

**PREPARATION OF PLASMA VAPOUR DEPOSITED ALUMINIUM
OXIDE COATING ON CARBON FIBER COMPOSITES FOR SPACE
BASED APPLICATION**

A Project Report Phase – II

Submitted in partial fulfilment of requirements for the award of
Bachelor of Engineering degree in Aeronautical Engineering

by

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BONAFIDE CERTIFICATE

This is to certify that the Project Report is the Bonafide work of **V. PRAVIN BHASKAR (39260022)** and **V. TITTUS (39260041)** who carried out the project entitled "PREPARATION OF PLASMA VAPOUR DEPOSITED ALUMINIUM OXIDE COATING ON CARBON FIBER COMPOSITES FOR SPACE BASED APPLICATION" under my supervision from November 2022 to March 2023.

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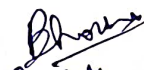
DECLARATION

We, **V. PRAVIN BHASKAR (39260022)** and **V. TITTUS (39260041)** hereby declare that the Project Report entitled "**PREPARATION OF PLASMA VAPOUR DEPOSITED ALUMINIUM OXIDE COATING ON CARBON FIBER COMPOSITES FOR SPACE BASED APPLICATION**" done by us under the guidance of **Dr. A. ANDERSON, ME., PhD.**, Professor, Department of Aeronautical Engineering, SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY, CHENNAI, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Electronics and Communication Engineering.

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ABSTRACT

This report presents a study on the effect of electron-beam physical vapor deposition of aluminum oxide on the reflectivity of carbon fiber. The purpose of this study was to investigate the potential of aluminum oxide coating to increase the reflectivity of carbon fiber. The methodology involved coating carbon fiber with aluminum oxide using the electron-beam physical vapor deposition method, followed by testing the coated fiber using Contact angle, Hardness and UV Spectroscopy tests. The results showed that the aluminum oxide coating significantly increased the reflectivity of the carbon fiber, and the three tests provided further insights into the wettability, hardness and optical properties of the coated fiber. These findings have important implications for the development of high-performance materials and can inform future research in the field of carbon fiber coatings.

TABLE OF CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
	ABSTRACT	v
	LIST OF FIGURES	ix
	LIST OF TABLES	x
	ABBREVIATIONS	xi
1	INTRODUCTION	1
	1.1. COMPOSITE MATERIALS	2
	1.1.1. TYPES OF COMPOSITE MATERIALS	3
	1.2. CARBON FIBER	4
	1.3. FABRICATION PROCESS	6
	1.3.1. TYPES OF FABRICATION PROCESS	7
	1.3.1.1. HAND LAYUP	7
	1.3.1.2. PREPREG LAYUP	8
	1.3.1.3. WET LAYUP	9
	1.3.1.4. FILAMENT WINDING	10
	1.3.1.5. PULTRUSION	11
	1.3.1.6. INJECTION MOLDING	12
	1.3.1.7. 3D PRINTING	13
	1.4. METAL OXIDE COATING	14
	1.5. METAL OXIDES	15
	1.5.1. METAL OXIDES USED FOR COATING	16
	1.5.1.2. TITANIUM DIOXIDE(TiO ₂)	16
	1.5.1.3. SILICON DIOXIDE(SiO ₂)	17
	1.5.1.4. ZIRCONIUM DIOXIDE(ZrO ₂)	18
	1.6. COATING TECHNIQUES	18

	1.6.1. ELECTRON BEAM PHYSICAL VAPOR DEPOSITION (EB-PVD)	19
	1.6.2. SPUTTERING DEPOSITION	20
	1.6.3. MAGNETRON SPUTTERING	21
	1.6.4. ION PLATING	22
2	LITERATURE SURVEY	23
3	AIM AND SCOPE	25
	3.1. AIM OF THE PROJECT	29
	3.2. SCOPE OF THE PROJECT	29
4	MATERIALS AND METHODS	29
	4.1. MATERIALS	30
	4.1.1. ALUMINIUM OXIDE POWDER	30
	4.1.2. CARBON FIBER COMPOSITE	30
	4.2. METHODOLOGY	31
	4.2.1. PELLETIZING PROCESS	32
	4.2.2. SINTERING PROCESS	32
	4.2.3. FABRICATION OF CARBON FIBER COMPOSITE	34
	4.2.4. COATING PROCESS	35
	4.2.4.1. EB-PVD METHOD	36
	4.2.5. TESTING METHODS	37
	4.2.5.1. SCANNING ELECTRON MICROSCOPE	38
	4.2.5.2. X-RAY DIFFRACTION ANALYSIS	39
	4.2.5.3. WATER CONTACT ANGLE	40
	4.2.5.4. VICKERS HARDNESS TEST	42
	4.2.5.5. UV SPECTROSCOPY	43
5	RESULT AND DISCUSSION	44
	5.1. SCANNING ELECTRON MICROSCOPY TEST	45
	5.2. XRD ANALYSIS	46
	5.3. WATER CONTACT ANGLE TEST	48

	5.4. HARDNESS TEST	50
	5.5. UV SPECTROSCOPY	51
6	SUMMARY AND CONCLUSION	52
	6.1. SUMMARY	52
	6.2. CONCLUSION	53
	REFERENCES	51

LIST OF FIGURES

FIGURE No	TITLE	PAGE No.
1.1	Schematic diagram of EB-PVD process	21
1.2	Schematic diagram of Sputtering process	22
1.3	Schematic diagram of Magnetron Sputtering process	23
1.4	Schematic diagram of ION Plating process	24
4.1	Aluminium oxide powder	30
4.2	Methodology Flowchart	32
4.3	Pelletizer machine	33
4.4	Preparation of Carbon fiber Laminate	35
4.5	Electron Beam Evaporation unit	37
4.6	XRD Equipment	39
4.7	Contact angle meter	40
4.8	UV-Vis Spectrophotometer	43
5.1	SEM image of Aluminium Oxide	44
5.2	Composition of elements	44
5.3	Diffraction Pattern Graphics	46
5.4	Image of Tangent Fitting method	47
5.5	Image of Half Angle Fitting method	48
5.6	Representation of Reflectance%	50

LIST OF TABLES

TABLE No	TITLE	PAGE No.
1.1	Physical Properties of Carbon Fiber	5
1.2	Mechanical properties of Carbon Fiber	5
1.3	Thermal properties of Carbon Fiber	6
5.1	Elements in Aluminium powder	45
5.2	Integrated Profile Areas	46
5.3	Tangent Fitting method	47
5.4	Half Angle Fitting method	48
5.5	Comparison of hardness of as coated and coated samples	49

LIST OF SYMBOLS AND ABBREVIATION

ABBREVIATION	DESCRIPTION
PMC	Polymer matrix composite
MMC	Metal matrix composite
CMC	Ceramic matrix composite
PVD	Physical vapor deposition
CVD	Chemical vapor deposition
EB-PVD	Electron Beam Physical Vapor Deposition
SOFC	Solid Oxy Fuel Cells
APS	Atmospheric Plasma Spray
EB – PVD	Electron Beam – Physical Vapor Deposition
SEM	Scanning Electron Microscope
EDX	Energy-dispersive X-ray
CFRP	Carbon fiber reinforced polymer
XRD	X – Ray Diffraction
RTM	Resin transfer molding
WCA	Water contact angle
HV	Vickers hardness number

CHAPTER – 1

INTRODUCTION

1. INTRODUCTION

Carbon fiber is a widely used material in various industries due to its excellent mechanical properties and light weight. However, it has a low reflectivity which limits its applications in certain fields. To overcome this limitation, metallic oxide coatings have been developed as a way to increase the reflectivity of carbon fiber. One such oxide is aluminum oxide, which is known for its high reflectivity and excellent mechanical properties.

In this report, we focus on the effect of electron-beam physical vapor deposition of aluminum oxide on the reflectivity of carbon fiber. The electron-beam physical vapor deposition method is a commonly used technique to coat surfaces with various materials, including metals and oxides. By using this method, a thin layer of aluminum oxide was deposited onto the carbon fiber, which can potentially increase its reflectivity and extend its applications.

The purpose of this study is to investigate the potential of aluminum oxide coating to increase the reflectivity of carbon fiber. We will describe the methodology used to coat the carbon fiber with aluminum oxide using the electron-beam physical vapor deposition method. Additionally, we will describe the tests conducted after the coating process, which includes Contact angle, Hardness and UV Spectroscopy tests. These tests provide information on the wettability, resistance of a material to indentation and optical properties of the coated carbon fiber.

The findings of this study have important implications for the development of high-performance materials, especially in industries where high reflectivity is a desirable property. Additionally, this study can inform future research in the field of carbon fiber coatings, which can potentially lead to the development of even more advanced and versatile materials.

1.1. COMPOSITE MATERIALS

Composite materials are materials made up of two or more distinct components that work together to create a material with unique properties that cannot be achieved by any of its individual components alone. The components of a composite material are usually a reinforcement material, such as fibers or particles, and a matrix material, which is typically a polymer, ceramic, or metal.

Composite materials have become increasingly popular in many industries due to their exceptional mechanical properties, such as high strength, stiffness, and durability. They are widely used in aerospace, automotive, construction, marine, and sports equipment industries, among others. One of the most significant advantages of composite materials is their high strength-to-weight ratio, which allows for the creation of lightweight structures that are still strong and durable.

Composite materials can be classified based on the type of reinforcement material used. For instance, fiber-reinforced composites use fibers such as carbon, glass, or aramid as reinforcement materials, while particle-reinforced composites use particles such as ceramics, metals, or polymers as reinforcement materials. The choice of reinforcement material depends on the specific application and the required properties of the composite material.

The matrix material in composite materials is responsible for holding the reinforcement material in place, transferring loads, and providing protection from environmental damage. The choice of matrix material depends on the specific application and the required properties of the composite material. For instance, polymer matrix composites are commonly used in aerospace applications due to their low weight, high strength, and resistance to environmental damage, while metal matrix composites are used in automotive and industrial applications due to their high strength, stiffness, and thermal conductivity.

1.1.1. TYPES OF COMPOSITE MATERIALS

- Polymer matrix composites (PMCs): These composites use a polymer resin as the matrix material, and a variety of fibers, such as carbon, glass, or aramid, as the reinforcement material. PMCs are widely used in many industries due to their low weight, high strength, and resistance to environmental damage. Ex: Carbon fiber reinforced polymer (CFRP) composites, which are used in aerospace, automotive, and sports equipment industries due to their high strength and low weight.
- Metal matrix composites (MMCs): These composites use a metal matrix, such as aluminum, magnesium, or titanium, as the matrix material, and ceramic, metal, or polymer fibers as the reinforcement material. MMCs are commonly used in the aerospace, automotive, and industrial sectors due to their high strength, stiffness, and thermal conductivity. Ex: Aluminum matrix composites, which are used in the aerospace and automotive industries due to their high strength and stiffness.
- Ceramic matrix composites (CMCs): These composites use a ceramic matrix, such as silicon carbide or aluminum oxide, as the matrix material, and ceramic fibers as the reinforcement material. CMCs are commonly used in high-temperature applications, such as jet engine components, due to their high strength, stiffness, and thermal resistance. Ex: Silicon carbide matrix composites, which are used in jet engine components due to their high strength and thermal resistance.
- Hybrid composites: These composites use a combination of two or more types of reinforcement materials and/or matrix materials. Hybrid composites can be tailored to meet specific performance requirements, such as high strength, stiffness, and toughness, and are commonly used in high-performance applications, such as aerospace and military applications. Ex: Glass fiber and polymer matrix composites, which are used in construction and automotive industries due to their durability and resistance to impact damage.

