Investigation of Welding Parameters Effects on Microstructure and Mechanical properties of FSW AA5052-H32 and AA6061 –T6 Dissimilar Al Alloy Welded Joint

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Abstract

The 5052-H32 and 6061-T6 dissimilar aluminium alloys with a thickness of 5 mm were welded by Friction stir welding (FSW). Microstructural and mechanical properties of the FSW joint and base metal were researched employing optical microscopy (OM) and universal testing machine (UTS), respectively. Meanwhile, the tensile properties and microhardness at room temperature were sustained. The outcomes show that the base materials are more effective to mingle in the weld nugget when 5052 alloys are positioned on the advancing side. The minimum hardness of the weld joint occurs on the heat-affected zone (HAZ) of the 5052 alloy side, where the failure occurs which can be defined as a ductile fracture. The maximum tensile strength and the elongation of the weld joint are 165.84 Mpa and 11.6% respectively.

Keywords: Dissimilar Friction Stir Welding, AA5052-H32, AA6061-T6, microstructure, mechanical properties

1. Introduction

FSW is a solid-state joining process that is accomplished by the age of heat at the collating largely supported by friction between the heat resistant rotating tool and workpiece interface, plastic deformation of the workpiece [1].

Aluminium and aluminium alloys which are lighter weight and higher specific strength than ferrous material have found wide applications in recent years. The AA6061 alloys are extensively used in marine frames, storage tanks, pipelines, and aircraft applications. Although these alloys are readily weldable by fusion welding, they suffer from severe softening in the HAZ due to the reversion of Mg_2Si precipitates during the welding thermal cycle. Such mechanical impairment presents a major problem in engineering design. In recent years, FSW (FSW) has validated its capability as a commercial joining process for aluminium alloys. In the marine and rolling stock industries, the FSW process is exploited for the production of large prefabricated aluminium panels, which are fabricated from aluminium extrusion [2-3]. AA5052-H32 aluminium alloy is a high corrosion resistance stabilized aluminium alloy used for automotive and marine structural applications. The consequence of tool shoulder diameter on heat input during FSW of AA5052-H32 alloy was studied [4-5]. Several studies focusing on mechanical and metallurgical properties of friction stir welded aluminium alloy joints with or without welding flash have been reported. [6-9]

Elangovan et al. [10-12] broadly considered the impacts of various tool designs on a scope of aluminium combination and dissimilar material joining. Their examination in practically all cases concluded in favor of the square pin tool because of its capability to produce better grain by pulsating stirring action. They analyzed the effect of tool pin profile and other FSW parameters on tensile strength of friction stir welded AA6061 through the construction of the mathematical model. Thus the joints created by square pin profile have better elasticity due than proper material stream better plasticization.

Many investigations were carried out on the similar FSW on AA5052-H32 aluminium alloys [13] and similar AA6061 aluminium alloys [14-18]. FSW has been proved to be successful for a great series of different aluminium alloys. In this study, the 5 mm thick plates were subjected to FSW of dissimilar aluminium alloys. The aim was to evaluate the fsw dissimilar joint weld-ability of the thick AA5052-H32 and AA6061-T6 plates and to examine the effects of the various stages of the dissimilar joint on the mechanical properties of the FSW joints.

2. Materials and Methods

2.1 Materials, Heat treatments, and Welding

A joint layout of a 150mm×100mm×5mm rolled plates were used for FSW. The parent metal AA5052-H32 is solution strain hardened non-heat treated and the parent metal 6061-T6 is solution treated and artificially aged aluminium alloy plates were used. Details of the mechanical properties at ambient temperature of the parent materials are presented in Table 1 and details of the chemical compositions shown in Table 2. The tool was made in H13 high-speed steel, M2, quenched at 1020ºC, characterized by a 50~55 HRc. AA5052-H32 and AA6061-T6 were individually kept in the advancing side and retreating side of the FSW joint line. The FSW line was perpendicular to the rolling direction of parent metals. This joint decision was made to induce the most extreme mechanical combination. In this work, butt joints of the selected aluminium alloys plates were made by the FSW machine. The FSW process parameters used to fabricate the joints are listed in Table 3. The joints were fabricated at different rotational speed of 900, 1100 rev/min and same feed rate of 28 mm/min. The dissimilar butt welding was carried out automatically in the FSW machine. Tensile tests were conducted to analyse the mechanical properties of the weld joints achieved by the FSW process of the two different materials of the present study. Tensile test specimens were sectioned in the longitudinal and transverse direction respect to the weld line with a wire cut electrical discharge machine.

