Experimental investigation of hardness of FSW and TIG joints of Aluminium alloys of AA7075 and AA6061

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ABSTRACT. This paper reports hardness testing conducted on welded butt joints by FSW and TIG welding process on similar and dissimilar aluminium alloys. FSW joints were produced for similar alloys of AA7075T_{651} and dissimilar alloys of AA7075T_{651}- AA6061T_6. The Friction stir welds of AA7075 & AA6061 aluminium alloy were produced at different tool rotational speeds of 650,700, 800, 900, 1000 and transverse speed of 30, 35, 40 mm/min. TIG welding was conducted along the rolling direction of similar and dissimilar aluminium plates. The Brinell hardness testing techniques were employed to conduct the tests; these tests were conducted on the welds to ascertain the joint integrity before characterization to have an idea of the quality of the welds

KEYWORDS. FSW; Rotation Speed; Transverse Speed; Hardness.

INTRODUCTION

Friction Stir Welding (FSW), a solid state joining process was developed and patented by the Welding Institute (TWI) in 1991 [1]. FSW is considered to be the potentially useful solid state welding technique in which welding is done below the melting point of the work piece material [2-3]. Because of low heat input and absence of complete melting, FSW offers several benefits over the conventional fusion welding process. Metallurgical benefits includes good dimensional stability, repeatability, no loss of alloying elements, excellent mechanical properties in the joint area due to re crystallized micro structure in the stir zone. Environmentally the process is a green one because it eliminates grinding wastages, no harmful emissions, required minimum surface cleaning [4]. FSW has various application in the fields of marine like hulls, superstructures, storage vessels for the shipbuilding, in aerospace like airframes, fuselages, wings, fuel tanks; in railway like high speed trains, railway wagon; in automotive like chassis, truck bodies [5]. A cylindrical shouldered tool with different pin probe is rotated and slowly plunged into the joint line between plate materials, until the shoulder of the tool forcibly contacts the upper surface of the material and the pin is a short distance from the back plate. The pieces are rigidly clamped onto a backing plate in a manner that prevents the abutting joint faces from being forced apart. The fixturing prevents the plates from spreading apart or lifting during welding. Frictional heat is generated between the tool shoulder and the work piece. This heat causes the latter to reach a visco-plastic state that allows traversing of the tool along the weld line. The plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged by the intimate contact of the tool shoulder and the pin profile. It leaves a solid phase bond between the two pieces [6]. The Fig. 1describes the basic principle of the FSW process. Caroline et al [7] has welded AA2014-T_6 and AA7075-T_6 aluminium alloys for various welding parameters. Torque, Temperature, macrograph and micro hardness were measured and concluded that torque, temperature and hardness profile depend on the amount material mixture in the stir zone. S. Rajakumar et.al [8] studied the influence of process parameters on friction stir welding of Al 7075 alloy and concluded that higher tool rotation speed resulted in higher heat generation which caused slower cooling rate and leads to formation of coarse grains which in turn produced lower hardness. Moreira et al [9] produced FSW of AA6082-T_6 with AA6061-T_6. The welds exhibited intermediate properties and the tensile tests failures occurred near the weld edge line where a minimum value of hardness was observed. Khodir et al [10] studied the microstructure and mechanical properties of dissimilar joints of 2024-T_3 to 7075-T_6 Al alloy and observed that the rise in welding speed caused formation of kissing bond and pores especially when the 2024 Al alloy plate was located on the retreating side. Minimum hardness was observed in the HAZ of both sides and their values increased with welding speed. Shen et al [11] used AA 7075 plates of 2 mm thickness, for various rotational speeds and the dwell time. They investigated the microstructure and the mechanical properties of the refilled friction Stir Spot Welding of AA7075. The keyhole of the weld was refilled successfully, the microstructure of the weld exhibits variations in the grain additionally, they observed, and defects associated to the material flow, such as hook, voids, bonding ligament and incomplete refill. Vladvoj et al [12] presents the results of microstructure analysis, hardness measurements and tensile tests of FS-welded sheets of two aluminium alloys AA5083 and AA7075.Ericsson and Sandstrom [13] investigated the influence of welding speed on fatigue behavior of FSW, MIG and TIG process. Moreira et al. [14] investigated the fatigue behavior of joints of FSW and metal inert gas (MIG) welding. Squillace et al. [15] investigated the microstructure and pitting corrosion resistance in TIG and FSW joints for 2024-T3 alloy. Munoz et al. [16] investigated the microstructure and mechanical properties of FSW and TIG for Al-Mg-Sc alloy. Taban et al [17] studied the microstructure and mechanical properties in MIG, TIG and FSW joints for 5083-H321 aluminum alloy. This paper presents the effect variable rotational speed and transverse speed on hardness properties of similar FSW joints of AA7075-T_{651} and dissimilar FSW joints of AA7075-T_{651}-AA6061-T_6 and also comparison between FSW and TIG welding were studied.

