



MECHANICAL BEHAVIOUR OF DISSIMILAR ALUMINUM MATERIALS JOINTS USING FSW WITH VARIOUS TOOL PROFILE

G. Swaminathan¹, S. Sathiyamurthy² and P. Naveen Chandran³

¹Bharath Institute of science and Technology, Bharath University, Chennai, India

²Department of Automobile Engineering, Eswari Engineering College, Chennai, India

³Department of Automobile Engineering, Bharath University, Chennai, India

E-Mail: ssnathan79@gmail.com

ABSTRACT

In modern structural concept demand reduction of both weight as well cost of production and fabrication of materials. Aluminum alloys has gathered wide acceptance in the fabrication of light weight structures requiring a high strength to weight ratio. Friction stir welding is at present widely used for the welding aluminum alloys. In this work defect free joints of AA6063-T6 and AA7075-T651 alloy plates of 6.35mm of thickness were butt jointed using friction stir welding. The quality of the joints are influenced by process parameters such as tool rotational speed, axial force and feed rate. The effect of these parameters on tensile strength, impact strength and microhardness of the joints were discussed. The results showed that the tool rotational speed has significant influence of tensile strength. Welding speed and tool profile dominated the impact strength. Microhardness value were found at the in around of the weld zone.

Keywords: dissimilar aluminum alloys, process parameters, tensile strength, impact strength, micro hardness.

1. INTRODUCTION

Friction stir welded process was invented at the welding institute United Kingdom in 1991. Friction stir welding is used to weld aluminum and its alloys [1]. The FSW process employed a rotating tool having a smaller diameter pin, extended from the tool shoulder. The rotating tool is slowly erected between edges of the rigidly clamped plates within the through-thickness of the work pieces, but does not touch the bottom of the work pieces. The rotating tool initially develops frictional heat during tool plunge. The frictional heat generated by tool softens the surrounding work piece material and allows the tool to move along the joint line. The Traversing motion of the tool under the axial force causes the plasticized material to flow from the front to the back of the tool. This transported material then cools down and consolidates to form the solid-state joint. Temperature during welding does not exceed the melting point of base metals. The energy input to the FSW process, heat generation, microstructure evolution and the joint properties are controlled by the process parameters such as Tool rotation speed, Welding speed and axial force and the tool geometry like size and profile [2]. The process parameters governing this joining process, Tool rotation speed has been found dominant parameters for Tensile strength followed by welding speed. Axial force shows small effect on tensile strength compared to other parameters [3], [4]. Aluminum alloys AA2xxx and AA7xxx series are essential classes of alloys widely used in aerospace industry. AA7xxx series alloys are usually chosen for their high strength, while 2xxx series alloys are generally designated where fatigue is a challenging problem and for applications where higher service temperatures may be encountered. AA7075 and A2024 have numerous applications in common. [5], [6]. The increase in the tool rotational speed, welding speed and axial force leads to the increase in the ultimate tensile strength and it reaches a maximum value and then decreases. This trend is common

for yield strength and percentage of elongation [7]. The effect of tool rotation speed and travel speed are researched by non-destructive test, tensile test and macro structure analysis for Al2195-T8. From non-destructive test, defect free process range is classified. Tensile strength and elongation show different value according to process range [8]. Tensile properties of the friction stir welded joints increased with the increase of tool rotational speed, welding speed and tool axial force up to a maximum value, and then decreased. Total elongation of joints increased with increase of rotational speed and axial force, but decreased by increasing of welding speed, continuously [9]. Materials and the mechanical properties of FSW-welded solid-solution hardened AA5083 and aging heat-treated A6082 aluminum alloys were studied. There was variation in the crystallographic orientation, and grain size in the weld zone. The crystallographic orientation in the stir zone of AA5083 revealed a random distribution, and that of A6082 was close to strong shear texturing. The overall peak temperatures of AA5083 and AA6082 were similar. The peak temperature of AA6082 near the heat-affected zone was high enough to affect the aging precipitates in A6082 [10]. Based on preliminary trials, the independent process parameters affecting the mechanical properties were identified as tool rotational speed (N), welding speed (S) and axial force (F). In this investigation aluminum alloys AA 7075- T651 to AA6063-T6 of 100 mm in length, 50 mm in width and 6.35 mm in thickness were joined by friction stir welding. Microhardness value were measured along the weld direction and discussed.

