Jurnal Kejuruteraan 35(2) 2023: 411-419
https://doi.org/10.17576/jkukm-2023-35(2)-12

Welding Investigation on AA6063-T6 Aluminium alloy during Friction Stir Welding process

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Received 27 January 2022, Received in revised form 2 September 2022
Accepted 2 October 2022, Available online 30 March 2023

ABSTRACT

The Friction stir welding (FSW) is widely used to weld aluminium alloy for industrial applications such as shipbuilding, aerospace and automobile due to its lighter weight and high strength. The current work is carried out to examine the different process parameters to weld AA6063-T6 aluminum alloy with FSW process. The tool rotation speed, feed, plunging depth and dwell time are considered as the welding parameter. The three test coupons have been welded at three different rotational speeds. The tensile strength and hardness at the weld vary with the speed of rotation of the tool. The higher tensile strength is achieved at lower tool rotational speed. The tensile strength achieved at 1000rpm and 1400rpm is 191Mpa and 131rpm respectively. The higher strength is achieved due to the refinement of grains and recrystallization in stirred zone. The microstructure test confirms the presence of uniformly fine grains at weld area and equiaxed grains at HAZ region.

Keywords: AA 6063 T6; rotational speed; tensile strength; hardness; microstructure

INTRODUCTION

Friction stir welding (FSW) has emerged as one of the vital alternative technologies which has good potential to be used in major industries like automobiles, aerospace, shipbuilding. In the FSW process the generation of heat is through the rotation of a cylindrical tool at the joining point of the two plates. As the tool rotates and moves along the workpiece with the joining of plates, the softened material would extrude around the tool. The tool profile contains one pin and one shoulder which is non-consumable in nature. The aim of the tool shoulder is to heat the base metal frictionally with producing the downward forging action (Ceschini et al. 2007; Panda et al. 2015). FSW process illustration is shown in Figure 1. Earlier it was used only for aluminum alloys but with the advancement of technology and materials it is also used for other materials. In friction stir welding, a rotating cylindrical tool with respective pin geometry is plunged into the spindle and contacts it with the upper surface of the workpiece. In this process heat is generated because of the friction and visco-elastic dissipation of mechanical energy at high strain rates which softens the material and weld is produced.

