EFFECT OF STRAIN RATE ON NANO FILLED COMPOSITE MATERIALS

COMPOSITE MATERIALS

Dr. SUJESH G, Ms. RINCHU P

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"To Mom and Dad,
You have always been my pillars of support, my constant encouragers, and the guiding lights in my life. Your unwavering love and belief in me have been the fuel that propelled me forward on this incredible writing journey. Through the highs and lows, you've been there with words of wisdom and warm embraces. This book is a tribute to your boundless love and the sacrifices you made to see me succeed. Thank you for being my biggest cheerleaders and for showing me that anything is possible with determination and love.
With all my heart"

Sujesh G

FOREWORD

In the ever-evolving landscape of technology, staying ahead of the curve is no easy feat. As a Professor and Head at Department of Aeronautical Engineering, I have witnessed countless advancements and innovations that have reshaped the way we interact with the digital world. It is with great enthusiasm that I introduce Sujesh G's latest masterpiece, Effect Of Strain Rate On Nano Filled Composite Materials

I have had the privilege of collaborating with Sujesh G over the years, and their expertise and dedication to the field are unparalleled. Within the pages of this technical opus, Sujesh G weaves together a tapestry of knowledge that spans the complexities of composite materials.

Effect Of Strain Rate On Nano Filled Composite Materials is not just another technical manual; it is a beacon of enlightenment for both aspiring and seasoned professionals. The clarity of explanations and the comprehensive coverage of critical topics demonstrate Sujesh G's commitment to empowering readers with the tools they need to excel.

One of the remarkable aspects of this book is its accessibility. Sujesh G has successfully bridged the gap between theory and practice, making even the most intricate concepts approachable and applicable. Whether you are a seasoned expert or just starting on your technical journey, Effect Of Strain Rate On Nano Filled Composite Materials will undoubtedly enrich your understanding and broaden your horizons.

As you embark on this enlightening voyage through the digital realm, I encourage you to embrace the wisdom that Sujesh G imparts on

these pages. Their passion for the subject matter is infectious, and their dedication to nurturing the next generation of technologists shines brightly throughout.

It is my honour to introduce Effect Of Strain Rate On Nano Filled Composite Materials and extend my heartfelt congratulations to Sujesh G for their remarkable achievement. I have no doubt that this book will become an indispensable asset to all who seek to explore and conquer the ever-expanding frontiers of technology.

Dr. Lakshminarayanan V

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PREFACE

Welcome to Effect Of Strain Rate On Nano Filled Composite Materials ! As the author of this technical endeavor, I am delighted to share with you the knowledge and insights that have been meticulously gathered and curated within these pages.

Effect Of Strain Rate On Nano Filled Composite Materials emerged from a passion for Composite Materials, fueled by countless hours of research, experimentation, and collaboration with fellow experts in the field. My aim in writing this book is to provide a comprehensive resource that not only explains the fundamental principles but also delves into the practical applications that are so crucial in today's fast-paced technological landscape.

In the following chapters, you will embark on a journey that covers a wide range of topics, from the foundational concepts to the cutting-edge advancements that are shaping the future of Composite Materials. Each chapter is designed to build upon the previous one, allowing you to develop a deep understanding of the subject matter gradually.

To ensure the accessibility of the content, I have strived to strike a balance between technical rigor and approachability. Whether you are a seasoned professional seeking to expand your expertise or a newcomer eager to explore the fascinating world of Composite Materials, I hope you will find this book to be a valuable companion in your quest for knowledge.

Throughout this journey, I have been fortunate to receive support and inspiration from a multitude of individuals, whose contributions have enriched the content of this book. I would like to express

my sincere gratitude to all those who have shared their wisdom and insights with me.

I must also acknowledge the unwavering support of my family and friends, who have been a constant source of encouragement throughout this writing process. Their belief in me and this project has been a driving force that kept me motivated to deliver nothing short of excellence.

As with any technical work, knowledge continues to evolve, and new discoveries are made every day. I encourage you to view this book as a stepping stone in your quest for understanding Composite Materials. Embrace curiosity, challenge assumptions, and continue to explore the ever-expanding frontiers of technology.

I hope that Effect Of Strain Rate On Nano Filled Composite Materials will serve as a valuable resource and guide on your journey of exploration and growth. May it ignite your passion for Composite Materials and inspire you to push the boundaries of what is possible.

Thank you for joining me on this exciting adventure, and I wish you every success in your pursuit of technical excellence.

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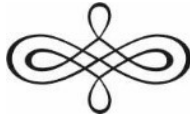
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1. COMPOSITE MATERIALS

Aerospace structural engineers are always in search of material with high specific strength and stiffness in their pursuit to produce structure of low wait and cost. Monolithic metals and their alloys cannot always meet the demands of today's advanced technologies. Only by combining several materials can one meet the performance requirements. Researches and studies lead them to the concept of composite material.

1.1 DEFINITION OF COMPOSITE MATERIAL.

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the *reinforcing phase* and the one in which it is embedded is called the *matrix*. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous.

1.1.1 ADVANTAGES OF COMPOSITE STRUCTURE

- High specific strength and high specific stiffness.

- Long fatigue life.

- Low density.

- Corrosion resistance.

- Wear resistance.

- Temperature dependent behaviour.

- Environmental stability.

- Thermal insulation and conductivity.

- Acoustic insulation.

1.1.2 DISADVANTAGES OF COMPOSITE STRUCTURES

Even though composite structures have above mentioned advantages same time it poses some limitations also. Disadvantages are listed below:

- Use of composites is more challenging.

- Materials are less predictable.

- Complex damage like fiber cracks, matrix cracks, interface debonding, delamination, micro buckling, etc.

- Brittle, not ductile failure.

- Structural health monitoring and non destructive inspection of composites is much more difficult than metals.

1.2 CLASSIFICATIONS OF COMPOSITE MATERIALS.

Composite material can be classified by the geometry of reinforcement as particulate, flake and fiber or by the type of matrix as polymer, metal, ceramic and carbon .

1.2.1 BASED ON TYPE OF MATRIX.

- **POLYMER MATRIX COMPOSITE (PMC)**

The most common advanced composites are polymer matrix composites (PMCs) consisting of a polymer (e.g., epoxy, polyester, urethane) reinforced by thin diameter fibers (e.g., graphite, aramids, boron). For example,

graphite/epoxy composites are approximately five times stronger than steel on a weight for weight basis. The reasons why they are the most common composites include their low cost, high strength, and simple manufacturing principles. The main disadvantage of PMC are their low maximum working temperature, high co efficient of thermal expansion. Strength and stiffness are low compared with metal and ceramics.

