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# Effect of Tool Geometry on Mechanical Properties of Friction Stir Welding Dissimilar Butt Joint of AA2024 and AA6061

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**ABSTRACT:** Friction stir welding works on the principle of a rotating pin emerging from a cylindrical shoulder which is plunged between two pieces of sheet and moved forward along the joint line. The material is heated by friction between the rotating shoulder and the work piece surface and simultaneously stirred by the profiled pin leaving a solid phase bond between the two pieces to be joined.

This present report investigates on the characterization of dissimilar friction stir butt welded AA2024 and AA6061 aluminum alloy. By keeping the parameter such as rotational speed and welding speed and varying the tool tilt angle. Tensile test and micro hardness test were conducted to analyze the mechanical behavior of the joint. Macrostructure, Microstructure and SEM were conducted to examine the metallurgical changes in every joint. The optimized process parameters of welding speed and tool rotational speed were 40mm/min and 1000rpm respectively.

**KEYWORDS:** AA2024, AA6061, Friction stir welding, Dissimilar butt weld, Tool pin profile, Mechanical property.

## 1. INTRODUCTION

In engineering Aluminium and its alloys widely used in aerospace, automotive, and shipbuilding industries due to their good ductility, resistance to corrosion, high strength and low density. Conventional fusion welding of aluminium and its alloys involves melting of the material which results in solidification cracking. Therefore solid state liquid is more suitable for joining aluminium and its alloy for as there is no melting of the material. Hence the defects like solidification caking, porosity, segregation and liquid cracking on heat affected zone would be avoided by using this technique. Friction stir welding is a solid-state welding process, which means that the materials are joined without reaching melting point. In FSW, a cylindrical shouldered tool with a profiled pin is rotated and plunged into the joint area between two pieces of sheet or plate material. The parts have to be securely clamped to prevent the joint faces from being forced apart. Frictional heat between the wear resistant welding tool and the work piece causes the latter to soften without reaching melting point, allowing the tool to traverse along the weld line. The plasticised material, transferred to trailing edge of the tool pin, is forged through intimate contact with the tool shoulder and pin profile. On cooling, a solid phase bond is created between the work piece. In FSW tool pin profile plays an important role in mechanical properties and microstructural changes.

In this study AA2024 and AA6061 were joined using friction stir welding process using three different tool pin profiles namely cylindrical threaded, tapered and squared. Kolaraj, et al. (2012) has investigated the FS welding of AA2219-AA5083 alloy by changing various tool pin profiles and concluded that, cylindrical threaded pin produce defect free weld with good tensile strength. Xue, et al. (2017) welded Al-Cu dissimilar metals and found better tensile strength were achieved in the plates which was welded at 1000 rpm and they also concluded that defect free weld could be obtained when the plates that had superior mechanical properties were fixed on the advancing side. Arora, et al (2010) has experienced on FS welding of AA6061 by changing ratio of shoulder to pin diameter and reported that the defect free welding can be obtained when keeping the D/d ratio is 3:1.

## II. EXPERIMENTAL PROCEDURE

In this study dissimilar friction stir welding of 6mm thick plates of AA2024 and AA6061 aluminium alloy was carried out using friction stir welding equipment. The specimen was prepared in the dimensions of 100mmx50mmx6mm. The

chemical composition and mechanical properties of AA2024 and AA6061 is tabulated in table. Welding was carried out by placing AA2024 in the advancing side and AA6061 on the retreating side. EN8 (08M040) tool steel is selected as the tool material because of high strength. The weld was performed using three different pin profiles viz cylindrical threaded, tapered and cuboid with an 18 mm shoulder diameter and 4.7 mm pin length was kept constant. Experiments were done at a welding speed of 40mm/min, rotational speed of 1000 rpm and three different tilt angles 1.5°, 2° and 2.5°. After welding the specimens were prepared using the wire cut EDM for various tests to get the mechanical properties of the samples. Tensile test was carried out using INSTRON 8801 UTM according to ASTM E8/E8M standards for sub size specimen and evaluates the yield tensile strength, ultimate tensile strength and percentage elongation. In the macro examination the different zones present in the specimen were observed such as stir zone or weld zone, TMAZ (Thermo Mechanically Affected Zone), HAZ (Heat Affected Zone) and base metal or parent metal. The microstructural examination was carried out using metallurgical microscope using etchant as Keller’s reagent (150ml of H<sub>2</sub>O + 3ml of HNO<sub>3</sub>+ 6ml of HCL + 6ml of HF) with etching time of 10 sec and magnification of 100x to find the microstructure of various zones. Micro hardness was done using Vickers micro hardness tester with load 100gf and dwell time of 10 sec.

