

FSW of high-strength dual phase steel to aluminum AA6061-T6: Enhancing strength and cost-efficiency through buttering

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INTRODUCTION

Lightweight, high-strength materials such as dual-phase (DP) steels are widely used in automotive panels due to their combination of ductile ferrite and hard martensite, offering high strength and cold formability. However, conventional joining of Al to DP steel is challenging due to interfacial intermetallic compound (IMC) formation driven by high heat input and differing material properties. Friction stir welding (FSW), a low-temperature solid-state process, mitigates IMCs, residual stresses, and HAZ softening while preserving fine microstructure. In Al/DP steel FSW, the tool material is critical due to wear of the tool in contact with hard DP. Tungsten carbide (WC) and its composites are preferred for their hardness, ensuring tool integrity and longevity, while materials like PCBN, and W-Re are also suitable. Tool wear significantly affects cost and limits FSW adoption for steels, especially dual phase steels. This study examines the effect of an SS316L interlayer in AA6061-T6/DP steel FSW, focusing on H13 tool life, microstructural evolution, and joint mechanical properties.

Experimental Detatils

As it is clear from figure (1-a), DP steel sheet (12 cm×11 cm×1 mm) was friction stir welded to AA6061-T6 (16 cm×5 cm×3 mm). To study the effect of alloying elements, SS 316L was buttered on DP steel edge via TIG. FSW was performed using a H13 tool steel pin (50 HRC). Tensile samples (10 mm) were prepared using wire-cutting. Microstructure of the DP steel-AA6061 joint interface was examined on a cold-mounted specimen.