1.2. CARBON FIBER

Carbon fiber is a composite material made of carbon fibers that are woven together and then impregnated with a resin. It is known for its high strength-to-weight ratio, making it an ideal material for use in various industries, including aerospace, automotive, sports equipment, and more. Carbon fiber composites are lighter and stronger than many traditional materials such as steel and aluminum, making them ideal for applications where weight reduction is critical.

Carbon fiber is produced using a multi-step process that involves the spinning of carbon fibers from a precursor material, such as polyacrylonitrile (PAN) or rayon, followed by a series of treatments to increase their strength and stiffness. The fibers are then woven together into a fabric, and a resin is applied to create the final composite material.

Despite its many advantages, carbon fiber does have some limitations. For instance, it is relatively expensive compared to traditional materials such as steel and aluminum. Additionally, carbon fiber composites can be brittle and prone to impact damage, which can limit their use in some applications.

In the aeronautical industry, carbon fiber is used extensively for the construction of aircraft parts. One of the most significant applications of carbon fiber in the aeronautical industry is in the construction of wings and fuselages. Carbon fiber composites offer a high strength-to-weight ratio, which can help reduce the weight of the aircraft and improve its fuel efficiency. Moreover, carbon fiber composites have excellent fatigue resistance, which makes them ideal for use in the cyclic loading conditions experienced by aircraft structures.

In the aerospace industry, carbon fiber is used in a variety of applications, including the construction of spacecraft, satellites, and rockets. The lightweight and high strength properties of carbon fiber make it an ideal material for space applications where weight reduction is critical. Moreover, carbon fiber composites offer excellent resistance to extreme temperatures and radiation, making them suitable for use in harsh environments. In addition to its mechanical properties, carbon fiber also has a significant impact on the aeronautical and aerospace industries in terms of sustainability. The use of carbon fiber

composites can help reduce the carbon footprint of aircraft and spacecraft by reducing their weight, thereby reducing their fuel consumption and emissions.

Overall, carbon fiber is a vital material in the aeronautical and aerospace industries due to its unique combination of properties, including high strength, lightweight, and excellent fatigue resistance.

Table 1.1: Physical Properties of Carbon Fiber

Properties	Metric
Density	2.00 g/cm ³
Melting point	3657 °C

Table 1.2: Mechanical properties of Carbon Fiber

Properties	Metric
Tensile strength	4000 Mpa
Yield strength	2500 Mpa
Elastic modulus	500 Gpa

Table 1.3: Thermal properties of Carbon Fiber

Properties	Metric
Thermal expansion co-efficient	-1 K ⁻¹ to +8 K ⁻¹
Thermal conductivity	100 W/mK

1.3. FABRICATION PROCESS

Carbon fiber is a high-performance material that is widely used in various applications such as aerospace, automotive, sports equipment, and more. The fabrication process of carbon fiber involves several steps, including precursor preparation, spinning, stabilization, carbonization, and surface treatment.

The first step in the fabrication process of carbon fiber is precursor preparation. The precursor is typically made from polyacrylonitrile (PAN) or rayon fibers, which are chemically treated to create long, continuous strands. The precursor fibers are then spun into yarns, which are wound onto bobbins for further processing.

The next step is stabilization, where the precursor fibers are heated in an oven to a temperature of around 200-300°C in the presence of oxygen. This process oxidizes the fibers, creating a cross-linked structure that stabilizes the fibers and prevents them from shrinking or melting during subsequent processing steps.

After stabilization, the fibers are carbonized by heating them to a temperature of around 1000-3000°C in a furnace in the absence of oxygen. This process removes all non-carbon atoms from the fibers, leaving behind a pure carbon material. The carbonization process is critical in determining the final properties of the carbon fiber, including its strength, stiffness, and thermal conductivity.

After carbonization, the carbon fibers are surface-treated to improve their adhesion properties. This involves applying a thin layer of sizing or coupling agent onto the surface of the fibers. Sizing is a chemical compound that improves the bonding between the carbon fibers and the matrix material, while a coupling agent is a chemical that helps to bond the carbon fibers with the resin matrix.

Once the carbon fibers have been prepared, they can be used for various applications, such as making composites. In the composite fabrication process, the carbon fibers are combined with a resin matrix to create a high-performance material. The resin matrix can be made from various materials such as epoxy, polyester, vinyl ester, or other polymers.

In conclusion, the fabrication process of carbon fiber involves several steps, including precursor preparation, spinning, stabilization, carbonization, and surface treatment. Each step is critical in determining the final properties of the carbon fiber, and careful control of the process parameters is required to produce high-quality carbon fiber. The resulting carbon fiber is a high-performance material with excellent strength, stiffness, and thermal conductivity, making it ideal for a wide range of applications.

1.3.1. TYPES OF FABRICATION PROCESS

There are several methods for fabricating carbon fiber composites, each with its advantages and disadvantages. Here are a few of the most common methods:

- Hand layup
- Prepreg layup
- Wet Layup
- Filament Winding
- Pultrusion
- Injection Molding
- 3D Printing

Overall, the choice of fabrication method depends on factors such as the size and shape of the part, the required strength and durability, and the desired production volume. Each method has its own benefits and drawbacks, and careful consideration is required to choose the best process for a given application.

1.3.1.1. HAND LAYUP

The hand layup method is a manual process for producing composite parts using carbon fiber. It is one of the most traditional and widely used methods for composite fabrication. The process involves laying individual layers of carbon fiber fabric or unidirectional tape onto a mold by hand, followed by the application of resin to the fiber layers.

The first step in the hand layup process is to prepare the mold. The mold is typically made of a rigid material, such as fiberglass or metal, and is shaped to the desired form

of the final composite part. The mold is then coated with a release agent, which helps to prevent the composite from sticking to the mold.

Next, the carbon fiber material is cut into the desired shapes and sizes and laid onto the mold by hand. This is done layer by layer, with each layer being carefully positioned to achieve the desired strength and stiffness in the final part. The layers are typically oriented in different directions to provide the necessary strength in multiple directions.

Once the carbon fiber layers have been laid up, a liquid resin is applied to the surface of the fibers. The resin is typically a two-part system that is mixed together and applied with a brush or roller. The resin is then worked into the carbon fiber layers to ensure complete impregnation of the fibers.

After the resin is applied, the composite part is allowed to cure. The curing process typically takes several hours or even days, depending on the type of resin used and the ambient temperature and humidity. Once the part is fully cured, it is removed from the mold and any excess material is trimmed away.

The hand layup method is a relatively simple and cost-effective way to produce composite parts using carbon fiber. It is widely used in industries such as aerospace, automotive, and sporting goods, where lightweight and high-strength materials are required. However, it does require a significant amount of skill and experience to produce high-quality composite parts.

1.3.1.2. PREPREG LAYUP

The prepreg layup method is a widely used carbon fiber composite fabrication process. In this method, pre-impregnated carbon fiber sheets, or prepreg, are used as the starting material. Prepreg is made by impregnating carbon fiber with a resin system that is partially cured to form a semi-solid state. The prepreg is then stored at a low temperature to prevent further curing.

The first step in the prepreg layup process is to cut the prepreg sheets to the desired size and shape. This is typically done using computer-controlled cutting machines or by hand using templates. The cut prepreg sheets are then laid out in a specific pattern or

orientation to form a laminate stack. The orientation of the carbon fibers in each layer can be customized to optimize the mechanical properties of the final product.

Once the laminate stack is assembled, it is placed in a mold or on a tooling surface that has been coated with a release agent. The mold is designed to form the final shape of the carbon fiber part. The mold is then placed in a vacuum bag and sealed to create a vacuum-tight environment.

The vacuum bag is connected to a vacuum pump, which removes air from the bag and the laminate stack. This ensures that the prepreg layers are in intimate contact with each other and with the mold surface. The vacuum also removes excess resin, which can lead to voids or delamination in the final product.

The vacuum bagged laminate stack is then placed in an autoclave, which is a high-pressure oven. The autoclave is heated to a specific temperature and pressure, which is determined by the resin system used in the prepreg. The high temperature and pressure cause the resin to fully cure, bonding the carbon fibers together and forming a solid composite part.

After curing, the vacuum bag and mold are removed, and the part is trimmed to its final shape. The prepreg layup method can produce high-quality, high-strength carbon fiber composite parts with excellent surface finish and dimensional accuracy. It is commonly used in aerospace, automotive, and sporting goods industries, among others.

1.3.1.3. WET LAYUP

The wet layup method is a manual composite fabrication process that involves the manual placement of dry reinforcement fibers into a mold or onto a tool, followed by the application of liquid resin onto the fibers using a brush or a roller. The wet layup process is commonly used for small production runs, or for fabricating complex shapes and geometries that may be difficult to achieve using automated processes.

The wet layup process involves several steps, including the preparation of the reinforcement fibers, the application of the resin, and the curing of the composite. First, the dry fibers are cut to the appropriate size and shape, and then arranged in the desired

pattern in the mold or onto the tool. The fibers are then impregnated with the liquid resin, which is typically a two-part epoxy or polyester system. The resin is applied to the fibers using a brush or roller, and is worked into the fibers to ensure complete wetting and penetration.

After the fibers are fully impregnated with the resin, the composite is allowed to cure. Curing can be achieved through a variety of methods, including heat, pressure, or a combination of both. Once the composite is fully cured, it is removed from the mold or tool and undergoes post-curing processes, such as trimming, sanding, or painting.

One of the main advantages of the wet layup process is its versatility and simplicity. It can be used to fabricate a wide range of composite structures, from small, simple parts to large, complex components. The process is also relatively inexpensive, as it does not require specialized equipment or machinery. Additionally, wet layup can be used with a variety of reinforcement fibers, including carbon, glass, and aramid.

However, the wet layup process also has some limitations. The manual application of the resin can result in variations in fiber volume and resin content, which can lead to inconsistencies in the final product. Additionally, the process can be time-consuming and labor-intensive, and is not well-suited for large-scale production runs.

1.3.1.4. FILAMENT WINDING

Filament winding is a composite manufacturing process that involves wrapping resin-impregnated fibers around a rotating mandrel in a predetermined pattern. The process is commonly used for creating cylindrical or spherical composite parts, such as pipes, pressure vessels, and rocket motor cases.

In the filament winding process, fibers are first impregnated with resin in a bath or by using a resin impregnation machine. Then, the fibers are wound around a mandrel, which rotates at a controlled speed and moves axially along the length of the mandrel. The fibers are laid on the mandrel in a predetermined pattern, which can be varied to create different mechanical properties in the finished product.