Analyze the effect of FSW on mechanical properties of AA7005/10 vol. % Al_2O_{3p} composite and found a crack at the center-line of the weld which indicates the absence of major defects such as permeability or reinforcement segregation. They reported the high and low value of fatigue ratio which shows that fatigue life at the higher strain ranges (Ceschini et al. 2007). Investigates the impact of different pin profile on AA6063 during FSW and reported some defects which were enhanced in hexagonal, conical and triangular type of tool pin profile. They concluded that the tapered cylindrical pin shows the tensile strength of 162MPa with five grain structure (Goel et al. 2018). Using Taguchi design of experiment, they scrutinize the effect of friction stir welding on AA6061 which were performed through threaded cylindrical pin profile. This resulted in the equiaxed grains at the weld nugget zone and the significant factor becomes the welding speed (Ranjan et al. 2015). Investigates the consequence of different welding parameters on the dissimilar aluminum alloys with friction stir welding. They found that with increase of welding speed, HAZ decreases and experienced the over aging and coarsening of precipitates (Ravikumar et al. 2014). Scrutinize the propagation of fatigue crack behavior in friction stir welding of AA6063-T6. They reported that the grain size in the stirred zone was better fine and at the weld zone the FCP rate was higher than base metal (Tra et al. 2012). Compares the fatigue crack growth between the two dissimilar aluminum alloys and it was found that FCP of friction stir weld is lower than that of base material. From SEM observation, the weld nugget zone was delimited and rough and fractured surface would arise for AA6061-T6 alloy (Moreira et al. 2008). Determine the impact of pin geometry on 2014 aluminum alloy in friction-stir welding. They found that the grains were fine in the nugget zone and best bonding is with screw pitched taper pin (Zhao et al. 2005). Investigates the influence of welding parameters on the interface bonding on aluminium alloys. They concluded that due to collision of welding tools and particles, some breakage of B_4C particles were observed in the nugget zone (Guo et al. 2012). **S**tudied and scrutinized the effect of tool pin and shoulder profiles on AA6063/SiC composites. Though for flat shoulders, practical distribution is better when square pin is used and concluded that the tool geometry plays a vital role in front of process parameters of friction stir processing (Gangil et al. 2018). Studied the effect of process variables on AA6063-T6 with friction stir processing. The finalized results exhibit a refined and uniform grain structure size with some defects which leads to mechanical property enhancement (Karthikeyan et al. 2011). Focuses on the study of different aluminum alloys by friction stir welding. They told us due to formation of kissing bonds, the reduction in tensile strength could be seen when AA2024 was carried on the advancing side (Khodir et al. 2008). Investigated the different process parameters of dissimilar aluminium alloy during friction stir welding. They revealed that material mixing becomes much more effective on the advancing side of AA6061 but seamless bonding attains between the two AA6061 and AA7075 indicates the failure of the joint at the location in HAZ (Heat Affected Zone) (Guo et al. 2014). Scrutinize the effect of various shoulder profiles on properties of friction-stir welded joints. They concluded that the nugget zone shows the small and equiaxed grains from three shoulder geometries on the welded joint (Scialpi et al. 2007). Using a pin-eccentric tool, investigates dissimilar aluminum alloys during friction-stir welding. Through their work study, they found the elongated and equiaxed grains with a zig-zag line in the nugget zone (Chen et al. 2019). Studied the optimization of tool pin profile and welding speed on AA6063. They reported the good quality of the welded specimen through a tensile test (Dumpala et al. 2016). Scrutinize the outcome of axial force and tool profile on zone formation in AA6061.They revealed to us that due to insufficient heat input the defective joint would produce a straight cylindrical pin profile and found better tensile strength with square pin (Elangovan et al. 2008). Investigates the changes and effect on mechanical properties while doing welded and post welding on AA6082. They concluded that the elongated rolled structure and ultra-fine equiaxed grains were captured and AA6082 would be more influential while post-welding (Danaf et al. 2013). Investigates the properties of Al. 5083/St-12 which were fabricated by friction-stir welding. They told us that the layered structure has the most hardness present and all the regions have the same elastoplastic and cavity decreases while decreasing in travel speed (Movahedi et al. 2011). Scrutinize the consequences of shoulder to pin diameter (D/d) ratio on tensile strength during friction stir welding. They found that lower the D/d ratio, higher the tensile strength due to the more pin diameter and dynamic recrystallization (Khan et al. 2015). Carry-out different shoulder to pin diameter ratio on tensile strength of SiC composites. They reported that the agglomeration of SiC particles makes a stress field which prohibits the redistribution of stress and the shoulder diameter shows the greater impact on loading without any defect. In current work, the base material AA6063 aluminium alloy has been welded with FSW process by varying the tool rotational speed and keeping other parameters constant (Vijayavel et al. 2014).

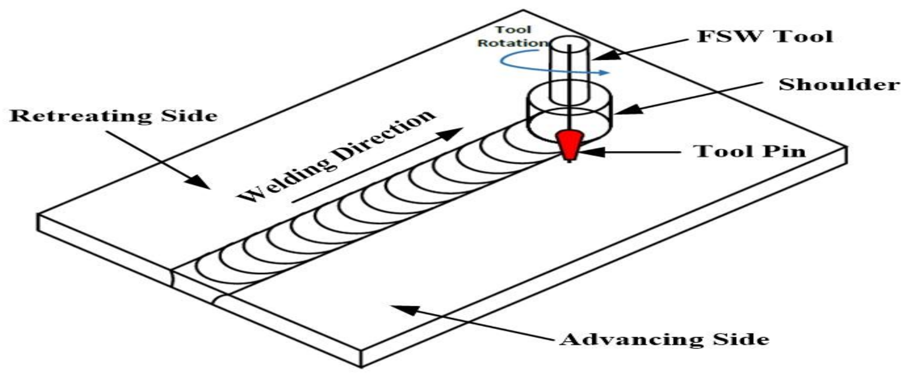

FIGURE 1. Principle of friction stir welding process (adapted from Banjare et al., 2017)

