FSW of Magnesium and Copper: A Step Forward to Weld Magnesium and Steel

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INTRODUCTION

In the wake of increasing environmental concerns and carbon dioxide (CO2) pollution, The demand for joining dissimilar metals and alloys across various industries has witnessed a significant surge in recent years. Copper and magnesium, both extensively utilized in transportation and advanced technologies, present considerable challenges in joining due to their differences in melting temperatures, distinct mechanical and physical properties, and the formation for brittle intermetallic compound (IMC) during conventional fusion welding processes. In this pioneering study, 3 mm thick AZ31 sheets were successfully joined to 3 mm thick Cu sheets using a novel lap-butt configuration via the friction stir welding process (FSW). Remarkably, a defect-free joint was achieved through the FSW process. It was observed that, except for localized regions, no significant IMCs layers were formed at the joint interface. The ultimate tensile strength of the joint reached an impressive 171 MPa, accompanied by a ductile fracture mode. A minimum 0f 50% increase in UTS with respect to the published literature, was the main outcome of the present research. This implied the potential of copper as an intermediate layer between steel and magnesium for welding.

Experimental Detatils

In this study, as illustrated in Figure 1, pure Cu and AZ31 sheets with a thickness of 3 mm were positioned in butt configuration with an additional 3 mm thick AZ31 sheet placed on top of them in a lap-butt joint configuration. FSW process was carried out using an H13 tool with dimension represented in Figure 1b. Tensile testing was used to assess the UTS of the joints. The interface of the joints were characterized by scanning electron microscopy (SEM) and optical microscopy (OM).

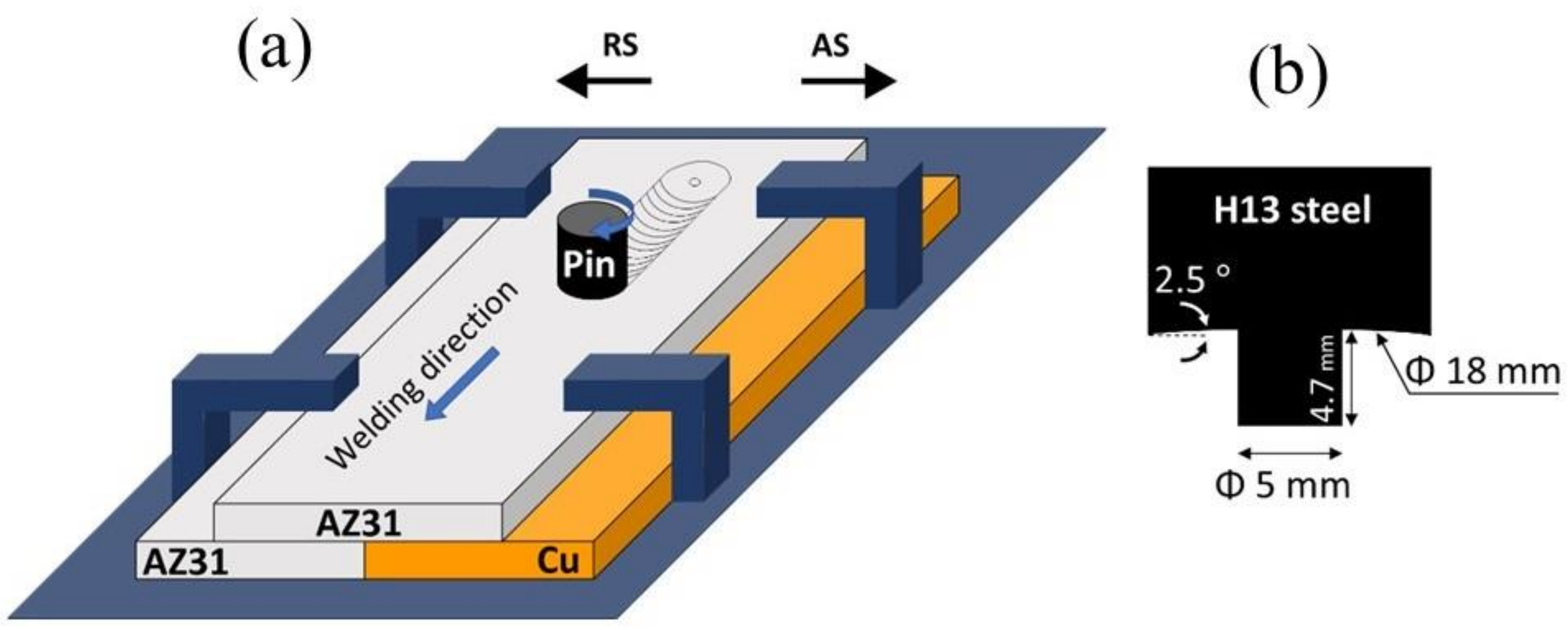

Figure 1 – (a) Schematic of FSW process of AZ31/Cu. (b) Schematic of the FSW tool.