2. EXPERIMENTAL PROCEDURES

A. Materials and methodology

In this investigation, aluminum alloys of AA7075- T651 to AA6063-T6 sheets with thicknesses 6.35mm were used. The sheet was sliced to required size



by hacksaw cutting and followed by grinding the edges for effective butting. The chemical composition and mechanical properties of parent metal of aluminum alloys shown in the Table-1 and Table-2. The joint was initially obtained by securing the plates in position of butting each other using mechanical clamps. A non-consumable tool made up of Mild steel and flame hardened two different pin profile was used to fabricate the joints. Figure-1 shows that welding tools with flat cylindrical shoulder diameter of 18 mm, pin diameter of 6mm straight, pin length of 5.7mm and taper tool of major diameter 6mm, minor diameter of 4mm were used. High strength aluminum alloy AA7075-T651 at the retreating side and by placing the aluminum alloy AA6063-T6 at the advancing side. Generally soft alloy is located at the retreating side; the

fabricated weld strength greater than soft alloy is at the retreating side [11].



Figure-1. Circular straight and taper tool pin profile.

Table-1. Chemical composition (wt%) of AA6063 and A7075 aluminum alloy.

Element	Al	Si	Fe	Cu	Mg	Mn	Zn	Ti	Cr
AA6063	97.5	0.6	0.35	0.1	0.9	0.1	0.1	0.1	0.1
AA7075	87.5	0.4	0.5	2.0	2.9	0.3	6.1	0.2	0.28

Table-2. Mechanical properties of AA6063 and AA7075 aluminum alloy.

Element	UTS (MPa)	YS (MPa)	% Elongation	Hardness
AA6063	151	103	25	52
AA7075	622	573	10	195

The rotating tool probe was plunged to a predetermined depth in between the plates to be welded. After the dwell time, the tool was passing through forward at the end of which the joint formed. The tool is withdrawn after the weld is completed, leaving a hole at the end. By varying process parameters a large number of trial experiments were conducted to determine the working range.

B) FSW process parameters and specimen preparation

In this present study, three process parameters such as tool rotational speed, welding speed, axial force were selected for in this study shown in the table 3. It has used to fabricate the dissimilar joints using FSW machine developed by R.V Machine Tool, Model No: SPM104, Coimbatore as shown in Figure-2. A straight cylindrical tool and Taper cylindrical tool with tilt angle 1.5° probe was plunged to a predetermined depth at the interface of the butting surface of the plates to be welded. After reside time, the tool was transverse forward at the end of which the joint formed by single pass. The tool is take back after the weld is completed, leaving a hole at the end. The test specimen of size 100 mm length, 50mm width and 6.35 mm thick are prepared from aluminum alloy AA7075-T651 and AA6063-T6 rolled plates before and after weld as shown in Figure-3. ASTM E8 guidelines were followed for preparing the tensile test specimens shown in figure-4. Electromechanically controlled universal Testing machine

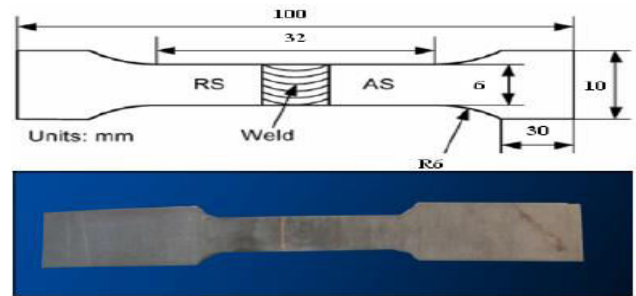
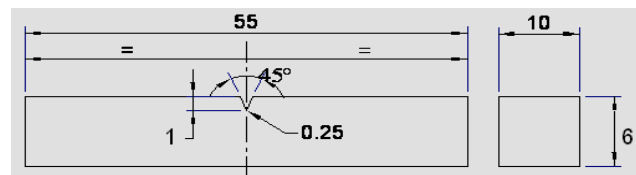
(Make: FIE, Model: UTN 40) was used to evaluate the tensile properties of the specimen. Charpy impact specimen was prepared with notch at weld center. ASTM E23 standard followed for impact testing and shown in Figure-5. Impact test was carried out on a pendulum type impact testing machine at room temperature. The amount of energy absorbed is fracture was recorded and shown in the Table-4.



