

The Effect of Milled Fiber Fillers on Static and Dynamic Properties of Epoxy Resin and Fibers – A Comprehensive Study and Investigation

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Abstract - For different weight percentages of each material added to the resin, the resin study of Kevlar and Carbon milled fibers was undertaken. The samples were then subjected to a three-point bending test for static testing on the Universal Testing Machine (UTM). A fatigue testing machine is used to conduct the dynamic testing. Additionally, structural stimulation of the material samples is performed using ANSYS software to verify the results. Additionally, the composite sample DMA (Dynamic Mechanical Analysis) is carried out. A load versus displacement graph was made for each fiber proportion in order to establish which portion of the filler must tolerate a greater level of force. To examine the flexural characteristics of the samples, flexural strength, flexural modulus, and flexural toughness have been plotted against the weights of the milled fibers supplied. In static testing, flexural strength, flexural, and flexural modulus each experience a rise of 141.6% and 0.45%, respectively, for samples with carbon milled fibers at a weight percentage of 3.5%. Flexural strength increases by 119% for samples containing Kevlar milled fibers at a weight percentage of 0.375%, whereas Flexural modulus decreases by 5%. In case of static testing of E-glass composite samples with different fillers, the Flexural properties increase in an optimal way. Also, in case of DMA, the E-glass composites incorporating milled carbon fibres and milled hybrid fibres have storage moduli that are 26.5% and 22.3% greater, respectively. While the storage modulus fell by 19.2% in E-Glass composite sample with milled Kevlar fibers. Also, the glass transition temperature also increases in an optimal way as expected. The Structural simulation is also made for verifying the results obtained from the experimental procedure.

Key Words: Mechanical Properties, Fibers, Fillers, Epoxy Resin, Composites and ANSYS

1.INTRODUCTION

1.1. COMPOSITE: AN OVERVIEW

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 fibres, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc. Advanced composites are composite materials that are traditionally used in the aerospace industries. These composites have high performance reinforcements of a thin diameter in a matrix material such as epoxy and aluminium. Examples are graphite/epoxy, Kevlar R/epoxy, and boron/ aluminium composites. These materials have now found applications in

commercial industries as well. 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 aluminium, and ceramics such as calcium- alumino silicate. 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. An aramid fiber is an aromatic organic compound made of carbon, hydrogen, oxygen, and nitrogen. Its advantages are low density, high tensile strength, low cost, and high impact resistance. Its drawbacks include low compressive properties and degradation in sunlight. The two main types of aramid fibers are Kevlar 29R and Kevlar 49R. Both types of Kevlar fibers have similar specific strengths, but Kevlar 49 has a higher specific stiffness. Kevlar 29 is mainly used in bulletproof vests, ropes, and cables. High performance applications in the aircraft industry use Kevlar 49. The fiber is produced by making a solution of proprietary polymers and strong acids such as sulfuric acid. The solution is then extruded into hot cylinders at 392°F (200°C), washed, and dried on spools. The fiber is then stretched and drawn to increase its strength and stiffness.

1.2. EPOXY RESINS

Epoxy resins are the most used resins. They are low molecular weight organic liquids containing epoxide groups. Epoxide has three members in its ring: one oxygen and two carbon atoms. The reaction of epichlorohydrin with phenols or aromatic amines makes most epoxies. Hardeners, plasticizers, and fillers are also added to produce epoxies with a wide range of properties of viscosity, impact, degradation, etc. Although epoxy is costlier than other polymer matrices, it is the most popular PMC matrix. More than two-thirds of the polymer matrices used in aerospace applications are epoxy based. The main reasons why epoxy is the most used polymer matrix material are High strength, Low viscosity and low flow rates, which allow good wetting of fibers and prevent misalignment of fibers during processing, Low volatility during cure, Low shrink rates, which reduce the tendency of gaining large shear stresses of the bond between epoxy and its reinforcement, Available in more than 20 grades to meet specific property and processing requirements.

1.3. ADVANTAGES OF COMPOSITES

Low weight- GRP profiles are low in weight. This makes them easier to work with and means that great weight savings can be achieved on the finished structure. Great strength- Building Profiles give you the same great strength as steel, but at only a quarter of the density. It is also possible to make weight savings in comparison with aluminium, as the density is 30 % lower. Corrosion-free- Fiberglass profiles are resistant to aggressive chemicals, and liquids. This makes them ideal for wastewater treatment plants, swimming pools, cooling towers and construction, where there is a risk of corrosion.

Chemical resistance- Fiberglass profiles are resistant to aggressive chemicals, liquids and alkalis. This makes them ideal for wastewater treatment plants, swimming pools, cooling towers and construction, where there is a risk of corrosion. Electrical insulation- GRP profiles provide electrical insulation and minimise the complexity of earthing. This makes the profiles a future-proof choice where the costs of both installation and future inspections can be reduced considerably. Easy to work with- GRP profiles are just as easy and fast to work with as timber. This means that solutions which incorporate profiles can be installed easily on site or adjusted to fit existing components, such as piping systems, etc. Minimal maintenance- GRP profiles have unrivalled durability and a long life, even in demanding conditions.

1.4. DISADVANTAGES OF COMPOSITES

High cost of fabrication of composites is a critical issue. For example, a part made of graphite/epoxy composite may cost up to 10 to 15 times the material costs. A finished graphite/epoxy composite part may cost as much as \$300 to \$400 per pound (\$650 to \$900 per kilogram). Improvements in processing and manufacturing techniques will lower these costs in the future. Already, manufacturing techniques such as SMC (sheet moulding compound) and SRIM (structural reinforcement injection moulding) are lowering the cost and production time in manufacturing automobile parts. Mechanical characterization of a composite structure is more complex than that of a metal structure. Unlike metals, composite materials are not isotropic, that is, their properties are not the same in all directions. Therefore, they require more material parameters. For example, a single layer of a graphite/epoxy composite requires nine stiffness and strength constants for conducting mechanical analysis. In the case of a monolithic material such as steel, one requires only four stiffness and strength constants. Such complexity makes structural analysis computationally and experimentally more complicated and intensive. In addition, evaluation and measurement techniques of some composite properties, such as compressive strengths, are still being debated. Repair of composites is not a simple process compared to that for metals. Sometimes critical flaws and cracks in composite structures may go undetected.

1.5. THREE-POINT BENDING TEST

The three bending test is a widely used method in structural analysis to evaluate the mechanical properties and strength of materials. It involves applying a load to a specimen that is supported at two points while a third point applies the force. This test is particularly useful in determining the flexural strength and stiffness of materials. During the test, the specimen is placed horizontal on two supports, with a loading point positioned at the center. A force is then applied downward on the loading point, causing the specimen to bend. As the load increases, the specimen undergoes deformation, and the resulting stress and strain distribution along its length are measured.

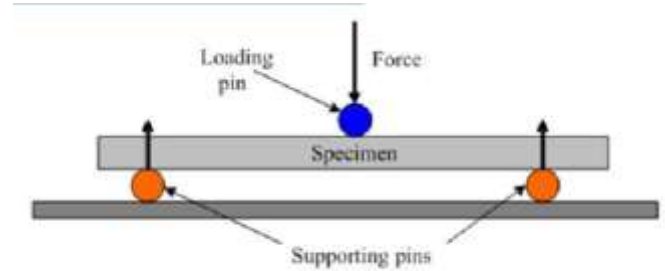


Figure 1 Three-point bending test

One of the key advantages of the three-point bending test is its ability to simulate realworld conditions, as many structural elements experience bending loads in practical applications. This test provides valuable information about a material's ability to withstand bending forces and its resistance to fracture. By analyzing the stress-strain relationship obtained from the three-point bending test, several important material properties such as modulus of elasticity, yield strength, ultimate strength and fracture toughness can be determined. This information is crucial for designing and assessing the structural integrity of various components such as beams, columns, and other load bearing elements.

1.6. DYNAMIC MECHANICAL ANALYSIS (DMA)

Dynamic Mechanical Analysis (DMA) is a sophisticated technique used to study the mechanical properties and behavior of materials under dynamic or varying loads. It is particularly used in analyzing viscoelastic materials, which exhibit both elastic and viscous properties, such as polymers, rubbers, composites and biomaterials. DMA involves subjecting a sample to oscillating forces, typically in the form of stress, strain or temperature, while simultaneously measuring its response in terms of mechanical properties like stiffness, damping and viscoelastic behavior.

The primary objective of DMA is to understand how a material's mechanical properties change with respect to different frequencies, temperatures or deformation amplitudes. By applying controlled mechanic stimuli to the sample, DMA allows researchers to investigate its dynamic modulus, loss modulus and damping coefficient, among other parameters. This information is crucial for designing and optimizing materials in various industries, including automotive, aerospace, construction and biomedical.

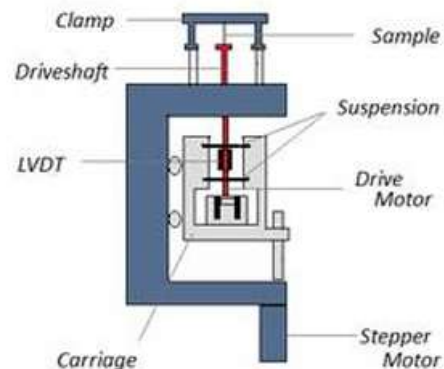


Figure 2 DMA Instrument

DMA instruments consist of a sample holder, a force or stress applicator and a displacement or strain sensor. The sample is typically subjected to sinusoidal or oscillatory loads, and the resulting mechanical response is measured and recorded. The analysis of the data provides valuable insights into a material's

viscoelastic behavior, including glass transition temperature, storage and loss moduli and the frequency dependence of mechanical properties. Dynamic mechanical analysis (DMA) is often used to measure properties that change with temperature, like the storage modulus (E'), the loss modulus (E''), and the damping factor ($\tan\delta$). The glass transition temperature (T_g) of the neat epoxy and filler-modified epoxy with rmCF, rmKF, and rmBF composite specimens was found by using the loss modulus, E'' . For the DMA measurements, a NETZSCH DMA 242 with a 3-point bend was used. Samples were made that were 80 mm x 10 mm x 3 mm. Using a heating rate of 30C/min and a fixed frequency of 5 Hz, the samples were tested at temperatures between 30 and 200oC.

