Mechanism of Toughness Enhancement of Brittle Fracture by Intermittent η-Intermetallic in Al/Cu Joint Made by FSW

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Introduction

Aluminum-copper joining is demanding due to its applications in electrical vehicles. One important factor in this join is mechanical durability. In this study, a clean and uniform Al/Cu interface was created using the Friction Stir Welding (FSW) technique, which allowed the investigation of the mechanism of pure brittle fracture in Al-Cu IMCs, using a notched tensile specimen. Fracture surfaces were analyzed in detail using scanning electron microscopy (SEM) and microstructural characterization techniques. Fractography results showed that the brittle fracture was multilayered and multi-faceted, with an intergranular fracture observed between the Al2Cu and Al4Cu9 IMCs. It was found that this multilayer fracture, induced by the intermittent AlCu between Al2Cu/Al4Cu9, provided the high tensile strength of the compound (173 MPa) compared to the values reported in the literature. A comparison of the Al/Cu joints with Al/steel joints also confirmed the contribution of this fracture deflection to the improved joint strength.

Methodology

A commercially pure aluminum EN AW-1050A and a commercially pure copper EN CW004A, both with a thickness of 3 mm, were clamped onto the FSW table in a butt configuration. The FSW tool was manufactured from hard tool-steel (H13) with a 14.5 mm shoulder diameter, a 3.5 mm pin diameter, and a 2.8 mm pin length. A 1mm too offset into Cu was used to make sure the joining (figure 1a). SEM was used in both secondary electron (SE) and back scatter (BS) modes to evaluate the IMCs at the interface. Notched tensile specimens were used to evaluate the joint strength by concentrating the stress at the interface (Figure 1b).

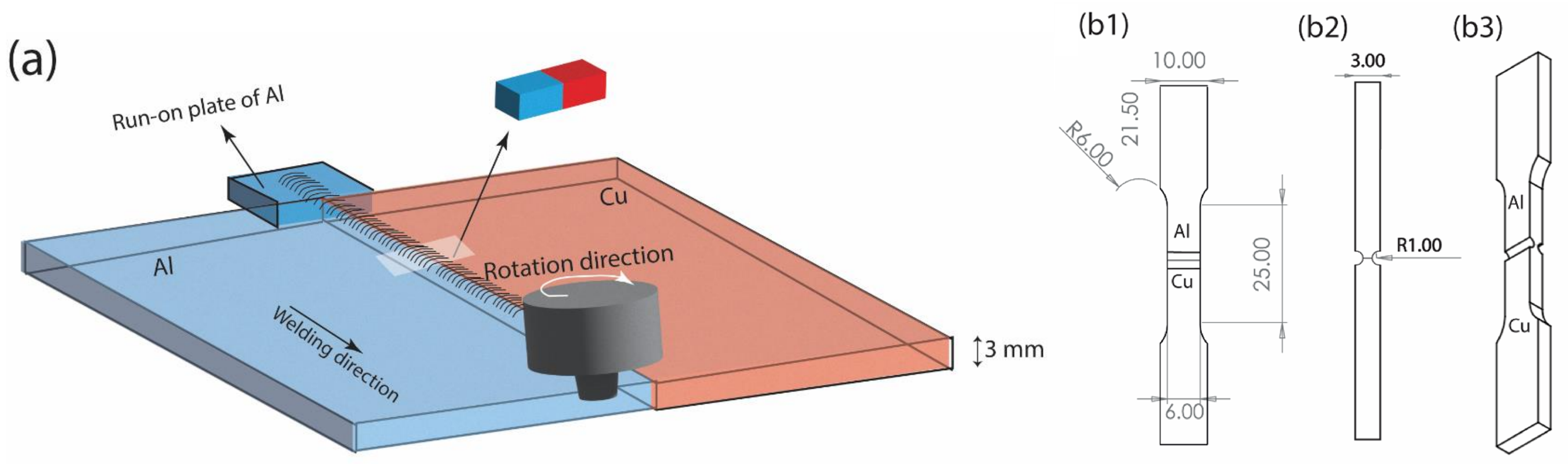
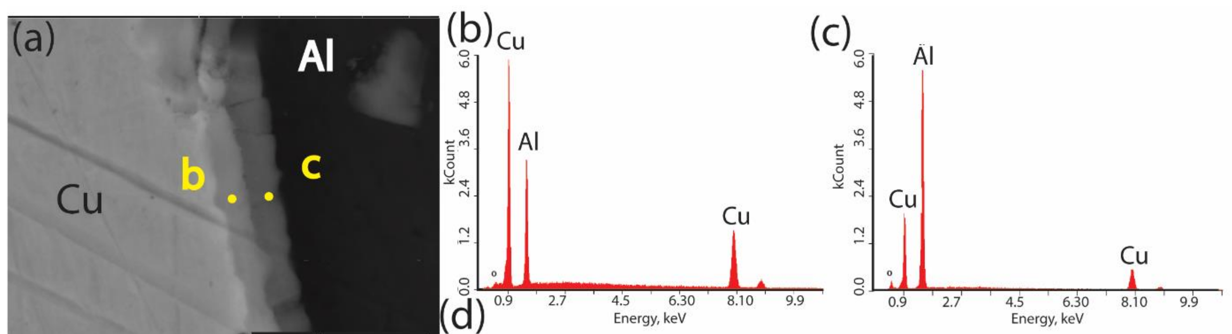


