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This is to certified that the work contained in the thesis titled ***"Synthesis, Characterization and Mechanical Properties of Uncoated and Coated ABO_w Reinforced Aluminium Matrix Composites"*** by ***"Mr. Neeraj Pandey"*** (Roll No. 16031007), has been carried out under my supervision and this work has not been submitted elsewhere for a degree.

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I, **Neeraj Pandey** (Roll No.16031007), certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of *Asso. Prof M.R.Majhi* and *Late Prof. I. Chakraborty* from 2016 to 2021, at the **Department of Ceramic Engineering**, Indian Institute of Technology Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and credited the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not will fully copied from any other's work, paragraphs, text, data, results, *etc*., reported in journals, books, magazines, and reports dissertations *etc*., or available at websites and have not included them in this thesis and have not cited as my own work.

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It is certified that the above statement made by the student is correct to the best of our knowledge.

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I sincerely crave the readers' indulgence towards the misprint & other lapses (if any) in the thesis.

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(NEERAJ PANDEY)

Their Blessings and Prayers are enduringly with me to succeed in my life cycle.

ABSTRACT

An increasing demand of new materials for the various fields of engineering application such as automotive, railway, marine, building component, solar panels and aerospace application. Due to wide range of application, new materials require to meet miscellaneous demands such as good mechanical strength, high resistance to wear, stable and high friction coefficient, elevated thermal stability, high stiffness, resistance to corrosion. It is very complicated to attain such properties in monolithic form or solo material. Therefore, composite material have been tailored to meet these combinations of properties for a wide range of application.

Therefore to fulfill this continuous demand of such materials up to a level, low density aluminium metal matrix composites with enhanced performances. In the present investigation, powder metallurgy and compo-casting technique are considered to be the most viable for developing the aluminium and its alloy based composites due to certain advantages, such as easy to perform and very economical. The different ceramics reinforcing phases are used such as ABO and SiO_2 coated ABO whiskers due to their high hardness, high chemical stability, and high modulus, grain refining effect, better corrosion and wear resistance. There are broadly two categories of aluminium based composites known as ABO_w. Coated ABO_w reinforced composites are developed depending on the weight percentage of reinforcement into the aluminium and its alloy (Al-319) matrix composites.

Subsequently, the developed aluminium and Al-319 alloy composites have undergone various characterisations for their microstructural, physical, mechanical, and dry sliding behavior. The various characterizing and analytical tools such as X-ray

diffraction (XRD), scanning electron microscopy (SEM), high-resolution scanning electron microscopy (HRSEM), energy dispersive analysis (EDAX), transmission electron microscopy (TEM) have utilized for microstructural observation. The hardness, mechanical strength (tensile, flexural strength, compressive strength etc.) and dry sliding wear behavior of developed material have been measured according to the specific standards. The fracture and worn surfaces behavior of all the material studied in the present investigation were examined under SEM, EDAX and SPM (scanning probe microscope).

After various characterizations, it is observed that the developed aluminum based composites have better mechanical and wear properties as compared with aluminium matrix due to uniform distribution and good wettability of the reinforcing phases in the aluminium matrix. Therefore, the developed aluminium based composites can be successfully used for various engineering applications such as structural components in electric vehicles, solar panels, railway components, marine and aerospace industries etc.

Keywords: Hydrolysis route, Coating, Powder metallurgy, Compo-casting, Physical properties, Mechanical properties and Dry sliding wear properties.

TABLE OF CONTENT

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations	Description
MMCs	Metal Matrix Composites
CMMCs	Ceramic Metal Matrix Composites
PMMCs	Particle Metal Matrix Composites
MA	Mechanical Alloying
CA	Cast Aluminum
PM	Powder Metallurgy
PMCs	Polymer Matrix Composites
FRMMCs	Fiber Reinforced Metal MatrixComposites
ABOw	Aluminum Borate Whisker
MBOw	Magnisium Borate Whisker
WDP	Wet Dispersion Process
CMCs	Ceramic Metal Matrix Composites
CVD	Chemical Vapor Deopositon
µm	Micro Meter
nm	Nano Meter
HC	Hybrid Composites
C1	Composite-1
C2	Composite-2
C3	Composite-3
S	Sample
SEM	Scanning Electron Microscopy
HRSEM	High Resolution Scanning Electron Microscopy
TEM	Transmission Electron Microscopy

MPa	Mega Pascal
EDS	Electron dispersive spectroscopy
TGA	Thermo Gravimetric Analysis
DTA	Differential Thermal Analysis
GPA	Giga Pascal
DCS	Diametral Compressive Strength
YS	Youngs' Modulus
FS	Flexural Strength
σ	Flow Stress
σ_c	Strength of the Composites
σ_f	Strenght of the Reinforcement
σ_m	Strength of the Matrix
V_f	Volume Fraction of The Reinforcement
V_m	Volume Fraction of The Matrix
ROM	Rule of mixture
CTE	Coffiencent of Thermal Expansion
ASTM	American Society for Testing Materials
G	Shear Modulus of The Matrix
β	Geometric Constant
W	Normal Load
H	Hardness of Softer Surface
Q	Volume of Material Wear Out
K	Wear coefficient or the coefficient of wear
F	Frictional Force
μ	Coefficient of Friction
m/s	Meter Per Second
UTS	Ultimate Tensile Strength

