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The effect of friction stir processing on the friction stir welded AA1050-H14 and AA6082-T6 joints

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ABSTRACT

In this paper, the single-pass friction stir processing technique was applied to the friction stir welded dissimilar aluminium joints. This was done to create a comparative analysis of the mechanical properties of the friction stir processed FSW and unprocessed FSW welded joints of the AA1050-H14 and AA6082-T6 where different positioning (advancing and retreating) were used to assess which positioning gives better mechanical properties. A rotational speed of 1200 rpm, traversing speed of 40 mm/min and a tool tilt of 2° were used as for both friction stir welding and friction stir processing. The tests conducted include tensile tests, microstructure, microhardness. The fracture surfaces of tensile testing were further analysed using the scanning electron microscopes (SEM) with Oxford energy-dispersion spectrometry (EDS). The Ultimate tensile strength of 83.2 MPa, percentage elongation of 22.13% and yield strength 61.1 MPa were found on the friction stir processed joint. The friction stir processed joint also had a maximum microhardness of 80HV which was higher than that of the unprocessed one. The results show that FSP resulted in the improvement of the mechanical properties due to the grain size refinement. The positioning of aluminium alloy 1050-H14 on the advancing side and AA6082-T6 on the retreating side yielded better results for both unprocessed friction stir welded joints and friction stir processed joints.

Selection and peer-review under responsibility of the scientific committee of the 10th International Conference of Materials Processing and Characterization.

1. Introduction

Aluminium alloy 6082-T6 is as an Al-Mg-Si alloy consisting of sufficient plasticity for extrusions and contains very high relative strength. This alloy has excellent weldability, formability, and machinability and is mostly used in the manufacturing of high-speed trains [1–3]. Aluminium alloy 1050-H14 is a grade consisting of moderate strength with excellent corrosion resistance, high ductility and a reflective appearance. Aluminium alloy 1050-H14 is mostly used in industries like food industries for containers, lamp reflectors, etc. [4]. In such industries, there is a great demand to improve product performance, this then resulted in an increase of welding dissimilar materials [5]. Dissimilar materials can be aluminium alloy to aluminium alloy [6,7], aluminium to copper [8,9], aluminium to magnesium [10,11], etc. The most recently used method of joining such materials is the friction stir welding (FSW), which is a solid-state joining method invented by The Welding Institute (TWI) of United Kingdom in 1991 [12]. One of many challenging decisions during FSW of dissimilar alloys is determining the material positioning. Chaudhari et al. [13] suggested that the hardest material should be positioned on the advancing side in order to increase the heat input during welding. Additionally, the positioning of the material was found to be dependent on welding conditions [14]. The welding of dissimilar materials results in the formation of intermetallic compounds which compromises the joint quality. This then called for the requirement of post-processing of the joint. Friction stir processing came as the joint enhancing technique. Friction stir processing (FSP) is defined as the microstructural modification technique which was derived from FSW. FSP works the same way as the FSW but does not join metals instead it strengthens the properties of the joint [15].

It has been shown that FSP could be used to break the large second phase particles into smaller and more resistant fragments. The reduction of these large second phase particles was studied through microstructural analysis which enhanced the tensile properties of the material used [16]. Kalashnikova and Chumaevskii, [17] showed that FSP can be used efficiently to the TiC particles distribution in aluminium based samples. A 2 mm groove was pre-

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Table 1
Chemical composition aluminium alloy 6082-T6 [20].

	Mg	Zn	Cr	Si	Mn	Fe	Cu+Ag	Al
6082-T6	1.1	0.20	0.25	0.90	0.70	0.50	0.10	Bal

Table 2
Chemical composition aluminium alloy 1050 [21].

	Al	Mg	Zn	Si	Mn	Fe	Cu	V
1050	99.5	0.05	0.05	0.05	0.05	0.4	0.05	0.05

Table 3
FSW welding parameters.

Rotational Speed (rpm)	Travelling speed (mm/min)	Vertical force (kN)	Tilt angle
1200	40	4.5	2°

pared on the AA6082 plate in which the reinforcement particles were dispersed using the tool. This resulted in improved mechanical properties of the AA6082 plate [18,19]. There are many studies that have been done on the use of FSP technique in modifying single material however there is a limited work when it comes to the application of FSP technique on the welded joints.