- ## MATAL MATRIX COMPOSITES (MMC)

Metal matrix composites (MMCs), as the name implies, have a metal matrix. Examples of matrices in such composites include aluminum, magnesium, and titanium. Typical fibers include carbon and silicon carbide. Metals are mainly reinforced to increase or decrease their properties to suit the needs of design. For example, the elastic stiffness and strength of metals can be increased, and large coefficients of thermal expansion and thermal and electric conductivities of metals can be reduced, by the addition of fibers such as silicon carbide. Metal matrix composites are mainly used to provide advantages over monolithic metals such as steel and aluminum. These advantages include higher specific strength and modulus by reinforcing low-density metals, such as aluminum and titanium; lower coefficients of thermal expansion by reinforcing with fibers with low coefficients of thermal expansion, such as graphite; and maintaining properties such as strength at high temperatures. MMCs have several advantages over polymer matrix composites. These include higher elastic properties; higher service temperature; insensitivity to moisture; higher electric and thermal conductivities; and better wear, fatigue, and flaw resistances. The drawbacks of MMCs over PMCs include higher processing temperatures and higher densities.

- ## CERAMIC MATRIX COMPOSITES (CMC)

Ceramic matrix composites (CMCs) have a ceramic matrix such as alumina calcium alumino silicate reinforced

by fibers such as carbon or silicon carbide. Advantages of CMCs include high strength, hardness, high service temperature limits for ceramics, chemical inertness, and low density. However,   ceramics by themselves have low fracture toughness. Under tensile or impact
loading, they fail catastrophically. Reinforcing ceramics with fibers, such as silicon carbide or carbon, increases their fracture toughness because it causes gradual failure of the composite. This combination of a fiber and ceramic matrix makes CMCs more attractive for applications in which high mechanical properties and extreme service temperatures are desired.

- ## CARBON CARBON COMPOSITES (CCC)

Carbon–carbon composites use carbon fibers in a carbon matrix. These composites are used in very high-temperature environments of up to 6000°F (3315°C), and are 20 times stronger and 30% lighter than graphite fibers. Carbon is brittle and flaw sensitive like ceramics. Reinforcement of a carbon matrix allows the composite to fail gradually and also gives advantages such as ability to withstand high temperatures, low creep at high temperatures, low density, good tensile and compressive strengths, high fatigue resistance, high thermal conductivity, and high coefficient of friction. Drawbacks include high cost, low shear strength, and susceptibility to oxidations at high temperatures.

1.2.2 BASED OF GEOMETRY OF REINFORCEMENT.

- *Particulate* **composites** consist of particles immersed in matrices such

as alloys and ceramics. They are usually isotropic because the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature, oxidation resistance, etc. Typical examples include use of aluminum particles in

rubber; silicon carbide particles in aluminum; and gravel, sand, and cement to make concrete.

- *Flake* composites consist of flat reinforcements of matrices. Typical flake materials are glass, mica, aluminum, and silver. Flake compos ites provide advantages such as high out-of-plane flexural modulus, higher strength, and low cost. However, flakes cannot be oriented easily and only a limited number of materials are available for use.

- *Fiber* composites consist of matrices reinforced by short (discontinuous)

or long (continuous) fibers. Fibers are generally anisotropic and examples include carbon and aramids. Examples of matrices are resins such as epoxy, metals such as aluminum, and ceramics such as calcium–alumino silicate. Continuous fiber composites are emphasized in this book and are further discussed in this chapter by the types of matrices: polymer, metal, ceramic, and carbon. The fundamental units of continuous fiber matrix composite are unidirectional or woven fiber laminas. Laminas are stacked on top of each other at various angles to form a multidirectional laminate.

- *Nanocomposites* consist of materials that are of the scale of nanometers

($10-9$ m). The accepted range to be classified as a nanocomposites is that one of the constituents is less than 100 nm. At this scale, the properties of materials are different from those of the bulk material Generally advanced composite materials have constituents on the micro scale ($10-6$ m). By having materials at the nanometer scale, most of the properties of the resulting composite material are better than the ones at the microscale. Not all properties of nanocomposites are better; in some cases, toughness and impact strength can decrease. Applications of nanocomposites include packaging applications for the military in which nanocomposite films

show improvement in properties such as elastic modulus, and transmission rates for water vapor, heat distortion, and oxygen.

1.3   NEED OF NANOCOMPOSITES.

Fiber reinforced polymers (FRPs) are composite structures that use a polymer as the matrix and a fiber, such as glass or carbon, as the reinforcing agent.   The fibers improve strength properties in the direction they are aligned in the matrix .   The fibers can be oriented in any direction, making the material tailorable for many different applications.   The result is a material that has the strength and stiffness of steel, but at only $\frac{1}{4}$ of the weight .   The disadvantage of FRPs is that the polymer has weak mechanical properties limiting the potential to improve the strength to weight ratios even further.   One way to overcome these limitations is to improve the strength of the polymer using nanomaterials, thus creating a nanocomposites.   Nanocomposite is a term which illustrates a composite material in which the reinforcing agents are nano-particles.   Nanocomposites have the potential to be implemented as a new high strength matrix in a composite. The nanoparticles used are on the order of 10^{-9} m in size and come in a variety of different forms including spheres, platelets, fibers etc . Using nanoparticles to create nano composites has been investigated since the early 1990's, and improvements in strength, modulus, and fracture strength have been seen for a variety of nanocomposites systems.   The nanoparticles used provide improved interfacial surface area and smaller inter particle distances, which are believed to contribute to improved mechanical properties .   Although no substantial conclusions have been made on how mechanical properties of composites behave based on changes in the size of the reinforcing agent, materials engineers are experimenting with different nanoparticles/polymer combinations .

1.4   IMPORTANCE OF STRAIN RATE STUDIES.

In many technological applications, under dynamic loading conditions, the response of a structure designed with static properties might be too conservative. The main reason is that mechanical properties of composites vary

significantly with changing the strain rate. Unlike metals, which have been studied extensively over a wide range of strain rates, only limited amount of information is available on the effects of strain rate on the response of fibrous composites. For the evaluation of structural behaviour of polymeric materials, their response under high strain rate loading should be clearly understood. However, the mechanical responses of such materials under high strain rate loading are not completely understood.
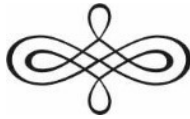
2. MATERIAL SELECTION

2.1 FIBRE MATERIALS.

Fibre material are combination of two or more materials such that final construction exploits certain properties from each. In the construction of glass, carbon fibre reinforced plastics, the high strength , high stiffness of the fibre are combined with a low-density stable matrix to create a combined material with desirable material properties . Contemporary composite results from research and innovation from past few decades have progressed from glass fibre for automotive bodies to particular composites for aerospace and space applications.