Results and Discussion

Figure 2a shows the macrograph of the weld. The pattern of material flow caused this welding zone is shown in figure 2b.

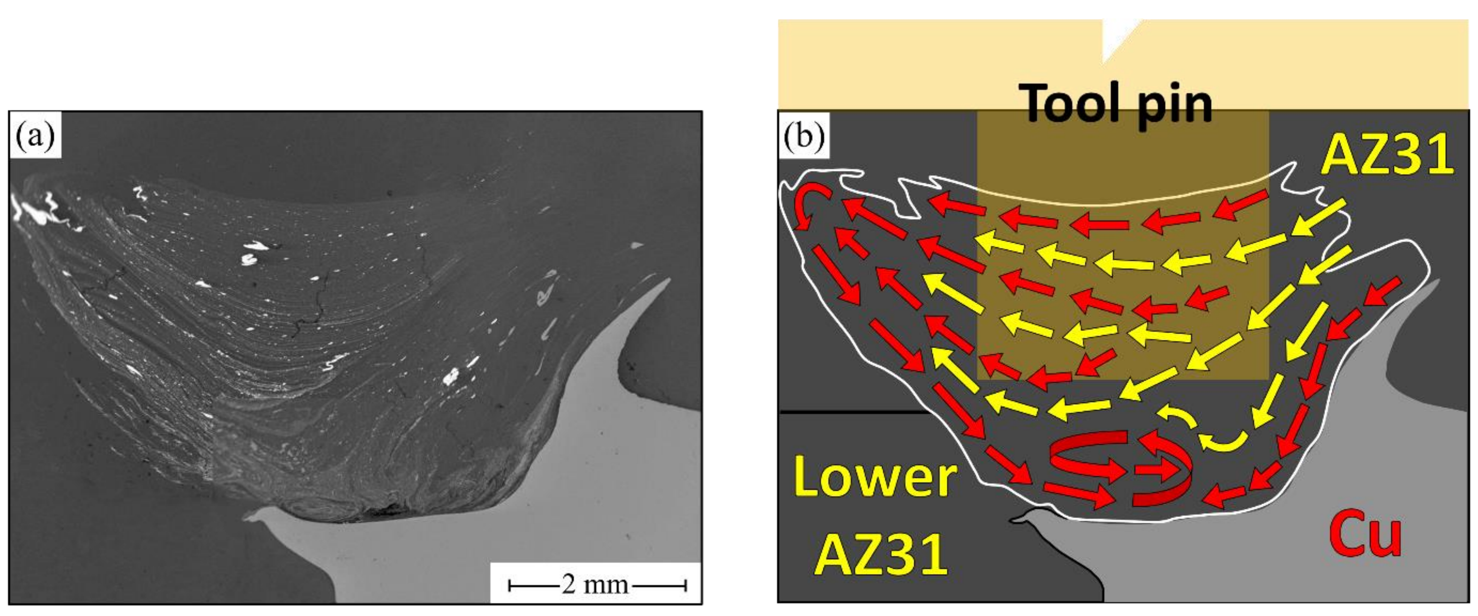

Figure 2 – (a) Macrograph of the weld. (b) The pattern of material flow.

Fragments of Cu are detached from the surface of the pure Cu sheet due to the rotational motion and subsequently penetrate into the stir zone. A vortex-like zone forms beneath the tool pin, where a AZ31 piece is placed onto the Cu/AZ31 but joint. The downward force of the pin induces a swirling interaction between Cu and Mg. OM image of the weld zone is shown in figure 3 where the flow pattern is visible.