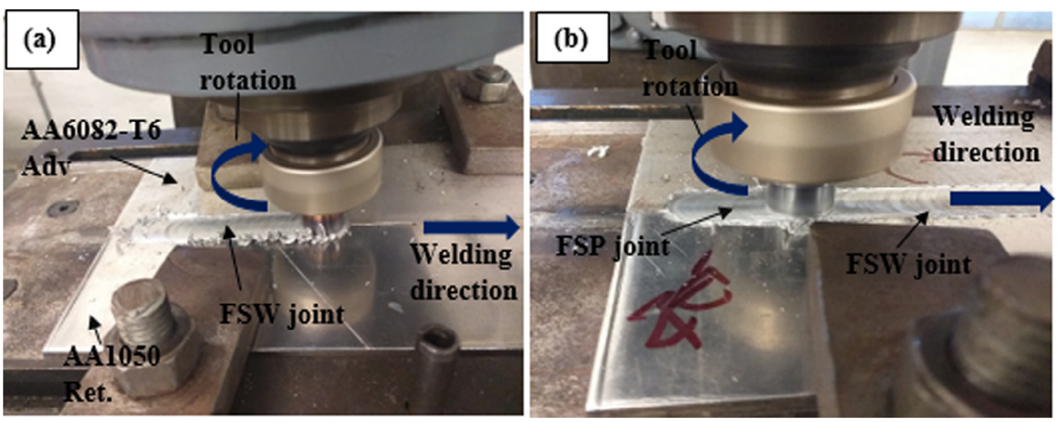

Fig. 1. (a) FSW setup; (b) FSP setup.

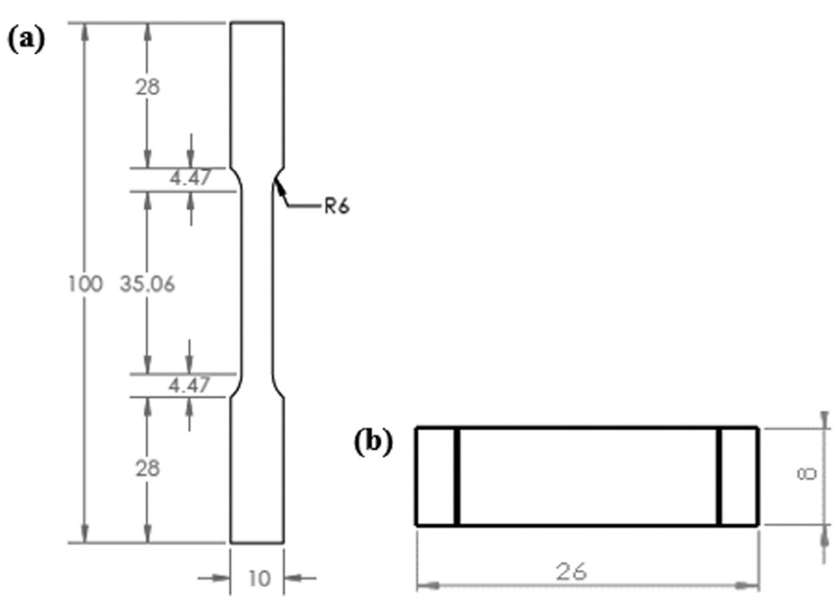

Fig. 2. Specimen geometry with dimensions in mm (a) Tensile test; (b) Microstructure specimen.