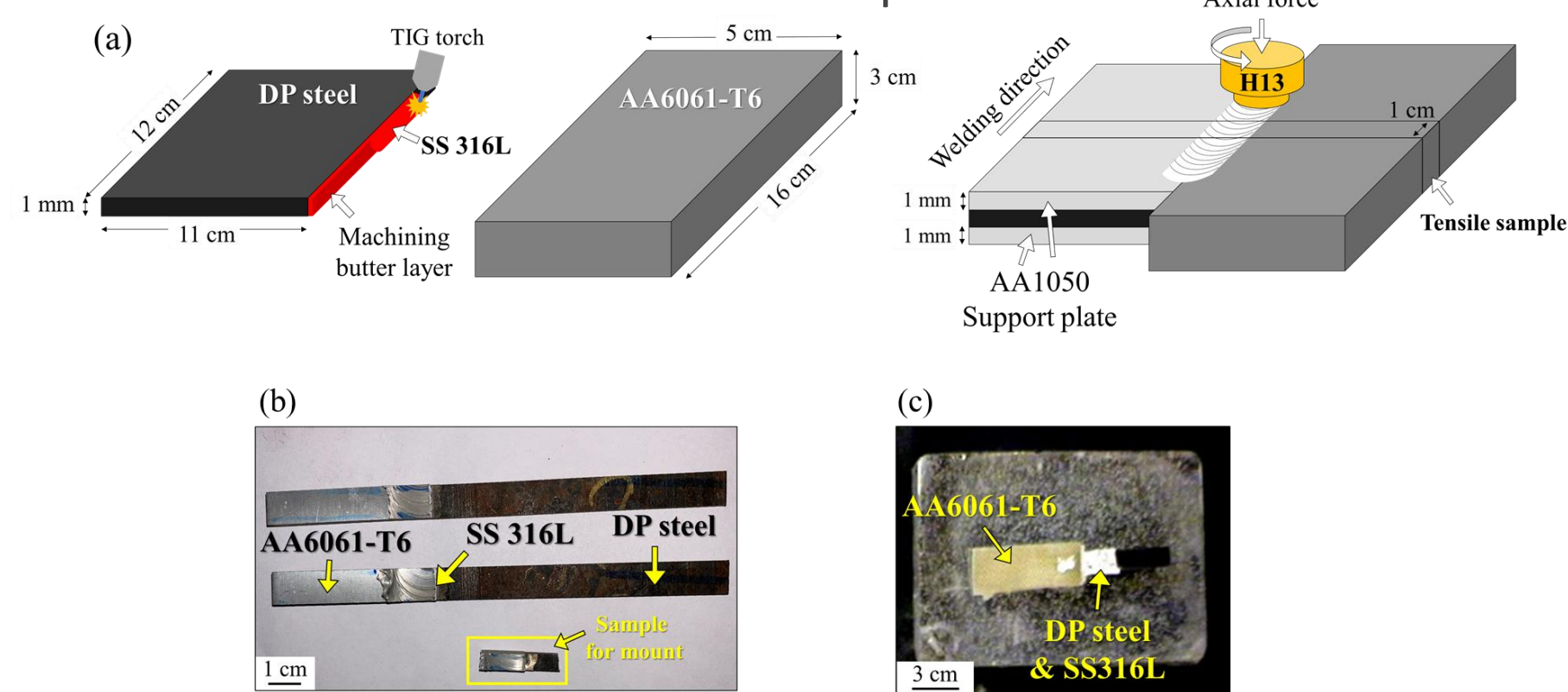


Figure 1-(a) schematic of DP steel-AA6061 FSWed, (b) samples after wire cut and (c) cold-mounted sample.

Results and Discussion

Here, no result of FSW of Al to DP steel without butter layer is provided, because the FSW tool failed immediately after plunging to the interface of Al/DP. Following results correspond to the joints made by buttering the DP steel. Figures (2-a) to (2-d) show SEM images of the DP steel-AA6061 interface. No cracks, discontinuities, or IMCs were observed at the AA6061-T6/DP steel interface. Elemental mapping (figures (2-e) to (2-k)) confirmed atomic diffusion of Al into the IMCs nodules without thick and visible Al-Fe intermetallic formation.

Figure (3-a) shows tensile results: AA6061-T6/DP steel with SS316L interlayer sustained $\sim 5200 \pm 200$ N, failing in ductile mode after necking. This corresponds to a UTS of 520 MPa. Absence of IMCs and defects contributed to strength. Figure (3-b) illustrates microhardness: ~ 300 HRC (DP steel), ~ 150 HRC (AA6061-T6). Interface hardness was intermediate, with sharp variation in the stir zone due to Al-Fe mixing. Figure (3-c) to (3-f) confirms ductile fracture in both AA6061-T6 and DP steel, evidenced by dimples, elongated voids, and significant plastic deformation.

