The Mechanical Characterization of Recycled Milled Basalt Fiber Fillers on Flexural Properties of Natural Fiber Reinforced Polymer Composites for Sustainable Developments and High-Performance Industrial Applications

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Abstract— ***The aerospace, automotive, and energy industries can use fiber-reinforced polymer composites due to their high specific strength and stiffness. However, unexpected external impacts in work cause internal damage and residual strength loss in composite structures. Another ongoing issue is the sustainable management of composite materials' end-of-life. This research paper describes the mechanical characterization of recycled milled basalt fiber fillers on flexural properties of Natural Fibre Reinforced Polymer Composites for Sustainable Developments and Industrial Applications. An optimized recycled milled fiber filler percentage is examined by incorporating the recycled ball-milled basalt fiber filler into the epoxy laminates from 0.5% to 3% weight percentages concerning epoxy laminates. Finally, the 1% filler incorporated epoxy laminates showed better results than the base samples. Then, the 1% recycled milled basalt fiber filler material was incorporated into basalt fiber and areca nut fiber with epoxy resin and hardener to make the composite laminates for flexural testing. The flexural testing was carried out with the help of an INSTRON Universal Testing Machine (UTM) i.e. the three-point bending test to determine the flexural characteristics. The recycled milled basalt fiber filler incorporated basalt and areca nut epoxy composite laminates show higher flexural properties than the base samples with 0% filler material. There is an increase of 96.51% and 22.78% in flexural strength (MPa) for basalt/epoxy and areca nut/epoxy filler incorporated polymer composites than the base samples. Through toughening mechanisms like filler/matrix interlocking, individual debonding, crack deflection, and bridging, micrographs captured using a scanning electron microscope (SEM) showed that recycled fillers provide a higher level of stiffness, better energy dissipation, less damaged area, and overall improved hardness. Thus, the fillers' role in the resistance to damage propagation increases. This research helps improve composite material performance and sustainability.***

Keywords— ***polymer composites, recycled milled fillers, flexural properties, basalt fibre, sustainability***

I. INTRODUCTION

As discussed in the abstract, composite materials and structures are major research areas that are well-suited for aerospace and automotive applications. Generally, composites are cheaper and have a good strength-to-weight ratio. Recent day researchers have focused greatly on developing a material with matrix and fiber along with fillers (either natural or synthetic). The addition of fillers influences the mechanical properties of the composite materials significantly. To prepare a material that satisfies various properties and to enhance mechanical properties, the filler addition to the matrix and hybridization of fibers are a better option. This review paper briefly describes only the addition of fillers to the mechanical properties of a composite material [29]. The filler addition influences the properties of the composites which depends on the filler size, shape, aspect ratio, surface area, etc. to meet the current trends of the material for the engineering applications.

The addition of fillers to the matrix enhances properties and processability and reduces the cost of material. The fillers may be micro or nano-sized particles. From the various research studies, it is concluded that the use of nanosized filler would be an ideal option to improve properties as nano-sized particles are characterized by as high aspect ratio and specific surface area. The interaction between the polymer fiber and matrix increases with the addition of an optimum composition of fillers. After a certain limit of addition of fillers results in decreased properties because the agglomerations of the fillers take place. Hence, the application of nanofillers within the polymer matrix is an extensive research area in the field of engineering and technology.

Natural fibers are environment friendly, as it is biodegradable, and good recyclability. They are cheaper than conventional synthetic fibers. They are abundant in nature, and renewable, causing low risk to human health. Composites replace conventional materials like steel, aluminum, etc in most of the aircraft components due to their high strength toweight ratio. But almost all synthetic fibers are used in aerospace due to their higher strength than natural ones, and for safety. However, by using milled fillers of natural fibers, I try to improve the strength of natural fiber composite up to about 70-80% of that of synthetic fibers, so that natural fiber composites may be incorporated in aircraft components shortly. The damaged or utilized composites can be treated appropriately (mechanically, chemically, or thermally to extract the fibers alone to be used as fillers in new composite laminates, as these fibers can be milled (powdered/chopped), and used as fillers to enhance the mechanical properties of the composites.

