ABSTRACT

In the manufacturing sector, especially in the automobile and the aerospace industries, a perpetual demand for low weight alloys is present in order to reduce the weight of the vehicle without compromising the properties exhibited by the existing material. Aluminum alloys find themselves as ideal candidates in these applications. Although aluminum is compatible with the existing manufacturing processes and has attractive qualities, it has less room-temperature formability than steel. The extended forming limits that are now possible with superplastic forming can significantly improve the ability to manufacture complex shapes from materials with limited formability.

Superplastic alloys exhibit elongations of several hundred percent under carefully selected experimental conditions, when subjected to small tensile stresses. These alloys are used to manufacture components of intricate geometry required for the aerospace and transportation industries at considerably reduced costs. However, the initial processing to produce grain coarsening resistant, fine-grained (< ~ 10 - 20 μm) material which is not prone to cavitation, increases the cost of the starting material for superplastic forming.

Friction stir processing (FSP), a surface processing technique of recent origin, is based on the same techniques and principles as Friction Stir Welding (FSW). The process modifies the microstructure in selective locations (usually surfaces) by the combined effects of stirring action,
frictional heat and pressure. This local creation of defect-free microstructures leads to improvements in mechanical properties and formability characteristics in the processed alloy. It has been successfully applied to various aluminum alloys for improving their mechanical properties. Further, the refined microstructures resulting from FSP have also led to superplasticity in aluminum based alloys. Yet, FSP is affected by the material flow which in turn is influenced by the process and tool parameters.

In this study, surfaces of cast aluminum A319, A356, A413, Al2285 and wrought aluminum AA6063-T6 alloys were subjected to FSP with an aim to investigate the influences of process parameters on these alloys. An attempt has also been made to identify the influence of first mode of metal transfer on the tensile properties of A319, A356 and A413 aluminum alloys. In addition the friction stir processed aluminum A319 and AA6063- T6 alloys with refined microstructure have been subjected to bi-axial stressing to study their formability characteristics.

FSP was conducted using a special purpose friction stir welding machine under different process parameters. The mechanical properties of significance, to design, such as yield strength, ultimate tensile strength, ductility and microhardness were evaluated for the base and processed materials. The tensile specimens were prepared along the direction of processing according to the standards ASTM B557M for cast aluminum alloys and ASTM 308-07B for wrought aluminum alloys. It was observed that an inhomogeneous microstructure and defects like porosity, cracks, blow holes etc. lead to a reduction in the strength, hardness and elongation to
fracture of cast aluminum alloys. During friction stir processing, these defects are eliminated due to the frictional heat generated between the tool and the material which leads to material flow (severe plastic deformation). As a result, the mechanical properties are improved in comparison with those of the base material. The results also indicate that the axial force, tool feed and tool rotational speed have major influence in determining the strength, ductility and hardness of the processed material, which is attributed to the refining and / or dissolution of the intermetallic particles.

Moreover during friction stir processing, there are two modes of metal transfer namely first mode and second mode metal transfer. The first mode of metal transfer occurs due to the frictional heat generated between the tool shoulder and the plate and takes place as layer-by-layer deposition of metal one over the other. The percentage first mode of metal transfer was quantified using Matlab v 7.0 software by drawing contour plots. It was observed that the first mode of metal transfer during friction stir processing of cast aluminum alloys has a direct correlation with their tensile and yield strengths.

As friction stir processing is basically a grain refinement technique through severe plastic deformation, aluminum A319 and AA6063 –T6 alloys with refined microstructure were subjected to biaxial stressing to form hemispherical components. Five single passes were made continuously with an overlap of 1.5 mm on the work-piece in order to obtain a relatively large rectangular area of refined grain structure suitable for bi-axial stressing. Five pass FSP was carried out at the same parametric conditions in which the cast
aluminum A319 alloy exhibited the highest tensile ductility at room
temperature after the single pass FSP. The specimens were then stressed
under various pressures (0.6 MPa and 0.8 MPa) and temperatures (534 K,
570 K and 603 K). None of the A319 specimens formed into hemispherical
components could achieve the die cavity radius of 26 mm. The as-cast
material could be formed only to a maximum bulge height of 3.5 mm before
failure. The friction stir processed sheet, formed with a gas pressure of
0.6 MPa and 603K (0.68Tm) reached a maximum bulge height of 17.5 mm.

Uni-axial hot tensile tests conducted on friction stir processed
AA6063-T6 aluminum sheets showed that, its optimum superplastic forming
temperature and strain rate are 617 K and 10^{-2}s^{-1}. The specimens were then
subjected to biaxial stressing at a forming pressure of 0.4 MPa and they
achieved the full height of the hemisphere. Theoretical modeling of the
characteristics of the formed components were carried out using Matlab v 7.0
software and finite element modeling was carried out using Abaqus v 6.4.8
software. The results of the developed theoretical model and the finite
element model correlate closely to experimental results with the variation less
than ±10 %.