1.7. STRUCTURAL STIMULATION

Structural simulation plays a crucial role in predicting the behaviour and performance of materials under various loading conditions. The three-point bending test is widely used to evaluate the mechanical properties and strength of materials, providing valuable insights for design and manufacturing purposes. The simulation is to be conducted using ANSYS, a powerful finite element analysis (FEA) software. The material properties and dimensions of the test specimen were defined, including young's modulus, Poisson's ratio, and the geometry of the beam. A meshing technique was employed to discretize the specimen, ensuring accurate representation of its geometry, and allowing for reliable stress and deformation calculations. The loading conditions were set up to replicate a three-point bending test, with the beam supported at two points and a force applied at the midpoint. The simulation considered linear elastic behaviour, assuming the material obeys Hooke's law. The analysis provided important results such as stress distribution, deflection, and load-displacement curve. The stimulation results will reveal the stress distribution along the beam's cross section, highlighting regions of high stress concentration. The deflection of the specimen under the applied load is also to be determined, indicating the beam's flexibility and resilience. Furthermore, the load-displacement curve provides insights of material's stiffness, yield point and ultimate strength.

2. LITERATURE SURVEY

Biraj Dhibar, Et al., "Sugarcane Bagasse Reinforced Polyester Composites (2018)". The conclusions drawn from this paper are Tensile and bending properties in sugarcane bagasse reinforced composites are highest for 10% bagasse fiber composites and decline as the percentage of fiber increases. On the other hand, when the percentage of fiber rises, the water absorption also rises. J. Wu, X.H. Cheng, "The tribological properties of Kevlar pulp reinforced epoxy composites under dry sliding and water lubricated condition (2006)". The paper produced the result as addition of Kevlar pulp into epoxy can reduce friction coefficient and specific wear rate of the materials in sliding against stainless steel under both dry and wet conditions. For 40% weight percentage of Kevlar pulp, optimum wear resistance was obtained. Nabilah Afiqah Mohd. Radzuan, Et al., "Effect of milled carbon fiber filler on electrical conductivity in highly conductive polymer composites (2015)". The conclusions of the paper are the electrical conductivity of the composite incorporated with CNT and CB as secondary fillers and Carbon fiber as primary filler has been analyzed. The addition of the CNT provided better through plane conductivity

compared to addition of CB. Also, the electrical conductivity of composite with CF as primary filler is higher when compared with composite made of graphite as primary filler and CNT as secondary filler.

Sanjay Soni, Et al., "Synthesis and Characterization of Epoxy based Hybrid Composite Reinforced with Glass Fiber and Milled Carbon (2017)". Glass fiber composite with epoxy matrix and milled carbon fibers as fillers shows increased impact resistance for upto 2% weight percentage of milled carbon fibers and on increasing shows decrease in impact resistance. Similar pattern is followed for flexural strength also. But in case of tensile properties, the properties increase with increase in weight percentage of milled carbon fibers. H.P.S Abdul Khalil, Et al., "Exploring biomass-based carbon black as filler in epoxy composites: Flexural and Thermal properties (2010)". Epoxy Composites containing 5% carbon black obtained from agricultural waste materials like bamboo stem, coconut shell than a neat epoxy polymer. Also, the thermal stability of epoxy composites was and oil palm empty fruit bunch has higher flexural strength and flexural modulus also increased by the addition of the carbon black (CB). Mohd. Yusuf Zakaria, Et al., "Effect of the addition of Milled Carbon fibers as a secondary filler on the electrical conductivity of Graphite/ epoxy composites for electrically conductive material (2015)". A Graphite epoxy polymer with milled carbon fibers shows an increase of epoxy polymer without carbon milled fibers. The flexural strength has also 30% in electrical conductivity for 2%CF content when compared with 8 a graphite increased for the single filler system. Aamer Khan, Et al., "Low-Cost Carbon Fillers to improve Mechanical properties and Conductivity of Epoxy composites (2015)". The mechanical and electrical performance of two types of Carbon fillers (MWCMTs and Biochar) dispersed in epoxy resin were investigated. In case of mechanical properties, Biochar has higher strength and stiffness. Also, Biochar also increases the microwave properties.

P.Surya Nagendra, Et al., (2016) "A study on Dynamic Mechanical Analysis of Natural Nano Banana Particle Filled Polymer Matrix Composites". The temperature affects the polymer resins' dynamic characteristics. Internal damping should be made easier by the fact that when temperature rises, the storage modulus E' declines and the loss modulus E'' rises. According to the DMA investigation, the physical interaction between the polymer and nanoparticles is responsible for the higher modulus and the positive shift in the position of the $\tan\delta$ peak. M.J.M.Ridzuan, Et al., (2016) "Thermal behaviour and dynamic mechanical analysis of Pennisetum purpureum/glass-reinforced epoxy hybrid composites". The hybrid P. purpureum/glass-reinforced composites with the 5% alkali-treated P. purpureum fibers had the highest storage and loss moduli. For the neat epoxy, the highest damping factor value was noted. T_g values of 64 C were found for both the neat epoxy and the hybrid composite made with untreated P. purpureum fibers. However, the T values of the hybrid composites with the P. purpureum fibers treated with 5% and 10% alkali were 67 and 63 C, respectively. Ankita Hazarika, Et al., (2014) "Dynamic mechanical analysis, biodegradability and thermal stability of wood polymer nanocomposites". The exfoliation and dispersion of nanoclay in the composites were investigated using TEM. After nanoclay was added to the composites, their thermal stability improved, and it continued to do so as the nanoclay content of the composites increased. The increase in storage modulus, loss modulus, and

mechanical loss factor for composites treated with polymer and nanoclay suggested improved interfacial contact between clay, crosslinker, and wood. P. Ghosh, Et al., (1996) "Dynamic Mechanical Analysis of FRP Composites based on different fiber reinforcements and epoxy resin as the matrix material". Dynamic mechanical thermal analysis was performed on three composite laminates made from E-glass or N-glass chopped strand mats (CSMs), Jute (J) fabrics, and amine-cured epoxy resin as the matrix material over the temperature range of 30–180°C at a fixed frequency of 1 Hz. Between 0.21 and 0.25 percent of the total volume was made up of fibers. The three fibers have a mutually reinforcing effect in the following order: E-glass, N-glass, Jute. Glass-Jute hybrid composites have E' values that fall between those of glass- and Jute-reinforced composites. S.N.Goyanes, Et al., (2002) "Dynamic Mechanical Analysis of Particulate Filled Epoxy Resin". The storage modulus and loss tangent were determined at frequencies ranging from 7.8 to 323 Hz and from ambient temperature to 460 K. The storage modulus increased significantly as increased; however this rise was greater in the rubbery zone than in the glassy region. The filler concentration had no effect on the storage modulus's frequency dependency in the glassy zone but had a modest effect in the rubbery zone. H.P.S. Abdul Khalil, Et al., (2013) "Dynamic Mechanical Analysis of Activated Carbon Filled Epoxy Nanocomposites". The influence of activated carbon on the mechanical characteristics of epoxy composites was evaluated using dynamic mechanical analysis. In the case of AC employing KOH, the storage modulus of 5% AC-CNS filled epoxy composite (2885 MPa) is higher than that of 5% AC BS and 5% ACEFB. The neat epoxy exhibits the highest $\tan\delta$ curve peak height (0.65), indicating a significant degree of molecular mobility. E. Logakis, Et al., (2008) "Structural, Mechanical and Electrical characterization of epoxy-amine/Carbon black nanocomposites". T_g dependence on filler material exhibits unusual behaviour. An increase to a maximum, comparable to around 0.7% w/w CB, followed by a drop. The increase in high temperature modulus (rubbery state) with increasing filler content suggests that the CB functions as a traditional filler and that the polymer interacts with the filler particles. It is surprising that the filler content has no effect on the low temperature modulus (glassy state).

3. EXPERIMENTAL PROCEDURE

3.1. FILLERS AND CHEMICALS USED

3.1.1. Carbon fillers



Figure 3 Carbon filler

Milled fibers are a short form of carbon fibers, typically approximately 100µm in length, used as a reinforcing material in the composites industry. Milled carbon fibers manufactured from recycled carbon fibers are used in a wide range of applications when there is a need for improving mechanical properties like tensile strength and modulus, dimensional stability and also for improving electrical and electrostatic conductivity. The very high tensile strength and isotropic orientation of milled carbon fibers also reduces shrinkage and distortion in cast or laminated composite materials. Since carbon fibers are electrically conductive, milled carbon fibers can be mixed into paints, resins and other materials to make them electrically conductive or anti-static.

3.1.2. Kevlar filler

Milled Kevlar fibers are a very resilient material widely used for its strength and durability. This indicates that the milled Kevlar fibers are often used in very high stress applications such as body armour material, hull reinforced and tyre production. It is also a fantastic non-toxic alternative to asbestos. These fibers and flocks can also be added during pre-form production to friction products, seals and gaskets.



Figure 4 Kevlar filler

3.1.3. Epoxy and hardener

Epoxy resin Araldite LY 556 is extensively used as a reinforcing material due to its medium viscosity and chemical resistivity. Property of this resin can be easily modified within wide limits with the help of fillers and hardeners. The composition of this resin is based on Bisphenol-A which makes it suitable for high performance FRP composite applications such as pultrusion, pressure moulding, filament winding and so on. This resin is known for its exceptional mechanical, good fiber impregnation and thermal and dynamic properties. Also, Epoxy resin LY 556 is having a low tendency to crystallize and hence it is preferred for aircraft and aerospace adhesives. Hardener Aradur HY 951 is a low viscosity, unfilled epoxy casting resin system hardener, curing at room temperature with high filler addition possibility. The salient properties of this hardener include good mechanical strength, good resistance to atmospheric and chemical dehydration and excellent electrical properties. Mixing an epoxy resin and a hardener together starts a chemical reaction that produces heat- an exothermic reaction. It is claimed that after curing the bond is impervious to boiling water and to all common organic solvents.