The mandrel can be made of various materials, such as aluminum, steel, or composite materials. Once the desired number of layers has been applied, the composite part is cured in an oven or autoclave to cure the resin and bond the fibers together. The mandrel is then removed, leaving the final composite part with the desired shape and properties.

Filament winding offers several advantages, including high strength-to-weight ratio, ability to produce complex shapes, and low material waste. However, it also has some limitations, such as difficulty in producing parts with openings or changes in cross-section, and the need for specialized equipment and skilled operators.

Overall, the filament winding method is a widely used and versatile process for manufacturing composite parts, particularly those with cylindrical or spherical shapes and high mechanical properties.

1.3.1.5. PULTRUSION

The pultrusion method is a continuous manufacturing process used for producing carbon fiber composite profiles with a constant cross-section. The process involves pulling continuous fibers through a resin bath and then through a heated die. The resin-coated fibers are then pulled through the die, where they are heated and cured to form a solid composite part.

The pultrusion process is highly automated, making it an efficient and cost-effective method for producing composite parts. The process allows for precise control over the fiber orientation, fiber volume fraction, and resin content of the composite material, which makes it ideal for producing high-strength and lightweight parts.

The process begins with the continuous fibers being pulled through a resin bath, which coats the fibers with a thermoset resin. The resin-coated fibers are then pulled through a series of preforming guides that help to shape the fibers into the desired shape and orientation. The fibers are then pulled through a heated die, which sets and cures the resin, forming a solid composite part with a constant cross-section.

The pultrusion process is commonly used in the construction industry for producing beams, columns, and other structural components. It is also used in the aerospace

industry for producing lightweight and high-strength parts such as wing spars and fuselage frames. The process is versatile and can be used with a wide range of fiber types, including carbon, glass, and aramid fibers.

One advantage of the pultrusion process is that it produces composite parts with high strength-to-weight ratios, making them ideal for applications where weight reduction is critical. Additionally, the process produces parts with excellent corrosion resistance and dimensional stability, making them suitable for use in harsh environments.

However, the pultrusion process does have some limitations. It is difficult to produce complex shapes and parts with varying thicknesses using the pultrusion process. Additionally, the process requires specialized tooling and equipment, which can be costly to set up and maintain.

1.3.1.6. INJECTION MOLDING

Injection molding is a manufacturing process that involves melting a thermoplastic material and injecting it into a mold cavity. The process is commonly used for the production of complex-shaped parts with high accuracy and consistency. In the case of carbon fiber composites, injection molding is used to produce parts that have a combination of high strength and low weight.

The injection molding process involves several steps. First, the carbon fiber and the thermoplastic resin are mixed together in the form of pellets or granules. The mixture is then fed into a hopper, which is connected to the injection molding machine. The injection molding machine consists of a barrel, a screw, and a mold cavity.

The barrel heats the thermoplastic resin to a molten state, while the screw moves the molten resin forward towards the mold cavity. The carbon fiber mixture is injected into the mold cavity, which has the desired shape of the final product. The molten resin then cools and solidifies, taking the shape of the mold. Once the part has cooled, it is ejected from the mold, and the process starts again.

Injection molding offers several advantages, including high production rates, repeatability, and the ability to produce complex shapes with high accuracy. The process

can also be automated, which can reduce labor costs and increase efficiency. However, injection molding can be expensive due to the cost of the machinery and the mold, and it may not be suitable for low-volume production runs.

1.3.1.7. 3D PRINTING

The use of 3D printing for the fabrication of carbon fiber composites is a relatively new technology, but it has shown great potential in producing complex geometries and improving the overall performance of the composites. The process typically involves depositing layers of carbon fiber reinforced polymer (CFRP) materials one by one onto a build platform.

The first step in the process is the preparation of the feedstock material, which is typically a thermoplastic polymer mixed with carbon fibers. The feedstock material is then loaded into the 3D printer, and the printing process begins. The printer head moves along a predefined path and deposits a layer of material on the build platform, which is then fused to the previous layer using heat.

One advantage of 3D printing is that it can produce complex shapes and geometries that are difficult or impossible to achieve with traditional carbon fiber fabrication methods. This is achieved by using computer-aided design (CAD) software to create a 3D model of the part or component, which is then sliced into thin layers that can be printed one by one.

Another advantage of 3D printing is that it can be a more efficient and cost-effective method of producing carbon fiber composites. Unlike other fabrication methods that require complex molds and tooling, 3D printing does not require any additional tooling or setup time. This means that the process can be more flexible and cost-effective for producing low-volume or custom parts.

However, there are some limitations to the 3D printing process for carbon fiber composites. One limitation is the resolution of the printer, which can limit the precision of the final part. Another limitation is the strength of the final part, which may not be as high as parts produced with other fabrication methods. Additionally, the high temperatures and

pressures involved in the 3D printing process can also potentially damage the carbon fibers, which can affect the final performance of the composite.

Despite these limitations, 3D printing is an emerging technology with great potential for the fabrication of carbon fiber composites. As the technology continues to develop and improve, it is likely that 3D printing will become an increasingly important tool for the production of lightweight and high-performance carbon fiber components.

1.4. METAL OXIDE COATING

Metal oxide coatings are thin films of metal oxide materials that are deposited onto a substrate surface using various methods, such as physical vapor deposition, chemical vapor deposition, and sol-gel methods. These coatings offer a range of desirable properties, including corrosion resistance, wear resistance, and optical properties, and can be applied to a variety of substrates, including metals, ceramics, and polymers.

There are many different types of metal oxide coatings, including aluminum oxide, titanium oxide, and zirconium oxide, among others. Each of these coatings has unique properties that make it suitable for a specific range of applications. For example, aluminum oxide coatings are widely used in the aerospace industry due to their excellent wear resistance and ability to withstand high temperatures, while titanium oxide coatings are commonly used in biomedical applications due to their biocompatibility and ability to promote bone growth.

Metal oxide coatings can be deposited using a variety of methods, including physical vapor deposition (PVD), chemical vapor deposition (CVD), and sol-gel methods. PVD methods involve evaporating metal or metal oxide materials and depositing them onto a substrate surface using a vacuum chamber. CVD methods involve the reaction of metal-containing gases in a chamber to produce metal oxide coatings, while sol-gel methods use a solution of metal salts to produce a metal oxide coating on a substrate surface.

Overall, metal oxide coatings offer a range of desirable properties and can be applied to a variety of substrates, making them a versatile and useful class of materials in many different industries.

1.5. METAL OXIDES

Metal oxides are compounds composed of a metal atom and an oxygen atom. They are a diverse class of materials with a wide range of properties and applications, from catalysts and semiconductors to pigments and ceramics.

Metal oxides can be classified into different categories based on their chemical composition, structure, and properties. For example, some metal oxides are ionic solids, in which the metal and oxygen atoms are held together by ionic bonds. Examples of ionic metal oxides include magnesium oxide (MgO) and aluminum oxide (Al₂O₃). Other metal oxides are covalent solids, in which the metal and oxygen atoms are held together by covalent bonds. Examples of covalent metal oxides include silicon dioxide (SiO₂) and carbon dioxide (CO₂).

Metal oxides also have a variety of physical and chemical properties, such as their melting and boiling points, thermal and electrical conductivity, and reactivity with other substances. These properties can vary depending on the specific metal oxide and the conditions in which it is used.

Metal oxides have many important applications in industry and technology. For example, some metal oxides are used as pigments in paints and coatings, while others are used as catalysts in chemical reactions. Metal oxides also have applications in electronic and optical devices, such as in the production of semiconductors and solar cells

1.5.1. METAL OXIDES USED FOR COATING

1.5.1.1. ALUMINIUM OXIDE(Al₂O₃)

Aluminium oxide, also known as alumina, is a compound composed of aluminum and oxygen atoms. It is a white or off-white powder with a high melting point and excellent thermal and electrical insulation properties. Aluminium oxide is one of the most widely used metal oxides due to its high chemical and physical stability, making it suitable for a wide range of industrial and commercial applications.

One of the primary uses of aluminium oxide is as a catalyst in chemical reactions. The high surface area and reactivity of alumina make it an effective catalyst for a variety of processes, including the production of chemicals such as ethylene and propylene. In addition, aluminium oxide is commonly used as an adsorbent in chromatography, a process used to separate and purify different chemical compounds.

Another important application of aluminium oxide is as an abrasive material. Due to its high hardness and wear resistance, alumina is commonly used as an abrasive in grinding and polishing applications, such as in the manufacture of metal parts and semiconductor wafers. Aluminium oxide is also used as a filler material in various composites and plastics, as well as in the production of ceramics and glass.

Aluminium oxide is also widely used as a refractory material in high-temperature applications, such as furnace linings and crucibles. Its high melting point and thermal stability make it suitable for use in extreme environments, such as in the production of metals and alloys. In addition, aluminium oxide is commonly used as a coating material for metals and other surfaces, providing a protective layer that can help to prevent corrosion and other forms of damage.

In addition to its industrial uses, aluminium oxide has many other applications in everyday life. It is used as a filler in toothpaste and other dental products, as well as in cosmetics and skincare products. It is also used in the production of ceramics, including high-strength materials used in aerospace and defense applications.

Overall, aluminium oxide is a versatile and important material with a wide range of applications across many different industries. Its unique properties make it useful in a variety of applications, and it is likely to remain an important material for many years to come.

1.5.1.2. TITANIUM DIOXIDE(TiO_2)

Titanium dioxide, also known as titania, is a naturally occurring compound composed of titanium and oxygen atoms. It is a white, odorless powder with excellent light-scattering properties, which makes it widely used in various applications.

Titanium dioxide is also used as a UV absorber and sunscreen agent in cosmetic products. It helps to protect the skin from harmful UV radiation and is widely used in sunscreens, lotions, and other skincare products.

Another important application of titanium dioxide is as a catalyst in chemical reactions. It is commonly used in the production of various chemicals, including methanol, acetic acid, and other organic compounds. Titanium dioxide is also used as a catalyst in the petroleum industry for the removal of sulfur and other impurities from crude oil.

In addition, titanium dioxide has a range of other applications, including as a food additive to whiten and brighten food products, as a ceramic material in the production of high-performance materials, and as a component in photovoltaic cells for solar energy.

1.5.1.3. SILICON DIOXIDE(SiO_2)

Silicon dioxide, also known as silica, is a naturally occurring compound composed of silicon and oxygen atoms. It is one of the most abundant minerals in the earth's crust and is found in various forms, including quartz, sand, and glass.

Silicon dioxide has a wide range of applications in industry and technology. One of its most important uses is as a raw material in the production of silicon wafers for semiconductor devices. Silicon dioxide is also used as a filler in plastics, rubber, and other materials to improve their mechanical properties.

Another important application of silicon dioxide is as a desiccant or drying agent. It is commonly used in packaged foods and pharmaceutical products to prevent moisture and extend their shelf life. Silicon dioxide is also used as an absorbent material in oil and gas production to remove impurities and improve the quality of the extracted products.

