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Influence Of Tool Shape On Mechanical Properties And Microstructure Of Friction Stir Welded Aluminium Alloys

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Abstract:
Most of the work has been dedicated to the study of flow of materials, the effect of welding parameters on the microstructure, mechanical properties and fatigue properties. but mechanical and microstructure properties of alluminium alloys AA6063 and AA 1100 are not describe with different parameters. Experiment conducted on the two aluminium alloys of AA1100 and AA 6063-T6. Plates of two alloys having 6 mm thickness were cut into the required size (150 mm x 60 mm) by power hacksaw. Rectangular butt joint configuration was prepared to fabricate the joints. For clamping the two plates specially fixture design has been made .Experiment was conducted at CTR Ludhiana by CNC milling machine with particular parameters.

1.Introduction
Friction stir welding (FSW) is a solid state welding process developed and patented in 1991 at TWI. a solid-state welding process which avoids the formation of solidification cracking and porosity associated with fusion welding processes..Friction stir welding (FSW) is considered to be the most significant development in the last years in metal joining techniques. Friction Stir Welding technology, if compared to traditional welding techniques, reduces the presence of distortions and residual stresses and is being targeted by modern aerospace industry for high performance structural applications.

2.Principle Of Operation
FSW is a solid state process in which a specially designed rotating tool, composed by a shoulder and a pin, is inserted into the edges of the sheets to be welded, with a proper tilt angle, until the shoulder gets in contact with the top surface of the sheets; then the rotating tool is moved along the welding line.During the process, heat is generated by plastic deformation as well as by the friction between the tool and the work-pieces. The work-pieces are ultimately joined by the stirring action of the softened (but always solid) material.

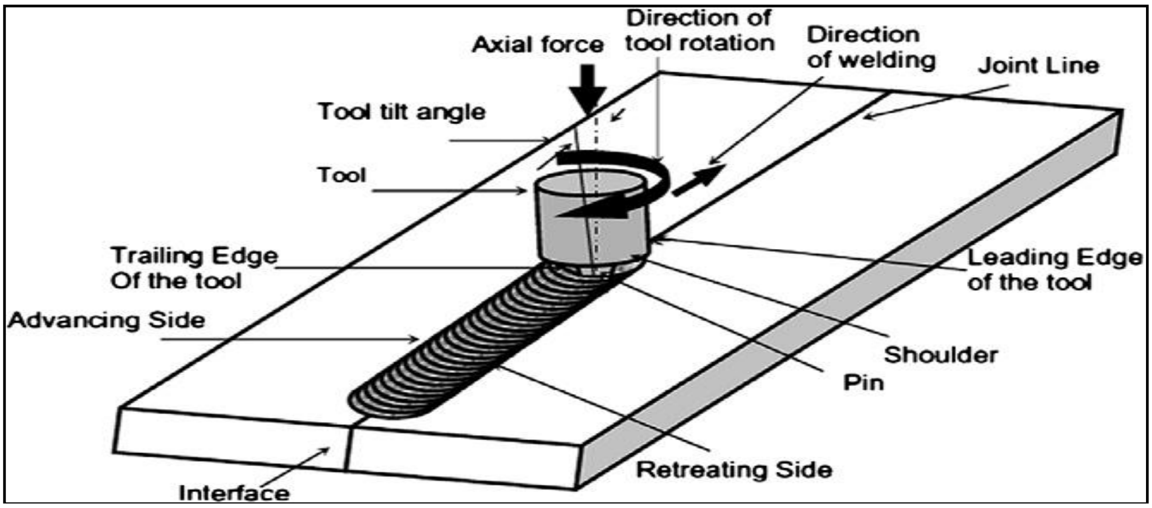

Figure 1: Friction Stir Welding

Microstructure Classification of Friction Stir Welds :The first attempt at classifying microstructures was made by P L Threadgill. This work was based solely on information available from aluminum alloys. However, it has become evident from work on other materials that the behavior of aluminum alloys is not typical of most metallic materials, and therefore the scheme cannot be broadened to encompass all materials. A more comprehensive scheme has been developed by TWI, and has been discussed with a number of a appropriate people in industry and academia. This has also been accepted by the Friction Stir Welding Licenses Association. The system divides the weld zone into distinct regions as shown in Figure 2.