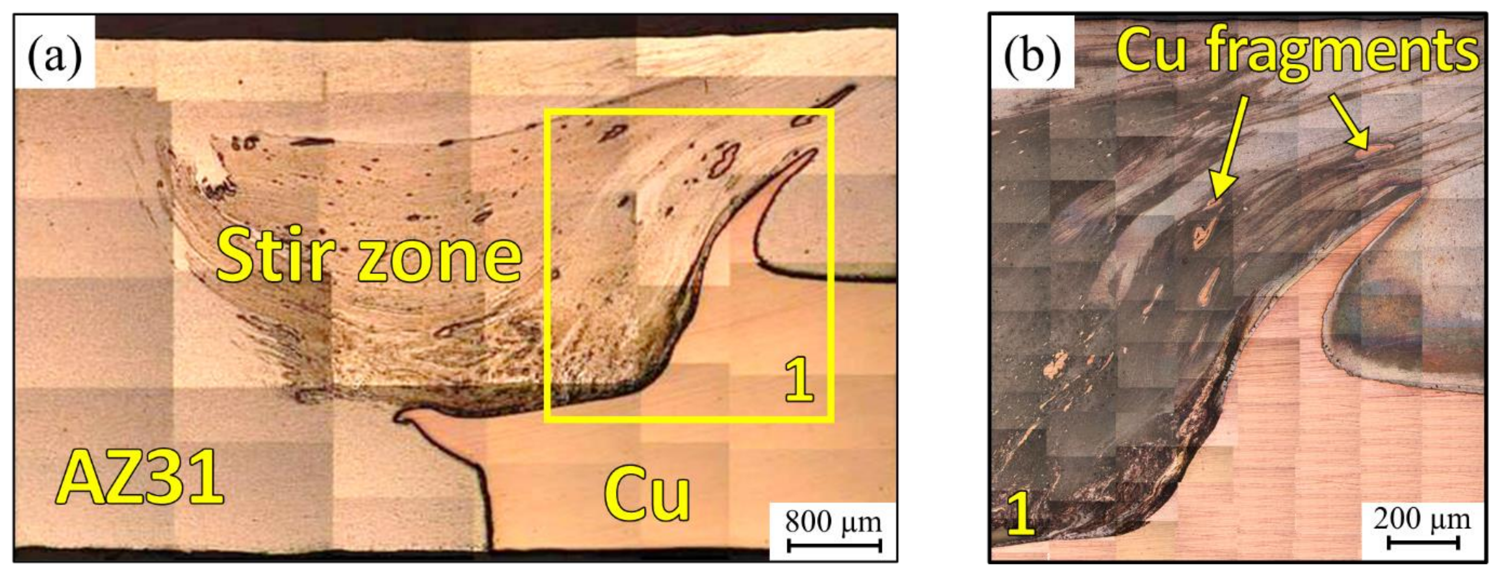

Figure 3 – (a) OM image of the weld zone. (b) Higher magnification of the interface.

Table 1 shows a comparison of the strength of the joints made in this study with other studies. A significant improvement is obvious. This is mainly due to lower IMC thickness caused by using a butt-lap configuration.

Table 1. Comparison of the strength of the joints made in this study with others.

Reference	UTS (Mpa)	IMCs	Descriptions
Xie et al.	130	Mg_2Cu & $MgCu_2$ (1 – 2 μm)	AZ31B/Cu by FSW in 50 mm/min and 925 rpm
Abhijeet et al	93	MgZn & $MgZn_2$ (2 – 4 μm)	AZ31/Cu-8Zn with Zn layer by FSW in 20 mm/min and 200 rpm
Hao et al.	124	Mg_2Cu & $MgCu_2$ (0.5 – 2.5 μm)	AZ31/Cu by FSW in 50 mm/min and 600 rpm 1 mm offset toward Cu in butt configuration
Abhijeet et al.	68	Mg_2Cu & $MgCu_2$	AZ31/ Cu-8Zn by FSW in 20 mm/min and 1200 rpm
Yuhua et al	86	$MgCu_2$	AZ31/Cu by FSW in 38 mm/min and 1180 rpm in butt configuration
Present article	171	Mg_2Cu & $MgCu_2$ (0 – 25 μm)	AZ31/Cu by FSW in 20 mm/min and 250 rpm in lap-butt configuration

CONCLUSION

In conclusion, in the investigation into the FSW AZ31/Cu in a novel lap-butt configuration the following significant findings is observed:

A defect-free joint was successfully achieved at dissimilar joint interface. Crucially, no continuous IMC layer was observed at the primary joint interface. This absence is a key factor contributing to enhanced interfacial strength. Mg2Cu and MgCu2 were formed around Cu particles or in specific, localized areas of the joint interface, where the IMC layer thickness was measured to be approximately 25 micrometers. The joint exhibited a remarkable ultimate tensile strength of 171 MPa. During tensile testing, crack initiation and propagation were consistently observed to occur centrally within the stir zone. Furthermore, detailed examination of the fracture surfaces revealed characteristic dimple patterns, indicative of a ductile fracture mechanism.

The results of the present study can be used to join magnesium to steel using an interlayer butter of Cu on steel. This prevents direct contact of magnesium to steel which are immiscible and cannot establish metallurgical bonding.