Table 1. Mechanical Properties of Parent Materials 5052-H32 and 6061-T6

Alloy	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Average Hardness (HV)
AA5052-H32	195	222	65

AA6061-T6	266	325	110

Table 2. Chemical Composition of Parent Materials 5052-H32 and 6061-T6 (Mass Fraction, %)

Alloy	Mg	Mn	Fe	Si	Zn	Cu	Cr	Ti	Al
AA5052-H32	2.63	0.061	0.27	0.118	0.025	0.051	0.212	0.0041	BAL
AA6061-T6	0.812	0.061	0.323	3.01	0.072	1.142	0.184	0.02	BAL

Table 3. Process Parameters and Tool Geometry for FSW of Aluminium Alloys

Process parameters	AA5052-H32 and AA6061-T6
Tool rotation speed (Rpm)	900, 1100
Tool traverse speed (mm/min)	28
Axial force (KN)	10
Tool pin profile	Triangular pin
Tool pin one side (mm)	5
Tool shoulder diameter (mm)	20
Tool pin length (mm)	4.7

2.2 Optical microscopy, Scanning electron microscopy and Hardness

Metallographic considerations were carried out on polished (1µm) and etched surfaces. The etching was carried out using Keller's reagent and Weck's reagent. Modified reagents were used to broadcast the microstructure. The material flow, grain size, and grain orientations were put through using an optical microscope. The tensile test was carried out in a 100 kN electro-mechanical controlled universal testing machine. The tensile specimen was loaded as per ASTM specifications at the constant strain rate of 1.5 kN/min. Three tensile specimens from each joint were formulated and investigated, and the average value was taken for evaluation. The yield strength, ultimate tensile strength, % of elongation and joint efficiency were analyzed from un-notched tensile specimens. Notch tensile strength and notch strength ratio were analyzed by introducing notch in the standard smooth tensile specimen. The Scanning electron microscope (SEM) operating at 10-15 kV (ZEISS) was used to analyze the fractured surfaces of the tensile test specimens. A Vickers microhardness tester (Wilson Wolpert – Germany) was employed for measuring the hardness across the transverse cross-section of the various zones from the left side of the base metal to the right side of the base metal of FSW joints. Hardness data were secured utilizing a microhardness tester, with a test load of 100 g and dwell time 10 s.

3 Result and discussion

3.1 Weld structure

The surface appearance of dissimilar joints is revealed in figure 1. It is obvious from the figure that the joints created at tool rotational speed utilizing triangular pin profiles are defect-free. The straight pin profiles tool has more contact zone. The moving of plasticized material from the AS to the RS is uniform from top to bottom of the joint when straight pin profiles are utilized. Figure 1 curved lines showing the interface between dissimilar aluminium alloys was observed from the smooth surface.

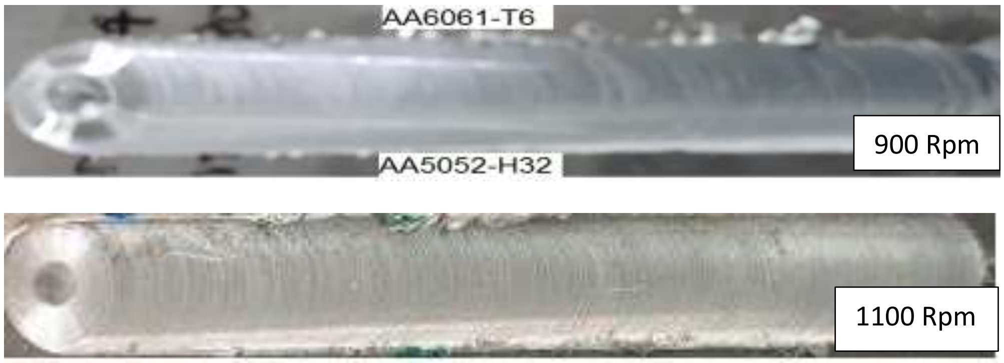


Figure. 1 Surface Aspects of Dissimilar Weld Prepared by FSW at Various Rotation rates

3.2 Macrostructure

Optical macrographs of the cross-section of a dissimilar weld under different rotational speeds are presented in Fig 2. The structure looked like an onion ring pattern [21]. No obvious welding defect was found in the joint, indicating that sound weld of AA5052-H32 alloy and AA6061-T6 alloy can be obtained by FSW From Fig 2.b, it could be found that a simple bond interface was formed on the top of joint in AS and an intermixed structure existed in the weld center of the joint due to the materials flow during dissimilar FSW. Producing defect-free weld with efficient material mixing is important to achieve a strong joint. An excellent surface finish of the weld appeared and the materials were mixed inferior at the lower surface in the SZ from Fig 2.a. also discontinuous welding defect was found in the root of the weld joint [20]. It could be found that the mixing of parent materials was formed on the lower surface of the joint in AS. The typical microstructural zones, including base material (BM), heat affected zone (HAZ), thermo-mechanically affected zone (TMAZ), and stir zone (SZ) or nugget zone (NZ) could be observed in a cross-sectional macrograph of the dissimilar weld. When all is said and done, weld nugget shapes can be classified as, basin-shaped weld nugget that widens near the upper surface and elliptical weld nugget [1]. The shape of the weld nugget changes by the tool size and thermal conductivity of the parent metal. As the tool geometry was the same but the thermal conductivity of the aluminium alloys base material were different. In this case, a basin- shaped weld nugget was observed at 1100rpm [22].

