ABSTRACT

The invention of new materials has widened the scope for usage in contemporary material science and their development. One of them is metal matrix composite (MMC) whose properties can be modified to suit various applications. The application of MMCs as brake rotor material commands worldwide attention, owing to their light weight, superior mechanical properties, high thermal conductivity, specific heat and better wear resistance than conventional materials. Among them, particle reinforced aluminum based MMCs invite more attention due to their ease of manufacturing in large volumes and property advantages.

Cenosphere fly ash, with SiO_2, Al_2O_3, Fe_2O_3 as main ingredients as well as oxides of Mg, Ca, Na, K, etc., as the insignificant constituents, is largely cheap and of low level density materials that is richly obtainable as solid waste derivative of coal burning in thermal power plants. Cenosphere particle consists of hollow spheres made up of ceramic outer surface with low-density ie, less than 700 kg/m^3. The present research work has been undertaken with an objective to explore the use of low-cost cenosphere as a reinforcing material in aluminum alloy (AA) 6063.

As cenosphere size is an important factor contributing to the strength of the composite, in the present study cenosphere in the size range of 1-100 micron was used to conduct all experiments. The liquid phase route to casting are economical for the manufacture of MMCs. The manufacturing method adopted for producing cenosphere-AA6063 was stir casting, customized to suit the current study after careful consideration of various parameters. The volume percentages of cenosphere particulate considered were 5, 10, 15 and 20 throughout the study.

The manufactured cenosphere reinforced aluminum metal matrix composites were analyzed with the aid of chemical analysis and scanning electron microscope (SEM) to confirm chemical bonding and proper distribution respectively. Proper distribution of particles ensured good density distribution with acceptable porosity. The density of the composite was found to decrease with increasing cenosphere content. The composites were tested for hardness, compressive strength, tensile strength, damping factor, co-efficient of thermal expansion, tribological and corrosion behaviors as per ASTM standards and the results were compared with those of base alloy.

The hardness of the cenosphere composite increased considerably with increasing cenosphere reinforcement content. The addition of 5 and 10 percent by volume of cenosphere has increased the compressive strength by 4 and 11 percent, respectively. The addition of smaller quantities of cenosphere i.e., below 10 percent by volume was found to increase the tensile strength by 3.5-9 percent. The fracture surface from tensile test was investigated using SEM. The presence of hard and brittle cenosphere particulates in the soft and ductile aluminum alloy metal matrix causes fine micro-cracks to initiate at low values of applied stress. Modal analysis was performed on specimens and the natural frequencies and damping factors were obtained.

The presence of cenospheres in AA6063 matrix decreased its co-efficient of thermal expansion (CTE). Dry sliding wear tests were conducted using a pin-on-disc apparatus. The wear rate and co-efficient of friction (COF) were evaluated as a function of applied load, sliding velocity and volume content of the particles. The composite with 5 and 10 volume percent showed the greatest improvement in tribological performance. It was found that with an increase in the cenosphere content, the wear resistance increased. Analysis of variance (ANOVA) was used to investigate the influence of the parameters on both the wear rate and coefficient of friction.

From the results, it was observed that the mean of all experimental values lies within a 95% confidence interval. The result showed that along with individual factors the combined effect of factors also has influence on wear rate and COF. A correlation between the tribological parameters was established by a second order regression model. It was demonstrated that the predicted results obtained using this equation were consistent with experimental observations. The value of adjusted R^2 was over 93%, which means that the regression model provides adequate explanation of the relationship between the factors and the results.

The predicted wear rate and coefficient of friction were compared with the actual values and a good conformity was observed. The surface morphology and wear mechanism of the pins were investigated using SEM and were correlated with wear test results. An examination of the micrographs revealed severe patches and grooves resultant of plastic deformation of AA6063 composite and comparatively mild grooves and patches on the composite with 5 and 10 percent volume of cenosphere. The formation of a matrix-reinforcement layer on the tribosurface prevents direct contact of the specimen with the rotating steel disc surface which reduced the severity of the worn surface of the composite material.

Corrosion experiments were conducted on specimens using electrochemical impedance spectroscopy (EIS) and DC polarization techniques when immersed in seawater solution open to air and at room temperature. A better corrosion resistance was observed in the composite with 10 percent cenosphere by volume compared to other percents and base alloy. SEM images showed practical evidences of the corrosion protection ability of composites. In order to ensure that the temperature distribution and stress induced are within allowable limits, a finite element analysis (FEA) was carried out on the disc brake rotor. The stress and deformation of the cenosphere composite brake disc and cast iron models were computed and compared.

Stress and deformation values were found to be lower in case of composite brake disc. Under repeated braking, the temperature rise in cenosphere composite brake disc was observed to be lesser than that in the cast iron brake disc. To validate the simulation results 10 percent cenosphere composite brake disc was cast using sand casting technique and machined to achieve the final component. The experimental results obtained validated the simulation predictions within acceptable limits. Thermal capability of brake disc was ensured by studying temperature variation through vehicle testing procedure of disc brake. The manufacturability and machinability of composite brake disc did not have any major practical constraints.

Cost reduction is one of the important benefits acquired using the cenosphere reinforced composite. Manufacturing cost showed a cost reduction of 2.5% when compared to AA6063 along with 20% weight reduction. Apart from cost and weight reduction, life cycle cost will yield significant cost benefits. The suitability of aluminum cenosphere composite for brake disc application was evaluated based on weight, wear, frictional coefficient, temperature rise, strength, manufacturability and cost. Ultimately, the study outlines that the cenosphere composite can replace the conventional materials used for brake applications owing to better performance.