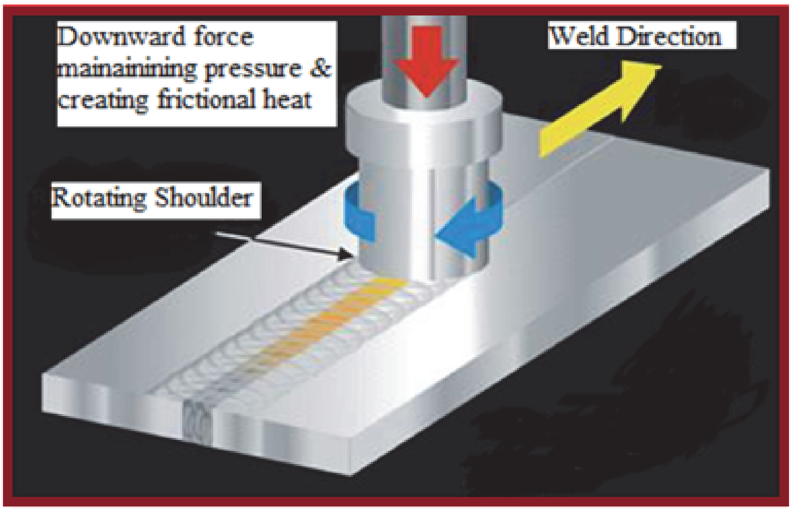

Figure 1: Working Principle of Friction Stir Welding.

MATERIALS AND EXPERIMENTAL METHODS

Materials

Aluminium alloys AA7075-T_{651} and AA6061-T_6 sheet was cut on shear machine and brought to required size of 150 mm x 70 mm x 6.35 mm for FSW & TIG welding.

The FSW tool employed was square trapezoidal pin of H13 tool steel material with dimensions of 4mm bottom face and 6mm top face, 20mm flat shoulder diameter and 6mm pin height. The chemical composition of base material is as shown in Tab. I.

Chemical Composition %												
	Elements	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Zr
$AA7075T_{651}$	Required	0.4	0.5	1.2-2	0.3	2.1-2.9	0.18-0.28	-	5.1-6.1	0.2	-
	Contents	0.05	0.18	1.4	0.04	2.5	0.19	-	5.9	0.08	-
	Elements										
$AA6061T_6$	Required	0.4-0.8	0.7	0.15-0.40.	0.15	0.8-1.2	0.04-0.35	-	0.25	0.15	-
	Contents	0.62	0.45	0.2	0.13	1.05	0.09	-	0.03	0.07	-

Table I: Chemical Composition of Base Aluminium Alloys

Welding Procedures - FSW Method.