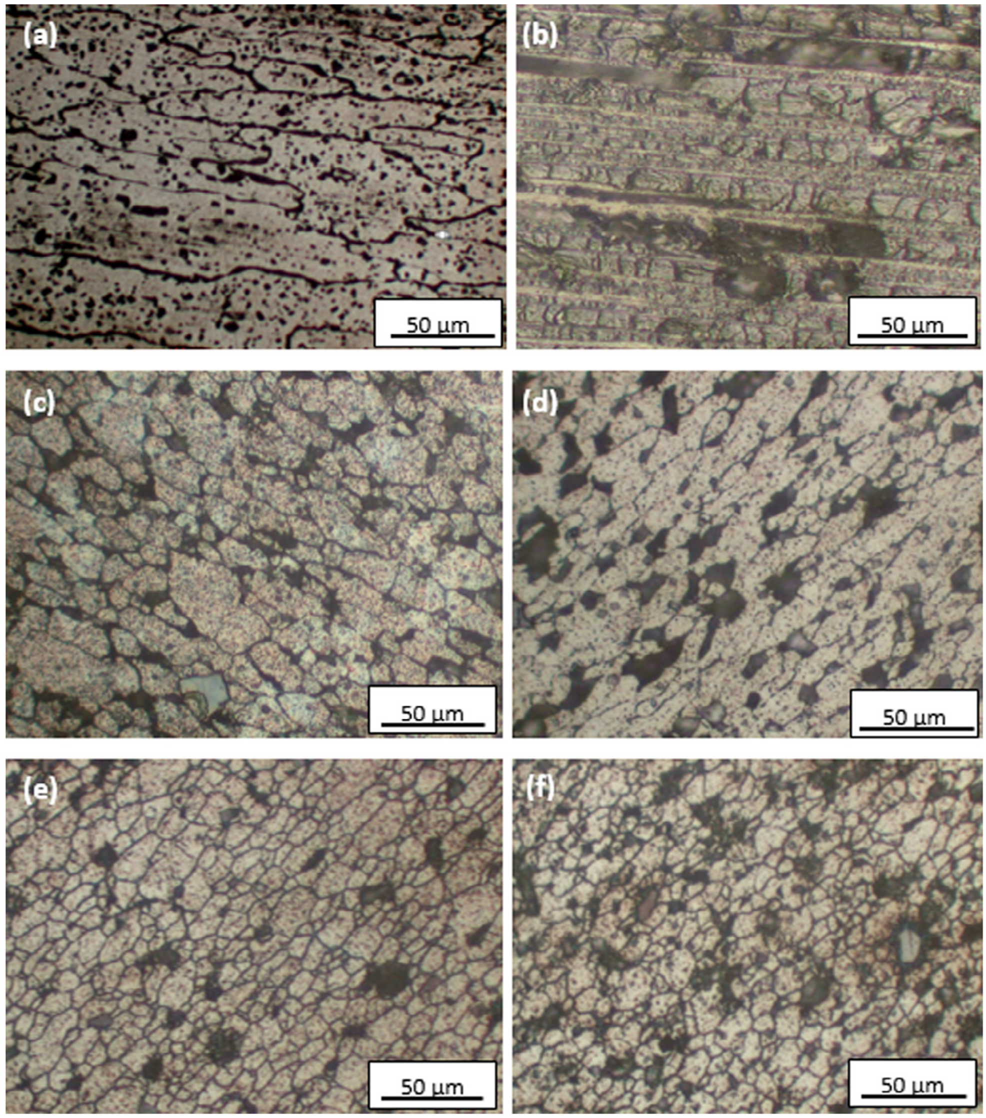

Fig. 3. Optical micrographs using objective 20× magnification 50 µm (a) AA6082-T6 BM; (b) AA1050-H14 BM; Stir zones (c) Unprocessed FSWed joint AA1050-H14 advancing side, (d) Unprocessed FSWed joint AA1050-H14 retreating side; (e) Friction stir processed FSWed joint AA1050-H14 advancing side; (f) Friction stir processed FSWed joint AA1050-H14 retreating side.

The present paper reports on the mechanical properties of the friction stir processed FSWed AA1050-H14 and AA6082-T6 joint. Moreover, the impact of material positioning is also reported.

2. Experimental procedure

The 6 mm thickness of dissimilar AA1050-H14 and AA6082-T6 were used in forming the joint. The plates were cut into 400 × 70 × 6 mm so as to fit the FSW backplate. The chemical composition of each material used in welding is shown in Tables 1 and 2. The semi-automated milling machine was used in performing FSW and FSP. The parameters used for welding and processing are shown in Table 3. The high carbon steel (H13) tool with a spiral profile was used in the performance of FSW and FSP [22,23]. The shoulder diameter of the tool was 20 mm while the pin was 5.8 mm long with 7 mm diameter. The positioning of alloys was varied during welding i.e. 1050-H14 placed on the advancing side and later 6082-T6 on the advancing side. This was done so as to analyze the positioning impact [6,7,24]. The performance of FSW and FSP is depicted in Fig. 1(a) and (b).