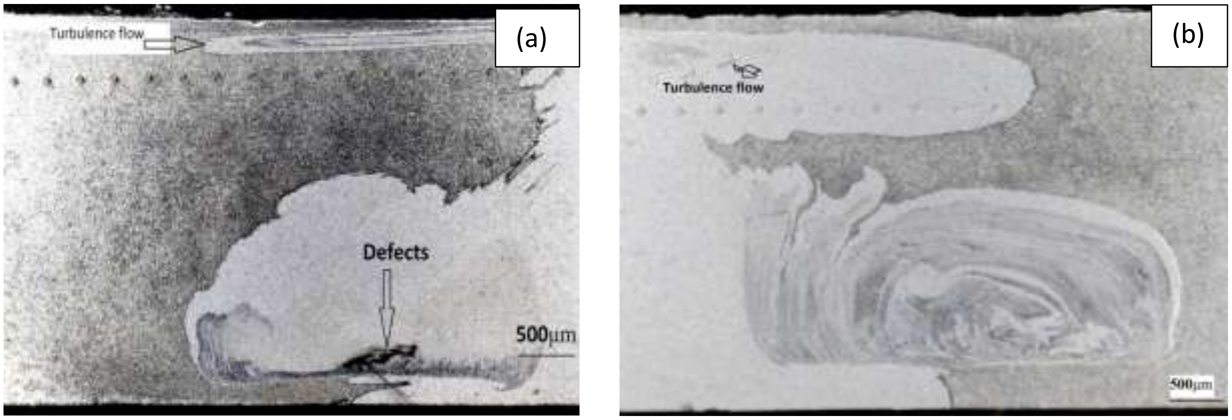


Figure. 2 Macrographs of the Weld Joint Cross-Sections (a) 900rpm, (b) 1100 rpm

3.2 Microstructure

Figure.3 (a) shows the base material microstructure of AA5052-H32 aluminium alloy. The microstructure of the parent metal AA 5052 grains flow along the direction of rolling, the fine particles precipitated are Mg_2Si and $MgAl_2$ in primary aluminium solid solution. The grains are smaller than that of AA6061-T6 aluminium alloy. Figure.3 (b) indicates the microstructure of the parent metal at the other side of the weld. The parent metal being AA6061 which is solution treated and precipitation hardened shows the eutectic component as Mg_2Si is present along the direction of grain boundaries in the parent metal 6061.