Table 1 chemical composition of base metal AA6061 and AA2024 in weight %

Elements	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Zn %	Ti %	Al %
AA2024	0.5	0.5	4.4	0.6	1.5	0.1	0.25	0.15	Balance
AA6061	0.7	0.7	0.3	0.15	0.9	0.2	0.25	0.25	Balance

Table 2 Mechanical properties of base metal AA6061 and AA2024

PROPERTIES	AA6061	AA2024
Yield tensile strength (MPa)	145	324
Ultimate tensile strength (MPa)	240	470
Percentage elongation	22	19
Hardness Vickers (HV)	107	137

**Tool design:**

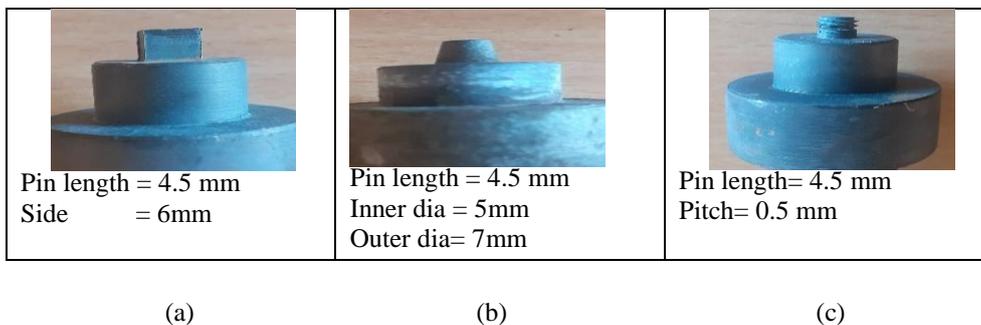


Fig 1 Tool used in FSW (a) cuboid tool (b) tapered tool (c) cylindrical thread tool

Table 3 Process parameters

S.No	Material used	Tool design	Rotational speed	Traverse speed	Tilt angle
1	AA2024 + AA6061	Cylindrical threaded	1000	40	1.5°
2					2°
3					2.5°
4		Tapered			1.5°
5					2°
6					2.5°
7		Cuboid			1.5°
8					2°
9					2.5°



(a)

(b)



(c)

Fig.2 Welded samples (a) Cylindrical thread with different tilt angle (b) tapered with different tilt angle (c) Cuboid with different tilt angle

Due to high heat generation in the advancing side than the retracting side more chips are formed in the advancing side of the weld.

IV. RESULTS AND DISCUSSION

1. TENSILE TEST

Table 4 tensile test result of weld samples

Sample	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Fracture location
CT 1.5	203	116	11.50	HAZ
CT 2	208	160	8.50	HAZ
CT 2.5	199	150	14.50	HAZ
T 1.5	196	149	11.00	TMAZ
T 2	203	148	10.50	BASE
T 2.5	203	133	9.00	WELD
C 1.5	200	171	10.50	HAZ
C 2	203	157	12.00	HAZ
C 2.5	199	146	14.00	WELD