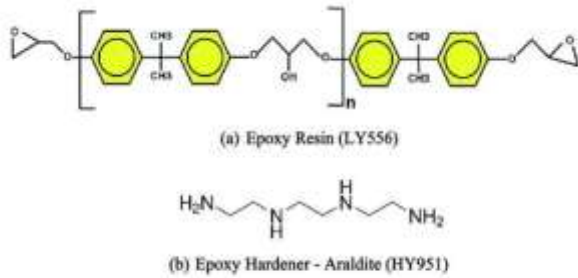


Figure 5 Chemical composition of Epoxy and Hardener

3.2. FABRICATION

A silicone mould is created to hold the matrix and filler material mixture as part of the preparation for the specific laminate. This mold enables the simultaneous curing of ten samples. Using previously prepared composite samples with the identical dimensions, the mould's impressions are created. For static flexural testing, the sample is estimated to be 150 mm x 25 mm in size. The process for creating the test specimen starts once this mold is prepared. The epoxy resin LY 556 and the hardener HY 951 are mixed in a 10:1 ratio to create the base sample. The epoxy resin is quantified and removed from samples that contain Kevlar fibers that have been machined. The necessary weight percentage of milled Kevlar fibers is then determined. The milled Kevlar fibers utilized have weight percentages of 0.25%, 0.375%, 0.5%, 0.675%, 0.75% and 1% respectively. In each weight percentage, five samples have been fabricated and tested for more accurate results. So, a total of 30 samples has been made with different weight percentages of milled Kevlar fillers. Following the measurement of the necessary quantity of Kevlar fibers, the milled Kevlar fibers are combined with the epoxy resin using a magnetic stirrer. Using a magnetic stirrer, the epoxy resin and milled fiber mixture is blended for an hour. The magnetic stirrer helps ensure that the fibers and epoxy resin are mixed uniformly.



Figure 6 Magnetic stirrer

The fibers are combined, then placed into silicone molds where they are allowed to cure for 24 hours. After the fibers have been post-cured, the samples are left in the temperature chamber for two hours at 90°C. The same process is used to fabricate samples using milled carbon fibers. However, when using milled carbon fibers, the epoxy resin and milled fiber mixture is stirred for 30 minutes using a magnetic stirrer.



Figure 7 Sonicator

This is followed by placing the mixture in a sonicator for ultrasonic dispersion. The sonicator is simple to use and adaptable since it effectively disperses the particles in the epoxy. With the aid of the shock waves generated by cavitation in the ultrasonic mixture, it breaks down the surrounding covalent bonds.



Figure 8 Temperature Chamber

The milled carbon fibers utilized have weight percentages of 0.5%, 1%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4%, and 4.5%, respectively. In the same manner, five samples in each weight percentage have been created and evaluated to ensure more precise findings. So, 45 samples in all have been created using various weight ratios of milled Carbon fillers. After the mixture has been ultrasonically dispersed, it is mechanically stirred by adding the hardener. The mixture is then put into the silicone mold and allowed to set for 24 hours. The same procedure is followed for the remaining weight percentages.

S.No	Weight percentage of milled Carbon fillers	Weight percentage of milled Kevlar fillers	Weight percentage of milled fillers in hybrid samples
01	0.094%	0.28%	0.375%
02	1.75%	0.187%	1.937%
03	1.75%	0.375%	2.125%
04	2.625%	0.875%	3.5%
05	3.5%	0.187%	3.687%
06	3.75%	0.375%	3.875%

Table 1 Combinations of weight percentage of milled Carbon and Kevlar fillers used for hybrid samples

Additionally, milled Carbon and Kevlar fillers are used in various ratios to create the epoxy and E-glass composite sample materials. As a result, the ratios listed in the table below are used to create these hybrid samples. The hand lay-up approach is used to fabricate the E-Glass composite samples. The manufacture of composites uses the same 10:1 resin to hardener ratio. The same process is used to combine milled fibers and a resin-hardener combination. The E-glass fibers are laid manually onto the mold surface ensuring proper orientation and alignment. The fibers are then impregnated with resin- hardener and milled fibers mixture using a roller. This step ensures that the fibers are properly wetted out and bonded with the resin. After complete impregnation, additional layers are added to build up the desired thickness and strength. Finally, the composite laminate is left to cure under controlled temperature and pressure conditions allowing the resin to harden and bond the fibers together resulting in a rigid and durable E-Glass composite structure. The table below shows the number of E-Glass composite as well as epoxy samples fabricated for static flexural testing process. From the epoxy samples fabricated and tested, the weight percentages of samples obtained will finally be tested and optimal results have been obtained which are then used for fabrication of E-Glass composite samples.

Composition of the sample	Epoxy samples	Total no of samples
Base sample without filler	05	05
Sample with 0.25% milled Kevlar fillers	05	30
Sample with 0.375% milled Kevlar fillers	05	
Sample with 0.5% milled Kevlar fillers	05	
Sample with 0.675% milled Kevlar fillers	05	
Sample with 0.75% milled Kevlar fillers	05	
Sample with 1% milled Kevlar fillers	05	
Sample with 0.5% milled Carbon fillers	05	45
Sample with 1% milled Carbon fillers	05	
Sample with 1.5% milled Carbon fillers	05	
Sample with 2% milled Carbon fillers	05	
Sample with 2.5% milled Carbon fillers	05	
Sample with 3% milled Carbon fillers	05	
Sample with 3.5% milled Carbon fillers	05	30
Sample with 4% milled Carbon fillers	05	
Sample with 4.5% milled Carbon fillers	05	
Sample with 0.375% milled Hybrid fillers	05	
Sample with 1.937% milled Hybrid fillers	05	
Sample with 2.125% milled Hybrid fillers	05	
Sample with 3.5% milled Hybrid fillers	05	110
Sample with 3.687% milled Hybrid fillers	05	
Sample with 3.875% milled Hybrid fillers	05	
Total no of epoxy samples		110

Table 2 Quantity of epoxy samples fabricated for static testing and their filler composition.

Dynamic Mechanical Analysis (DMA) is done only for E-Glass composite samples with optimal results from static three-point bending test. For Dynamic Mechanical Analysis, E-Glass composite samples were made in the size of 80 mm x 10 mm x 3 mm. The E-glass composite samples are fabricated

with the composition of milled fillers in the ratios listed in the table below.

S.No	Composition of the Filler	No. of samples (For Static testing)	No of Samples (for DMA)
01	E-Glass composite without fillers	05	01
02	E-Glass composite with 0.375% milled Kevlar filler	05	01
03	E-Glass composite with 3.5% milled Carbon filler	05	01
04	E-Glass composite with 0.375% milled hybrid filler (0.28% milled Kevlar + 0.094% milled Carbon fibers)	05	01
Total no of samples		20	04

Table 3 Quantity of composite samples fabricated for static testing and DMA and their filler composition

3.3. PROCEDURE FOR STATIC TESTING

Pure epoxy, 0.25%, 0.375%, 0.5%, 0.675%, 0.75%, and 1% milled Kevlar fiber composition samples, and 0.5%, 1%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4%, and 4.5% milled carbon fiber composition samples were created. The samples are tested using a Universal Testing Machine (UTM). The table below lists the specifications of the Universal Testing Machine. The flexural properties of the samples have to be examined, hence a three-point bending test is performed.

UNIVERSAL TESTING MACHINE Specifications	
Force capacity 100 kN	
Minimum test speed	0.1 mm/min
Maximum test speed	500 mm/min
Crosshead return speed	700 mm/min

Table 4 Specifications of Universal Testing Machine (UTM)

With the loading device in the center, the sample should be positioned evenly on the UTM's supports. To create a span, the supports should be placed so that their distance from one another is greater than the length of the sample. To guarantee that the sample is appropriately aligned, the supports should be raised or lowered to the proper height and level. The loading device should be used to exert pressure on the sample's center after the UTM has been set to the proper load rate.



Figure 9 Epoxy Samples with milled Carbon fibers after testing



Figure 10 Epoxy Samples with milled Kevlar fibers after testing

As the force is raised, the UTM should gauge and note the sample's load and displacement. Continue the test until the sample breaks or deforms. To determine the material's flexural strength and stiffness, the data gathered during the test should be analyzed. The yield strength, elastic modulus, and other material parameters can all be determined using the UTM software. The sample's concave side is compressed during this test, while its convex side is under tension.

3.4. PROCEDURE FOR DYNAMIC MECHANICAL ANALYSIS (DMA)

The DMA testing procedure first involves the fabrication of the sample which has dimensions of 80mm length, 10mm width and 3mm thickness. The sample is then loaded onto the DMA machine, and the desired testing parameters such as temperature, frequency and strain amplitude are set. Using a heating rate of 30C/min and a fixed frequency of 5 Hz, the samples were tested at temperatures between 30 and 200oC. The DMA machine applies oscillatory forces or deformations to the sample while simultaneously measuring its mechanical response, including modulus, damping and viscoelastic behavior. The DMA findings are expressed in terms of temperature-, time, and frequency-dependent storage modulus (E'), loss modulus (E''), and damping factor ($\tan \delta$).

3.5. PROCEDURE FOR STRUCTURAL SIMULATION

The testing procedure in ANSYS first includes creating the 3D geometry of the beam according to the required length, width and thickness specified by the ASTM standards. Appropriate material properties such as young's modulus, Poisson's ratio and other relevant properties of the beam specimen are given. These properties determine the material's behaviour under loading conditions. The mesh of the beam is done by using ANSYS's meshing tools with appropriate element type and mesh density to ensure accurate representation of the geometry and capture stress concentrations. Also, it is to be ensured that the mesh is refined in regions where the stress concentrations is expected to be high, such as loading point and support points. Appropriate boundary conditions are being applied to simulate the three-point bending test. The beam is fixed at two support points by constraining their degrees of freedom in the relevant directions. A displacement load is applied at the mid-point such that the bending load is simulated. Based on the experimental setup, the magnitude of load is taken. The solution process will compute the stress distribution, deflection, and other relevant outputs. Once the analysis is done, the results are post processed to visualise and interpret the data. The load-displacement curves, stress contours and deflection profiles are plotted to analyse the behaviour of the beam specimen.