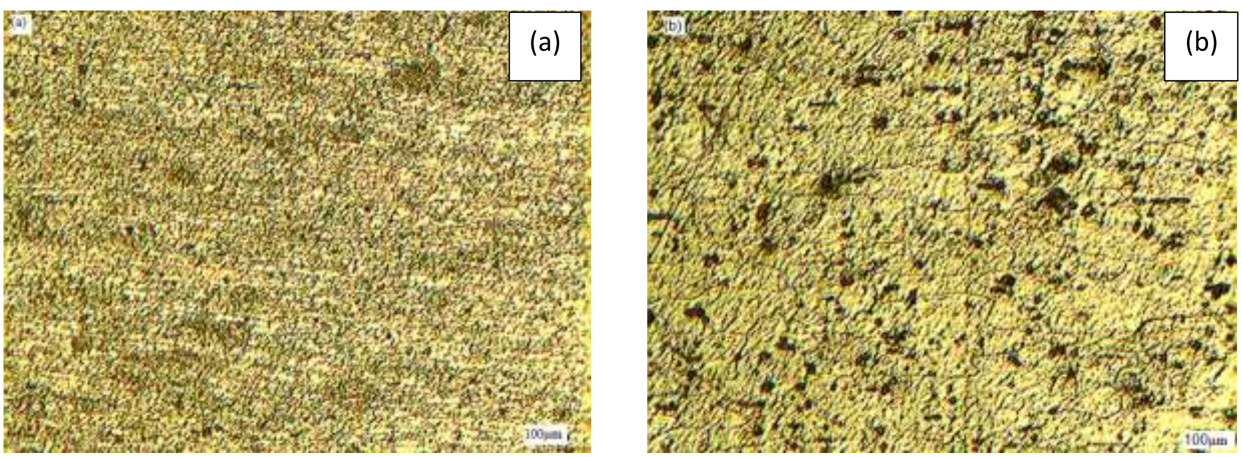
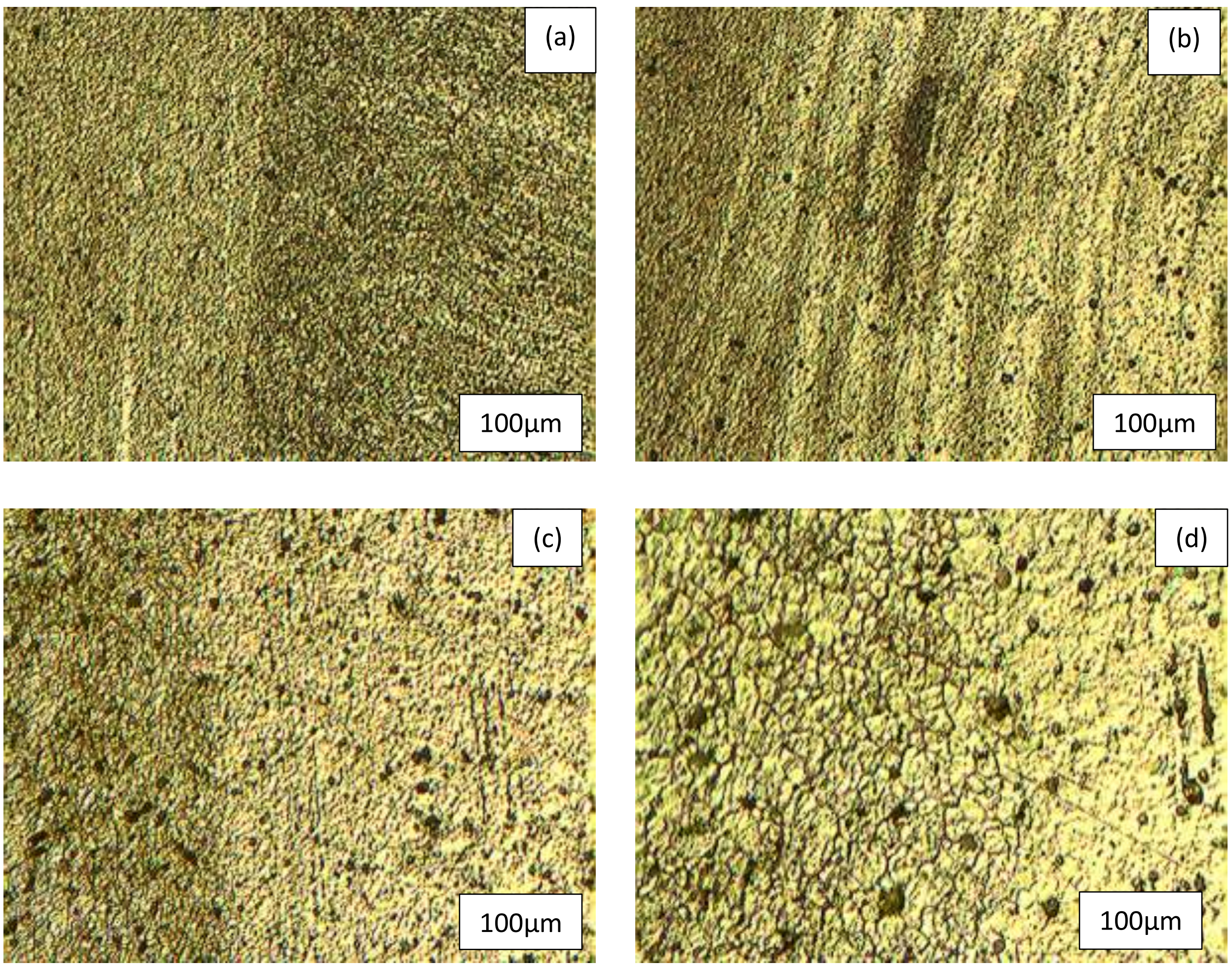


Figure. 3 Optical Micrographs of Parent Materials: (a) AA5052-H32 (b) AA6061-T6

Figure 4 presents the microstructure in nugget area at the cross section of the joint made by triangular pin tool under different rotational speed at 900, 1100 rev /min at same traverse speed 28 mm/min. Three distinct zones, this stir zone, thermo mechanically affected zone (TMAZ), and heat affected zone (HAZ) have been recognized. Figure 4 (a) (b) indicates the images of 5052-H32 HAZ at 900 rpm and 1100 rpm. Fig 4 (b) shows the rolling grains have vanished due to heat. The parent metal is at the right side and the nugget zone is at the left side of the image. Figure 4 (c) (d) presents the images of