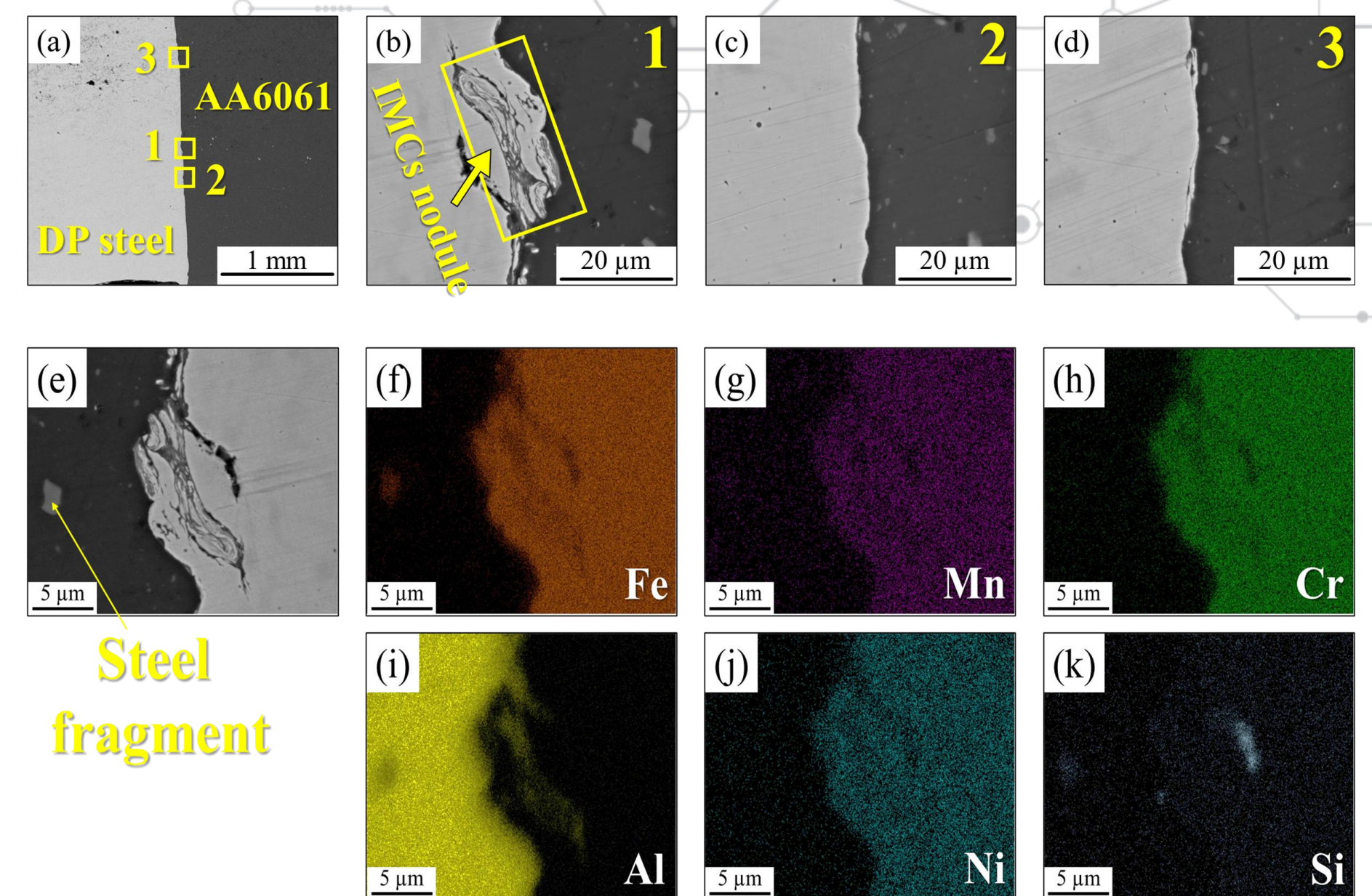


Figure 2 – (a-d) SEM images of AA6061-T6/DP steel FSWed with SS316L as a buttering layer and (e-k) elemental mapping of Fe, Mn, Cr, Al, Ni and Si

Tool material plays a key role in the cost-effectiveness of FSW. While WC and PCBN provide longer lifetimes, their very high purchase and fabrication costs limit their use in both lab-scale research and industry. In this study, H13 tool steel was successfully applied for welding AA6061-T6/DP steel due to usage of an SS316L interlayer. H13 significantly reduced the overall cost of welding while still achieving high-quality, defect-free joints. This confirms H13 as a practical and economical choice for experimental and prototype-scale FSW of dissimilar materials.

