ABSTRACT

Friction Stir Processing (FSP) is a solid state material processing technique to alter the mechanical and metallurgical properties of material. FSP is one of the variant of Friction Stir Welding (FSW), following the basic working principles of FSW. FSP comprises a rotating tool, which is inserted into the base metal to alter microstructure in a way that improves a property of interest. When the rotating pin contacts the surface, plastic deformation of material takes place rapidly. The tool shoulder provides forging action to the work material that helps to restrict expelling out of processed material during the process.

FSP results in dynamic recrystallized fine grain structure in the stir zone (SZ) due to intense plastic deformation of the material, which makes FSP as a promising technique to refine grain microstructures of given alloy. Since fine grain microstructure of an alloy is a primary requirement to obtain superplasticity, FSP can be considered recent advancement in material processing technology to obtain superplasticity for various alloys. Superplasticity is an ability of material to undergo more than 200% uniform elongation before fracture takes place. Superplastic material offers designer and manufacturer to create unitized structure by avoiding joint.

Among aluminum alloys, AA 7075 (Al–Zn–Mg–Cu) is extensively used in applications where high levels of precision and performance are more important factors than cost due to its high strength to weight ration and good fracture toughness. AA 7075 is used in aerospace and marine applications as a structural component, oil/gas equipment and some applications in automotive as well. Joint performance of this alloy is too low due to high susceptibility to weld cracking, which makes AA 7075 extremely difficult to join using traditional fusion welding techniques. Therefore, applications of AA 7075 are largely limited to those where welding is not required. FSP of AA 7075 exhibits superplasticity, which removes requirement for joining and allows for fabrication of various shaped unitized structures. As per available literature, there is a need of the data which shows the effect of process parameters and tool geometry on FSP superplasticity. Also, very limited literature available for hybrid FSP in order to enhance grain refinement. Therefore, based on research gap above mentioned aspects were studied independently through the experimentations followed by testing. The experimental
methodology has been described, which includes outline of the experiments, experimental setup, metallurgical and mechanical examination methods.

The process parameters (tool rotation, travel speed, and tilt angle) play important role on resulting microstructure and hence superplasticity. It was observed that grain size increased with increasing tool rotation speed, and decreased with increasing traverse speed. But tool tilt had no significant effect on grain size. Also, at higher tool tilt distorted grains were observed in microscopic images. The highest average value of hardness was obtained for low heat input value corresponds to higher tool rotation and traverse speed. In this study, hardness has shown no dependency on the grain size of the SZ due to strengthening phase particles. Process parameter of 765 rpm, 31.5 mm/min and 2° tool tilt (low heat input) only exhibited superplastic elongation of 225% because of an appropriate material flow without any defect.

The effect of pin profiles on heat generation during plunge stage and superplastic behaviour were separately investigated. First, influence of pin profiles on the temperature distribution around the tool during plunge has been studied. FSP tools with different pin profiles such as conical, square, pentagonal, and hexagonal under same process parameters have been used to study heat generation during plunge stage. Temperature profile was found asymmetric around the tool. During plunging stage, it was observed that the temperature due to plastic deformation at pin was less than the temperature caused by friction on the workpiece. Compared to other pin profiles, pentagon pin generated more temperature during the plunging. Further, tool shoulder had significant influence on the workpiece temperature compared to tool pin. Second, effect of polygonal pin profiles on FSP superplasticity were studied. Three different polygonal pin profiles of square, pentagon and hexagon were used. Fine grain uniform microstructure without cavitation in the SZ was observed in sample produced by square pin only. All polygonal pin profiles indicated sticking of workpiece material around tool pin that resulted in non-uniform grain microstructure in the SZ. Uniform superplastic elongation of 227% was obtained in the gage region of the sample produced using square pin profile.

The hybrid FSP using active cooling approach has been proposed in order to enhance grain refinement. In this study, three different cooling medium such as compressed air, water, and CO$_2$ were used, keeping process parameters (765 rpm, 31.5 mm/min, 2°) constant during FSP. These hybrid samples were compared with natural cooling sample. It was found that hybrid
FSP samples reported low process temperature and high cooling rate in comparison to normal FSP. This was resulted into inhibition of the grain growth and consequently reduction of the grain size in hybrid FSP samples. CO$_2$ cooling sample was found to achieve the smallest grain size (1.96 µm) among hybrid samples due to the lowest process temperature and higher cooling rate during FSP.

**Keywords:** 7075, aluminum, cooling, forming, friction, FSP, grain, hybrid, pin, plunge, parameters, processing, recrystallization, square, strain, stir, superplasticity, temperature.