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EFFECT OF TOOL PIN PROFILE AND WELDING PARAMETERS ON MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF AA5083 JOINTS PRODUCED BY FRICTION STIR WELDING

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Abstract : *In the present experimental study, Friction stir welding of AA5083 aluminum alloy plates with a thickness of 6 mm was performed. The effect of tool pin profile and welding parameters on mechanical properties of the joints and microstructure was investigated. Two different tools, cylindrical pin and square pin profile designed for friction stir welding of Aluminum plates. The mechanical properties increased with increasing the tool rotational speed from 1000 to 1200 rpm. Furthermore mechanical properties also found to improve as the welding speed decreases from 60 mm/min to 20 mm/min and the same phenomenon was found to happen while using square pin profile tool. The microstructure of the dissimilar joints revealed that at low welding speeds, higher rotational speeds and using square pin profile tool, the improved material mixing was observed.*
Keywords*: Friction Stir Welding, AA5083 Al Alloy, Welding Parameters & Tool Shape, Mechanical Properties & Microstructure.*

I. INTRODUCTION

Welding is one of the fast growing technologies used for joining materials which is almost used by all the fabricating industries (Handa and Chawla, 2013). Recently, requirements for the automotive industry have been increasing due to its reduction in mass, fuel consumption and environmental impact (Kwon et al., 2009). Because of aluminum’s light weight, it has been considered an energy saving structural material in advanced applications (Hirata et al., 2007). Friction stir welding (FSW), a solid state joining technology, was invented in 1991 by The Welding Institute (TWI) of UK (Casalino et al., 2014). It is an eco-friendly fabrication technique, involving energy efficiency and versatility to provide a satisfactory combination of microstructure and mechanical properties of assemblies (Hirata et al., 2007). For joining light metals, especially aluminum and its alloys, this technique avoids the formation of solidification cracking and porosity (Xu et al., 2013). FSW also reduces the presence of distortions and residual stresses (Cavaliere et al., 2008). Moreover it significantly improves weld properties.FSW is an appropriate solid state welding technique to effectively join any combination of dissimilar aluminum alloys (Palanivel et al., 2014). In friction stir welding (FSW), a non-consumable tool with a specially designed pin and shoulder is inserted into the joint line between the two pieces of plate material, which are butted together. The heating is accomplished by friction between the tool and the workpiece and plastic deformation of workpiece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. It leaves a solid phase bond between the two pieces (Mishra and Ma, 2005).
FSW parameters are tool geometry, axial force, rotational speed, traverse speed and tool tilt angle. General convention is, where the direction of the velocity vector of the tool and traverse direction are same that side is called the advancing side of the weld, and when the direction of the velocity vector opposite to the traverse direction, it is called the retreating side (Kumar and Kailas, 2008). The schematic diagram of friction stir welding technique is shown in figure 1.

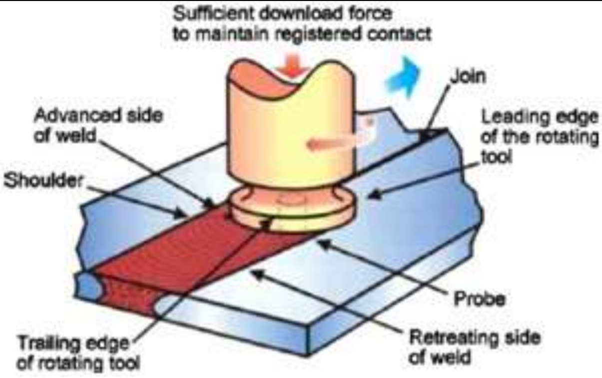


Fig. 1: Schematic diagram of FSW technique (Xu et al., 2009)

Characteristics of friction stir welded joints are influenced by material flow and temperature distribution across the weld which are dictated by Tool design and welding parameters such as welding speed and tool rotational speed. Tool design is one of the most important factors to consider when designing a FSW joining process. The tool must perform many functions, including generating heat, promoting mixing, breaking up the joint line, dispersing oxide layers, creating forging pressure, containing material within the joint, thereby preventing surface weld flash, and preventing the formation (or minimizing the impact) of defects such as wormholes, sheet-thinning, or hooking defects (Gibson et al., 2014).

