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Title: **Some Studies on Friction Stir Welding (FSW) of Non Ferrous Dissimilar Materials**

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ABSTRACT

Copper (Cu) is predominantly used material as a conducting element in electrical and electronic components due to its high electrical conductivity. Aluminium (Al) being lighter in weight and more cost effective than Cu, is able to replace Cu either fully or partially to make lighter and economic electrical components. Conventional methods of joining Al to Cu, such as fusion welding processes, suffer from many shortcomings. Friction Stir Welding (FSW) is a solid state welding process which overcomes the shortcoming of the fusion welding processes.

Based on the preliminary investigations, four FSW parameters i.e. shoulder diameter at two levels (16 mm and 18 mm), pin offset at three levels (0.5 mm, 0.65 mm and 0.8 mm), welding speed at three levels (50 mm/min, 63 mm/min and 80 mm/min) and rotational speed at three levels (710 rpm, 900 rpm and 1120 rpm) were finally selected and experiments were performed as per the Taguchi's L_{18} mixed level design to produce eighteen welds. FSW was performed using a FSW tool of cylindrical pin profile. The welds were characterised on the basis of the microstructural evaluation of the welded joint and measurement of different properties of the weld, i.e., tensile strength, impact strength, microhardness, electrical conductivity, weld temperature, and traverse force. The collected data for different properties under varying conditions of the FSW parameters were statistically analysed using analysis of means (ANOM) and analysis of variance (ANOVA) in order to establish the interrelationship between the process parameters and the weld qualities. Scanning electron microscopy (SEM) was also performed to observe the detailed microstructure of the different weld portions.

FSW of Al 6101 and pure Cu was successfully performed in butt configuration at various FSW process parameter combinations. Defect-free weld joints without any flash, voids, surface grooves etc. were obtained at all the process parameter combinations. The maximum ultimate tensile strength (UTS) of 206 MPa which was 82.73% of the Al-6101was obtained. Careful examination of the fracture location revealed that majority of the welded joints fractured from the SZ but a few fractured from the TMAZ of Al and TMAZ of Cu. The average microhardness

(μH) for all the joints was also obtained and it was found that the μH values varied in the range from 70.56 to 99.53 HV. μH of the BMs used in the present study, i.e., Al-6101 and pure Cu was 82 HV and 98 HV respectively. The maximum μH was observed at the stir zone which underwent intense plastic deformation. The formation of hardened intermetallic particles took place in the stir zone which along with the severe plastic deformation resulted in higher hardness.

Electrical conductivity of all the joints were also measured and it was observed that the FSW produced the good quality joint of dissimilar materials ,i.e., Al-Cu without compromising with the electrical conductivity of the joints as the electrical conductivity of the joint was at least equal to that of Al. The optimal combination of the FSW parameters which yielded maximum electrical conductivity was found to be $A_2B_1C_2D_2$ i.e. shoulder diameter 18 mm, pin offset 0.5 mm, welding speed 63 mm/min and rotational speed 900 rpm. From the results of temperature measurements it was observed that the distribution of temperature during FSW showed similar profile of temperature variation at advancing side (AS) and retreating side (RS) for all the three selected thermocouple locations (start, mid and end). The peak temperature values were higher Al side (RS) due to the provision of the pin offset at the RS, therefore, the higher amount of Al has to sustain the frictional forces than Cu. From the various traverse force plots, it was observed that the traverse force is highly sensitive to variation in FSW process parameters and ambient temperature. Three distinct zones namely SZ, TMAZ and HAZ both on the AS and RS were identified from the macrostructure. The careful observation of grains and structure revealed that the TMAZ at the both sides of the joint and the HAZ is easily identifiable at Cu side but the HAZ of Al side is very difficult to identify. The larger shoulder diameter creates additional frictional heat and also increases the forging action, therefore, the higher strength Cu deforms plastically in higher amount and travels to a longer distance towards Al side. Increment in the FSW tool offset values considerably reduces the amount of Cu movement from AS to RS. Cu fragments alignment in the stirring direction enhances the strength to the weld joint. The weld zone during FSW of Al and Cu comprises of the combination of the lamellar structure and homogenously mixed zone. The bottom of the weld zone mainly consists of the lamellar structure.