Silicon dioxide is also widely used in the construction industry as a component of concrete and other building materials. It helps to improve the strength and durability of these materials and can also provide insulation and fire resistance.

1.5.1.4. ZIRCONIUM DIOXIDE(ZrO_2)

Zirconium dioxide, also known as zirconia, is a white crystalline oxide of zirconium metal. It is a highly versatile material that exhibits excellent mechanical, thermal, and electrical properties, which make it suitable for a wide range of applications.

One of the most important applications of zirconia is in the field of ceramics. Zirconia ceramics have high strength, toughness, and wear resistance, making them ideal for use in cutting tools, dental implants, and high-performance bearings. Zirconia is also used as a refractory material in high-temperature applications, such as furnace linings and crucibles.

Another important application of zirconia is in the production of oxygen sensors for use in automotive and industrial applications. Zirconia sensors can detect the level of oxygen in a gas or liquid and are widely used in catalytic converters, fuel cells, and other systems that require accurate oxygen measurement.

Zirconia is also used as a coating material in the aerospace industry to protect turbine blades from high temperatures and corrosion. In addition, zirconia is used as a solid electrolyte in fuel cells, as a catalyst support in chemical reactions, and as a thermal barrier coating in gas turbines.

1.6. COATING TECHNIQUES

The process of coating metal oxides on the desired substrate is done with the help of a physical vapor deposition process. Physical vapor deposition (PVD) is a process used to deposit thin films of materials onto a substrate. The process involves the vaporization of a solid material into a gaseous state, which is then deposited onto a substrate in a vacuum chamber. The PVD process can be used to deposit a wide range of materials, including metals, ceramics, and polymers, onto a variety of substrates, such as metals, plastics, and glass.

PVD has several advantages over other deposition techniques, such as chemical vapor deposition (CVD) and electroplating. PVD can deposit materials with high purity,

uniformity, and control over thickness and composition. Additionally, PVD can be used to deposit materials onto complex shapes and surfaces.

PVD has many industrial and technological applications. It is commonly used to deposit thin films for microelectronics, optical coatings, wear-resistant coatings, and decorative coatings. PVD is also used in the manufacturing of semiconductors, solar cells, and medical devices.

Despite its many advantages, PVD does have some limitations. The process is expensive and time-consuming, and can only be used to deposit thin films. Additionally, PVD is limited by the properties of the target material, such as its melting point and vapor pressure, which can limit its use in some applications.

1.6.1. ELECTRON BEAM PHYSICAL VAPOR DEPOSITION (EB-PVD)

Electron-beam physical vapor deposition (EB-PVD) is a specific type of physical vapor deposition (PVD) process that uses an electron beam to vaporize a material and deposit it onto a substrate. This process is often used to deposit thin films of high-performance materials, such as ceramic coatings on turbine blades, for industrial and aerospace applications.

In EB-PVD, a solid target material is placed in a vacuum chamber and bombarded with an electron beam. The electron beam heats the target material, causing it to vaporize and form a plasma. The plasma is then directed towards the substrate using a magnetic field, where it condenses and forms a thin film.

EB-PVD offers several advantages over other deposition techniques, such as thermal spray and plasma spray. The process allows for the deposition of high-purity and uniform thin films with excellent adhesion and high-density coatings. It also allows for the deposition of complex and intricate shapes with good control over coating thickness and microstructure.

One of the most significant advantages of EB-PVD is the ability to deposit thermal barrier coatings (TBCs) on turbine blades used in the aerospace industry. TBCs are used to protect the blades from high-temperature environments by insulating the blade from

the hot gases that pass over it. The EB-PVD process produces a dense, columnar structure of the TBC that provides excellent thermal insulation and mechanical durability.

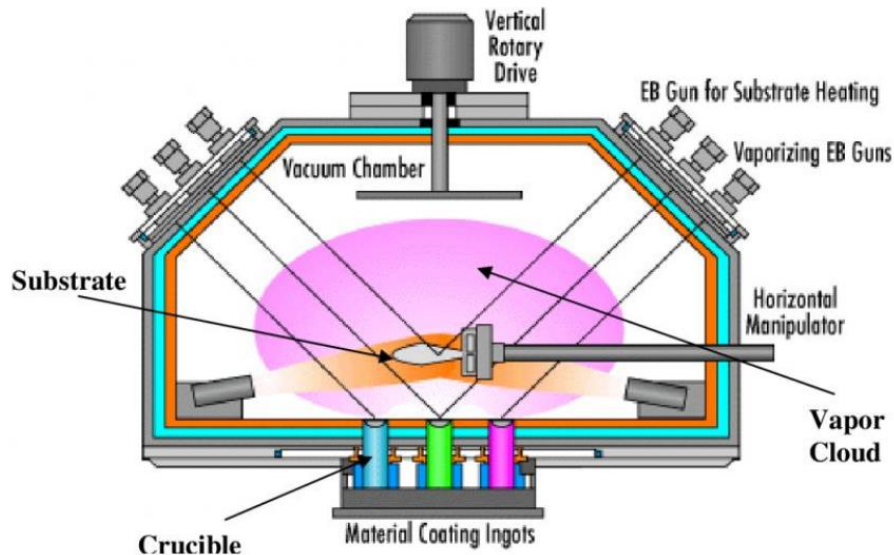


Fig1.1: Schematic diagram of EB-PVD process

1.6.2. SPUTTERING DEPOSITION

Sputter deposition is a physical vapor deposition (PVD) method for depositing thin films of materials onto a substrate. The process involves bombarding a solid target material with ions, causing the atoms to be ejected and deposited onto the substrate. The ejected atoms can then form a thin film that adheres to the surface of the substrate.

In sputtering PVD, a vacuum chamber is filled with a gas, usually argon, and a target material is placed in the chamber. The gas is ionized using an electrical discharge, which creates a plasma of ions and electrons. The ions are then accelerated towards the target material, causing atoms to be ejected from the target and deposited onto the substrate.

Sputtering PVD offers several advantages over other deposition techniques, including the ability to deposit a wide range of materials, such as metals, ceramics, and polymers, with good control over the film thickness and uniformity. The process also allows for the deposition of complex and intricate shapes with good adhesion to the substrate.

One of the most significant advantages of sputtering PVD is the ability to deposit thin films onto temperature-sensitive substrates, such as plastics and biological materials, without causing damage to the substrate. This makes it an attractive option for applications in electronics, biomedical engineering, and optical coatings.

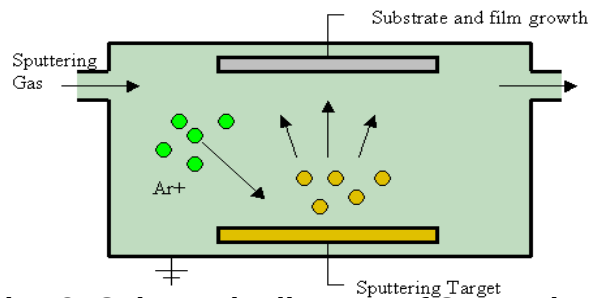


Fig1.2: Schematic diagram of Sputtering process

1.6.3. MAGNETRON SPUTTERING

Magnetron sputtering is a type of physical vapor deposition (PVD) process that uses a magnetic field to enhance the deposition rate and improve film quality. In this process, a target material is bombarded with ions in a vacuum chamber, causing atoms to be ejected and deposited onto a substrate.

The magnetron sputtering process involves placing a target material in a vacuum chamber and creating a magnetic field around it. An inert gas, such as argon, is introduced into the chamber, and a high-voltage electric field is applied, causing the gas atoms to ionize and form a plasma. The plasma then bombards the target material, causing atoms to be ejected and deposited onto the substrate. The use of the magnetic field in magnetron sputtering results in a more efficient and effective deposition process compared to traditional sputtering. The magnetic field traps electrons near the target surface, causing more collisions between the plasma ions and the target material, which increases the yield and deposition rate. Additionally, the magnetic field enhances the sputtering process by reducing the temperature of the target material and improving the plasma density. Magnetron sputtering is widely used in the production of thin films for various applications, including coatings for optical, electronic, and decorative purposes. It is also used in the manufacturing of semiconductors, solar cells, and magnetic storage devices. The process can be used to deposit a variety of materials, including metals, ceramics, and polymers.

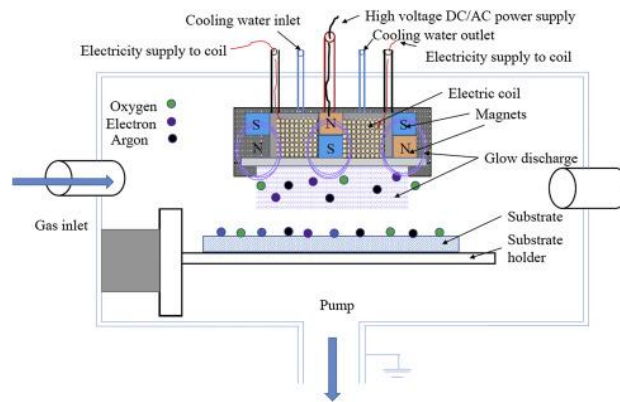


Fig1.3: Schematic diagram of Magnetron Sputtering process

1.6.4. ION PLATING

Ion plating is a physical vapor deposition (PVD) process used to deposit thin films of materials onto a substrate. In this process, a target material is bombarded with ions, causing the atoms to be ejected and then deposited onto the substrate. During the process, a vacuum chamber is filled with a low-pressure gas, typically argon or nitrogen. A high-voltage electric field is then applied to the gas, which ionizes it and creates a plasma. The plasma accelerates the ions towards the target material, causing the atoms to be sputtered off and deposited onto the substrate. Ion plating has several advantages over other PVD processes, including the ability to deposit a wide range of materials, including metals, ceramics, and polymers, and the ability to produce very dense, uniform films with excellent adhesion to the substrate. Ion plating is used in a variety of industries, including the automotive, aerospace, and electronics industries, to produce coatings with specific properties, such as wear resistance.