Figure-2. Friction stir welding machine.

**Table-3.** FSW process parameters and tool details

S. No	Process parameters	Values
1	Tool Rotational Speed (rpm)	1000, 1100, 1200
2	Weld Speed(mm/min)	30, 45, 60
3	Axial Force (KN)	4, 5, 6
4	Tool Profile(Circular)	Straight, Taper
5	Tool Shoulder Diameter (mm)	18
6	Tool pin diameter (mm)	6
7	Tool pin length (mm)	5.7

**Figure-3.** Before and after welding.**Figure-4.** Tensile test specimen.**Figure-5.** Impact test specimen.

2. RESULT AND DISCUSSIONS

A. Effect of process parameters and tool profile on tensile strength

Table-4. FSW process parameters and mechanical properties.

SP.ID	Tool rotational speed (rpm)	Axial force (KN)	Welding speed (mm/min)	Tensile strength (Mpa)		Impact strength (Joules)	
				Straight tool	Taper tool	Straight tool	Taper tool
SP1	1000	4	30	146.86	146.98	18	24
SP2	1000	5	45	147.38	146.04	16	18
SP3	1000	6	60	140.89	144.82	12	24
SP4	1100	4	45	142.88	145.46	10	18
SP5	1100	5	60	134.87	143.53	12	10
SP6	1100	6	30	149.97	148.56	22	18
SP7	1200	4	60	144.25	143.32	10	18
SP8	1200	5	30	147.04	146.13	16	22
SP9	1200	6	45	153.98	153.84	10	10

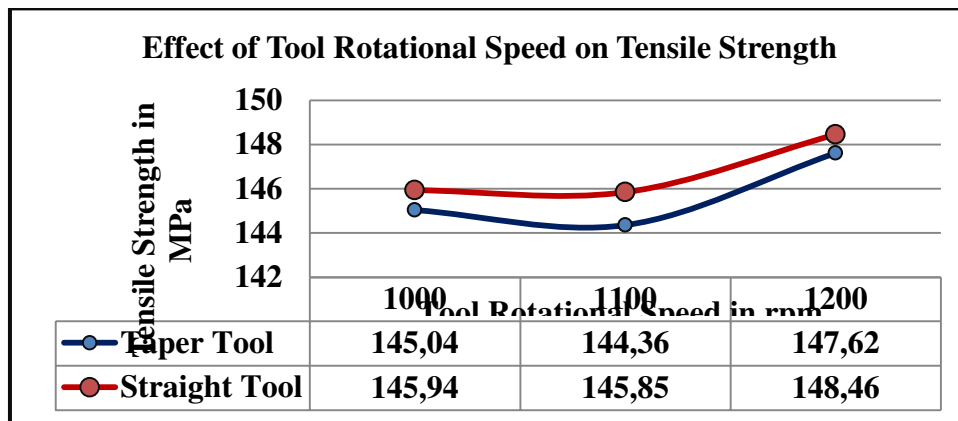


Figure-6. Effect of tool rotational speed on tensile strength.

The relation between joint tensile strength and tool rotation speed is shown in Figure-6. Pin rotation speed of 1200 rpm made a good joint, showing the maximum tensile strength of about 148 MPa for straight tools and 147.62 for Taper tools, which was about 83% of the AA6063 base metal tensile strength. At the maximum pin rotation speed of 1200 rpm, oxidation occurred during the welding process due to Mg in the Al base metal

however, there is no direct evidence of oxidation of Mg in the Al. The weld could not be completed and the joint fractured during machining to make a tensile test specimen. According to the above results, straight cylindrical tool pin profile produce the sound tensile strength joints and pin rotation speed of 1200 rpm was adopted thereafter as the optimal rotation speed for the welding experiments.