6062 –T6 HAZ at 900 rpm and 1100 rpm. The nugget zone shows fine fragmented particles of the weld and the parent metal shows the heat affected zone with dense grains. Figure 4 (e) (f) shows images of WNZ at 900rpm and 1100 rpm. The nugget regions where the two base metal have undergone fragmentation and re-crystallization. They have formed alternate layer in vertical direction of the tool used. The interface zone of the nugget zone and the parent metal 6061. The parent metal 6061 is at the left side and the nugget zone is at the right side of the image. The stir zone or weld nugget is mainly composed of recrystallized aluminium alloy grains (Fig 4(e) and 4(f)), and the grains in this region becomes significantly smaller when compared with the initial grains size of the aluminium alloy base metal (Fig 3(a, b)). The finest grains in the stir zone are due to dynamic recrystallization induced by plastic deformation and frictional heating during FSW. Heat input and plastic deformation inversely affect the dynamic recrystallized grain size [13].



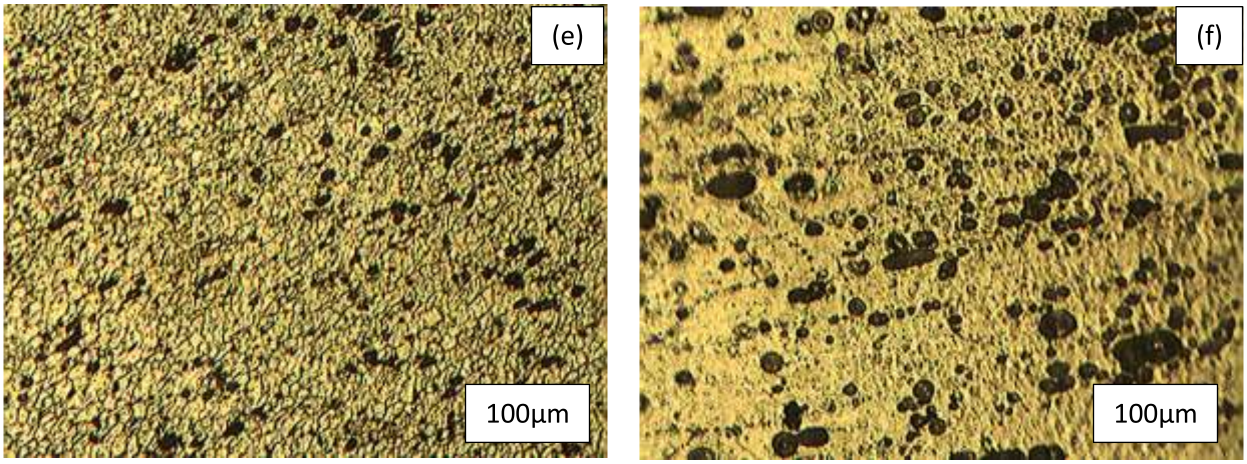


Figure. 4 Optical Micrographs of Weld Samples: (a) 5052 HAZ of 900 rpm (b) 5052 HAZ of 1100 rpm (c) 6061 HAZ of 900 rpm (d) 6061 HAZ of 1100 rpm (e) WNZ of 900 rpm (f)WNZ of 1100 rpm

3.3 Tensile properties

Figure 5 shows the stress –strain curve for the defect free weld joint at 1100 rpm. The tensile strength of FSW weld joint has achieved 74.7% with AA5052-H32 and 51.02% with AA6061-T6 individually. The ultimate tensile strength of the weld joint has reached 165.84 MPa, indicating the weld joint efficiency of 74.7% to the weak base metal with 1100 rpm and 28 mm/min. Furthermore, the elongation, as well as the strength of both the base materials, is found to be higher than that of the friction stir-welded sample.

By increasing the rotational speed at 1100 rpm and constant traverse speed of 28 mm/min, the UTS weld joint was increased. As the grain size of the specimens decreased, the UTS of the weld joint were increased. All the tensile test samples are fractured at HAZ near 6061-T6. The UTS of sample 1 is almost the same as that of sample 2. The fracture of the samples 900 rpm and 1100 rpm has occurred at the breakage point 8.16% and 11.6% respectively, thus indicating the samples has more ductility. The yield strength value of 900 rpm is almost different as that of 1100 rpm. Hence we can conclude that specimens welded at higher welding speed show better ductility.