Fibre which is encapsulated in a polymer resin matrix forms a composite fibre laminate. Also referred to a structural member designed to stiffen a moulded part. The primary function of the reinforcement is to carry the loads along their longitudinal direction. Organic and inorganic fibers are used to reinforce the composite material. Almost all organic fibre has low density and flexibility. Inorganic fibre are of high modulus, high thermal stability and possess greater rigidity than organic fibre and notwithstanding the diverse advantages of organic fibre which render the composites in which they are used.

Mainly , the following different types of fibre namely, glass fibres, silicon carbide fibres , high silica and quartz fibres , aluminum fibres, metal fibres and wires, graphite fibres , aramide fibre and multiphase fibres are used. Glass fiber and carbon fibres are mainly used in the aviation industries. The material chosen for this project is Glass fiber.

2.1.1 GLASS FIBERS.

Glass fibres are the most common of all reinforcing fibres for polymeric matrix composites (PMC). The principal advantages of glass fibres are low cost, high tensile strength, high chemical resistance, and excellent insulating properties. The disadvantages are relatively low tensile modulus and high density (among the commercial fibres), sensitivity to abrasion during handling (which frequently decreases its tensile strength), relatively low fatigue resistance, and high hardness (which causes excessive wear on molding dies and cutting tools). The two types of glass fibres commonly used in the fibre-reinforced plastics (FRP) industry are Eglass and S-glass. Another type, known as C-glass, is used in chemical applications requiring greater corrosion resistance to acids than is provided by Eglass. E-glass has the lowest cost of all commercially available reinforcing fibres, which is the reason for its widespread use in the FRP industry. S-glass, originally developed for aircraft components and among all fibres in use. However, the compositional difference and higher manufacturing cost make it more expensive than E-glass. A lower cost version of S-glass, called S-2-glass, is also available. Although S-2-glass is manufactured with less-stringent non military specifications, its tensile strength and modulus are similar to those of S-glass.

Glass fibre are silica based and contain host of the other oxides of calcium and iron. Glass fibres are the earliest known fibre used to reinforce the material. Ceramic and metal fibres were subsequently found out and put to extensive use , to render composites stiffer more resistant to heat. Material Composition of different glass fibers are shown in table 3.1

Here in this study i am using bidirectionaly woven E-glass fibre.

Chemical combination of this fibre is in the given table.

Composition	E- glass	C- glass	S- glass
SiO_2	55.2	65.0	65.0
Al_2O_3	8.0	4.0	25.0
CaO	18.7	14.0	--
MgO	4.6	3.0	10.0
Na_2O	0.3	8.5	0.3
K_2O	0.2	--	--
B_2O_3	7.3	5.0	--

Table 2.1 Composition of different glass fibres

2.1.2 E-Glass.

E-glass is a good electrical insulator and it has good strength and reasonable young's modulus. There are mainly used for reinforcement of polyester, epoxy and phenolic resins. This type of glass fibers are cheaply available in various forms. Continuous strands is group of 204 individual fibers, roving is a group of parallel strands. Chopped fibre consist of strand chopped to length between 5mm and 50mm. It also available in form of woven fabric.

Properties	Value	Unit
Density	2.55	g/cm^3
Tensile strength	1750	Mpa
Young's modulus	72.3	Gpa
Co-efficient of thermal expansion	$4.7\ e^{-6}$	k^{-1}

Table 2.2 Properties of E- glass

2.1.3 ADVANTAGES OF E-GLASS FIBRE

- High tensile strength and strain to failure

- Good thermal resistance.

- Good chemical resistance.

- Good moisture resistance.

- Low cost.

IN this study I used bidirectionaly woven E- glass fibre cloth of 600 GSM (grams per square metre). It is available in 640mm cloth width.

Fig 2.1: Bidirectionaly woven E-Glass

2.2 EPOXY RESIN

Epoxy is one of the major thermoset matrix materials.

Epoxy resin is formed out of chemical Reaction between bisphenol and epichlorohydrin. To speed up the

reaction and also to form effective cross linking, curing agents like aliphatic or aromatic amines or acid anhydrides are added.

Epoxy or **Polyepoxide** is a thermosetting epoxide polymer that cures (polymerizes and cross links) when mixed with a catalyzing agent or

"Hardener". Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A. Epoxy adhesives are a major part of the class of adhesives called "Structural Adhesives" or "Engineering Adhesives" (which also includes polyurethane, acrylic, cyanoacrylate, and other chemistries.) These high performance adhesives are used in the construction of aircraft, automobiles, bicycles, golf clubs, skis, snow boards, and other applications where high strength bonds are required. Epoxy adhesives can be developed that meet almost any application. They are exceptional adhesives for wood, metal, glass, stone, and some plastics. They can be made flexible or rigid, transparent or opaque/colored, fast setting or extremely slow.

Epoxy adhesives are almost unmatched in heat and chemical resistance among common adhesives. In general, epoxy adhesives cured with heat will be more heat- and chemical-resistant than when cured at room temperature. Epoxies are sold in hardware stores, typically as two component kits. They are also sold in boat shops as repair resins for marine applications. Epoxies typically are not used in the outer layer of a boat because they are deteriorated by exposure to UV light. They are often used during boat repair and assembly, and then over coated with conventional or two pot polyurethane paint or marine varnishes that provide UV protection. Epoxy is a copolymer; that is, it is formed

from two different chemicals. These are referred to as the "resin" and the "hardener". The resin consists of monomers or short chain polymer with an epoxide group at either end. Most common epoxy resin are produced from a reaction between epichlorohydrin and bisphenol – A though the latter may be replaced by similar chemicals. The hardener consists of polyamine monomers. For

example Triethylenetetramine (TETA) . When these components are mixed together the amine group react with epoxide group to form a covalent group. Each NH group can react with an epoxide group, so that the resulting polymer is heavily cross linked and it thus rigid and strong.

The process of polymerization is called curing and can be controlled through temperature. Curing temperature varies from room temperature to approximately 350f. The most common cure temperature range is 250f to 350 f. The hot curing generally yields greater temperature resistance. Cure pressure are generally considered as low pressure molding from vacuum to 100psi.

The extensive use of epoxy resin is due to

- The ease with which it can be processed.

- Excellent mechanical properties.

- High hot and wet strength properties.

- Resistance to degradation by water and other solvents.

Epoxy resin have an excellent electrical thermal and chemical resistance . it commonly use to increase the strength of fibrous reinforcement or mineral fillers. The variety of combination of epoxy resin and reinforcement provide wide latitude in properties obtained in moulded parts.