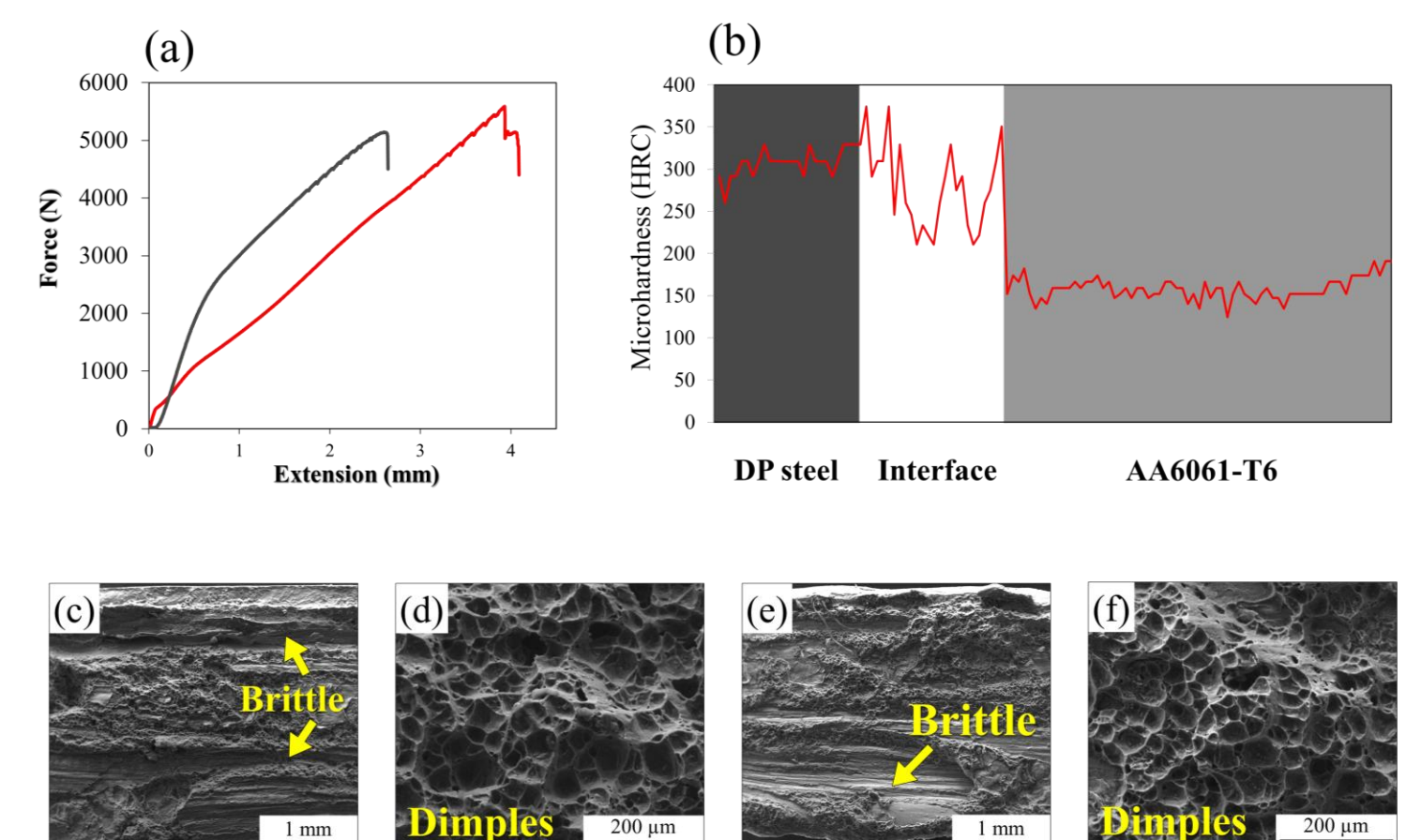


Figure 3- (a) Force-extension curve, (b) microhardness and (c-f) SEM images of fracture surface

CONCLUSION

AA6061-T6 (16×5×3 mm) was successfully friction stir welded to DP steel (12×11×1 mm) using an SS316L buttering layer. Buttering enables an H13 tool steel pin (50 HRC) to be used as a cost-effective choice over WC and PCBN for such an infeasible joining. Tensile tests showed a UTS of 520 MPa with ductile fracture features, while microhardness revealed ~ 300 HRC (DP steel), ~ 150 HRC (AA6061-T6), and intermediate hardness at the interface. The absence of cracks, thick IMCs, and other defects ensured strong joint integrity. This study highlights H13 as a practical, low-cost tool material enabling high-quality FSW of dissimilar Al/high-strength steel joints.

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