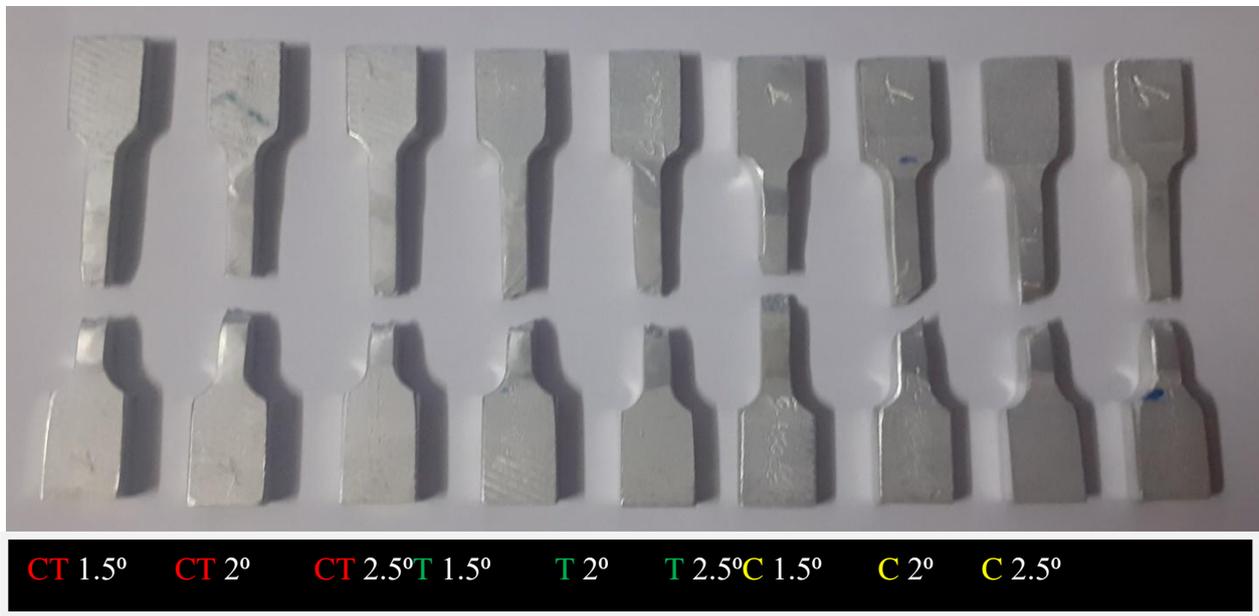


Fig.3 Tensile result samples of Cylindrical Thread (CT), Tapered (T) and Cuboid (C) for tilt angle 1.5°, 2° and 2.5°

The tensile properties of Cylindrical thread tool, tapered tool and cuboid tool for different tilt angle 1.5°, 2° and 2.5° were shown in table 4. From the tensile test result high tensile strength are obtained in the cylindrical threaded pin profile than both tapered and cuboid pin profile. Then the tilt angle with 2° gives highest tensile strength compare with 1.5° and 2.5°. cylindrical threaded pin profile with tilt angle 2° gives high tensile strength of 208MPa and tapered pin profile with tilt angle 1.5° gives lowest tensile strength of 196MPa among all of the combinations.