Here in this study ARALDITE LY 556 is used as epoxy resin and ARADUR HY 951 as hardener.

2.2.1 ARALDITE LY 556 AND ARADUR HY 951

Araldite LY556 is a solvent free epoxy resin of medium viscosity. It can be mixed with hardener HY 951 to give casting with good mechanical and electrical properties. For this combination room temperature is enough for perfect curing. It will take 2-4 hours for curing in room

temperature. We can increase the curing rate by increasing the temperature by the help of heating Owen.

The mixing proportion for above combination is:

LY 556   ---   100 parts by weight

HY 951   ---   10 to 12 parts by weight.

2.3 NANO FILLERS

Nanotechnology could bring another revolution to the world of material science ,much like biotechnology or gene technology has already done .This sophisticated technology involves adding relatively small amount (<10 %)of specially treated nano-scale inorganic or organic particles to a variety of plastics. It has the potential to dramatically improve polymer performances including heat resistance , barrier properties , strength, stiffness or dimensional stability ,as well as flame retardancy . All of these performance benefits are available without increasing the density or reducing the light transmission properties of the base polymer.

Nanofillers have for many years had a high significance in the plastics industry. Nanofillers are basically understood to be additives in solid form, improvements in certain mechanical or physical properties. The activity of active fillers filling of a certain volume and disruption of the conformational position of a polymer matrix, and also the immobilization of adjacent molecule groups and possible orientation of the polymer material.

The activity of active fillers may have a variety of causes, such as the formation of a chemical bond (e.g., cross linking by carbon black in elastomers) or filling of a certain volume and disruption of the conformational position of a polymer matrix, and also the immobilization of adjacent molecule groups and possible orientation of the polymer material.

2.3.1 SILICON DIOXIDE (SiO_2) NANO FILLER

Here in this study the nano filler used is spherical silicon dioxide($SiO2$).

Nanometer silicon dioxide (SiO2) can improve the capabilities of materials for its strong electric property. Nanometer silicon dioxide is to treat nanometer silicon dioxide (resin) with resin acceptor special technology, so that it has good dispersion. Nanometer silicon dioxide (resin) can improve the tensile strength, impact strength, breaking extension rate, stability of resin and keep its transparency.

The application of nanometer silicon dioxide in resin:

1. <u>Heat resistance:</u> Nanometer silicon dioxide can adhere to the resin interface and absorb lots of strike energy because of its big surface volume. So nanometer silicon dioxide can improve the intension, toughness and heat resistance of resin evidently.

2. <u>Intension and toughness:</u> Nanometer silicon dioxide (resin) can greatly improve the tensile strength, impact strength, breaking extension rate, stability of resin.

<u>**Specification:**</u>

Appearance : White powder
Particle size : 15nm
Assay % : ≥99.5
PH: 5-7

Fig 2.2: Nano powder

Dosage:The dosage of resin and nanometer silicon dioxide by weight is 100:5. Customers can adjust their dosage according to their systems.

2.4 Method of dispersion:

Nanometer particles are easy to reunite for their extra small size and big surface volume, so that it can not improve the intension and toughness of polymer effectively. For this reason, the nanometer particles should be dispersed well when we produce nanometer compound material. Treatment, such as mill, cutting with high speed, ball-grind, ultrasonic etc. can help nanometer particles to disperse evenly in resin.

Here in this study silicon dioxide uses about 5% wt of resin. Electric stirrer are used for dispersing the filler in resin. We can use filler up to 25% wt of resin, but as we increasing the filler content it will increases the viscosity of the epoxy resin. Increment in viscosity affects the fabrication works.

We can also add some resin acceptor to improve the dispersion of nanometer silicon dioxide in resin. The rate of them is 5:100.

Fig 2.3: 5-15nm Silicon dioxide(SiO_2) nano powder
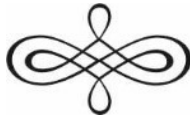
3. FABRICATION OF COMPOSITE LAMINATE

Fabrication of laminated composites includes selecting a material system or a group of material system and determining the stacking sequence for the laminate based on applied loads and constraints on optimizing and constraining factor such as cost ,weight as related to aerospace industry. Here in this study I made three 300mm X 300mm composite plate. For these fabrication I used Three different Fabrication Technique .

3.1 FABRICATION TECHNIQUES USED.

- HAND LAY-UP

- VACUUM BAGGING

- AUTOCLAVE

3.1.1 HAND LAY-UP:

Matrixes/Resins are impregnated by hand into fibers which are in the form of chopped strand mat ,woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates are left to cure under standard atmospheric conditions.

Materials Options:

Resins: Epoxy, polyester, vinyl ester, phenolic and any other resin.

Fibers: Glass, Carbon, Aramid and any other reinforcement, although heavy aramid fabrics can be difficult to wet-out by hand.

Cores: Any core materials can be used provided that should be compatible with resin system, i.e. polystyrene core cannot be used with polyester or vinylester resin system.
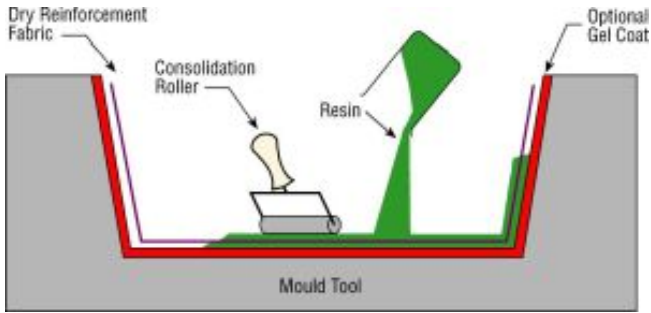

Fig 3.1:   Hand Lay-up processing

Main Advantages:

• Low capital Investment.

• Simple principles to fabricate the part.

• Low cost tooling, if room-temperature cure resins are used.

• Wide choice of suppliers and material types.

Main Disadvantages:

• Resin mixing, laminate resin contents, and laminate quality are very dependent on the skills of laminators. Low resin content laminates cannot usually be achieved without the incorporation of excessive quantities of voids.

- Health and safety considerations of resins. The lower is molecular weight of hand lay-up resins generally means that they have the potential to be more harmful than higher molecular weight products. The lower viscosity of the resins also means that they have an increased tendency to penetrate clothing etc.

- Limiting airborne styrene concentrations to legislated levels from polyesters and vinyl esters is becoming increasingly hard without expensive extraction systems.

- Resins need to be low in viscosity to be workable by hand. This generally compromises their mechanical/thermal properties due to the need for high diluents/styrene levels.

Typical Applications:

Standard wind-turbine blades, boats, architectural moldings, etc.