4. RESULTS AND DISCUSSION

The milled Kevlar and Carbon fibers are manufactured after being weighed in accordance with the chosen weight percentages. For this investigation, plain epoxy samples are compared to milled carbon fiber concentrations of 0.5%, 1%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4%, and 5% weights. Additionally, the milled Kevlar fiber concentrations are 0.25%, 0.375%, 0.5%, 0.675%, 0.75%, and 1%. The samples are examined for flexural characteristics using the Universal Testing machine (UTM))



Figure 11 Three-point flexural test

The three-point bending method is applied for testing and load is exerted till the point of rupture. The results obtained from the flexural test are tabulated, plotted and discussed below.

4.1. EPOXY SAMPLES (STATIC TESTING)

4.1.1. Epoxy samples with milled Kevlar fibers

It is very well known that cured pure epoxy is brittle in nature i.e., it fractures when subjected to stress but has little tendency to deform before rupture. Furthermore, it has a poor capacity to resist the impact and vibration of loads. From the Force vs Position graph for milled fibers, it can be seen that the ultimate yield force gradually increases with the increase in milled fibers concentration.

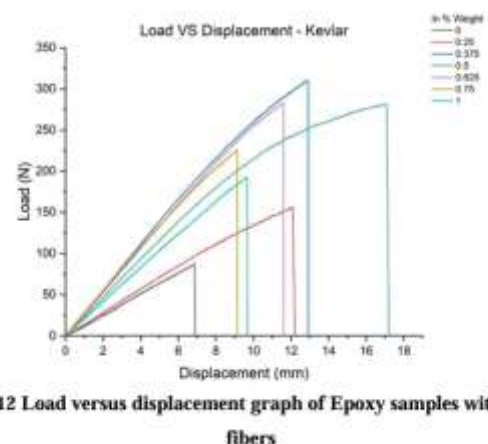


Figure 12 Load versus displacement graph of Epoxy samples with Kevlar fibers

Also, from the graphs it can be noted that up to a particular weight concentration, the ultimate yield force increases with increase in weight percentage. After that, the ultimate yield force decreases with increase in weight percentage. The percentage at which the maximum ultimate yield force is obtained is taken as the percentage of interest for which the flexural properties are analysed. For samples with milled Kevlar fibers, the maximum ultimate yield force is obtained for 0.375% weight percentage. The flexural strength, flexural

toughness and flexural modulus are the properties that are being analysed. For this purpose, these values are being plotted against weight percentage of milled fibers to get the required values.

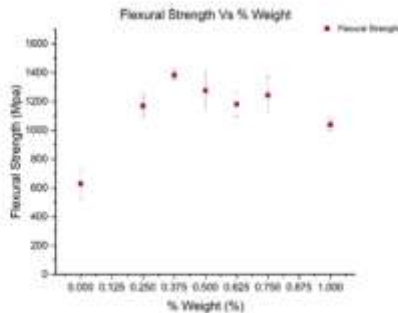


Figure 13 Flexural strength versus weight concentration graph for Epoxy samples with milled Kevlar fibers

Flexural strength refers to the ability of a material to resist bending or deformation when subjected to an external force or load. It measures the maximum stress a material can withstand before it breaks or fractures. For Epoxy samples with different concentrations of milled Kevlar fibers, the maximum flexural strength is obtained for samples with 0.375% milled Kevlar fibers which is 1383.25 MPa.

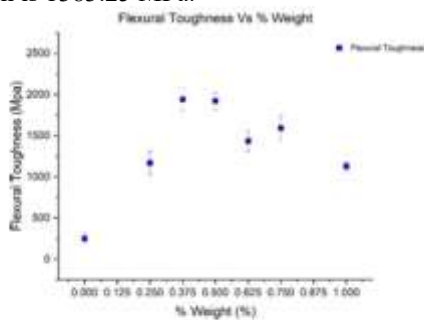


Figure 14 Flexural toughness versus weight concentration graph for Epoxy samples with milled Kevlar fibers

Flexural toughness is the ability of the composite to absorb energy and resist fracture when subjected to bending loads. In this case, epoxy samples with 0.375% of milled Kevlar fibers has the higher flexural toughness value of 1943.09 MPa compared to Epoxy samples with other weight percentages of milled Kevlar fibers. The area under the curves for the plot of each weight percentage depicts the energy absorbed to proceed to failure which is essentially the toughness of the material. From a primary analysis, it is noted that as the weight percentage of the milled fibers increases, the toughness also increases which can be visualized from the graph above.

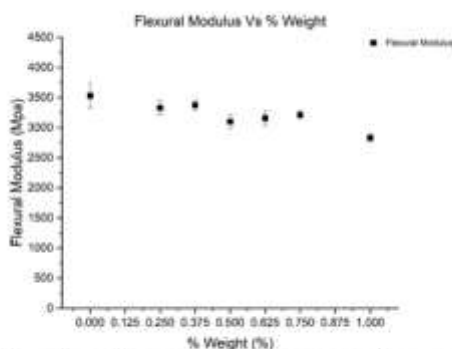


Figure 15 Flexural modulus versus weight concentration graph for Epoxy samples with milled Kevlar fibers

In case of flexural modulus too, Epoxy samples with 0.375% of milled Kevlar fibers has the higher flexural toughness value of 3374 MPa compared to Epoxy samples with other weight percentages of milled Kevlar fibers. From the graphs above plotted, it is evident that all the three flexural properties are higher for 0.375% weight percentage of milled Kevlar fibers. These properties are being compared with the base sample of epoxy resin without any milled fibers which is being tabulated below.

Properties	Base Sample (MPa)	Sample with 0.375% milled Kevlar fibers (MPa)	Percentage increase (%)
Ultimate yield stress	71.22	290.18	307.44
Flexural Strength	629.28	1383.25	119
Flexural Toughness	250.03	1943.09	677
Flexural Modulus	3532	3374	-5

Table 5 Comparison of properties of Base Epoxy samples and Samples with 0.375% milled Kevlar fibers

4.1.2. Epoxy samples with milled Carbon fibers

In the same manner, the flexural properties of the sample with milled carbon fibers are also calculated and analysed. For samples with milled carbon fibers, the weight concentration of the milled fibers starts from 0.5% to 5% with an increment of 0.5%.

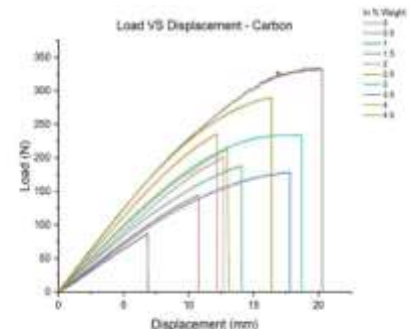


Figure 16 Load versus displacement graph of Epoxy samples with Carbon fibers

From the graphs, it is concluded that after 3.5% weight concentration of milled carbon fibers, the flexural properties and load carrying capacity of the sample decreases which indicated that the weight percentage that is to be concentrated is 3.5%. The graphs also show that, up to a certain weight concentration, the ultimate yield force increases as weight % increases. The ultimate yield force then decreases as weight % rises. The maximum ultimate yield force for samples made of milled carbon fibers is attained at 3.5% weight percentage.

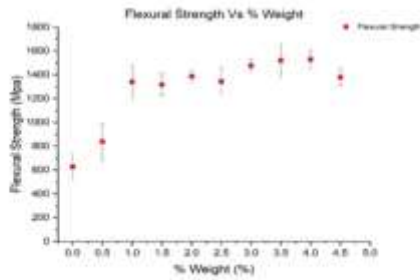


Figure 17 Flexural strength versus weight concentration graph for Epoxy samples with milled Carbon fibers

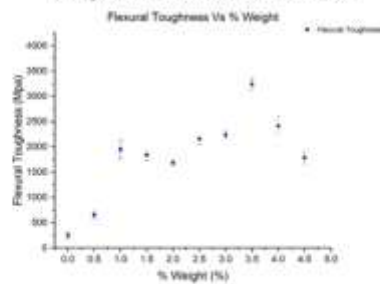


Figure 18 Flexural toughness versus weight concentration graph for Epoxy samples with milled Carbon fibers

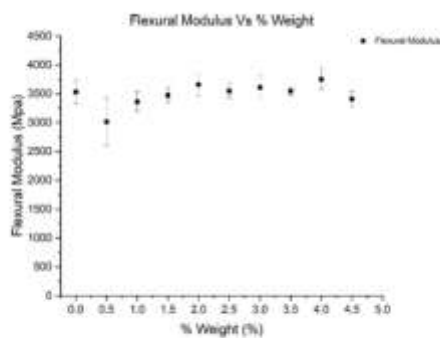


Figure 19 Flexural modulus versus weight concentration graph for Epoxy samples with milled Carbon fibers

The above three graphs depict the flexural properties of the milled carbon fibers. Form the graphs it is evident that all the three flexural properties are higher for 3.5% weight percentage of milled carbon fibers. These properties are being compared with the base sample of epoxy resin without any milled fibers which is being tabulated. The load carrying capacity, flexural strength, flexural toughness and flexural modulus of the samples with milled carbon fibers gets a maximum value for 3.5% concentration of the milled fibers. Also, it is to be noted that all the above-mentioned increases with increase in weight concentration of the milled fibers up to 3.5% weight percentage of the milled fibers.

Properties	Base sample (MPa)	Sample with 3.5% milled Carbon fibers (MPa)	Percentage increase (%)
Ultimate yield stress	71.22	303.202	325.73
Flexural Strength	629.28	1520.19	141.6
Flexural Toughness	250.03	2969.81	1087.8
Flexural Modulus	3532	3548	0.45

Table 6 Comparison of properties of Base Epoxy samples and Samples with 3.5% milled Carbon fibers

4.1.3. Epoxy samples with both milled Carbon and Kevlar fibers

The flexural properties of the epoxy samples containing milled carbon and Kevlar fibers have also been examined. The weight percentage of the milled fibers was examined and measured by repetitive iterations, and the findings are shown in the graphs below.