Tensile tests were performed using a Hounsfield 50 K tensile testing machine with Horizon operating software. The ASTM E8 standard was followed for specimen design and for tensile testing. The specimen geometry is shown in Fig. 2(a). The microstructure tests were performed using Motic Instruments AE2000Met Inverted Metallurgical Microscope. Prior to the performance of the microstructural analysis. The specimens were cut into sizes, see Fig. 2(b). The cut specimens were mounted, hand polished and etched. The Vicker's microhardness test was performed using the ASTM: E384-11. Same specimen design as the one in Fig. 2(c) was used.

3. Results and discussions

It should be noted that the friction stir welded and friction stir processed (FSPed) specimens were cut in the middle of each friction stir welded (FSWed) joint. The micrographs for the base materials AA1050-H14 and AA6082-T6, unprocessed and friction stir processed micrographs are shown in Fig. 3. The AA1050-H14 grain sizes presented in Fig. 3(a) were ranging from 19.45 to 31.15 µm

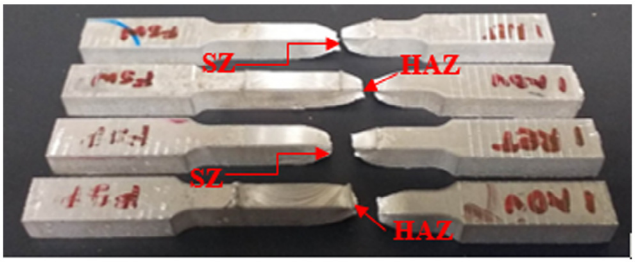

Fig. 4. Post tensile test specimens.

and for AA6082-T6 grain sizes (see Fig. 1(b)) were ranging from 10.4 to 14.7 μm. The grain sizes of unprocessed FSWed joint with AA1050-H14 located on the advancing side and AA60682-T6 on the retreating side were measured to be 7.1–10.4 μm. When AA1050-H14 was placed on the retreating side the grain size 6 to 8 μm. The grain sizes of the friction stir processed FSWed joint with AA1050-H14 located on the advancing side we ranging from 4.4 to 6.1 μm, while the ones with AA1050-H14 on the retreating side were ranging from 2.6 to 4.9 μm. FSP significantly refined the grain sizes of the dissimilar joint [11,20,21,29].

Fig. 4 presents the failure locations of the processed and unprocessed specimens after the performance of tensile tests. The specimen failed on the 1050-H14 side when the same material was placed on the advancing side during welding. The failure occurred on the stir zone when 1050-H14 was placed on the retreating side. Similar behaviour is also observed on the processed joints [25–27]. Table 4 present the tensile test results for the unprocessed and friction stir processed FSWed joints. The ultimate tensile strengths (UTS) of the joints where the weaker alloy was placed on the retreating side are higher than those on when it was placed on the retreating side. The maximum UTS was found to be on the friction stir processed FSWed joint. Furthermore, all the UTS obtained were lower in comparison to both base metals [20]. TheFSPed and

Table 4
Tensile test results.

Technique	Specimen	Yield strength	Ultimate Tensile Strength (MPa)	Elongation (%)
	AA6082-T6	**236**	**280**	**10**
	AA1050-H14	**85**	**105**	**6**
FSW	AA1050-H14 Adv.	29.2	48	20.3
	AA1050-H14 Ret.	54.9	80.1	20.47
FSP	AA1050-H14 Adv.	61.1	83.2	20.6
	AA1050-H14 Ret.	58.6	81.5	22.13