## 2. MICROSTRUCTURAL EVALUATION

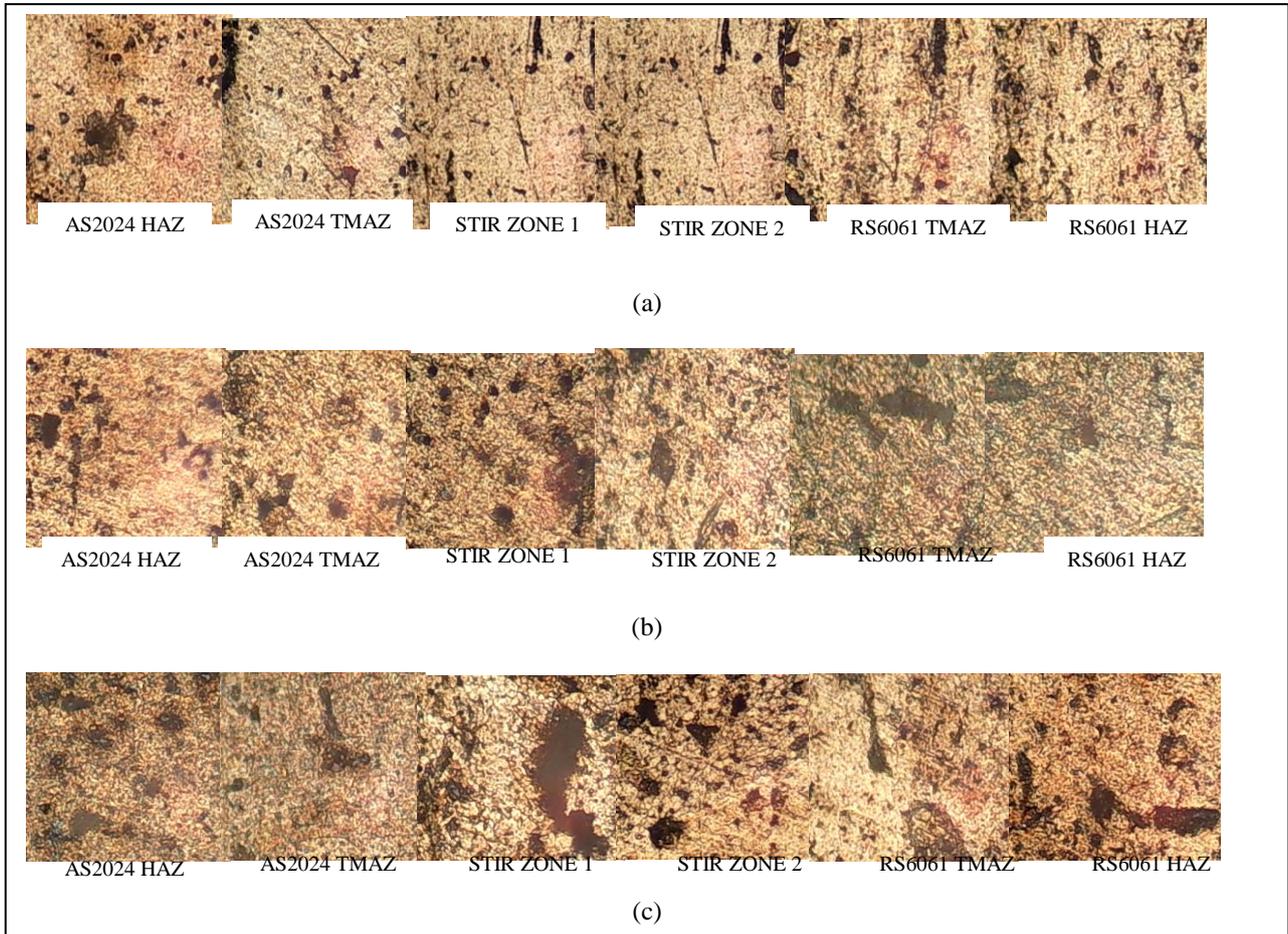
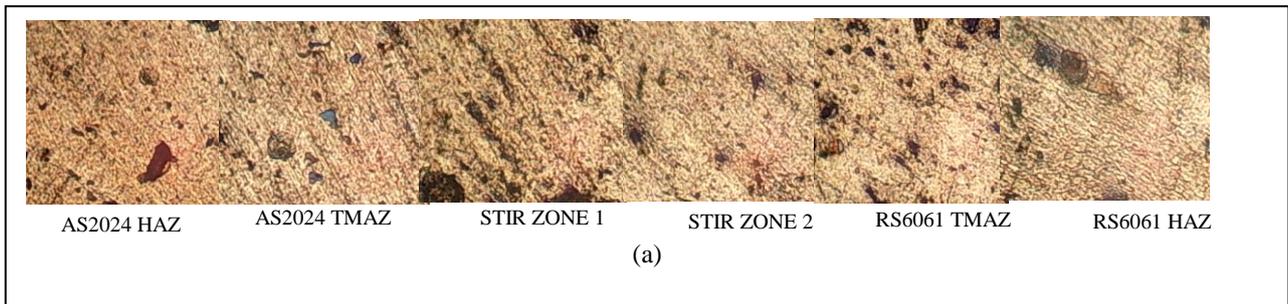


Fig 4 Microstructure of cylindrical thread tool with tilt angle (a) 1.5° (b) 2° (c) 2.5°