Generally, the addition of fillers along with resin and fiber improves mechanical properties. Including fillers in the interlayer enhances the delamination resistance by providing a bridging effect, therefore demanding additional energy to initiate the crack in the interlaminar domain, which results in turn in enhanced fracture toughness. The mechanism observed suggests that crack propagation is stabilized even leading to its arrest/deflection, as a considerable amount of milled fiber filler was oriented transverse to the crack path. In contrast, at higher filler loading, a tendency towards stress concentration grows due to local agglomeration and improper dispersion of excess fillers in inter/intralaminar resin channel, causing poor adhesion to the matrix, which leads to a reduction in fracture toughness, and strength and strain to failure. This research paper describes the computational and experimental investigation & analysis on the effect of milled basalt fibre fillers on static flexural properties of the natural fibre composites for aerospace and automobile applications.

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 fibers, 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 aluminum. Examples are graphite/epoxy, Kevlar R/epoxy, and boron/aluminum 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 aluminum, and ceramics such as calcium aluminum silicate. Composites are strong but lightweight, making them ideal for creating lighter products. They are also resistant to harsh weather conditions, chemicals, and fuels, as well as corrosion and wear, and usually don't need special anti-corrosion treatment. Composites can be molded into complex shapes and structures. Composites require little maintenance once installed. Composites can insulate against electricity and heat. Composites can absorb and withstand impacts. Composites can improve fuel efficiency in transportation. Composites can be made in a wide range of colors. Composites can be easily repaired.

Synthetic fibers are non-biodegradable and are more expensive than Natural fibers. They cause environmental degradation and have moderate recyclability. Natural fibers are environment friendly, as it is biodegradable, and have good recyclability. They are cheaper than conventional synthetic fibers. They are abundant in nature, and renewable, causing low risk to human health. Composites replace conventional materials like steel, aluminum, etc in most of the aircraft components due to their high strength-to-weight ratio. But almost all synthetic fibers are used in aerospace due to their higher strength than natural ones, and for safety. However, by using milled fillers of natural fibers, I try to improve the strength of natural fiber composite up to about 70-80% of that of synthetic fibers, so that natural fiber composites may be incorporated in aircraft components shortly. The damaged or utilized composites can be treated appropriately (mechanically, chemically, or thermally to extract the fibers alone to be used as fillers in new composite laminates, as these fibers can be milled (powdered/chopped), and used as fillers to enhance the mechanical properties of the composites, which is carried out exactly in this project work.

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 and available in more than 20 grades to meet specific property and processing requirements.

1.3 Significance of Natural Fillers

Filler materials are particles added to resin or binders (plastics, composites, concrete) that can improve specific properties of composite material. These can be milled or chopped fibers, which form good bonding with resin material, improve its mechanical, and thermal properties, and prevent crack propagation. The current demand for high-performance green composites has resulted in the use of natural fillers as a reinforcement in the epoxy matrix, which is also a means of recycling. The need to utilize green materials for a sustainable environment has caused an upsurge in the use of natural materials in the composite industry because the sustainability of the products during processing and end-of-life is important. Natural fillers are sustainable potential materials as reinforcing agents for different polymer matrices in varying applications such as automobile, construction, aerospace, toys, defense, sporting goods, and electronic applications. The other advantages of natural fibers are their easy availability, easy manufacturing process, less energy consumption, renewability, and good mechanical properties. These advantages make natural fillers an alternative to traditional fillers in many applications such as construction and infrastructure, furniture, and rotor blade materials. Plant-based fillers such as banana fiber, hemp, sisal, pineapple, bamboo, flax, peanut particles, etc., have been widely used as reinforcement for various polymer matrices. Studies have shown that plant fibers are an excellent replacement for carbon and glass fibers in many semi-structural applications. Filler materials come in a few diverse forms: glass beads, short glass fibers, and long glass fibers. In plastics by tonnage. Glass fiber fillers are used to increase the mechanical properties of the thermoplastic or thermoset such as flexural modulus and tensile strength. There is normally no economic benefit to adding glass as a filler material. Some disadvantages of having glass in the matrix include low surface quality, high viscosity when melted, poor weldability, and warpage. Hence there has been much research carried out using natural fillers. For, example Abdelmalik et al. studied the variations in tensile strength and insulation properties of the epoxy composites with the addition of eggshell powder in which he observed that the tensile strength of epoxy composites was increased with the increasing addition of eggshell powder, and the best results were observed for 4 wt% filler, which was followed by a reduction for the composite with 5% filler content due to the agglomeration of the particles. With these scopes of using natural fillers, I have chosen Basalt and Arecanut fibers and recycled milled basalt fiber fillers, to be incorporated in epoxy resin for composite fabrication. Thus, this research work is an innovative approach as I have selected the natural fibers for composite performance enhancement and sustainability.