The FSW joints were produced for similar alloys AA7075 and dissimilar alloys AA7075-AA 6061.The FSW welding parameter used in this experiment were tool rotation speed of 650,700, 800 rpm, 900 rpm and 1000 rpm; transverse speed of 30 mm/min, 35 mm/min and 40 mm/min. The tool tilt was maintained 0^0 during the experiment and plunge depth was of 6mm throughout the weld path. Tool tip plunge feed was 10 mm/min throughout the weld path. The plates to be welded by FSW process were fixed by a clamping fixture on a Joyti CNC vertical machining center PX20 series as shown in Fig. 2. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the FSW joint.

Figure 2: Friction stirs welding on VMC machine with FSW joint.

Welding Procedures - TIG Method.

TIG welding was conducted on TIG weld machine along the rolling direction of plates. The TIG joints were also produced for similar alloys AA7075 and dissimilar alloys AA7075-AA6061.The The welding parameter used in TIG welding were; welding filler wire for TIG welding was Al-Si alloy with diameter of 4 mm, the flow rate of argon shield was 15 L/min, the welding voltage and current were 80 V and 280 A, respectively, and the speed of welding was 15 mm/s.

Hardness Testing Method

Using hardened steel ball indenter of 10mm diameter was fixed on the BHN machine demonstrated in the experimental set up as shown in Fig. 3.

Figure 3: Brinell hardness Testing Machine.

The FSW specimen was mounted on to the machine and the machine was loaded with load of 250 kgf for time of 20seconds and then removed. The resulting depth of impression was measured by the help of a microscope as shown in Fig. 4.

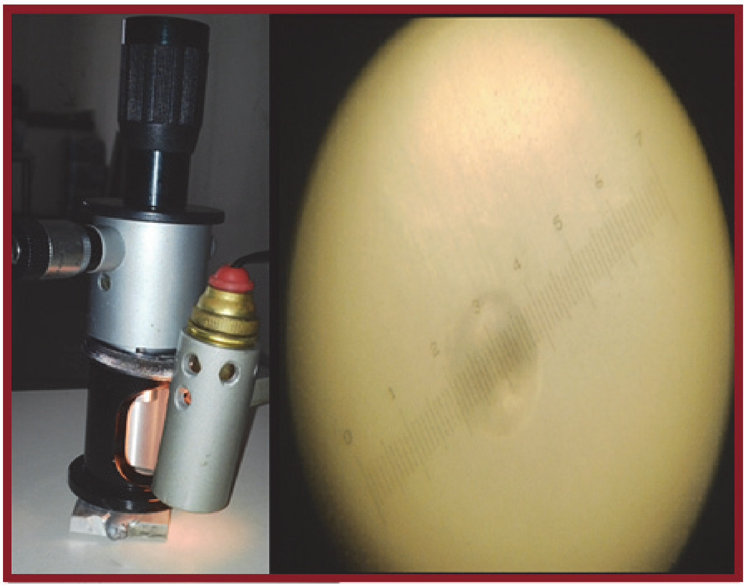

Figure 4: Microscope with depth of impression.

A chart was then used to convert depth of impression to Brinell hardness number. All friction stir welded samples for different weld parameter were tested for Brinell hardness and the impression converted into BHN is shown in Tab. II for various FSW weld parameter. In Tab. II, sample number A to G presents FSW joints of similar alloys AA7075T$_{651}$ and sample number A1, A4 presents FSW joints of dissimilar alloys AA7075T$_{651}$- AA6061T$_{6}$. B1, B2 represents similar and dissimilar joints of TIG welding respectively.

FSW Sample No.	Rotation Speed (RPM)	Transverse Speed (mm/min)	Impression (d) (mm)	BHN
A	900	30	1.62	121
B	900	35	1.90	87.4
C	900	40	1.80	97.4
D	800	30	1.71	108
E	800	35	1.62	121
F	800	40	1.70	109
G	1000	30	2.10	71.4
H	1000	35	1.70	109
A1	700	40	2.80	40.0
A4	650	35	2.20	65.0
B1	-	-	2.50	50.1
B2	-	-	2.11	70.7

Table II: Brinell hardness Test Result.