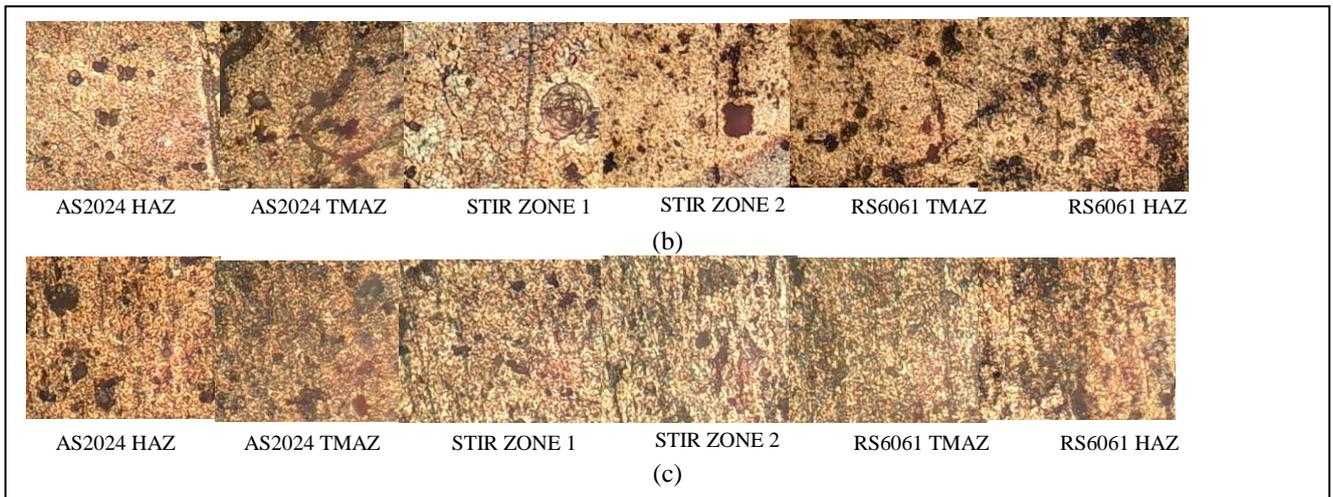


Fig 5 Microstructure of tapered tool with tilt angle (a) 1.5° (b) 2° (c) 2.5°

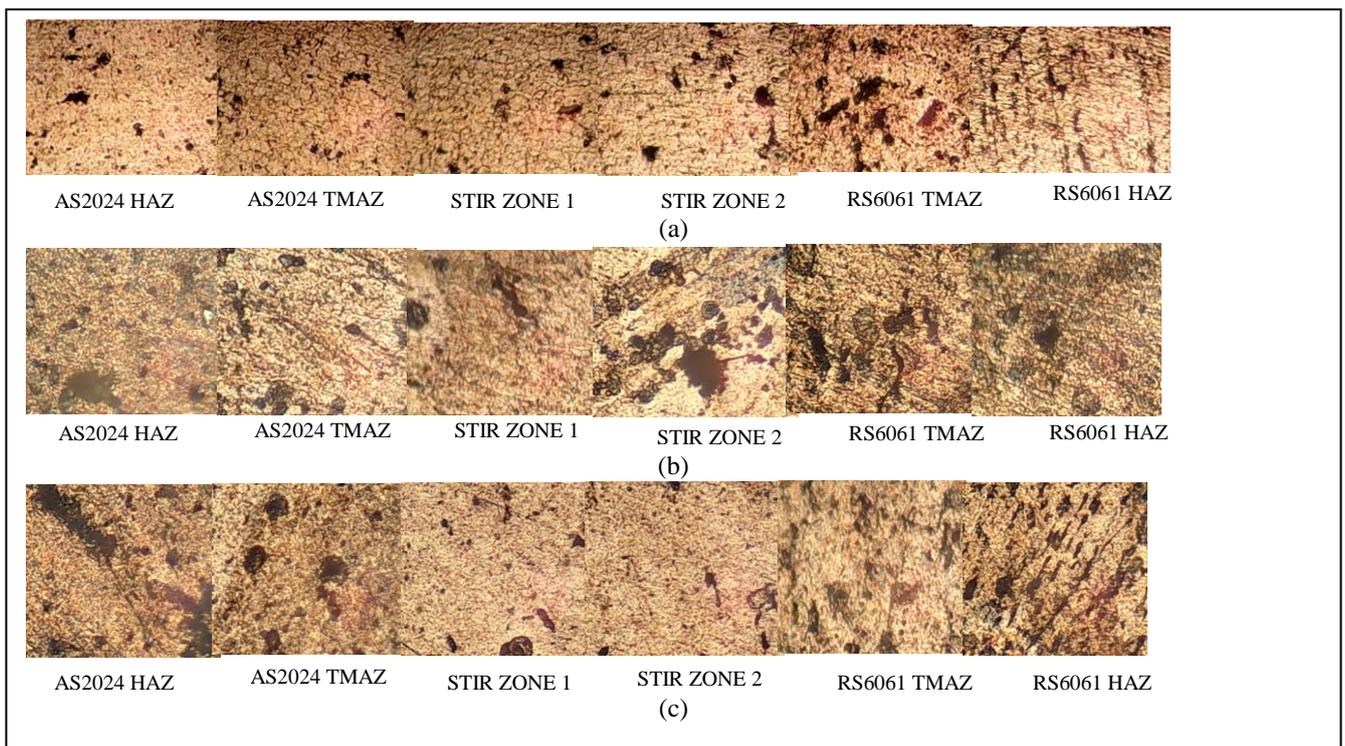


Fig 6 Microstructure of cuboid tool with tilt angle (a) 1.5° (b) 2° (c) 2.5°



3. MICROHARDNESS SURVEY

Table 5 Hardness survey of welded samples

Tilt angle	AS2024 BM	HAZ	TMAZ	STIR ZONE	HAZ	TMAZ	RS6064 BM
CT1.5°	74.6	65.6	65.4	42.1	35.2	44.0	64.1
CT2°	65.9	57.7	72.8	39.3	33.6	40.0	60.6
CT2.5°	69.8	75.0	50.0	47.8	50.8	48.9	58.2
T1.5°	64.8	66.0	69.9	33.1	38.0	33.9	55.6
T2°	71.1	58.7	65.4	33.8	38.0	40.1	43.9
T2.5°	62.6	56.7	49.7	31.8	38.6	35.2	49.7
C1.5°	67.3	74.7	61.4	38.5	39.9	36.5	60.7
C2°	70.4	62.9	70.2	32.4	36.7	35.0	59.8
C2.5°	66.7	61.2	70.8	35.0	45.6	37.1	54.6