MATERIALS AND METHODS

The AA6063 aluminum alloys with dimensions 150mm×50mm×3mm were taken as the base material. The square butt joint, aluminum plates were fabricated using the FSW process. The experiment was performed on an CNC machine Make: AMS (2016) and Model- MCV-400. The experimental trials on AA6063 during FSW is shown in Table 1. The experimental setup of the FSW process is depicted in Figure 3. Acetone was used before the experimental trial as it cleanses the impure layer of the material and the fabrication finish will be better. The experimental trials were performed to identify the macrostructure, hardness testing and for tensile testing at various rotational speeds. A rotating tool of high carbon high chromium steel was used to join the material which is non-consumable in nature, configuration of tool is shown in Figure 2. The tool was held and fixed to spindle and weld the two plates at different tool rotation and at fixed plunging depth. The Chemical composition of base metal AA6063 is depicted in Table 2.

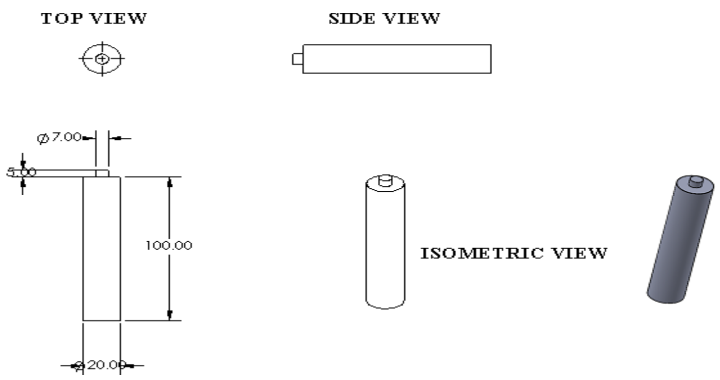

FIGURE 2. FSW tool configuration

TABLE 1. Experimental trials on AA6063 during FSW

S. No.	Tool Rotation Speed (rpm)	Feed (mm/min)	Plunging depth	Dwell time (seconds)
1	1400	30	3.2	15
2	1200	30	3.2	15
3	1000	30	3.2	15

