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Effect of welding parameters on mechanical properties of dissimilar Friction Stir Processed AA 8011 and AA 5083-H321 aluminium alloys

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Abstract. The weight reduction and fuel economy are gaining importance in marine, defence and transportation industries to get the quality of the welded joints. The problems in fusion welding of aluminium alloys such as solidification shrinkage, hot cracking and residual stresses which degrade the strength of the welded joints. The innovative green joining technology, friction stir welding (FSW) process was implemented in addition to nanoparticles such as Al_2O_3 and SiC in similar and dissimilar aluminium alloys. In this work, the study was done on the effects of Friction Stir Processing (FSP) parameters on microhardness and tensile properties of AA5083-H321 and AA8011-H24 dissimilar aluminium alloy joints. The tensile test was conducted to evaluate the tensile properties of the welded joints. The Vickers microhardness test was carried out to examine the quality of the welded joints. It was observed that the similar AA8011 aluminium alloy combination with nanoparticle Al_2O_3 has maximum tensile properties and microhardness compared to other combination of joints.

1. Introduction

The friction stir welding process is the modern and eco-friendly solid-state joining process which is used to join relatively the light-weight materials, especially Aluminium and its alloys based on its industrial applications, such as shipbuilding, aerospace and automobile [1]. This process is ideally well suited for filling the voids, welding of dissimilar aluminium alloys because it does not involve melting, the weld solidification cracking of the welded joints. Further improvement of the weld quality of the joints, the Friction stir processing was applied in addition with nanoparticles which will overcome the variety of problems as in fusion welding of aluminium alloys such as porosity, the formation of brittle structures, and liquation cracking in the thermo-mechanically affected zone (TMAZ) [2].

The tool geometry plays a critical role in material flow and plastic deformation, it governs the development of heat due to the friction between the friction stir welding tool and the butt surfaces of the base materials [3]. The newly developed non-consumable tool consists of a different shoulder and pin geometry which is used to produce the dissimilar joints using the friction stir welding process [4]. The function of tool shoulder is to provide the latent heat by the application of a tool rotation speed and transverse speed over the surface of the base material being welded and the large amount of compressive force which makes the recrystallization process between the atoms in the welded joints [5-8]. The function of the tool pin is to move the highly plasticized material from the tool pin in the vertical direction. The different profiles of pin shape which plasticizes the material due to friction and the

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compressive force of the tool into the work materials [9]. The process parameters, such as rotational speed, welding speed and others are used for aluminium alloys and their combination with or without nanoparticles for generating the oxide layer breaking and mixing of the combinations [10]. The tool geometry plays a critical role in material flow and in turn, governs the transverse rate. The tool shoulder minimizes the formation of voids in the aluminium alloys [11, 12]. The friction stir processing (FSP) improves the aluminium alloys and their combinations toughness and flexibility in the specific area of the microstructure of the aluminium alloys with the formation of fine grain [13, 14]. The very limited earlier discussions have been made on the effects of process parameters on the strength properties of the dissimilar friction stir welded AA5083-H321 with AA 8011-H24 aluminium alloys. During this investigation, the focus was made on the effects of the process parameters on the microstructure and microhardness of the dissimilar friction stir welded/processed AA 5083-H321 with AA 8011-H24 aluminium alloys.

2. Experimentation

The cold worked non-heat treatable of AA 8011-H24 [15] and AA 5083-H321 [16] aluminium alloys (purchased from Virwadia steels, Chennai). The plates were cut into the dimensions of 150 x 150 x 6 mm by Power Hacksaw cutting machine. The mechanical properties and chemical compositions of the AA 8011-H24 and AA 5083-H321 aluminium alloys are specified in Table 1 and Table 2 respectively. The cut specimens for friction stir welding process are cleaned by an ultrasonic sonicator bath at a temperature at 40^o C for 15 minutes for each specimen to remove the foreign particles and also cleaned with acetone. The computerized friction stir welding machine was used to produce the dissimilar friction stir butt welded joints of AA8011-H24 and AA5083-H321 aluminium alloys.