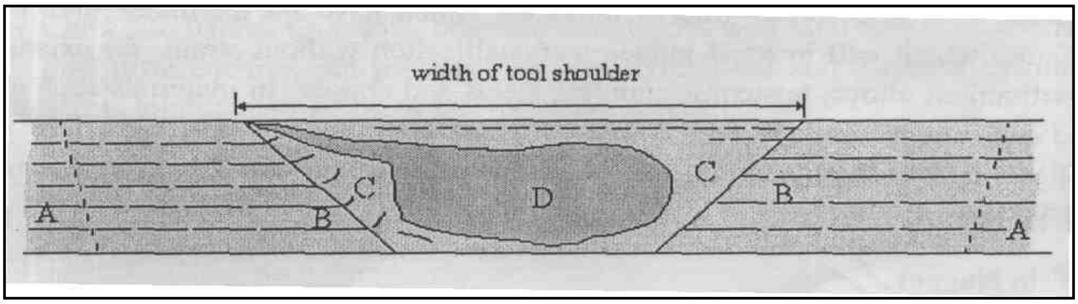

Figure 2: Welding Zones

- Unaffected material
- Heat affected zone (HAZ)
- Thermo-mechanically affected zone (TMAZ).
- Weld nugget (Part of thermo-mechanically zone)

3.Experimental Procedure

Two aluminium alloys are used as a experimental material of different grades. For welding tool high speed steel is used for frictional stir welding. Specifications of materials are following.Two aluminium alloys are used as a work piece material in the form of two plates .The size of work piece materials of AA1100 and AA6063- T6 are given in Table 1below: The chemical composition of two aluminium alloys of AA1100 and AA6063- T6 checked by Glow discharge spectrometer at CTR, Ludhiana and percentage of various elements are given in the Table 1 and 2 respectively.

Specification	Values of S-1	Values of S-1
Material	Aluminium	Aluminium
Grade	AA1100	AA6063-T6
Length	150 mm	150 mm
Width	60 mm	60 mm
Thickness	6 mm	6 mm

Table 1: Specifications Of Work Piece Materials

Elements	Percentage
AL	99 min
CU	0.20 max
SI+Fe	0.95 max
Mn	0.05 max
Zn	0.10 max
Others total	0.10 max

Table 2: Chemical Composition Of AA1100

Elements	Percentage
AL	95.6 -98
SI	0.8 max
Fe	0.7 max
CU	0.40 max
Mn	0.15 max
Mg	1.2 max
Cr	0.35 max
Zn	2.5 max
Ti	0.15 max
Others total	0.15 max

Table 3: Chemical Compositions Of AA6063–T6

Two tools are used for welding process having different pin profiles these are square thread (ST) and straight cylindrical (SC) are shown in fig. 1.1. High speed steel used for make the shank and shoulder of the tool and high carbon steel used for make the pin profile of the tool. Dimension of tools are given in the Table 4.

Specification	Values
Tool material for shank, shoulder and pin profile	HSS and HCS
Hardness for shank, shoulder and pin profile	62 HRC and 58 HRC
Shank diameter	10 mm
Shoulder diameter	14 mm
Pin diameter	6 mm
Pin length	5.7 mm

