rotational speed 1200 rpm, (c) hexagonal tool with rotational speed 1600 rpm, (d) square tool with rotational speed 1600 rpm.

The microstructural behaviour of aluminium alloys joined with Friction Stir Welding was studied at different conditions. The micrographs were taken from the weld nugget.

A very fine grained microstructure was obtained of the stir zone for joint fabricated at tool rotational speed 1200 rpm and tool with hexagonal pin profile as shown in Fig. 5 (a).

The hexagonal pin profile tool produces sufficient amount of frictional heat due to large number of pulses which resulted as fine grain structure is obtained. It can also be clearly observed form the micrographs that the grain structure of the stirred zone varies with the change in tool pin profile.

A fine grain structure was also obtained at tool rotational speed 1600 rpm and joint fabricated with hexagonal tool pin profile as shown in Fig 5 (c). This is because of flat faces of tool pin profile produces good stirring action. Due fine grain structure the higher value of micro hardness obtained at these parameters.

The FSW joint fabricated with Square pin profile tool at tool rotation speed 1600 rpm produces in sufficient heat due to this coarse grain structure was obtained at these parameters as shown in Fig 5 (d).

Hardness of weld joints was measured from the top of the weld. The values of Hardness measured are shown in bar chart in Fig. 6.

The highest hardness values has been recorded for the joint, produced by using Hexagonal tool profiled tool at 1200 rpm tool rotational speed and by using Hexagonal tool profiled tool at 1600 rpm tool rotational speed. The lowest hardness value has been recorded for the joint, produced by using Square pin profiled tool and at 1200 rpm tool rotational speed by using Square pin profiled tool and at 1600 rpm tool rotational speed.

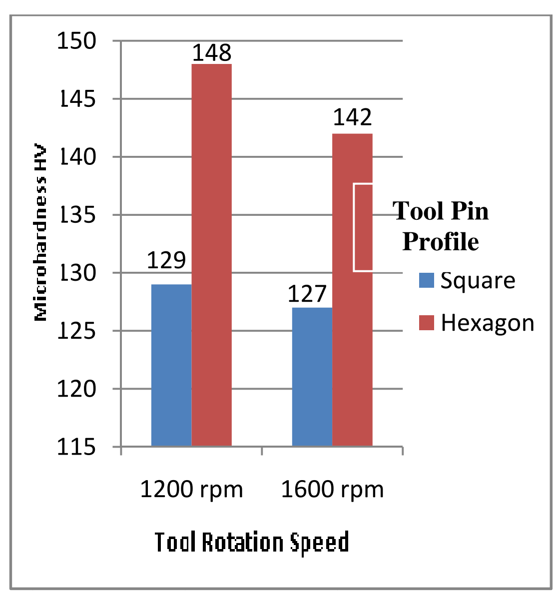

Fig. 6 Effect of rotation speed & tool pin profile on the micro-hardness of SZ

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 then 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 [21].

IV. CONCLUSIONS

In this study, the aluminium alloy 6061 and 6063 are successfully welded with Friction Stir Welding. It has been found that the combination of tool rotation speed and tool pin profile has great effect on the on the mechanical and metallurgical properties of weld joint. Rotational speed is provide proper stirring action and plastic flow of material on other hand tool pin profile produces sufficient heat due to flat face of pin profile which results a defect free joints are obtained in this study.

1. The joint fabricated by using tool rotational speed 1200 rpm and tool with hexagon pin profile had given superior mechanical properties.
2. A very fine grain structure was obtained at tool rotation speed 1200 rpm and tool with hexagon profile.
3. This was clear from X-ray Radiography that joints are free from internal defects, cracks and porosity.
4. Good stirring action and sufficient amount of frictional heat was produced in the stirred zone which results the proper plasticized flow of the material and in turn to produce defect free welds.

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