1.4 Three Point Bending Test – Flexural Testing

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 horizontally 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.

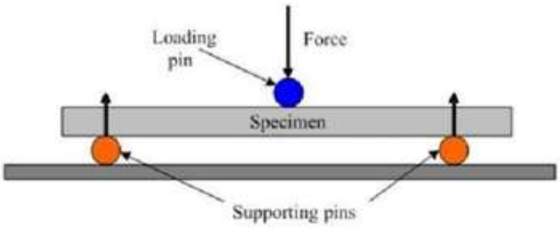

Figure 1: Three Point Bending Test

One of the key advantages of the three-point bending test is its ability to simulate real-world conditions, as many structural elements experience bending loads in practical applications. This test provides valuable information about a material's ability to withstand banding 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.

II. LITERATURE SURVEY

[1] Effect of nanofillers on the properties of natural fiber reinforced polymer composites.

Investigation of the effect of nanofillers on the mechanical properties of fiber-reinforced polymer composites. The addition of nanofillers influences the mechanical properties and water absorption properties. To keep a balance in terms of properties, it is evident to use the optimum composition of filler material to improve properties significantly. Various nanofibers are used as fillers such as granite, nano-Sio2, CNT, graphene, etc.

[2] Effect of Natural Fillers on Mechanical Properties of GFRP Composites.

This paper briefly presents the effect of natural fillers on the mechanical properties of the GFRP composites. The natural fillers used are rice husk, wheat husk, and coconut coir. The matrix materials used along with GFRP are polyester and epoxy resins. The addition of fillers leads to the cost and weight reduction of the glass fiber-reinforced composites. From the paper, I found that the natural fillers with polyester-based composites provide better results than the epoxy-based composites. Water absorption is more in polyester-based composites. In general, I infer that to improve the properties of the GFRP, coconut coir fillers should be used instead of rice husk and wheat husk.

[3] Influence of milled glass fillers on the impact and compression after impact behavior of glass/epoxy composite laminates.

Investigation into the effect of milled glass fiber fillers on GFRP with epoxy resin was carried out in this research study. With the optimum usage of the milled glass fiber filler on GFRP with epoxy resin, I can infer that the improvement in impact damage and residual CAI behaviors was evident. The glass filler-loaded samples resulted in a higher peak force than the baseline samples of GFRP. Thus, the improved properties of the glass fiber filler loaded GFRP are very good materials for the application of materials in aerospace and automotive industries as they possess good load-bearing applications.

[4] Influence of Milled Glass Fiber Fillers on Mode I & Mode II Interlaminar Fracture Toughness of Epoxy Resin for Fabrication of Glass/Epoxy Composites.

Investigation of mode I and mode II interlaminar fracture toughness tests on GFRP were performed with various loadings of recycled milled glass fiber. The addition of milled glass fiber fillers (5 wt.%) with GFRP along with epoxy resin resulted in significant improvement in the interlaminar fracture toughness without affecting the flexural properties. Fractured surfaces analyzed using scanning electron microscopy (SEM) revealed several mechanisms, such as crack deflection, individual debonding, and filler/matrix interlocking, all contributing in various ways to improve fracture toughness.

[5] Influence of filler material on properties of fiber reinforced polymer composites: A review.

This paper briefly reviews the influence of filler material on the properties of FRP composites. In many cases, the addition of fillers with FRP composites resulted in obtaining higher mechanical and thermal properties. Filler material increases the adhesion between fiber and matrix and thus enhances water resistance. The filler addition increases the sound absorption coefficient of the FRP composites due to the porosity nature of the filler. Such filler reinforced composites find their applications in many areas requiring electrical conductivity, dielectric medium, and in electrical and electronics applications due to the formation of dense percolation networks.