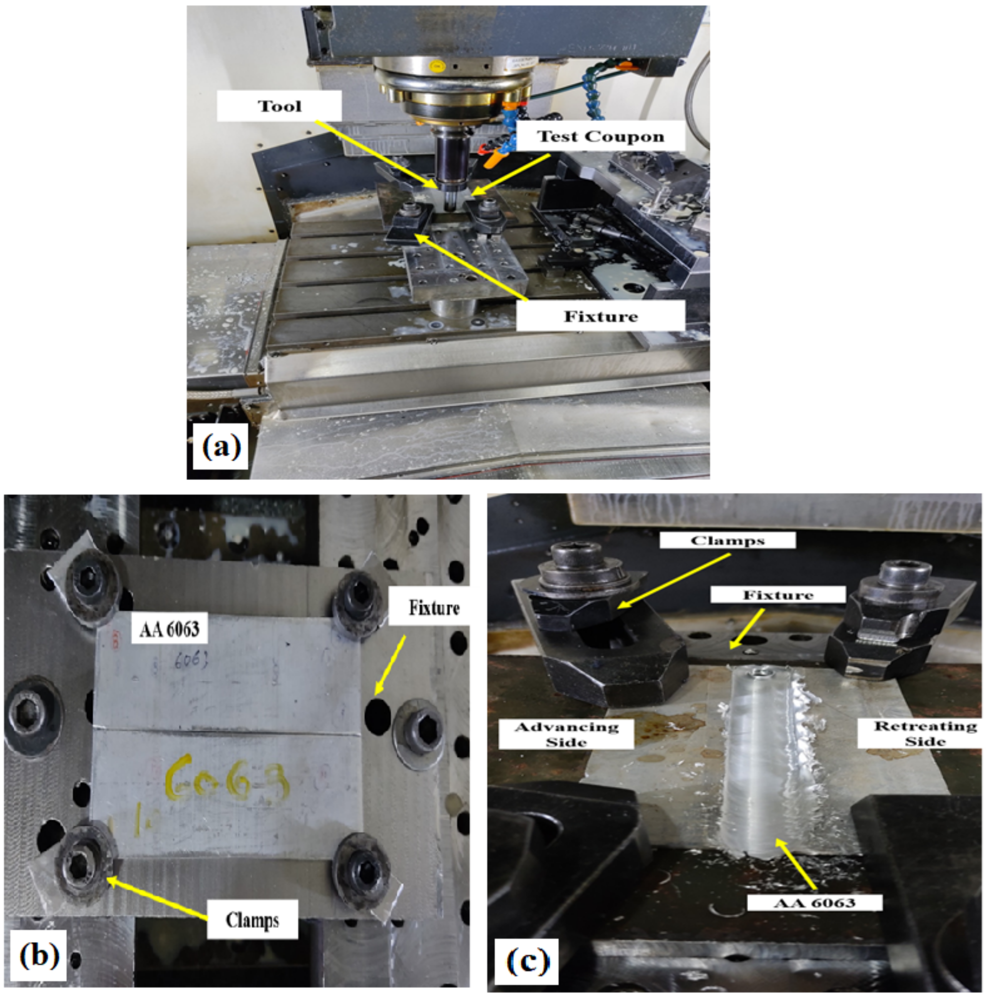

FIGURE 3. Experimental setup of FSW process (a) Tool Setup (b) Fixture Setup (c) Welded sample of AA6063 at CNC

TABLE 2. Chemical elements of base metal AA6063

Elements	Al	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Cr
Wright %	97.5	0.4	0.35	0.1	0.1	0.5	0.01	0.1	0.1	0.1