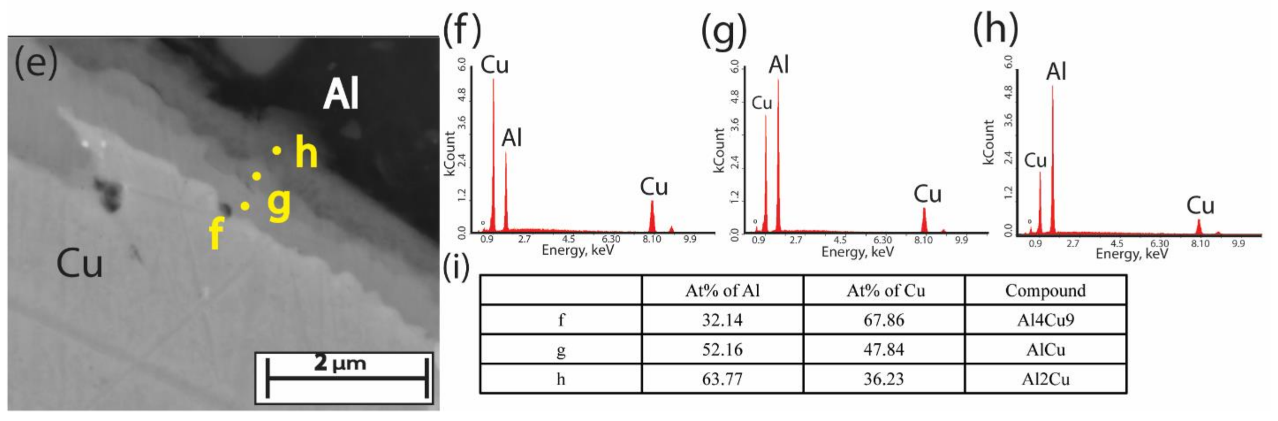
Figure 1. a) Schematic of FSW process for Al/Cu joining. b) Drawing of notched tensile specimen.

Results and Discussion



(d)

	At% of Al	At% of Cu	Compound
b	33.35	66.65	Al4Cu9
c	65.84	34.16	Al2Cu



(i)

	At% of Al	At% of Cu	Compound
f	32.14	67.86	Al4Cu9
g	52.16	47.84	AlCu
h	63.77	36.23	Al2Cu

Figure 2. a) BS SEM image of the vertical interface of Al/Cu joint. b,c) EDS analyses of points b and c. d) The table of chemical compositions. e) BS SEM image of the corner interface of Al/Cu joint. f,g,h) EDS analyses of points f, g, and h. i) The table of chemical compositions. .