3.1.2 VACUUM BAGGING TECHNIQUE

Vacuum bagging (or vacuum bag laminating) is a clamping method that uses atmospheric pressure to hold the adhesive or resin-coated components of a lamination in place until the adhesive cures. (When discussing composites, "resin" generally refers to the resin system— mixed or cured resin and hardener—rather than unmixed 105 epoxy resin.) Modern room-temperature-cure adhesives have helped to make vacuum bag laminating techniques available to the average builder by eliminating the need for much of the sophisticated and expensive equipment required for laminating in the past. The effectiveness of vacuum bagging permits the laminating of a wide range of materials from traditional wood veneers to synthetic fibers and core materials.

Vacuum bagging uses atmospheric pressure as a clamp to hold laminate plies together. The laminate is sealed within an airtight envelope. The envelope may be an airtight mold on one side and an airtight bag on the other.

When the bag is sealed to the mold, pressure on the outside and inside of this envelope is equal to atmospheric pressure: approximately 29 inches of mercury (Hg), or 14.7 psi. As a vacuum pump evacuates air from the inside of the envelope, air pressure inside of the envelope is reduced while air pressure outside of the envelope remains at 14.7 psi. Atmospheric pressure forces the sides of the envelope and everything within the envelope together, putting equal and even pressure over the surface of the envelop   The pressure differential between the inside and outside of the envelope determines the amount of clamping force on the laminate. Theoretically, the maximum possible pressure that can be exerted on the laminate, if it were possible to achieve a perfect vacuum and remove all of the air from the envelope, is one atmosphere, or 14.7 psi. A realistic pressure differential (clamping pressure) will be 12–25 inches of mercury (6–12.5 psi).
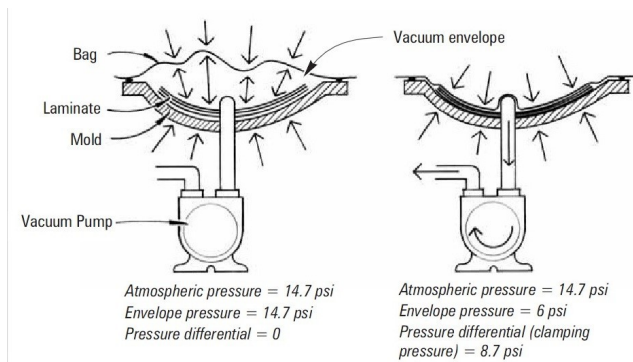

Fig 3.2:   A typical vacuum bagging lay-up before and after vacuum is applied.

Vacuum Bagging materials

The vacuum bagging system consists of the airtight clamping envelope and a method for removing air from the envelope until the epoxy adhesive cures. This

section discusses the components of this system, which include both specialized equipment and commonly available materials.

- **Release fabric**

Release fabric is a smooth woven fabric that will not bond to epoxy. It is used to separate the breather and the laminate. Excess epoxy can wick through the release fabric and be peeled off the laminate after the laminate cures. It will leave a smooth textured surface that, in most cases, can be bonded to without additional preparation. Surfaces that will subject to highly-loaded bonds should be sanded.

- **Perforated film**

A perforated plastic film may be used in conjunction with the release fabric. This film helps hold the resin in the laminate when high vacuum pressure is used with slow curing resin systems or thin laminates. Perforated films are available in a variety of hole sizes and patterns depending on the clamping pressure, and the resin's open time and viscosity.

- **Breather material**

A breather (or bleeder) cloth allows air from all parts of the envelope to be drawn to a port or manifold by providing a slight air space between the bag and the laminate.

- **Vacuum bag**

The vacuum bag, in most cases, forms half of the airtight envelope around the laminate. If you plan to use vacuum pressure of less than 5 psi (10 hg) at room temperatures, 6-mil polyethylene plastic can be used for

the bag. Clear plastic is preferable to an opaque material to allow easy inspection of the laminate as it cures. For higher pressure and temperature applications, specially manufactured vacuum bag material should be used.

- **Mastic sealant**

Mastic is used to provide a continuous airtight seal between the bag and the mold around the perimeter of the mold. The mastic may also be used to seal the point where the manifold enters the bag and to repair leaks in the bag or plumbing.

- **The plumbing system**

The plumbing system provides an airtight passage from the vacuum envelope to the vacuum pump, allowing the pump to remove air from and reduce air pressure in the envelope. A basic system consists of flexible hose or rigid pipe, a trap, and a port that connects the pipe to the envelope. A more versatile system includes a control valve and a vacuum throttle valve that allow you to control the envelope vacuum pressure at the envelope. A system is often split to provide several ports on large laminations, or may include some type of manifold within the envelope to help channel air to a single port. A variety of pipe or tubing can be used for plumbing as long as it is airtight and resists collapsing under vacuum.
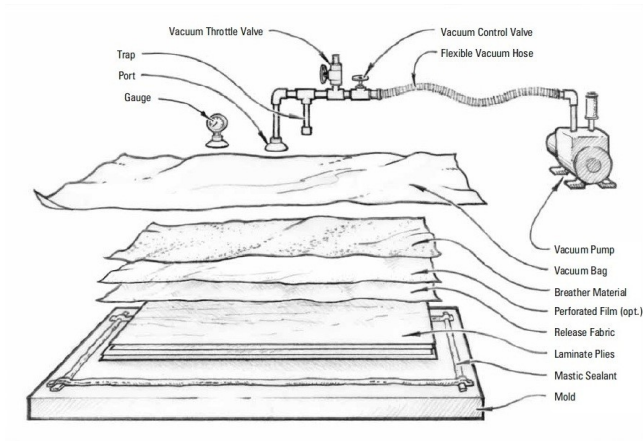
Fig 3.3: Typical components of a vacuum bagging system.

Materials Options:

Resins: Primarily epoxy and phenolic. Polyesters and vinyl esters may have problems in case of excessive extraction of styrene from the resin by the vacuum pump.

Fibers: The consolidation pressures mean that a variety of heavy fabrics can be wet-out.

Cores: Any.

Main Advantages:

- Higher fiber content laminates can usually be achieved than with standard wet lay-up techniques.

- Lower void contents are achieved than with wet lay-up.

- Better fiber wet-out due to pressure and resin flow throughout structural fibers, with excess into bagging materials.

- Health and safety: The vacuum bag reduces the amount of volatiles emitted during cure.

Main Disadvantages:

- The extra process adds cost both in labour and in disposable bagging materials.

- A higher level of skill is required by the operators.

- Mixing and control of resin content still largely determined by operator skill.

Typical Applications:

race car components, core-bonding in production boats.