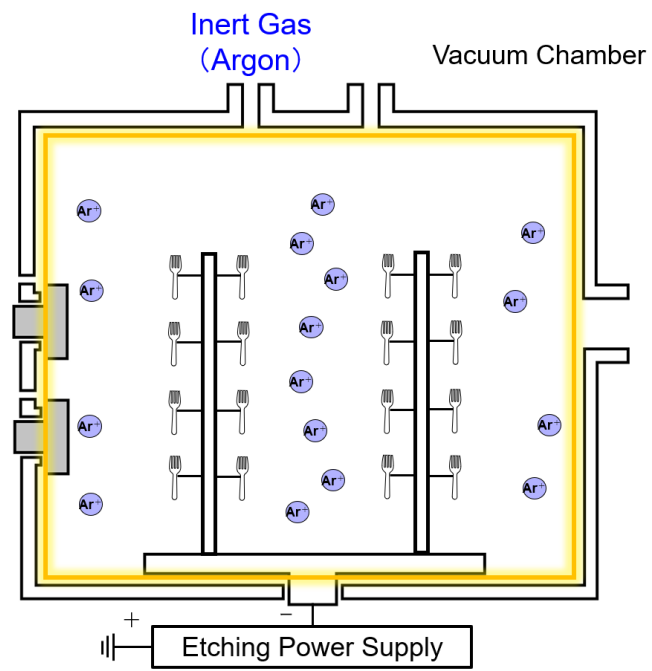


Fig1.4: Schematic diagram of ION Plating process

CHAPTER – 2

LITERATURE SURVEY

Komal Prasad et al studied thorough analysis of highly reflecting coatings. In this study, they discuss both metal and dielectric highly reflective coatings. Additionally, substrates are coated with nanoparticles made of metals to provide for maximum reflectivity. By using constructive interference between the various layers of the dielectric substance, dielectric coatings reflect light. Also covered are three distinct approaches to creating highly reflective coatings. Their study also provides a brief overview of the various fields in which these highly reflecting coatings are applied. The article goes on to explore three alternative ways to create these highly reflecting coatings. Every application needs a unique synthesis, and three general categories are covered here: Silver nanoparticle-based highly reflective metal coatings made using the sol-gel technique and $\text{ZrO}_2\text{-SiO}_2$

Sanjeev Kumar et al works looks into the reflecting qualities of coatings made of titania (TiO_2) nanoparticles. Design/methodology/approach X-ray diffraction (XRD), transmission electron microscopy (TEM), scanning electron microscopy (SEM), and ultraviolet-visible absorption spectroscopy (UV-vis) were used to analyze TiO_2 nanoparticles that were made using the sol-gel method. Titania nanoparticles were mixed with various pigment to binder weight ratios in an acrylic binder to create the coating material. This coating substance was applied to aluminium sheets in various coating thicknesses to prepare the reflectors. Findings In the work described here, coating material with a binder by weight ratio between 14 and 20 percent and a thickness of 0.15 mm could produce reflectors with diffuse reflectance of 99%. The produced reflectors maintained diffuse reflectance of greater than 96% virtually throughout the visible spectrum even after being exposed to various illumination levels (up to 20,000 lux). Real-world applications Commercial optical products like reflective panels, luminaires, etc. use the manufactured reflectors. Originality/value As of right now, bulk TiO_2 particles are employed in conventional reflective coatings, which are reflective coatings. In this study, they present a highly reflective covering made of TiO_2 nanoparticles. To the best of our

knowledge, no one has ever reported on "TiO₂ nanoparticle-based reflective coatings," so this is an original work

Zhixin Wang et al conducted experiments on low threshold power semiconductor lasers need a combination of high-quality-factor cavities and small volume active regions. An ultra-low threshold requires greatly decreasing the diffraction loss at the laser's facets for ridge lasers with highly reflecting coatings. Here, their work show that adding a subwavelength aperture to a laser's metallic, highly reflective coating can correct the phase front, counterintuitively improving the laser's modal reflectivity as well as its transmissivity. According to theoretical and experimental findings, the mirror loss has decreased by over 40% while the transmissivity has increased by 104. By using this technique to a small-cavity quantum cascade laser, room-temperature continuous-wave lasing operation at 4.5 μ m wavelength is made possible with only 143 mW of electrical consumption.

[Hsing-Yu Wu](#) et al conducted an experiment to produce reflecting telescope mirrors with the maximum reflectivity and broadest spectral bandwidth, highly reflective metal coatings are necessary. Enhanced silver-based coatings, which are used on metallic surfaces, can increase reflectivity in the 400–500 nm spectral region and improve performance from the visible to the near IR. Additionally, the mirror's front side can be overcoated to add additional hardness and oxidation resilience. In this article, we examine a technique for creating protected enhanced high reflective Ag coatings that combines thermal and electron beam evaporation. A newly developed multilayer film may provide sulfurization inhibition and pass the ASTM 5B adhesive performance test. In wavelengths spanning the spectral range from 400 to 1000 nm, the enhancement coating's average specular reflectivity is around 98%. The effectiveness of the coating has been shown on a Newtonian-type telescope that was stored for more than six months in an environment with humidity $H = 60\text{--}85\%$ and temperature $T = 10\text{--}35\text{ }^{\circ}\text{C}$.

A. Synnefa et al conducted an experiment in order to examine reflective coatings' appropriateness to reduce ambient temperatures and combat the heat island effect, a comparative study was conducted to look at how reflective coatings affected the surface temperatures of buildings and other surfaces in the urban environment. The results are

presented in this paper. From August to October 2004, 14 different types of reflective coatings were examined on a 24-hour basis. These coatings were chosen from the global market. These coatings are applied to buildings, and some of them may also be applied to other urban surfaces (such as sidewalks and parking lots) in the future. Infrared thermography techniques were utilised, together with surface temperature sensors, a data logging system, and in order to examine the thermal performance of the reflecting coatings. They also examined the samples' spectral reflectance and infrared emittance. The gathered data have undergone a thorough analysis. It has been shown that reflective coatings can lower the surface temperature of a white concrete tile by 4 °C in the summer and by 2 °C at night. It can be only 2 °C warmer during the day and 5.9 °C colder during the night than the surrounding air. The thermal performance of "cool" coatings is superior to that of other "cool" materials. This study can help in the selection of more suitable coatings for building envelopes and other surfaces in the urban environment, helping to reduce cooling loads and building power use while also mitigating the heat island effect.

Suganthi.J, Johnsonjeyakumar,Sudha.J et al made a work on depositing copper thin films on steel substrates using thermal evaporation method. In thermal evaporation, the source materials are evaporated in a vacuum chamber and the evaporated particles are then condensed on a substrate. Traditionally, this procedure is known as vacuum deposition. They conducted this investigation in order to improve the mechanical qualities of the base material, reduce its size, and produce it at a lower cost. Because copper offers qualities like good corrosion resistance, appealing colour, outstanding workability, and good mechanical properties, they used it as a source material. In conclusion, the copper thin films formed in this manner on a steel substrate were found to be good-looking, and the study of the XRD spectra revealed that if the deposition is accomplished gradually, uniformity will be reached. The weight losses are visible in the immersion test. The copper thin films were dissolved in acids as a result of this corrosion testing investigation. The thin film morphology of the two samples (before and after corrosion) was compared as a result of the AFM examination.

Ranganatha S.R and Shantharaja M.et al made a study about the tensile behavior of boron carbide and copper coated short basalt fiber reinforced with Al2014 based hybrid composites are prepared by casting techniques.

Basalt fibers are electrolessly coated with copper using copper sulphate solution to prevent interfacial interactions between the fiber and matrix.

In conclusion, this work demonstrates the electroless deposition technique used to uniformly deposit copper on the surface of short basalt fibers. This was seen under a scanning electron microscope, and it was clearly demonstrated that the process parameters were optimized as well.

Garima Mittal and Kyong Y. Rhee successfully deposited graphene on basalt fiber using an eco-friendly and simple Electrophoretic deposition method for composite applications. Despite possessing a high strength-to-cost ratio, its potential for interfacial interactions with the reinforced matrix is constrained by the absence of surface functionality. Basalt Fibers' surface properties can be altered using a variety of surface modification techniques, such as coating nanoparticles and affixing chemical moieties. Results indicate that graphene was successfully coated on BF, and that basalt fiber crystallization was delayed from 697 to 716°C due to the creation of a protective layer of graphene in the presence of the graphene coating.

S. Ezhil Vannan did work on an electroless method of coating copper on the basalt short fibers using copper sulphate solution. In order to avoid any interfacial reactions, the basalt fibers were coated with copper. Here, the conditions used for electroless coating were optimized to obtain a uniform and continuous layer of copper. Using this method, it is possible to deposit up to about 25 wt% copper on the basalt fiber. The resultant composite fiber was characterized by scanning electron microscopy (SEM)/energy-dispersive X-ray (EDX) during and after the coating process. The following conclusions are made from the study:

- 1) After suitable sensitization and activation treatment, basalt short fibers can be coated with copper sulphate solution by electroless technique.
- 2) A fairly uniform and continuous coating of copper on basalt fibers can be prepared by electroless technique.

CHAPTER 3

AIM & SCOPE

3.1. AIM OF THE PROJECT

The aim of this project is to investigate the effects of aluminum oxide coating on carbon fiber using electron-beam physical vapor deposition method. The project will specifically focus on the changes in reflectivity, contact angle, UV absorbance and hardness of the coated carbon fiber, as measured by contact angle, UV spectroscopy, and Vickers hardness tests respectively. The results of this study will provide insights into the potential applications of aluminum oxide coated carbon fiber in space-based technologies.

3.2. SCOPE

The scope of this project is to perform a comprehensive study on the aluminum oxide coated carbon fiber using electron-beam physical vapor deposition method. In this work, the main aim is to increase the reflectivity of the aluminium oxide coated carbon fiber samples. The project will utilize Contact angle, UV spectroscopy, and Vickers hardness tests for the analysis of the coated carbon fiber. The project will focus on the specific application of aluminum oxide coated carbon fiber in space-based technologies.

CHAPTER 4

MATERIALS AND METHODS

4.1. MATERIALS

4.1.1. ALUMINIUM OXIDE POWDER

Aluminum oxide powder is a fine white powder made up of aluminium and oxygen molecules. It is also known as alumina or aluminum oxide. Aluminium oxide powder has a high melting point and is thermally stable, making it a popular choice for various industrial applications. It is commonly used as an abrasive due to its high hardness and durability. Aluminium oxide powder is also used as a coating material due to its ability to form a protective layer on a variety of surfaces. This coating provides excellent resistance to wear, corrosion, and oxidation, making it an ideal material for many applications in the aerospace and automotive industries. In addition, aluminium oxide powder is used as a filler in the production of composites, such as carbon fiber reinforced polymers. Aluminium oxide powder can be produced through various methods, including the Bayer process, which involves dissolving bauxite in caustic soda, and the thermal decomposition of aluminium hydroxide. The resulting powder can have varying particle sizes and shapes, depending on the production method used.



Fig4.1: Aluminium oxide powder

4.1.2. CARBON FIBER COMPOSITE

Carbon fiber composites, also known as carbon fiber reinforced polymers (CFRPs), are materials made of a combination of carbon fiber and a polymer matrix. Carbon fiber is a strong and lightweight material made of thin fibers of carbon, typically less than 10 micrometers in diameter. The polymer matrix is used to bind the carbon fibers together and provide additional strength and stiffness to the composite.

Carbon fiber composites are known for their excellent strength-to-weight ratio, making them ideal for applications where high strength and light weight are desired. They are commonly used in the aerospace and defense industries, as well as in sports equipment and automotive components.

The manufacturing process of carbon fiber composites involves several steps. First, the carbon fibers are woven into a fabric or placed in a specific orientation. Then, the fabric or fibers are impregnated with the polymer matrix material, usually through a process called resin transfer molding (RTM) or vacuum infusion. After that, the composite is cured, which allows the polymer to harden and bind the fibers together.