Table 4: Specification of Welding Tool

Various equipment used for conducting the experimental work these are microvicker hardness tester, universal tensile testing machine (UTM), polishing machine, optical microscopy machine.
CNC milling machine was used to fabricate the joints at the production department of Central Tool Room (CTR) Ludhiana. Computer numerical control (CNC) is an NC system that utilizes a dedicated stored program to perform some or all of the basic numerical control functions. Specially designed fixture was used for holding the work pieces tightly to fabricate the joints of two aluminium alloy plates and also avoid the vibrations and misalignment during the process. The specially design fixture according to the work piece dimensions. Micro hardness test was conducted by Microvicker hardness Tester (Make Akashi, Model:MVK-H2,Japan. Temperature:24^0C) at Institute For Auto Parts & Hand Tools Technology, Ludhiana. Polishing machine was used at University College Engineering, Patiala to make the mirror like shape of work pieces. Microstructure was checked by optical microscopy machine at Institute For Auto Parts & Hand Tools Technology, Ludhiana.
Results and Discussions: These tests were conducted by Microvicker Hardness Tester (Make Akashi, Model:MVK-H2,Japan. Temperature,24^0C) at Institute For Auto Parts & Hand Tools Technology, Ludhiana. The constant load was used for a time period of 15sec. Micro Hardness of Base Materials of AA1100 and AA6063 -T6 before the experiment checked by Microvicker Hardness Tester. The table 5 (before the experiment) & 5 (after the experiment) shows the values of specimen micro hardness and Fig 4 shows the variation of micro hardness of different specimen according to that value respectively.

Specimen no.	Type of material	Micro harness (HV 0.2)
S-1	AA1100	48.5
S-2	AA 6063 T-1	81.4

Table 5: Micro Hardness Values Of Base Materials

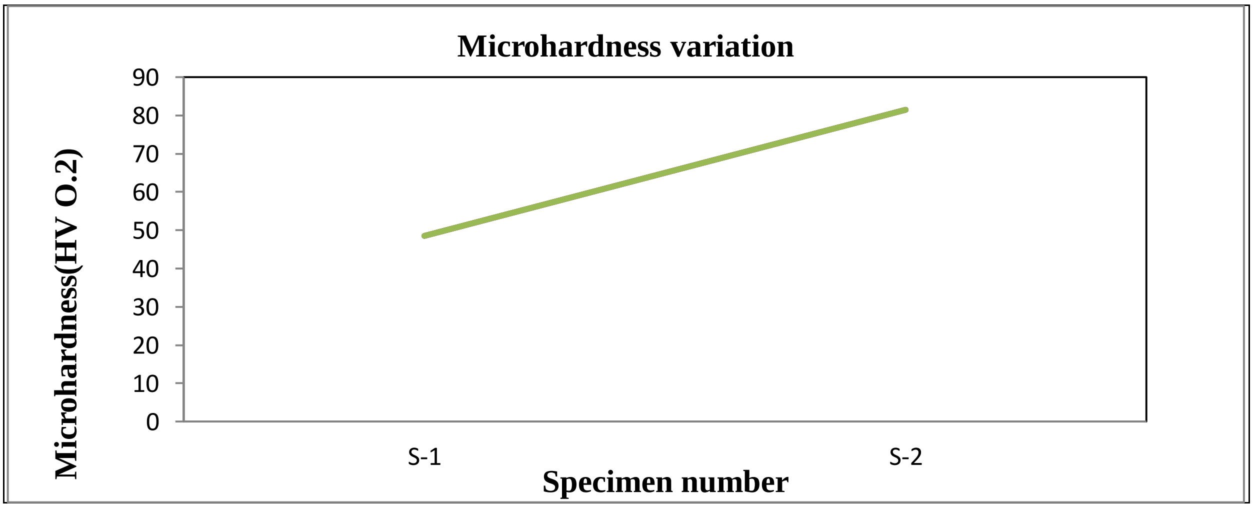

Figure 3: Variation Of Micro Hardness Of Base Materials

From the Figure-3, its value shows that the micro hardness of base material of aluminium alloy AA6063 T-1 (S-2) is greater than aluminium alloy AA1100 (S-1) before the experiment. After the welding of twelve pieces in the form of butt joint by friction stir welding, micro hardness of welding joints of Friction Stir Processed (FSP) Zone checked. Values of micro hardness are given below:

Specimen no	Tool pin profile	Speed (rpm)	Feed (mm/min)	Micro hardness(HV 0.2)
S-1	SC	1800	50	41.5
S-2	ST	1800	50	40
S-3	SC	2000	50	4
S-4	ST	2000	55	42
S-5	SC	2200	55	48.5
S-6	ST	2200	55	42.5
S-7	SC	2300	55	50.5
S-8	ST	2300	55	41.5
S-9	SC	2400	45	49.3
S-10	ST	2400	45	44
S-11	SC	2500	45	53
S-12	ST	2500	45	42.5

Table 6: Micro Hardness Values Froms-1 To S-12 After The Experiment

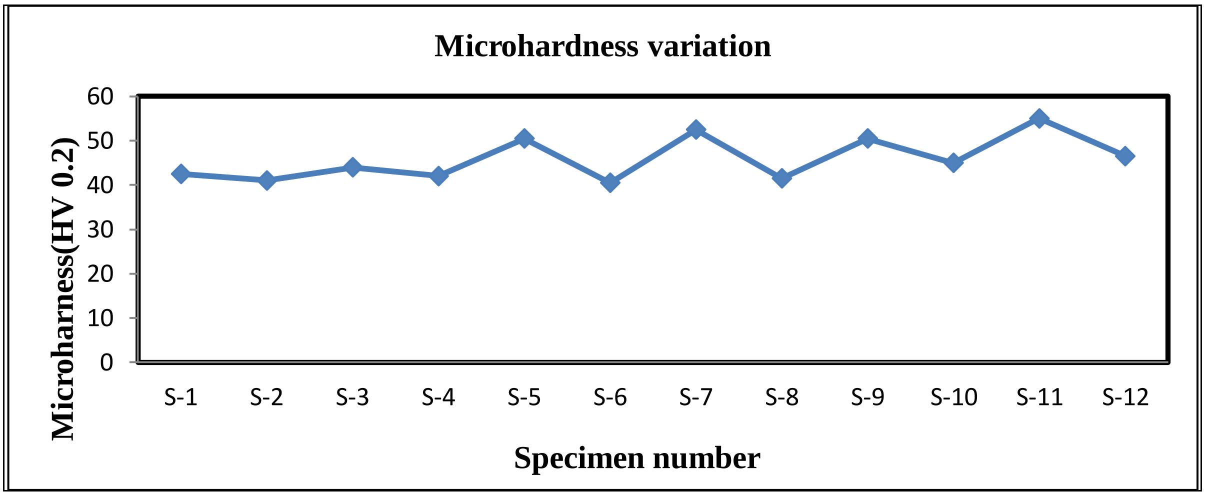

Figure 4: Variation Of Micro Hardness

After the experiment figure 4 shows the variations of micro hardness at welding joints of specimen from S-1 to S-12. Result shows that the micro hardness increases with increasing the speed of tool. Micro hardness of S-1 with speed 1800rpm, SC pin profile and feed 50 mm/min higher value than the S-2 with same speed, feed but ST pin profile. Similarly micro hardness from specimen S-3 to S-8 increases with increases the speed, feed with SC pin profile than ST pin profile with same parameters. But the value of the specimen S-9 to S-10 is decreases with speed 2400 rpm, SC pin profile and feed 45 mm/min than previous parameters. When the speed increases from 2400 to 2500 rpm with same feed, SC pin profile then micro hardness of specimen S-11 is mostly higher than others. There for values of high micro hardness are obtained by using the straight cylindrical pin profile with increases the speed than the square thread pin profile tool with same speed.