3.1.3 AUTOCLAVE TECHNIQUE

Autoclave molding is a modification of pressure-bag and vacuum-bag molding. This advanced composite process produces denser, void free moldings because higher heat and pressure are used for curing. It is widely used in the aerospace industry to fabricate high strength/weight ratio parts from pre impregnated high strength fibers for aircraft, spacecraft and missiles. Autoclaves are essentially heated pressure vessels usually equipped with vacuum systems into which the bagged lay-up on the mould is taken for the cure cycle. Curing pressures are generally in the range of 50 to 100 psi and cure cycles normally involve many hours. The method accommodates higher temperature matrix resins such as epoxies, having higher properties than conventional resins. Autoclave size limits part size.

It is only possible to apply ~1000 mbar pressure with a vacuum bag process on its own. In order to achieve greater levels of consolidation it is normal to use an autoclave. For composite structure manufacture, an autoclave is a pressure vessel with pipe work to allow a vacuum to be maintained in the bagged work-piece. Temperature control is normally by gas- or electric-heating with a proportional-integral-derivative (PID) controller. This is a pressure vessel which permits precise control of the internal temperature and pressure. The combination of vacuum within the bag and pressure outside the bag ensure good consolidation and assist in making the laminate conform to tight radii. The gas in the autoclave may be air for low temperature curing resin systems, but an inert gas (often nitrogen) is used at higher temperatures to slow the deterioration of seals and to minimise the risk of fire.

Fig 3.4: Large size Autoclave used in Aircraft industry

3.2   FABRICATION OF MODELS

Here for this study total three models are fabricating.

Model 1: GFRP with plane epoxy

Model 2: GFRP with nano filled epoxy fabricated by vacuum bag technique.

Model 3: GFRP with nano filled epoxy fabricated by autoclave technique.

3.2.1 FABRICATION OF MODEL 1:

Here in all model 5 layers of bidirectionaly woven E-glass fibre cloth were used. Glass fibre plies in the size of 300mm x 300mm are cutted from the roving by the help of rulers and scissors.
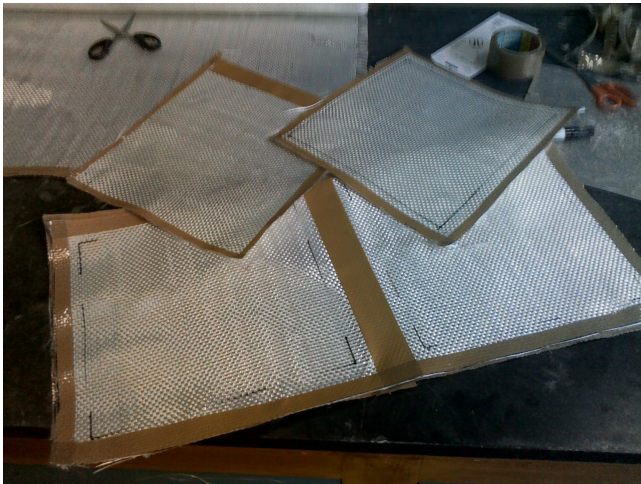

Fig 3.5: Glass fibre cutting

For first model that is for plane epoxy type, plane epoxy hardener mixture is used as reinforcement.

The specimen is first hand laid by conventional hand lay - up procedure.

Araldite LY556, Hardener HX951 in the ratio 10:1 by weight was used as matrix material.

Specimens were fabricated by vacuum bagging technique developed in laboratory. In vacuum bagging technique first we want to fabricate the laminate by hand layup technique.

A layer of mix was applied on the mould and a layer of roving. The fiber was impregnated with the help of a rover. After that again mix applies on that, like this 5 layers of fiber are impregnated one over other. After this, uncured specimen was placed in a vacuum bag setup. Vacuum bag lamination is a clamping method that used atmospheric pressure to hold the resin coated component of a lamination in place until the adhesive cures. The uncured laminate is sealed within an air tight envelope. On top of envelope a vacuum was connected which evacuated the air inside the envelope which create a pressure difference between outside and inside of envelope creates required clamping pressure. This clamping pressure holds the laminate plies together until it cures. The laminate was allowed to cure at this clamping pressure about two hours. After that 24 hours curing in normal atmospheric pressure was allowed.

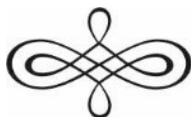### 3.2.2 FABRICATION OF MODEL 2:

For second model that is nano filled glass epoxy composite, the procedure is same. But before mixing epoxy with the hardener NANO filler should be mixed well with epoxy. It should take six hour to dissolve filler in epoxy. We can do this mixing by electric stirring equipment. After the six hours of mixing it is better to keep the mixture ideal for one hour to avoid voids.

Here silicon dioxide nano filler (5% wt of resin) is mixed well with plane epoxy. Filled epoxy/hardener combination was applied directly on the glass fibre plies with the help of brushes and rollers. After that vacuum bagging curing is applied on the fabricate.

3.2.3 FABRICATION OF MODEL 3:

Third model is nano filed GFRP fabricated by autoclave technique.

In autoclave technique we can adjust the clamping pressure. Here in this set up we can change the climbing pressure between 0-100 psi. After the conventional hand layup procedure the uncured fabricate is placed inside the autoclave for curing. Here climbing pressure is maintained at 2ATM(30 psi). And inside temperature is maintained at 50°C. After the autoclave curing of two Hours it is allowed to cure in normal atmospheric condition for 6 hours.

4. TESTING METHODS AND EQUIPMENTS

After the fabrication of models my next aim was to calculate the material properties of fabricated model. I did tensile and flexural bending test on the samples with the help of universal testing machine (UTM).

4.1 TENSILE TESTING (ASTM D3039)

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to uniaxial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics.

The tensile test is carried out by applying longitudinal or axial load at a specific extension rate to a standard tensile specimen with known dimensions   (gauge length and cross sectional area perpendicular to the load direction) till failure. The applied tensile load and Extension are recorded during the test for the calculation of stress and strain.

The tensile characterisation was conducted according to ASTM D3039 testing standard using standard UTM machine. The test where conducted at various loading rates. The UTM machine have a mechanism to change the

loading rate as per the need. Here testing were carried out at 5-500mm/min.
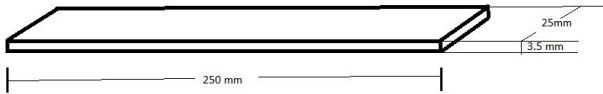
4.1.1 TENSILE TESTING SPECIMEN.

25mm

3.5 mm

250 mm

Fig 4.1: Testing specimen as per ASTM standard

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Fig 4.2: Tensile Testing setup

4.1.2 PROPERTIES THAT OBTAINED FROM TENSILE TESTING

Ultimate Tensile Strength : Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before *necking*, which is when the specimen's cross-section starts to

significantly contract. Tensile strength is the opposite of compressive strength and the values can be quite different.

