Abstract

The demand for high performance innovative materials is growing day by day with the rapid advancement of aerospace, automotive, construction and automation industries. Aluminium Metal Matrix Composites (AMCs) are well known as one of the light weight, high performance new age materials with tailored properties. The large-scale production and application of AMCs are limited due to complex fabrication method and higher cost of conventional reinforcements like silicon carbide, alumina, boron carbide, tungsten carbide, zirconia etc. Meanwhile, industrial by product of cast iron smelting, cupola slag is often discarded as solid waste. This cupola slag has the potential to be used as economic reinforcement materials. This study addresses two major challenges such as, the demand for affordable high performing AMCs and need to manage industrial solid waste sustainably. This research explores the potential to enhance material properties while maintaining the environmental sustainability by investigating the reuse of cupola slag as novel reinforcement in AMCs.

The state of the art indicates a significant gap to be bridged in development of AMCs. Most of the academicians have concentrated on conventional reinforcements making the AMCs costly. The machinability degradation with increased tool wear due to presence of hard discontinuous abrasives is another challenge prominent in the literature. Limited investigations have explored the reuse of industrial solid waste as reinforcement. The introspection on potential of cupola slag as reinforcement remains severally unattended. In spite of the fact, that cupola slag has physical and chemical properties similar to hard ceramic abrasives as it contents oxides like SiO_2, Al_2O_3, and CaO. These oxides may improve the properties of composites. A few studies have focused on slag reinforced composites structural, mechanical, and machinability characteristics. However, detailed investigations on quality, machinability, heat treatment of cupola slag reinforced composites with robust analysis of enhancements and their underlying mechanisms has been observed to be scarce. This thesis addresses these gaps by systematically investigating the feasibility and performance of novel cupola slag reinforced AMCs.

The objective of this research is to introspect the key parameters in determining industrial applicability of cupola slag reinforced AMCs. The experimental investigations aim to develop, characterize, analyse machinability and heat treatment effect on novel cupola slag reinforced composites. The composites are fabricated following economic and simple stir casting method. The reinforcement cupola slag particle with varying average size (40, 100μm) and weight percentage (3%, 5%, and 7%) has been incorporated in Al-4.5-Cu (commercially LM11) matrix. Microstructural analyses using X-ray diffraction (XRD), energy dispersive X-ray spectroscopy (EDS) equipped scanning electron microscopy (SEM) and optical microscope are performed to evaluate particle distribution, bonding, and grain refinement. Mechanical testing focused on properties like microhardness, density, porosity, tensile properties along with fractography and specific strength has been performed. The machinability of the slag composites for dry tuning in conventional lathe has been evaluated on the basis of common indices such as cutting force, tool wear, material removal rate (MRR), power consumption, chip thickness and surface roughness. The effect of solution heat treatment on newly developed composites has been investigated in details. The potential of cupola slag to be reuse as reinforcement have been assessed along with enhancement of properties of AMCs.

The results indicates that cupola slag is an effective reinforcement for AMCs. Microstructural characterizations showed refinement of grains from 138.9 μm in the base alloy to 27.7 μm in heat-treated composites with 7 wt.% slag. SEM and EDS analyses confirmed uniform particle distribution and strong bonding with clean interfaces between the slag particles and the aluminium matrix. Mechanical properties analysis reveals an approximate increase of 47% from base LM11 in microhardness and 70% enhancement of ultimate tensile strength for heat treated composites with 7 wt.% particle content. The density of the cupola slag reinforced composites reduces by 11% demonstrating the lightweight nature. These ensures the suitability of cupola slag reinforced LM11 composites as economic, high performing, light weight material for demanding industrial applications. The machinability analysis further supports industrial applicability of these novel composites. The incorporation of cupola slag enhanced the machinability indices like low cutting force, tool wear and surface roughness. The particle debonding and participation in micro cutting along with self-lubricating nature of reinforcements contributes to better machinability especially in 7 wt.% slag reinforced composites. The heat treatment enhances these properties making composites more suitable for high precision machining.

The study also highlights the environmental benefits of industrial waste reuse. Cupola slag uses as reinforcements provides sustainable solution to waste management while reducing the dependence on expensive reinforcements for fabrication of AMCs. This dual approach addresses both material innovation and environmental sustainability, contributing to global efforts in creating eco-friendly engineering solutions. This work represents a significant step toward integrating waste-derived reinforcements into advanced materials, providing a pathway for sustainable and innovative engineering practices.