ABSTRACT

The utilization of industrial wastes is beneficial because it conserves natural resources and reduces the cost of raw materials. Hence, it is considered as one of the major issues in developing countries. The production of alumina from bauxite by Bayer’s process generates red-mud as a major waste material. The red-mud contains oxides of iron, aluminium and titanium and silica with other minor constituents like, sodium- and calcium-oxides with traces of elements like zinc, vanadium, nickel and phosphorous. Depending upon the quality of bauxite, the quantity of red-mud produced varies from 55-65%. It is estimated that nearly 2 to 70 million tons of red-mud is generated every year throughout the world. Hence, the disposal and utilization of red-mud become vital since, it determines the environmentally-related issues. The studies have been carried out using red-mud because of its industrial importance. Based on the survey of literature on utilization of red-mud in India, it was observed that red-mud was used as a component to make cement, bricks, and pigments and also in the recovery of some valuable metal like zinc, titanium and vanadium. However, much research has not been carried on the use of red-mud as a reinforcement material for the preparation of metal matrix composites (MMCs). Consequently, few researchers had investigated the mechanical properties of aluminium matrix reinforced hard inter-metallic compound for making load bearing auto-components.

Aluminium alloy A356 is one of the materials used widely in automobile industries for making components like brake drum, parts of truck chassis and engine parts due to its properties like high strength, low weight castability, machinability, weldability and corrosion resistance, etc. The A356 alloy properties can be improved by adding reinforcement materials like SiC, Al₂O₃, etc. The main objective of this research work is to explore the use
of red-mud as a reinforcement material in A356 alloy matrix. For this, red-mud was collected from MALCO, an aluminium making unit located in Mettur, Tamilnadu, India. The red-mud particles of 53 microns (as per ASTM 270 Code) were sieved after proper drying. The collected material was preheated up to 500°C before adding to molten A356 alloy to produce A356 red-mud metal matrix composites (A356-RM MMCs).

Further, this research work investigated the effect of different percentages of red-mud reinforcements, artificial ageing conditions (temperature and time) and particulate size on the properties of A356-RM MMCs. For this, specimens were prepared and the mechanical and wear properties of the composite specimens were tested and the results were analyzed. The microstructures of the specimens were examined. This research work was carried out in three phases. In the first phase A356-RM MMC discs were manufactured by stir-casting techniques using A356 alloy reinforced with different weight percentages (5, 10, 15 and 20%) of red-mud. The size of the discs was (based on ASTM E122): 165 mm outer diameter and 85 mm inner diameter with 10 mm thickness and the tolerance of ±0.5 mm. The microstructures of the specimens were analyzed with the aid of optical microscope for the confirmation of proper distribution of the particulates. Pins of 10 mm sizes were machined from the brake-shoe liner of the commercial passenger car. Later, the sliding wear tests were carried out on a pin-on-disc machine on both unreinforced alloy and A356-RM MMC specimens. The wear rate and coefficient of friction were evaluated for specified contact loads, sliding velocities and volume fractions of red-mud particulate. The wear surface morphology and wear mechanism of the disc were investigated using Scanning Electron Microscope (SEM) and were correlated with the wear test results. Based on the study, it was found that A356-RM MMC containing 20% of red-mud exhibits less wear rate than other composition MMCs. The hardness of A356-RM MMCs and unreinforced alloy were
examined using Vickers micro-hardness testing machine and observed that
the magnitude of hardness is increased with the increase of volume fraction of
red-mud particles. The density was measured experimentally and found closer
to the theoretically estimated density. The tensile strength of specimens were
tested as per ASTM E8-B557 standard using an universal testing machine.
The ultimate tensile strength is found to be increased as reinforcement
percentages of volume fraction increases.

