Effect of Rubber and Silicon Carbide inclusions on Mechanical and Damping Properties of Carbon Fiber Reinforced Composite Materials

A Project Report submitted in Partial fulfillment requirements

For the award of the Degree of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

By

M. SASI KUMAR (315126520134)

K. BANGARU NAIDU (315126520109)

K. HARSHA VARUN GUPTA (315126520095)

K. BABU SAI SRIVATSA (315126520087)

K. VEENA SHARMILA (315126520113)

Under the esteemed Guidance of

Mr. K. Naresh Kumar M.Tech, (PhD)

ASSISTANT PROFESSOR

PRAGNANAM BRAHMA

ANITS

DEPARTMENT OF MECHANICAL ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)

(Affiliated to A.U., Approved by AICTE, Accredited by NBA & NAAC with 'A' Grade)

SANGIVALASA, VISAKHAPATNAM – 531162

2015 - 2019

Effect of Rubber and Silicon Carbide inclusions on Mechanical and Damping Properties of Carbon Fiber Reinforced Composite Materials

A Project Report submitted in Partial fulfillment requirements

For the award of the Degree of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

By

M. SASI KUMAR (315126520134)

K. BANGARU NAIDU (315126520109)

K. HARSHA VARUN GUPTA (315126520095)

K. BABU SAI SRIVATSA (315126520087)

K. VEENA SHARMILA (315126520113)

Under the esteemed Guidance of

Mr. K. Naresh Kumar M.Tech, (PhD)

ASSISTANT PROFESSOR

DEPARTMENT OF MECHANICAL ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)

(Affiliated to A.U., Approved by AICTE, Accredited by NBA & NAAC with 'A' Grade)

SANGIVALASA, VISAKHAPATNAM – 531162

2015 - 2019

CERTIFICATE

This is to certify that the project entitled "**Effect of Rubber and Silicon Carbide inclusions on Mechanical and Damping Properties of Carbon Fiber Reinforced Composite Materials** " describes the bonafied work carried out by **M. SASI KUMAR (315126520134), K. BANGARU NAIDU (315126520109), K. HARSHA VARUN GUPTA (315126520095), K. BABU SAI SRIVATSA (315126520087), K. VEENA SHARMILA (315126520113)** under my guidance in partial fulfillment of the requirements for the award of Degree in "**Bachelor of Engineering**" in Mechanical Engineering by Andhra University under my supervision and guidance during the academic during the academic year 2015-2019

APPROVED BY	PROJECT GUIDE
13.4.19	
Dr. B. Naga Raju, PhD	**K. Naresh Kumar, M.Tech (Ph.D)**
Head of the Department	Asst. Professor
Dept. of Mechanical Engineering	Dept. of Mechanical Engineering
ANITS	ANITS
Sangivalasa	Sangivalasa
Visakhapatnam	Visakhapatnam

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCE
Sangivalasa-531 162 VISAKHAPATNAM Dist A P

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINATIONS

EXTERNAL EXAMINER:

INTERNAL EXAMINER:

ACKNOWLEDGEMENT

We present this report on **"Effect of Rubber and Silicon Carbide inclusions on Mechanical and Damping Properties of Carbon Fiber Reinforced Composite Materials"** in the partial fulfillment of the requirement for the award of BACHELOR OF ENGINEERING in MECHANICAL ENGINEERING.

We intend to express our thanks with sincere obedience to **Prof. T. Subrahmanyam,** Principal, ANITS and **Prof. B. Naga Raju,** Head of the Department, Mechanical Engineering, ANITS for providing this opportunity to express our deep and sincere thanks to our esteemed guide **Mr. K. Naresh Kumar,** Assistant Professor, Mechanical Engineering Department, ANITS, A source of constant motivation and best critic, for his inspiring and infusing ideas in getting our project done successfully.

Lastly we are grateful to one and all who have contributed either directly or indirectly in the completion of the project.

M. SASI KUMAR (315126520134)

K. BANGARU NAIDU (315126520109)

K. HARSHA VARUN GUPTA (315126520095)

K. BABU SAI SRIVATSA (315126520087)

K. VEENA SHARMILA (315126520113)

ABSTRACT

In this research work, an attempt is made to study the mechanical and damping properties of CF reinforced composite material. The filler materials considered in this study is Sic, rubber powder, graphite powder and barium sulphate. Epoxy resin polymer matrix is used to bind CF and remaining ingredients together. Hand layup technique is used to fabricate four Composite sheets with varying wt. % of ingredients. The contents of rubber powder and Sic are varied by keeping remaining ingredients as constant. Each Composite sheet of dimensions (24x30) cm are fabricated of thickness 5mm each. The contents of rubber powder is varied as (1wt%,0.8wt%,0.6wt% and 0.4wt%) and Sic is varied as (0.7wt%,0.6wt%,0.5wt% and 0.4wt%) for all the composite sheets. Specimens are cut according ASTM standards for evaluating mechanical properties and damping properties of all the specimens. Scanning electron microscope images are taken to observe the grain distribution and uniform distribution of all the ingredients. The best configuration of materials are selected for the fabrication of composite sheet used in various industries.

Key Words: Carbon fiber, Epoxy Resin, Sic and Rubber, Mechanical Properties

CONTENTS

Chapter-1

INTRODUCTION

CHAPTER – 1

INTRODUCTION

1.1 HISTORY OF COMPOSITE MATERIALS

The idea of combining several components to produce a new material with new properties that are not attainable with individual components is not of recent origin.2, 3 Humans have been creating composite materials to build stronger and lighter objects for thousands of years. The first use of composite dates back to the 1500 B.C. when early Egyptian and Mesopotamian settlers used a mixture of mud and straw to create strong and durable buildings. Straw continued to provide reinforcement to ancient composite products including pottery and boats. Later, in 1200 A.D. the Mongols invented the first composite bow. Using a combination of wood, bone, and "animal glue," bows were pressed and wrapped with birch bark. These bows were extremely powerful and extremely accurate. Composite Mongolian bows provided Genghis Khan with military dominance, and because of the composite technology, this weapon was the most powerful weapon on earth until the invention of gunpowder.

1.2 SCOPE OF THE COMPOSITE MATERIAL:

The technology of composite materials has experienced a rapid development in the last four decades. Some of the underlying reasons and motivations for this development are

a. Significant progress in material science and technology in the area of fibers, polymers, and ceramics.
b. Requirements for high performance materials in aircraft and aerospace structures.
c. Development of powerful and sophisticated numerical methods for structural analysis using modern computer technology.

The initial driving force in the technology development, dominated by the aerospace industry, was performance through weight savings. Later cost competitiveness with more conventional materials become equally important. In addition to these two requirements, today there is a need for quality assurance, reproducibility and predictability of behavior over the lifetime of the structure.

New development continue in all areas. For example, new types of carbon fibers have been introduced with higher strength and ultimate strain.

1.3 INTRODUCTION TO COMPOSITE MATERIALS

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined macroscopically to produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure, differentiating composites from mixtures and solid solutions.

The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites which are known as Robotic Materials.

Examples of Composite materials in day to day life:

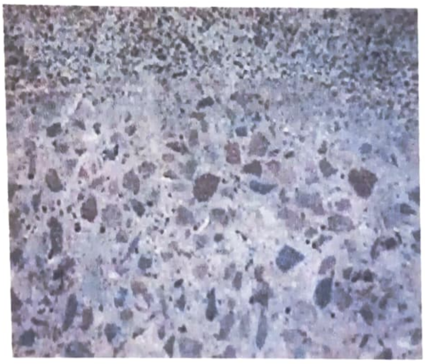


Fig - 1.3(a) Concrete is a mixture of cement and aggregate, giving a robust, strong material that is very widely used

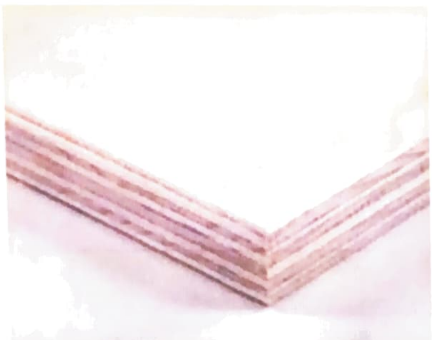


Fig - 1.3(b) Plywood is a widely used composite in construction

1.3.1 CHARACTERISTICS OF COMPOSITES:

Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement or reinforcing material whereas the continuous phase is termed the matrix. The orientation of the reinforcement affects the isotropy of the system. When the reinforcement is in the form of particles, with all their dimensions approximately equal, the composite behaves essentially as an isotropic material whose properties are independent of direction. The reinforcement constituents is reinforces the mechanical properties of matrix. The reinforcement is harder, stronger and stiffer than matrix in most of the cases.

The general requirements of composite materials are:

a. The second phase (particles or fibers) must be uniformly distributed throughout the matrix and must not be in direct contact with one another.
b. The constituents of the composite should not react with one another at high temperatures which lead to premature failure of the composite due to interfacial bond.
c. The reinforcement phase should be well bonded to the matrix material.
d. In general, both the matrix and the fiber should not have greatly different coefficient of linear expansion.

1.3.2 CLASSIFICATION OF COMPOSITES

The classification of composite materials is clearly explained in the form of a diagram as shown in below.

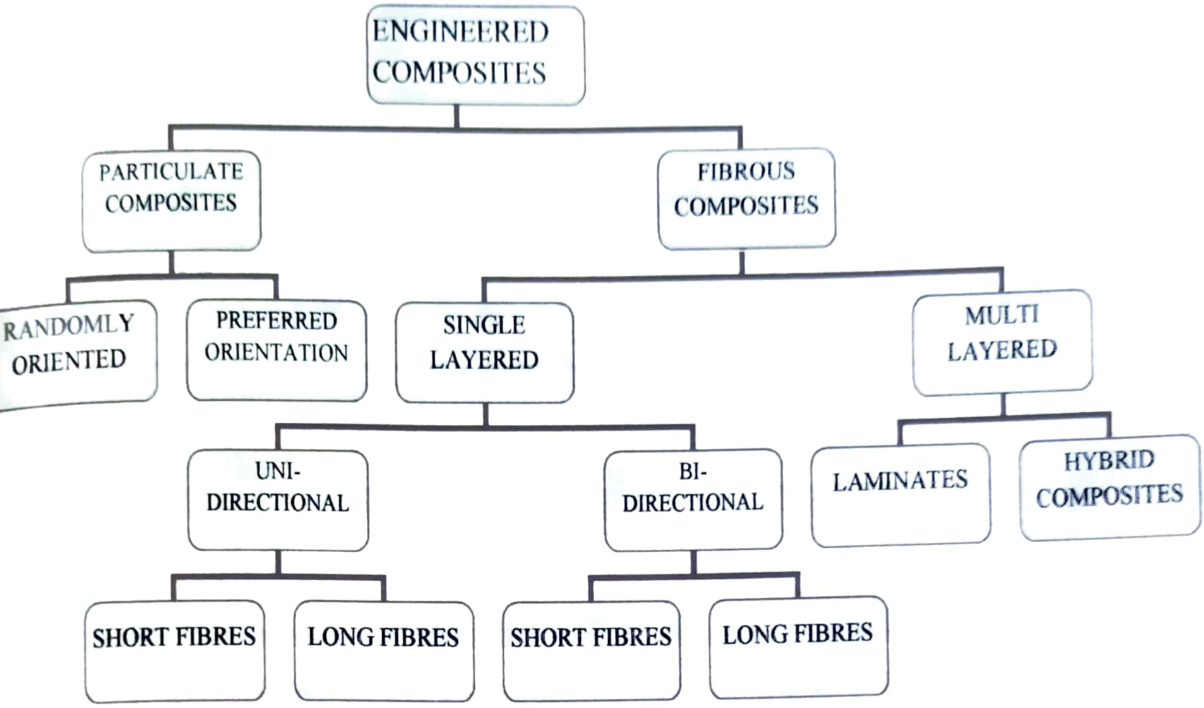


Fig - 1.3.2 Classification of composites

a) Continuous Fiber Reinforced Composites

Continuous fiber composites are primarily reinforced with high performance carbon or armed (e.g. Kevlar) fibers. These composites are utilized in applications such as aircraft components, where the exceptional fiber properties can be fully exploited. Some commonly used continuous fiber composite processing methods includes compression molding, hand lay-up, filament winding and Pultrusion. Such materials however, cannot always be adapted to mass production and are often limited to simple shaped items.

b) Short fiber reinforced composites

Short fiber composites are primarily reinforced with chopped fibers such as glass, Graphite and cellulose fibers. These types of composites are cheaper and easier to fabricate, and are well established in many applications where medium to low strengths and stiffness are required. Compared to continuous fiber composites, short fiber composites can be easily processed. For the short fiber composites, with a thermoplastic matrix, it is thus possible to mass produce complex shaped products by means of extrusion, injection molding and compression molding.

c) **Matrix material based**

(i) **Metal Matrix Composites (MMC)**

Metal matrix composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a disperse ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase. They have many advantages over monolithic metals like higher specific modulus, higher specific strength, better properties at elevated temperatures, and lower coefficient of thermal expansion. Because of these attributes metal matrix composites are under the consideration for wide range of application viz. combustion chamber nozzle (in rocket, space shuttle), housing, tubing, cables, Heat exchangers, structural members.

(ii) Ceramic Matrix Composites (CMC)

Ceramic matrix composite composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase). One of the main objectives in providing ceramic composites is to increase the toughness. Naturally it is hoped and indeed often found that there is a concomitant improvement in strength and stiffness of the ceramic matrix composites.

(iii) Polymer Matrix Composites (PMC)

Polymer matrix composite is composed of a matrix from thermoset (Unsaturated Polyester (UP), Epoxy (EP)) or thermoplastic (Polycarbonate (PC), Polyvinylchloride, Nylon, Polystyrene) and embedded glass, carbon, steel or Kevlar fiber (dispersed phase). This is the most commonly used composite. The reason for this is twofold. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular, their strength and stiffness are low when compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and does not require high temperatures.

1.3.3 TYPES OF REINFORCEMENTS IN COMPOOSITES

Reinforcement increases the strength, stiffness and temperature resistance capacity and lowers the density of MMC. In order to achieve these properties the selection depends on the type of reinforcement, its method of production and chemical compatibility with the matrix. The different types of reinforcements used in composites are shown below.

a) Particulate Reinforcement

A composite whose reinforcement may be classified as particles is called a particulate composite. Particulates are the most common and cheapest reinforcement materials. They produce the isotropic property of MMCs which shows promising application in structural fields. The particles and matrix material in a particulate composite can be any combination of metallic and nonmetallic materials. The choice of a particular combination depends on the desired end properties. In general, particles are not very effective in improving fracture resistance. However, particles of rubberlike substances in brittle polymer matrices improve fracture resistance by promoting and then arresting crazing in the brittle matrices .Particulate composites consist of relatively coarse and nearly spherical particles embedded into a homogeneous matrix. Their formation is not usually motivated by its strength but by increasing the hardness of composites.

b) Fibrous Reinforcement

Fibers, because of their small cross-sectional dimensions, are not directly usable in engineering applications. They are, therefore, embedded in matrix materials to form fibrous composites. The matrix serves to bind the fibers together, transfer loads to the fibers, and protect them against environmental attack and damage due to handling Reinforcing fibers in a single-layer composite may be short or long compared with its overall dimensions. Composites with long fibers are called continuous-fiber-reinforced composites, and those with short fibers, discontinuous-fiber-reinforced composites. Chopped fibers also may be blended with resins to make a reinforced molding compound. These fibers tend to become oriented parallel to the direction of material flow during a compression- or injection-molding operation and thus get a preferential orientation. Composites fabricated in this manner are not isotropic

c) Whiskers

Single crystals grown with nearly zero defects are termed as whiskers. They are usually discontinuous and short fibers of different cross-sections made from several materials like graphite, silicon carbide, copper, iron etc. Whiskers have a definite length to width ratio greater than one having extraordinary strengths up to 7000 MPa.

d) Laminates

Laminar composites can be described as materials comprising layers of materials bonded together. The orientation of fiber may change from layer to layer. There may be several layers of two or more metal materials occurring alternately or in a determined order as required for specific purposes.

e) Hybrids

They are the multi layered composites with mixed fibers, e.g. Mixture of glass and carbon incorporated into a matrix.