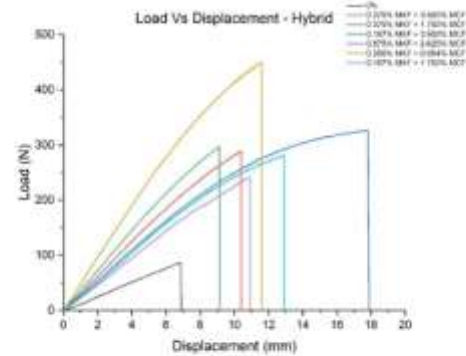


Figure 20 Load versus concentration graph for Epoxy samples with both milled carbon and Kevlar fibers

From the load versus displacement graph, it is clearly depicted that the hybrid Epoxy samples with 0.280% Milled Kevlar fibers (MKF) and 0.094% Milled Carbon fibers (MCF) shows the highest load carrying capacity among all other epoxy samples of different weight percentages.

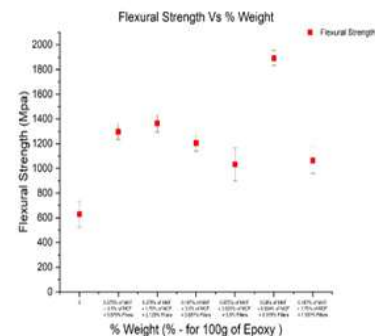


Figure 21 Flexural strength versus weight concentration graph for Epoxy samples with both milled Carbon and Kevlar fibers

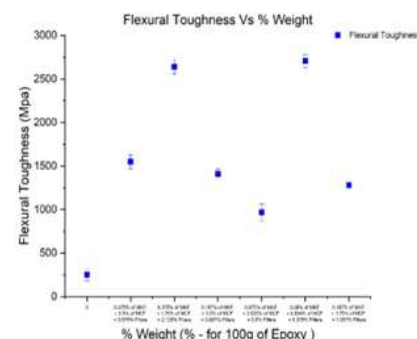


Figure 22 Flexural toughness versus weight concentration graph for Epoxy samples with both milled Carbon and Kevlar fibers

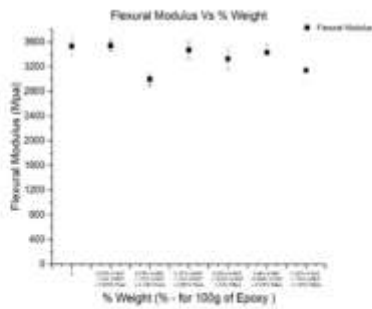


Figure 23 Flexural modulus versus weight concentration graph for Epoxy samples with both milled Carbon and Kevlar fibers

Properties	Base samples (MPa)	Sample with both milled Carbon and Kevlar fibers(MPa)	Percentage increase (%)
Ultimate yield stress	71.22	432	506
Flexural Strength	629.28	1891.33	201
Flexural Toughness	250.03	2538.78	915
Flexural Modulus	3532	3430	-3

Table 7 Comparison of properties of Base Epoxy samples and Samples with 0.375% milled hybrid fibers

The flexural characteristics of the epoxy samples with milled hybrid fibers are shown in the three graphs above. The graphs clearly show that samples with 0.280% milled Kevlar fibers (MKF) and 0.094% milled carbon fibers (MCF) had higher values for all three flexural parameters. These characteristics are contrasted with those of an epoxy resin base sample that contains no milled fibers and is being tabulated.

4.2. E-GLASS COMPOSITE SAMPLES (STATIC TESTING)

The load versus displacement graphs is plotted for E-Glass composite samples with 0.375% milled Kevlar fibers, 3.5% milled Carbon fibers and 0.375% milled hybrid fillers (0.28% milled Kevlar fibers and 0.094% milled Carbon fibers) and also for composite samples without any fillers.

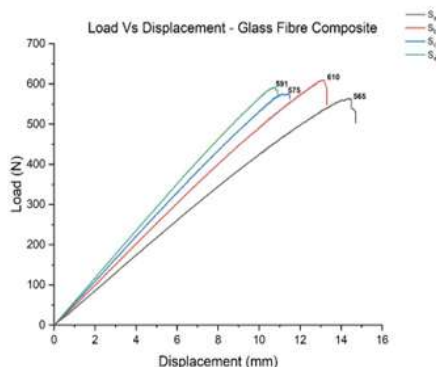


Figure 24 Load versus concentration graph for E-Glass composite samples without fillers

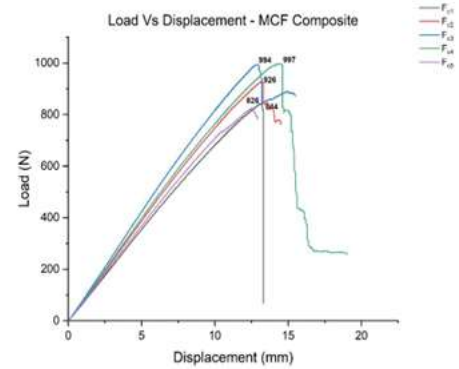


Figure 25 Load versus concentration graph for E-Glass composite samples with milled Carbon fibers

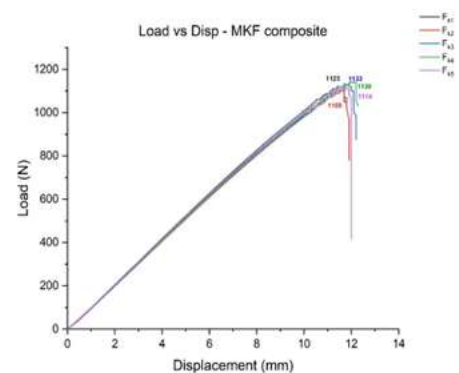


Figure 26 Load versus concentration graph for E-Glass composite samples with milled Kevlar fibers

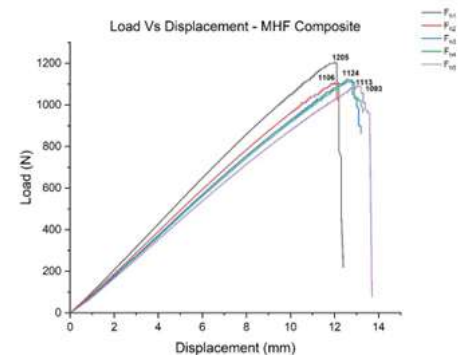


Figure 27 Load versus concentration graph for E-Glass composite samples with both milled Carbon and Kevlar fibers

A consolidated load versus displacement graph is created using the values from the graphs mentioned above so that it is possible to compare and analyse the load carrying capacity of E-Glass composites with various filler compositions. From the below graph, it is clearly evident that the E-Glass composite sample with both milled Carbon and Kevlar fibers exhibit higher load carrying capacity when compared with composite samples containing some other filler composition. The E-Glass composite sample with 0.094% milled carbon fibers and 0.28% milled Kevlar fibers shows a highest load carrying capacity of 1205 MPa whereas the E-Glass composite sample with 3.5% milled carbon fibers, 0.375% milled Kevlar fibers and E-Glass composite sample without fillers exhibit a load carrying capacity of 997 MPa, 1133 MPa and 610 MPa respectively.

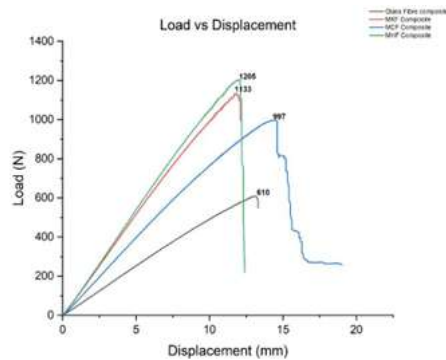


Figure 28 Comparison of Load versus concentration graph for E-Glass composite samples with different fillers

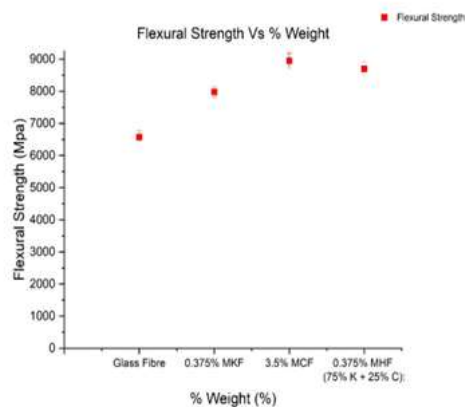


Figure 29 Comparison of Flexural strength versus weight percentage graph for E-Glass composite samples with different fillers

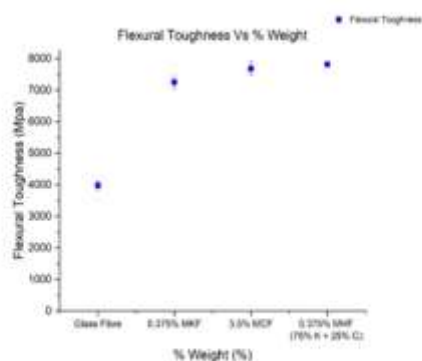


Figure 30 Comparison of Flexural toughness versus weight percentage graph for E-Glass composite samples with different fillers

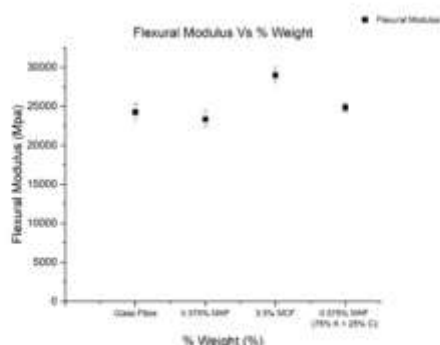


Figure 31 Comparison of Flexural modulus versus weight percentage graph for E-Glass composite samples with different fillers

The three forementioned graphs demonstrate how the flexural properties depend on the filler weight percentage. It is evident that when compared to other composite samples, the E-Glass composite sample with 3.5% milled carbon fibres exhibits higher values for flexural properties. Furthermore, when compared to composite samples without any fillers, whatever fillers are utilised, the flexural characteristics as well as the load carrying capacity improve.

