CHAPTER 1

INTRODUCTION

There is a constant requirement of novel materials for various engineering applications such as automotive, railway, marine, structural components, military equipment, and aerospace industries etc. In the beginning, the automobile industry mainly focused more on electric power than gasoline power. Robert Davidson built the first electric car in 1837, but its manufacturing and sale started in the 1890s in the USA (United States of America) and Europe. In the USA, electric cars overcame the conventional internal combustion engine-driven vehicles in the late 1890s. Steel weighs three times that of aluminium per cubic foot, thus making aluminium a better choice for lightweight electric vehicles. This enables them to travel more distance for the same power before the battery discharges. With various manufacturing processes like injection molding, additive manufacturing, and surface coating, aluminium metal powder is gaining importance in various fields such as aerospace engineering, marine engineering, etc.

The aluminium protects the passengers and body of the car better in case of a crash, while the crash management system absorbs the energy thus generated. In such a situation, the car's body was not much affected and only the bumper needed to be replaced. During accidents, to ensure the passengers' safety and security, the toughness and strength of the chassis play a key role. The materials developed with hollow microspheres of ceramic reinforced in metal alloys absorb more energy per unit weight than monolithic alloys after impact. In **Figure 1.1,** it can be seen that these aluminium-based revolutionary materials can be used to develop vehicle frame or reinforcement boxes, as they provide better vehicle dynamics, torsional stiffness, and energy absorption during vehicle impact [1].

Figure 1.1: Electric Car body structure [1]

The automotive sheets used for structures and body panels could play a key role. Aluminium shows a balanced performance, such as being lightweight, having better corrosion resistance, good formability, high specific strength, and relatively low cost. The density of aluminium alloy is only one-third of steel. Considering structural optimization due to material replacement, the overall weight of rail car-body is decreased by 50% when aluminium is used. This degree of reduction deserves an effort in engineering application. The earth's crust comprises nearly eight wt% (by mass). Still, the stability of its silicates and oxides and its high affinity for oxygen has resisted its separation from long ago. At the end of the nineteenth century, this made its application in engineering economics [2].

Figure 1.2: Typical car-body of high-speed train made of aluminium alloy [3]

The use of aluminium alloy can significantly reduce the net weight of rail passenger cars while it meets the safety requirements in strength and rigidity. Generally speaking, a car body made of aluminium alloy is 30%~50% lighter than steel. For high-speed and double-deck trains, the most effective way to make vehicles light is to increase the proportion of aluminium used in vehicles as much as possible. Aluminium alloy has good corrosion resistance. The surface of aluminium alloy is easy to form a layer of dense oxide film, which has an excellent anti-oxidation ability in the atmosphere. Therefore, car-body (**Figure 1.2)** made of aluminium alloy has better corrosion resistance than steel, especially in the components that are not easy to be coated, such as the box structure and some of its internal beams and columns, aluminium counterparts show obvious advantages [3].

An axle box (**Figure 1.3**) is one of the essential bearing parts of automotive, train bogie, and transfer joint of motion. In the case of the train, when it is running, the axle box bears vertical force, longitudinal force, and transverse force. Therefore, the bearing condition of the axle box body is complex, and its structure and performance stability is essential for the safe operation of the train. 7050 aluminium alloy forgings show high strength and toughness, significantly reducing unsprung weight. The weight of forged aluminium products decreases 62.5% compared to the traditional carbon steel one [4].