BS SEM images taken from the interface are shown in figures 2a and e. EDS analyses were taken from layers of IMCs. Al4Cu9/AlCu/Al2Cu were the IMCs detected at the interface. AlCu was intermittently placed between Al4Cu9 and Al2CU. The SEM images from the fracture surfaces of the tested tensile specimen (Figure 3) shows a stepped fracture surface. Images in BS mode shows these steps correspond to different IMCs.

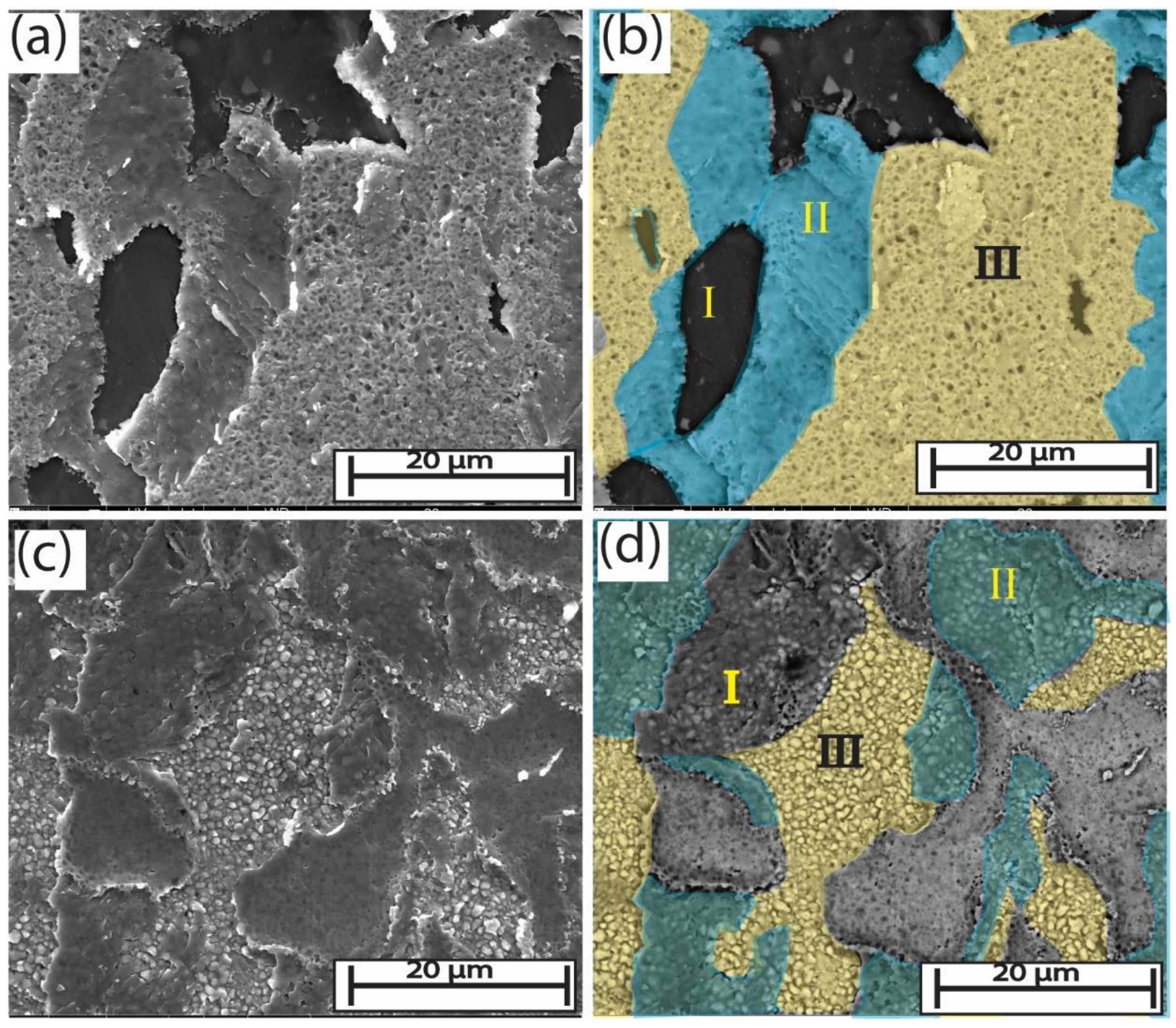


Figure 3. -SE and BS SEM images of the fracture surface taken from a,b) Al side and c,d) Cu side.