1.3.4 ADVANTAGES OF COMPOSITE MATERIALS

Composites have unique advantages over monolithic materials, such as high strength, high stiffness, long fatigue life, low density, and adaptability to the intended function of the structure. Additional improvements can be realized in corrosion resistance, wear resistance, appearance temperature dependent behavior, environmental stability, thermal insulation and conductivity, and acoustic insulation. The basis for the superior structural performance of composite materials lies in the high specific strength (strength to density ratio) and high specific stiffness (modulus to density ratio) and in the anisotropic and heterogeneous character of the material. The latter provides composites with many degree of freedom for optimum configuration of the material system.

1.3.5 DISADVANTAGES OF COMPOSITE MATERIALS

Although composite materials have certain advantages over conventional materials, composites also have some disadvantages. The common one being high manufacturing costs. However, as improved manufacturing techniques are developed, it will become possible to produce composite materials at higher volumes and at lower cost. Some of the limitations are:

a) Mechanical characterization of a composite structure is more complex than a metal structure.

b) Repair of composites is not a simple process compared to that of metals.

c) Composites do not have a high combination of strength and fracture toughness compared to metals.

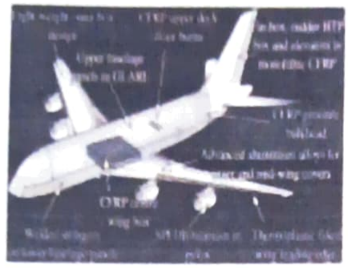
d) Composites do not necessarily give higher performance in all the properties used for material selection like strength, toughness, formability, join ability, corrosion resistance, affordability etc.

1.3.6 APPLICATIONS OF COMPOSITE MATERIALS

Composites are important materials used widely not only in the aerospace industry but also in a large and increasing number of commercial applications including [23]

a. Automotive applications such as internal combustion engines, engine blocks piston tie rod, truck and automobile chases etc.
b. Medical applications include Prostheses, wheel chairs and orthofiles.
c. Sports equipment's such as tennis racquets, ski poles, skis, fishing rods, golf clubs, bicycle frames and motor cycle frame.
d. Thermal control and electronic packaging.
e. Train, and Fan blades in turbine engines, aircraft compressor blades, wing boxes and other aircraft and spacecraft applications.
f. Mechanical components, such as brakes, drive shafts, and flywheels.
g. Tanks and pressure vessels.
h. Dimensionally stable components.
i. Process industries equipment requiring resistance to high temperature corrosion, oxidation, and wear.
j. Offshore and onshore oil exploration and production.
k. Marine structures.
l. Bullet proof.
m. Construction of Bridges

BULLET PROOF



AIRCRAFTS

AUTOMOBILE PARTS

BOATS HULLS

SPORT'S KITS

BUILDING CONSTRUCTION

Fig - 1.3.6 APPLICATIONS OF COMPOSITES.

1.3.7 FIBER REINFORCED COMPOSITE:

A fibre-reinforced composite (FRC) is a composite building material that consists of three components:

i) The fibres as the discontinuous or dispersed phase,

ii) The matrix as the continuous phase, and

iii) The fine interphase region, also known as the interface.

This is a type of advanced composite group, which makes use of rice husk, rice hull, and plastic as ingredients. This technology involves a method of refining, blending, and compounding natural fibres from cellulosic waste streams to form a high-strength fibre composite material in a polymer matrix. The designated waste or base raw materials used in this instance are those of waste thermoplastics and various categories of cellulosic waste including rice husk and saw dust.

FRC is high-performance fibre composite achieved and made possible by cross-linking cellulosic fibre molecules with resins in the FRC material matrix through a proprietary molecular re-engineering process, yielding a product of exceptional structural properties.

An attempt to minimize or eliminate flaws enhances the strength of a material. Flaws in the form of cracks that lie perpendicular to the direction of applied loads are particularly detrimental to strength. Therefore, compared with the strength of the bulk material, man-made filaments or fibers of non-polymeric materials exhibit much higher strengths along their lengths because large flaws that may be present in the bulk material are minimized owing to the small cross-sectional dimensions of the fiber.

TABLE - 1.3.7: PROPERTIES OF VARIOUS MATERIALS

MATERIAL	TENSILE MODULUS (E) (GPa)	TENSILE STRENGTH (GPa)	DENSITY (p) (g/cm3)	SPECIFIC MODULUS (E/p)	SPECIFIC STRENGTH
FIBERS					
E-glass	72.4	3.5	2.54	28.5	1.38
S-glass	85.5	4.6	2.48	34.5	1.85
Graphite (high modulus)	390.0	2.1	1.90	205.0	1.1
Graphite (high tensile strength)	240	2.5	1.90	126	1.3
Boron	385	2.8	2.63	146.0	1.1
Silica	72.4	5.8	2.19	33.0	2.65
Tungsten	414	4.2	19.30	21.0	0.22
Beryllium	240	1.3	1.83	131.0	0.71
Kevlar 49 (aramid polymer)	130	2.8	1.50	87.0	1.87

CONVENTIONAL MATERIALS	TENSILE MODULUS (E) (GPa)	TENSILE STRENGTH (GPa)	DENSITY (p) (g/cm3)	SPECIFIC MODULUS (E/p)	SPECIFIC STRENGTH
Steel	210	0.34-2.1	7.8	26.9	0.043-0.2
Aluminum alloys	70	0.14-0.62	2.7	25.9	0.052-0.2
Glass	70	0.7-2.1	2.5	28.0	0.28-0.8
Tungsten	350	1.1-4.1	19.30	18.1	0.057-0.2
Beryllium	300	0.7	1.83	164.0	0.38

1.4 INTRODUCTION TO CARBON FIBER

1.4.1 INTRODUCTION

Carbon fiber is a long thin strand of carbon atoms that are bonded together in a honeycomb crystal lattice called Graphene. Some of the Graphene layers are folded around each other in random orientations but most are aligned parallel to the long axis of the strand. This makes the fiber incredibly strong along the axis of the strand. (Highest APF). The strands are usually wound into a yarn then woven into a fabric. The fabric is then mixed with epoxy and molded to form the desired shape. Since 1950s CFs are extensively used in polymer matrix composites for a wide range of applications like aviation, nuclear and automotive industries. CF is primarily preferred for composite materials due to its excellent properties, such as high specific strength and stiffness, thermal stability, conductivity, tensile modulus, self-lubrication and corrosion resistance. Carbon fiber reinforced polymers have been found to possess superior wear resistance compared to other fibers. Now days CF reinforcements are widely used in civil engineering constructions to mix CF and cement in better weight proportion ratio to achieve higher mechanical strength for bridge constructions, dams, buildings etc. The future of CF is very bright with vast potential in many different industries like alternate energy, fuel efficient automobiles, construction and infrastructure, oil exploration etc. The usage of CFs in polymer composites without any surface treatment on the fiber leads to poor inter laminar shear strength between fiber and matrix. Surface treatments on CF can increase the surface area and acid functional groups such as carboxyl and hydroxyl groups on the fiber surface for improving the inter laminar shear strength between fiber and matrix for effective stress transfer at the interface.

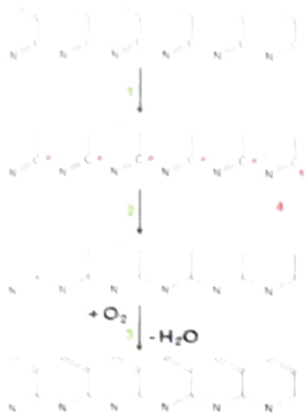


Fig - 1.4.1 Molecular structure of carbon fiber

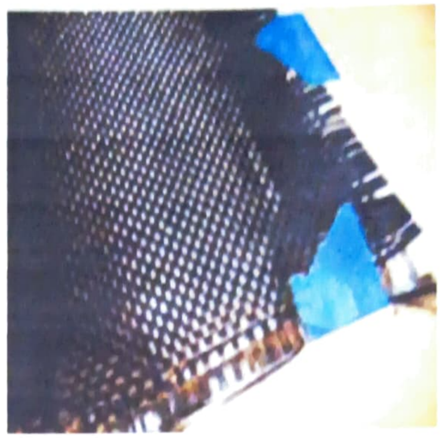


Fig - 1.4.2 Carbon fiber matte

1.4.2. HISTORY OF CARBON FIBER

During the 1970s, experimental work to find alternative raw materials led to the introduction of carbon fibres made from a petroleum pitch derived from oil processing. These fibres contained about 85% carbon and had excellent flexural strength. Unfortunately, they had only limited compression strength and were not widely accepted. What once began as a space age material for the aerospace market has now become commercialized. Today, carbon fibres are an important part of many products, and new applications are being developed every year. The United States, Japan, and Western Europe are the leading producers of carbon fibres.

1.4.3. APPLICATIONS OF CARBON FIBER

a) Aerospace Engineering

Tail of an RC helicopter, made of Carbon fibre reinforced plastic. The wings on the Grumman X-29 experimental plane made use of a feature of composites that allow them to bend in one direction but not another.

b) Civil Engineering

Carbon fibre reinforced concrete offers innovative solutions for civil engineering. Reinforcing steel, cast iron, timber and concrete to make them stronger instead of retrofitting or destroying old structures. Wrapping it around columns will make the structure stronger with its tensile strengths. The less likely to collapse because of the carbon fiber tightly holds the columns in place.

c) High Performance Carbon Fibers

Unique combination of High Strength and Stiffness with Light Weight. Oxidized Acrylic Fibers and High Carbon content carbon fibers with unique combination of flame, heat and friction resistance.

d) Technical Fiber (PYRON)

High temperature and flame resistance, significant market potential, Performance competitive with higher cost materials, such as Nomax and Kevlar at lower cost

Markets: Aircraft brakes, automotive brake pads, protective clothing, automotive flame protection.

e) Commercial Grade Carbon Fiber (PANEX)

Reinforcement fibers for advanced composites, less expensive to produce than aerospace grade

Markets: wind turbines, concrete reinforcements, automobile structural parts, high pressure vessels, oil drilling equipment, sporting goods.

f) Wind Energy (fastest growing market for carbon fibers)

Carbon fiber is the enabling material for wind turbines over 3.5 MW. Wind Power has grown approximately 25% annually and this growth rate is expected to continue for the next 10 years. Significantly growing demand for the higher MW producing turbines. Economic and technical forces overwhelmingly favor the use of carbon fibers.

g) Off-shore oil and gas exploration Driving Force

Offshore developments will continue moving to deeper waters. Carbon fibers provide less weight and more stiffness and strength to deep-water oil exploration enabling deep water systems to operate at depths unreachable with traditional materials.

h) Automotive Industry

Automotive body is also made up of carbon fiber (bonnet, bumper, engine cover, car body parts

i) 3D Printing

Carbon fibers have been used for 3D printing applications from the start. Using carbon fibers for 3D printing applications helps in creating parts that have exceptional mechanical properties with a sleek carbon fiber appearance.

j) In marine applications

Carbon fiber reduces weight without sacrificing strength. The next generation of yachts, cruisers and racing vessels will be lighter and stronger when made with carbon fiber composites. Tough, durable carbon composite material stands up to the extremes of marine environments.

k) Infrastructure products

Carbon fiber fabrics are used in systems for strengthening and upgrading of existing structural members made of concrete, steel, masonry or timber. When combined with a suitable resin, carbon fiber fabrics can be applied to a variety of surfaces including walls, pipes, columns, bridge decks and beams. These provide a lightweight solution for repairing degraded structures and restoring load bearing capacity.

l) Sports industry

The high-strength, light-weight properties of carbon fiber have taken sporting goods to the next level of performance. Golf shafts, racquets, skis, snowboards, hockey sticks, fishing rods, and bicycles have all been advanced through carbon fiber reinforcements. Carbon fiber has been described as a game-changing material, and this couldn't be truer as it is in sporting goods.

Fig - 1.4.3(a) Applications of Carbon fibers in various industries

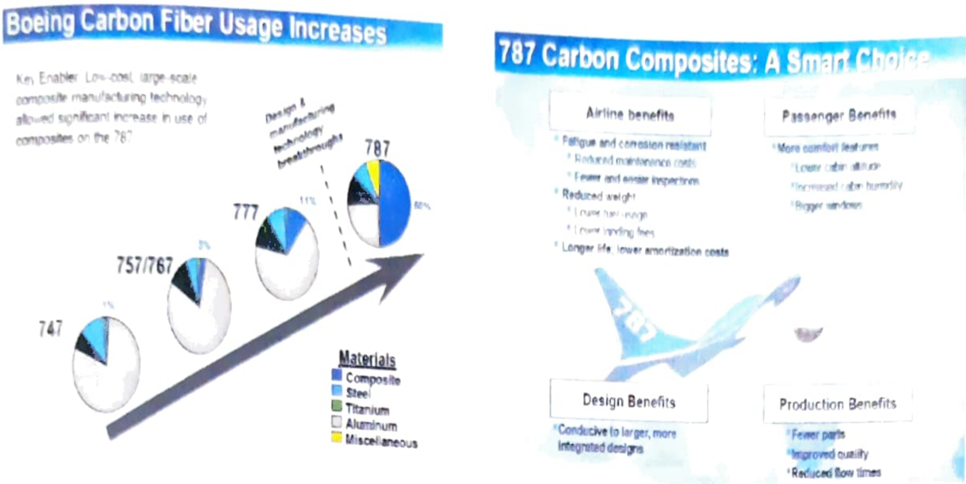


Fig - 1.4.3(b) carbon fibers in boeing

Carbon fibre usage is very high up to 50% in boeing-787 due to its high strength to weight ratio, fatigue and corrosion resistant, low density, aesthetic appearance and many other thermal and physical properties of carbon composites.

1.4.4 TYPES OF CARBON FIBER

Carbon fibres are classified based on two types.

1) Based on precursor fiber materials

2) Based on mechanical properties

1.4.4.1 BASED ON PRECURSOR FIBER MATERIALS

The raw material used to make carbon fiber is called the precursor.