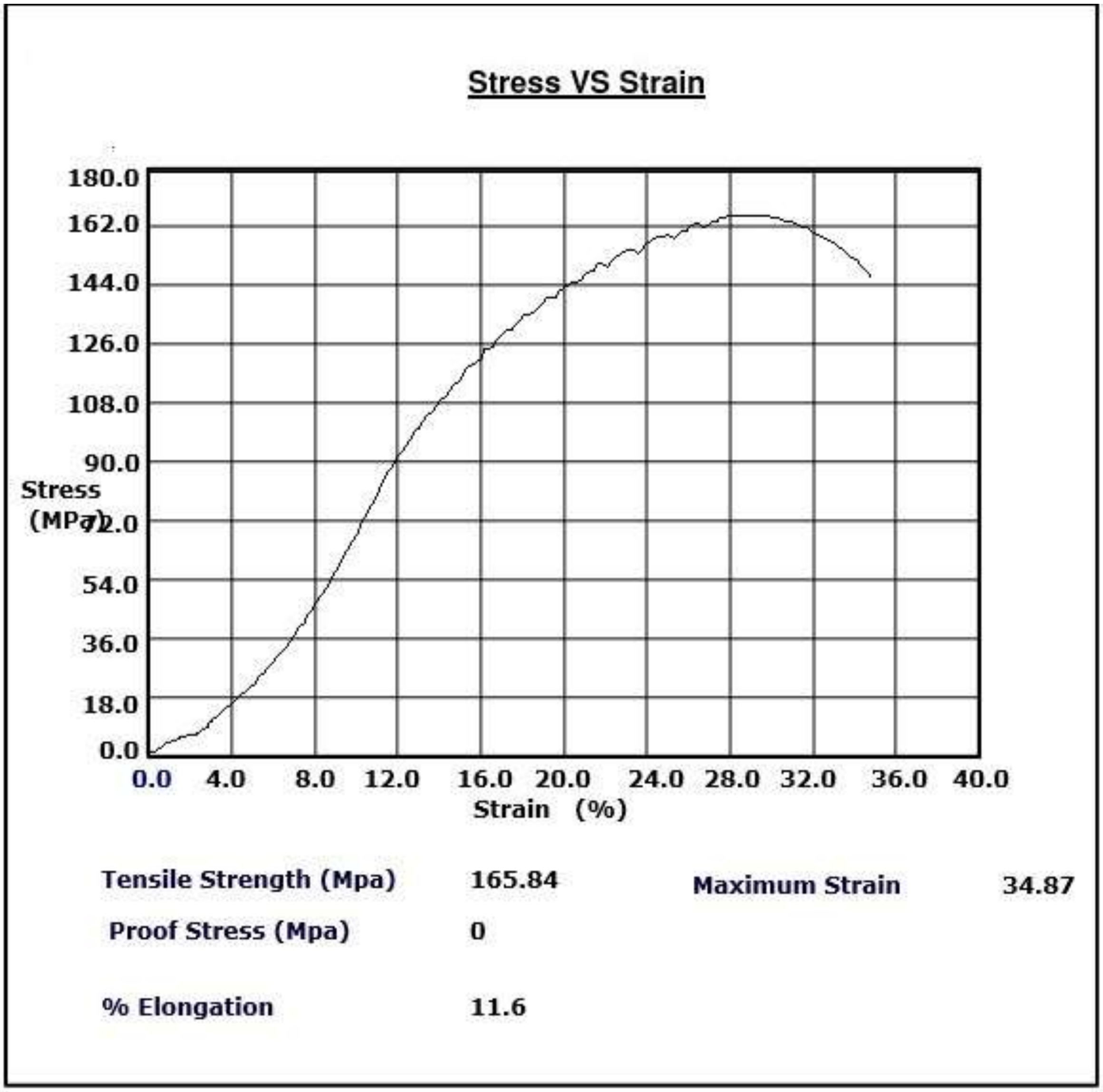


Figure. 5 Stress- Strain Curve for Triangular Pin Profile at 1100rpm

3.4 Microhardness

In the following, the effects of rotational and transverse speeds on the microhardness of the prepared samples were studied. The microhardness measurement for 32 points in the base metal aluminium alloys is shown in Table 1. The figure represents the microhardness variations of the dissimilar joint of the FSWed specimens. Figure.6 shows hardness profile of FSW dissimilar joint along the mid-thickness of transverse cross-section. For the as-rolled sheet, the hardness started to increase in HAZ on the (AS) and decreases in HAZ on the (RS). The TMAZ had the lowest hardness value compared with the weld NZ. This could be attributed to significant annealing softening and dynamic recrystallization. The NZ showed the highest hardness compared with base metal .The hardness change of the NZ is due to increase in fine grains in that region.