The UTS is usually found by performing a tensile test and recording the stress versus strain; the highest point of the stress-strain curve is the UTS. It is an intensive property; therefore its value does not depend on the size of the test specimen. However, it is dependent on other factors, such as the preparation of the specimen, the presence or otherwise of surface defects, and the temperature of the test environment and material.

Tensile strengths are rarely used in the design of ductile members, but they are important in brittle members. They are tabulated for common materials such as alloys, composite materials, ceramics, plastics, and wood.

Tensile strength is defined as a stress, which is measured as force per unit area. For some non-homogeneous materials (or for assembled components) it can be reported just as a force or as a force per unit width. In the SI system, the unit is the Pascal (Pa) (or a multiple thereof, often mega Pascal's (MPa), using the mega-prefix); or, equivalently to Pascal's, Newton's per square metre (N/m²). The customary unit is pounds-force per square inch (lbf/in² or psi), or kilo-pounds per square inch (ksi, or sometimes kpsi), which is equal to 1000 psi; kilo-pounds per square inch are commonly used for convenience when measuring tensile strengths.

Tensile modulus of elasticity(young's modulus): Tangent or secant modulus of elasticity of a material subjected to tensile loading. Alternate terms are Young's modulus and modulus of elasticity in tension. It can be measured in a tensile test or in a dynamic test where it is related to resonant frequency on a cylindrical rod by the equation:

$$E = \frac{4\pi^2 \, 1^2 \, \rho \, f^2}{k^2 \, j^4}$$

where E is modulus of elasticity; 1, length of the rod; *p*, density; f, resonant frequency; k, radius of gyration of the rod about an axis normal to the rod axis and plane of motion ($d/4$ for cylindrical rods) and j, a constant dependent on the mode of vibration. Tensile modulus of elasticity is approximately equal to compressive modulus of elasticity within the proportional limit.

Young's modulus, also known as the tensile modulus, is a measure of the stiffness of an elastic material and is a quantity used to characterize materials. It is defined as the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law holds In solid mechanics, the slope of the stress-strain curve at any point is called the tangent modulus. The tangent modulus of the initial, linear portion of a stress-strain curve is called *Young's modulus*. It can be experimentally determined from the slope of a stress-strain curve created during tensile tests conducted on a sample of the material. In anisotropic materials, Young's modulus may have different values depending on the direction of the applied force with respect to the material's structure.

Poisson's ratio (): named after Siméon Poisson, is the ratio, when a sample object is stretched, of the contraction or transverse strain (perpendicular to the applied load), to the extension or axial strain (in the direction of the applied load).

When a material is compressed in one direction, it usually tends to expand in the other two directions perpendicular to the direction of compression. This phenomenon is called the Poisson effect. Poisson's ratio

(nu) is a measure of the Poisson effect. The Poisson ratio is the ratio of the fraction (or percent) of expansion divided by the fraction (or percent) of compression, for small values of these changes.

Conversely, if the material is stretched rather than compressed, it usually tends to contract in the directions transverse to the direction of stretching. Again, the Poisson ratio will be the ratio of relative contraction to relative stretching, and will have the same value as above. In certain rare cases, a material will actually shrink in the transverse direction when compressed (or expand when stretched) which will yield a negative value of the Poisson ratio.

Fig 4.3: Specimens after tensile testing

4.2 THREE POINT FLUTURAL BENDING TEST:

The three point bending flexural test provides values for the modulus of elasticity in bending, flexural stress, flexural strain and the flexural stress-strain response of the material. The main advantage of a three point flexural test is the ease of the specimen preparation and testing. However, this method has also some disadvantages: the

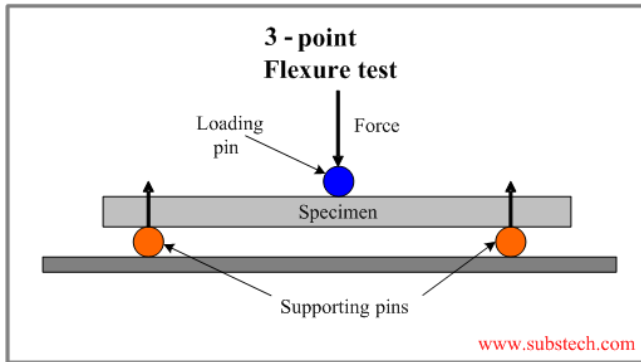results of the testing method are sensitive to specimen and loading geometry and strain rat

Fig 4.4: Schematic diagram of 3-point flexure test

There test method covers the determination of flexural properties of unreinforced and reinforced plastics., including high modulus composites and electrical insulating material in the form of rectangular bars molded directly or cutted from sheets, plastics or molded shapes. These test methods are generally applicable to both rigid and semi rigid materials. Flexural strength cannot be determined for those material that do not break or that do not fail in the outer surface of the test specimen within 5% strain limit of these test methods. There test method utilizes a three point loading system applied to a simply supported beam
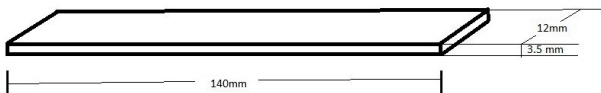
4.2.1 COMPRESSION TESTING SPECIMEN
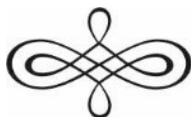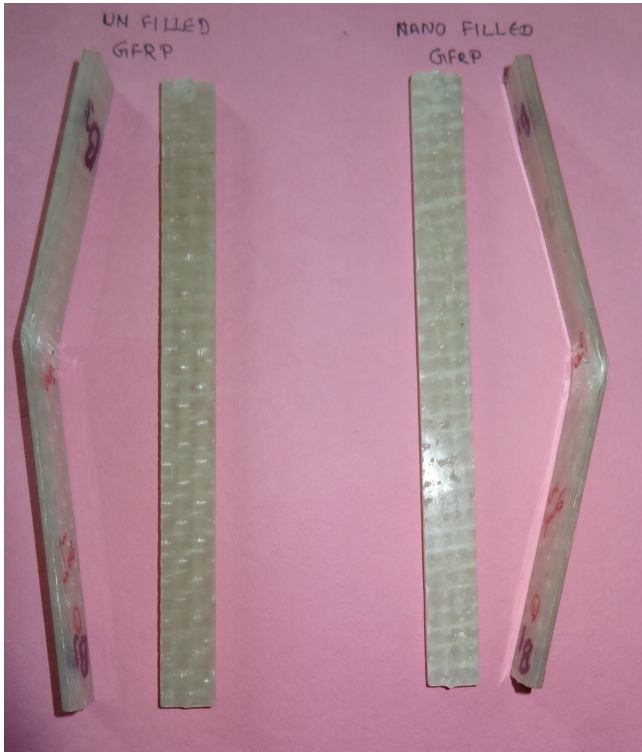

Fig 4.5: Test specimen size as per ASTM standard

Fig 4.6: Specimens before and after bending test

5. EFFECT OF STRAIN RATE ON PHYSICAL PROPERTIES

Mechanical properties of plane GFRP and nano filled GFRP are validating through stress strain relations. The mechanical properties such as tensile strength, tensile modulus, flexural strength and elongation are observed at different loading rates and maid its comparison study. This study aims to show the improvement in mechanical properties while adding nano filler in plane epoxy and also to study its behaviour at various strain rates. Effect of climbing pressure on fabrication also studied. Here i am discussing the results that obtained during my experimental studies.

