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Current Developments in Friction Stir Welding (FSW) and Friction Stir Spot Welding (FSSW) of Aluminium and Titanium Alloys

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Abstract: To fabricate joints of dissimilar materials such as alumnium and titanium with excellent joint properties with limited defects, there is a need to use effective joining techniques. Friction stir welding (FSW) and friction stir spot welding (FSSW) are solid-state welding techniques considered environmentally friendly joining techniques. The two techniques have been used to join numerous materials including aluminium, copper, and titanium. Joining dissimilar materials has seen a huge expansion worldwide due to the high demand for dissimilar joining exhibiting specific properties to be used for specific applications. This short review presents the resulting properties of joints made with aluminium and titanium using friction stir welding and friction stir spot welding. Microstructure evolution, mechanical properties, and other properties are presented and critically reviewed. Many aluminium and titanium alloys have been welded using several process parameters and tool geometries. In FSW it has been seen that aluminium/titanium exhibited high strength when the rotational speed is well controlled. From the gathered information it was concluded that the tool rotational speed was associated with heat input and low speed resulting in low heat input. This produced fine recrystallized grains, especially at the joint interface. On the other hand, FSSW has also been utilized to weld Al to Ti. Results showed that parameters such as rotational speed and dwell time had an impact on the formation of intermetallic compounds (IMCs) including Ti_3Al and mechanical properties were achieved. It was observed that FSSW between aluminium and titanium has not been well researched, therefore there is a need to further study the behavior of the two materials when spot welded. It is expected that the augmentation of knowledge on the fabricated joint behavior will lead to the expansion of these techniques for specific applications and to the optimization of FSW and FSSW between alumnium and titanium alloys.

Keywords: friction stir welding (FSW); friction stir spot welding (FSSW); aluminium, titanium; itermetallic compounds

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1. Introduction

The joining of materials with different properties has been a focus of numerous studies. Many joining techniques including resistance welding and friction welding have been used to join similar and dissimilar materials [1,2]. Friction stir welding (FSW) was developed and known as a reliable solid-state joining technique [3]. On the other hand, friction stir spot welding (FSSW) is a variant of FSW and is an established alternative joining procedure for resistance welding. FSW and FSSW use a non-consumable spinning tool for joining different materials. The schematic illustrations of friction stir welding and friction stir spot welding are shown in figure 1.

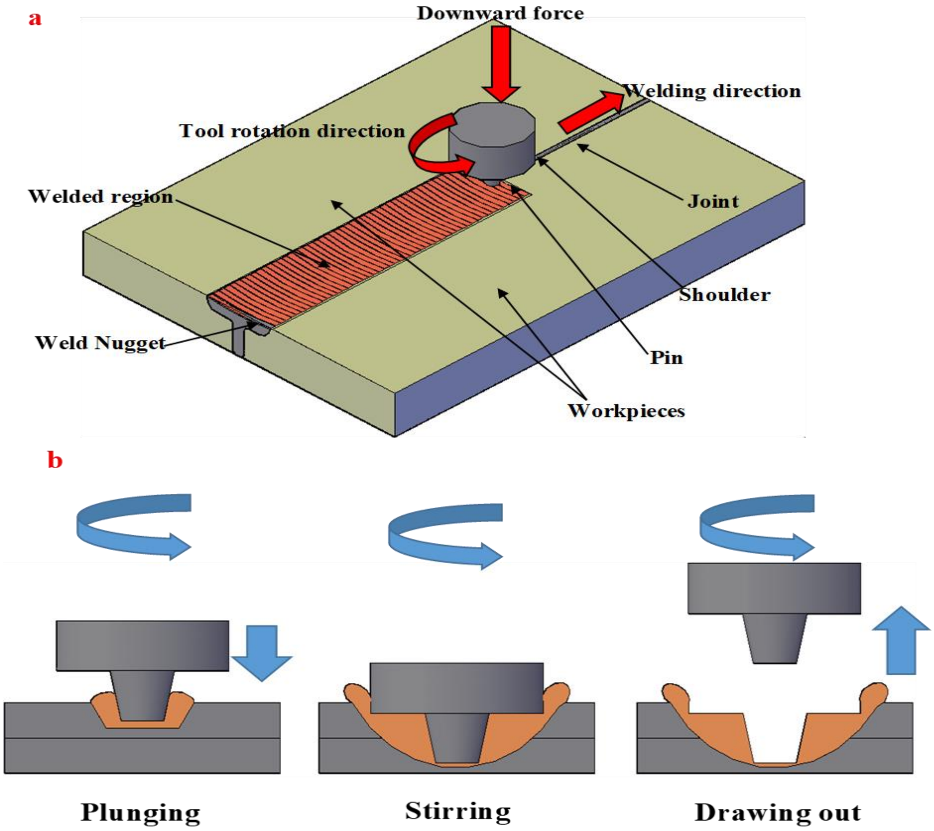

Figure 1. (a) Friction stir welding and (b) friction stir spot welding illustrations.

