A combined full-field imaging and metallography approach to assess the local properties of friction stir welded (FSW) copper-stainless steel joints

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Abstract:

The Friction Stir Welding (FSW) process was employed to join 2 mm thick sheets of copper (Cu) and 304 stainless steel (SS). To establish the local material morphology in the weld, various metallography techniques were used, including EBSD, SEM and optical microscopy. From these techniques, varying microstructural features of the weld zone (i.e. the Heat Affected zone (HAZ), the Thermomechanically affected Zone (TMAZ) and the weld nugget) were identified. Microhardness variations were mapped in the Cu-SS joint to analyse the hardness distributions across various zones. Digital Image Correlation (DIC) and Thermoelastic Stress Analysis (TSA) were used to evaluate the mechanical properties and stress redistribution at the weld.

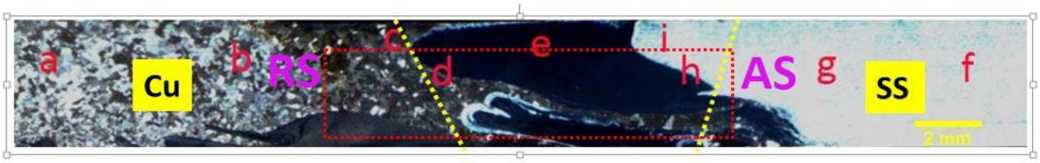
Keywords: FSW, Cu, SS, DIC, TSA, Metallography, Microhardness, local properties

Introduction:

During welding, wide differences in the physical properties of dissimilar materials especially their melting point can lead to problems, e.g. where one of the materials attains its melting point much earlier than the another material during fusion welding processes. The result is the formation of defects such as intermetallic phases, porosity, hot cracking, and solidification cracking [1]. Hence dissimilar material welded joints often suffer a reduction in mechanical properties and subsequent early failure under service loading. To tailor the properties of dissimilar materials such as stainless steel with copper, a suitable welding process needs to be defined, but the wide difference in properties, such as melting point (Cu-1085^{0}C, SS-1400-1500^{0}C), thermal conductivity (Cu-401 W/m-K, SS-17-19 W/m-K), crystal structure (Cu- FCC, SS- either BCC or FCC depending on the phase temperature), makes the welding task challenging. This is because the Cu conducts heat energy 10 times faster than the SS, rapidly dissipating the heat away from the weld zone making it difficult to achieve the melting point during fusion welding. All fusion welding processes suffer from this drawback. FSW is a "solid-state" welding process that does not involve the melting of the base materials. Instead, the joining is achieved by the forging action of a non-consumable tool and also due to the friction between the rotating tool shoulder and surface of the workpiece, which develops severe plastic deformation in the workpiece. Hence the requirement for a lower heat input enables dissimilar materials to be joined without melting, which eliminates many of the drawbacks of the fusion welding processes [2].

Experimental work:

304 SS and Cu were friction stir welded; the zones across the welded region are shown in Fig.1.The associated microhardness 2D contour plot (Fig. 2) shows the hardness distribution across the Cu-SS joint as located in Fig. 1. Optical micrographs were captured at various locations are shown in Fig. 3. The FSW weld nugget (stir zone) has fine recrystallized grains and the HAZ's (Cu & SS) have wide variations in their grain size compared to their corresponding base metals (BM). These significant variations result in the heterogeneous characteristics of the FSW [3]. Large fluctuations in the hardness distribution were observed in the weld nugget. This is because the weld nugget is a mixture of Cu and SS generated as a result of the stirring action of the FSW tool. This hardness variations in the mixture corresponds to the wide variations between the actual average Vickers hardness values of Cu (HV: 85-95) and SS (HV: 250-280).



a-Base metal (Cu) **d**-Copper interface **g**-HAZ (304 Stainless Steel) [dotted box] -HV Measurements
b-HAZ (Cu) **e**-Weld nugget (Stir zone) **h**-Stainless Steel interface
c-TMAZ (Cu) **f**- Base metal (304 SS) **i**-TMAZ (304 Stainless Steel)

Fig. 1 Macrostructure along a transverse section of the friction stir welded Cu-SS joint