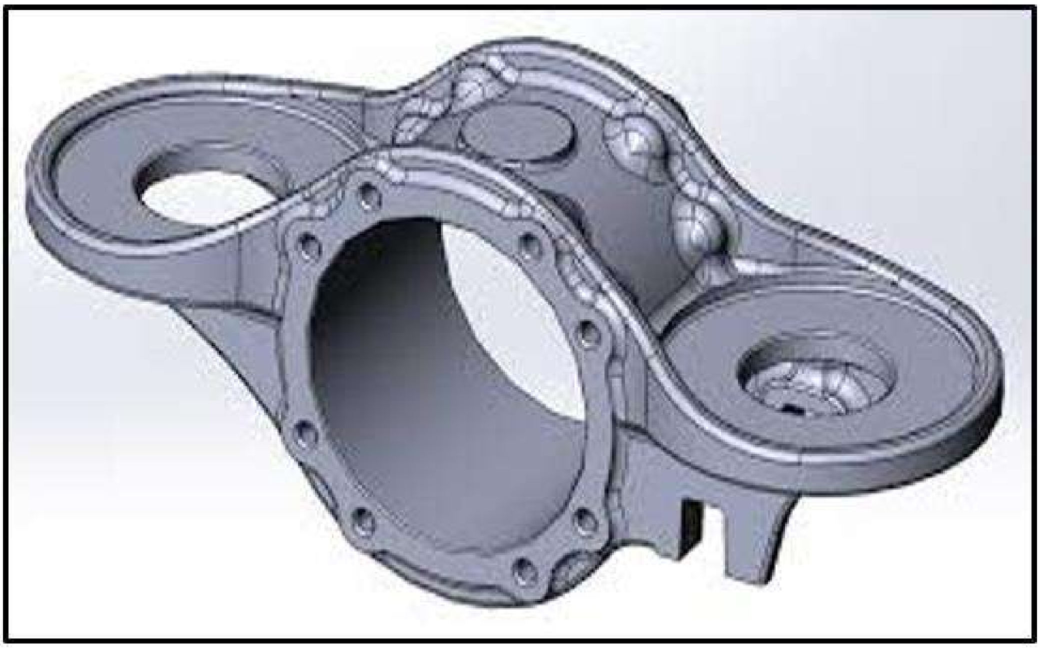

Figure 1.3: Model of an aluminium alloy axle box [4]

The low density and toughness, high strength, and corrosion resistance of aluminium enable the designers to achieve a weight reduction of about 15-20% compared to steel or composite designs. This makes it an interesting choice for high-speed vehicles such as patrol boats, ferries, military crafts, fishing vessels, hydrofoils, leisure craft, workboats, and cargo vessels (**Figure 1.4**). The thin passive oxide coating formed on aluminium when exposed to the atmosphere provides corrosion resistance. This continuous coating prevents further oxidation, unlike oxide coatings formed on conventional steels. However, this protective coating can be attacked by or dissolved in high alkali or acidic media.

Figure 1.4: Model of aluminium alloy petrol boat [4]

During the First World War, various military applications increased the demand for aluminium in different forms. Combat vehicles' military requirements have their specifications of armour. For example, 5XXX series strain hardenable alloys are used for all aluminium military vehicles produced to date. Likewise, protection at all angles is provided by 7XXX series heat-treatable alloys. In combat vehicles, aluminium armour is used by keeping in mind the minimum weight for a given level of protection. Compared to steel the, aluminium is free from low-temperature embrittlement and greater rigidity, due to thicker sections, for the same protection. Greater rigidity as much as nine times that of steel eliminates the need for any structural secondary support. Aluminium also finds application in other military equipment such as electronic hardware and bridges.

Figure 1.5: Model of 2024 aluminium alloy aircraft [5]

Extrusions of the 2014-T6 alloy were mainly used to design the Ponton bridge during world war II and are still in use and production [4]. An increased yield strength obtained by cold deformation and natural ageing led to the development of 2024 and 319 alloys widely used in the aircraft industry. They were used mainly in sheet forms for wings and fuselage (**Figure 1.5**), owing to their fatigue resistance and high tensile strength (470MPa). Aluminium 6061 alloy is most commonly used for aircraft, especially in homemade ones. The maximum strength provided by 2219 alloys at elevated temperatures led to their application in fuel tanks on first successfully launched space shuttles [5]. The technical characteristics, such as ease of service, fabrication, and maintenance of 7050-T7451 aluminium alloy, make it a suitable choice for structural components of flight airframes. The lifecycle of 7050 alloys is predicted using a modelling framework based on process variants linked to life-limiting microstructural features [6-7].

