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Enhancing High-Temperature Durability of Aluminum/Steel Joints: The Role of Ni and Cr in Substitutional Diffusion Within Intermetallic Compounds

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INTRODUCTION

In the wake of increasing environmental concerns and carbon dioxide (CO_2) pollution, manufacturers have turned to reducing fuel consumption by reducing the weight of transportation vehicles, including cars, ships, and airplanes. Therefore, the usages of light metals such as aluminum and magnesium alongside steel and their joining became important. On the other hand, dissimilar metals joining and welding, such as Al-St, is highly challenging due to differences in melting point, thermal and electrical conductivity, cooling rate and heat capacity. Moreover, brittle intermetallic compounds often form at the Al–Fe interface, specially in elevated temperature (fusion welding), making the joint prone to cracking and weakening the joint strength. In recent years, friction stir welding (FSW) process of Al-St alloys has been used due to the reduction in IMCs layer formation due to the lower heat input, improved mechanical properties, economic efficiency, environmental friendliness and the absence of the need for consumables materials. The influence of SS316 as an intermediate layer on inhibiting IMC growth during the friction stir welding (FSW) of AA1050-ST37 and enhancing joint mechanical strength has been studied.

Experimental Detatils

According to figure (1), AA1050 (5 × 50 × 150 mm) and St37 (2 × 50 × 150 mm) sheets were butt-welded by FSW at 950 rpm, 20 mm/min, with a 1.3 mm tool pin offset toward steel and 0.1 mm plunge depth. To unify the thickness of the aluminum and steel sheets, two AA1050 sheets with thicknesses of 1 mm and 2 mm were used under and above the steel, respectively. Two joint types were produced: A-series with a 316L stainless steel interlayer on the steel surface, and B-series without an interlayer. To investigate the post-welding heat treatment, A- and B-series samples were heat treated for 90 min at 400 ◦C (A2 and B2) and 550 ◦C (A3 and B3) subsequently cooled in the air. A1 and B1 correspond to the as-welded joints.

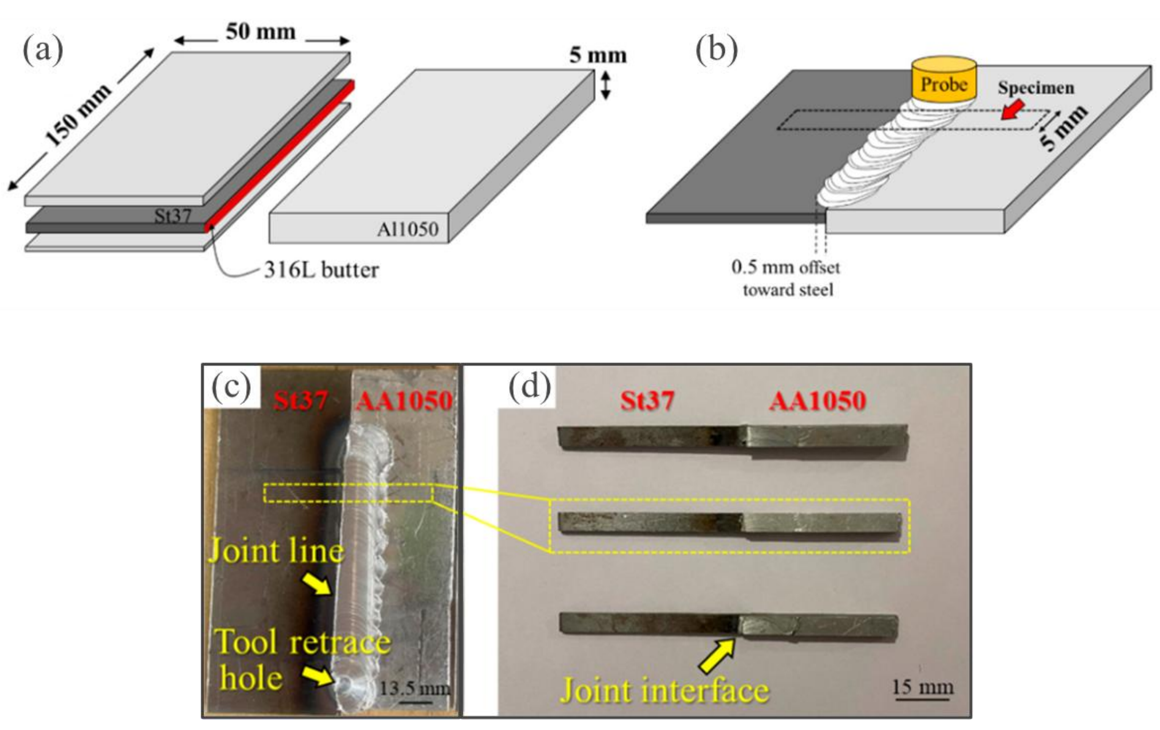

Figure 1 – (a, b) Schematic of AA1050/St37 sheets arrangement for dissimilar joining before FSW process and after FSW process, (c) FSWed sample and (d) Tensile specimens.