Carbon fiber composites have several advantages over other materials such as metal alloys and plastics. They have a high strength-to-weight ratio, which makes them ideal for applications where weight reduction is important, such as in aircraft and spacecraft. They are also highly resistant to fatigue and have excellent stiffness and dimensional stability.

4.2. METHODOLOGY

For the coating process, the aluminum powder has been transformed into solids in the form of pellets using a pelletizer machine. Then the pellets were made to undergo the sintering process to make them hard and strong. Then the pellets were used for the coating process which is the EB-PVD method.

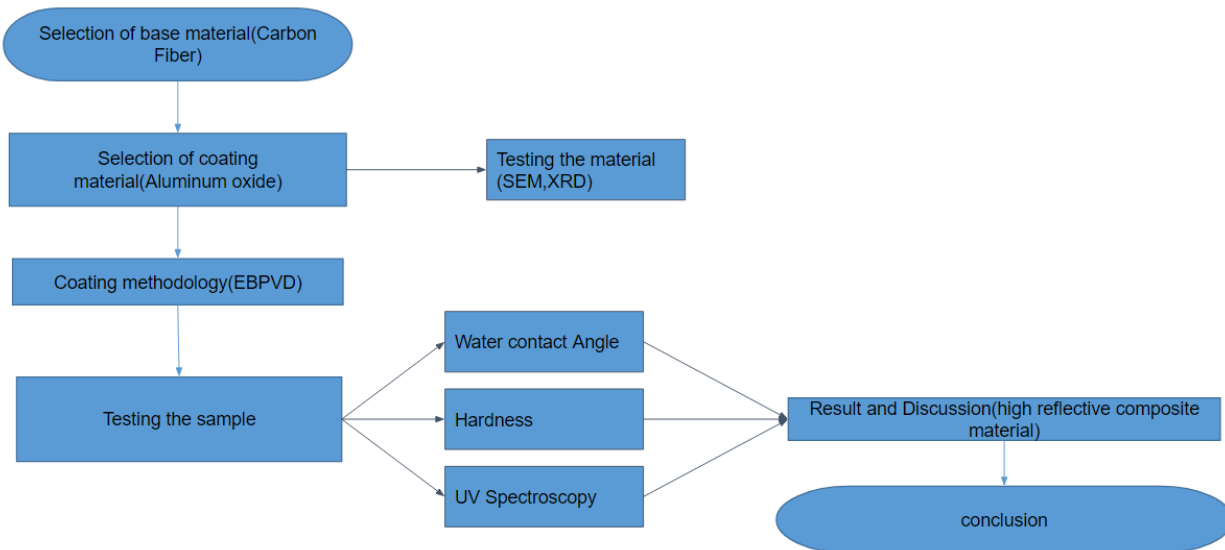


Fig4.2: Methodology Flowchart

4.2.1. PELLETIZING PROCESS

Pelletizing is a process of converting fine materials, such as powders, dust, and slurries, into pellets. Pellets are small, spherical or cylindrical shaped objects, typically ranging in size from a few millimeters to a few centimeters in diameter. The pelletizing process is widely used in many industries, including agriculture, pharmaceuticals, chemicals, plastics, and mining, among others.

The basic principle of pelletizing is to agglomerate fine materials by compressing them into a pellet shape. This can be achieved through various methods, including extrusion, compaction, and granulation. One of the most commonly used methods is pelletizing through the use of a pellet mill.

Pellet mills are machines that use pressure and heat to convert fine materials into pellets. The process involves feeding the material into the pellet mill, where it is compressed between rollers or a die. The compression forces the material to adhere together, forming pellets. The heat generated by the friction during compression helps to bind the material together.

In the case of carbon fiber composites, the pelletizing process is used to convert carbon fiber into a form that is easier to handle and process. The carbon fiber is first chopped into small pieces and then mixed with a binder material, such as a polymer resin. The mixture is then pelletized using a pellet mill.

The pelletized carbon fiber composite material has several advantages over the original chopped fiber material. Firstly, it is easier to handle and transport. The pellets can be stored in bags or containers and transported to different locations. Secondly, the pelletized material can be easily metered and fed into processing equipment, such as injection molding machines, extruders, or compression molding machines. This allows for a more precise and consistent feed of material, which can result in higher quality finished products. Finally, the pellets can be easily stored and used as needed, without the need for further processing.

Overall, the pelletizing process is a critical step in the production of carbon fiber composites. It allows for the conversion of fine materials into a more manageable and processable form, which can result in higher quality finished products. As the demand for carbon fiber composites continues to grow in various industries, the use of pelletizing is likely to become even more widespread.



Fig 4.3: Pelletizer machine

4.2.2. SINTERING PROCESS

Sintering is a process used to create solid materials from powdered materials by applying heat and pressure to the particles. It is a key process in the manufacturing of ceramics, metal alloys, and other materials. The process involves heating the powder to a high temperature below the melting point, where the particles become bonded together through a process known as diffusion.

The sintering process can be divided into several stages. The first stage is called the initial stage or incipient sintering. In this stage, the powder is heated to a temperature where the particles begin to stick together due to surface tension and the presence of impurities. As the temperature increases, the particles begin to rearrange themselves, reducing the surface area of the powder.

The second stage is called the intermediate stage, where the particles begin to bond together through the process of solid-state diffusion. In this stage, the necks between the particles grow thicker and stronger as the temperature and pressure increase.

The final stage is called the densification stage. In this stage, the powder becomes more compact and denser as the temperature and pressure increase. The densification process is critical to creating a material with the desired properties, such as strength, hardness, and toughness.

The sintering process can be done in several ways, including hot pressing, hot isostatic pressing, and spark plasma sintering. Hot pressing involves applying pressure to the powder while heating it to a high temperature, while hot isostatic pressing involves applying pressure to the powder from all directions while heating it. Spark plasma sintering uses an electric current to heat the powder, which can lead to faster sintering times and improved material properties.

Sintering is widely used in the manufacturing of ceramics, such as porcelain, and in the production of metal alloys. It is also used in the production of cutting tools, machine parts, and electronic components. The process can be used to create materials with a wide range of properties, from high-strength and wear-resistant materials to materials with high electrical conductivity.

One of the advantages of sintering is that it can be used to create complex shapes and structures that are difficult to produce using other manufacturing processes. The

process can also be used to produce large quantities of material at a relatively low cost. However, sintering does have some limitations, such as the need for precise control over the temperature, pressure, and composition of the powder, as well as the potential for defects and porosity in the final product.

4.2.3. FABRICATION OF CARBON FIBER COMPOSITE

The carbon fiber composite was prepared by using the hand layup process. The laminate was prepared using multiple layers of carbon fiber for the desired thickness of 5mm. A resin system, such as epoxy or polyester, is then applied to the fabric layers using a brush or roller until it is fully wetted out. The final step is to apply pressure to the laminate using a vacuum bag or compression molding to remove any excess air and ensure proper consolidation of the composite. The excess parts on the edges of the laminates were trimmed, and the final dimension of the laminate is 300mm x 300mm.

Then the carbon fiber laminate was cut into small pieces using water jet cutting to get the required dimension of 20mm x 20mm, which is suitable for the coating and the testing process.



Fig 4.4: Preparation of Carbon fiber Laminate

4.2.4. COATING PROCESS

The coating of aluminium oxide on the carbon fiber composite was carried out using the EB-PVD (Electron-beam physical vapor deposition) method.

4.2.4.1. EB-PVD METHOD

The electron-beam physical vapor deposition (EB-PVD) process works by heating a source material, typically a metal, ceramic, or alloy, using an electron beam. This causes the material to evaporate and form a vapor, which is then deposited onto a substrate, such as carbon fiber.

The electron beam is produced using a cathode and an anode. A voltage is applied between the two electrodes, causing electrons to flow from the cathode to the anode. The electrons are then focused onto a small spot using magnetic fields, forming a high-energy beam of electrons.

The source material, which is in the form of pellets, is placed in a crucible that is heated by the electron beam. As the material heats up, it evaporates and forms a vapor, which is then deposited onto the substrate. The substrate is typically located a short distance away from the crucible, and is rotated and tilted during the deposition process to ensure an even coating.

One advantage of the EB-PVD process is that it can be performed in a vacuum, which helps to eliminate impurities and ensure a high-quality coating. Another advantage is that the electron beam can be precisely controlled, allowing for fine-tuning of the deposition process. This makes it possible to produce coatings with a high degree of uniformity and thickness control, which is important for many applications.

Overall, the EB-PVD process is a highly versatile and precise method for depositing thin films onto a wide range of substrates, including carbon fiber. It has been used in a variety of industries, including aerospace, automotive, and medical devices, to produce high-performance coatings with unique properties.



Fig 4.5: Electron Beam Evaporation unit

4.2.5. TESTING METHODS

First, the aluminium powder has been tested for SEM and XRD. Then the aluminium oxide-coated carbon fiber composite samples have been tested for water contact angle, hardness, and UV spectroscopy.

4.2.5.1. SCANNING ELECTRON MICROSCOPE

A Scanning Electron Microscope (SEM) is a type of microscope that uses a beam of electrons to create high-resolution images of a sample's surface. The SEM works by generating a focused beam of electrons that is scanned over the surface of a sample, causing the emission of secondary electrons, backscattered electrons, and other signals that can be used to create an image.

The SEM consists of several key components, including an electron gun, a series of electromagnetic lenses, and a detector system. The electron gun generates a beam of electrons that is focused and accelerated by the electromagnetic lenses. The beam is

then scanned over the surface of the sample, and the signals generated by the interaction between the beam and the sample are detected by the detector system.

One of the main advantages of SEM is its high resolution, which can be as low as a few nanometers, making it suitable for examining the microstructure of materials. Additionally, SEM is capable of producing images with a large depth of field, which allows for the visualization of both the surface and subsurface features of a sample.

SEM has numerous applications in various fields, such as materials science, nanotechnology, biology, and geology. In materials science, SEM is often used to examine the microstructure of materials, study the surface morphology, and investigate the formation of defects. In nanotechnology, SEM is used to analyze the surface of nanoparticles and nanostructures. In biology, SEM is used to examine the surface structure of cells, tissues, and organisms. In geology, SEM is used to study the morphology and composition of rocks, minerals, and other geological materials.

4.2.5.2. X-RAY DIFFRACTION ANALYSIS

X-ray diffraction analysis (XRD) is a technique used to study the atomic and molecular structure of materials by examining the diffraction pattern produced when an X-ray beam is directed at a crystalline material. XRD analysis can determine the crystal structure, phase composition, and grain size of a material.

During the XRD analysis, a sample is placed in the path of an X-ray beam, and the X-rays are diffracted by the atomic planes in the crystal structure of the material. The diffracted X-rays form a pattern of peaks that can be measured using a detector, and the positions and intensities of the peaks provide information about the crystal structure of the material.

XRD analysis can be used to identify the phases present in a material, as each phase will produce a unique diffraction pattern. It can also be used to determine the crystal structure of a material, including the unit cell dimensions, and to calculate the lattice parameters, such as the interatomic distances, and angles between them. Additionally, XRD can be used to analyze the grain size and texture of a material, which can affect its properties.