[6] Polypropylene-Matrix Polymer Composites with Natural Filler.

Investigation into the effect of natural filler on polypropylene matrix polymer composites was carried out. The filler material used in this research study is walnut shell flour filler with various concentrations. A small effect on the filler fraction size was studied and observed. The low density of the material depends in particular on the material porosity. The composite material was characterized by low density, which increased with the rising filler content. The composites produced with filler are characterized by an increase in hardness and stiffness along with the increase in the filler content in the polypropylene matrix and a decrease in tensile strength was observed.

[7] Biochar is a cheap and environmentally friendly filler able to improve polymer mechanical properties.

This research study reports the use of biochar derived from the maple tree as a filler material in epoxy resin matrix composites. The stiffness of the matrix was enhanced by the addition of small amounts of Biochar. Higher filler contents led to lower enhancement of the stiffness. The biochar filler addition affects thecompositebehavior transforming theblankepoxy from brittle to ductile composite. The addition of filler enhanced the young modulus and resilience. 1wt% addition led to a small enhancement of tensile toughness. From the study, I can infer that the addition of an optimum amount of biochar filler material influences the mechanical properties of the composite laminates.

[8] The Effect of Filler Particle Size on the Mechanical Properties of Waste Styrofoam Filled Sawdust Composite.

Investigation into the effect of filler particle size on the mechanical properties of waste styrofoam-filled sawdust composite was carried out. The composites contained wt.% of 70 and 30 of Styrofoam and sawdust. The compatibilizer used was maleic anhydride. Results concluded that the incorporation of 150 microns has increased the mechanical properties of the composite such as tensile strength (33 MPa), flexural strength (15.4 MPa), and impact strength (300 J/cm2). The scanning electron microscopy (SEM) images of the 150- micron composite sample showed good distribution and a reduced amount of the voids present in the composite.

[9] Role of fillers in the production of wood-polymer composites.

Investigation of the effect of various properties by incorporating the filler with wood polymer composites (WPC). The resulting physical and mechanical properties are much greater than expected. The possibility of using WPC with fillers in outdoor construction work was confirmed with the properties of water absorption and swelling composition. The filler incorporated WPC materials have a sufficiently high resistance to climatic factors.

[10] Effect of Hybrid Filler Oil Palm Boiler Ash – Bentonite on Thermal Characteristics of Natural Rubber Compounds.

Investigation on the thermal characteristics of natural rubber compounds with the addition of hybrid filler that is the oil palm boiler ash bentonite. The mechanical properties of the natural rubber compounds increase significantly with the addition of the hybrid filler. From the study, it is inferred that there is excellent interaction between the natural rubber compounds and hybrid filler material system and hence proved that the material is semicrystalline so that it can be processed.

[11] Effect of Fillers Loading on the Mechanical Properties of Hardwood Sawdust/Oil Bean Shell Reinforced Epoxy Hybrid Composites.

This research study aims to prove that HSD, OBPS, and epoxy would be a substitute for Wood-based material composites in many industrial applications. The addition of natural fillers to epoxy matrix material improved the mechanical properties of the composite laminate (up to 50%), but after further increment in the weight of fillers led to a decrease in the mechanical properties. From the study, it is inferred that the composite material's mechanical properties are completely influenced by the filler loading and matrix adhesion.

[12] Effect of Fillers on E-Glass/Jute Fiber Reinforced Epoxy Composites.

Investigation on the effect of mechanical properties of fiber-reinforced epoxy composite with the addition of varying concentrations of bone and coconut shell powders was carried out. The maximum impact strength was observed in the composite filled with 15% volume bone powder. The maximum ultimate tensile strength was observed in a composite filled with 10% volume coconut shell powder. Thus, it is inferred that the filler addition influences the mechanical properties of the fiber-reinforced composites.

[13] Effect of fillers on mechanical properties of PTFE-based composites.