Properties	Base sample (MPa)	Sample with 0.375% milled Kevlar fibers (MKF) (MPa)	Sample with 3.5% milled Carbon fibers (MCF) (MPa)	Sample with 0.280% milled Kevlar and carbon fibers (MPa)
Ultimate yield stress	585.25	1122.4	917.4	1128.2
Flexural strength	438.37	531.89	596.77	580.22
Flexural Toughness	3976.7	7256.8	7683.8	7819.7
Flexural Modulus	24250	23360	28980	24840

Table 8 Comparison of properties of Base E-Glass composite sample and Samples with different milled fibers

4.3. E-GLASS COMPOSITE SAMPLES (DMA)

The DMA findings are expressed in terms of temperature-, time-, and frequency dependent storage modulus (E'), loss modulus (E''), and damping factor ($\tan \delta$). DMA results show that the glass transition occurred at various temperatures and time periods, depending on the testing procedure.

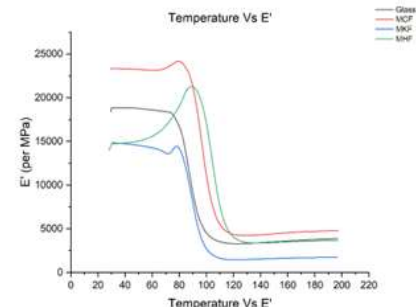


Figure 32 Comparison of Storage modulus versus Temperature graph for E-Glass composite samples with different weight percentage of fillers

Composites have storage moduli that vary with temperature. E-Glass composites with milled Carbon fibers and milled hybrid fibers are found to increase the storage modulus by 26.5% and 22.3%. While for E-Glass composites with milled Kevlar fibers, the storage modulus decreased by 19.2%, indicating some issue in a successful integration of milled Kevlar fibres in the composite. It is expected that there will be increased interaction between the polymer chains and the surfaces of the recycled milling fillers when the glass transition temperature rises. Fillers are believed to increase the glass transition temperature of the soft phase by slowing down the moving sections of the chain and forming an interphase zone. The storage modulus rises in the presence of recycled milled fillers, possibly as a function of both the mechanical limitations and the viscoelastic matrix in which the fillers are embedded. When the particles are concentrated enough, they prevent the matrix from moving and deforming, which allows the stress from the epoxy to be transferred to the reinforcement of the recycled milled fillers.

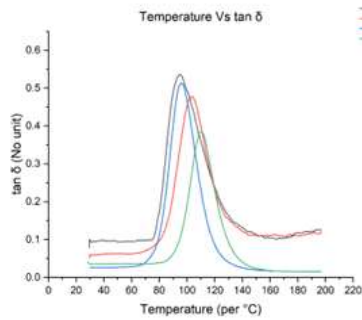


Figure 33 Comparison of Damping factor ($\tan \delta$) versus Temperature graph for E-Glass composite samples with different weight percentage of fillers

A plot of the $\tan \delta$ versus temperature for E-Glass composites with milled Carbon fibers, milled Kevlar fibers and milled hybrid fibers and base composites is presented in the above figure. Multiple factors, including interphase zones, fibre breakage, fibrematrix interfaces, frictional resistance, and matrix cracking, contribute to the damping properties of composite materials. The glass transition region was also where the damping factor was highest for the base composite. On the other hand, when recycled milled fillers were included, the damping curve sloped downward. The glass transition temperature for base composite was 95.4oC and the Tg shifted towards higher values with 104 oC, 96.7 oC and 110 oC for milled Carbon fibers, milled Kevlar fibers and milled hybrid fibers composites and the corresponding damping factors were 0.53, 0.51, 0.47 and 0.38 for base composite, milled Carbon fibers, milled Kevlar fibers and milled hybrid fibers composites, respectively.

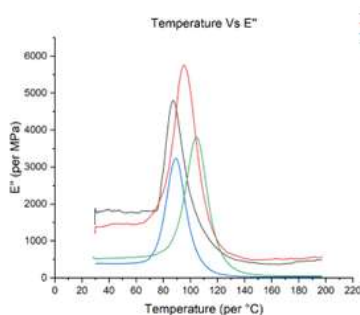


Figure 34 Comparison of Loss modulus versus Temperature graph for E-Glass composite samples with different weight percentage of fillers

With the addition of recycled milled fillers modified composites, the intensity of the $\tan$ peak was seen to decrease. Hybrid milled fillers composite showed a maximum damping parameter of 0.38, an increase of 24% over milled Carbon fibers and milled Kevlar fibers. It has been demonstrated that the loss modulus provides more accurate estimations of Tg than the damping factor. There were several unexpected patterns in the loss modulus value, which measures the viscous dissipation of the composites. The loss modulus for composites changed with fillers falls as temperature rises. The Tg of milled filler modified composites is inferred from the aforementioned graph to be slightly higher and to have a wider range of transition area than the baseline composite sample. For the base and filler modified epoxy composites with milled carbon fibres, milled Kevlar fibres, and milled hybrid fibres, respectively, Tg values of 87, 95, 89, and 105°C were recorded. This indicates that the only composite with a

significant transition temperature that could be used is the one with hybrid fillers.

4.4. STRUCTURAL SIMULATION IN ANSYS

The structural simulation is done for the E-glass composite sample without fillers, with 0.375% milled Kevlar fibers, 3.5% milled Carbon fibers and 0.375% milled Hybrid fibers. In order to assess the stress distributions, the load displacement and stress-strain curves have also been displayed, along with the equivalent stress, strain and deformation contours. The deformation contour obtained from the ANSYS simulation of the three-point bending test provides crucial information about the structural response of the beam specimen under the applied load. By analyzing the deformation contour, it is possible to identify areas of significant deflection and deformation. In this beam specimen, it is noted that the deformation is maximum at the loading point which is at the centre of the beam.

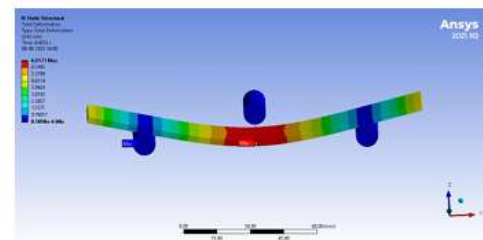


Figure 35 Deformation contour of E-Glass composite without fillers

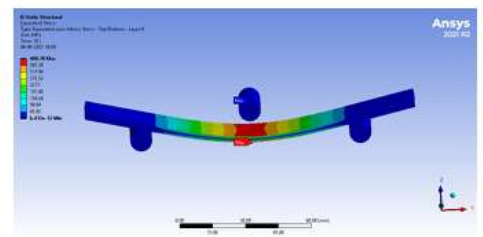


Figure 36 Equivalent stress contour of E-Glass composite without fillers

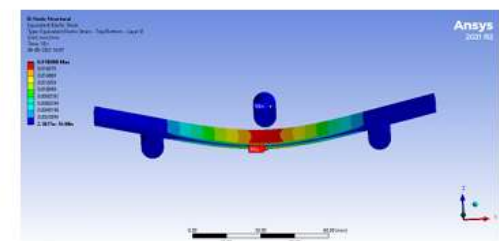


Figure 37 Equivalent strain contour of E-Glass composite without fillers

The stress contour obtained from the ANSYS simulation of the three-point bending test provides valuable insights into the behaviour of the beam specimen under loading conditions. By analyzing the stress distribution, it is possible to identify regions of high stress concentrations, such as near the loading points or at the supports. These regions indicate potential areas of weakness or failure.

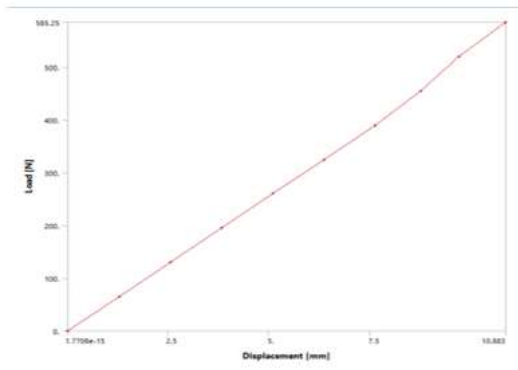


Figure 38 Load versus displacement graph for E-Glass composite without fillers

The Load versus displacement graph plotted above is obtained from the simulation results done using ANSYS. From the graph, it is clear that the maximum load that can be taken by the composite sample is 585.25 MPa. And, Also the displacement caused by the ultimate load is 10.883mm.

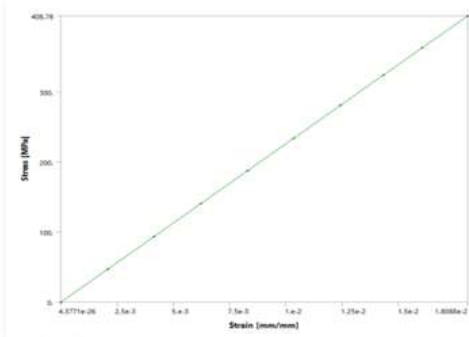


Figure 39 Stress versus Strain graph for E-Glass composite without fillers

From the stress versus strain graph obtained from the simulation, it is noted that the maximum stress and strain that the composite sample can withstand is 406.78 MPa and 0.018088 respectively. In the similar fashion, the equivalent stress and deformation contour has been plotted for other samples too.