II. Experimental Procedure

The square butt fsw of aluminum alloy aa5083 plates with the size of 75 mm in width, 120 mm in length and 6 mm in thickness each was conducted on an adapted vertical cnc milling machine installed at Central Tool Room, Ludhiana. a clamping fixture was utilized in order to fix the specimens to be welded on a milling machine. The fsw tools were machined from en8 carbon steel material. One tool has a cylindrical pin and the second tool has a square pin. The shoulder diameter and the shoulder height of the tool for fsw were 18 mm and 65 mm. The probe had a diameter of 6 mm and a height of 5.7 mm. The two prepared aluminum pieces were firmly clamped into the fixture. The welding process was carried out by rotating the tool at 1000 and 1200 rpm and by varying welding speed at 20, 40 and 60 mm/min. The tool was mounted on the vertical spindle. The rotating tool was made to pass through from the butt joint. afterwards within a fraction of time, sufficient heating was achieved due to the rubbing action between tool and plates. The bed was given automatic feed, along the joint direction. In this way welding was achieved the friction stir welding process of two aluminum plates is shown in figure 2. two types of en8 carbon steel tools are shown in figure 3.

Fig. 2: Vertical Milling Machine

Fig. 3: Tools used for FSW.

5083 Aluminum-magnesium alloys are strain hardenable and have excellent corrosion resistance, toughness, weldability and moderate strength. Especially with their high corrosion resistance and moderate strength, AA5083 alloys are widely used in shipbuilding industry (Gungor et al., 2014). In this experimental work, the plates were prepared with 150×120×6 mm^3 dimensions. The chemical composition of AA5083 aluminum alloy presented in Table 1.

Table 1: Chemical composition of AA5083

Elements	Percentage
Cu	0.03
Fe	0.16

Si	0.1
Mn	0.66
Mg	4.5
Zn	0.03
Cr	0.06
Ti	0.07
AI	Balance

Various equipment used for conducting the research work, tensile test was performed on a universal testing machine, Model UT100, capacity of 1000 KN, least count is 0.05 KN. The standards are taken from ASTM (American society for testing and material) Internationals. A vicker micro hardness tester (Make FIE, Model No HV 50) was employed for measuring the hardness across the transverse section of the joint with a load of 1 Kgf and dwell time of 15 sec. Metallographic specimens were cut mechanically from the welds and polished using abrasive disks and cloths. The chemical etchant was the Keller's reagent (1 ml hydrofluoric acid, 1.5 ml hydrochloric acid, 2.5 ml nitric acid and 95 ml water) to reveal the microstructure of the weld region. The microstructures were observed on optical microscope.The total 12 experiments were performed. The welding parameters were selected as per the table no. 2, after the experiments, the pieces were cut into the samples of required dimensions for performing the tensile tests, micro hardness and microstructure.

Table 2 Different friction stir welded joints

Specimen No.	Tool pin profile	Tool rotational speed (rpm)	Feed rate (mm/min)
S-1	Cylindrical	1000	20
S-2	Cylindrical	1000	40
S-3	Cylindrical	1000	60
S-4	Square	1000	20
S-5	Square	1000	40
S-6	Square	1000	60
S-7	Cylindrical	1200	20
S-8	Cylindrical	1200	40
S-9	Cylindrical	1200	60
S-10	Square	1200	20
S-11	Square	1200	40
S-12	Square	1200	60

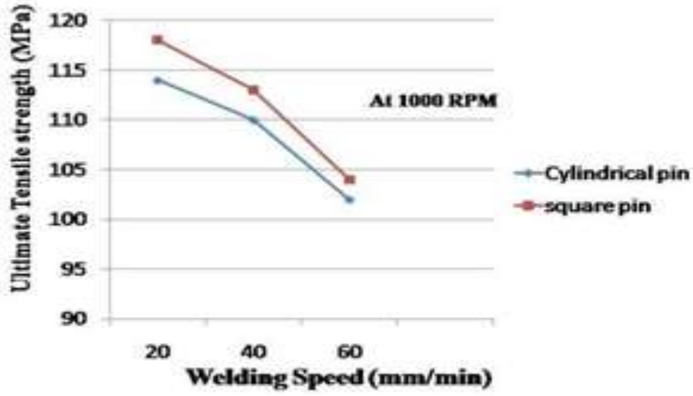
III Results & Discussions

Results of Ultimate Tensile Strength:-

It can be concluded from table 3 that with increase in tool rotational speed and decrease in welding speed with both tool pin profiles the tensile strength of friction stir welded joint increases. The figure 4 (a) and figure 4
(b) shows the variation of ultimate tensile strength of different samples with respect to table 3. Comparing the tensile strength results of pieces welded by square tool with that of pieces welded by cylindrical tool, it is concluded that the ultimate tensile strength of pieces welded by square tool is more than that of pieces welded by cylindrical tool. The possible causes for the effects of different welding parameters on tensile strength are interpreted and presented as follows:-