Results and Discussion

Figure (2) shows SEM images of the AA1050–St37 interface. According to figures (2-a) and (2-c) SEM analysis showed no IMCs at the Al–St interface in A1 (as-weld with SS316) and A2 (400 °C with SS316). In B1 (as-weld) and B2 (400 °C), IMC layers of 2–4 µm formed, becoming continuous after heat treatment. As can be seen in figure (2-b), defects such as cracks and discontinuities in the IMCs layer have been observed. As it is clear from figures (2-e) and (2-f), in A3 (550°C with SS316), the IMC layer thickened to ~10 µm, while in B3 (550 °C), excessive IMC growth led to joint failure. Figure (2) shows SEM images of the interfaces. Excess IMC growth in B-samples with respect to A-samples is evident.

Figure (3) shows the UTS of the joints. The highest UTS belongs to sample A2. Using a SS316L interlayer increased UTS by ~48% (168 → 354 MPa) compared to B2, due to Cr and Ni addition. Heat treatment at 400 °C improved A2 by stress relief, while B2 was weakened despite little IMC growth, as IMC uniformity promoted crack propagation. B3 strength dropped to zero at 550 °C.

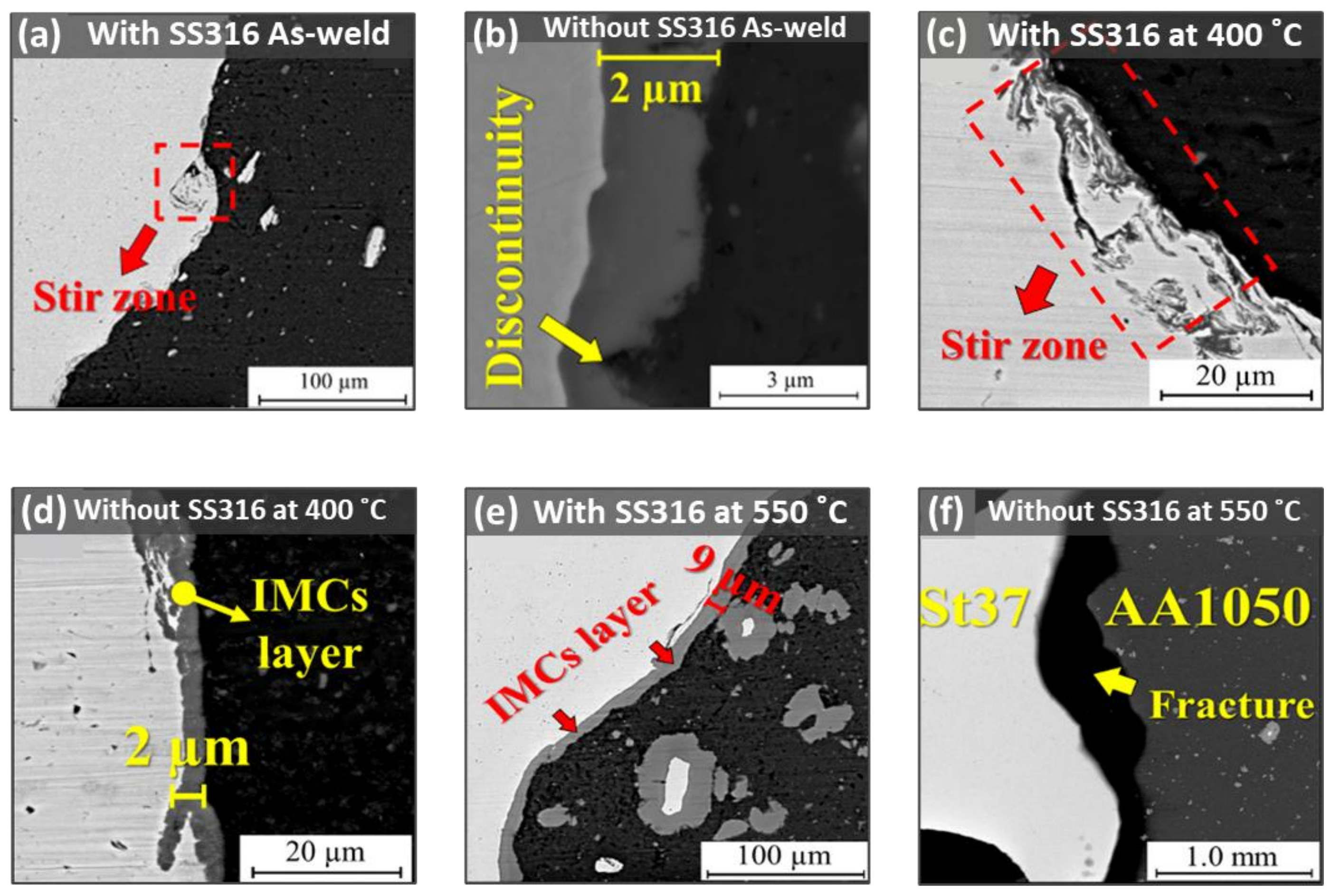

Figure 2 – SEM images of samples (a) A1, (b) B1, (c) A2, (d) B2, (e) A3 and (f) B3.

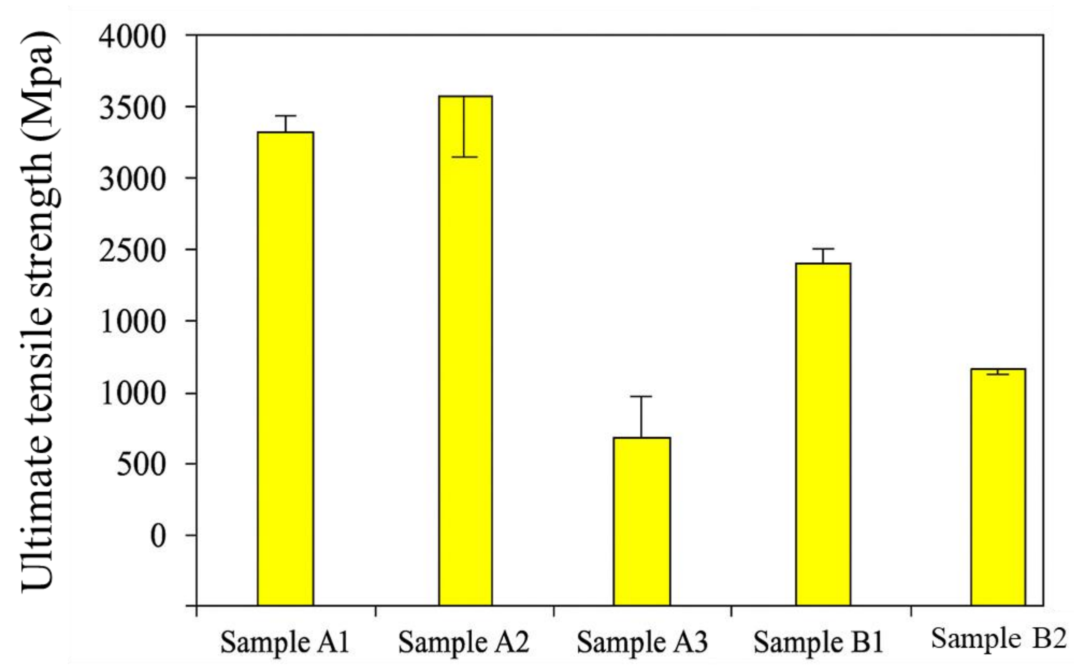

Figure 3- Ultimate Tensile Strength of the joints.

CONCLUSION

The incorporation of a SS316L interlayer on the steel surface effectively suppressed IMC formation during FSW, limiting the thickness to below 100 nm. This barrier effect not only reduced brittle phase formation but also provided a more stable interface for mechanical loading. At 400 °C, joints with the interlayer exhibited an increase in UTS from 325 to 350 MPa, which is mainly attributed to the release of residual stresses without noticeable IMC growth. In contrast, conventional joints without the interlayer showed a strength drop from 225 to 150 MPa after annealing at the same temperature. This reduction was linked to the elimination of irregularities in the IMC layer, making crack propagation easier and thereby reducing toughness. At higher temperatures (above 500 °C), the beneficial effect of the interlayer became more pronounced: while conventional joints completely failed, interlayered joints retained significant strength due to the diffusion-barrier role of Cr and Ni. These findings demonstrate that the interlayer markedly improves the thermal durability and reliability of Al–St joints for high-temperature applications.

Reference

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