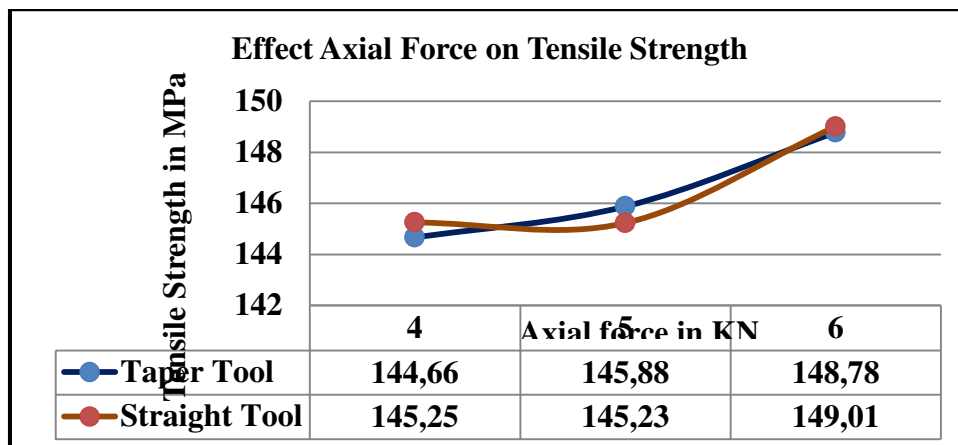


Figure-7. Effect of axial force speed on tensile strength.

Effect of axial force on Tensile strength of joints are presented in the Figure-7. It clearly shows that axial force increased from 4 kN to 6 kN tensile strength increased. Increasing the axial force, heat generation also increased consequently tensile strength increased. The press force of tool on work pieces affects the contact state, whereas the contact state affects the forming of weld. When the press force is not enough, the surface metal of

the weld "floats" upward and overflows the surface of work pieces, resulting in holes at the bottom of the welding. When the press force is too large, the frictional force between the tool's shoulder and the work pieces's surface increases, the tool's shoulder will cohere with the materials of work pieces and there will be flashes and burs on the weld face.

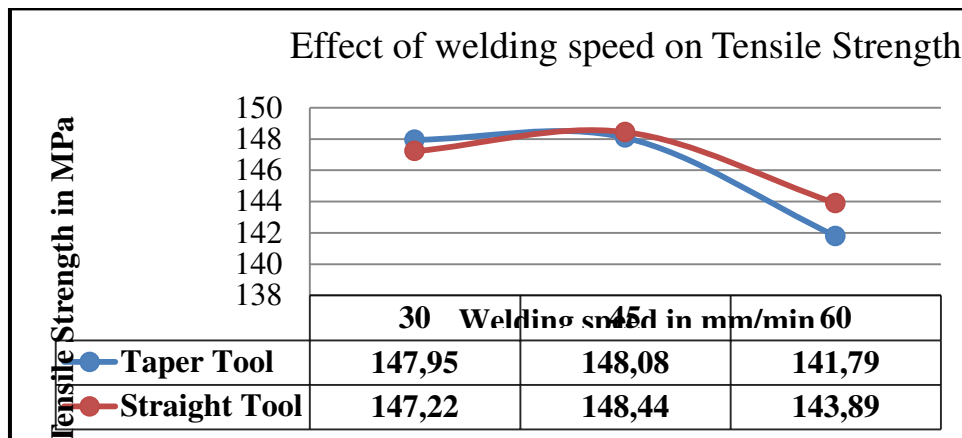


Figure-8. Effect of welding speed on tensile strength.

From the Figure-8 at lower welding speed the tensile strength is high and higher welding speed tensile strength was less. When the welding speed is small, the frictional heat makes the temperature in the weld too high (may reach or excess the melt point), the materials will be porous, inducing fluidification crack, and the weld surface will be irregular. On the other hand, when the welding

velocity is high, the frictional heat is not sufficient to plasticize the materials beneath the tool's shoulder and around the probe, the work pieces could not be welded properly.

B. Effect of process parameters and tool profile on impact strength

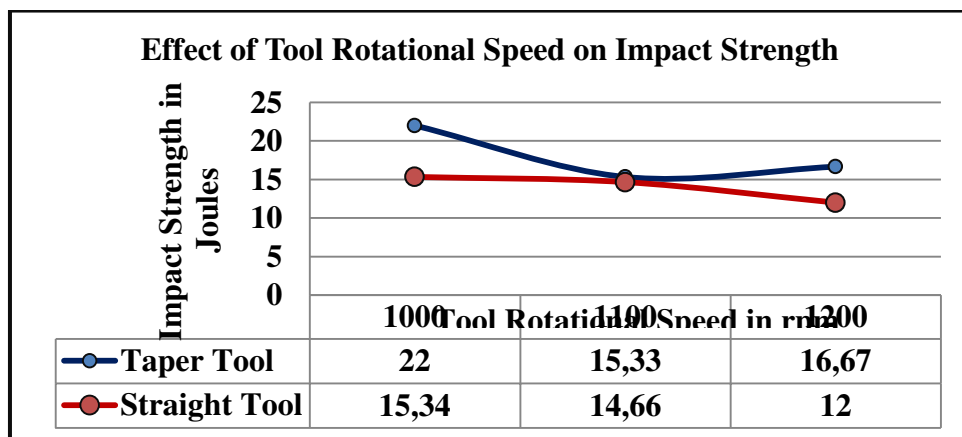


Figure-9. Effect of tool rotational speed on impact strength.