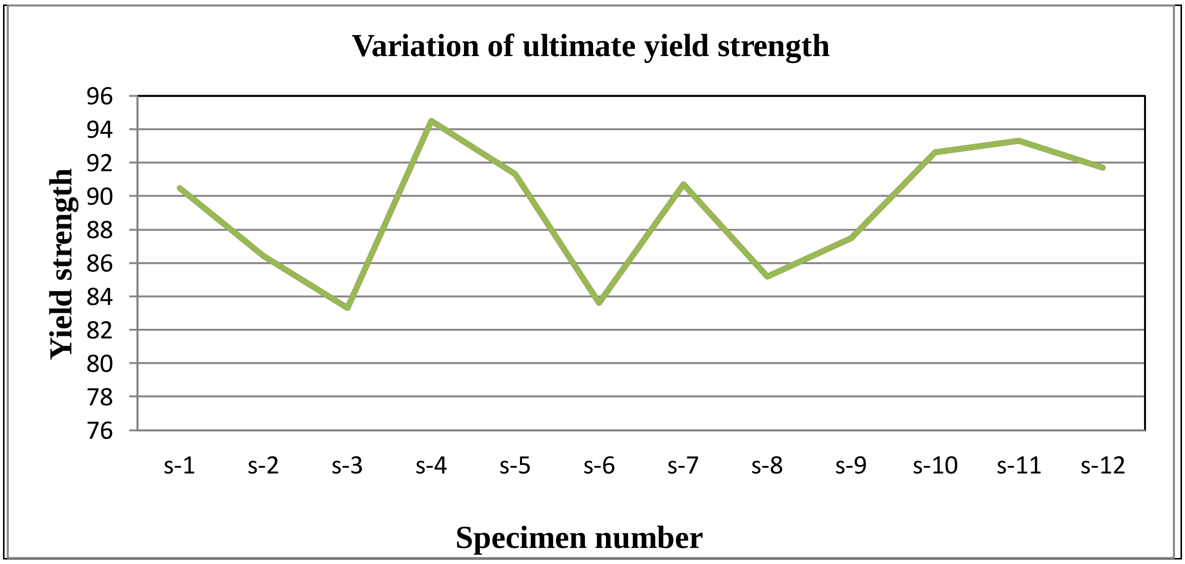

Figure 5: Variation Of Ultimate Yield Strength

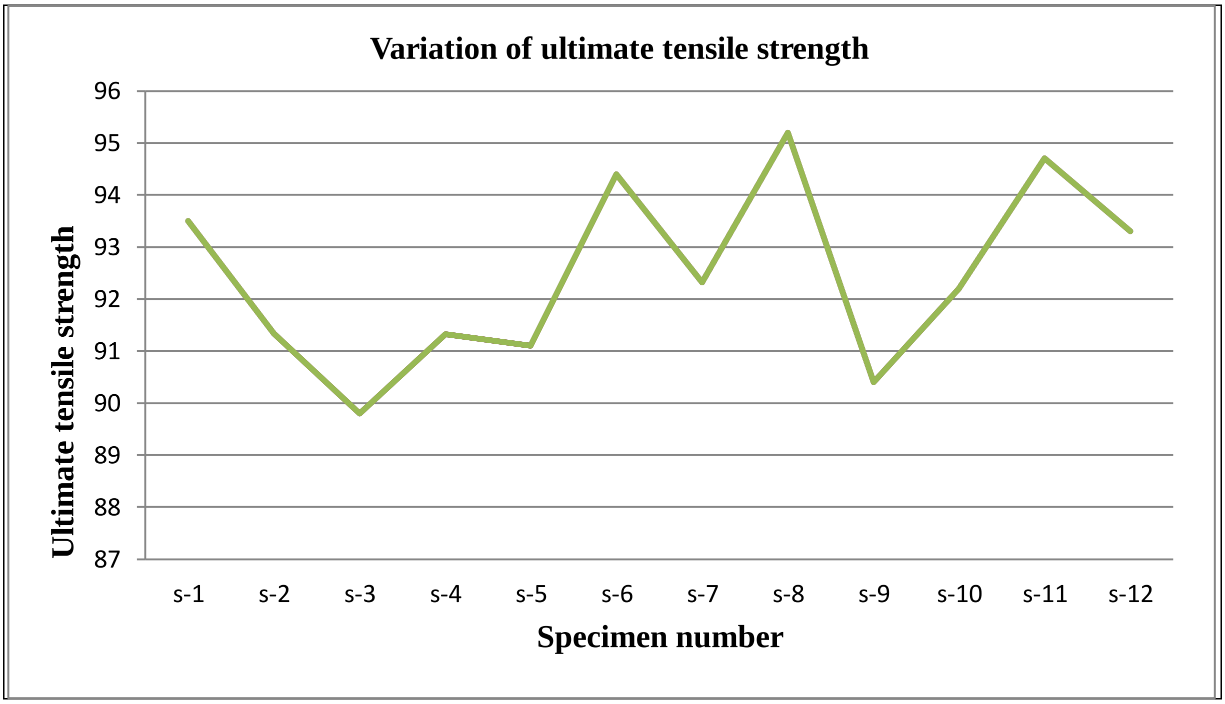

Figure 6: Variation Of Ultimate Tensile Strength

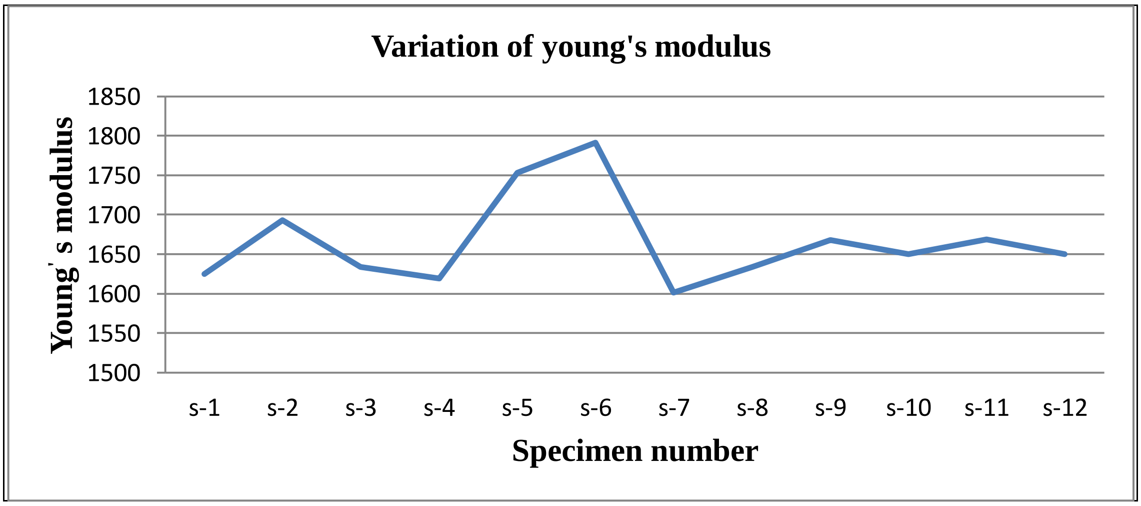

Figure 7: Variation Of Young's Modulus

For this observation pieces were polished with the help of water papers with different grades (P-400,P-600,P-800,P-10000,P-1200,P-1500,P-2000) by polishing machine. After this to obtain the mirror like shape diomend paste and hyfan fluid was used. Then these pieces were etched in the etchent (hudro flouric acid) to obtain the grains in the pieces. Microstructure of all pieces checked by Optical Microscopy as ASTM atInstitute For Auto Parts & Hand Tools Technology, Ludhiana.Microstructure are shown in Fig 8 below.

