ABSTRACT

Aluminium matrix composites (AMCs) with nanoparticle reinforcement exhibit superior mechanical properties compared to conventional AMCs. Stir casting, a widely used fabrication method for AMCs, faces challenges like agglomeration and poor wettability of nanoparticles. This study focuses on AA6082/B_4C_p metal matrix nanocomposites developed through ultrasonic-assisted stir casting, incorporating B_4C nanoparticles and Ti-based flux (K_2TiF_6) as reinforcement. Ultrasonic vibration, applied post-mechanical stirring, ensures uniform distribution of nanoparticle using a custom-made setup. The formation of secondary phases (Al_3Ti, $TiSi_2$) refines the matrix microstructure and enhances B_4C wettability.

The effect of processing temperature, % wt. of 'B_4C and K_2TiF_6' and vibration time and interaction of these three parameters on mechanical properties have been characterized. Box Behnken design and Response Surface Methodology optimize parameters for balanced compressive strength and failure strain. Under optimal conditions, a 22% improvement in compressive strength and a 144% increase in fracture strain are achieved, with significant grain refinement (342 μm to 78 μm).

To further enhance AMC properties, multi-axial forging (MAF), a severe plastic deformation process, is applied. MAF involves subjecting a material to a large plastic strain by application of sequential compression in all the three principal axes. A true strain of 0.1 (approx.) was imparted in each direction, leading to a total effective strain of 0.3 in each cycle. The process has also been simulated using finite element method. The strain inhomogeneity from centre to surface has been predicted by finite element simulation of multi-axial forging with Voce hardening model and it correlated well with the experimentally determined microhardness variation. The strain inhomogeneity factor (IF) was highest after cycle 1 and it decreased significantly later in 2^{nd} and 3^{rd} cycles for the composite. The peak load predicted through FE simulation for each pass agreed well with the experimental values for both the alloy and the composite. In MAF experiments, it was found that a total true strain of 0.894 (three cycles) could be imparted to the composite in MAF before failure whereas only a total true strain of 0.293 (one cycle) could be imparted to the AA6082 alloy.

Microstructural changes due to MAF are examined through SEM, EDS, and EBSD. After three MAF cycles, the composite exhibits a refined grain structure (154 µm to 52 µm) and a bimodal grain distribution. B_4C nanoparticle distribution improves with more MAF cycles. Dislocation density varies with cycles, influenced by dislocation annihilation and recovery. An intermetallic phase (Al_5FeSi) with a Chinese script pattern emerges with increasing strain. Crystallographic texture evolution correlates with observed variations in yield strength during MAF.

Keywords: Aluminium Matrix Composites, Ultrasonic Assisted Stir Casting, Optimization, Ultimate Compressive Strength, Failure Strain, Multi-Axial Forging, Finite Element Simulation, Strain Inhomogeneity, Microstructure, Crystallographic Texture.