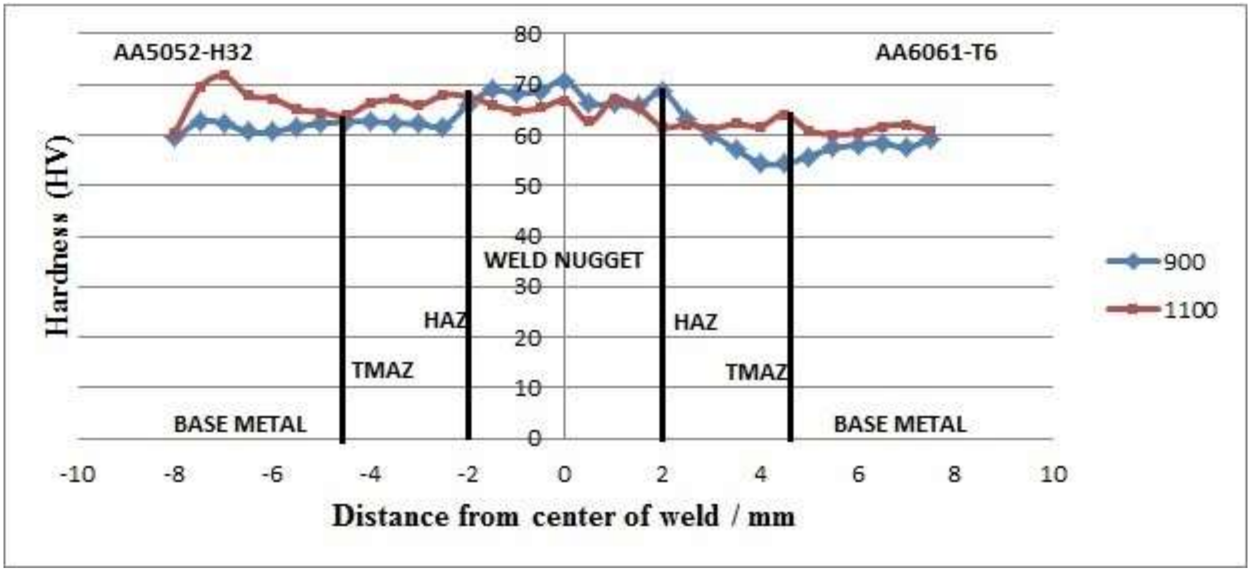


Figure. 6 Microhardness across the Weld line

4. Conclusions

In the present work, the effects of rotation speed on microstructural and mechanical properties of friction stir-welded of dissimilar aluminium alloys of 5052-H32 and 6061-T6 were investigated. The main conclusions are follows:

(1) At the same welding speed of 28 mm/min, 5052-H32 and 6061 –T6 dissimilar aluminium alloys were jointed without defects at rotation speed from 900 and 1100 rpm. The weld joint made by triangular pin at 1100 rpm gave maximum UTS of 165.84 Mpa, which was 74.7 % of the weak base metal.

(2) After FSW, the weld joint of 1100 rpm sample gave the highest elongation of 11.6 % when compared to 900 rpm. Both UTS and elongation of weld joints decreased compared with the BM, which is due to increase in grain size between NZ and TMAZ.

(3) The sample made by 900 rpm showed pin hole defects when compared to sample made by 1100 rpm which is shows no defects.

References

1. *Misra RS, Ma ZY. FSW and processing. Mater Sci Eng: R Rep 2005: vol 50:1-78 https://doi.org/10.1016/j.mser.2005.07.001*
2. *STALEY J T. "Aluminium-based products for the aerospace industry produced using non-traditional processing" first international conference on processing Materials for properties. Honolulu, Hawaii, USA: The Minerals, Metals and Materials Society (TMS), 1993*
3. *Hrishikesh Das, Debayan Chakaraborty, Tapan Kumar Pal, "High- cycle fatigue behavior of friction stir butt-welded 6061 aluminium alloy", Trans. Nonferrous Met. Soc. China 24(2014) 648-656 https://doi.org/10.1016/S1003-6326(14)63107-1*
4. *Kwon Yong-Jai, SHIM Seong-Beom, PARK Dong- Hwan, FSW of 5052 aluminium alloy plates, "Trans. Nonferrous Metals of China, 2009, 19: 23-27. https://doi.org/10.1016/S1003-6326(10)60239-7*
5. *TUFARO L N, MANZONI I, SVOBODA HG, "Effect of heat input on AA5052 friction stir welds characteristics", Procedia Materials Science, 2015, 8: 914-923. doi: 10.1016/j.mspro.2015.04.152*