Friction stir welding and friction stir spot welding processes use a non-consumable rotating tool consisting of a pin and a shoulder that is forced into the edges of the workpieces [4]. It should further be noted that in the solid-state joining processes, few defects are produced and that is because the materials to be joined do not reach their melting temperatures [5]. Friction stir welding and friction stir spot welding have been used to join a large number of materials [6,7]. On the other hand, FSW and FSSW between aluminium and titanium are not well-researched [8–36]. These solid-state joining techniques have gained popularity because the welding of dissimilar materials using advanced and conventional fusion techniques is challenging due to the differences in the metallurgical and mechanical properties of the materials to be joined [31]. Titanium alloys are widely utilized in aerospace, rail transportation, and biomedical sectors because of their excellent properties (High strength, high melting point, corrosion resistance) while the aluminium alloys also display excellent properties including low density, high strength, and good processability. Furthermore, aluminium alloys are also less costly while titanium alloys are expensive and have poor processibility that prevents their extensive utilization [21,37–39]. Since the two alloys exhibit different properties including the melting point, thermal conductivity, and linear expansion coefficient; consequently, a proper joint configuration is essential. Moreover, the welding of aluminium to titanium has a major application in the aerospace industry in the fabrication of body structures where high strength and light weight are needed to reduce fuel consumption [31].

For FSW and FSSW, the titanium is put on the advancing side since it has been reported that the harder materials should be placed on the advancing side to maximize the performance of the fabricated joints [21,40,41]. During FSW and FSSW of Al to Ti, there is usually the formation of intermetallic compounds (IMCs), however, it has been reported that when the right process parameters and tool geometries are used, there is a significant reduction of IMCs and that is linked to the generation of heat (heat input) [42–47]. And that has an effect on the resulting properties of the fabricated joints. More studies are needed to be carried out to further understand the behaviour of the two materials when joined using FSW and FSSW. Therefore, this review provides a short overview of the current trend in FSW and FSSW between aluminium and titanium alloys.

2. Friction Stir Welding (FSW) Between Aluminium and Titanium Alloys

A number of studies are available in the open literature on FSW between Al and Ti focusing on the effects of the process parameter on the microstructural evolution and mechanical properties of the fabricated joints. The observation was that the process parameters especially the rotational speed and traverse speed resulted in higher heat input and that impacted the resulting properties.

Patel et al [12] used hybrid approaches of FSW to join pure Ti and AA6061-T651 aluminium alloy. They indicated that water cooling can be explored as a novel processing condition when friction stir welding aluminium to titanium. They further said that the tensile strength was improved for the joints fabricated with water-cooling and that was attributed to grain refinement and strengthening however when the cooling was reduced the tensile strength was negatively affected. A similar trend was observed for the microhardness results. They also observed the presence of intermetallic compounds at the joint interface. In other studies, the presence of intermetallics was observed by Wu et al. [21], on FS Welds of Ti-6Al-4V and AA6061 when the rotational speed was raised. On the other hand, when the rotational speed was lower, a pure homogeneous interface without intermetallic compound (IMC) and small interface thickness was observed. Additionally, the mechanical properties were also affected by the process parameters. Also, Geyer et al. [17], friction stir welded AA2024-T3 to Ti-6Al-4V overlap joints and observed that high rotational speed results in high heat input resulting in welding defects such as hooks and thicker layer of IMC at the interface of Ti-6Al-4V and AA2024-T3 weld joint. In another study, when the traverse speed was increased the grain size decrease was observed, and observed an excessive formation of intermetallics within the alumnium to titanium mixture (Ti-6Al4V and AA6061) [13].

3. Friction Stir Spot Welding (FSSW) Between Aluminium and Titanium Alloys

When compared to FSW between alumnium and titanium, FSSW of Al to Ti has not received the same attention. Limited studies are published in the open literature. 28. Nasir et al. [28] investigated the FSSW of AA7075-T651 to Ti-6Al-4V alloys using carbon fiber-reinforced polymer (CFRP) as an interlayer material. The effect of welding parameters and the presence of the interlayer material was investigated. Results showed an increment in the shear tensile strength (maximum) and that was due to the heat input that melted the carbon fiber-reinforced polymer interlayer material and resulted in the enhancement of the formed bond between the materials. They also indicated that the dwell time has a significant effect on the shear tensile load (Figure 2b). However, the hardness values were principally affected by the tool rotational speed as depicted in Figure 2 c. The SEM/EDS analysis showed the presence of intermetallic compounds (Ti_3Al and Ti-Al-C) and those were found to impact the shear tensile strength of the fabricated joints (Figure 2 a). The formation of intermetallics depended on the heat cycle of a weld joint which was linked to the process parameters utilized namely rotational speed and dwell time [28].