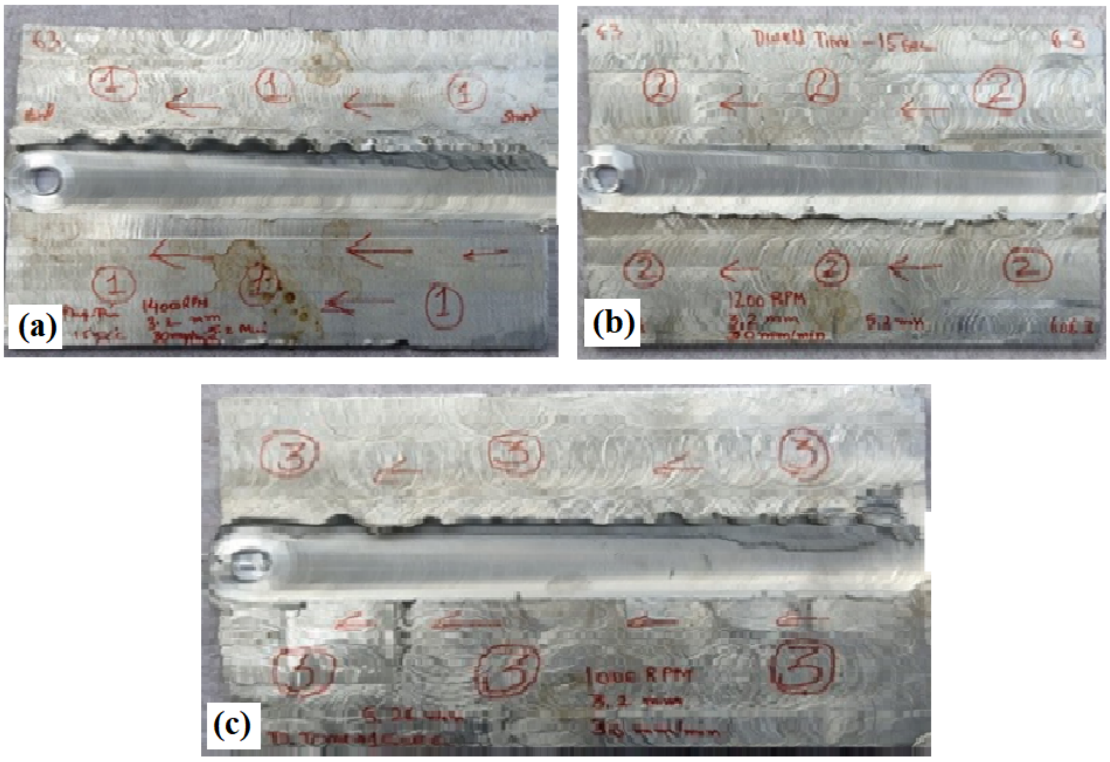

FIGURE 4. Welded specimen of AA6063 during friction-stir welding

RESULTS AND DISCUSSIONS

EVALUATION OF TENSILE STRENGTH

The tensile test was carried out using the International Standard (IS 1608: Part1: 2018) method of testing at room temperature to optimize the tensile properties such as ultimate tensile strength, yield strength, and ductility using the Universal Testing Machine (UTM). The Welded test coupons during FSW at different rotational speed viz. 1400rpm, 1200rpm and 1000rpm respectively is depicted in Figure 4. The higher rpm sample i.e. at 1400rpm, the tensile strength outputs the 131N/mm^2 with 6% elongation. The stress-strain curve shows the maximum elongation with more load sustainable capacity as shown in Figure 5(a). While at 1200rpm, the tensile strength shows the value of 158N/mm^2 with 10.5% elongation and performs lower in testing as shown in the stress-strain graph depicted in Figure 5(b). The welded sample at 1000 rpm has the maximum tensile strength 191N/mm^2 with 9% elongation. The tensile strength and elongation would also depend upon the hardness of the welded sample. As HAZ and TMAZ perceive the lower hardness as compared to stirred zone due to different grain size and the location of fracture if happened at HAZ or base metal shows the higher hardness of weldment. The stress strain curve indicate that higher strength is obtained at rotational speed of 100rpm, while lower at 1400rpm. The maximum tensile strength obtained at lower rotational speed of cylindrical tool due to the refinement of grains and recrystallization in the stirred zone. But the reduction could be seen at tensile strength due to tempered condition of material and failure always occurred at center of weld.