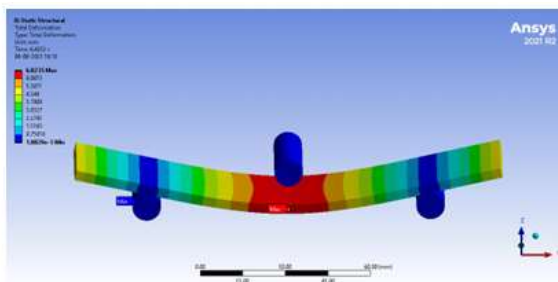


Figure 40 Deformation contour of E-Glass composite with 0.375% milled Kevlar fibers

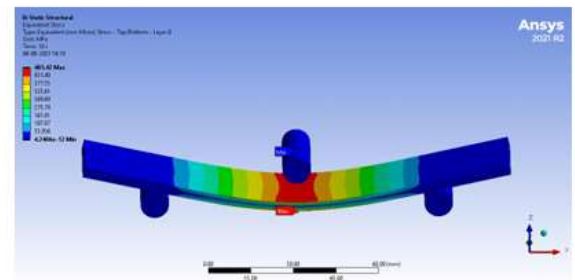


Figure 41 Equivalent stress contour of E-Glass composite with 0.375% milled Kevlar fibers

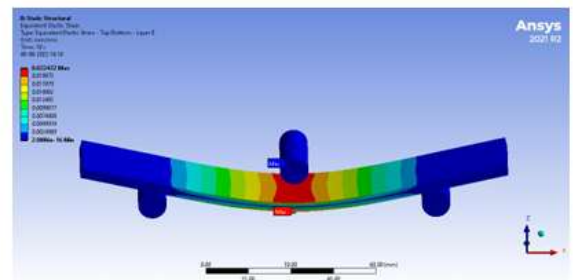


Figure 42 Equivalent elastic strain contour of E-Glass composite with 0.375% milled Kevlar fibers

The stress contours information aids in identifying critical areas which in turn helps in identifying the area of interest of failure. Additionally, the stress contour helps in assessing the overall structural integrity of the specimen, ensuring that it remains within the acceptable stress limits. Also, the load versus displacement and stress versus strain graphs has also been plotted for other concentrations of fillers. The result from the below graphs depicts that the maximum load that can be taken by the E-Glass composite sample with 0.375% milled Kevlar fibers is predicted as 1122.4 MPa which causes a deformation of 10.681mm in the sample.

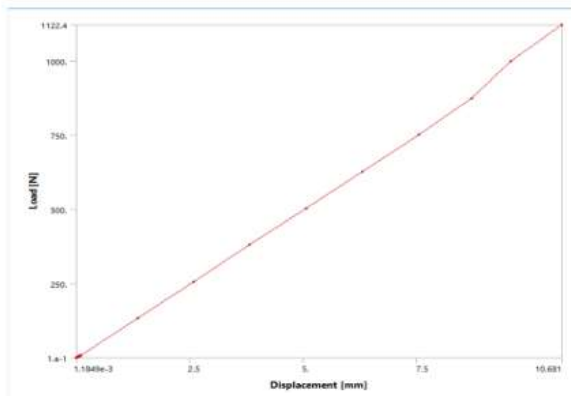


Figure 43 Load versus displacement graph for E-Glass composite with 0.375% milled Kevlar fibers

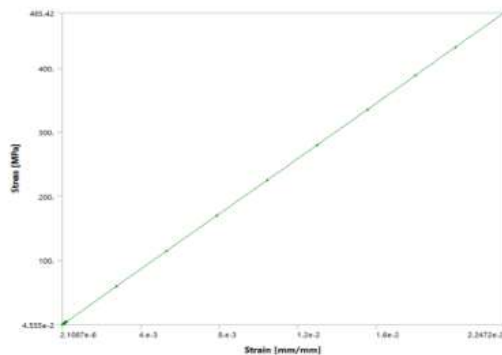


Figure 44 Stress versus Strain graph for E-Glass composite with 0.375% milled Kevlar fibers

Also, from the stress versus strain graph, it is concluded that the E-Glass composite with 0.375% milled Kevlar fibers experience a maximum stress of 485.42 MPa and the corresponding maximum strain value is calculated as 0.022472.

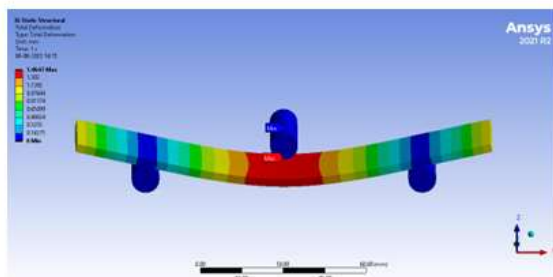


Figure 45 Deformation contour of E-Glass composite with 3.5% milled Carbon fibers

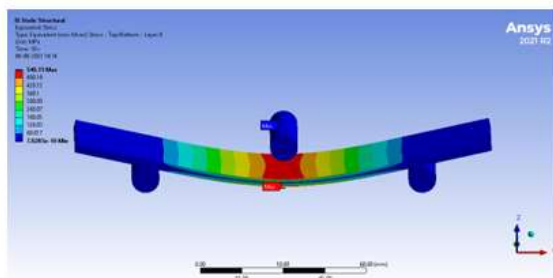


Figure 46 Equivalent stress contour of E-Glass composite with 3.5% milled carbon fibers

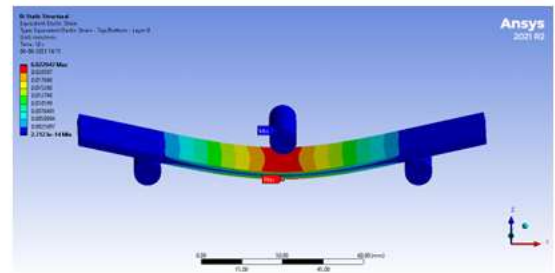


Figure 47 Equivalent elastic strain contour of E-Glass composite with 3.5% milled carbon fibers

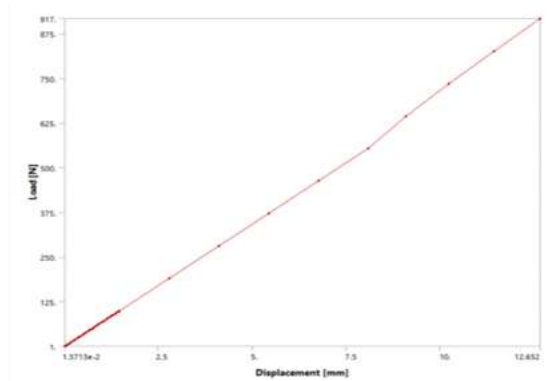


Figure 48 Load versus displacement graph for E-Glass composite with 3.5% milled Carbon fibers

In case of E-Glass composite samples with 3.5% milled carbon fibers as fillers, the total deformation and equivalent stress contours have been simulated for three-point bending test.

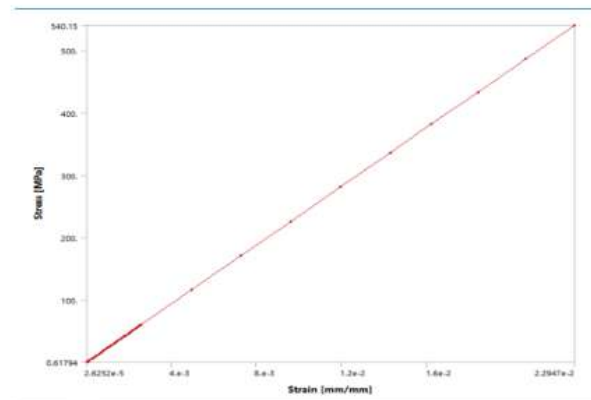


Figure 49 Stress versus Strain graph for E-Glass composite with 3.5% milled Carbon fibers

The load versus displacement graph for the above-mentioned composite sample shows that the maximum stress that the composite withstands before fracture is 917 MPa with the total deformation of the specified beam as 12.652 mm. The stress versus strain graph depicts that the maximum stress that the composite can withstand is 540.15 MPa which corresponds to maximum strain value of 0.02295.

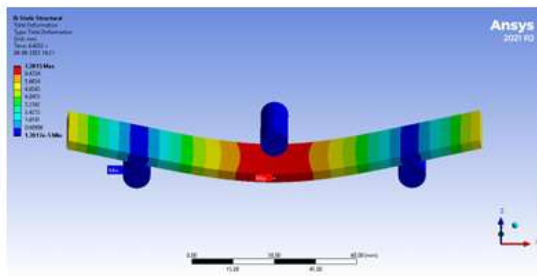


Figure 50 Deformation contour of E-Glass composite with 0.375% milled Hybrid fibers

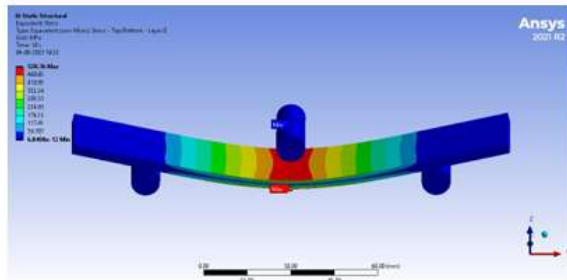


Figure 51 Equivalent stress contour of E-Glass composite with 0.375% milled Hybrid fibers

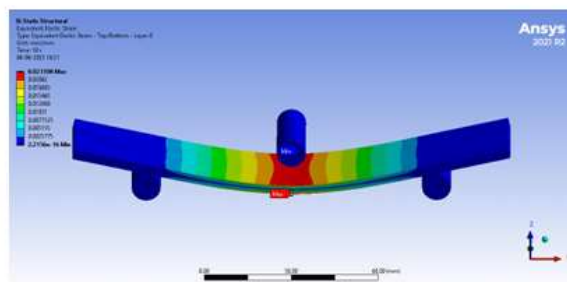


Figure 52 Equivalent elastic strain contour of E-Glass composite with 0.375% milled Hybrid fibers

The deformation contour and the Equivalent stress contour has been plotted for E-Glass composite samples with 0.28% milled Kevlar fibers and 0.094% milled Carbon fibers by using the ANSYS simulation for three-point bending test.