Furthermore, some studies were carried out on the refill friction stir spot welding (RFSSW) between aluminum and titanium [22,26,27]. Friction stir spot welding was used to join AA5754-H22 to Ti-6Al-4V and the keyhole was refilled [27]. In this study, it was observed that the refill process had a substantial effect on the microstructure evolution changes along the welded part and that had a direct effect on the mechanical properties and corrosion behavior of the fabricated welds [22]. It can be said and has been reported that the refill process of the formed keyhole during FSSW will affect the integrity of the fabricated joint. Therefore, this process should be encouraged, investigated, and utilized to achieve better surface finish and properties.

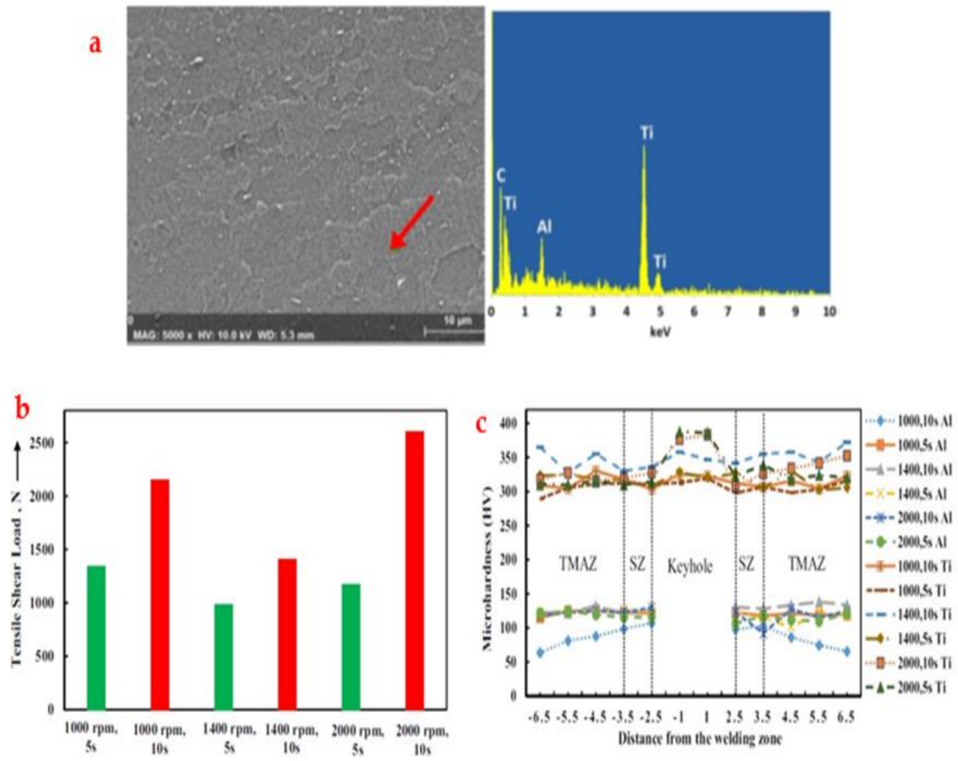

Figure 2. FSSW of AA7075-T651 to Ti-6Al-4V alloys using carbon fiber-reinforced polymer interlayer (a) SEM/EDS, (b) shear tensile strengths, and (c) Microhardness profiles [28].

4. Conclusions

Friction stir welding and friction stir spot welding between aluminium and titanium have been successfully carried out using various tool geometries and process parameters. Process parameters such as rotational speed, traverse speed, and tool plunge depth have an important in the integrity of the fabricated weldments. To produce joints with excellent properties, the heat input must be controlled and that can be achieved by using higher rotational speed and lower traverse speed for FSW. As for FSSW, not much information is available on the effect of process parameters. Therefore, more studies are needed to produce more data which would lead to the optimization of the solid welding process. It was further noticed when FSW is used to join titanium alone or aluminium alone, the two materials demonstrated an improved corrosion resistance. Therefore, studies on the corrosion resistance of FSW and FSSW between aluminium and titanium should be carried out and investigated. This would enable the two technologies to be vastly used.

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