Charpy impact toughness of FSW joint was evaluated and presented in Figure-9. The impact toughness of unwelded base metals is 8 Joules. However, the impact toughness of Friction stir welded joint with notch placed at the weld zone region and reached maximum 16.67 J at 1200 rpm, compared to the other rotational speeds. It is observed that the joint fabricated at a tool rotational speed of 1200 rpm made of H13 tool material exhibited higher impact strength 16.67 joules and this may be due to

optimum heat generation which is sufficient to cause free flow of plasticized material. Figure-9 shows that between impact strength and tool rotational speed, it can be concluded that as the tool rotational speed increases, the impact strength decreases. It is due to because as tool rotational speed increases, more heat is produced, thus lowering cooling rate and resulting coarse structure. As the final microstructure is coarse, so the impact strength decreases for both tool pin profiles.

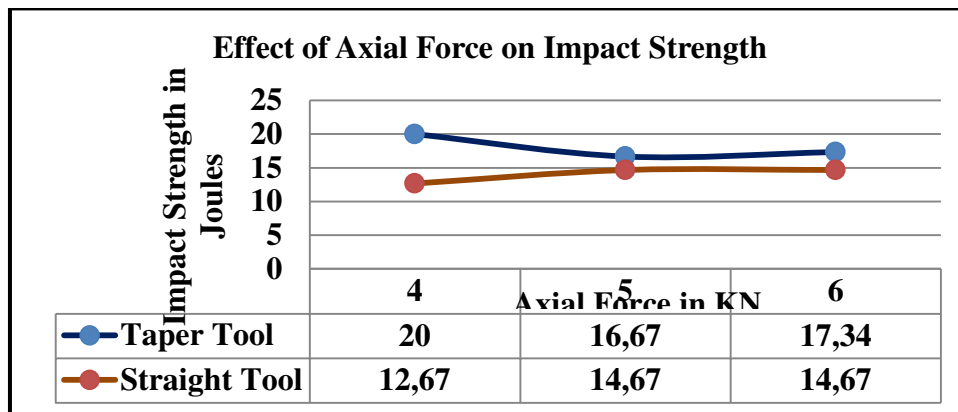


Figure-10. Effect of axial force on impact strength.

Charpy impact toughness of FSW joint was evaluated and presented in Figure-10. The impact toughness of parent metal was 8 Joules. However, the impact toughness of FSW joint with notch placed at the weld zone region and reached maximum 20 J at 4KN axial force for Taper pin profile and 14.67 J for square pin

profile compared to the other axial force. It is observed that the joint fabricated at a tool rotational speed of 1200 rpm made of H13 tool material exhibited higher impact strength 20 joules and this may be due to optimum heat generation which is sufficient to cause free flow of plasticized material.

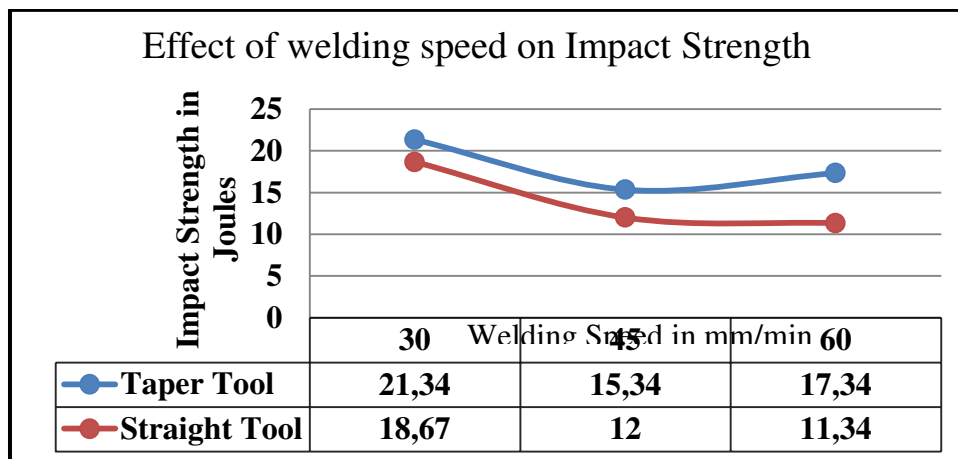


Figure-11. Effect of welding speed on impact strength.

