ABSTRACT

Many specific properties of aluminum alloys including light weight and good structural strength enable them to be applied for structural parts. The demand of aircraft and automotive industries for light weight materials is met by aluminum alloys. The aluminum alloys AA6XXX and AA5XXX are extensively used in the fabrication of aircraft structures and other structural applications. AA6351-T6 (Al-Mg-Si) alloys are readily weldable, they suffer from severe softening in the Heat Affected Zone (HAZ) because of reversion (dissolution) of Mg$_2$Si precipitates during weld thermal cycle. AA5083-H111 (Al-Mg-Mn) series aluminum alloy having high levels of Mg which impose poor weldability by fusion welding process due to its increased susceptibility to stress corrosion cracking behavior. Dissimilar welding of these two alloys is frequently faced in those structures.

The conventional fusion welding of aluminum and its alloys is a great challenge for designers and technologists due to numerous welding defects which includes voids, hot cracking, distortion, precipitates dissolution, loss of work hardening, hot cracking and lack of penetration in the joint. Also, conventional fusion welding of aluminum alloys leads to the melting and re-solidification of the fusion zone which results in the formation of brittle inter-dendritic structure and eutectic phases. The formation of brittle structure in
the weld zone leads to the drastic decrease in the mechanical properties like lower hardness, strength and ductility.

Friction Stir (FS) welding is a relatively new solid state joining technique which offers a number of advantages over the conventional fusion welding process, and it is used to join aluminum alloys that are difficult to weld by fusion welding processes. It has compatibility to any alloy composition, and produces the welded joints by eliminating the defects with improved mechanical properties. Development of the Friction Stir Welding (FSW) has provided an alternative improved way of producing dissimilar aluminum joints, in a faster and reliable manner. The various parameters such as tool pin profile, tool rotational speed, welding speed and axial force play vital roles in FSW process in order to analyze the weld quality. The above considerations formed the background of the present investigation in which dissimilar aluminum alloy AA6351-T6 and AA5083-H111 is joined using FSW.

The FS welding tool with five different tool pin profiles of Straight Square (SS), Straight Hexagon (SH), Straight Octagon (SO), Tapered Square (TS) and Tapered Octagon (TO) were designed and manufactured. The central composite design with 4 parameters each with 5 levels, and 31 runs were selected for conducting experiments on dissimilar FS welding of aluminum alloys. Response Surface Methodology (RSM) was applied to develop linear regression model for establishing the relationship between the FSW process parameters and responses such as tensile properties (UTS and percentage of elongation) and dry sliding wear properties (wear resistance and
wear rate). Analysis of variance (ANOVA) technique was used to check the adequacy of the developed model. The effect of FSW parameters such as tool pin profile, tool rotational speed, welding speed and axial force on tensile and dry sliding wear behaviors were analyzed using the developed mathematical models. Each process parameter significantly influenced the tensile and dry sliding wear behavior of the joints. It was found that the dissimilar FS welded joints fabricated using straight square tool pin profile exhibits better tensile and wear properties irrespective of other process parameter. The mathematical models were optimized using Generalized Reduced Gradient (GRG) method and Response Surface Methodology (RSM). The Artificial Neural Network (ANN) model was developed with help of MATLAB R 2009a software to predict the tensile and dry sliding wear behavior of the joints by incorporating the FSW process parameters. The developed model was capable of predicting values with less than 5% error.

Extensive metallurgical characterization of FS welded dissimilar aluminum alloy AA6351-T6 and AA5083-H111 were carried out. The macrostructure of all the dissimilar joints were observed and found that the joints fabricated using tool pin profiles SS, SH and SO are defect free. A tunnel at the bottom of the joint is always present when tapered tool pin profiles were used. The welded joints exhibited the presence of different zones such as Weld Zone (WZ), Thermo Mechanically Affected Zone (TMAZ) and Heat Affected Zone (HAZ). Three different regions namely unmixed region, mechanically mixed region and mixed flow region were observed in the WZ. The mixed flow region was absent in the joints
fabricated using tapered pin profiles. The mixed flow region contains a structure of alternative lamellae of both the aluminum alloys. A complex vortex like flow pattern was found visible. Different grain size in the various zones is observed. WZ has finer grains and TMAZ has elongated grains. Joints welded using SS tool showed very fine equiaxed microstructure compared with other tool pin profile. The microhardness survey across FS dissimilar welded AA6351-T6 and AA5083-H111 joints indicated that the weld zone showed lowest hardness value compared with other zone. The SEM fractrograph indicated that the observed failure mode was ductile fibrous fracture. Worn surface of the joints made by straight tool showed fewer cracks due to absence of the defects on the joints. Worn surface of the joints made of tapered tool exhibits deep groove and severely damaged regions due to defects on the joints.