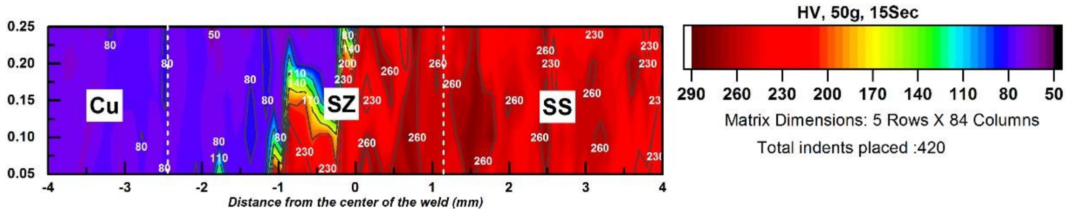


Fig. 2 Microhardness 2D-contour map of Cu-SS FSW joint over the region shown in Fig. 1

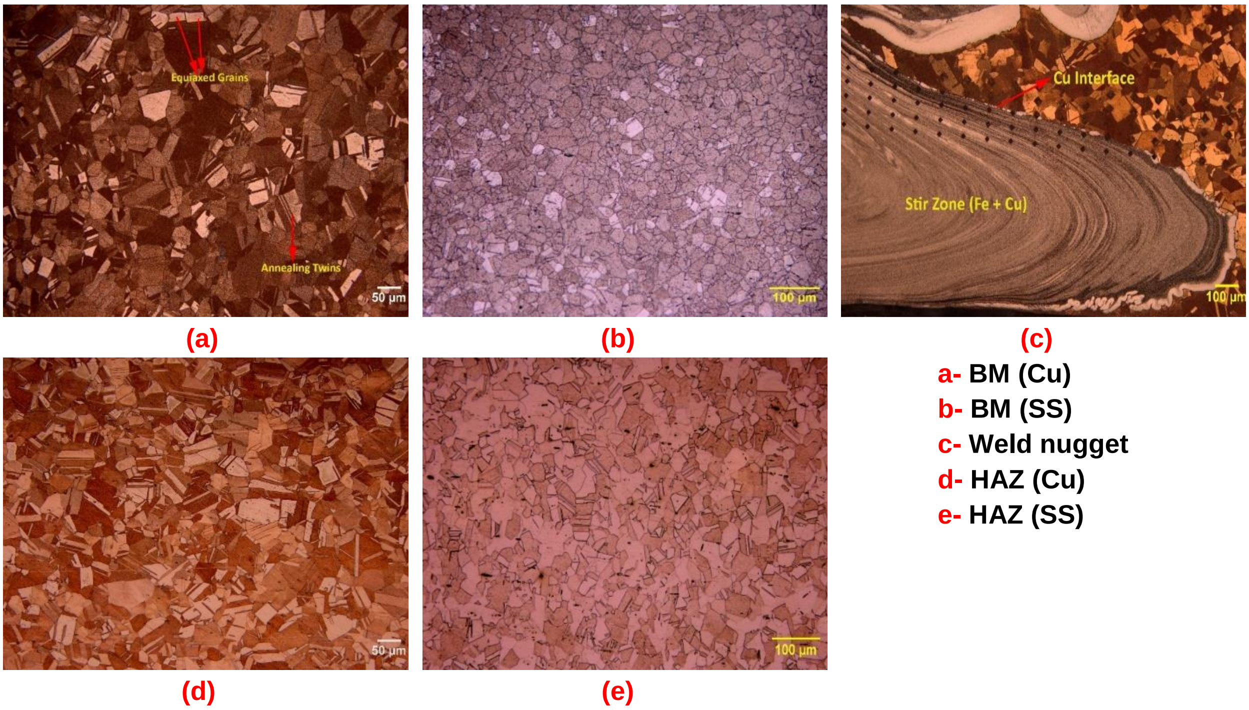


Fig. 3 Microstructures at different zones of the friction stir welded Cu-SS Joint

Future work:

To evaluate the local properties, high resolution DIC will be conducted on specimens of Cu-SS FSW joints loaded in uniaxial tension. From optical micrographs, the position of various zones can be measured accurately and this will define the regions of interest used in the DIC study corresponding to the various weld zones (HAZs, TMAZs, weld nugget). TSA will be used to evaluate the stress distribution in the weld.

References:

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