Effect of welding speed on impact strength was presented in Figure-11. The maximum impact strength of 21.34 joules were obtained at a welding speed of 30mm/min. This may be due to enough time for heat generation which is sufficient for mixing of plasticized materials. At highest welding speed of 60 mm/min there was insufficient time for heat generation, so the impact value is low.

C. Effect of process parameters and tool profile on micro hardness

The measurement of the hardness distribution is a suitable method for estimating the mechanical properties of the joint. For the study of friction stir welded seams, the measurement of Vickers hardness is appropriate since the hardness values may vary significantly and unsteadily over the small distinct zones [12]. Vickers's hardness tests were conducted across various regions of the weld spacing of (10mm) shown in Figure-12 and the values presented in Table-5 for straight Circular tool and Table-6 for Taper cylindrical tool profile.

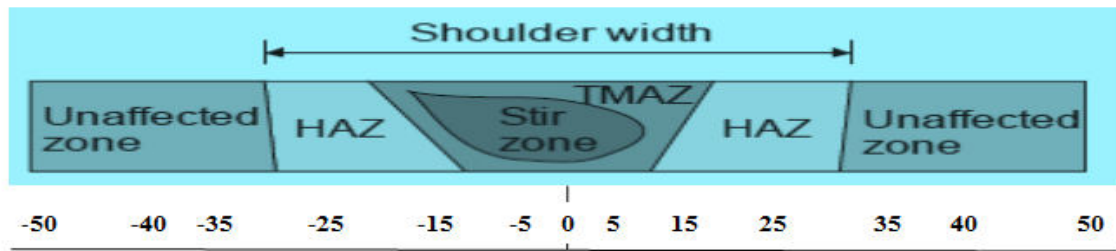


Figure-12. Micro hardness measurement location.

Table-5. Micro hardness of welded joint [Circular straight tool].

SP ID	AA6063					WZ	AA7075				
	-40	-35	-25	-15	-5	0	5	15	25	35	40
SP1	48	48	50.2	53.1	53.6	90.5	135.5	142.5	156.8	185.4	192
SP2	49.5	49	54.2	56.7	59.3	102.9	146.5	154.7	167.4	184.9	190
SP3	51	47	52.8	55.1	56.1	117.9	142.8	168.4	176.9	190.2	194
SP4	52.3	54	59.3	62.8	67.6	134.2	152.4	172.3	189.3	192.6	196
SP5	48	49.5	50.6	51.2	50.2	104.8	135.1	148.8	165.8	178.6	187
SP6	52	53.2	60.1	64.8	66.7	115.4	127.4	156.4	170.5	193.6	197
SP7	53	64.3	70.4	78.9	85.1	104.3	139.8	158.6	172.2	191.2	195
SP8	51	53.2	57.8	60.5	62.1	129.9	149.4	159.2	167.8	189.8	194
SP9	52	54.5	56.2	58.7	59.9	101.2	144.4	162.4	175.6	193	194

Table-6. Micro hardness of welded joint [Circular taper tool].

SP ID	AA6063					WELD ZONE	AA7075				
	-40	-35	-25	-15	-5	0	5	15	25	35	40
SP1	49	57.6	60.3	63.4	64.5	70.8	144.5	152.4	168.9	186.7	195
SP2	48	50.2	54.2	55.2	55.9	76.5	134.9	148.6	173.4	183.6	192
SP3	47	49.6	51.3	52.1	52.2	89.6	130.2	136.8	174.9	188.2	191
SP4	52	51.6	52.6	53.7	55	80	123.3	134.5	169.3	176.9	189
SP5	49	50.8	54.6	57.2	60	76.8	149	159.5	172.4	185.6	190
SP6	50	54.6	59.3	64.3	68.9	80.3	134.1	148.6	178.4	190.3	194
SP7	49.7	50.2	53.1	56.1	56.7	99.8	138.5	150.7	176.4	189.4	190
SP8	48.8	49.7	51.8	53.6	54.4	97.2	147.4	160.2	168.4	180.6	188
SP9	55	60.4	75.6	86.4	95.2	96.1	141.5	158.6	173.7	182.8	191

