Abstract

At present, there has an increasing interest in developing lightweight, low cost and high strength material for structural applications where metal foam stands to be an emerging material. Among the metallic foam, lightweight aluminium foam is the most demanding material in the scientific community and industrial applications due to its lighter weight, crash resistance property, environmentally friendliness, and recyclability. As a result, it has a wide range of applications in lightweight construction, vehicle design, thermal insulation, acoustic, damping, and electromagnetic shielding. However, the commercially available aluminium foam suffers from lower strength, poor cell wall morphology, in addition to having a higher processing cost and the problem of reproducibility. In the past, a large number of studies have been undertaken to develop aluminium foam by stir casting route, powder metallurgy route using gasifier as a foaming agent. However, an extensive effort needs to be undertaken to understand processing rote and the effect of process parameters on the density and mechanical properties of the foam. In addition, a comparison of the properties of the metal foam developed by different processing routes has not been studied in detail.

The present work aims at the development of aluminium foam using a foaming agent with and without of addition of space holder by stir casting route, development of aluminium foam with cenosphere as space holder by powder metallurgy route, and development of aluminium foam with cenosphere as space holder by spray foaming route. The detailed study included understanding the effect of process parameters on the microstructure, phase, density and porosity distribution, mechanical properties, wear, and electrochemical properties. A detailed nanoindentation study has been carried out to evaluate the cell wall mechanical properties of the aluminium foam. Finally, the comparative behaviour of the aluminium foam developed by stir casting, powder metallurgy and spray forming route has been undertaken to understand the effect of processing route on the behaviour of the aluminium foam.

In stir casting route attempts have been made to develop aluminium foam using (1 to 3 wt.%) calcium carbonate ($CaCO_3$) as foaming agent (with and without addition of cenosphere as space holder). It is observed that with increasing the foaming agent (1-3

wt.%) there is decrease in relative density (0.31 to 0.23), decrease in hardness (56 HV to 47 HV), and yield strength (1.95 to 1.62 MPa) in compression. With the addition of cenosphere as reinforcement there is increase in density and mechanical property of the foam. In addition, there is also change in nanomechanical properties of the cell wall with the addition of cenosphere.

In powder metallurgy route aluminium cenosphere composite foam has been developed where the main variable was cenosphere content. It is observed that the density of composite foam decreases from 2.7 g/cm^3 for as received aluminium and 2.02 to 2.44 g/cm^3 for composite foam and it decreases with increase in cenosphere percentage. Hardness of the foam increase from 30 HV for as received aluminium to 66 HV for 50 vol.% cenosphere dispersed aluminium. The increased hardness is due to presence of hard cell wall of the cenosphere. The yield strength of the foam increases with increase in the compaction pressure (27.5 MPa for 125 MPa compaction pressure to 88.7 MPa for 375 MPa compaction pressure). It is also found to increase with increase in cenosphere content up to 20 vol.% cenosphere and decreases with further increase in cenosphere content. A detailed study of the wear resistance against tungsten carbide (WC) ball under fretting wear mode shows that the wear resistance of the foam increases up to 30 vol.% cenosphere following which it decreases. The study of mechanism of wear reveals that the mode of wear is due to the combined effect of adhesive and abrasive modes. The corrosion study in a 3.56 wt.% NaCl solution shows that corrosion rate increases up to 30 vol.% cenosphere following which it decreases. The detailed study of mechanism of corrosion by EIS and post corrosion microstructure analysis shows that the interface between the cenosphere and aluminium is the potential site for initiation of corrosion.

For the development of aluminium foam by spray forming route initially the free flowing aluminium cenosphere composite powder has been developed using 10 vol.%, 30 vol.%, and 40 vol.% cenosphere and aluminium in a planetary ball mill with ball to powder ratio of 10:1 using steric acid as media at 250 rpm for 7 hrs. Spray forming was conducted using a conventional plasma spraying unit to the dimension of 20 mm×20 mm×5 mm. The density of the foam product was found to vary from 1.83 to 2.03 g/cm^3 and decrease with increase in cenosphere content. The microhardness of the composite foam was found to increase from 56-66 HV and decreases with increase in cenosphere content. The yield strength, plateau strength, and energy absorption decrease with addition of cenosphere. The fretting wear test against tungsten carbide ball showed an increased wear resistance compared to as received aluminium. The corrosion resistance in 3.56% NaCl solution shows a marginal decrease in corrosion resistance with increase in cenosphere content. The study of corrosion mechanism by EIS analysis shows that the impedance of the foam decreases with addition of cenosphere mostly localized corrosion occur. Finally, a detailed comparison of performance of aluminium cenosphere composite foam developed by different processing rote has been undertaken to understand the effect of processing route on the performance of the aluminium foam developed in the present study.

The present thesis has been divided into total six chapters. Chapter 1 provides a brief introduction of aluminium foam, composite foam and their applications in various fields. It also focuses on the characteristic feature of the fabricated aluminium foam and composite foam. Chapter 2 deals with the literature related to different processing methods to fabricate foam, and the reported literature related to the properties of foam, like, mechanical, tribological, electrochemical and their applications. This is followed by identification of the gaps in the literature and formulation of objectives adopted for addressing the problems associated with fabrication of foam. Chapter 3 states the information on materials and methods used in the present study. Moreover, this chapter also deals with the different characterization techniques opted in the present work. Chapter 4, results and discussion on developed foam by using (a) Stir casting route to development of foam by using calcium carbonate foaming agent ($CaCO_3$), and cenosphere space holder, (b) Powder metallurgy route to fabrication of foam by using cenosphere space holder, and the (c) Spray forming route to fabrication of foam by using cenosphere space holder. In addition, a detailed study on the effect of varying percentages of cenosphere on density, porosity, microstructure, mechanical properties, wear properties and corrosion properties on developed foam. Chapter 5 provides the summary and conclusions of the study in detail. Finally, in Chapter 6 the future scope and other possibility of present research work on composite foam have been discussed in detail.

Keywords: Aluminium foam; composite foam; stir casting; powder metallurgy; spray forming; ball milling; microstructure; cell wall strength; compressive property; Nanoindentation; wear; corrosion; EIS.