Table 3: Results of Ultimate Tensile Strength

Spec No.	Tool pin profile	Tool rotational speed (rpm)	Feed rate (mm/min)	Ultimate Tensile Strength (MPa)
S-1	Cylindrical	1000	20	114
S-2	Cylindrical	1000	40	110
S-3	Cylindrical	1000	60	102
S-4	Square	1000	20	118
S-5	Square	1000	40	113
S-6	Square	1000	60	104
S-7	Cylindrical	1200	20	112
S-8	Cylindrical	1200	40	110
S-9	Cylindrical	1200	60	111
S-10	Square	1200	20	126
S-11	Square	1200	40	118
S-12	Square	1200	60	117



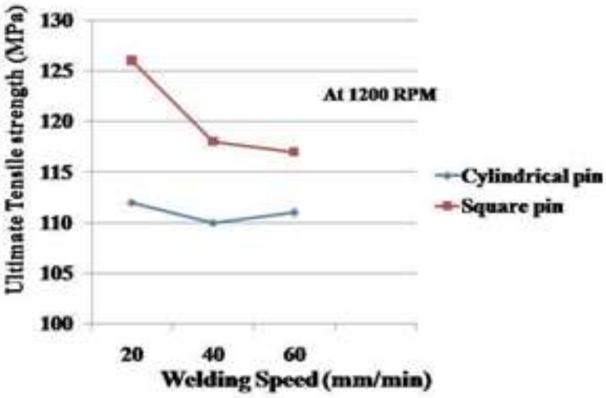


Fig 4 (a): Variation of Ultimate tensile strength (MPa) at 1000 rpm. Fig 4 (b): Variation of Ultimate tensile strength (MPa) at 1200 rpm.

The joints were fabricated using a tool of square pin profile and cylindrical pin profile. The friction stir welded joints have lower tensile strength if they are fabricated using the cylindrical tool pin profile, as compared to the joints fabricated by square pin profile. The square type of tool pin profile produces good material stirring quality and mixing of plasticized metals during welding. The severe plastic deformation due to intense stir of square pin profile results in higher strain energy relative to cylindrical pin profile. The lower tensile strength of the cylindrical pin profile is attributed to the presence of defect in the stir zone. The increase in tool rotational speed of square pin profile results increases the tensile strength of friction stir welded joint. At a rotational speed of 1200 rpm, the frictional heat generated is highest, which results in better plastic flow of the materials being Friction Stir Welded and therefore, highest tensile strength is observed. But the decrease in tool rotational speed decreases the tensile strength and results in poor plastic flow of materials being friction stir welded and therefore lower tensile strength is observed. The decrease in welding speed leads to increase in the tensile strength up to maximum value. At lowest welding speed of 20 mm/min the highest tensile strength is observed. At lower welding speeds, the quantity of heat supplied to the plasticized deforming material in the weld zone is greater and therefore wider is the softened area around the stirring tool leading to more improved metal flow and hence more effective bonding in the weld. On the other hand increase in welding speed results in a decrease of tensile strength. At higher welding speeds, tool results in lower heat input per unit length of weld which in turn reduces stirring action of the material due to poor flowability in the weld area resulting in poor tensile strength The above results are useful to have a better understanding of the effects of process parameters, to fabricate the joints with desired tensile properties

IV Results of Micro hardness:-

Microhardness of the material mainly reveals it strength (Kaushal et al. 2019, 2021, Singh et al. 2020) Micro hardness test was performed in order to characterize the hardness in the vicinity of the weld affected area. The micro hardness tests were performed on a cross section perpendicular to the weld line, using 1 Kgf load for a dwell period of 15 Sec. The average microhardness in the weld nugget decreased with increase in welding speed from 20 to 60 mm/min and completely reverse trend was noticed with the increase in tool rotation speed from 1000 to 1200 rpm with square pin profile as shown in figure 5.