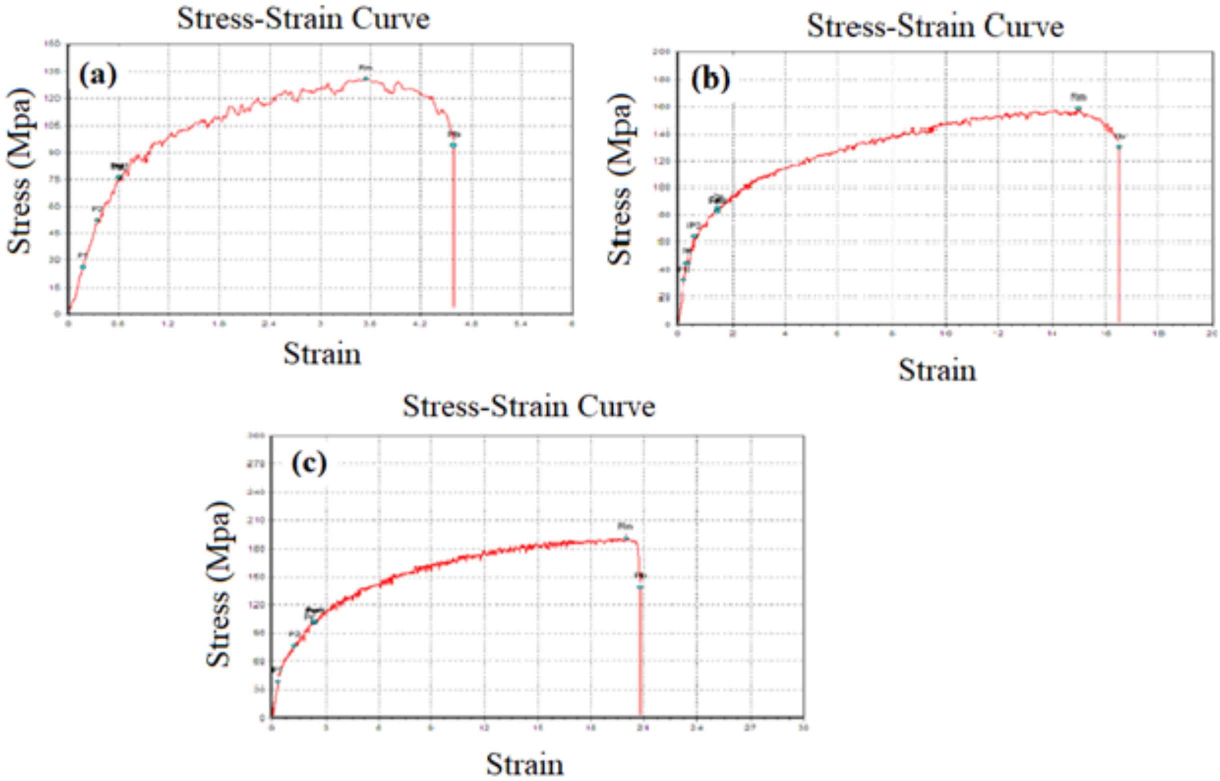

FIGURE 5. Stress-Strain curve (a) 1400rpm (b) 1200rpm (c) 1000rpm

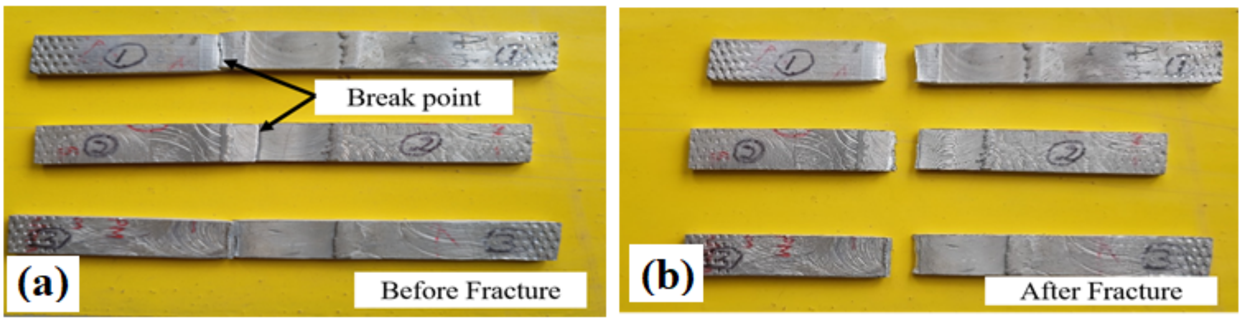

FIGURE 6. Fractured tensile specimen (a) Before fracture (b) After fracture

HARDNESS TEST OF THREE WELDED COUPONS

The hardness test was carried out through micro-hardness testing (Model: VM-50) in accordance with Indian Standard (IS 1501 part-1: 2013). The welded sample at 1400rpm shows the 67HV0.5 at weld metal while the sample at 1200rpm and 1000rpm shows the lower hardness value at weld and average at HAZ which was 63HV0.5 and 57HV0.5 respectively. The result shows the high hardness at high rpm (tool rotation per min). This is because the weld region which contains TMAZ and HAZ become softened due to which the hardness reduces because of some thermomechanical conditions in friction stir welding. But in nugget zone NZ, the recrystallization occurs due to excessive plastic deformation which increases the hardness. As in AA6063 T6, the tempered conditions of aluminium reduces the hardness after friction welding. Hardness of aluminium also depends upon the grain size, growth of nucleation, density and precipitation distribution but several previous studies present no effects of above all on the hardness.

MICROSTRUCTURE STUDY AND RESULT EVALUATION

For the analysis of microstructure, grain size, phase area, cracks, weld nugget zone, etc. microstudy has been performed. Samples were cut from transverse cross-sections in the direction and then testing was carried out through a metallurgical microscope (BMI-101A). Friction stir welding consists of four different zones, Nugget Zone (NZ), Thermomechanically Affected Zone (TMAZ), Heat Affected Zone (HAZ), and Base Metal (BM). As in FSW weld, the nugget zone NZ experiences the highest strain and undergoes recrystallization. The microstructural observation is given in Figure 7. At rotational speed 1400 rpm shows full penetration in the base structure which consists of fine grains while the weld area shows uniformly fine grains observed throughout the matrix. While at 1200rpm also shows the equiaxed fine grains in HAZ area and weld area shows the uniformly fine grains which indicate the better surface finish of welding. In accordance with this, the microstructure of the weld results with fine grains. The cylindrical pin of the tool prevailed the less defects made with some micro voids at 1000 rpm. Due to agglomeration, the zigzag line is shown with a faying line which is showing the presence of Al_2O_3. The welded specimen at 1000 rpm shows the good bonding at interface of the aluminum matrix in the composite zone with uniform distribution of particles throughout the matrix.