In second phase, the specimens were prepared using stir-casting
technique for making pin of 5 mm diameter and 40 mm length, by varying the
weight percentages of red-mud as (5, 10, 15 and 20%) then A356-RM MMC
pins were subjected to heat treatment process in order to improve their
mechanical properties, since the aluminum alloys can be strengthened by
precipitating second phase particles within the alloy’s matrix by a well-
designed heat treatment process. All the specimens were solution treated at
540°C for 4 hours and then quenched in water. Prior to artificial ageing, the
solution treated samples were kept at room temperature for 24 hours for
natural ageing process. The artificial ageing was done using an electric
furnace. The artificial ageing was carried out at different temperatures, 100°C,
200°C, 300°C and 400°C and the artificial ageing durations were also varied
as 2, 4, 6 and 8 hours. After 2, 4, 6, 8 hours duration, the samples were taken
out of the furnace and cooled in still air in order to find out the peak ageing
condition. The wear rates were examined using a pin-on-disc machine with
counter face hardened steel (EN31) disc. The wear surface morphology and
wear mechanisms of the disc were investigated using SEM and were
correlated with the wear test results. The mechanical properties of this A356-
RM MMCs and the unreinforced alloy were tested by Vickers hardness test
machine and tensile test machine. A comparative study of the tribological
behavior of cast A356-RM MMCs and the heat-treated A356-RM MMCs had
been carried out. The test results revealed that the heat-treated A356-RM
MMCs showed better tribological and mechanical properties than that of un-heat-treated A356-RM MMC. It was found that the specimen artificially aged for 4 hours at 200°C produces better wear characteristics.

This investigation is further extended to optimize the wear test parameters using Design of Experiment (DOE) approach. A plan of experiments generated using Taguchi L$_{27}$ orthogonal array was employed to analyze the tribological behavior of A356-RM MMCs. The MINITAB 16 software was used for DOE and analyzing the test results. The wear test parameters: contact load, sliding velocity and particulate weight percentages were optimized. The developed analysis of variances and signal to noise ratio were used to analysis the influence of applied contact load, sliding velocity and weight percentages of reinforcement on wear rate and coefficient of friction. The correlations between the parameters and wear rate and coefficient of friction were established through multi-linear regression analysis using the MINITAB 16 software. The present study considers ‘smaller the better’ case to identify the optimum conditions for dry sliding wear and friction coefficient. The results indicated that the wear rate and friction coefficient had been highly influenced by contact load, percentages of reinforcement and sliding velocity. Finally, a confirmation test has been carried out to predict the wear rate as well as friction coefficient. The investigation results showed that the wear rates of the specimens are increased with increasing contact load, weight percentages of reinforcement and sliding velocity. The predicted wear rate and coefficient of friction using the models were found to be closer to that of the experimentally observed results. The A356-RM MMC with 15% (optimum weight percentage) red-mud exhibited better mechanical properties than other MMCs.

In the third phase, the specimens were prepared using stir-casting technique using particulates of 53, 75 and 103 µm particles of optimum
volume percentage, 15% of red-mud. Pin of 5 mm diameter and 40 mm, was cut from the specimen for the wear test. The specimen was machined to get specimens for tensile test as per ASTM E4 standard. All the specimens were solution-treated at 540°C for 4 hours and then immersed in water. Prior to artificial ageing, the solution-treated samples were kept at room temperature for 24 hours for natural ageing process. The artificial ageing was conducted in an electric furnace at optimum condition obtained by previous experimental study (for 4 hours duration at 200°C). Then, the samples were taken out of the furnace and cooled in still air. First, sliding wear and abrasive wear tests were conducted using the specimens at room temperature under dry conditions. The worn-out surface of the sliding wear test and abrasive wear test specimens were analyzed using SEM. The thermal conductivity test, compression test, damping test, micro-hardness test, tensile test, impact test and corrosion test were conducted on the specimens prepared, to analyze the effects of particulate sizes on these properties. The corrosion tests were conducted in different environments: acidic, alkaline and marine environments. The results obtained from all the above tests were analyzed to identify the optimum particulate sizes producing better mechanical properties. The present study recommended that the use of A356 reinforced with red-mud can show better results and lead to the reduction of environmental impacts of red-mud.

The thesis research shows that the reinforcement of A356 alloy with red-mud particles of 53 \( \mu \)m, 15% volume fraction, and 4 hours ageing duration at 200°C can be used to obtain better mechanical properties for A356-RM MMC. The current research also demonstrates another usage for the red-mud waste produced from the Al making industries.