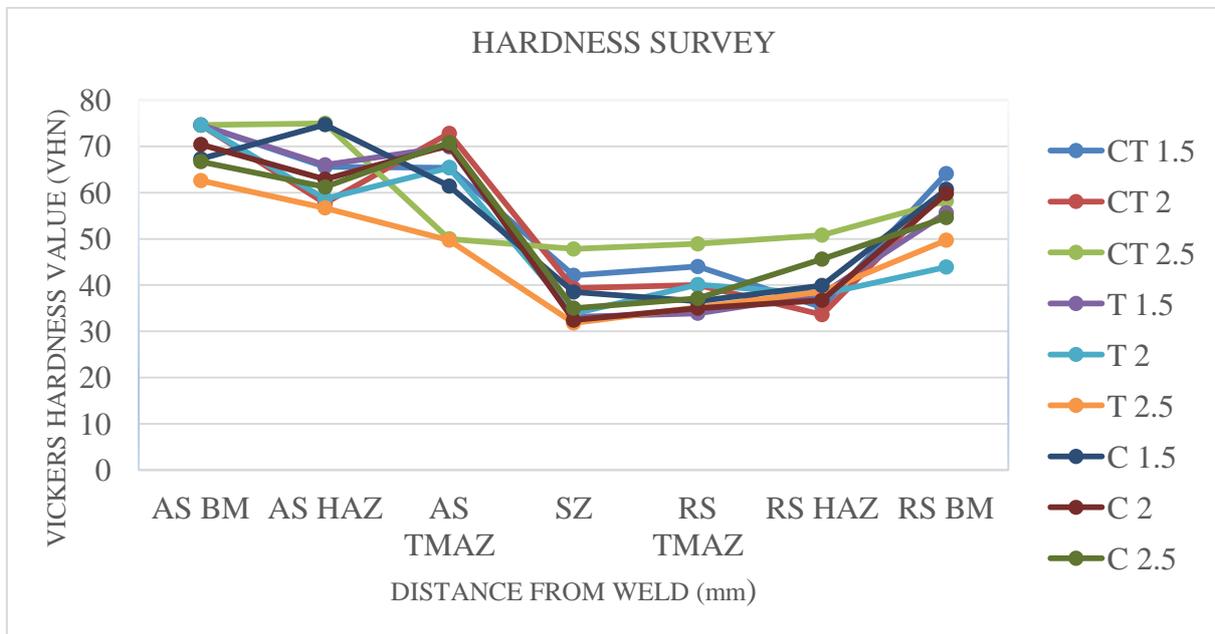


Fig 7 Comparison of hardness of the welded samples

In the Vickers hardness survey of different pin profile and different tilt angle was studied. The sample welded using cylindrical threaded pin profile gives more hardness with other pin profile such as tapered and cuboid pin profiles. In which 2.5° tilt angle gives more hardness value 47.8 VHN with other angle 1.5° and 2° hardness value 39.3VHN and 42.1VHN respectively.

## VI. CONCLUSION

In the above experiment the influence of the tool geometry in the weld was studied. From the above study following conclusions are made.

- The highest tensile strength was obtained in the cylindrical threaded pin with 2° tilt angle is 208MPa and lowest tensile strength was obtained in tapered pin profile with 1.5° tilt angle is 196Mpa. More increase in tilt angle will result in low tensile strength.
- Microstructure reveals  $\alpha$ -solid solution of aluminium with its inter metallics.
- In the Macro examination different zones in the FSW joint were observed and in weld zone trapezoidal nugget is formed and flush formed in the retracting side due to high heat production.
- In the micro hardness survey, the highest hardness value of weld zone is obtained in cylindrical threaded pin profile with 2.5° is 47.8VHN and lowest hardness value of weld zone is obtained in tapered pin profile with 1.5° tilt angle is 31.8. More in tilt angle will increase the hardness value.

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