Table 1 Mechanical properties of AA8011-H24 and AA5083-H321 aluminium alloys

Material	Tensile strength (MPa)	Yield strength (MPa)	Elongation at Break (%)	Density kg/m^3
AA 8011-H24	110	140	5.6	2869
AA 5083- H321	317	228	16	2660

Table 2 Chemical composition of AA8011-H24 and AA5083-H321 aluminium alloys

Material	Fe	Si	Mn	Mg	Zn	Ti	Cu	Al
AA 8011	0.7	0.5	0.5	0.3	0.1	0.02	0.13	Balance
AA 5083	0.4	0.4	0.4-1	4.9	0.25	0.15	0.25	Balance

In this work, the D2 steel tool with hexagonal pin shape, having the other dimensions of 18 mm shoulder diameter, 6 mm pin diameter having 2 mm side length and 5.7 mm pin length was used and shown in Figure 1. The FSW and tool parameters play a key role in deciding the quality of the weld strength and the details of the FSW parameters are tabulated in Table 3.

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Table 3 Welding parameters used for friction stir welding of butt joints

Sl. No.	Process Parameters	Details
1	Rotational speed, r/min	1200
2	Welding speed, mm/min	50
3	Plunge depth, mm	2
4	Tool Pin Profile	Hexagonal pin