5.1 Effect Of Strain Rate On Tensile Properties of Nano- Filled GFRP.

Tensile test were conducted on three different loading rates 5mm/min, 50mm/min, 500mm/min on nano filled coupon. This loading rates applied nominal strain rates of .00035S^{-1}, .0035S^{-1} and .035S^{-1} on the specimen. These strain rates are calculated by dividing loading rate of machine by the gauge length of the coupon.

1) Stress-Strain Relation:

The stress strain curve of the tested coupon under different strain rate is presented in figure:5.1. From Stress-Strain curves it is clear that mechanical properties of the specimen

depend on the loading rate. For tensile test performed at high loading rates, it has been observed that damage earlier in terms of strain level. As we increase the loading rate the curve shows slight non-linearity.

2)   Tensile mechanical propertie:

Extracted data after testing summarized in the   Table 5.1 which gives tensile strength and tensile modulus. To determine the stiffness (slope of stress- strain curve) linear portion of curve was fitted with a linear curve.
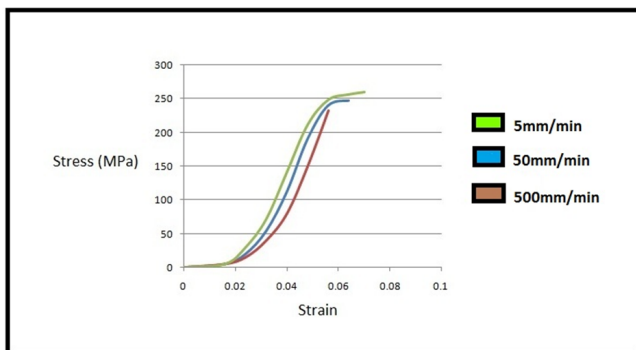

Fig 5.1: stress-strain diagram at various strain rate

Property	Tensile Strength(MPa)			Tensile Modulus(GPa)		
Loading Rate(mm/min)	5	50	500	5	50	500
SAMPLE 1	259.12	247.63	232.12	8.01	7.41	6.14
SAMPLE 2	261.28	246.30	231.98	8.25	7.28	6.21
SAMPLE 3	260.35	247.14	233.01	8.35	7.30	6.16
AVERAGE	**260.25**	**247.02**	**232.2**	**8.20**	**7.33**	**6.17**

Table5.1: Tensile properties at various strain rates.

Experimental results show gradual decrease in tensile properties such as tensile modulus and tensile strength as we increase the strain rate. This decrement is due to the increased brittleness of the GFRP material exhibited by the addition of nano filler.

5.2 Effect Of Strain Rate On Flexural Properties Of Nano- Filled GFRP.

Flexural Mechanical Properties: Flexural test were conducted on three different loading rates 50mm/min, 500mm/min on nano filled coupon. This loading rates applied nominal strain rates of $.0035S^{-1}$ and $.035S^{-1}$ on the specimen.   These strain rates are calculated by dividing loading rate of machine by the gauge length of the coupon.

As we increases the strain rate, material shows better flexural properties. Increase in loading rate increases the flexural strength slightly about 6.4% and rupture load by 6.5%. But displacement at rupture load decrease with increase in loading rate(about 2.8%). This deviation may be due to the inherent inertial problems associated with high-speed testing.

PROPERTIES	FLEXURE STRENGTH (N/mm²)		DISPLACEMENT (mm)		RUPTURE LOAD (KN)	
LOADING RATE	50mm/min	500mm/min	50mm/min	500mm/min	50mm/min	500mm/min
SAMPLE 1	11.3	12.1	10.92	10.20	0.46	0.49
SAMPLE 2	9.9	11.6	11.32	11.80	0.49	0.46
SAMPLE 3	11.5	11.1	11.72	11.00	0.43	0.52
AVERAGE	10.9	11.6	11.32	11.00	0.46	0.49

Table 5.2: Flexural properties at different strain rate

Stress-Strain Relation: The stress strain curve of the tested coupon under different strain rate is presented in figure:5.2. From Stress-Strain curves it is clear that mechanical properties of the specimen depend on the loading rate. For flexure test performed at high loading rates, it has been observed that damage delays in terms of strain level. Both flexure strength and rupture load improves with strain rate.
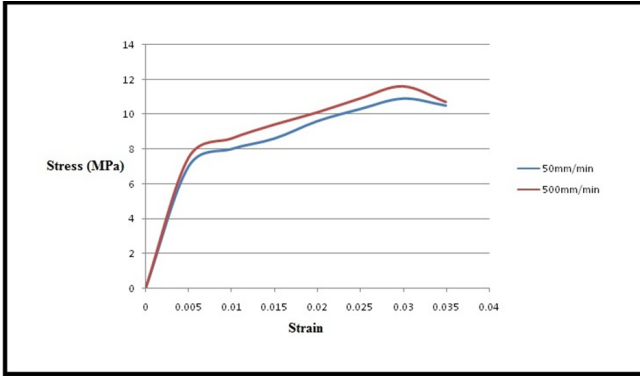
Fig 5.2: Stress strain curve of nano filled GFRP at various loading rate

Conclusion

Nano scaled silicon dioxide is good reinforcing component for GFRP because addition of it shows essential increase in stiffness (38.5%) and damage free range. So it is proven that nano filler can compensate the weak mechanical properties of GFRP exhibited by the polymer. But its tensile behaviour at higher strain rate is not satisfactory as compared to that at low strain rate. Stiffness of the material decreases about 34% as we increase the loading rate from 5mm/min to 500mm/min. It also increases the flexural strength about 22.5% at high strain rates. So nano scaled silicon dioxide filled GFRP is a good alternate for monolithic metal in mechanical industry especially in aerospace applications, but its usage will be limited for low rate of loading applications.

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