SYNOPSIS

Friction Stir Processing (FSP) is emerging as one of the most competent Severe Plastic Deformation (SPD) methods for producing bulk ultra-fine grained materials with improved properties. The significant advantage of FSP is that it can be used for localized microstructural modification which is not possible with the other common SPD techniques such as Equal Channel Angular Processing (ECAP), High Pressure Torsion (HPT), and Accumulative Roll Bonding (ARB). The process is derived from the basic principles of Friction Stir Welding (FSW), a solid state welding technique developed for the high strength aluminium alloys used in structural applications. In FSP, a non-consumable rotating tool with a shoulder and a pin is traversed along the region on the work-piece which is to be modified. In the present investigation on FSP, two heat treatable aluminium alloys with different hot deformation behaviour, 2024 (Al-Cu-Mg) and 2219 (Al-Cu) and a strain hardenable alloy 5086 (Al-Mg) has been considered.

FSP involves complex thermo-mechanical interactions and hence the optimization of process parameters is an important aspect to be considered for a successful processing. The number of process parameters involved is more in FSP and the three most important parameters are tool rotational speed, tool plunge depth (normal load on the work piece) and the tool traverse speed. These parameters are varied for a fixed tool geometry and tool tilt angle in a custom-built FSW/FSP machine. A parametric study has been carried out in order to have a clearer picture on the relative importance of various parameters by using tools of different pin lengths. The tool plunge depth and tool rotational speed are also varied in the parametric study. It has been observed that tool plunge depth is the most important parameter for the FSP of high strength aluminium alloys and the first parameter to be optimized. As per the inputs obtained from this parametric study, a systematic experimental procedure has been

developed (a bottom-up approach) for optimizing the most important process parameters of FSP.

The optimal process parameters obtained from the experimental bottom-up approach has helped in achieving bulk tensile strength higher than the starting material strength for the strain hardenable alloy 5086-O. In heat treatable alloys, due to the presence of a weaker heat affected zone the achievable strength in a single pass FSP were 93% and 80-85% of the starting material strength in the alloys 2024 and 2219 respectively. Micro-tensile testing of the samples taken from the nugget zone of the alloy 2024 indicated an ultimate tensile strength of 1.3 times the starting material strength. This strength increase is attributed to the combined effects of grain size strengthening and precipitation hardening.

FSP has been perceived as a grain refinement technique and hence the most important region in any processed sample is the nugget zone. Due to the continuous stirring of the tool pin at high rotation rates, it is possible that different regions in the nugget zone can develop varied microstructure and crystallographic texture. The nugget zone of the optimally processed samples are characterized in detail using the advanced characterization techniques such as Scanning Electron Microscopy (SEM), Electron Back-Scattered Diffraction (EBSD), X-Ray Diffraction (XRD) and Electron Probe Micro-Analyzer (EPMA) in order to understand the underlying micro-mechanisms of microstructure and texture evolution. Micro-texture studies on the alloys revealed gradients in textures across the thickness with the dominance of shear texture components. The bulk texture is weaker in all the three alloys. Bulk texture measurements revealed that the texture development during FSP is an alloy independent phenomenon. The dominant texture component observed is different in heat treatable and strain hardenable alloys. The dominant component of texture is identical in both the heat treatable alloys irrespective of the differences in optimal process parameters and the thickness of the plates used.

Microstructural evolution during FSP is more of an alloy dependent phenomenon. Particle Stimulated Nucleation (PSN) and Strain Induced Boundary Migration (SIBM) are observed as the dominant nucleation mechanisms of Dynamic Recrystallization (DRX) in the heat treatable and strain hardenable alloys respectively. Normal grain growth through the Burke and Turnbull mechanism is observed with the presence of few larger grains in the microstructure caused by geometrical coalescence. DRX has been observed to occur through separate nucleation and grain growth stage in all the three aluminium alloys and hence indicative of a discontinuous process. Bulk texture development during FSP has been correlated to the microstructure evolution with the mechanisms of PSN and SIBM both weakening the textures in all the alloys.

In order to expand the understanding as a commercially viable technique and studying the stability of FSP microstructure and texture, multiple processing routes have been employed. In the Multi-Pass FSP (MP-FSP), the processing is carried out at the same location and the objective is to study the stability of the processed samples under extreme conditions of strain and temperature. In Multi-Track FSP (MT-FSP), an overlap ratio of 0.33 is selected for the successive passes which will allow partial nugget zone penetration. MT-FSP can be used for producing large volume of fine grained materials. It is observed that the microstructure and crystallographic texture is stable under the mild and extreme conditions of strain and temperature. Subsequent heat treatment studies after FSP in the alloy 2024 confirmed that the processed microstructure is stable up to temperatures as high as 723K (450°C). These results are indicative of the advantage of FSP as a successful materials processing technique in which the retained lower strain energies leading to the development of a stable microstructure and texture. Compressive residual stresses are observed at different regions in the nugget zone of all the alloys after FSP. This is attributed to the combined effects of a solid state processing route and the optimal selection of process parameters.