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Microstructural characterization and mechanical properties of aluminum 6061-T6 plates welded with copper insert plate (Al/Cu/Al) using friction stir welding

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Abstract: Friction stir welding was used to join two aluminum 6061-T6 plates with an insert of a pure copper plate (Al/Cu/Al), and then the influence of the copper insert on the joint performance was studied. The dissimilar welding results were also compared with AA 6061 friction stir welds produced without copper insert (Al/Al). Optical and scanning electron microscopes were used for the microstructural observations of the welded samples. X-ray diffraction analysis was used to analyze phase component of the Al/Cu/Al specimen. A defect-free joint was observed for the Al/Cu/Al joint at a rotational speed of 950 r/min and a welding speed of 50 mm/min. Microstructural observation of the weld nugget zone (WNZ) demonstrates the formation of composite-like structure which promotes metallurgical bonding of aluminum and copper. XRD results show the formation of intermetallic compounds (IMCs), such as Al_4Cu_9 and Al_2Cu. Furthermore, it was observed that the hardness of the weld with the Cu insert plate is higher than that of other samples due to more dislocation density and a distinct rise in hardness values was observed due to the presence of IMCs. The ultimate tensile strength of the joint with copper insert plate is higher than that of the other sample due to the strong metallurgical bonding between Al and Cu.

Key words: friction stir welding; Al/Cu/Al; intermetallic compounds; microstructure; mechanical properties

1 Introduction

Aluminum and copper have been extensively utilized as industrial structure materials due to their distinctive properties, such as formability and ductility, corrosion resistance, heat transfer and electrical conductivity [1,2]. Aerospace, automotive and electronic industries have used numerous mixture components specifically for the aluminum/copper (Al/Cu) metallic combination which proves the significant mechanical properties [3,4]. However, a dissimilar joining of aluminum and copper is commonly problematic due to excessive dissimilarity in their physical and chemical properties [5−7]. Fusion welding technique has been used to create dissimilar joint between Al and Cu, but some problems happened such as solidification cracking, oxidation and formation of the undesirable amount of brittle Intermetallic compounds (IMCs) due to the high chemical affinity between Al and Cu, which resulted in poor mechanical properties [8−12]. Thus, some welding techniques such as explosive welding [13,14], diffusion bonding [15,16] and friction stir welding (FSW) have been established as unconventional welding methods for creating a joint between Al and Cu. FSW is a solid-state welding process developed by the welding institute (TWI) [17], which has been employed for welding of similar and dissimilar materials [18−25]. Generated temperature in this welding process is lower than the metal melting point which makes this method as a good candidate for welding dissimilar materials. Formation of the joint without any melting reduces the problems that occurs in the fusion welding. Therefore, many recent investigations have been done on the application of FSW in dissimilar joining between Al and Cu.

AKINLABI [26] studied the effect of welding parameters on the mechanical properties of joints between 5754 aluminum alloy (AA) and C11000 copper (Cu) generated with the friction stir welding process. He investigated the tensile strength using different welding parameters such as tool size, rotational speed and traverse speed. The results indicated that the joint created had joint efficiency of 86% when the rotation rate is 950 r/min and feed rate is 50 mm/min with the 18 mm

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shoulder diameter tool, which can be satisfactory for design objectives. The X-ray diffraction analysis revealed the presence of Al_4Cu_9 and Al_2Cu intermetallics at the stir zone. AKINLABI [26] also reported that a good material flow was obtained in welds generated at lower feed rate owing to high heat generated whereas the welds created at high feed rates led to worm hole defect formation. LIU et al [27] investigated the microstructural and mechanical properties in the friction stir welded 5A06 aluminum alloy to copper (T2). They found that the maximum ultimate tensile strength (UTS) obtained in FS welds of aluminum and copper was approximately 296 MPa when the tool rotational speed is 950 r/min, and the feed rate is 150 mm/min. XUE et al [28] studied the microstructural and mechanical properties of friction stir welded aluminum/ copper joints. It is observed that FSW Al/Cu joints failed in the HAZ of the Al side with a 13% of elongation. The yield strength and the ultimate tensile strength (UTS) were ~80% and ~90% of the Al base material respectively. However, in some specimens the fracture was located in particle-rich zone (PRZ), and the UTS was nearby 210 MPa which was much higher than Al base metal. LI et al [29] investigated the microstructural and mechanical properties in the friction stir welded 1350 aluminum alloy to pure copper. They reported that the hardness increased obviously in the stir zone due to the strengthening effect of the Al/Cu intermetallic compounds. Furthermore, they observed that the hardness at the lower region of the nugget zone is mostly higher than other regions owing to the intense stirring action of the tool pin which led to recrystallized grains. The UTS of the dissimilar joint was 152 MPa with 6.3% elongation, and the joint fractured in a ductile−brittle mixed fracture mode. AKINLABI et al [30] studied the influence of heat input on the mechanical properties of joints between aluminum and copper generated with the friction stir welding process. The joints were fabricated using different welding parameters in order to vary the heat input to the welds. The microstructural observation revealed that good metallurgical bonding was achieved at the joint interfaces of the welds produced. Higher Vickers microhardness values were observed at the joint interfaces resulting from strain hardening and the existence of intermetallics.

The purpose of the study is to introduce a new approach to the welding processes by incorporating characteristic features of composite structures with the similar weld joints. In order to fulfill this aim, the new approach of using Al/Cu/Al dissimilar weld joint has been utilized. Throughout this work, most of the references were made based on the dissimilar joining of Al and Cu. It has been thoroughly outlined that the mechanical properties of such welds are superior in terms of its tensile strength. However, the usage of this particular kind of welds is uncommon within the industries. On the other hand, Al/Al FSWed joint has been used for industrial application, especially in the circle of automotive and aerospace engineering. From our study, the similar Al/Al FSWed joint can be replaced with Al/Cu/Al joint for more optimum performance; since dissimilar joints have been proven to possess enhanced properties compared with similar joints and thus, will be able to withstand the loading conditions that these components will be subjected to on the field. Consequently, the essence of this study is to merge the desirable features of dissimilar welding with similar welding, which has more applications in the industries.

This work deals with the FSW process of AA6061 plates with and without the presence of copper inserts between the adjoining plates. Microstructure and mechanical analyses were performed to assess the influence of the copper insert on the joint performance. Many researchers have employed the FSW technique to weld similar and dissimilar materials, but this study presents a combination of the welding of two similar material plates (AL6061-T6) with a different material plate (copper) between them, by which a similar technique was conducted before using FSW as a weld marker technique for flow visualization in FSW, but there is a no attempt to investigate the mechanical properties. The hybrid welded sheet can be used in processes where higher tensile strength is required.

The properties of a joint, generated by FSW are directly related to the material flow around the tool. Several flow visualization studies in FSW have been conducted using a weld marker technique. This technique is based on the use of marker materials for tracing the material flow during welding. SCHMIDT et al [31] studied flow visualization in butt friction stir welds in AA2024-T3 via introducing a thin copper strip between the workpieces as a marker material as shown in Fig. 1. The material flow is visualized via the distribution of the Cu particles in the stir zone. SEIDEL et al [32] observed the visualization of the material flow in AA 2195 friction stir welds using a marker insert technique. AA5454-H32 thin strips were inserted into the faying surface of the two plates to be welded. Result shows the full three-dimensional plots of the distorted markers description which affords a good qualitative description of material flow in this welding. Moreover, DICKERSON et al [33] used a weld marker technique for flow visualization. Copper strips of 0.1 mm in thickness were inserted as a marker material in various series of aluminum alloys.