6. K.N. Krishnan, "The effect of post-weld heat treatment on the properties of 6061 friction stir welded joints", Journal of material science 37 (2002) 473-480. https://doi.org/10.1023/A:1013701104029
7. P. Periyasamy, B. Mohan, and V. Balasubramanian, "Effect of heat input on mechanical and metallurgical properties of friction stir welded AA6061-10% SiCp MMCs ", JMEPEG (2012) 21:2417-2428. https://doi.org/10.1007/s11665-012-0176-5
8. P.Janaki Ramulu, R. Ganesh Narayanan, Sathish V. Kailas, Jayachandra Reddy, "Internal defect and process parameter analysis during FSW of Al6061 sheets", Int J Adv Manuf Technol (2013) 65:1515-1528. DOI 10.1007/s00170-012-4276-z
9. YAN Yong, ZHANG Da-tong, QIU Cheng, ZHANG Wen, " Dissimilar FSW between 5052 aluminium alloy and AZ31 magnesium alloy", Trans.Nonferrous Met.Soc. China 20(2010) s619-s623. https://doi.org/10.1016/S1003-6326(10)60550-X
10. Elangovan .K, Balasubramanian.V. "Influences of pin profile and rotational speed on the formation of friction stir processing zone in AA2219 aluminium alloy", Mater Sci Eng A (2007) 495:7-18. https://doi.org/10.1016/j.msea.2006.12.124
11. Elangovan .K, Balasubramanian.V, Valliappan.M. "Influences of pin profile and axial force on the formation of friction stir processing zone in 6061 aluminium alloy", Int J Adv Manuf Technol, (2008) 38 ; 285-295. https://doi.org/10.1007/s00170-007-1100-2
12. Elangovan .K, Balasubramanian.V, Babu S. "Predicting tensile strength of friction stir welded AA6061 aluminium alloy joints", Mater Des (2009) 30:188-193. https://doi.org/10.1016/j.matdes.2008.04.037
13. Hossein Rostami, Salman Nourouzi, and Hamed Jamshidi Aval, "Analysis of welding parameters effects on microstructural and mechanical properties of Ti6Al4V and AA5052 dissimilar joint", Journal of Mechanical Science and Technology. (2018) Vol 32, 3371-3377. https://doi.org/10.1007/s12206-018-0640-8
14. Mishra RS, Mahoney MW. FSW and processing. ASM International 2007.
15. Luis Trueba Jr, Georgina Heredia, Daniel Rybicki, Lucie B. Johannes, "Effect of tool shoulder features on defects and tensile properties of friction stir welded aluminum 6061-T6", Journal of Materials processing technology,(2015), Vol 219:271-277. https://doi.org/10.1016/j.jmatprotec.2014.12.027
16. Masoud Ahmadnia, Saeid Shahraki, Mojtaba Ahmadi Kamarposhti, " Experimental studies on optimized mechanical properties while dissimilar joining AA6061 and AA5010 in a FSW process", Int J Adv Manuf Technol (2016) 87:2337-2352. https://doi.org/10.1007/s00170-016-8636-y
17. Mustafa A. Abdulstaar, Khaled J. Al-Fadhalah, " Microstructural Variation through Weld Thickness and Mechanical Properties of Peened Friction Stir Welded 6061 Aluminum Alloy Joints", Materials characterization.(2017) Vol 126, 64-73. https://doi.org/10.1016/j.matchar.2017.02.011
18. Abhijit Banik, Barnik Saha Roy, John Deb Barma, Subhash C.Saha,"An experimental investigation of torque and force generation for varying tilt angles, and their effects on microstructure and mechanical properties of fsw AA6061-T6", J Manuf Processes 31 (2018) 395-404. https://doi.org/10.1016/j.jmapro.2017.11.030
19. Rathinasuriyan. C and Senthilkumar. V.S, "Experimental investigation of weld characteristics on submerged friction stir welded 6061-T6 aluminium alloy", Journal of Mechanical Science and Technology. 31 (8) (2017), 3925-3933 . DOI 10.1007/s12206-017-0738-4
20. Shanavas.S, Edwin Raja Dhas, Murugan.N, "Weldablity of marine grade AA5052 aluminium alloy by underwater FSW", Int J Adv Manuf Technol,(2018) 95, pp 4535-4546. https://doi.org/10.1007/s00170-017-1492-6
21. Zhang .H.J, Wang.M, Zhu.Z, Zhang.X, Yu.T, Wu.Z.Q, "Nugget structure evolution with rotation speed for high rotation speed friction stir welded 6061 aluminium alloy", JMEPEG (2018) 27:1378-1386. DOI 10.1007/s11665-018-3228-7
22. H. Mohammadzadeh Jamalian. M. Farahani. M.K. Besharati Givi, " Study on the effects of FSW process parameters on the microstructure and mechanical properties of 5086-H34 Aluminum weld joints", Int J Adv Manuf Technol (2016) 83:611-621 https://doi10.1007/S00170-015-7581-5
23. Sato YS, Park SHC, Kokawa H. "Microtexture in the Friction-Stir Weld of an Aluminium alloy". Metall. Mater. Trans. A (2001) 32:3033-3042. DOI: 10.1007/s11661-001-0351-z