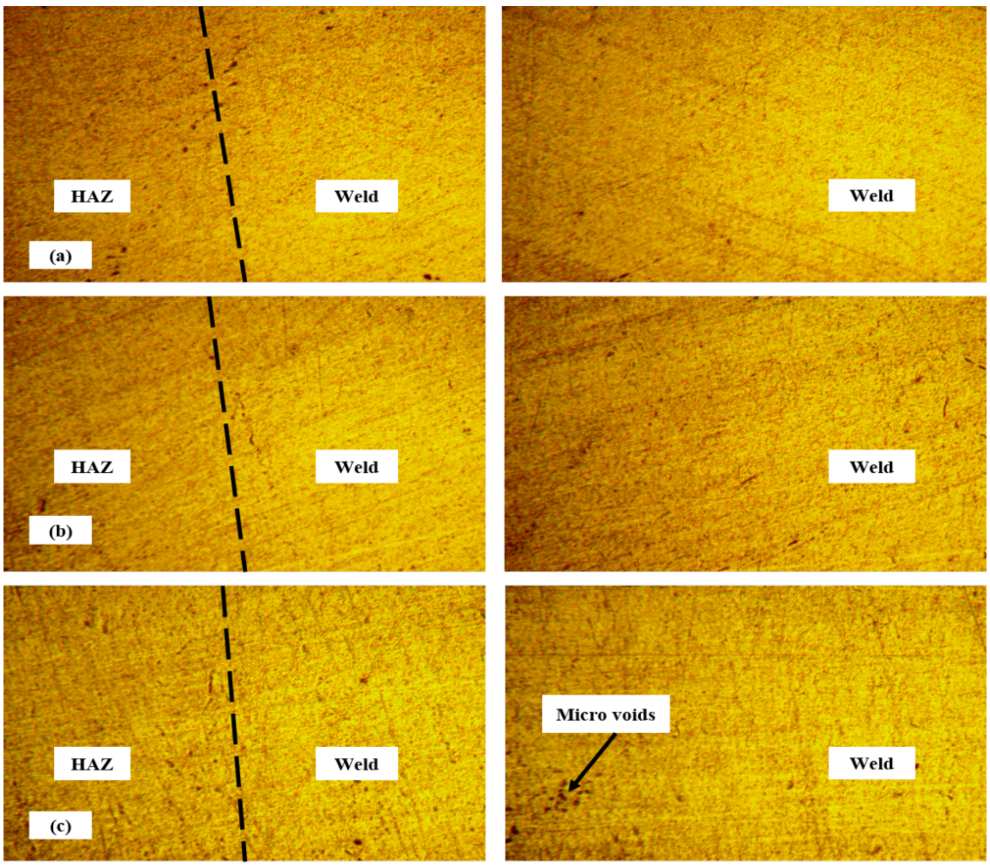

FIGURE 7. HAZ and Weld area at (a)1400 rpm (b)1200 rpm (c) 1000 rpm

CONCLUSION

The present work is based on friction-stir welding of AA6063 aluminium alloy and demonstrates the vitality of tool geometry and process parameters used during welding. The conclusions drawn from the investigation are given below:

1. The higher tensile strength is achieved at lower tool rotational speed. The tensile strength achieved at 1000rpm and 1400rpm is 191Mpa and 131rpm respectively. The higher strength is achieved due to the refinement of grains and recrystallization in stirred zone.
2. The hardness in weld at 1000rpm and 1400rpm is 57HV0.5 and 67HV0.5 respectively, this is due to formation of recrystallization at nugget zone at high rotational speed.
3. The microstructure study shows that all welded test plate shows the uniformly equiaxed fine grains throughout the matrix. It is due to higher stains experienced by the nugget zone which undergoes recrystallization.

ACKNOWLEDGEMENT

We would like to thank Department of Mechanical Engineering, AKGEC, Ghaziabad, Uttar Pradesh for supporting this study.

DECLARATION OF COMPETING INTEREST

None

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