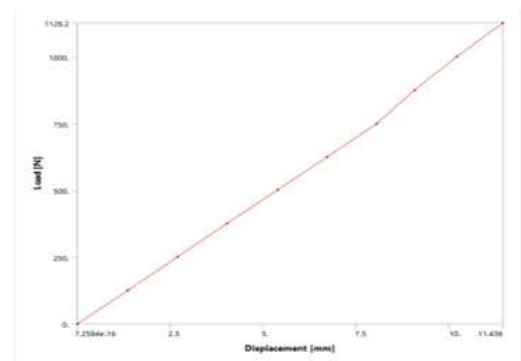


Figure 53 Load versus displacement graph for E-Glass composite with 0.375% milled Hybrid fibers

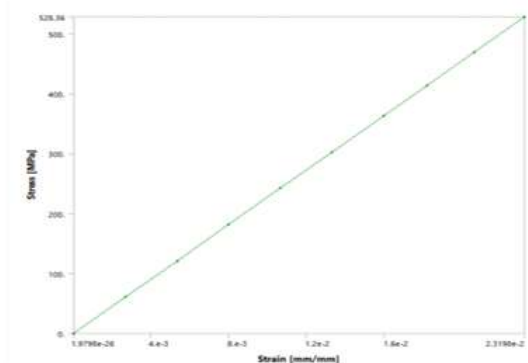


Figure 54 Stress versus Strain graph for E-Glass composite with 0.375% milled Hybrid fibers

It is noted from the graphs that the maximum load that the sample can withstand is 1128.2 MPa with total deformation of 11.436 mm. Also, the maximum stress that the composite sample withstand is 528.36 MPa with corresponding strain of 0.0232.

5. CONCLUSIONS

5.1. RESIN STUDY

The resin study of the samples with milled carbon and Kevlar fibers are analysed for further fabrication of the composite with the optimum weight percentage of the milled fibers showing desired results. Using milled fibers as fillers shows promising results in terms of flexural properties as well as load carrying capacity of the resin samples. From the graphs, it is found that for 0.375% weight concentration of milled Kevlar fibers, 3.5% weight concentration of milled Carbon fibers and 0.375% % weight concentration of milled Hybrid fibers (ie., 0.094% of milled Carbon fibers and 0.28% of milled Kevlar fibers), the maximum value of ultimate yield stress is obtained.

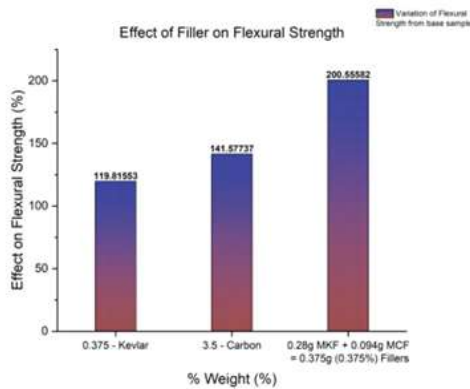


Figure 55 Effect of filler on flexural strength of Resin samples with fillers in comparison with base Epoxy sample

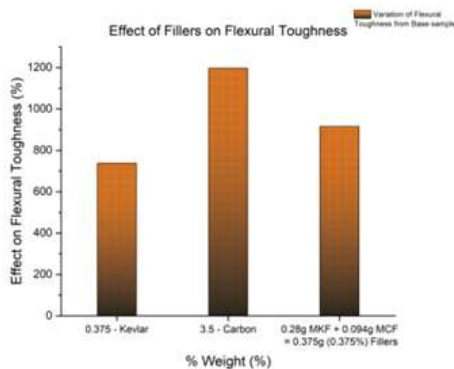


Figure 56 Effect of filler on flexural toughness of Resin samples with fillers in comparison with base Epoxy sample

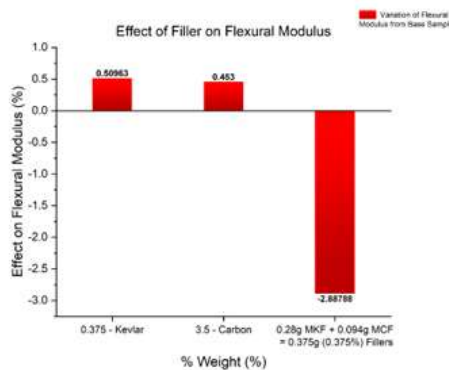


Figure 57 Effect of filler on flexural modulus of Resin samples with fillers in comparison with base Epoxy sample

Among these concentrations too, the Epoxy sample with milled hybrid fibers shows the optimum results when compared to base epoxy sample and epoxy sample with other fibers. After that particular concentration, increase in the concentration of the milled fibers causes decrease in the ultimate yield stress. So consequently, a decrease in the flexural properties is also noted for increase in the weight percentage after the optimum weight concentration. This happens because due to increasing weight percentage, agglomeration of the milled fibers takes place due to Vander Waals attraction between the molecules of the milled fibers.

5.2. E-GLASS COMPOSITE STUDY (STATIC)

The comparison of these filler infused samples has been done with the base resin samples without any fillers so that the variation in the flexural properties can be analysed.

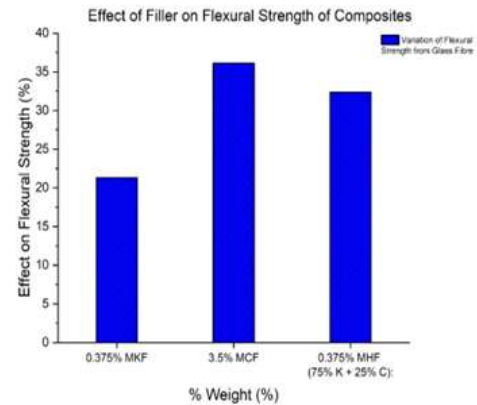


Figure 58 Effect of filler on flexural strength of composites with fillers in comparison with base composite sample

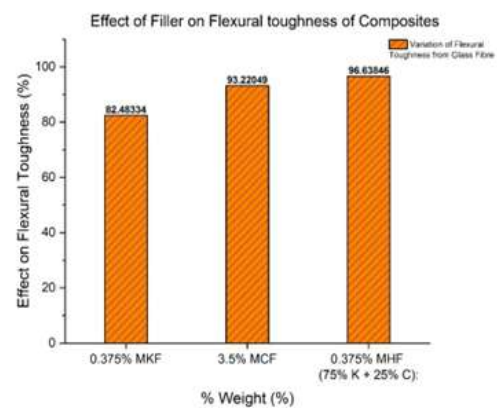


Figure 59 Effect of filler on flexural toughness of composites with fillers in comparison with base composite sample

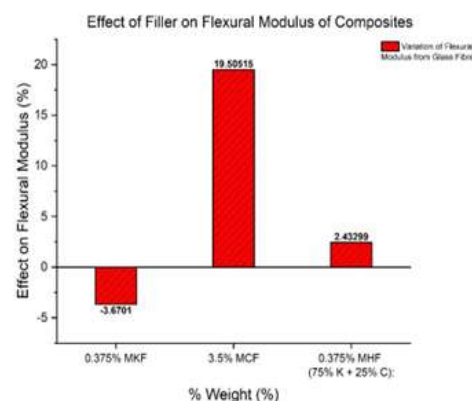


Figure 60 Effect of filler on flexural modulus of composites with fillers in comparison with base composite sample

The flexural strength as well as the flexural toughness increases with the incorporation of the fillers. And, in case of flexural strength, the E-Glass composite samples with 3.5% milled carbon fibers shows the highest increase. But on the other hand, the flexural toughness is higher for samples with E-Glass composite samples with 0.094% of milled Carbon fibers and 0.28% of milled Kevlar fibers. A peculiar observation is made in case of flexural modulus. Like flexural strength, the E-Glass composite samples with 3.5% milled carbon fibers shows the highest increase. But also, a decrease of 3% is observed for E-Glass composite samples with

0.094% of milled Carbon fibers and 0.28% of milled Kevlar fibers.

5.3. E-GLASS COMPOSITE STUDY (DMA)

In case of Dynamic mechanical Analysis of the E-Glass composite samples, damping factor ($\tan \delta$), storage modulus (E') and loss modulus (E'') has been plotted against temperature. E-glass composites incorporating milled carbon fibres and milled hybrid fibres have storage moduli that are 26.5% and 22.3% greater, respectively. While the storage modulus fell by 19.2% in E-Glass composite sample with milled Kevlar fibers. The glass transition temperature for the base composite was 95.4°C, and for the milled Carbon fibres, milled Kevlar fibres, and milled hybrid fibres composites, the T_g shifted towards higher values with 104°C, 96.7°C, and 110°C, respectively. The corresponding damping factors for each of these materials were 0.53, 0.51, 0.47°C, and 0.38 °C, respectively. As the temperature rises, the loss modulus for composites modified with fillers decreases. T_g values of 87, 95, 89, and 105°C were obtained from the temperature vs loss modulus graph for the base and filler modified epoxy composites with milled carbon fibres, milled Kevlar fibres, and milled hybrid fibres, respectively.

5.4. COMPOSITE STUDY (STRUCTURAL SIMULATION)

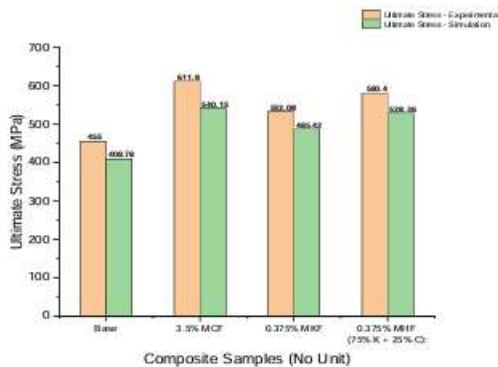


Figure 61 Comparison of Ultimate stress

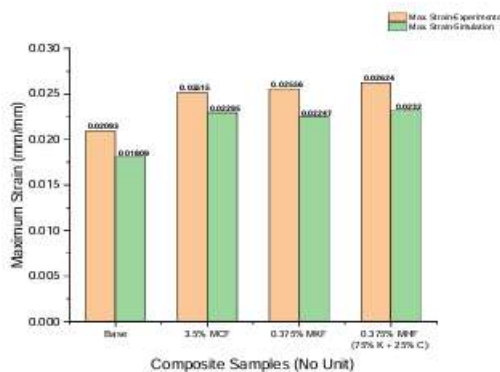


Figure 62 Comparison of Ultimate strain

The comparison graph results shows that the ultimate stress or ultimate strain calculated from the experimental calculation always exceeds the values calculated through simulation. Also, it is to be noted that the composite samples with 3.5% milled Carbon fibers exhibit higher ultimate stress whereas, the samples with 0.375% milled hybrid fibers exhibit higher ultimate strain values.

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