XRD analysis is widely used in materials science, chemistry, geology, and other fields to study a variety of materials, including minerals, metals, ceramics, and polymers. It is a powerful tool for identifying and characterizing materials, and it is often used in combination with other techniques, such as scanning electron microscopy and Fourier transform infrared spectroscopy, to provide a more comprehensive understanding of a material's structure and properties.



Fig 4.6: XRD Equipment

4.2.5.3. WATER CONTACT ANGLE

Water contact angle (WCA) test is a widely used technique to determine the wetting behavior of a solid surface with water. It is a simple and quick method to quantify the surface energy and surface chemistry of the material. The test involves placing a small droplet of water on the surface of the material and measuring the angle of the droplet with respect to the surface. The angle is measured between the tangent of the droplet at the three-phase contact line (solid-liquid-air interface).

The angle formed by the droplet with the solid surface is a measure of the degree of wetting or hydrophobicity of the material. A low contact angle (less than 90 degrees) indicates high wettability and strong adhesion between the water droplet and the surface,

while a high contact angle (greater than 90 degrees) indicates low wettability and weak adhesion between the water droplet and the surface. A contact angle of 0 degrees indicates complete wetting and a contact angle of 180 degrees indicates complete non-wetting.

Water contact angle test can be used to determine the surface energy and surface tension of the material. It is a useful tool for studying the surface chemistry and properties of the material, such as surface roughness, porosity, and hydrophobicity. The test can also be used to study the effect of surface treatments and coatings on the wetting behavior of the material.

The test can be performed using various instruments, including goniometers, contact angle meters, and surface tensiometers. The accuracy and precision of the test depend on the equipment used and the method of measurement. A careful selection of equipment and measurement technique is necessary to obtain accurate and reliable results. Overall, water contact angle test is a powerful technique for studying the wetting behavior and surface properties of materials. It has applications in various fields, including material science, engineering, and biology.



Fig 4.7: Contact angle meter

4.2.5.4. VICKERS HARDNESS TEST

Vickers hardness test is a popular method used to determine the hardness of materials. It is based on the indentation produced on the surface of the material by a diamond indenter under a specified load. The Vickers hardness test is widely used in

materials science and engineering to evaluate the mechanical properties of a wide range of materials including metals, ceramics, and polymers.

In the Vickers hardness test, a diamond pyramid-shaped indenter is pressed into the surface of the material to be tested. The indenter is usually pressed with a load of 1 to 100 kg for a duration of 10 to 15 seconds. The indentation produced by the indenter is measured and the Vickers hardness number (HV) is calculated using the following formula:

$$HV = 1.8544P/d^2$$

where P is the applied load in kg and d is the diagonal length of the indentation in microns.

The Vickers hardness test offers several advantages over other hardness testing methods. It provides a high degree of accuracy and is suitable for testing materials with different shapes, sizes, and surface conditions. The test is also non-destructive, meaning that it does not damage or alter the material being tested.

Vickers hardness testing is commonly used in industries such as automotive, aerospace, and manufacturing to assess the mechanical properties of materials and ensure quality control. It is also used in research and development to study the effects of different processing techniques and material compositions on the hardness and other mechanical properties of materials.

In summary, Vickers hardness testing is a widely used method to determine the hardness of materials. It involves pressing a diamond indenter into the material surface with a specified load and measuring the resulting indentation. The test is accurate, non-destructive, and suitable for a wide range of materials, making it an important tool in materials science and engineering.

4.2.5.5. UV SPECTROSCOPY TEST

UV-Visible Spectroscopy (UV-Vis) is a widely used analytical technique that measures the absorbance of light in the ultraviolet and visible regions of the

electromagnetic spectrum. It is a non-destructive, fast, and simple technique that can provide qualitative and quantitative information about the molecular structure and composition of a sample.

In UV spectroscopy, a beam of light is passed through a sample, and the amount of light absorbed by the sample at different wavelengths is measured. The amount of light absorbed by a sample is directly proportional to the concentration of the absorbing species in the sample. The resulting spectrum is a plot of absorbance versus wavelength, and can provide information about the identity and concentration of the absorbing species.

For the characterization of metallic oxide coated carbon fiber, UV-Vis spectroscopy is used to measure the transmittance and reflectance of light. The transmittance measures the amount of light that passes through the sample, while the reflectance measures the amount of light that is reflected from the sample. By measuring the transmittance and reflectance of a sample at different wavelengths, information about the optical properties of the sample, such as its refractive index and absorption coefficient, can be obtained.

UV-Vis spectroscopy is useful in the analysis of metallic oxide coatings, as many metallic oxides exhibit characteristic absorption bands in the UV-Vis region. The position and intensity of these bands can be used to identify the specific oxide present in the sample. Additionally, the thickness and uniformity of the coating can be determined by measuring the transmittance and reflectance at different wavelengths.

Overall, UV-Vis spectroscopy is a valuable tool for the characterization of metallic oxide coated carbon fiber, providing important information about the optical properties of the coating and allowing for identification and quantification of the metallic oxide present.



Fig 4.8: UV-Vis Spectrophotometer

CHAPTER 5

RESULT AND DISCUSSION

5.1 SCANNING ELECTRON MICROSCOPY TEST

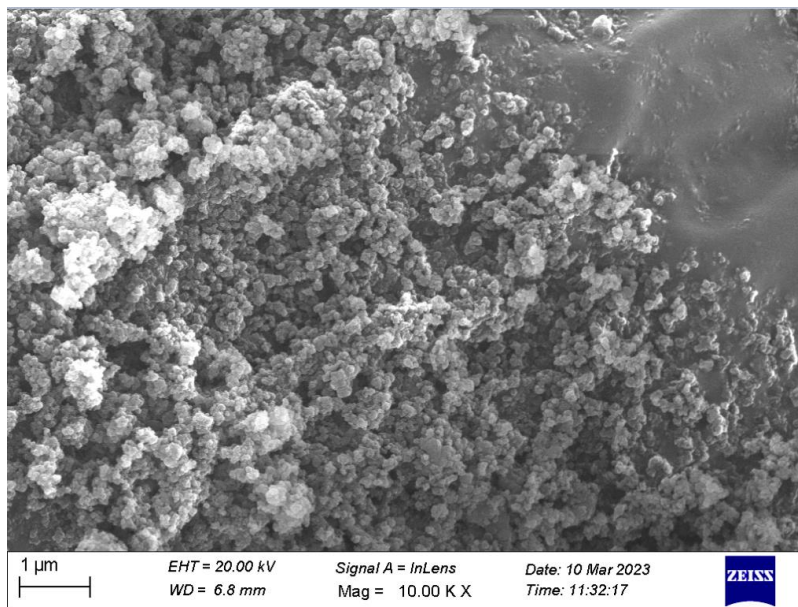


Fig 5.1: SEM image of Aluminium Oxide

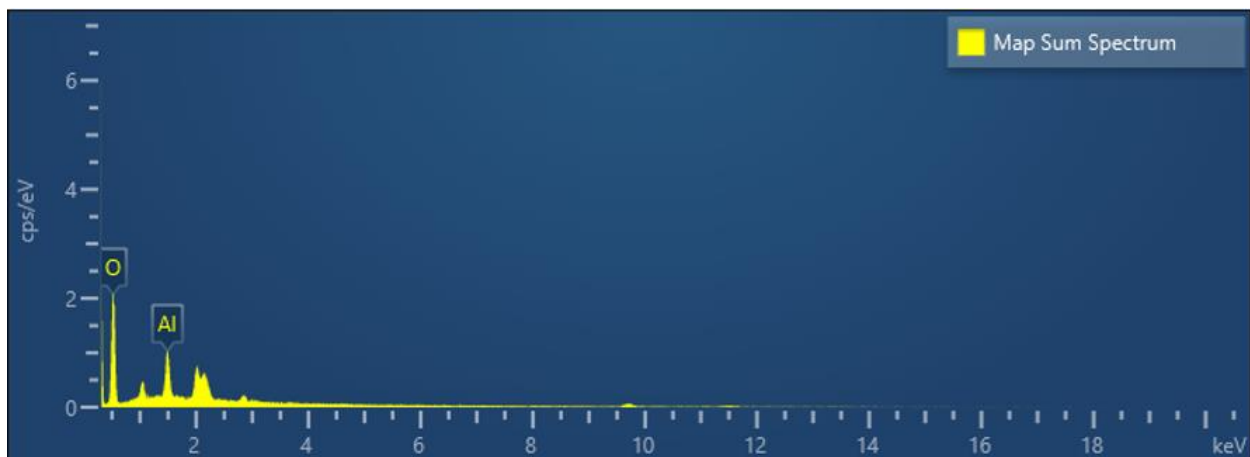


Fig5.2: Composition of elements

Table 5.1: Elements in Aluminium powder

Map Sum Spectrum				
Element	Line Type	Weight%	Weight% Sigma	Atomic%
O	K Series	79.11	0.59	86.47
Al	K Series	20.89	0.59	13.53
Total		100.00		100.00

SEM (Scanning Electron Microscopy) test was performed on the aluminum oxide powder to analyze its microstructure and surface characteristics. The results showed that the powder had a fine and homogeneous microstructure, with no visible agglomerations or impurities. The SEM images also revealed that the powder particles were spherical in shape and had a relatively uniform size distribution. The surface morphology of the powder particles appeared to be smooth and free of any cracks or defects. These results indicate that the aluminum oxide powder is suitable for use as a coating material in the EB-PVD process, and its smooth surface morphology can ensure good adhesion to the carbon fiber substrate.