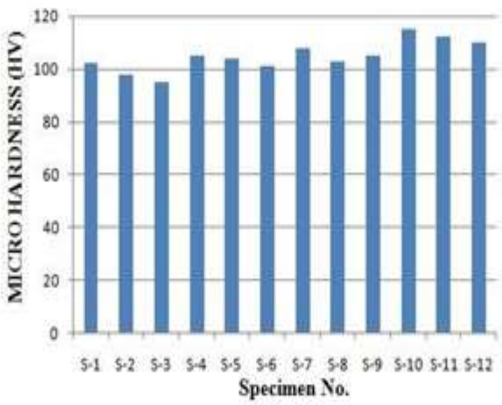


Fig 5: Variation of average micro hardness of different welded specimens

On the stir zone, the increase in microhardness was associated with re-precipitation of fine particles. As the tool rotational speed increased and welding speed decreased, more efficient mixing of the material were happened.

The decrease in welding speed and increase in tool rotational speed would increase the heat input per unit weld length. The improved weld nugget hardness was due to the reduction in the density of coarse second phase strengthening particles. The square pin profile showed higher hardness than that of with cylindrical pin profile in the stir zone. The square type of tool pin profile produces good material stirring quality and mixing of plasticized metals during welding. Cylindrical type of tool pin profile produces insufficient mixing of plasticized metals because tool pin is incapable of deforming appropriate metal during rotation leads to low micro hardness.

V Results of Micro structure:-

Microstructure characteristics plays a vital role on the overall performance of any surface (Kaushal et al. 2018, 2019).Thermal and mechanical stresses caused by tool stirring and axial force resulted in the formation of weld nugget zone, thermo mechanically affected zone and heat affected zone in friction stir welded joints. On the basis of the results obtained during mechanical characterization, the best parameters were selected and microstructure evaluation was carried out on those parameters. The micrographs of the centre of weld nugget zones, thermo mechanically affected zone and heat affected zone for welding speed of 20 mm/min and tool rotational speed of 1200 rpm with square tool pin profile are shown in figure 6.

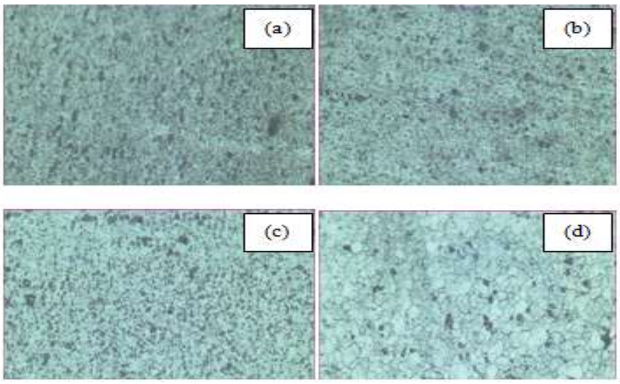


Fig 6:- shows Microstructure of various regions in weld zone using square pin profile at welding speed of 20 mm/min and tool rotational speed of 1200 rpm; (a) Base Metal (b) Heat affected zone (c) Thermo mechanical affected zone (d) Weld zone.

Images of weld zones cross section are outlined. Weld nugget is created by the penetrating tool pin. It is characterized by a recrystallized microstructure containing fine grains, which are formed as a result of the severe plastic deformation and high temperatures. Thermo mechanical affected zone of the friction stir weld is characterized by a highly deformed structure. Microstructural changes in thermo mechanical affected zone are driven by the combined influence of heat generated and deformation induced by the tool. Changing the welding speed and tool rotational speed can have significant effect on the flow of the material within the stir zone. The extent of mixing and interface disruption increases as the tool rotational speed was increased and the welding speed was decreased. At low welding speed, weld nugget is more homogeneous. Because high heat input per unit length results in more homogeneous temperature distribution and effective recrystallization and same trend was observed with increasing tool rotary speed. Because with increasing tool rotational speed heat inputs per unit weld length increases. A sound joint was obtained when adequate frictional heat and stirring was available.

VI Conclusion

In the present work, the effect of tool shape and welding parameters on the microstructure and mechanical properties of friction stir welded AA5083 aluminum alloys was investigated. The results can be summarized as follows:

- As the tool rotational speed increases and welding speed decreases the material mixing of material is made more efficiently.
- At low welding speeds and high rotational speeds, friction stir welding of AA5083 aluminum alloys revealed joints with satisfactory mechanical and microstructural properties.
- At low welding speeds and high tool rotational speeds FSW, increasing heat input per unit length of weld provided microstructural and mechanically better joints.
- The microstructure of the stir zones consisted of fine equiaxed grains at friction stir welding conditions in FS-welded 5083 Al alloy.
- Square pin profile of the tool is preferred over cylindrical pin profile due to the superior performance of the joints.

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