Study on the effect of process parameters in friction stir welding of dissimilar aluminum alloys

ABSTRACT

Friction Stir Welding (FSW) is a recent addition to the solid state joining processes that has paved way for joining materials that were considered difficult to be welded by conventional welding techniques. In this process, a cylindrical non-consumable tool, with a profiled probe (pin) rotating about its own axis is slowly plunged into the abutting edges of work pieces rigidly clamped to a backing plate. When the shoulder of the tool touches work piece surface, the tool is translated (with an axial force) along the length of the joint forming the joint in the solid state.

Aluminum alloys of dissimilar combinations are required to be joined for many industrial applications. Due to difficulties associated with welding dissimilar aluminum alloys, their usage in practical applications was hindered. Aluminum alloys like Al-Cu (2xxx) and Al- Zn-Mg (7xxx) have potential application in modern and future aircrafts. For example, the AA7075 plates were friction stir lap welded as skin with the AA2024 stringers in aerospace applications.

The tool rotational speed (TRS), welding speed (WS) and tool geometry are the key operating parameters that predominantly affect the FSW process. Successful application of FSW requires proper selection of these key parameters. This study aims to relate the key process parameters of FSW with weld characteristics and also to predict the thermal and mechanical characteristics of the weld joint made by FSW through appropriate modeling. Response surface methodology (RSM) was used to develop a regression model relating mechanical properties and process parameters. The work also aims to develop a physically valid FSW model, based on computational fluid dynamics (CFD) and verifying it by experimental work. Friction stir welding of AA2024 and AA7075 aluminum alloys was carried out at various TRS, WS and shoulder diameters (SD). Welding trials were made as per face centered, central composite design, with three parameters and three levels. The microhardness profiles were obtained from hardness measurements made along the midplane on the transverse cross section of the friction stir welded joints. In the nugget zone, hardness values show small peaks and valleys and when moving from the advancing side (AA2024) to the retreating side (AA7075), microhardness value increases. The minimum hardness of all the weldments occurs in the thermo mechanically affected zone (TMAZ) of the AA2024 side. The hardness increases in heat affected zone (HAZ) till it reaches base metal hardness.

Optical microscopy performed to study the microstructures of the friction stir welded joints, reveals different zones in the friction stir welded joints. Tensile strength and percent elongation of the friction stir welded joints were found by tensile testing. Fractographic study carried out using a scanning electron microscope reveals failure of tensile tested specimens was governed by coalescence of an array of randomly distributed micro voids.

Response surface methodology was used to develop regression equations that relate tensile strength and percent elongation of the friction stir welded joints to the process parameters. The model was used to study the
effect of TRS, WS and SD on the mechanical properties of the joints. The results indicate that an increase in TRS increases tensile strength and percent elongation. But higher TRS result in decrease of the tensile strength and percent elongation. When the WS increases the tensile strength and percent elongation decrease.

Numerical simulation of temperature distribution and material flow during FSW was accomplished using CFD based commercial package FLUENT6.3®. The pre-processor GAMBIT 2.0 was used to create and mesh the model. The model is a steady state model with moving heat source and appropriate boundary conditions. Heat generation is applied as heat flux at the shoulder workpiece interface. A User-Defined Function (UDF) is used to apply transient boundary condition on top surface of the work piece. Temperature dependent material properties were considered. Before implementing the threedimensional models, a feasibility study and validation with a two dimensional model using volume of fluid (VOF) approach are presented. The results indicate that the temperature increases with the TRS and decreases with increase in the WS. With the increase in Advance Per Revolution (APR), the viscosity on the advancing side descends whereas viscosity increases in the retreating side. This in turn reduces the size of the peak temperature zone around the tool. At the highest APR, the viscosity crossing was found to be more and the peak temperature was generated solely on the advancing side.

Three-dimensional heat flux model was used for simulation of dissimilar FSW of AA2024-AA7075 alloys. The maximum temperature generated during FSW was found to be between 80 to 90% of the melting temperature of parent material welded. TRS caused a significant increase in the peak temperature at lower TRS than at higher TRS.

Peak temperature was found to decrease with increase in WS. This was because at higher welding speeds, heat input per unit length decreases and heat was dissipated over a wider region of workpiece. At low WS, thermal profile was circular and at high WS it becomes elliptical. This was due to higher heat transfer to colder material in front of the tool and lower heat transfer to the material behind the tool, which was already heated by the tool.

Temperature was found to be higher under the shoulder. With increase of the SD, size of the higher temperature region increases. When the shoulder size was increased, the high temperature distribution extends laterally well beyond the shoulder region and the material under the shoulder was subjected to uniform heating. This uniform heating of larger portion of the material will reduce the forces acting on the pin and hence will improve the tool life. With increase of SD, material deformation also increases, hence flash may occur. Shape of the isoviscosity contour can correlate well with boundaries of stirring zone. Increasing the TRS increases the size of the stir zone. Increasing TRS causes the minimum viscosity in the stirred zone to decrease. This will enable material flow and also reduce the forces acting on the tool. When WS was increased the stirring zone size decreases, indicating that the material flow was affected at high values of WS.