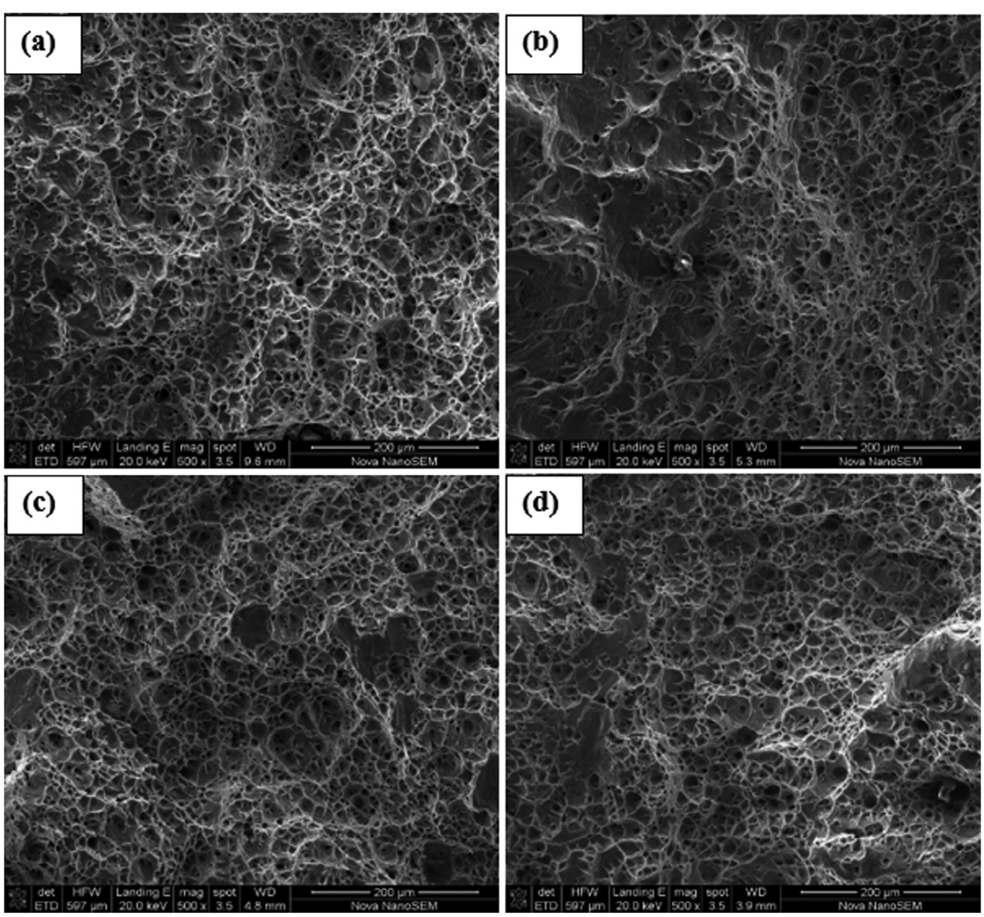

Fig. 5. SEM images at 500× magnification (a) FSW AA1050 advancing side and AA6082 on the retreating side; (b) FSW AA1050 retreating side and AA6082 on the advancing side; (c) FSP AA1050 advancing side and AA6082 on the retreating side; (d) FSP AA1050 retreating side and AA6082 on the advancing side.