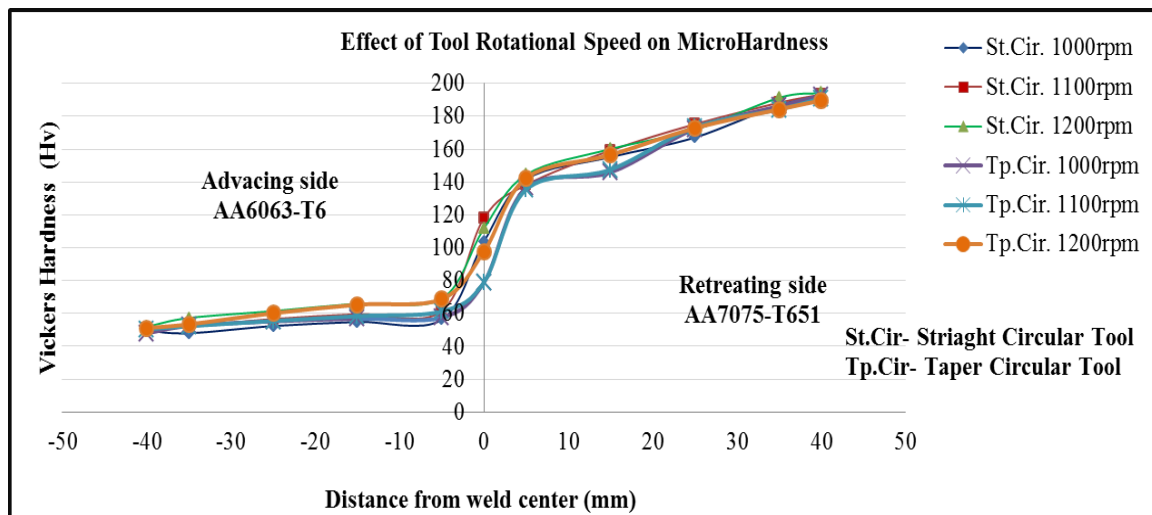


Figure-13. Effect of tool rotational speed on micro hardness.

The Microhardness measured using Vickers hardness testing machine. The hardness were measured towards right and from centre to left. All the Nine specimen where the Microhardness distribution was measured, the AA6063 alloy was placed at the Right side and AA7075 at the Left side, hardness was mesured towards right from centre to left. The weld zone has higher hardness compared with heat affected zone and Thermo mechanically affected zone due to smaller grain size at this zone. The change of microhardness at the Thermomechanically affected zone and Heat affectedzone

interface on the AA6063 side is smoothe than for AA7075 for both tool profile. In addition to that it was clearly showed in Figures 13, 14 and 15 harndess distribution in the Heat affected zone and Thermo mechanically affected zone in AA6063 side for all the welding speed ans axial force is same irrespective of rotational speed where as this variation was much higher in the AA 7075. This may be due to thermal cycle in the heat affected zone of the weld which is more influenced due to over aging of strengthening precipitation of AA7075 than in AA6063.