Based on the precursor fiber material the carbon fibers are classified into

a) PAN - BASED CARBON FIBERS

A type of the fiber, produced by carbonization of PAN precursor (PAN: Polyacrylonitrile), having high tensile strength and high elastic modulus, extensively applied for structural material composites in aerospace and industrial field and sporting recreational goods.

b) PITCH - BASED CARBON FIBERS

A type of the fiber, produced by carbonization of oil/coal pitch precursor, having extensive properties from low elastic modulus to ultra-high elastic modulus, extensively adopted in high stiffness components.

c) MESOPHASE PITCH - BASED CARBON FIBERS

The most important in carbon fiber production is mesophase pitch due to the ability to melt spin anisotropic mesophase pitch without filament breakage. The mesophase pitch forms a thermos tropic crystal, which allows the pitch to become organized and form linear chains without the use of tension. Mesophase pitch is made by polymerizing isotropic pitch to a higher molecular weight.

d) ISOTROPIC PITCH - BASED CARBON FIBERS

A type of carbon fiber in which the pitch is prepared from high boiling fractions of petroleum feedstock, usually heavy slurry oils produced in catalytic cracking of crude oil. The pitch may be subjected to additional treatments to reduce low molecular weight components.

e) RAYON - BASED CARBON FIBERS

A type of carbon fiber in which rayon is used as precursor fiber material. It occupies just 1% of the total carbon fibers used currently. Rayon is a manufactured fiber made from regenerated cellulose fiber. Rayon is made from purified cellulose, harvested primarily from wood pulp, which is chemically converted into a soluble compound. It is then dissolved and forced through a spinneret to produce filaments which are chemically solidified, resulting in fibers of nearly pure cellulose.

f) GAS - PHASE - GROWN FIBERS

Gas-phase-grown carbon fiber is manufactured through the catalytic decomposition of hydrocarbons such as methane and benzene in the vapor phase. These fibers contain circular cross sections and central hollow cores that have a few Nano meter diameters.

1.4.4.2 BASED ON MECHANICAL PROPERTIES

Based on the mechanical properties the carbon fibers are classified into

a) **Ultra-high elastic modulus type (UHM)**

Tensile elastic modulus: 600 Gpa or higher

Tensile strength: 2,500 Mpa or higher

b) **High elastic modulus type (HM)**

Tensile elastic modulus: 350-600 Gpa

Tensile strength: 2,500 Mpa or higher

c) **Intermediate elastic modulus type (IM)**

Tensile elastic modulus: 280-350 Gpa

Tensile strength: 3,500 Mpa or higher

d) **Standard elastic modulus type (HT)**

Tensile elastic modulus: 200-280 Gpa

Tensile strength: approximately 2,500 Mpa or higher

e) **Low elastic modulus type (LM)**

Tensile elastic modulus: 200 Gpa or lower

Tensile strength: 3,500 Mpa or lower

TABLE-1.4.4.1 showing the various properties of PAN, PITCH, RAYON Based Carbon Fibers:

PROPERTY	PAN	PITCH	RAYON
Dia (μm)	5 to 8	10 to 11	6.5
Density	1.7 to 2	2 to 2.2	1.7
Tensile modulus(G pa)	230 to 600	170 to 980	415 to 550
Tensile strength (Mpa)	1925 to 6200	2275 to 4060	2070 to 2760
CTE(x10^(-6)/°C)	-0.75 to -0.40	-1.6 to -0.9	…………
Thermal conductivity(W/mK)	20 to 80	400 to 1100	…………

Comparison with Other Structural Materials

a) Up to 75% lighter
b) Corrosion resistance
c) 3 times higher Tensile Strength
d) 2 times higher Stiffness
e) X-ray transparency
f) Low CTE (Coefficient of Thermal Expansion)
g) Chemical resistivity
h) Thermal and electrical conductivity

TABLE-1.4.4.2 CARBON FIBER VS STEEL

Material	Tensile strength (Gpa)	Tensile Modulus(Gpa)	Density(g/cc)	Specific Strength(Gpa)
Standard grade carbon fiber	3.5	230	1.75	2
High tensile steel	1.3	210	7.87	0.17

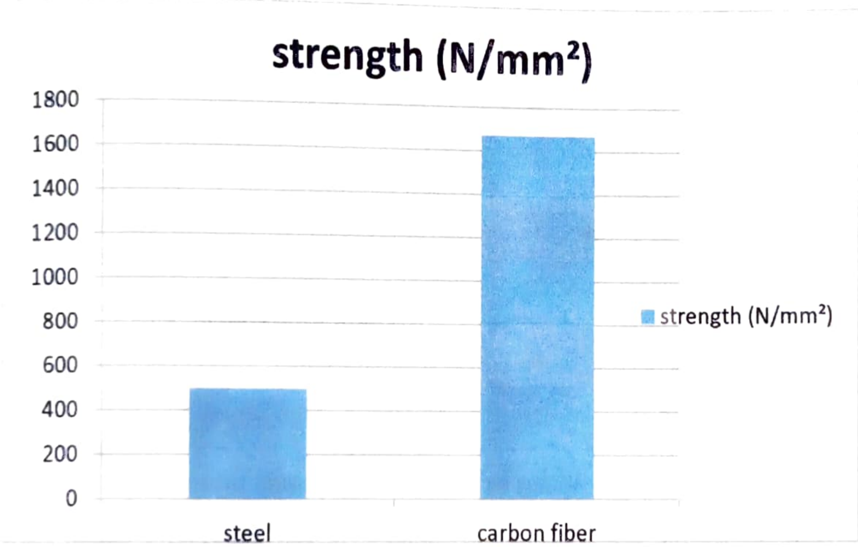


Fig - 1.4.4(a) Bar graph shows the comparison of strength between CF and steel for a given specific weight ratio.

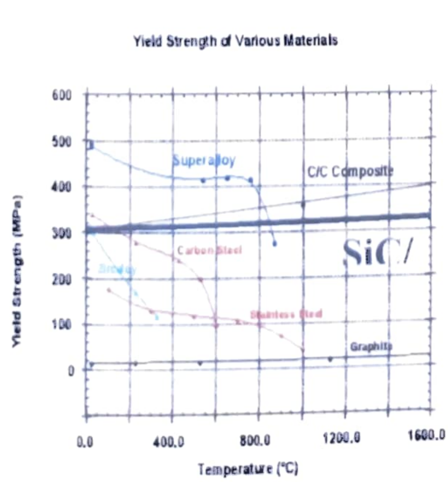


Fig - 1.4.4(b)

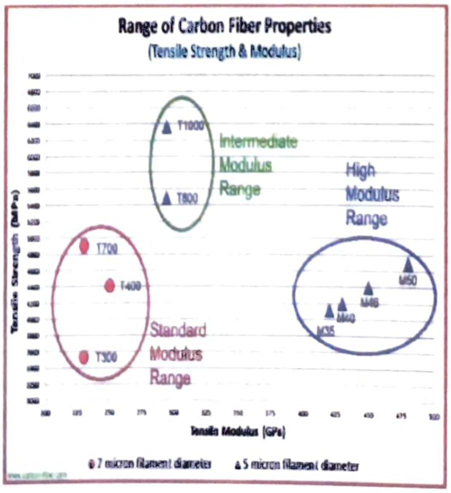


Fig - 1.4.4(c)

- It was observed from the above fig 1.4.11 the yield strength of carbon fiber composites is greater than stainless steel, graphite, sic and some zinc alloys.
- In fig 1.4.12 variation of tensile strength and modulus for different grades of carbon fiber out of which we are selected high modulus grade 12 CF for better properties and aesthetic appearance

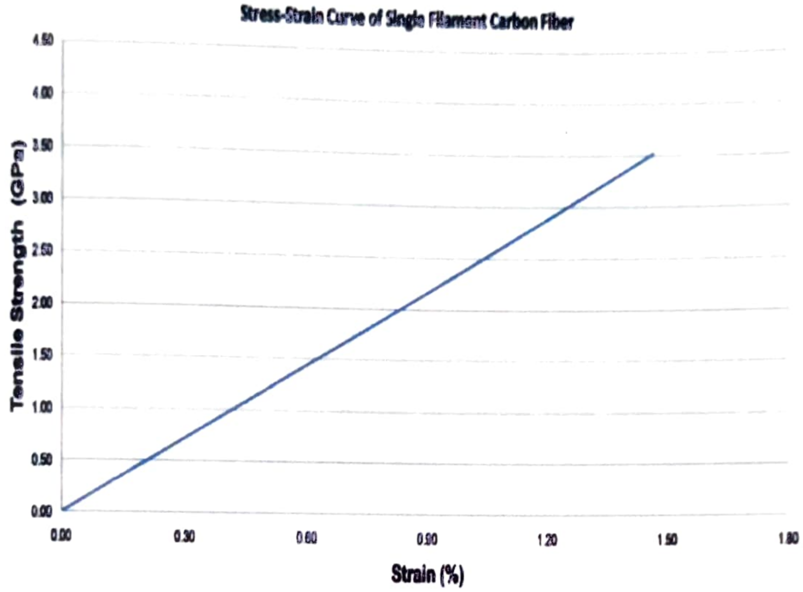
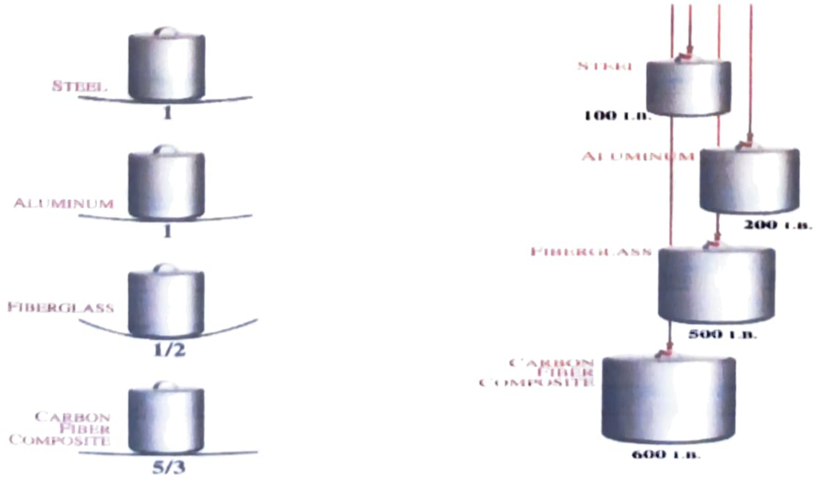


Fig - 1.4.4(d) Graph showing variation of tensile strength of single filament CF with respect to strain



Relative stiffness **Specific strength**

Fig - 1.4.4(e) Relative stiffness and Specific strength

From the above data indicated in the figure we concluded that the relative stiffness and specific strength of CF composites are high compared to conventional structural materials

1.4.5 PROPERTIES OF CARBON FIBERS

a) High strength

b) High stiffness

c) Withstand temperatures to >2500°C

d) High strength/weight ratio

e) Tensile moduli range from 28GPa to 690GPa

f) **Rigidity:** Carbon fiber is very rigid Rigidity or stiffness of a material is measured by its young modulus and measures how much a material deflects under stress. Carbon fiber reinforced plastic is over 4 times stiffer than glass reinforced plastic material.

g) **Fatigue resistance:** Resistance to fatigue in carbon fiber composites is good. Damage in tensile fatigue is seen as reduction in stiffness with larger numbers of stress cycles, (unless the temperature is high).

h) **Tensile strength:** Tensile strength or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, or failing.

i) **Thermal conductivity:** Carbon fiber is high thermal conductivity. Thermal conductivity is the quantity of heat transmitted through a unit thickness, in a direction normal to a surface of unit area, because of a unit temperature gradient, under steady conditions. In other words it's a measure of how easily heat flows through a material.

j) **Thermal expansion:** Carbon fiber is less thermal expansion. This is a measure of how much a material expands and contracts when the temperature goes up or down.

k) **Electrically conductivity:** Carbon fiber conductivity can facilitate Galvanic Corrosion in fittings. Careful installation can reduce this problem.

l) **Brittleness**: Carbon fiber is high brittleness due to high percentage of carbon content.

m) **Density:** Carbon fiber is high stiffness and strength at low density. Specific gravity of fiber is around 1.8

1.4.6. PRODUCTION OF CARBON FIBERS BASED ON TYPE OF PRECURSOR:

The precursor selected for the application should be able to produce large amounts of carbon fibers ease of manufacturing and cost effective. Therefore, based on these parameters four types of precursors are widely used and popular. They are:

1) **Acrylic precursors:**

These are used by the industrial manufacturers and it contains acrylonitrile monomer > 85%. The most widely used acrylic precursor to produce carbon fibers is PAN (Poly acrylo nitrile)

2) **Cellulosic precursors**

These precursors contain 44.4 % carbon. The reaction is more complicated than mere dehydration, and the carbon yield is only approximately 25-30 %.

3) **Pitch based precursors**

The carbon fibers yield from pitch based precursors is of 85%. The carbon fibers produced from this precursor have more graphitic structure and can possess high modulus .But , pitch based carbon fibers are having less compressive and transverse strengths compared to PAN based carbon fibers.

4) **Other forms of precursors**

The other forms precursors used to manufactures carbon fibers are vinylidene chloride and phenolic resins .These are not found to be commercially available because of having some limitations.

Production of Carbon Fiber from PAN

1) Heating/Stretching
2) Pre-carbonization
3) Carbonization
4) Surface Treatment

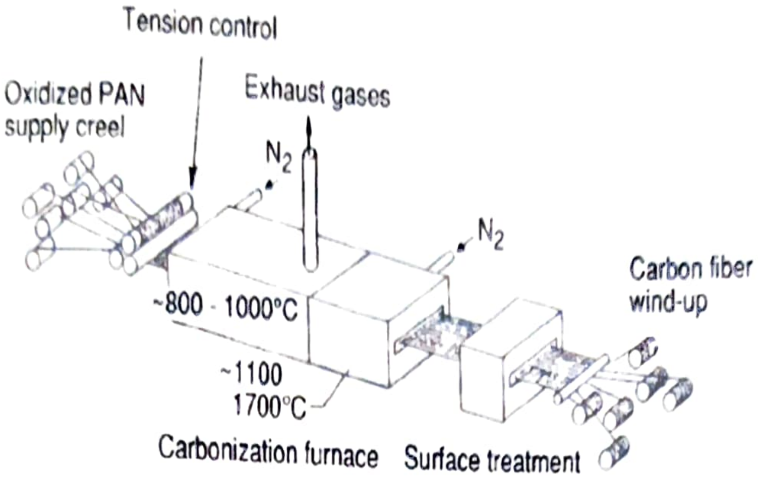


FIG 1.4.6(a) Figure showing production of carbon fiber from PAN

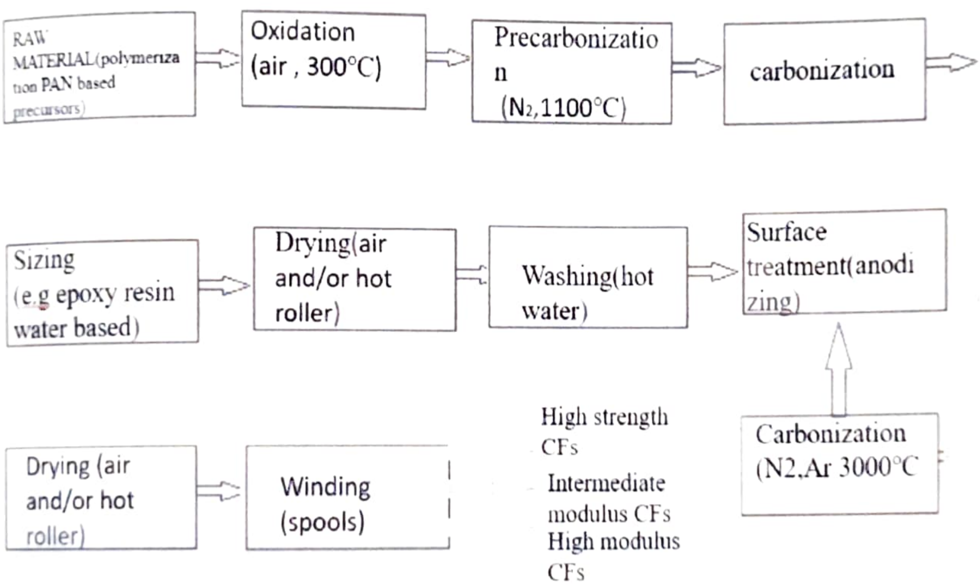


FIG 1.4.6(b) Figure showing Procedure of producing carbon fiber

1.4.7. FABRICATION METHODS OF CARBON FIBERS

The raw material used to make carbon fiber is called the precursor. About 90% of the carbon fibers produced are made from polyacrylonitrile (PAN). The remaining 10% are made from rayon or petroleum pitch. All of these materials are organic polymers, characterized by long strings of molecules bound together by carbon atoms. The exact composition of each precursor varies from one company to another and is generally considered a trade secret.