The proposed mechanism of failure of Al/Cu joints is provided in figure 4a. The deflection of crack through IMCs is found to be an important factor in increasing the fracture toughness of Al/Cu joints. A tensile strength of 173 MPa of Al/Cu joints in comparison with that of Al/St joint (90 MPa) infers the significance of deflection mechanism. Figures 4a and b show the mechanism of failure of Al/Cu and Al/St joints, respectively.

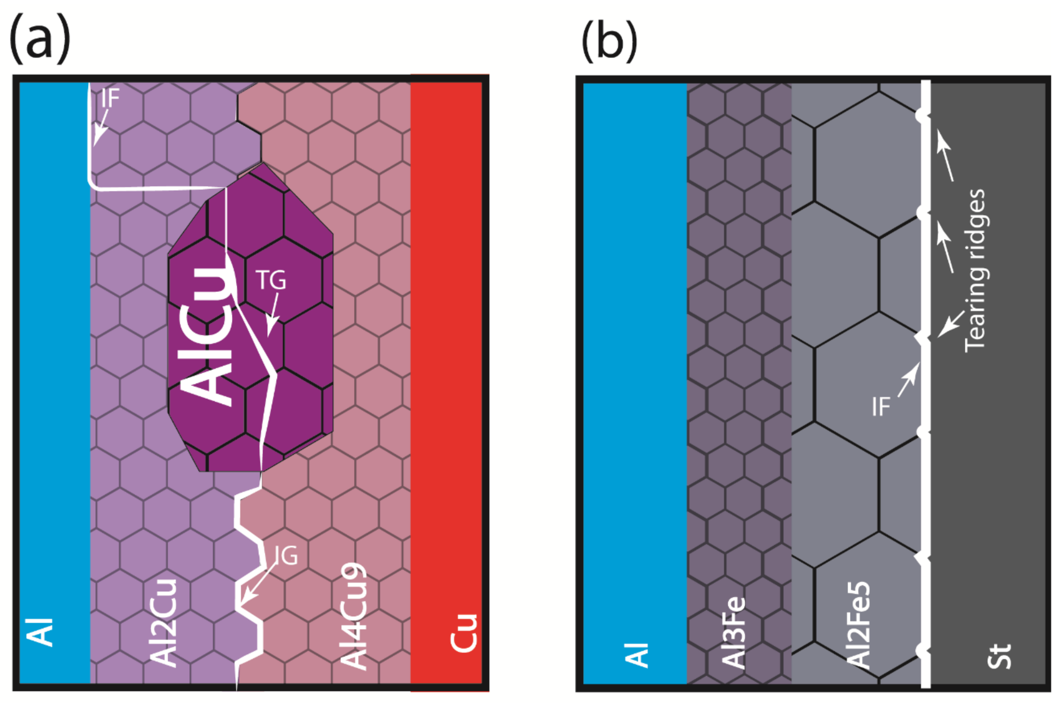


Figure 4. a) The schematic of failure of the Al/Cu interface. Intergranular fracture (IG), transgranular fracture (TG), and interfacial fracture (IF) are observed in this joint. b) The schematic of failure in Al/St joint. Only one type of fracture, IF, along with micro plastic deformation (tearing ridges) are observed in Al/St joints.

Conclusions

- The order of IMCs at the Al/Cu interface was Al2Cu, AlCu, and Al4Cu9, with AlCu intermittently placed between continuous Al2Cu and Al4Cu9 layers.
- The obtained fracture load of 173 MPa in this study was larger than the average reported in the literature (116 MPa).
- A comparison of the fractography between Al/Cu and Al/St joints verified the contribution of intermittent IMC layer to the enhancement of the fracture toughness.

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VBE2023 International Conference on Vehicle Body Engineering 2-3 November 2023 Porto, Portugal