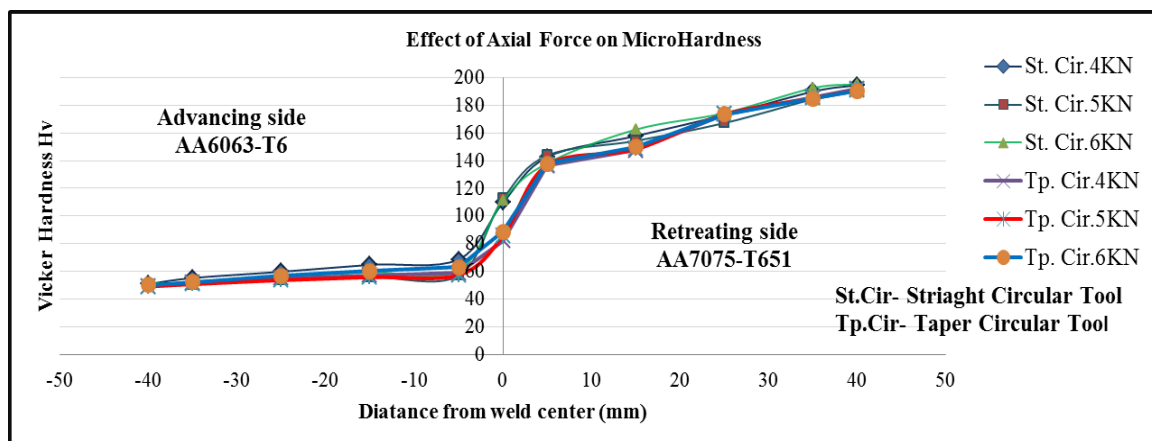


Figure-14. Effect of axial force on micro hardness across the weld.

The microhardenss curve goes down by decreasing the distance from the weld centre. The micro hardness curve becomes smoother after a certain point and

it is closer to the weld zone as the weld speed decreased and also the size of heat affected zone decreases whe the welding speed increases.

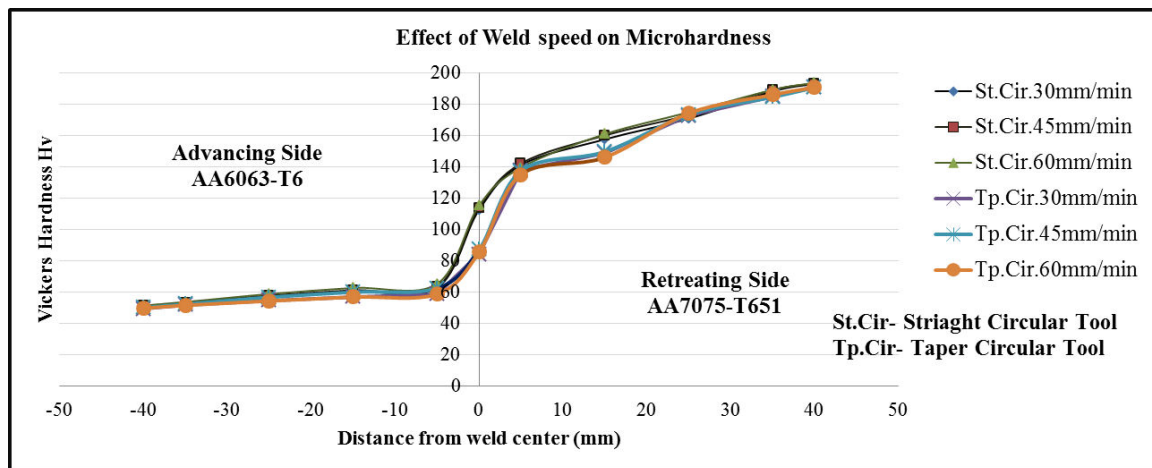


Figure-15. Effect of weld speed on micro hardness across the weld.

The microhardness curve goes up by decreasing the distance from the weld centre. The micro hardness curve becomes smoother after a certain point and it is closer to the weld zone as the weld speed decreased and also the size of heat affected zone decreases when the welding speed increases.

3. CONCLUSIONS

From the investigation, butt joining of dissimilar aluminum alloys of AA7075 and AA6063 were friction stir welded under varying process parameter with Circular straight and Taper tool pin profile and few mechanical properties of the joints were evaluated and concluded as follows:

- Friction stir welding were used to joint AA7075 and AA6063 in dissimilar combinations.
- The tool rotation speed and welding speed are found to affect the tensile strength of the FS welded AA7075 and AA6063 joints.
- Increasing the tool rotation speed increases the tensile strength of the FS welded AA7075 and AA6063 joints. Maximum Tensile strength was obtained from this investigation as 153.98 MPa while using straight tool.
- Increasing the welding speed resulted in a decrease in the tensile strength of the FS welded AA7075-AA6063 joints.
- The tool rotational speed of straight cylindrical tool creating more stirring action it may cause the tensile strength of the joint was high compared to taper cylindrical tool
- By increasing the axial force of the tool were found the tensile strength of the joint was increased and then decreased.
- The micro hardness variation was less in AA6063 side compared with AA7075 side for all the process condition and both tool profile.
- The failure location in tensile test was AA6063 heat affected zone for all the joints.
- The maximum Impact strength of 24 Joules obtained at lower tool rotational speed of 1000 rpm.

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