During the manufacturing process, a variety of gases and liquids are used. Some of these materials are designed to react with the fiber to achieve a specific effect. Other materials are designed not to react or to prevent certain reactions with the fiber.

1. **STABILIZING:** In this process the fibers are heated in air to about 390-590° F (200-300° C) for 30-120 minutes. This causes the fibers to pick up oxygen molecules from the air and rearrange their atomic bonding pattern. The stabilizing chemical reactions are complex and involve several steps, some of which occur simultaneously.

2. **PRE CARBONIZATION:** Once the fibers are stabilized, they are heated to a temperature of about 1830-5500° F for several minutes in a furnace filled with a gas mixture that does not contain oxygen. The lack of oxygen prevents the fibers from burning in the very high temperatures. The gas pressure inside the furnace is kept higher than the outside air pressure and the points where the fibers enter and exit the furnace are sealed to keep oxygen from entering. As the fibers are heated, they begin to lose their non-carbon atoms, plus a few carbon atoms, in the form of various gases including water vapour, ammonia, carbon monoxide, carbon dioxide, hydrogen, nitrogen, and others

3. **CARBONIZING:** In some processes, two furnaces operating at two different temperatures are used to better control the rate of heating during carbonization. In carbonization slower heating rate 1100°C – 2800°C only small diatomic molecules like H_2, N_2 are expelled faster heating rate. Final C content after carbonization 80% to >99% it is based on Temperature dependent .Overall Yield in carbonization 40-45%

4. **TREATING THE SURFACE:** After carbonizing, the fibers have a surface that does not bond well with the epoxies and other materials used in composite materials. To give the fibers better bonding properties, their surface is slightly oxidized. The addition of oxygen atoms to the surface provides better chemical bonding properties and also etches and roughens the surface for better mechanical bonding properties. The surface treatment process must be carefully controlled to avoid forming tiny surface defects, such as pits, which could cause fiber failure.

5. **SIZING**: After the surface treatment, the fibers are coated to protect them from damage during winding or weaving. This process is called sizing. Coating materials are

chosen to be compatible with the adhesive used to form composite materials. Typical coating materials include epoxy, polyester, nylon, urethane, and others.

1.4.8. ADVANTAGES OF CARBON COMPOSITES:

a) Weight saving.
b) High degree of freedom in form, material and process.
c) Easy to color.
d) Translucent.
e) High degree of integration of functions possible.
f) Strength, stiffness thermal and electrical resistance can be designed.
g) Low total maintenance costs.
h) Water and chemically resistant.
i) Use of durable materials possible.

1.4.9. DISADVANTAGES:

a) High material costs.
b) Sophisticated computational methods sometimes required.
c) Color and gloss preservation not always predictable.
d) Relatively limited knowledge on structural behavior of details and connection methods.
e) Stiffness and failure behavior can be undesirable; sensitive to temperature, fire and lightning strike.
f) Sensitive to UV light.
g) Recycling not yet well developed.
h) Sometimes capital intensive production methods (e.g. automated methods).

Chapter-2
LITERATURE REVIEW

CHAPTER - 2
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter deals with an extensive literature survey on the present research work. This literature search provides a background and guide for the entire study. Many authors gave different ideas related to their works on carbon fiber reinforced composite materials. The different papers reviewed are listed below.

Huibin Chang, Jeffrey Luo, H. Clive Liu, Songlin Zhang et al 2019 [1] worked on producing carbon fibers from polyacrylonitrile (PAN) fibers containing cellulose nanocrystals (CNC). In this study polyacrylonitrile fibers containing 40 wt% cellulose nanocrystals are successfully stabilized and carbonized to make carbon fibers. This study shows that biphasic carbon fibers can be made from the PAN/CNC system.

Wan-qian Li, Ji-Hua Zhu, Pi-yu Chen, Feng Xing, Dawang Li, MeiniSu et al 2019 [2] worked on developing a new cement-based material introducing chopped carbon fiber. The flexural performance of carbon fiber reinforced cementitious matrix plates with chopped carbon fibers was explored in this study. This study concludes that the carbon-fiber-reinforced cementitious matrix (C-FRCM)

containing a cement-based matrix and embedded carbon-fiber mesh is an alternative solution to FRP epoxy resin, addressing cost, durability, and reversibility issues. The results also show that the carbon fiber mesh is effective in strengthening the carbon-fiber-reinforced cementitious matrix.

MareenZöllner, Holger Lieberwirth, Philipp Kempkes, Ansgar Fendel et al 2018 [3] studied about Thermal resistance of carbon fibres/carbon fibre reinforced polymers under stationary atmospheric conditions and varying exposure times. In this study the influence of the temperature on CFRP under thermal treatment are examined. The results show that different sizes led to considerably different times of decomposition and decomposition start temperatures.

Muhannad Al Aiti, Dieter Jehnichen, Dieter Fischer, Harald Brünig, Gert Heinrich et al 2018 [4] studied on the morphology and structure formation of carbon fibers from polymer precursor systems. Throughout this review, they identify areas that require future research and development regarding the morphology and structure formation of CFs from emerging precursor systems.

Dalsu Choi, Hyun-Sig Kil, Sungho Lee et al 2018 [5] worked on fabrication of low-cost carbon fibers using economical precursors and advanced processing technologies. In this article, the authors reviewed series of previous achievements which incorporated low-cost precursors into CFs fabrication including novel acrylic polymers, polyethylene (PE), lignin and pitch. In this study prospective processing technologies which might be beneficial for reducing manufacturing cost of CFs are reviewed.

Asma A. Eddib and D.D.L. Chung et al 2019 [6] studied about the electric permittivity of carbon fibers. In this study the measurement is conducted along the fiber axis by capacitance measurement at 2 kHz using an LCR meter, with a dielectric film between specimen and electrode. It is observed that defects associated with a low degree of graphitization hinder conduction more than polarization.

M. Endo, Y.A. Kim, T. Hayashi, K. Nishimura, T. Matusita, K. Miyashita, M.S. Dresselhaus et al 2001 [7] discussed about the basic properties and applications of PAN carbon fibers. In this study the PAN carbon fibers obtained by carbonization were evaluated in terms of their microstructural development with heat treatment temperature (HTT), physical properties of a single fiber and of the bulk state. It is observed that PAN based carbon fibers have high tensile strength and high elastic modulus.

Mohit Sood, Gaurav Dwivedi et al 2017 [8] studied about the effect of fiber treatment on flexural properties of carbon fiber reinforced composites. This paper reviews how fiber treatments effected the flexural strength and modulus of natural fiber composites during 2000–2016. It is observed that the chemical treatments improved fiber interface bonding with matrix and impart more strengths to composites.

Fang Liu, Shiqiang Deng, Jianing Zhang et al 2017 [9] researched about mechanical properties of epoxy and its carbon fiber composites modified by nanoparticles. In this work, the compressive property of epoxies modified by different types of nanoparticles was firstly investigated for the following study on the compressive property of carbon fiber reinforced epoxy composites. The compressive and flexural results showed that rigid nanoparticles have evident strengthening effects on the compression and flexural responses of the carbon fiber composite laminates fabricated from fabrics.

R.Masilamani, N.V. Dhandapani, et al 2017 [10] studied about Usage of Carbon Fiber Reinforced Plastics in Automobiles. In this study it is discuss about in detail with the benefits of usage of CFRP in each parts of car. And there is detailed review about the properties which made CFRP suitable to make these parts. CFRP has extremely low shrinkage and expansion against heat which is a strong benefit for automobiles body.

Erich Fitzer, AntoniosGkogkidis, Michael Heine et al 1984 [11] studied about the carbon fibres and their composites. They observed that carbon fibre composites must be considered not only as high temperature materials-as in combination with a carbon matrix-but more often in combination with polymers as new optimum low-weight/high-stiffness structural materials for general purposes. Carbon fibre reinforced polymers plays a dominant role in aerospace developments.

Dany Arnoldo Hernandeza, Carlos Alberto Soufenb , Marcelo OrnaghiOrlandia et al 2017 [12] studied about Morphological characteristics analysis of before and after tensile tests were studied using scanning electron microscopy (SEM) technique to follow the failure evolution on carbon fiber reinforced polymer (CFRP) and epoxy resins. They were observed that Micrograph analysis of CFRP plate before tensile test shows some intrinsic manufacturing defects, which can influence the mechanical properties of the material and after tensile test shows that cracks propagation starts in manufacturing defects, which lead the carbon fiber to be pulled out instead of breaking.

Panimayam, Chinnadurai, R. Anuradha et al 2017 [13] studied about the assets of carbon fibre reinforced polymers of which have high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. Reinforced concrete columns have also an important function in the structural concept of many structures. But They observed that these columns are helpless to loads due to impact, explosion and also corrosion of steel reinforcement.

Ronald Hillock, Shain Howard et al 2014 [14] studied about utility of Carbon Fiber Implants in Orthopedic Surgery. The tensile strength of CF is greater than comparable metallic materials. They observed that there is a various surgical application of CF are defined, from biocompatibility within the human body and wound healing products to numerous surgical implantations.

2.2 SCOPE OF THE WORK :

Based on the literature work, we have identified that, few authors as conducted experimental tests to use CF more effectively in aggressive environmental conditions subjected to high temperature. Few of them considered different types of fibres and heat treatment processes to check the behavior of CF Reinforced composite degradation mechanisms. Few researchers used CF as reinforcement in civil constructions and implements in orthopedic surgery and achieved good results in terms of tensile strength. In this work, an attempt is made to use CF more effectively in aerospace, industrial and automotive sectors for further improvement of mechanical and damping properties. Hence Sic, rubber powder, graphite powder and barium sulphate inclusions are consider for the improvement of mechanical and damping properties of CF rein forced composite material.

Chapter-3

FABRICATION OF CARBON FIBER REINFORCED COMPOSITES

CHAPTER - 3

FABRICATION OF CARBON FIBER REINFORCED COMPOSITES

3.1 INTRODUCTION

The materials that are used in fabrication of carbon fiber reinforced composites and the process that was followed is discussed in this chapter.

3.2 MATERIALS REQUIRED FOR FABRICATION

1. Carbon Fiber
2. Epoxy Resin
3. Silicon Carbide
4. Rubber Powder
5. Graphite Powder

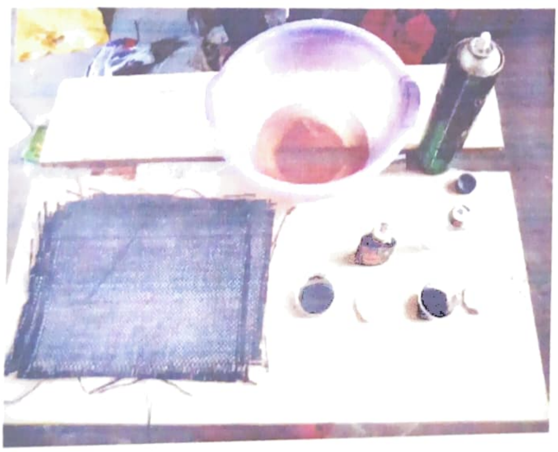


Fig 3.2 CF and ingredients before fabrication

3.2.1 EPOXY RESIN

Epoxy resins are polymeric or semi-polymeric materials whose applications are extensive and include coatings, adhesives and composite materials such as those using carbon fiber and fiber glass reinforcements. In general epoxies are known for their excellent adhesion, chemical and heat resistance, good-to-excellent mechanical properties and very good electrical insulating properties.

3.2.2 HARDENER

Hardener is high viscous liquid material mixed with resin in suitable proportion during the process of preparation of composites which helps in the solidification of the wet, smooth composite. It is used to harden the smooth composite hence it is called as hardener.

3.2.3 CATALYST

Catalysts are substances that increase the rate of a reaction by providing a low energy "shortcut" from reactants to products. In some cases, reactions occur so slowly that without a catalyst, they are of little value. Nearly all reactions that occur in living cells require catalysts called enzymes -without them life would be impossible. There are two important classes of catalysts

3.2.4 SILICON CARBIDE

Silicon carbide is composed of tetrahedra of carbon and silicon atoms with strong bonds in the crystal lattice. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. Chemical purity, resistance to chemical attack at Temperature, and strength retention at high temperatures has made this material very popular. Silicon Carbide is the only chemical compound of carbon and silicon. Today the material has been developed into a high-quality technical grade ceramic with very good properties (High strength, Low thermal expansion, high thermal conductivity, high hardness, excellent thermal shock resistance, superior chemical inertness).

Fig - 3.2.4 Silicon Carbide powder

3.3 INTRODUCTION TO FABRICATION PROCESS

3.3.1 WET/HAND LAY-UP

Fibers are first put in place in the mould. The fibers can be in the form of woven, knitted, stitched or bonded fabrics. Then the resin is impregnated. The impregnation of resin is done by using rollers, brushes or a nip-roller type impregnator. The impregnation helps in forming the resin inside the fabric. The laminates fabricated by this process are then cured under standard atmospheric conditions. The materials that can be used have, in general, no restrictions. One can use combination of resins like epoxy, polyester, vinyl ester, phenolic and any fiber material.

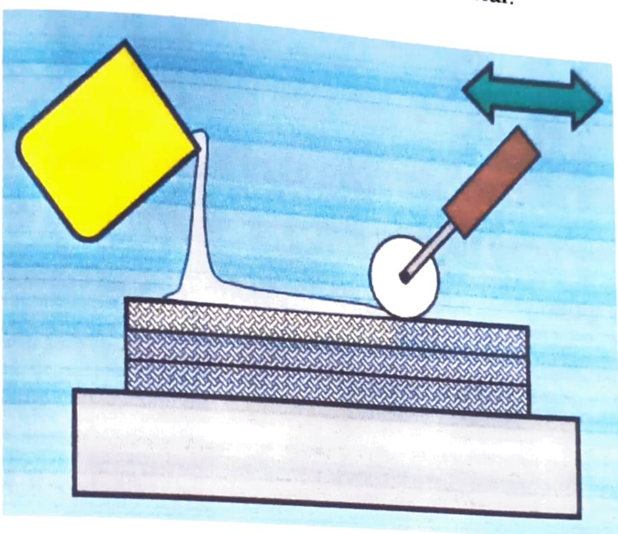


Fig - 3.3.1 HAND LAY UP METHOD

ADVANTAGES OF HAND LAY-UP

- The process results in low cost tooling with the use of room- temperature cure resins
- The process is simple to use.
- Any combination of fibers and matrix materials are used.
- Higher fiber contents and longer fiber as compared to other processes.