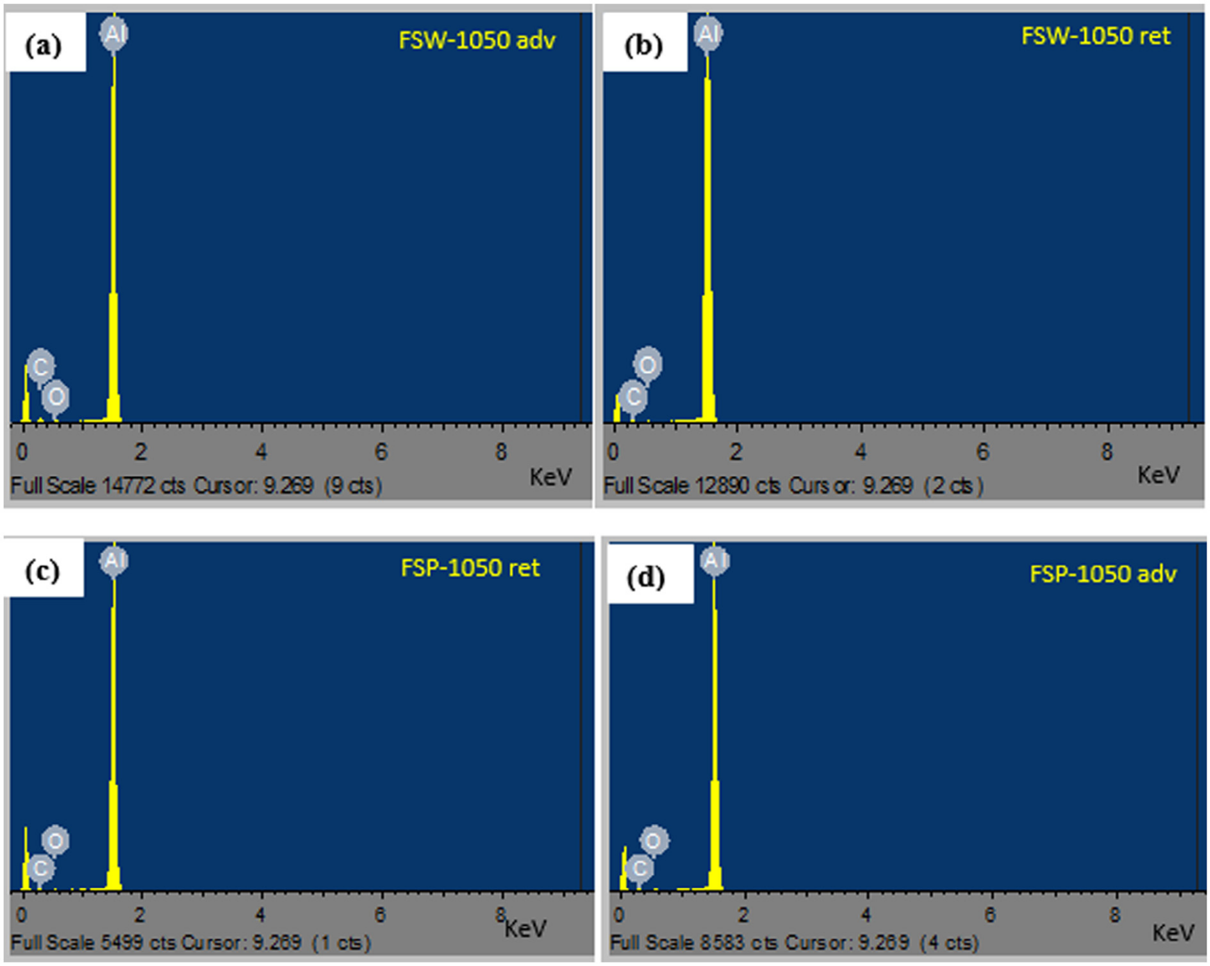

Fig. 6. EDS images (a) FSW AA1050 advancing side and AA6082 on the retreating side; (b) FSW AA1050 retreating side and AA6082 on the advancing side; (c) FSP AA1050 retreating side and AA6082 on the advancing side; (d) FSP AA1050 advancing side and AA6082 on the retreating side.

unprocessed joints were all having higher percentage elongation compared to the base metals. This suggests that the unprocessed and FSPed joints are more ductile compared to the base metals.

Fig. 5 shows the SEM results of an analysis conducted on the fractured surfaces of the post tensile test specimens. Fig. 5(a) and (b) show the unprocessed fractured surfaces where AA1050-H14 was placed on the advancing side and retreating side, respectively. Fig. 5(c) and (d) depict the fractured surfaces of FSPed joints with AA1050-H14 on the advancing side and on the retreating side respectively. Both unprocessed and processed specimens show a ductile failure which is revealed by a large number of equiaxed dimples with different sizes. The failure mode revealed by SEM results is in agreement with the percentage elongation values from Table 4 [28,29]. Fig. 6 shows the EDS mapping interface of the unprocessed and friction stir processed FSWed joints. The EDS results do not show any new phase formation post welding and processing.

The Vicker's microhardness results are presented in Fig. 7. The maximum microhardness of 80HV was obtained on the stir zone of the FSPed joint with AA1050-H14 placed on the advancing side of the joint. The maximum microhardness value of 50HV was observed on the unprocessed joint where the AA1050-H14 was placed on the retreating side. The FSPed joint has finer grains compared to unprocessed joint hence the difference in microhardness values [30].

4. Conclusion

The AA1050-H14 and AA6082-T6 dissimilar joints were successfully joined via friction stir welding and the same joints were later friction stir processed successfully. The application of FSP technique on the FSWed dissimilar aluminium alloys has increased the UTS of the joints. The ductility of both FSPed and the unprocessed joint was higher than the base metals hence higher percentage elongation. The highest tensile properties achieved were the percentage elongation of 22.13%, UTS of 83.2 MPa and yield strength of 61.1 MPa compared to all other joints. The highest microhardness value obtained was 80HV on the friction stir processed FWSed joint. The failure locations of the specimens post tensile tests suggests that the positioning of weaker material on the advancing side strengthens the joint. The FSPed and unprocessed joints showed a ductile failure mode based on the nature of fractured surfaces. The mechanical properties where AA1050-H14 was positioned on the advancing side and AA6082-T6 was positioned on the retreating side were higher than those when the weaker alloy was placed on the retreating side for both friction stir welded and friction stir processed joints. This then suggests that when welding dissimilar alloys, the material positioning has an impact on the outcomes.