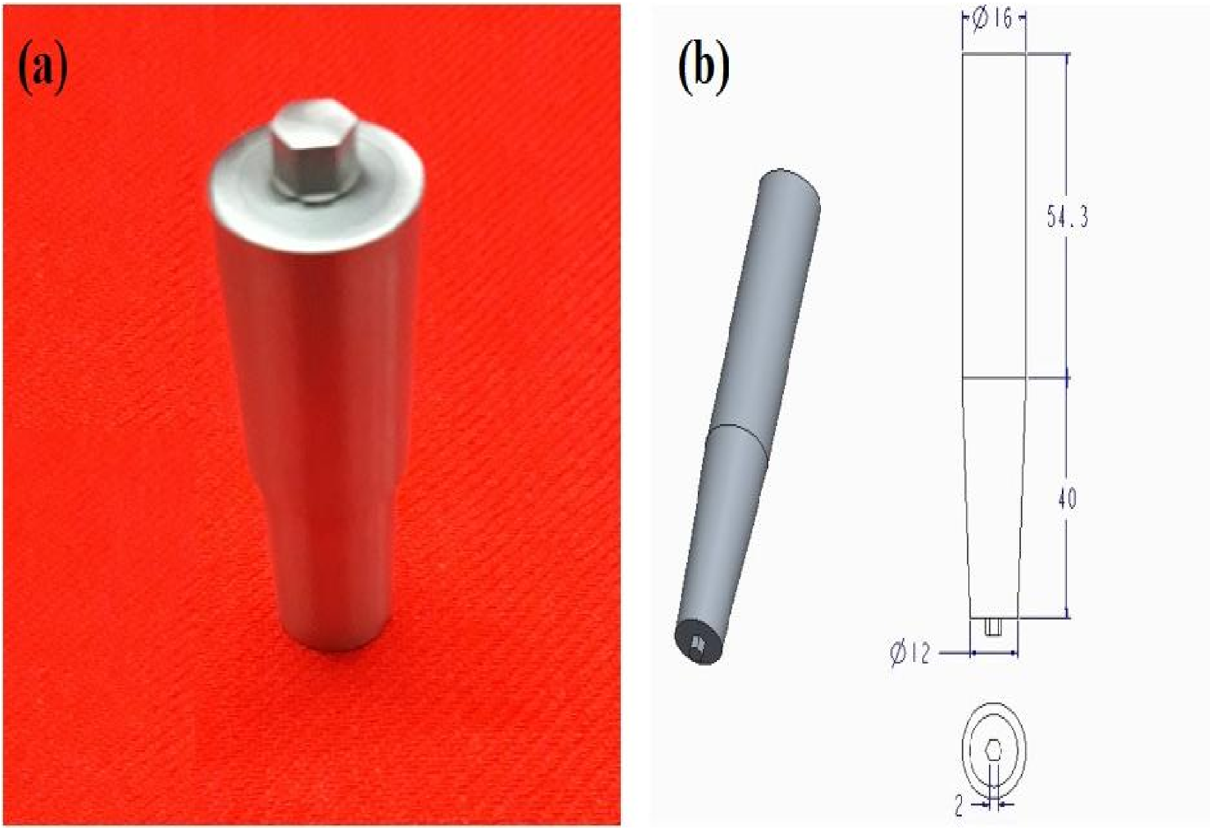


Figure 1 FSW Tool geometry

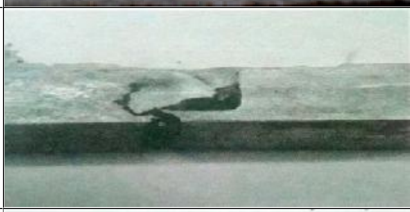
Ultrasonic cleaned specimens are cut into 10 x 10 x 6 on either side equal to the weldment for examining the microstructural properties. These specimens are moulded by the Bakelite granules and etched with Keller's etchant made in a composition of 5 cm^3 HNO_3 conc., 3 cm^3 HCL conc., 2 cm^3 HF conc., 190 cm^3 H_2O for 20 min and immediately these specimens are dipped in the water. This process increases the visualization of microstructure at the weldment. The microstructure analysis was made and analyzed on the etched specimens by Stereomicroscope (Magnification: 2 mm) and microhardness is also investigated by Vickers microhardness testing machine (Model: Wolpert, HV 0.5Kg) at Omega Inspection and Analytical Laboratory. The microstructures were observed by the scanning electron microscope with different magnifications (500 KX) and with EDS at PSG Tech College of Engineering, Coimbatore. Bothe macrostructure and hardness specimens were prepared as per its standards ASME E340 and IS: 1501 respectively.

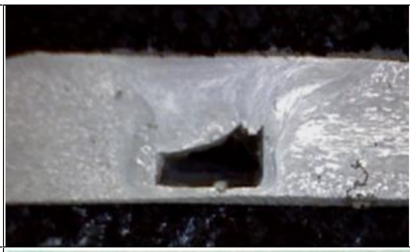
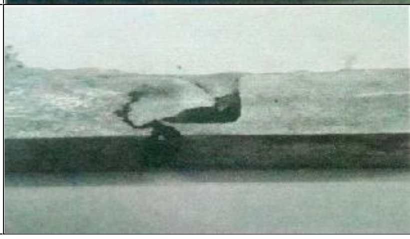
3. Results and Discussions

3.1 Analysis on the Macrostructure of the FSW/FSPed Butt Joints

The friction stir welding joints are successfully produced. The obtained joints show no porosity with some noticeable defects.

Table 4 Macrostructure of the FSW/FSPed Butt Joints

Sl.No.	**Specimen Details**	**Macrostructures**	**Inferences**
AA 8011 – AA 8011 Aluminium alloys			
1.	Without Nanoparticles		The tunnel defect is found at the advancing side due to higher welding speed and pin length.
2.	With Al_2O_3 Nanoparticles		The weldment is good and there is a proper mixing of nano particles.
3.	With SiC Nanoparticles		The weldment is good and there is a proper mixing of nano particles
AA 5083 – AA 5083 Aluminium alloys			
1.	Without Nanoparticles		The tunnel defect is found at the advancing side due to higher welding speed and pin length.
2.	With Al_2O_3 Nanoparticles		Cracks and Tunnel defect is formed due to improper mixing of nano particles due to higher welding speed
3.	With SiC Nanoparticles		The defect-free welded joints are observed.