DISADVANTAGES

- Since the process is worked by hands, there are safety and hazard considerations.
- The resin needs to be less viscous so that it can be easily worked by hands
- The quality of the final product is highly skilled dependent of the labour
- Uniform distribution of resin inside the fabric is not possible. It leads to voids in the laminates.
- Possibility of diluting the contents.

3.3.2 PULTRUSION

It is a continuous process in which composites in the form of fibers and fabrics are pulled through a bath of liquid resin. Then the fibers wetted with resin are pulled through a heated die. The die plays important roles like completing the impregnation and controlling the resin. Further, the material is cured to its final shape. The die shape used in this process is nothing the replica of the final product.

3.3.3 VACUUM BAGGING

This is basically an extension of the wet lay-up process described above where pressure is applied to the laminate once laid up in order to improve its consolidation. This is achieved by sealing a plastic film over the wet laid-up Laminate and onto the tool. The air under the bag is extracted by a vacuum pump und thus up to one atmosphere of pressure can be applied to the laminate to consolidate it.

3.3.4 CENTRIFUGAL CASTING

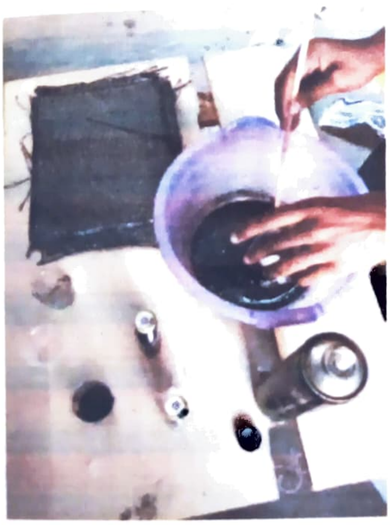
In this process the chopped fibers and the resin is sent under pressure to the cylindrical moulding. The moulding is rotating Due to centrifugal action, the mixture of resin and chopped fibers get deposited on wall of the moulding. Thus, the mixture gets the final form of the product.

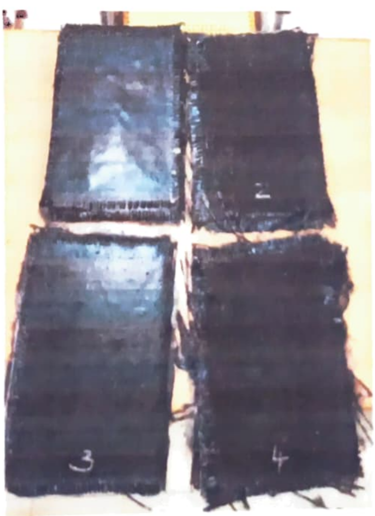
3.3.5 FILAMENT WINDING

This process is used in the fabrication of components or structures made with flexible fibers. This process is primarily used for hollow, generally circular or oval sectioned components Fiber laws are passed through a resin bath before being wound onto a mandrel in a variety of orientations, controlled by the fiber feeding mechanism, and rate of rotation of the mandrel. The wound component is then cured in an oven or autoclave. It can use resins like epoxy, polyester, vinyl ester and phenolic along with any fiber.

3.4 FABRICATION OF COMPSITE MATERIALS WITH HAND LAY-UP TECHNIQUE

This chapter describes about the method of fabrication and various tests that are to be conducted. Hand lay-up technique is the simplest and oldest open molding method of composite fabrication process. In this work, Silicon carbide, rubber powder of different weight percentages is mixed with epoxy resin, hardener and fiber reinforcements. The thickness of the composite sheet to be fabricated is controlled by the layers placed on the mould. After the preparation of composite sheets, the work pieces are cured for 24 to 48 hrs. So that work pieces will get hard. After this, the specimens were cut according to ASTM standards using cutting machine as shown in the figure.





(a) (b)

Fig - 3.4.1 (a-b) Fabrication by Hand Lay-Up method

Table - 3.4.2 showing the weight % of materials selected

Sheet Number	Fibre (%)	Epoxy resin (%)	Rubber powder (%)	Graphite (%)	Sic (%)	Barium Sulphate (%)	Accelerator and Hardener (%)
CF 1	27	65.8	1	0.35	0.7	0.9	4.25
CF 2	27	66.8	0.8	0.35	0.6	0.9	3.55
CF 3	27	67.5	0.6	0.35	0.5	0.9	3.15
CF 4	27	67	0.5	0.35	0.4	0.9	3.85

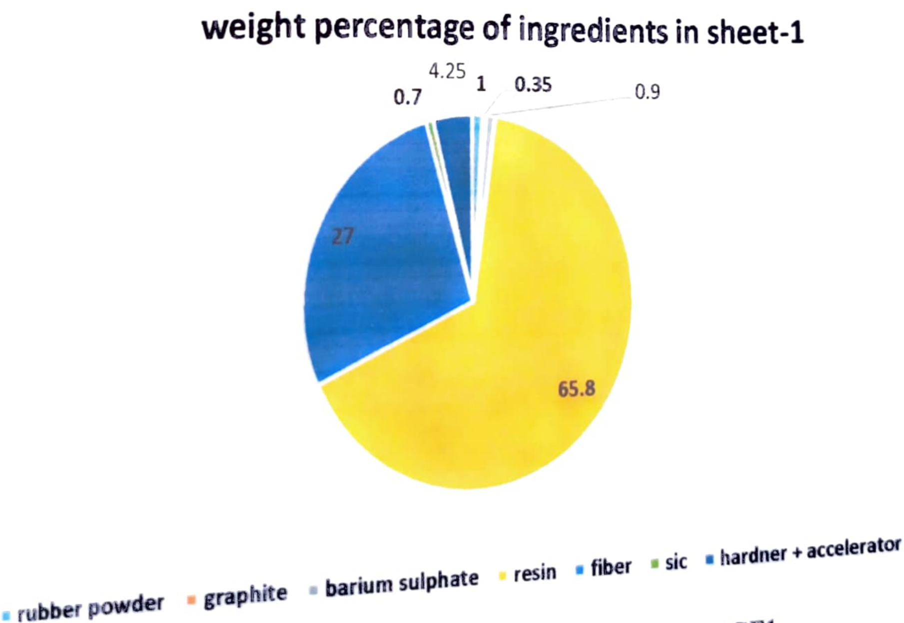


Fig - 3.4.3 PIE Diagram Showing Ingredients of CF1

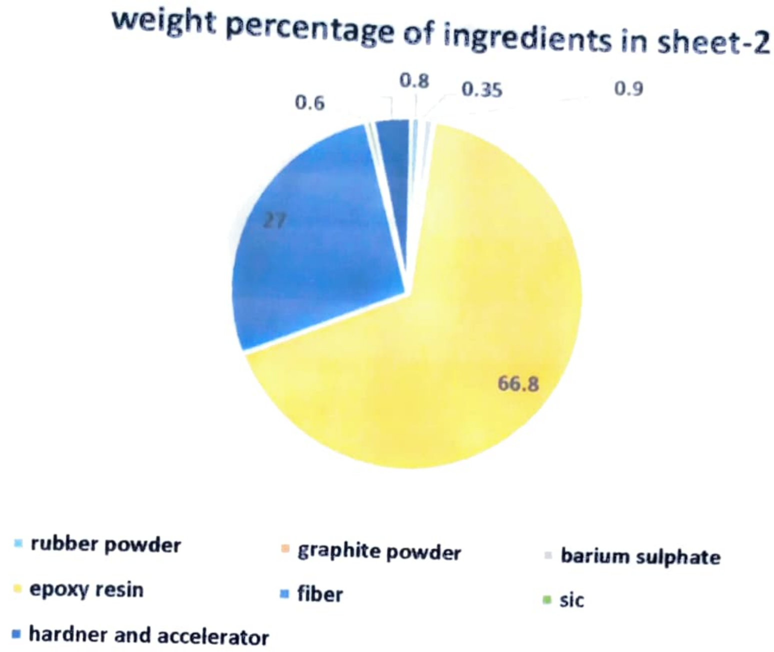


Fig - 3.4.4 PIE Diagram Showing Ingredients of CF 2

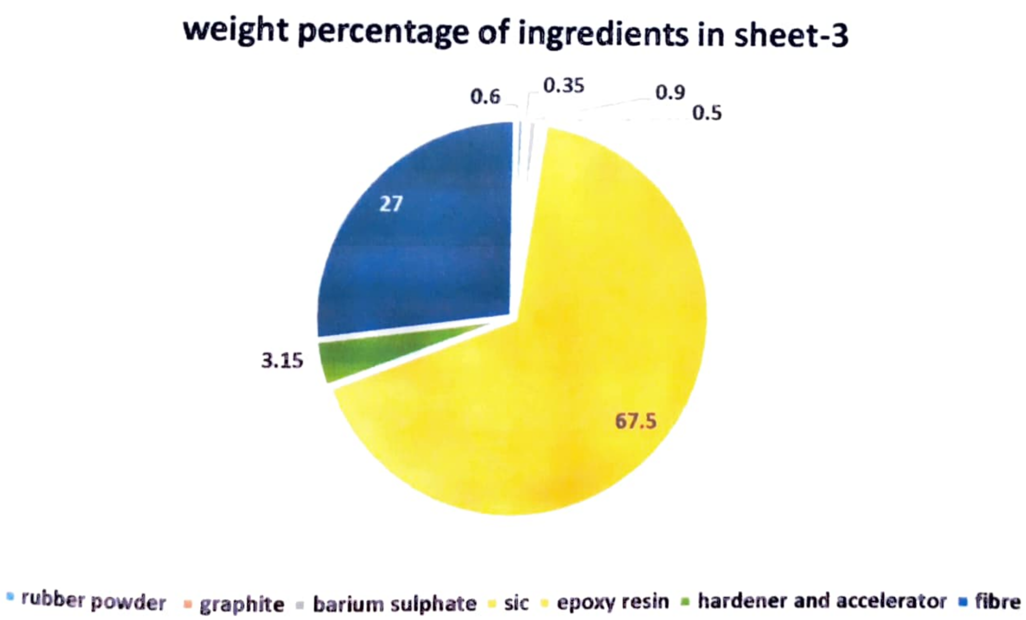


Fig - 3.4.5 PIE Diagram Showing Ingredients of CF 3

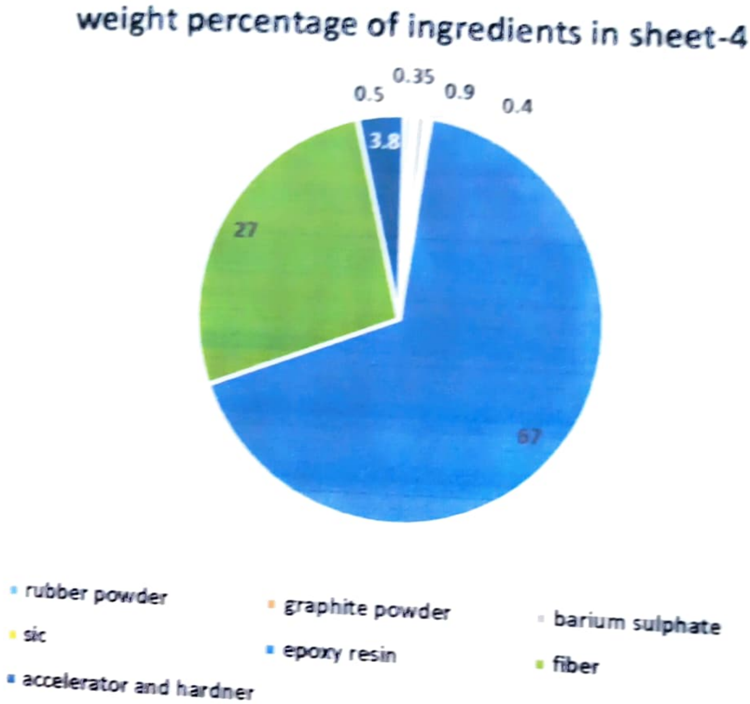


FIG-3.4.6 PIE Diagram Showing Ingredients of CF 4

CHAPTER - 4

TENSILE BEHAVIOR OF CFRP COMPOSITES

CHAPTER - 4

TENSILE BEHAVIOR OF CFRP COMPOSITES

4.1 INTRODUCTION

In this chapter the tensile behavior of different samples of CFRP composites are presented. The Tensile test was carried out on computerized UTM, as per ASTM standards. The four specimens were subjected to tensile test and their values were reported.

4.2 EQUIPMENT FOR TENSILE TESTING

A Computerized UTM Test is used to find the tensile properties of the composites. Operation of the universal testing machine is by hydraulic transmission of load from the test specimen to separately housed load indicator. The system is ideal since it replaces transmission of load: through levers and knife edges which are prone to wear and damage due to shock on rupture of test pieces. Load is applied by a hydrostatically lubricated ram. Main cylinder pressure is transmitted to the cylinder of the pendulum dynamometer system housed in the control panel. The cylinder of the dynamometer is also of self-lubricating design. The load transmitted to the cylinder of the dynamometer is transferred through a leverage to the pendulum. Displacement of the pendulum actuates the rack and pinion mechanism which operates the load indicator pointer and the autographic recorder. The deflection of the pendulum represents the absolute load applied on the test specimen.

Fig - 4.2 Tensile testing machine

4.3 METHOD OF TENSILE TESTING

Tensile test is the basic important test to evaluate the strength of any material. The machine is equipped with advanced load cell technology for faster testing and reduction of inertia errors. Tensile test is performed based on ASTM D638-02a standard. The specimens before test and after test are indicated below.

TENSILE TEST SPECIMEN (ASTM D 638 - 2A)

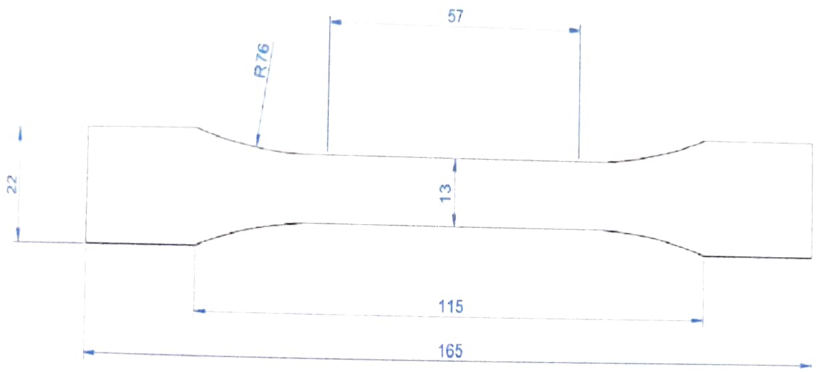


Fig - 4.3 Tensile test specimen with ASTM standards in CAD

Initially, the specimens are fixed between two clamping jaws firmly and loaded gradually with incremental load until failure takes place. The values of deformation against each load value are noted and tabulated. The breaking load for each specimen is noted and ultimate tensile strength values of all the samples with varying inclusions of (wt% of Sic and rubber powder) are observed for all the four specimens.

