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Effect of interlayers on softening of aluminum friction stir welds

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ABSTRACT

Effects of the zinc, copper and brass interlayers were studied on the microstructure evolution and mechanical properties of the wrought aluminum friction stir welds. Optical and scanning electron microscopes (SEM) as well as X-ray diffraction (XRD) analysis were used for investigation of the distribution, dissolution and reactions of the interlayers, grain structure in the stir zone and fracture surfaces. Longitudinal and transverse tensile and microhardness tests were also carried out in order to evaluate the mechanical properties of the welds. The results showed that without insertion of the interlayer, the joint efficiency (ratio of the weld strength to the aluminum base metal strength) was ~60%. While zinc and copper interlayers had no significant effect on the joint efficiency, insertion of the brass interlayer increased the joint efficiency up to ~90%. Microstructural observation indicated that brass interlayer was relatively well distributed inside the stir zone and Al_2Cu and Al_4Cu_9 intermetallic compounds were formed due to the solid-state reactions between the aluminum matrix and brass particles during welding leading to the increase in the weld strength. In the case of the zinc interlayer, no intermetallic compound was detected inside the weld zone and zinc was dissolved in the aluminum matrix to form a solid solution. Moreover, the joint welded using copper interlayer suffered from lack of distribution of the detached copper particles. Fracture analysis after tensile test showed that insertion of the interlayers generally changed the fracture location from the advancing side towards the retreating side due to the formation of a composite structure and increase in the strength of the advancing side.

1. Introduction

Due to high strength to weight ratio as well as the appropriate chemical and physical properties, aluminum and its alloys are widely used in various industrial applications. Therefore, similar and dissimilar joining of aluminum alloys is inevitable [1]. One of the most important concerns in fusion welding of the aluminum alloys is softening of the weld metal compared to the wrought and/or heat treated base metal which is caused premature failure during the service. This softening is attributed to the decrease in the dislocation density and dissolution or growth of the strengthening precipitates in non-heat treatable and heat treatable aluminum alloys, respectively. Furthermore, this behavior is directly affected by the heat-input during welding. In fact, the more is the welding heat-input, the higher is the weld metal softening [2]. Consequently, solid-state welding in which the temperature experienced by the weld metal is lower than that of the fusion welding could be a solution for the reduction of the weld metal strength [3]. In terms of fusion welding processes such as gas tungsten arc welding (GTAW), joint efficiency (ratio of the weld strength to the base metal strength) generally reaches to 50–70%. However, a literature review shows that joint efficiency of solid-state welds can be higher compared to the fusing welding [4,5]. Thus, in the recent decades, most researchers focused on the solid-state welding of the aluminum alloys.

Friction stir welding (FSW), as a relatively new solid-state welding process, has been confirmed to be an operative method for joining aluminum alloys [1]. During FSW, a non-consumable rotating tool is plunged into the abutting edges of the sheets and is forced to travel in the direction of the joint line. The tool with a specially designed probe and shoulder, control the material movement and consequent flow pattern in the FSW technique. Heat is generated due to the friction between the rotating tool and the workpiece as well as the severe plastic deformation resulting to the softening of the materials around the tool. Rotation of the tool stirs the softened materials and the tool probe pushes the material behind the tool [3,6]. Formation of a soft region in non-heat-treatable and work-hardened aluminum alloys causes a decrease in the weld strength compared to the base metal [7–9]. Therefore, researchers have focused on the insertion of the reinforcing particles such as SiC [10], $ZrSiO_4$ [11], TiC [12], Nb [13], tungsten [14], and copper powders [15] into the stirred zone in order to improve the strength of the FSW joints. Inserting the interlayers such as zinc [16–18] between the aluminum base sheets may be another approach for overcoming the weld metal softening. The latter approach

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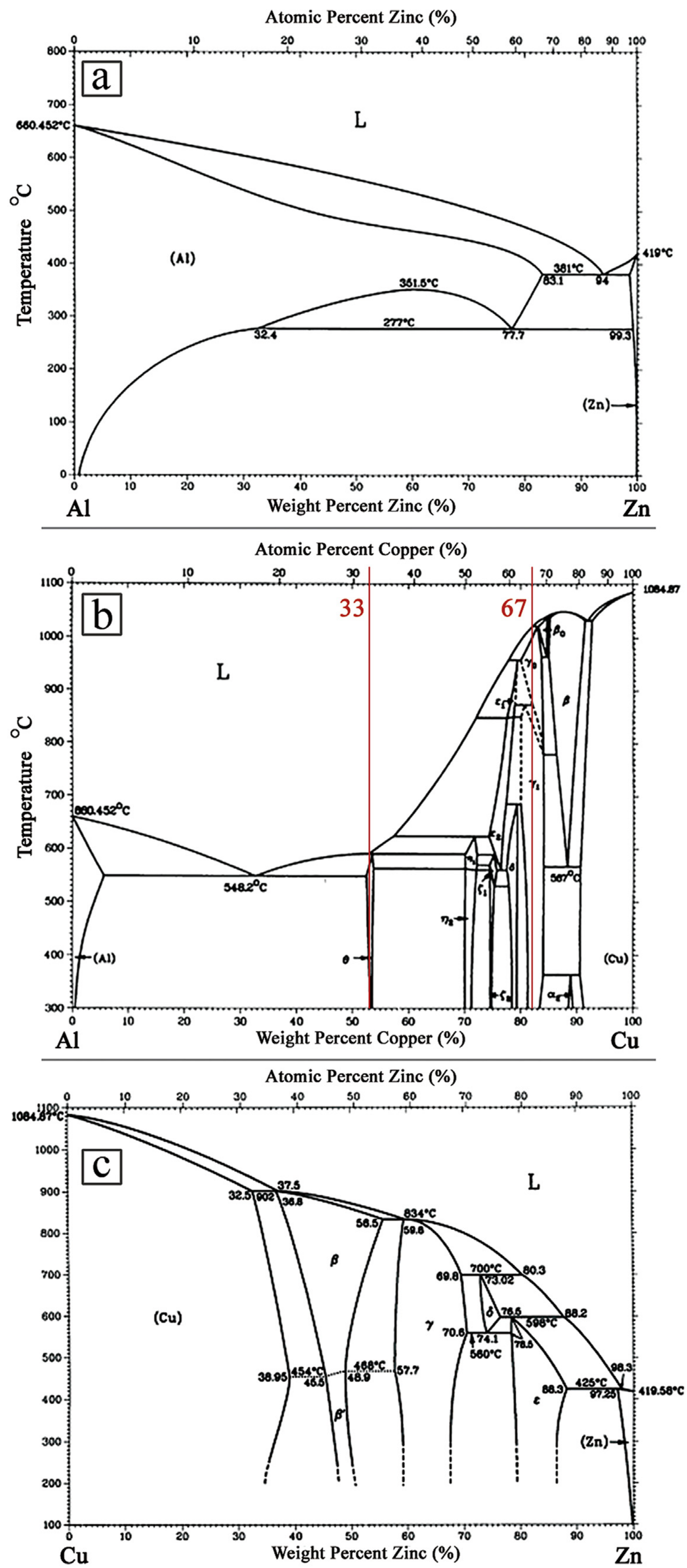

Fig. 1. Phase diagram of (a) Al-Zn, (b) Al-Cu and (c) Cu-Zn [38].