AA 8011 – AA 5083 Aluminium alloys			
1.	Without application of Nanoparticles		The cavity is formed at the lower part of the welded zone nearer the retreating side.
2.	With Al_2O_3 Nanoparticles		The cavity is formed as the material is dissimilar in the welding zone.
3.	With SiC Nanoparticles		The tunnel defect is found at the advancing side due to the higher welding speed.

From the Table 4, it is observed that the formation of tunnel defect observed in the root of the tool due to higher welding speed [17] and lower penetration into the AA8011-AA8011 aluminium alloys without addition of nanoparticles, whereas in addition with nanoparticles, such as Al_2O_3, and SiC in friction stir processed aluminium alloy of AA8011-AA8011 showed the defect-free structure in the stir zone due to the proper dynamic crystallization and material flow in the welded joints. The AA5083-AA5083 aluminium alloy With SiC Nan particles showed the sound defect-free weld while comparing to other welds of Similar AA 5083 aluminium alloy without nano addition and with Al_2O_3. Furthermore, the cavity and tunnel defect were found for all conditions of dissimilar aluminium alloy combinations [18] with and without nanoparticles in stir zone.

3.2 Analysis of the Micro Hardness of the FSW/FSPed Butt Joints

The similar friction stir welding of aluminium alloys showed the same base metal hardness in both advancing and retreating side. From the Figures 2 (b) and 2 (c),) the maximum hardness was obtained in friction stir processed aluminium alloys in addition to Al_2O_3 nanoparticles. The maximum hardness was achieved in the AA8011-H24 and AA5083-H321 aluminium alloys with Al_2O_3 addition and stated that the proper mixing of the nanoparticles in the aluminium alloys with the help of heat developed by the tool on the butt surfaces compared to the hardness of the other butt joints. Furthermore, in thermomechanically affected zone (TMAZ), the hardness value initially decreased than the hardness of the base aluminium alloys due to plastic deformation of material then it is drastically increasing in the stir zone similar results obtained by Ghosh et al. [19].

