Abstract

Friction stir welding (FSW) is a solid state welding technique, popular for joining of wide variety of materials such as aluminum, copper, titanium, magnesium and steel. FSW is further extended for joining of dissimilar materials considering its ability to solve challenges of dissimilar welding. However, the formation of intermetallic compounds (IMCs), deterioration of mechanical properties and unavailability of parametric effects are issues need to be considered as challenges of dissimilar Cu-Al FSW.

In the present investigation, dissimilar system of Cu-Al FSW is investigated for its tool design, process parameters, joint mechanisms and properties, microstructural changes and hybrid approaches such as heating assisted FSW and cooling enhanced FSW. Important tool design components such as tool pin features, pin diameter, shoulder diameter and shoulder to pin diameter ratio are studied for its effects on weldability and properties of dissimilar Cu-Al FSW. Taper tool pin profile, cylindrical tool pin profile and different polygonal tool pin profiles are investigated. Process parameters such as tool tilt angle, tool pin offset, welding speed are investigated individually for its influences on weldability and properties of dissimilar Cu-Al FSW. Remaining process parameters of FSW are kept constant for the establishment of individual effect of specific parameter. Novel hybrid approaches of heating assisted FSW (HFSW) and cooling enhanced FSW (CFSW) are implemented for dissimilar Cu-Al FSW. Effect of preheating current is investigated while cooling mediums of air and water are applied on dissimilar FSW individually for constant FSW process parameters.

The quality of welds produced under the different process parameters are initially assessed by the visual inspection of surface morphologies and macrographs. After that, the welded specimens are subsequently evaluated with microstructural features, tensile properties, fracture analysis, hardness profile analysis, scanning electron microscopy, electron dispersive spectrographs and X-ray diffraction characterizations.

Present study reveals that, the process parameters such as tool pin profile, tool tilt angle, tool pin offset and welding speed significantly affects the weldability and properties of dissimilar Cu-Al FSW. Tool pin profiles of taper and polygonal shapes have adversely affected the welds while cylindrical tool pin profile is most suitable for defect free butt joint configuration.

Fragmental defects are increased as the number of polygonal edges decreased. Defect free dissimilar Cu-Al friction stir welds are achieved by tool tilt angles of 2˚, 3˚ and 4˚ whereas major defects are reported for tool tilt angles of 0˚ and 1˚. Complex and heterogeneous microstructures are reported in the stir zone due to different size and shape of Cu particles in Al matrix. Material flow of dissimilar Cu-Al stir zone is affected by shape and size of Cu particles dispersed from Cu base material. Phases of IMCs such as CuAl, $CuAl_2$, Cu_3Al and Cu_9Al_4 are presented in the stir zone of dissimilar Cu-Al joints. Super hard stir zone is reported due to presence of different IMCs. Non-uniform hardness profile is reported across the cross section of dissimilar Cu-Al FS welds. HFSW at low preheating current of 80 Amp is attributed to improve the tensile strength up to some extent (nearly of 10 %), while major defects are reported at the higher preheating current of 120 Amp that consequently deteriorated the tensile strength. Besides, significant improvement in tensile strength is reported for cooling enhanced FSW technology relative to Normal FSW and HFSW. The maximum tensile strength of 158 MPa (76 % of the Cu base material) is reported at CFSW of water. The amount of IMCs formed in stir zone is increased with increase in preheating current in case of HFSW, while the formation of IMCs is drastically reduced with cooling effect in case of CFSW relative to NFSW.

Keywords: Aluminum, Copper, Dissimilar, Friction stir welding, Hybrid, Properties, Tool design