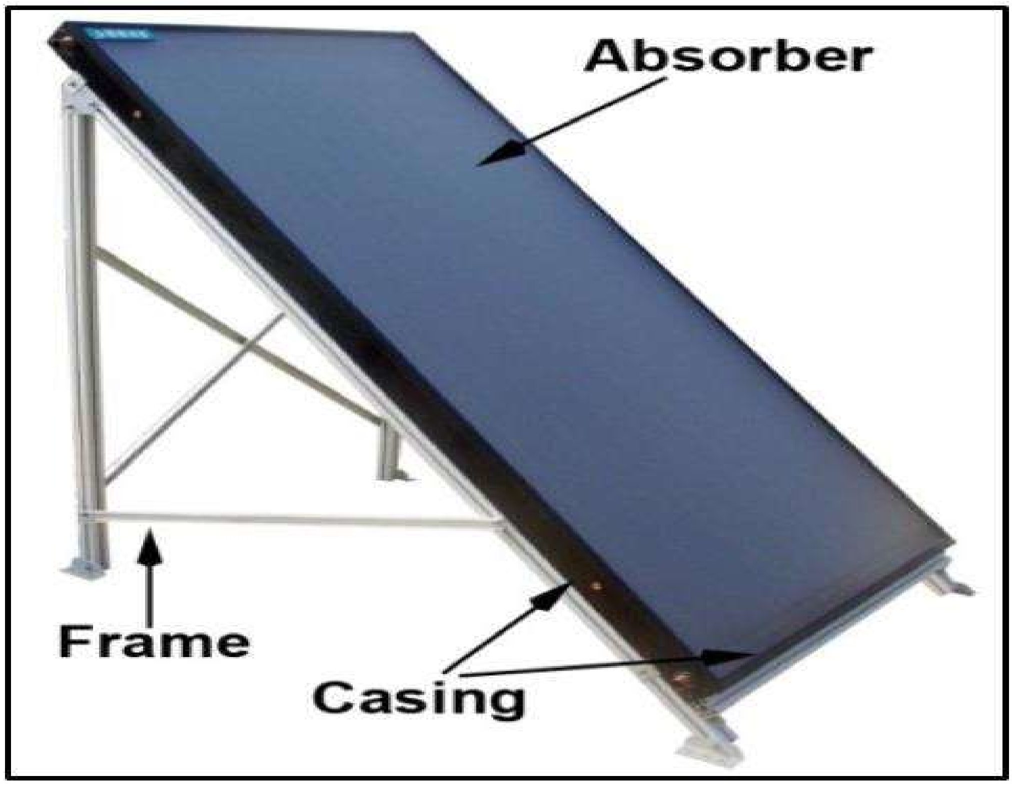

Figure 1.6: Different parts of a flat-plate collector [8]

Figure 1.6 shows part of solar power systems can be made using aluminium. Solar systems can be classified into three categories: solar thermal absorbers, photovoltaic solar cells, and concentrating solar power. These groups are made of aluminium alloys due to their unique properties. The high reflecting efficiency of aluminium and silver in the solar wavelength range makes them a good choice for reflectors of CSP systems. The best shape of reflectors to achieve the highest concentrating efficiency can be obtained by deforming aluminium easily. Compared to glass mirrors, reflectors made of aluminium are unbreakable, making it suitable for outdoor applications. Aluminized reflectors have better mechanical properties and are cost-effective as compared to silvered glass mirror ones, thus they are employed in solar technologies. Absorbers are made of steel, aluminium, and copper. Whilst frames and casing are made of steel and aluminium. Aluminium is preferred over steel due to its lightweight. As an anodic layer of aluminium has unique optic properties, it is a valuable material for solar absorption [8-9]. Aluminium alloy (6061) containing magnesium and silicon as alloying elements, has good machinability and high strength, is a valuable alloy for solar plants structure. Aluminium and its alloy's cheap and successful recycling process is another reason for its acceptance by many companies in different fields. Recycling can reduce water, air pollution, and energy usage thus saving money. Therefore recycling should be kept in mind while considering any material for domestic or industrial applications [10].

Composite materials are developed by combining the two or more chemically dissimilar materials at a microscope level. Composite materials display quite different physical, mechanical, and tribological behaviours than the behaviours of the constituents due to their synergistic effect. The continuous constituents in the matrix are called reinforcement. The materials which are embedded with hard ceramic reinforcement generally known as discontinuously reinforced metal matrix composites (DMMCs) reinforcement are embedded into materials. Thus, metal matrix composites merge the toughness and ductility of the matrix with good modulus and strength of ceramic reinforcement, leading to a higher compression and shear strength along with the potential to retain its good properties at higher working temperatures.It has been extensively investigated that good physical, tribological, and mechanical properties such as high specific modulus, strength, good wear resistance, and thermal stability can be achieved in metal matrix composites [10-11].