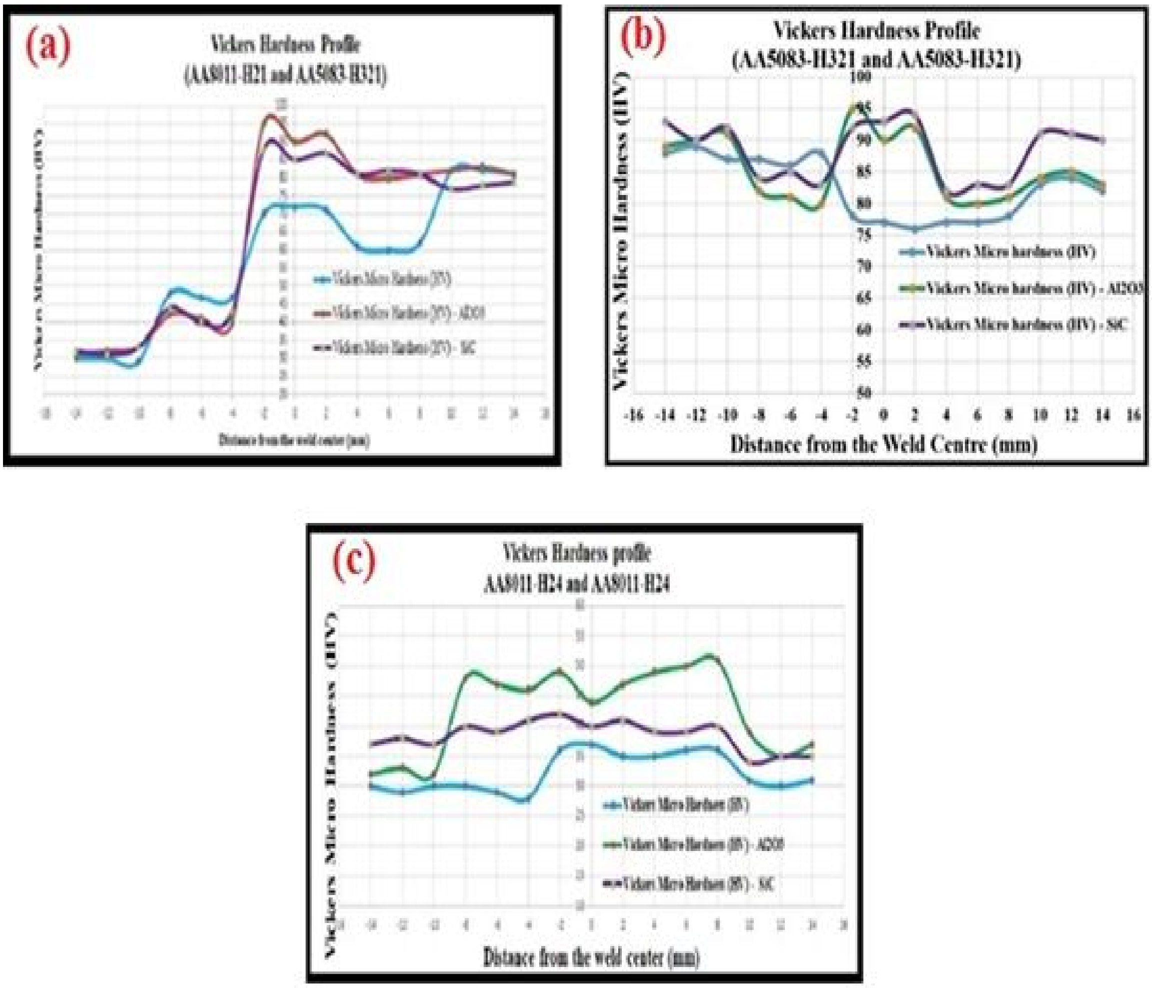


Figure 2 Micro Hardness of test specimens for different material combinations

3.3 Analysis of the Microstructure of the FSW/FSPed Butt Joints

The microstructure of the welded joints showed the quality of the weld based on the improvement of the strength properties and sound defect free joints. The microstructure analysis was carried for the dissimilar aluminium alloys of AA5083 H321-AA5083 H321 in addition to SiC Nano Particles shown in Figure 3. From the Figure, it was observed that the better weld appearance and joint strength was examined with nanoparticle SiC in AA5083 H321-AA5083 H321 aluminium alloys due to sufficient heat generation between the alloy materials and tool pin surfaces in stir zone whereas the improper diffusion of nanoparticles with aluminium alloys were observed in the thermo-mechanically affected zone [20] and heat affected zone which degrades the joint strength properties.

4. Conclusions

The effects of the process parameters on the microstructure and microhardness of the dissimilar friction stir welded/processed AA5083-H321 with AA 8011-H24 aluminium alloys were investigated and the following conclusions were derived:

- The macrostructure of both similar and dissimilar FSW/FSP of AA5083-H321 with AA 8011-H24 aluminium alloys in addition to nanoparticles Al_2O_3 and SiC showed the sound defect free joints compared to other joints.
- The maximum hardness was observed at the weld nugget zone in addition to nanoparticles Al_2O_3 in dissimilar AA8011-H24 and AA5083-H321 welded joints by proper material mixing and plastic deformation and fine grain formation occurred by the maximum frictional heat at the stir zone whereas the variations of hardness occurred at the thermomechanically affected zone which is lower than the hardness at the stir zone.
- The better microstructural results were observed in friction stir processing joints relate to the friction stir welded joints and the addition of nanoparticles improved the surface and joint properties.