RESULTS AND DISCUSSION

In heat treatable alloys, the precipitates only impart strength to the alloy. Dissolution of these strengthening precipitates weakens the mechanical properties of weld joints. In all the FSW joints, the temperature experienced during welding can induce an over ageing of the precipitate particle, resulting in decrease of mechanical characteristics. Actually, by inspecting hardness of FSW joints as shown in Fig. 5-6, the hardness values in all welded samples are reduced compared with base metal, this means that the generated heat during FSW causes softening of the welded area due to dissolution of precipitates (Fig. 7a).

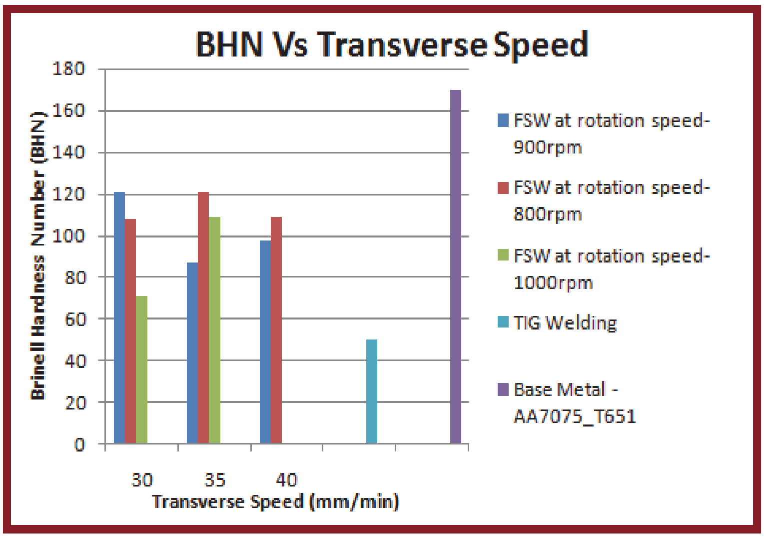

Figure 5: Effect of transverse speed on hardness for similar FSW & TIG joints.

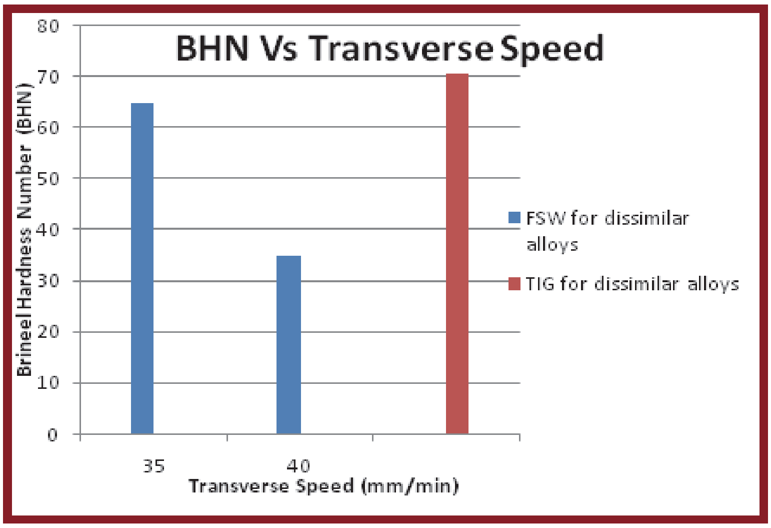

Figure 6: Effect of transverse speed on hardness for dissimilar FSW & TIG joints.