During past decades, composites of a light metal matrix reinforced with ceramic particles received widespread studies due to their superior mechanical properties. Aluminium reinforcement with $Al_{18}B_4O_{33}$ particulate is one of the most successful types of MMCs among them. Their high strength-to-weight ratio, better tribological properties, and good castability over monolithic alloys lead to their enhanced application in the aircraft or automotive industry. The superior properties obtained by reinforcing nano-sized particles of alumina and boric acid are important according to the latest requirements. New features and functions that can be performed by nanostructures are not possible with large structures and machines. The properties of composites can be enhanced by altering the physical and chemical properties (hardness, stability, conductivity, optical sensitivity, stability, melting point, etc.) of nanomaterials, as they have small dimensions. Production of high-performance composites with improved mechanical properties is obtained by reinforcing aluminium matrix with much smaller particles, submicron or nano-sized range. Various techniques are employed to manufacture aluminium matrix composites (AMCs). These could be classified as

i) Liquid-solid processing, e.g. semi-solid forming, compo casting.

ii) Solid-state processing, e.g. powder metallurgy with different pressing techniques such as hot or cold isostatic pressing.

iii) Liquid state processes, e.g. squeeze casting, stir casting, ultrasonic casting, pressure less infiltration, vacuum infiltration, and dispersion methods. [11]. We will briefly discuss these techniques in the next chapter.

Objective of the current work

The present investigation aims to develop an uncoated and coated alumina borate whisker reinforced in aluminium and aluminium (319-alloy) matrix composites. The hydrolysis route was adopted to synthesise and coat alumina borate whisker (reinforcement). In hydrolysis reaction, cleavage of chemical bonds is done by the addition of water and the reaction involves water and an organic chemical to form one or two new substances. In fact, it is the reverse of condensation reaction, in fact, in which a large molecule is formed by joining two smaller ones, thereby releasing a water molecule [12]. In hydration, the water reacts with the compound without decomposing it. Manufacture of alcohols e.g. ethanol, glycols, and propylene oxide, is done using this route. Following reversible chemical reaction represents the hydrolysis reaction where the formula AB means a chemical, in which A and B are atoms or groups, and the formula HOH represents water:

$$AB + HOH \rightleftharpoons AH + BOH \qquad (1.1)$$

The reactants (other than water) and products of the hydrolysis may be ionic molecules (in the case of salts, acids, and bases) or neutral molecules [13].

Powder metallurgy and compo-casting/rheo-casting route were adopted for the fabrication of reinforcement in the matrix. The powder metallurgy process involves three major stages. The primary material is converted physically into small particles in the first step. A mixture of powdered metals and ceramics is prepared by mixing in required proportions. Ball milling is performed to achieve better mechanical properties by mechanical alloying of mixture powder. A weakly cohesive structure that is closed to the final object, to be produced, is formed by injecting the powder into a mold and compacting it on a press. The final product is obtained by applying high pressure, temperature, long setting time, or their combination [14].

In the compo-casting/rheo-casting process, a metal between 25-50% solid and 50-75% liquid state is used, utilizing high pressure, cold chamber die casting machine to inject the semi-solid slurry into re-usable, hardened steel dies. It is also called the two-step mixing process. The matrix material is heated above its melting temperature to create a melt. The melt is kept semi-solid by cooling it between liquidus and solidus temperature. Preheated particles or whiskers are added and mixed at this stage. The viscous liquid produced by dispersion of solid particles or whiskers in liquid, is easier to control (without splashing and turbulence) than a fully liquid medium, thus giving an advantage over other processes. The semi-solid slurry having higher viscosity imparts shear force over agglomerates and better dispersions' separation [15].

The developed aluminium metal matrix composites are characterized using various techniques (e.g.: XRD, OM, SEM, HRSEM/EDS, DTA-TGA) and its microstructure, physical (densification, porosity), mechanical (modulus of rupture at room temperature and high temperature, compressive strength, tensile strength) and tribological (dry sliding) behaviors were explored. In the current investigation, the aluminium and aluminium (319) alloy are developed to discover their best for various engineering applications such as railway structures, aluminium tube-plumbing, electric vehicle or automotive structural components, marine engineering, etc.

Novelty statement for present work

Among the various high-cost processing techniques available for whisker reinforced MMCs, compo-casting and powder metallurgy can be accepted as a method for producing large quantities for commercial purposes. They are attractive and simple, flexible, and most economical for large-sized components to be fabricated. Although flexibility in manufacturing and component design is provided by liquid state processes such as vortex method and squeeze casting, very large specific surface area and high interfacial energy of ABO_w result in their aggregation and poor distribution in the melt. Therefore, special techniques are required to add ABO_w to the molten matrix.

Alumina borate whiskers reinforced aluminium (ABO_w/Al) composites possess not only quite excellent mechanical properties but also reasonably low prices, which will promote their widespread industrial applications in the future. Therefore, developing aluminium borate whiskers via hydrolysis route and reinforcing it in the aluminium matrix was done to obtain a class of tailored metal matrix composites. In addition to this whisker, the coating improved the interfacial reaction between whiskers and the matrix.