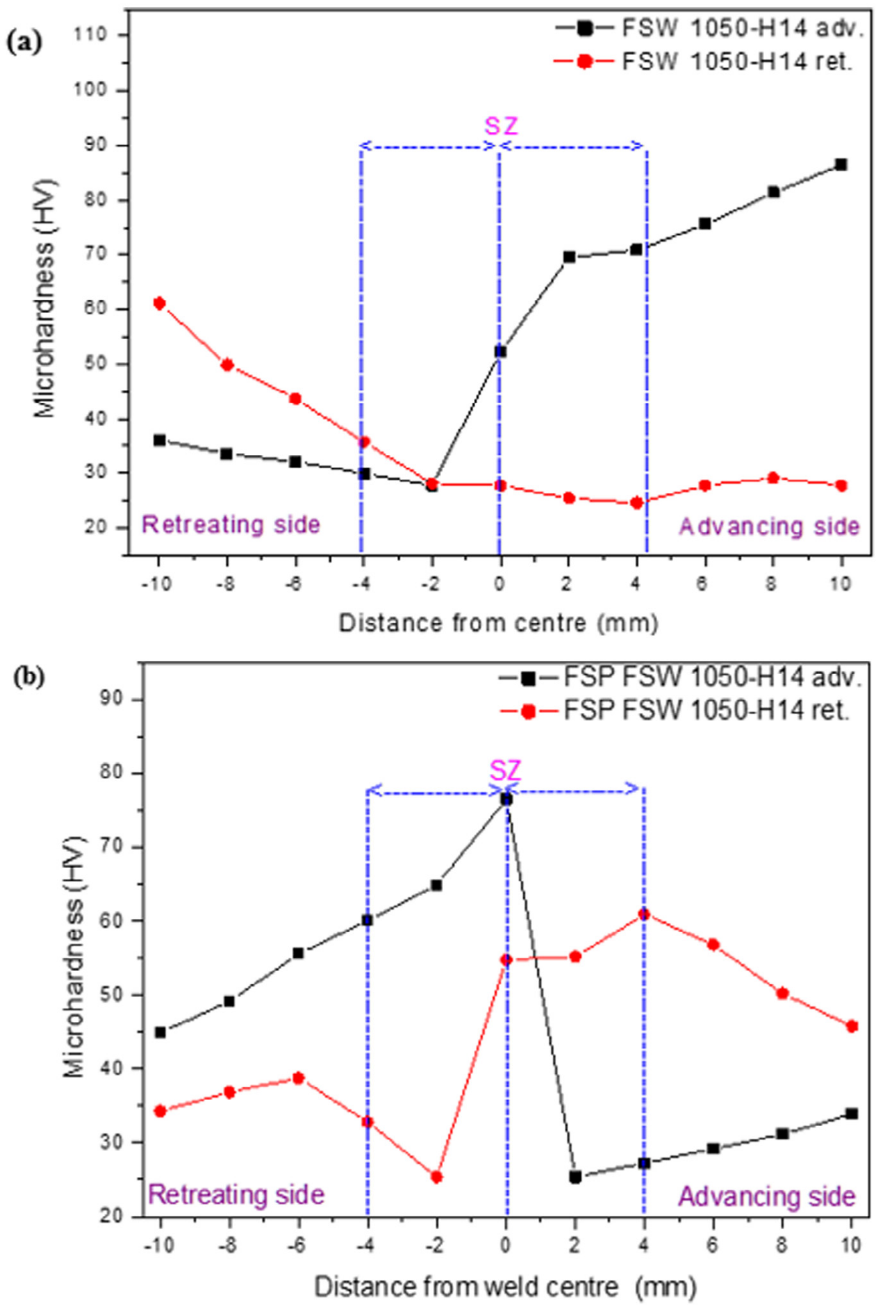

Fig. 7. Microhardness profiles (a) Friction stir welded joint; (b) friction stir processed FSWed joint.

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