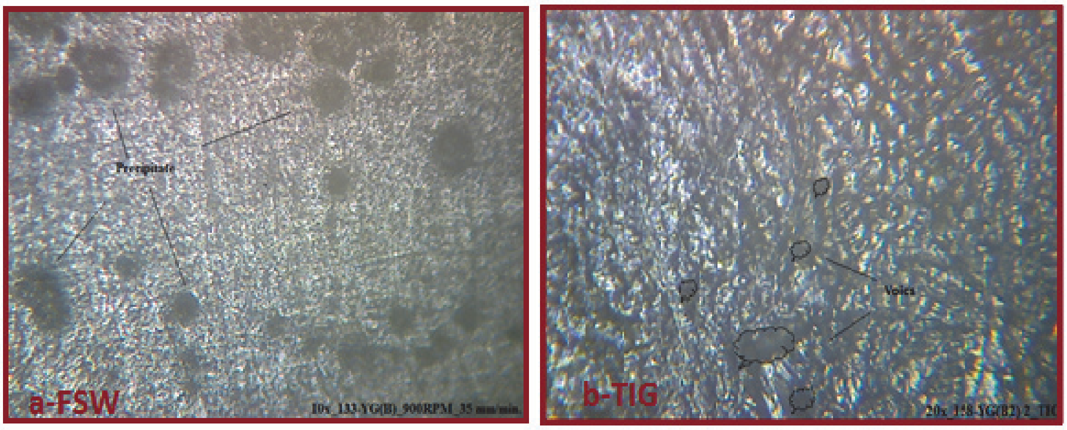

Figure 7: Microstructure of FSW and TIG showing precipitates and voids

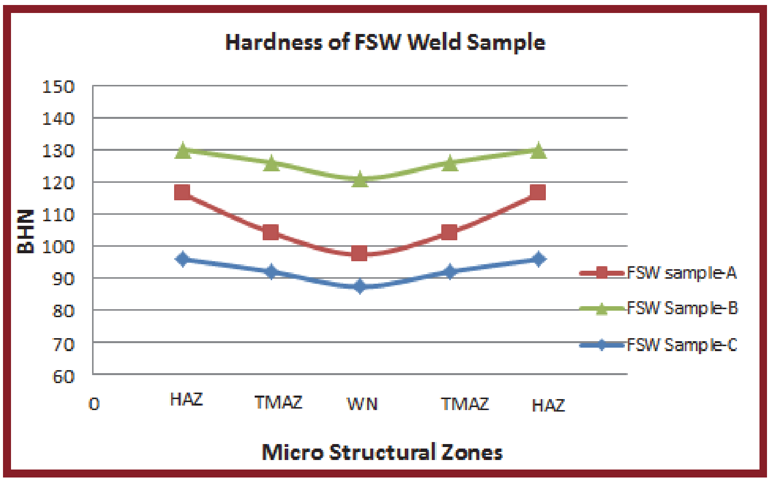

Figure 8: Hardness values in the microstructural weld zones.

FSW temperatures coming to the NZ and TMAZ will cause at least partial dissolution of the hardening phases. Normally, therefore, some softening within the NZ should be expected in heat treatable alloys that were welded in T-tempers. Some

grain coarsening and softening could also take place in the HAZ. The reducing in the weld hardness can be attributed to the dissolution of precipitates and subsequently the weld cooling rates do not favor nucleation and growth of all precipitates. The variation in hardness values in the microstructural weld zones are shown in Fig. 7.
Due to the high temperature required for fusion welding, the heat affected zone region was large as well as and the subsequent melting and solidification that occur, voids are common defects found in fusion welds. The presence of voids (Fig.-7b) in the TIG welds contributes to the reduced hardness (Fig. 5-6) observed during testing in respect of friction stirs welds.

CONCLUSION

The minimum hardness was recorded in the weld metal for TIG welding of about 50.1BHN for similar joint and 70.7 BHN for dissimilar joints. While for FSW joint the minimum hardness was recorded about 70.1 BHN and maximum hardness about 121BHN as compared with 170BHN for the base alloy. A hardness value has mixed result with respect to rotations speed and transverse speed for similar FSW joints. But in case of dissimilar FSW joints hardness value decreases with increase rotations speed and transverse speed. Hardness was strongly affected by precipitate distribution.The voids presence in the TIG welds contributes to the reduced hardness. It is observed that of FSW joints has more hardness than TIG joints.

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