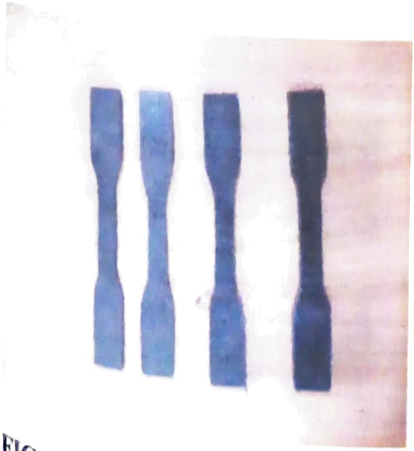


FIG-4.3.1 Tensile Test Specimens before failure

FIG-4.3.2 Tensile test specimen after failure

4.4 RESULTS OF TENSILE TEST:

Tensile test is the basic important test to test the specimen and evaluate its mechanical properties to assess the performance of composite material required for particular applications. In this test four specimen CF1,CF2,CF3 and CF4 are loaded in the compurterized universal testing machine and the deformation and stress values are observed with incremental of gradual application of load on the specimens. The load at break and corresponding tensile strength values are given in table 4.4

The tensile test results are tabulated below

Table 4.4

S No.	Material	Tensile strength (N/mm^{2})	Load at break (KN)
1	CF 1	164.28	8.230
2	CF 2	158.67	7.980
3	CF 3	151.56	7.340
4	CF 4	149.84	7.015

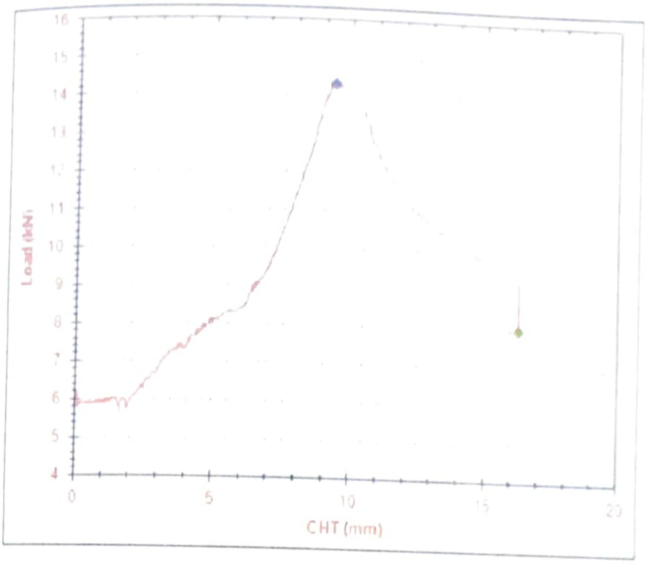


Fig - 4.4 Graph between load and CHT

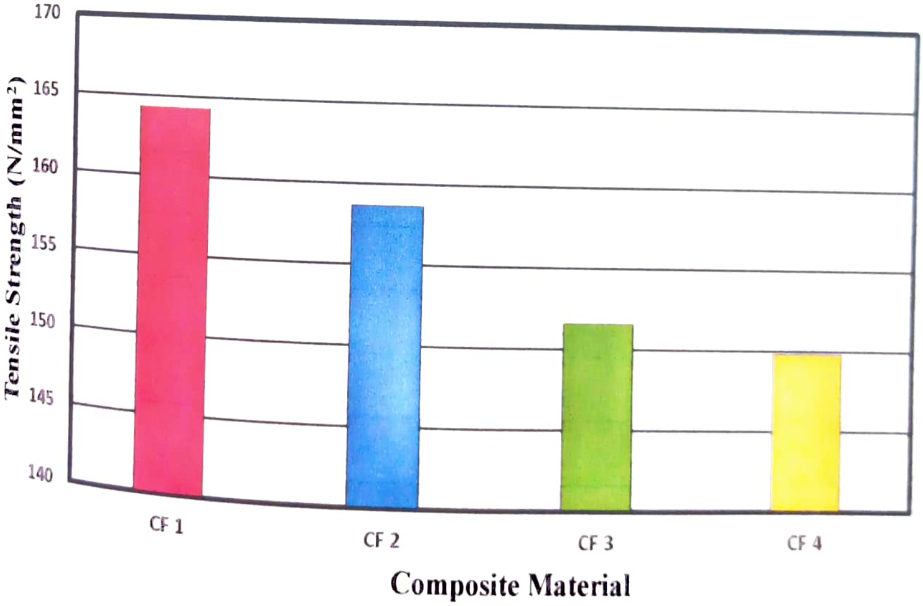


Fig - 4.4.1 Bar graph showing the tensile strength of carbon fiber specimens

4.5 ANALYSIS OF TENSILE TEST RESULTS

Based on the observations from Tensile test, carbon fiber reinforced composite material with selected ingredients can sustain more load with standing capacity and forms good tensile strength value of (164.28 N/mm^2) compared to remaining formulations of materials. The main reason to have better properties for the sample specimen CF-1 is the selection of ingredients and SIC present in the sample specimen. The load carried by the specimen is initially transmitted to the fiber and remaining to the ingredients. The higher the SIC content present in the sample results good tensile strength properties in the specimen. For the present configuration of material selection, SIC content of (0.7 wt%) exhibits good mechanical properties. The bonding behavior of carbon fibre reinforced carbon CF-1 is also greatly improved compared to remaining formulations. Hence CF-1 possess good mechanical properties shown in Fig 4.4.1 bar graph.

CHAPTER – 5

FLEXURAL BEHAVIOUR OF CFRP COMPOSITES

CHAPTER – 5

FLEXURAL BEHAVIOUR OF CFRP COMPOSITES

5.1 INTRODUCTION

In this chapter the flexural behavior of different samples of Carbon fiber reinforced plastics with different compositions is presented. The flexural test was carried out on computerized UTM as per the ASTM standards. The test specimens are prepared as per ASTM D 790125321275 mm. The four specimens were subjected to flexural test and their values were reported.

5.2 EQUIPMENT FOR FLEXURAL TESTING

A 10-ton capacity computerized UTM was used for conducting flexural test. The instrument is equipped with integrated computer compatible software in order to display various graphical results. And a special three-point loading attachment is provided for conducting flexural test.

Fig - 5.2 Flexural Testing Apparatus

5.3 METHODS OF FLEXURAL TESTING

There are three basic methods which cover the determination of flexural properties of the polymer.

Method 1: It is basically a three-point loading, utilizing center loading on a simply supported beam. A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose at the center. The maximum axial fiber stress occurs on a line under the loading nose.

Method 2: In this method a four-point loading system is utilized. Two load points equally spaced from their adjacent supporting points, with a distance between loading points equal to one third of the support span. In this test, the bar lies on two points each at an equivalent distance from the adjacent support points.

Either method can be used for conducting the experiment. Method 1 is used for materials that break at relatively at low loads. Method 2 is used particularly for those materials that undergo large deflections during testing. Standard test method ASTM D790, for flexural properties of reinforced polymer composites has been used to test the composites.

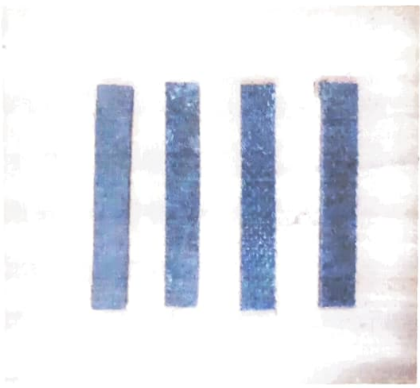


FIG-5.3.1 Flexural test Specimen

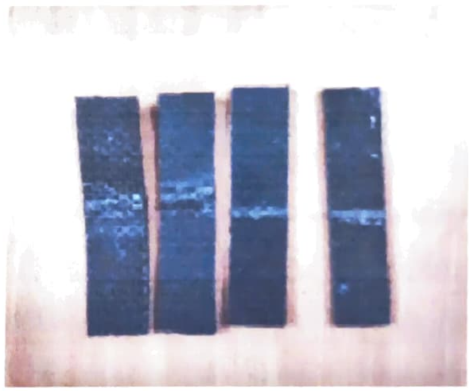


FIG-5.3.2 Specimen After Test

5.4 RESULTS OF FLEXURAL TEST

The flexural test results are tabulated below

S No.	Material	Flexural load (kg)	Flexural strength (kg/mm^2)
1	CF 1	63.6	202.8
2	CF 2	53.3	176.41
3	CF 3	42.1	134.76
4	CF 4	72.1	213.69

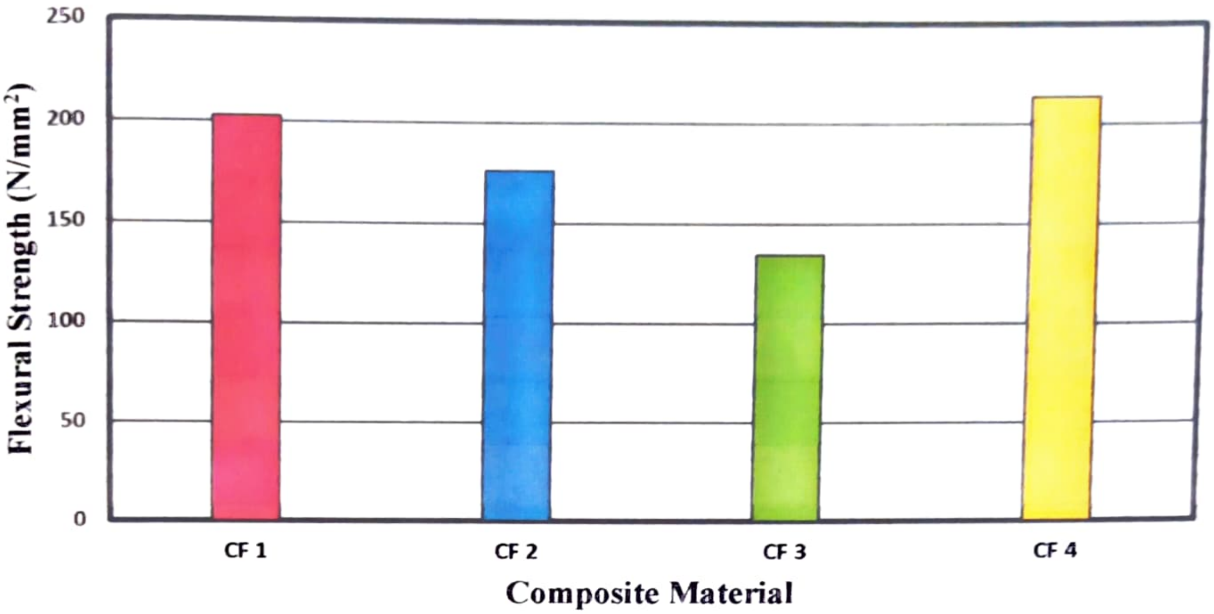


FIG-5.4 Bar graph showing the flexural strength of the carbon fiber specimens

5.5 ANALYSIS OF FLEXURAL TEST RESULTS

Based on the observations from Flexural test, carbon fiber reinforced composite material with selected ingredients can sustain more Flexural load with standing capacity and forms good flexural strength value of (213.69 Kg/mm^2) compared to remaining formulations of materials. The main reason to have better properties for the sample specimen CF-4 is the selection of ingredients and SIC present in the sample specimen. The load carried by the specimen is initially transmitted to the fiber and remaining to the ingredients. The perfect combination of SIC and other ingredients content present in the sample results good flexural strength properties in the specimen. For the present configuration of material selection, SIC content of (0.4 wt%) exhibits good mechanical properties. The flexural behavior of carbon fibre reinforced carbon CF-4 is also greatly improved compared to remaining formulations. Hence CF-4 possess good mechanical properties shown in Fig 5.4 bar graph.

CHAPTER - 6

HARDNESS OF CFRP COMPOSITES

CHAPTER - 6

HARDNESS OF CFRP COMPOSITES

6.1 INTRODUCTION

In this chapter, hardness of different samples of CFRP composites are presented. Hardness test is conducted as per ASTM D2240 standards specimen cut into 30x30mm. The ability of material to resist indentation or penetration is called hardness.

6.2 EQUIPMENT FOR HARDNESS TESTING

Brinell hardness testing machine was used to find the hardness of CFRP composites. The Brinell hardness testing machine is shown below. The brinell test consists of indenting the surface of the composite material by a hardened steel ball under a load.

Fig - 6.2 Hardness Testing Machine

6.3 METHOD FOR HARDNESS TESTING

The load is applied by a lever system and the specimen is placed on stage with its ground force upwards. The height of the specimen can be raised by hand wheel so that the specimen is brought into contact with the indenter which is forced into the specimen by the specified load. The formulation of brinell hardness number can be obtained from the relation.

The time of loading the indentation is important and it should allow equilibrium to be attained. The time of loading is 30 seconds for non-ferrous materials. The brinell test should be performed on smooth flat specimen from whom dirt and scale have been cleaned. The brinell test is simple to conduct and hardness number may be correlated with ultimate tensile strength.

Brinell hardness number (BHN) = $\frac{2F}{\pi D(D-\sqrt{(D^2-d^2)})}$

Experimentation specifications of Brinell's Hardness Tester

Ball Diameter-D (mm)	Load-F (kg)	Material
10	250	Plastics

6.4 RESULTS OF BRINELL HARDNESS TEST

The Brinell hardness test results are tabulated below

S No	Material	Brinell Hardness Number (BHN)
1	CF1	25.15
2	CF2	19.05
3	CF3	19.05
4	CF4	14.87

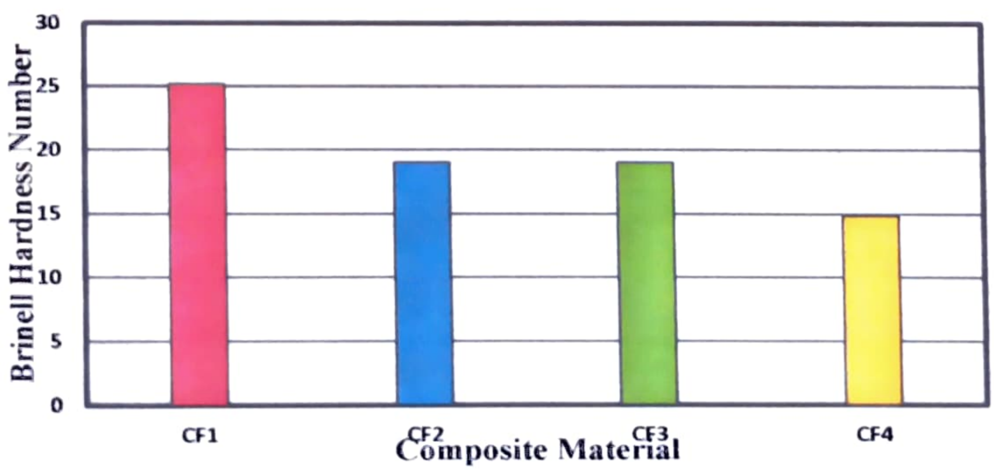


Fig-6.4 Bar graph showing Brinell hardness numbers of the carbon fiber specimens

6.5 ANALYSIS OF HARDNESS TEST RESULTS

Based on the observations from Hardness test, carbon fiber reinforced composite material with selected ingredients can sustain more indentation with standing capacity and forms good Hardness value (25.15) compared to remaining formulations of materials. The main reason to have better properties for the sample specimen CF-1 is the selection of ingredients and SIC present in the sample specimen. The indentation load carried by the specimen is initially transmitted to the fiber and remaining to the ingredients. The higher the SIC content present in the sample results good hardness properties in the specimen. For the present configuration of material selection, SIC content of (0.7 wt%) exhibits good mechanical properties. The bonding behavior of carbon fibre reinforced carbon CF-1 is also greatly improved compared to remaining formulations. Hence CF-1 possess good mechanical properties shown in Fig 6.4 bar graph.