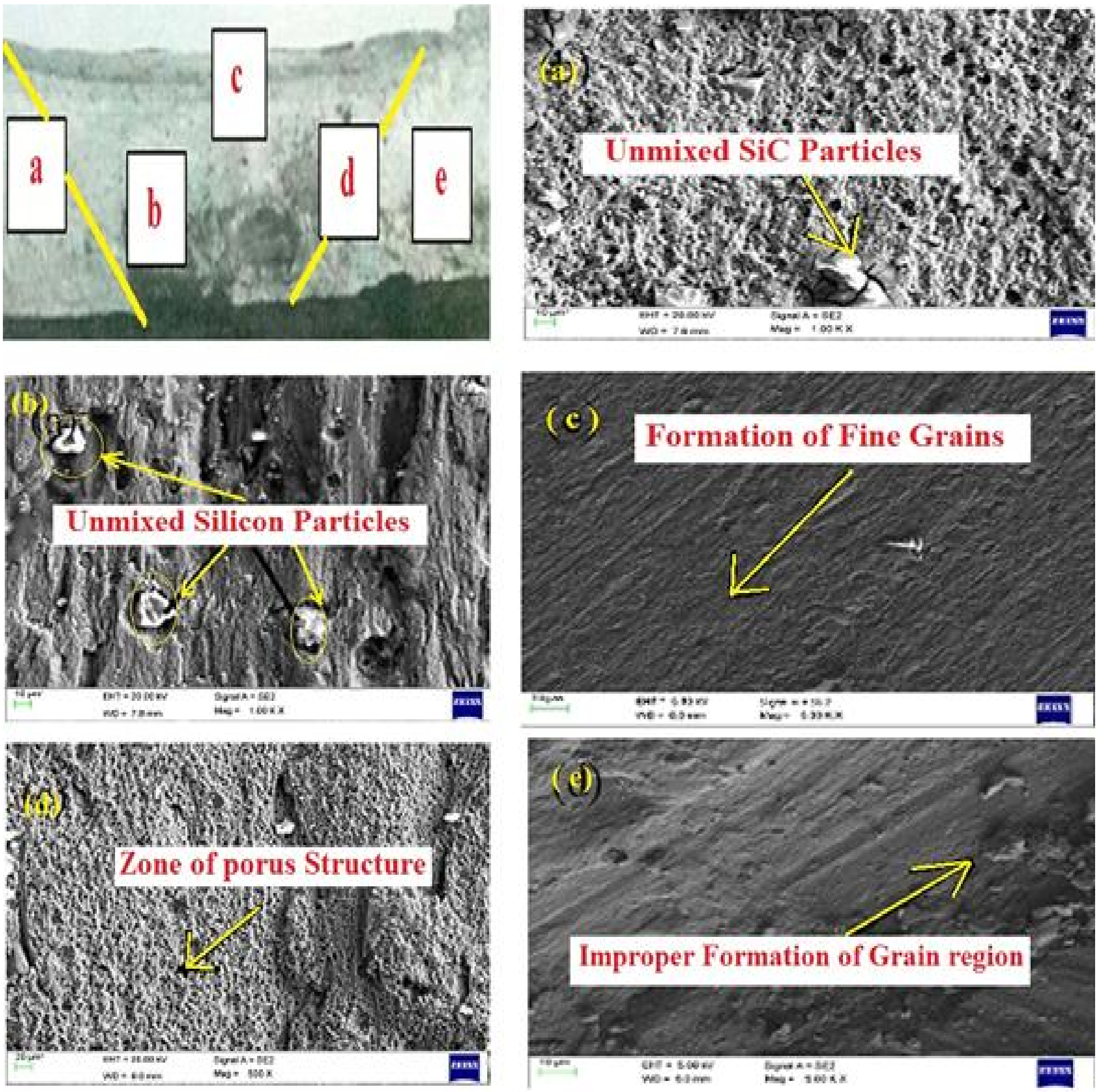


Figure 3 Microstructural analysis of the FSW/FSPed joints of the AA5083-H321 - AA5083-H321 with SiC (a) TMAZ at advancing side (b) TMAZ at retreating side (c) Nugget zone (d) HAZ at advancing side (e) HAZ at retreating side

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