UTM	Universal Testing Machine
JCPDS	Joint Committee on Powder Diffraction
MOR	Modulus of Rupture
HMOR	Hot Modulus of Rupture
Al	Aluminum
N	Newton
Wt%	Weight Persentage
Vol%	Volume Percentage
Ra	Average Roughness
Rq	Root Mean Square Roughness
TiO_2	Titanium oxide
SiO_2	Silicon Oxide
Cr_2O_3	Chromium trioxide
ZnO	Zinc Oxide
$Al_{18}B_4O_{33}$	Alumina Borate
Al_2O_3	Alumina
rpm	Rotation Per Minute
ºC	Degree Celsius
XRD	X-Ray Diffraction
SAED	Selected Area Electron Diffraction
Å	Angstrom
AP	Apparent Prosity
BD	Bulk Density
d	The Inter Planner Spacing
Ɵ	The Incident Bragg's Angle
λ	The Wavelength Of The X-Ray
hkl	Miller Inices

δ	Elongnation to Fracture
EDAX	Energy Dispersive Analysis X-Ray
W_a	Weight in Air
W_w	Weight in Water
g	Gram
Kg	Kilo-Gram
Mm	Milimeter
BHN	Brinell Hardness number
P	Load
D	Diameter of the ball
HRC	Rockwell Hardness Measured at C Scale
min	Minute
AFM	Atomic Force Microscopy
POD	Pin on Disc
V	Average cumulative volume loss
S	Sliding Distance

PREFACE

This thesis reports the preparation of Alumina Borate whisker (ABO_w) reinforced aluminum matrix composites fabricated using powder metallurgy and compo casting techniques. Both uncoated and coated whiskers were prepared using hydrolysis route. Oxides of titanium, silicon, zinc and chromium were used for whisker coating. Pure aluminium matrix and Al-319 alloy was reinforced with whiskers using powder metallurgy and compo-casting methods respectively. The identification of phases present in both reinforcement and composites was carried out by X-ray diffraction investigation. The microstructural study of the samples was also performed by a scanning electron microscopy (SEM) equipped with energy dispersive analysis of X-ray (EDAX) to explore the compositional analysis. High resolution (HR-SEM) helped in better understanding the coating of the ABO_w reinforcement and the bonding between the matrix and reinforcement phases. Transmission electron microscope (TEM) also showed the crystallographic structure and the composition of reinforcement and composites. The behavior of worn surfaces of the composites under load conditions was examined by scanning/atomic probe microscope (SPM/APM). The experimental density of reinforcement samples and composites was evaluated using Archimedes' principle with the help of the calculated weight of samples in the air and in water. The mechanical test of reinforcement samples, aluminium and A-319 alloy composites was executed on the Universal testing machine. Dry sliding friction and wear tests of the base aluminum and developed Al-319 alloy composites were performed on the pin-on-disc machine. Fractography analysis was carried out for the fractured surfaces of composites.

In thesis has the following **9** chapters.

Chapter -1: This chapter comprises the introduction of the composite and metal matrix composites with their classification based on matrix and reinforcement. A brief description of properties and wide range of applications of aluminium and its composites has been given with respect to their evolution as one of the promising materials in recent years.

Chapter-2: The literature review contains the review of the work on metal matrix composites associated with this study. This chapter includes a brief introduction related to associate composite material for this project, their synthesis processes, properties, drawbacks, and their utilization as a composite for industrial application.

Chapter-3: This chapter describes the materials used, the synthesis and fabrication process of reinforcements and composites. The characterization techniques and their principles are detailed here. Furthermore, the standard procedures to evaluate the mechanical and dry-sliding behaviour of the synthesized materials and composites are described. The next chapter depicts the findings of this thesis.

Chapter-4: This chapter of the thesis contains the discussion of the results of characterization of the reinforcement (alumina borate). It also explains the effect of content on the synthesis, microstructural, physical and thermo-mechanical properties of alumina borate whiskers. The microstructural behavior of reinforcement has been investigated by using SEM, EDS, XRD, and TEM. For thermo-mechanical analysis Differential thermal analysis (DTA/TGA) was carried out.

Chapter 5-: This chapter presents the result and discussion of properties of the coated reinforcement (alumina borate) with four metal oxides (Cr_2O_3, SiO_2, ZnO, and TiO_2). In this part, a comparative study of different coated metal oxides was carried out. The physical thermo-mechanical properties i.e. bulk density, apparent porosity and High-temperature modulus of rupture were measured for different coated sample.

Chapter 6-: This chapter presents the results and discussion part of the composites with uncoated reinforcement (ABO_w) and aluminum as a base metal developed by the powder metallurgy route. The developed composites have been examined for characterization and distribution of phases by XRD, EDAX, SEM, and HRSEM. The hardness, compressive strength, flexural strength, and dry sliding behavior of developed composites have been measured. The fracture behavior of tested composite was observed by SEM and EDAX.

Chapter 7-: This chapter presents the results and discussion part of the SiO_2 coated ABO_w as reinforcement and aluminum as a base metal. The microstructures, flexural strength and diametral compressive strength of fabricated composites was observed. The effects of SiO_2 coating on fabricated composites were evaluated at different reinforcement weight percentages.

Chapter -8: This chapter presents the results and discussion part of SiO_2 coated reinforcement and (Al-319) aluminium base alloy composites fabricated by compo-casting. The effect of coating on the whiskers/matrix microstructures, mechanical and tribological properties of the composites were investigated. Tensile and wear fractography of with and without SiO_2 coating whisker reinforced samples were studied by SEM.

Chapter 9-: This chapter lists the silent conclusions on the synthesis, microstructure, and physical mechanical and dry sliding friction and wear behaviors of the developed uncoated and coated composites using the powder metallurgy and compo-casting technique in the present investigation.

LIST OF FIGURES

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