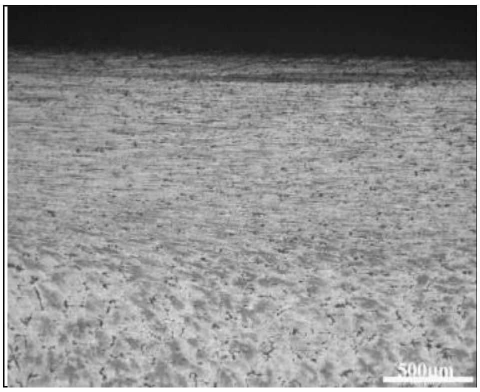

Figure: 8(a)

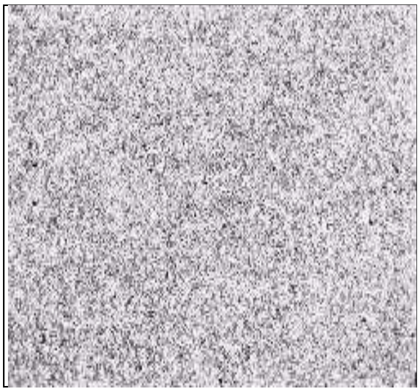

Figure: 8(b)

Figure: 8(c)

Figure: 8(d)

Fig. 8 Effect of tool profiles on microstructure of FSP zone with different speed (a) 1800 rpm with SC (b) 1800 rpm with ST (c) 2500 rpm with SC (d) 2500 rpm with ST.

The microstructural behavior of AA1100 and AA6063-T6 aluminium alloy joined by friction stir welding was studied at the FSP zone with different speed and tool pin. A strong difference in grain size and distribution was observed for different ranges of speed, feed and tool. The microstructure appears recrystallized but not so uniform because of the different temperature and true strain reached during deformation at lower speeds. By increasing the travel speed the nugget microstructure appears more fine and uniform. Grain size decreases with increasing welding speed. Macro structure observations showed that the joints fabricated at lower welding speeds more coarse than the joint fabricated at higher welding speed .Fig. 4.7(a)shows the microstructure have more coarse grains with welding speed 1800 rpm, SC pin profile and feed 50 mm/min than the fig. 4.7 (b) of joint fabricated with same speed ,feed but different pin profile (ST).when speed increases SC pin profile produce fine structure than ST pin profile shows fig. 4.7 (c) & (d) that microstructure obtained with the straight cylindrical pin profile at welding speed 2500 rpm and feed 45 mm/min more fine grain structure than the square thread pin profile.

4.Conclusion

In this investigation an attempt has been made to study the effect of tool pin profile and tool rotational speed on the formation of friction stir processing zone of two aluminium alloy of AA-1100 & AA-6063-T6. From this investigation, the following important conclusions are derived:

- Of the two pin profiles used in this investigation to fabricate the joints, straight cylindrical pin profiled tool give better mechanical properties.
- The micro hardness increases with increasing the speed of tool. Mostly values of high micro hardness are obtained by using the straight cylindrical pin profile tool than the square thread pin profile tool.
- The tool pin profile and tool rotational speed are having influence on tensile properties of the FSW joints. out of two pin profile used to fabricate the joints, straight cylindrical pin profile exhibited superior tensile properties compared to other joints. The joints fabricated at the rotational speed of 2500 rpm with straight cylindrical pin profile have shown higher yield strength, tensile strength, young's modulus and elongation compared to the joints fabricated at a rotational speed of 1800 rpm with straight cylindrical pin profile. This is because at higher rotational speed the frictional heat generated is higher.
- A strong difference in grain size and distribution was observed for different ranges of speed, feed and tool. The microstructure appears recrystallized but nor so uniform because of the different temperature and true strain reached during deformation at lower speeds. By increasing the travel speed the nugget microstructure appears more fine and uniform. Grain size decreases with increasing welding speed. Macro structure observations showed that the joints fabricated at lower welding speeds less fine than the joint fabricated at higher welding speed and also shows that microstructure obtained with the straight cylindrical pin profile at welding speed 2500 rpm and feed 45 mm/min more fine grain structure than the square thread pin profile.

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