CHAPTER - 7

IMPACT BEHAVIOUR OF CFRP COMPOSITES

CHAPTER - 7

IMPACT BEHAVIOUR OF CFRP COMPOSITES

7.1 INTRODUCTION

In this chapter the impact behavior of different samples of CFRP composites is presented. The Impact test was carried out on Charpy Load Impact testing machine as per the ASTM standards. The test specimens are prepared as per ASTM D256 (64mm × 12mm × 4mm). The four specimens were subjected to Impact test and their values were reported.

The equipment and the method for impact testing are discussed below. The analysis on the results of the experimental investigations for the impact strength various samples of carbon fibre reinforced polymer resin matrix composites of different weight ratios is presented.

7.2 EQUIPMENT FOR IMPACT TESTING

An analog load impact tester is used to find the impact strength of carbon fibre reinforced polymer resin matrix composite specimens. The equipment has working range from 0-300 with a minimum resolution of 0.2J. In this equipment the value of 1 Division is equal to 2 Joules.

Fig - 7.2 Impact testing Machine

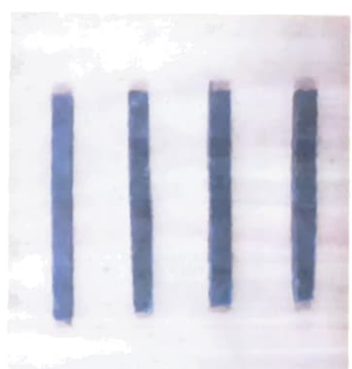


Fig - 7.2.1 Impact test specimens

7.3 METHOD OF IMPACT TESTING

Impact test is conducted as per ASTM D256 standards specimen cut in to 64 x 12.7 x 5 mm. The capacity of material to withstand such blows (impact or shock loads) without fracture is called impact strength. The material with high toughness will generally exhibit greater impact strength. Dynamic tests have been developed to establish impact resistance by using a notched specimen. The specimen is held in an anvil and is broken by a single blow of the pendulum, which falls from a fixed height (hl). After breaking the specimen, the pendulum continues to swing on the other side through a height(h2), if the weight of the hammer is W. then the energy delivered to the specimen to break it is W(hl-h2). The pendulum type impact machine is provided with scales and pointer, and scales are usually calibrated to read energy required to break the specimen in KJ.

$$\text{Impact strength} = \frac{\text{Energy in fracture}}{\text{cross-section area at notch}}$$

7.4 RESULTS OF IMPACT TEST

The impact test results are tabulated below

S No.	Material	Impact Strength (KJ/m^2)
1	CF 1	1200
2	CF 2	1025
3	CF 3	1200
4	CF 4	1250

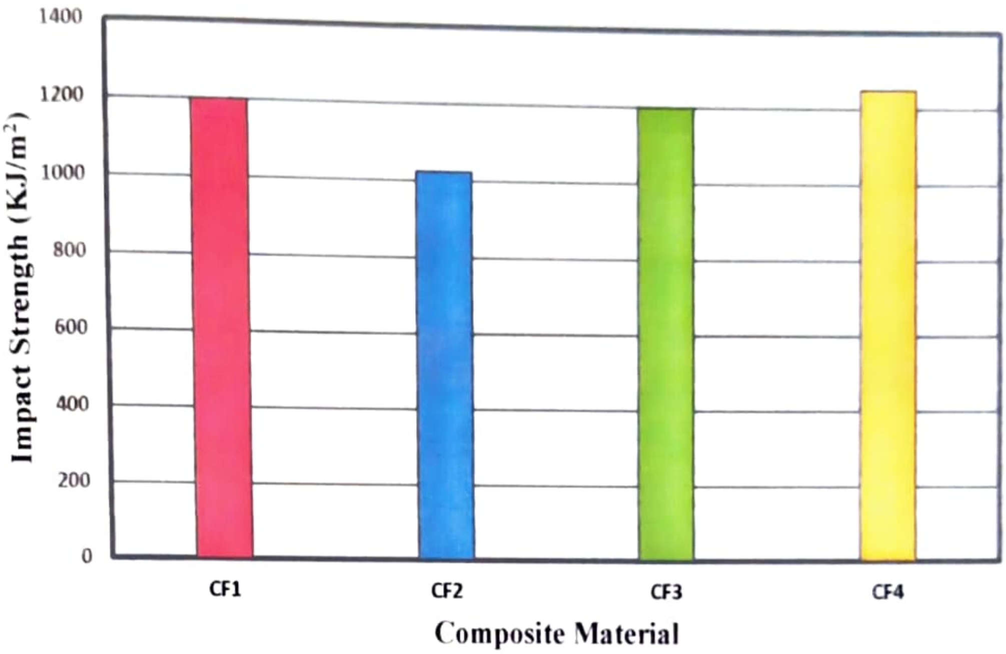


FIG-7.4 Bar graph showing the impact strength values of the carbon fiber specimens

7.5 ANALYSIS OF IMPACT TEST RESULTS

Based on the observations from Impact test, carbon fiber reinforced composite material with selected ingredients can sustain more Impact load with standing capacity and forms good impact strength value of (164.28 N/mm^2) compared to remaining formulations of materials. The main reason to have better properties for the sample specimen CF-1 is the selection of ingredients and SIC present in the sample specimen. The load carried by the specimen is initially transmitted to the fiber and remaining to the ingredients. The higher the SIC content present in the sample results good compression strength properties in the specimen. For the present configuration of material selection, SIC content of (0.7 wt%) exhibits good mechanical properties. The bonding behavior of carbon fibre reinforced carbon CF-1 is also greatly improved compared to remaining formulations. Hence CF-1 possess good mechanical properties shown in Fig 7.4 bar graph.

CHAPTER 8

COMPRESSION BEHAVIOUR OF CFRP COMPOSITES

CHAPTER 8

COMPRESSION BEHAVIOUR OF CFRP COMPOSITES

8.1 INTRODUCTION

In this chapter the Compressive behavior of CFRP composites with different compositions are presented. The compression test is carried out on Computerized Universal Testing Machine (UTM). The four specimens are subjected to Compression test and their values were reported. The results of experimental investigation for compression behavior are analyzed and compared.

8.2 EQUIPMENT FOR COMPRESSIVE TESTING

Compression test is conducted as per ASTM D3410 standards specimen cut in to 140mm x 12.7mm x 5 mm. Compressive test is conducted on computerized universal testing machine in a similar way as tensile test, but the direction of loading is reversed. Component subjected to compressive force does not deform uniformly. If the material is plastic instead of brittle, it bulges at its mid-section. In this test stress rises rapidly near the end of the test due to an increase in area of the specimen.

8.3 TEST PROCEDURE

The specimen is placed between two compressive rams parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data. The tests were conducted at room temperature of 25°C. The results are recorded for further analysis and comparison of compression strength among various samples of CFRP composites.

8.4 RESULT OF COMPRESSION TEST

Analysis of the results obtained from Compression tests of different samples of CFRP Composites are presented in this section. Compression strength of various composites are calculated from using the following relations

$$\text{Compression Strength} = \frac{\text{Maximum load(N)}}{\text{Cross sectional area}}$$

Type of Composite	Maximum Load (KN)	Load at Break (KN)	Ultimate Compressive Strength (MPa)
CF 1	600	190.94	715.13
CF 2	600	176.50	680.68
CF 3	600	161.91	642.75
CF 4	600	148.41	574.70

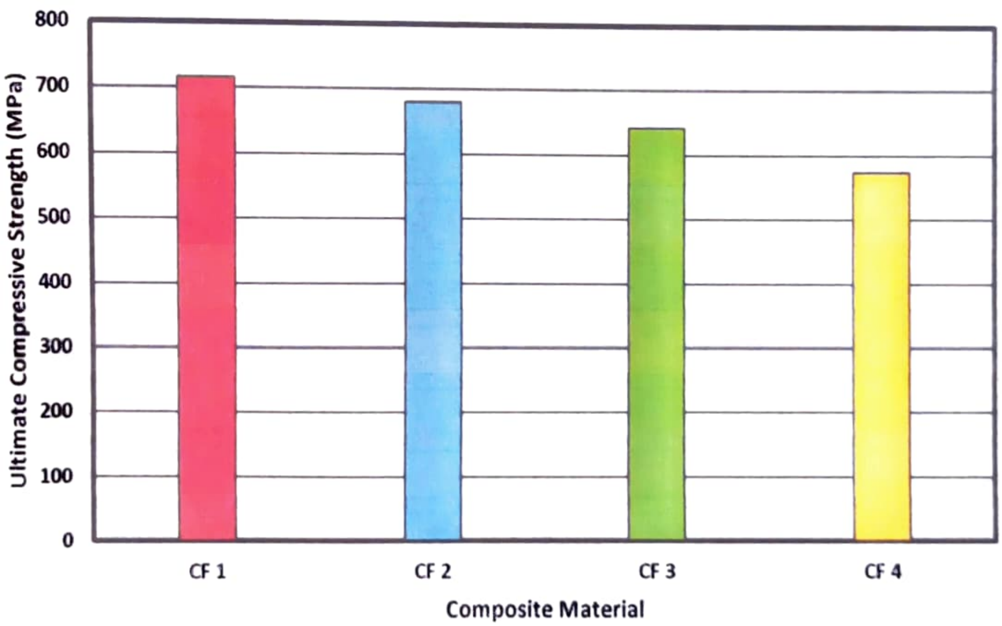


FIG-8.4 Bar graph showing the Compressive strength values of the carbon fiber specimens

8.5 ANALYSIS OF COMPRESSION TEST RESULTS

Based on the observations from Compression test, carbon fiber reinforced composite material with selected ingredients can sustain more compressive load with standing capacity and forms good compression strength value of (574.70 MPa) compared to remaining formulations of materials. The main reason to have better properties for the sample specimen CF-1 is the selection of ingredients and SIC present in the sample specimen. The load carried by the specimen is initially transmitted to the fiber and remaining to the ingredients. The higher the SIC content present in the sample results good compression strength properties in the specimen. For the present configuration of material selection, SIC content of (0.7 wt%) exhibits good mechanical properties. The bonding behavior of carbon fibre reinforced carbon CF-1 is also greatly improved compared to remaining formulations. Hence CF-1 possess good mechanical properties shown in Fig 8.4 bar graph.

CHAPTER - 9
VIBRATION ANALYSIS OF COMPOSITES

CHAPTER - 9

VIBRATION ANALYSIS OF COMPOSITES

9.1 INTRODUCTION

Natural frequencies and damping ratio of flash reinforced glass fiber epoxy composites are determined using Impact Hammer test. The samples are cut from the laminates in the form of beam of dimensions 190mm×20mm×5mm as shown below. The specimens are clamped in the bench vice in the form of cantilever beam of span 140mm.

9.2 EQUIPMENT FOR VIBRATION TESTING

The equipment used for vibration analysis using impact hammer technique are

a) Impact Hammer

b) Accelerometer

c) FFT analyzer

a) Impact Hammer

Impact hammer is an equipment which is used to excite the specimen so that the specimen will tend to vibrate at its natural frequency.

b) Accelerometer

Accelerometer is an instrument used for measuring the acceleration of a vibrating body. Accelerometer of B & K type 4507 is shown below. A sensor which is connected to the accelerometer senses the frequency of vibration of plate and coveys it to the FFT analyzer.

c) FFT Analyzer

FFT analyzer is the device which samples the input signal, computes the magnitude of sine and cosine components and displays the spectrum of these measured frequency components. FFT analyzer receives the signal from Accelerometer and is the primary device of this vibration set up

Fig - 9.2.1 Impact hammer **Fig – 9.2.2 FFT Analyzer**

9.3 PROCEDURE FOR VIBRATION TESTING

The connections of FFT analyzer, accelerometer, Impact hammer and cables to the system were done as per specifications. The accelerometer is placed near the free end of the beam to record the vibration signals. The experiment is conducted as cantilever beam in fix-free boundary conditions. The free vibration analysis is initiated by exciting the beam with impact hammer as shown in the figure. As a result, the beam starts vibrating with natural frequency. The above procedure is repeated by hitting the beam with Impact hammer four times the average output of the frequency response is recorded by FFT analyzer as shown in the figure. Impact testing for remaining specimens is conducted by repeating the above procedure.

Fig - 9.3 Working of FFT Analyzer

9.4 CALCULATION OF DAMPING RATIOS

Damping ratio is calculated by half wave bandwidth technique by calculating Q factor Q factor is calculated by taking reference bandwidth of 6dB below the peak value.

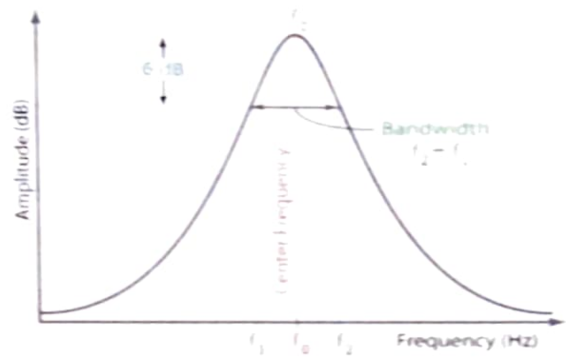


Fig - 9.4 Graph showing f_1 and f_2 values

Q factor is given by

$$Q = \frac{f_n}{f_1 - f_2}$$

Where

f_n = Natural frequency of the specimen in Hz

f_1 = First natural frequency corresponding to 6 dB line in Hz

f_2 = Second natural frequency corresponding to 6 dB line in Hz

Now damping ratio zeta(ζ) is given by $\zeta = \frac{1}{2Q}$

The table showing the natural frequencies of the composite materials

TYPE OF COMPOSITE	MODE 1	MODE 2	MODE 3
CF 1	36.13	73.88	149.38
CF 2	21.25	51.63	141.00
CF 3	31.25	62.25	148.25
CF 4	28.13	40.33	138.00