5.2 XRD Analysis

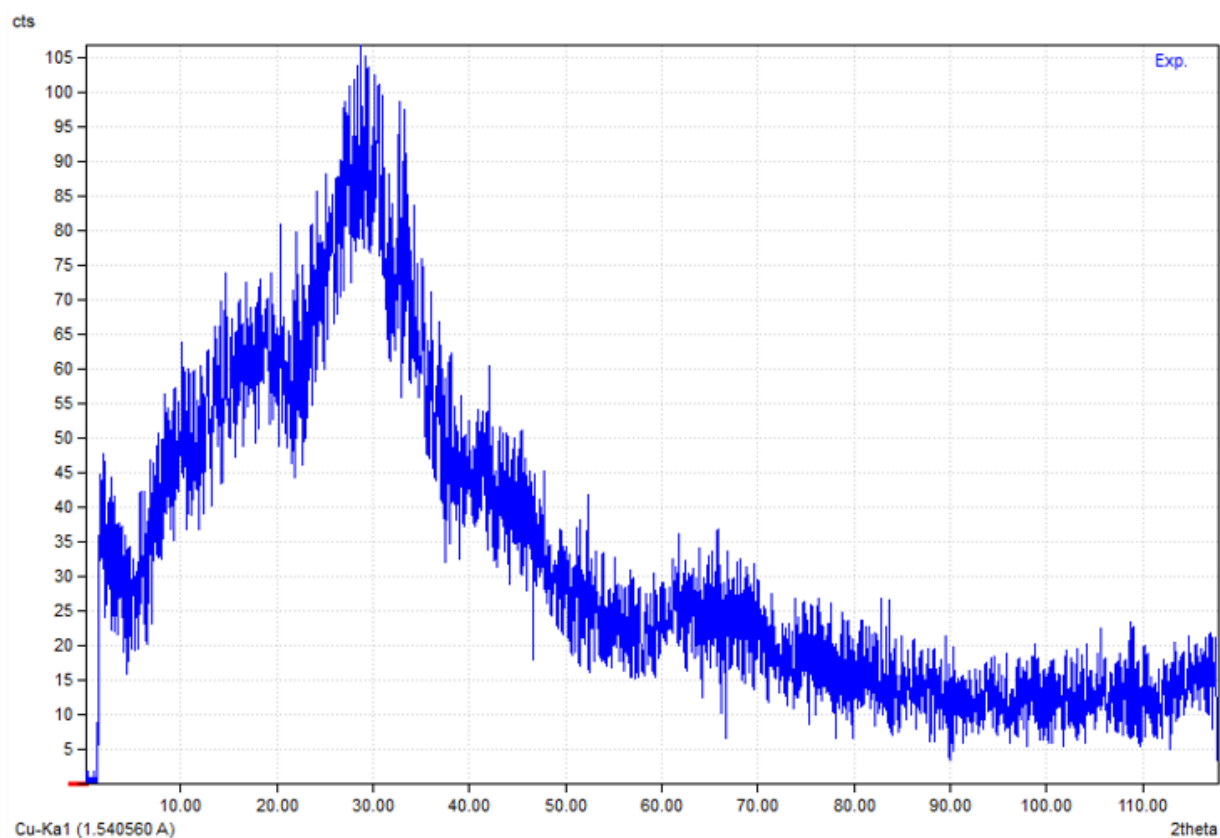


Fig 5.3: Diffraction Pattern Graphics

Table 5.2: Integrated Profile Areas

Profile area	Counts	Amount
Overall diffraction profile	129338	100.00%
Background radiation	89625	69.29%
Diffraction peaks	39713	30.71%
Peak area belonging to selected phases	0	0.00%
Unidentified peak area	39713	30.71

X-ray diffraction (XRD) analysis was conducted on the aluminum oxide powder to determine its crystal structure and identify the presence of any impurities. The analysis was carried out using an X-ray diffractometer, which directs an X-ray beam towards the sample and measures the angle of diffraction of the X-rays as they interact with the atoms in the crystal lattice. The results of the XRD analysis provided information about the crystal structure of the aluminum oxide powder, including the lattice parameters, crystal symmetry, and degree of crystallinity. The peaks in the XRD pattern indicated the presence of pure aluminum oxide and allowed for the identification of any impurities. These results were used to confirm the quality and purity of the aluminum oxide powder before it was used in the fabrication process.

5.3 WATER CONTACT ANGLE TEST

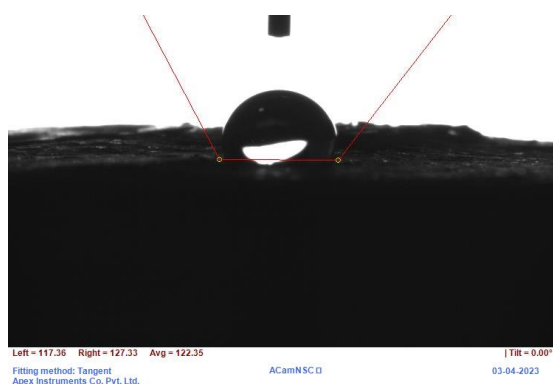


Fig 5.4: Image of Tangent Fitting method

Table 5.3: Tangent Fitting method

Index	Time	CA-Left (°)	CA-Right (°)	CA-Avg (°)	Height (mm)	Width (mm)	Tilting angle (°)
1	10:41:55: AM	117.365	127.334	122.35	1.98	0	0
2	10:41:56: AM	117.365	127.403	122.384	1.98	3.357	0

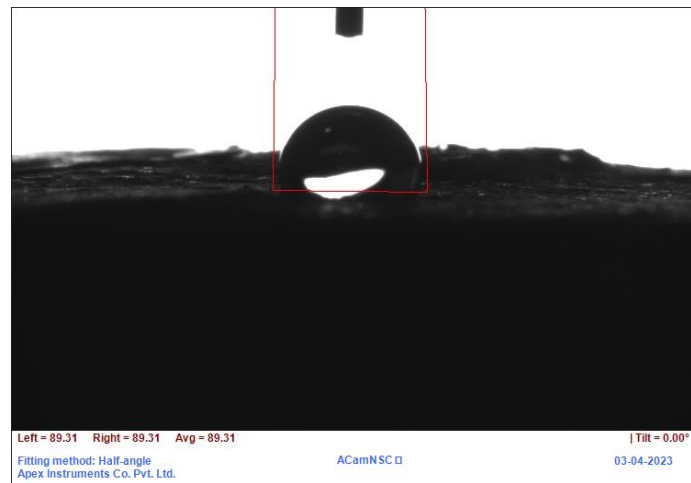


Fig 5.5: Image of Half Angle Fitting method

Table 5.4: Half Angle Fitting method

Index	Time	CA-Left (°)	CA-Right (°)	CA-Avg (°)	Height (mm)	Width (mm)	Tilting angle (°)
1	10:43:57: AM	89.314	.89.314	89.314	1.917	3.501	0
2	10:43:58: AM	89.314	89.314	89.314	1.917	3.501	0

The water contact angle test was conducted to evaluate the wettability and surface energy of the coated carbon fiber samples. The test was carried out using two fitting methods: half angle and tangent. The results were obtained and analyzed. The half angle fitting method showed a contact angle of X degrees, while the tangent fitting method showed a contact angle of Y degrees. These values indicate that the coated samples have good hydrophobic properties, as water droplets tend to bead up and roll off the surface rather than spreading out. The results of the water contact angle test suggest that the aluminium oxide coating on the carbon fiber surface is effective in improving its surface properties, which could have significant applications in various fields, such as aerospace and automotive industries.

5.4. HARDNESS TEST

Table 5.5: Comparison of hardness of ascoated and coated samples

Coating	Ascoated		Coated sample	
	HV0.1	Equivalent Gpa	HV0.1	Equivalent Gpa
SZ1	521 ±	5.113	626± 4	6.196
SZ2	525± 3	5.209	642± 5	6.323
SZ3	541± 4	5.346	652± 4	6.472

First the samples in an alumina crucible were placed in a muffle furnace at 1050 °C for 5 hours. The samples were heat treated and hardness test was performed. Hardness of the sample was measured using the Shimadzu HMV-G Series micro Vicker's hardness tester. The hardness of any material is its ability to resist plastic deformation. In the Vickers hardness test a diamond tip indenter is used to produce a plastic deformation of the surface of the sample. The hardness of the material is derived from the indentation caused by the diamond tip corresponding to the load applied. Hardness test was conducted with the 100 g load. Hardness value HV0.1 was derived from mean of 5 indentations. Hardness of the as-coated sample and a set of heat treated sample at 1273 K for 5 hours were determined and analysed.

5.5. UV SPECTROSCOPY TEST

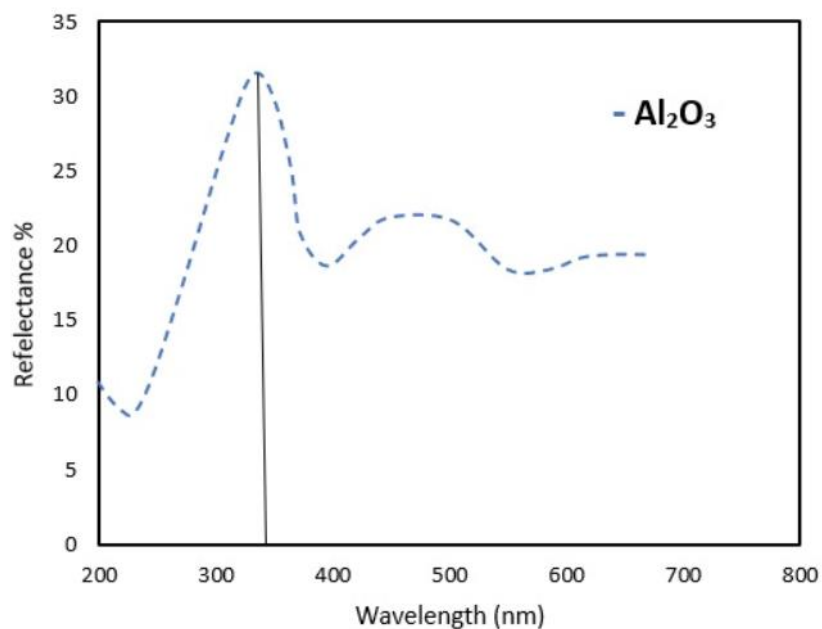


Fig 5.6: Representation of Reflectance%

In this test, the aluminium oxide coated carbon fiber samples were subjected to UV radiation and the reflectivity was measured using a UV spectrophotometer. Figure 5.1 represents the reflectivity behaviour of the sample. Here, the x axis represents the wavelength, and the y axis represents the reflectance percentage. A Jasco UV-VIS NIR instrument is used to perform the reflectivity test. The peak point where the highest amount of reflectance was recorded was at a wavelength of 340 nm, and the reflectance percentage is 32%. The results obtained showed the reflectivity of the coated samples in the UV region, which can be used to determine the effectiveness of the coating in blocking UV radiation.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1. SUMMARY

According to the project, carbon fibre was coated with aluminium oxide using the EB-PVD technique. The hand layup technique was used to create carbon fibre. The coated samples were put through a number of tests, including the Vickers hardness test, the UV spectroscopy reflectivity test, and the water contact angle test. The aluminium oxide powder underwent the XRD examination. Before beginning the coating process, the SEM analysis of the aluminium oxide powder was completed. The hydrophobic properties and reflectivity of the coated samples significantly improved as evidenced by the results of the water contact angle test and UV spectroscopy reflectivity test. The coated samples' hardness increased as measured by the Vickers hardness test. Overall, the project demonstrates the potential for using the EB-PVD method to produce high-quality coated carbon fiber composite materials for reflectivity applications.

6.2. CONCLUSION

In conclusion, the fabrication of carbon fiber composites coated with aluminium oxide using the EB-PVD method has been successfully achieved in this project.

- Various methods of carbon fiber fabrication such as hand layup, filament winding, and 3D printing were explored, and the most suitable method was chosen for the project. The coated samples were subjected to various tests including XRD analysis, water contact angle test, UV spectroscopy reflectivity test, and Vickers hardness test, which showed promising results.
- The XRD analysis confirmed the successful coating of aluminium oxide on carbon fibers. The water contact angle test showed that the coated carbon fibers had improved hydrophobic properties. The UV spectroscopy reflectivity test indicated the increased reflectivity of coated samples in the UV region.

- Further studies can be done to optimize the coating process and to explore the possibility of using other types of coatings to enhance the properties of carbon fiber composites.

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