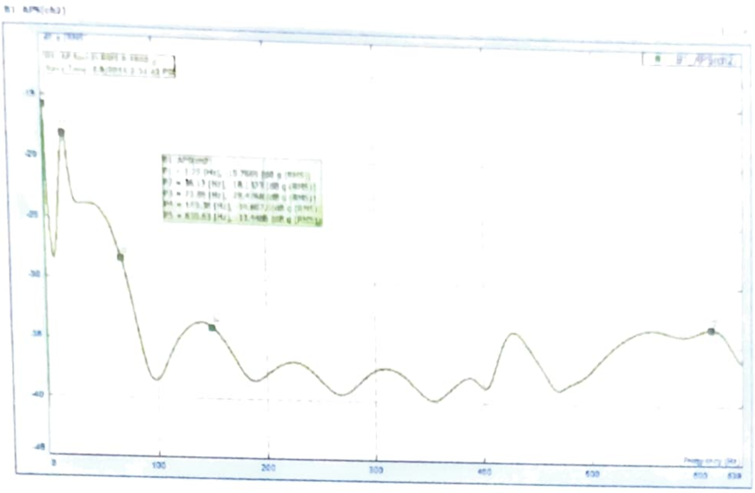


Fig 9.4.1 Frequency vs dB curve for CF 1 specimen

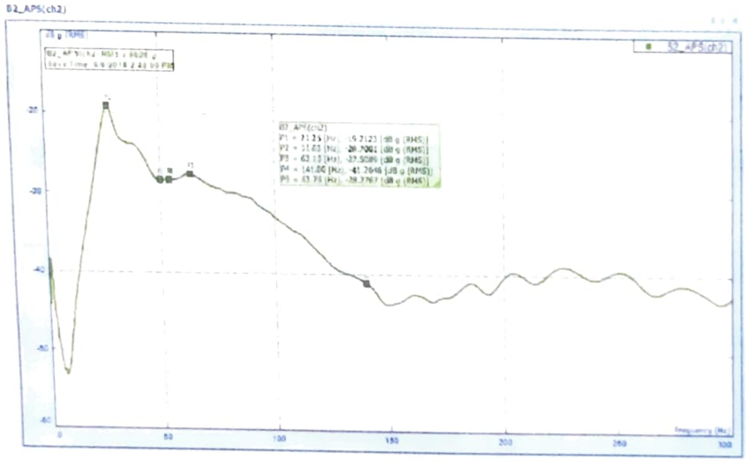


Fig 9.4.2 Frequency vs dB curve for CF 2 specimen

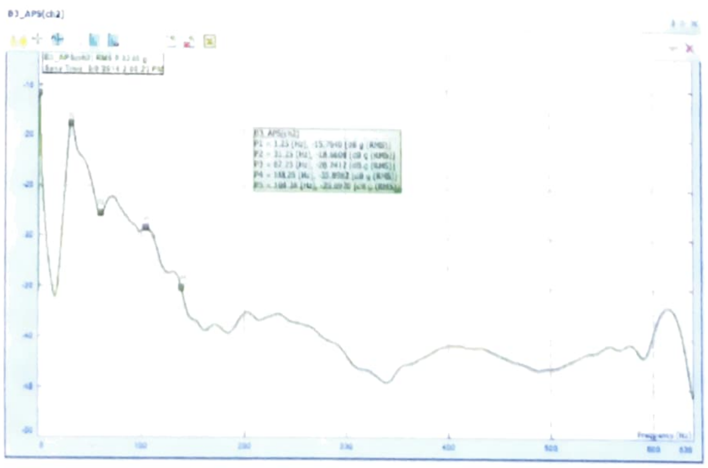


Fig 9.4.3 Frequency vs dB curve for CF 3 specimen

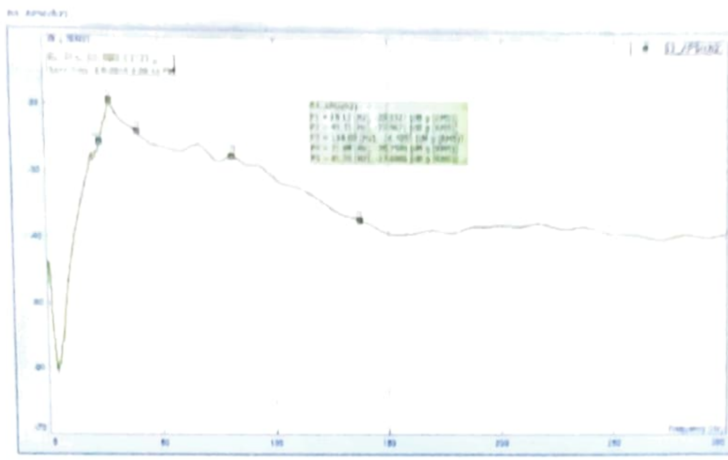


Fig 9.4.4 Frequency vs dB curve for CF 4 specimen

SHEET NO	DAMPING COEFFICIENT	DAMPING RATIO
CF 1	0.6523	0.7664
CF 2	0.4311	1.1596
CF 3	0.5320	0.9397
CF 4	0.3670	1.3621

Fig 9.4 (a) Table shows the Damping Coefficient and Damping Ratios

9.5 ANALYSIS OF VIBRATION TEST RESULTS

Based on the observations from Vibration test, carbon fiber reinforced composite material with selected wt% of rubber powder can sustain more vibrations which can with stand damping forces by making it under damped vibrations with good damping ratio value (0.7664) compared to remaining formulations of materials. The main reason to have better properties for the sample specimen CF-1 is the selection of specific ingredients and Rubber Powder present in the sample specimen. The vibrations carried by the specimen is initially transmitted to the fiber and remaining to the ingredients. The higher the Rubber Powder content present in the sample results better vibrational properties in the specimen. For the present configuration of material selection, Rubber powder content of (0.7 wt%) exhibits good vibrational properties. The bonding behavior of carbon fibre reinforced carbon CF-1 is also greatly improved compared to remaining formulations. Hence CF-1 possess good vibrational properties shown in Fig 9.4(a) table.

CHAPTER 10

SCANNING ELECTRON MICROSCOPE IMAGES

CHAPTER 10

SCANNING ELECTRON MICROSCOPE IMAGES

The Scanning Electron Microscope (SEM) images were taken to study the grain structure of the Carbon Fiber Reinforced Material (CF 1) which shows improved & better mechanical properties than other reinforced carbon fiber specimens.

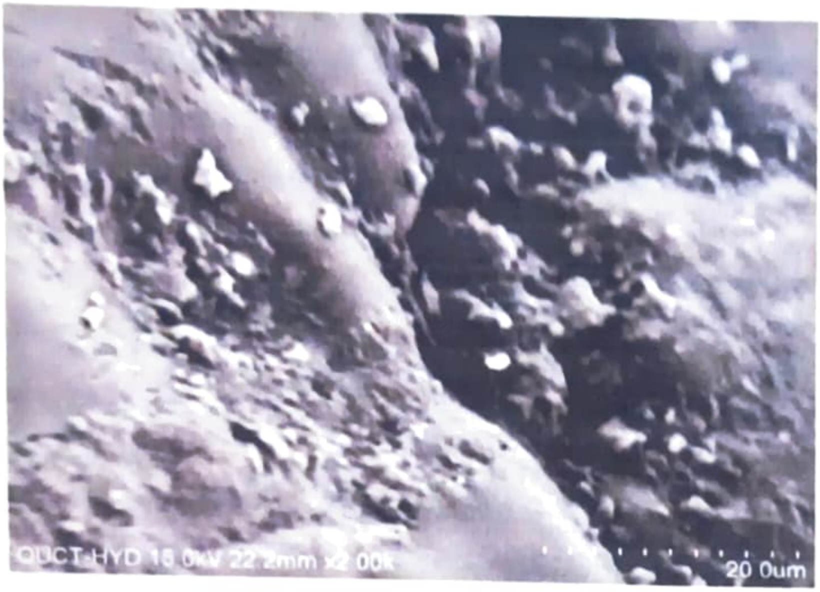


Fig - 10.1 SEM images of Specimen CF 4

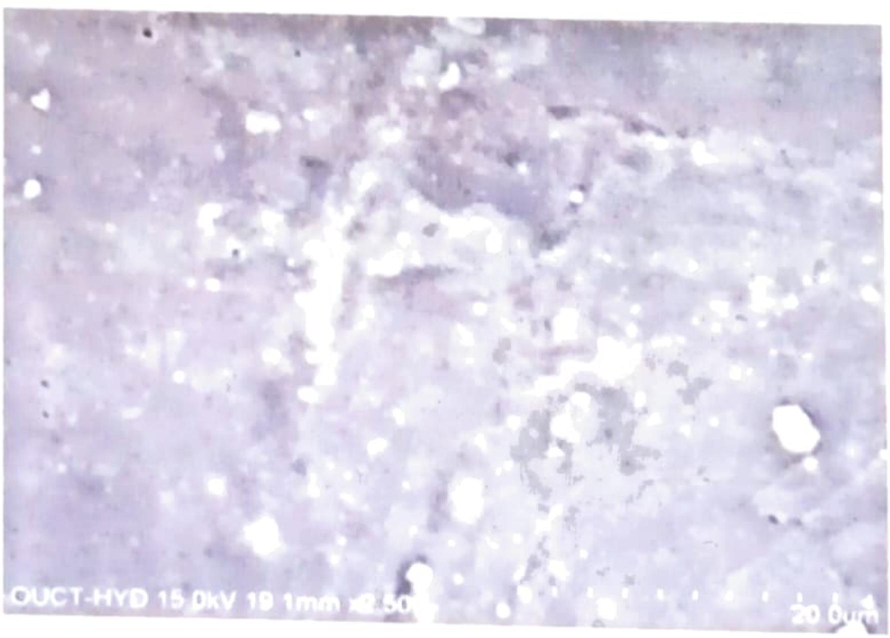


Fig - 10.2 SEM images of Specimen CF 1

Among all the four sample specimens, SEM images are taken for two samples CF1 and CF4 because, these sample composite specimens exhibit good mechanical properties compared to other composite specimens. Fig 10.1 and fig 10.2 indicates scanning electron microscope images observed using S-3700 N capacity SEM image equipment. Based on the observation of two samples, Fig 10.2 SEM image of carbon fiber reinforced composite CF1 exhibits uniform dispersion of all the ingredients throughout entire sample specimen. The inter-laminar attraction between all the ingredients is also greatly improved and possess good bonding behavior with respect to the polymer matrix compared to other formulations of materials. Hence CF1 sample specimen is capable of withstanding the more load and can achieve good mechanical properties compared to other sample specimens.

CHAPTER - 11

CONCLUSIONS

CHAPTER - 11

CONCLUSIONS

11.1 INTRODUCTION

Carbon fiber reinforced composite materials are fabricated by varying the content of rubber powder and silicon carbide and keeping remaining ingredients as constant. Four different formulations of composite material with varying weight percentages of filler inclusions are fabricated. Mechanical and damping results are performed as per ASTM standards. SEM images are observed to assess the uniform dispersion of ingredients.

11.2 CONCLUSIONS FROM TEST RESULTS

The results obtained from different tests are presented as per the order discussed in this report i.e., Tensile, Flexural, Hardness, Impact, Compression, Vibration results.

11.2.1 CONCLUSIONS DRAWN FROM TENSILE TEST RESULTS

a) The maximum tensile strength is obtained for sample CF 1 among all the samples.

b) It was observed that the sample CF 1 exhibit good tensile strength properties compared to remaining samples

c) It was observed that the tensile strength is decreasing from sample CF 1 to CF 4

11.2.2 CONCLUSIONS DRAWN FROM FLEXURAL TEST RESULTS

a) The maximum flexural strength is obtained for sample CF 4 among all the samples.

b) It was observed that the flexural strength decreased on going from CF 1 to CF 3 and then increased from CF 3 to CF 4.

11.2.3 CONCLUSIONS DRAWN FROM HARDNESS TEST RESULTS

a) The highest Brinell hardness number is obtained for sample CF 1

b) It was also observed that the Brinell hardness number is decreasing from sample CF1 to CF 4.

11.2.4 CONCLUSIONS DRAWN FROM IMPACT TEST RESULTS

a) The highest impact strength was observed from the sample CF 4

b) The variation of impact strength is very less with linearly decreasing from CF 1 to CF 3 and then increases from CF 3 to CF 4.

11.2.5 CONCLUSIONS DRAWN FROM COMPRESSION TEST RESULTS

a) The maximum compression strength is obtained for sample CF 1 among all the samples.

b) It was also observed that the compressive strength is decreased from CF 1 to CF 4.

11.2.6 CONCLUSIONS DRAWN FROM SEM IMAGES

a) The CF1 has good grain distribution and uniform dispersion compared to CF4

Comparison of strengths for different filler percentages

Type of CFRP samples	Tensile Strength (N/mm^2)	Flexural Strength (kg/mm^2)	Brinell's Hardness Number	Impact Strength (KJ/m^2)	Compression Strength (Mpa)	Damping Ratio
CF 1	164.28	202.80	25.15	1200	715.13	0.7664
CF 2	158.67	176.41	19.05	1025	680.68	1.1596
CF 3	151.56	134.76	19.05	1200	642.75	0.9397
CF 4	149.84	213.69	14.87	1250	574.70	1.3621

Therefore, based on the mechanical properties observed for all the specimens. Carbon fiber reinforced composite material (CF1) possess better values compared to other material configurations. The main reason to have better mechanical properties is the selection of ingredients like rubber powder and silicon carbide for improving mechanical and damping properties of the composite. The ingredients selected for CF1 possess good bonding behavior with respect to all ingredients. CF3 specimen exhibits good damping properties compared to remaining formulation of material. CF1 is selected for achieving good mechanical properties and used in aerospace and automobile etc applications. CF3 is also consider for usage in the aerospace industry to have good damping values. Based on the SEM observations CF1 exhibit good bonding behavior.

11.3 SCOPE FOR FUTURE WORK

This work can be extended for evaluation of wear properties of all the sample specimens and determination of surface roughness values to use the current existing materials in required field of application. The bonding behavior of the CF reinforced composite can be further clearly estimated by using alteration of polymer matrix materials and surface treatment methods. Thermal analysis can be performed to assess the performance of composite materials in aggressive environments subjected to severe temperatures.

REFERENCE

REFERENCES

1. Huibin Chang, Jeffrey Luo, H. Clive Liu et al, "Producing carbon fibers from polyacrylonitrile (PAN) fibers containing cellulose nanocrystals CNC " (2019) PP 1-18

2. Wan-qian Li, Ji-Hua Zhu, Pi-yu Chen, Feng Xing, et al. "Developing a new cement-based material introducing chopped carbon fiber" 217(2019) PP 234-243

3. MareenZöllner, Holger Lieberwirth, et al."Thermal resistance of carbon fibres/carbon fibre reinforced polymers" 85(2018) PP 327-332

4. Muhannad Al Aiti, Dieter Jehnichen , et al "Morphology and structure formation of carbon fibers from polymer precursor systems"(2018) PP 5-25

5. Dalsu Choi, Hyun-Sig Kil, Sungho Lee et al. "Fabrication of low-cost carbon fibers using economical precursors and advanced processing technologies" (2018) PP 33-56

6. Asma A. Eddib and D.D.L. Chung studied about the Electric permittivity of carbon fibers(2019) PP 1-22

7. M. Endo, Y.A. Kim, T. Hayashi, K. Nishimura et al. "Basic properties and applications of PAN carbon fibres" 39(2001) PP 1287-1297

8. Mohit Sood, Gaurav Dwivedi et al. "Effect of fiber treatment on flexural properties of carbon fiber reinforced composites". 27(2018) PP 775-783

9. Fang Liu, Shiqiang Deng, JianingZhang researched about Mechanical properties of epoxy and its carbon fiber composites modified by nanoparticles (2017) PP 1-8

10. R.Masilamani, N.V. Dhandapani et al. "Usage of Carbon Fiber Reinforced Plastics in Automobiles", vol-117, no.20(2017) PP 537-544.

11. rich Fitzer, AntoniosGkogkidis, Michael Heine et al. " Carbon fibres and their composites" , Vol-16,(1984) PP 363-392.

12. Dany Arnoldo Hernandeza , Carlos Alberto Soufenb , Marcelo OrnaghiOrlandia et al." Morphological characteristics analysis of before and after tensile tests" (2017) PP 951-961.

13. Panimayam ,Chinnadurai , R.Anuradha et al."the Assets of carbon fibre reinforced polymers" vol-10,no.8(2017) PP 199-210

14. Ronald Hillock, ShainHoward et al "Utility of Carbon Fiber Implants in Orthopedic Surgery" vol-4,no.1,(2014) PP 1-10