This research study focuses on the incorporation of fillers into the mechanical properties of polytetrafluoroethylene (PTFE). The different fillers that were used for the systematic study are glass, granite, graphite, garnet, alumina, antimony trisulphide, carbon, marble, mica, sand, bronze, wollastonite, porcelain, china clay, and tixolex – 25. Results indicated that the highest hardness value-based composites were found to be 15,20 and 25% in the case of garnet-filled PTFE, 50% in the case of marble-filled PTFE and 40% in porcelain-filled PTFE, 5% bronze-filled PTFE shows highest tensile strength and % elongation values. Some fillers failed to be incorporated as a filler due to various reasons such as failure in some experimental tests.

[14] Study on the Mechanical Properties of Natural Fiber Reinforced Hybrid Composites with Natural Rubber as a Filler.

Investigation on the effects of mechanical properties on the natural fiber reinforced hybrid composites with natural rubber as a filler material. The composites were fabricated by vacuum bagging technique. The tensile properties of ramie sisal composites remain the same despite the addition of filler. The tensile strength of the basalt-based composites was influenced by filler addition. The addition of natural rubber fillers enhanced the flexural properties of ramie-basalt composites. The impact properties are not influenced by the rubber composition.

[15] Effect of Silicon Carbide Fillers on the Mechanical Properties of Glass Fibre Reinforced Epoxy Polymer Composite.

Investigation on the effect of mechanical properties of GFRP with silicon carbide as micro and nanofiller. The composites were fabricated by the hand layup method. The tensile strength, hardness, and flexural strength of nano-filled composites are found to be higher than micro SiC-filled composites. At 5 wt.% fillerloaded nano SiC-filled composites performed better as compared to the micro SiC-filled composites.

[16] Low-Velocity Impact Induced Damage Evaluation and Its Influence on the Residual Flexural Behavior of Glass/Epoxy Laminates Hybridized with Glass Fillers.

This research work investigates experimentally the low velocity impact-induced damage behavior and its influence on the residual flexural response of glass/epoxy composites improved with milled glass fillers. The low velocity impact damage employing varying impact velocities (3 m/s, 3.5 m/s, and 4 m/s) was induced on the baseline and filler-loaded samples with different fiber orientations. The residual performance and their damage modes were characterized using post-impact flexural (FAI) test and acoustic emission (AE) monitoring. In all fiber orientations, the filler-modified glass/epoxy samples showed improved impact strength and stiffness properties. A substantial improvement in impact damage tolerance, especially for samples impacted at 3.5 m/s and 4 m/s was observed. The presence of filler at the interlaminar zone contributed to improved energy dissipation through filler debonding and pull-out. This further contributed to arresting the crack growth, showing reduced damaged area. The inclusion of milled fibers on glass/epoxy laminates enhanced the impact of toughness and residual flexural behavior.

[17] Polypropylene matrix composite with charcoal filler.

Incorporation of charcoal powder as filler to investigate the thermal, electrical, and mechanical properties of polymer composites. The samples were made by injection molding. After the experimental study and analysis, it is inferred that charcoal powder can be used successfully as a filler material for the polymer-based matrix to improve the mechanical properties of the composites. With an increase in the volume fraction of the filler in the matrix, the material's hardness increases significantly. The addition of filler into the matrix, increased electrostatic properties and worsened the electrical insulating properties.

[18] Usability of Pine Sawdust and Calcite Together as Filler in Polyester Composites.

This research study involves the investigation of polyester composites with polyester resin as matrix material and the fillers used are calcite and pine wood sawdust. Hence the usability of both natural and synthetic filler was investigated. Study from the tensile test, a partial decrease was observed as the sawdust filler increased, while this decrease was less in the case of calcite. No obvious change in impact properties was observed. The hardness results increased with the addition of both sawdust and calcite. It was understood from the SEM images that the fillers were homogeneously mixed in the structure. Finally, it is determined that the sawdust and calcite filler could be used together as fillers for material applications for large load bearing capacities.

[19] Natural Fillers as Potential Modifying Agents for Epoxy Composition: A Review

Epoxy resins as important organic matrices, thanks to their chemical structure and the possibility of modification, have unique properties, which contribute to the fact that these materials have been used in many composite industries for many years. Epoxy resins are repeatedly used in exacting applications due to their exquisite mechanical properties, thermal stability, scratch resistance, and chemical resistance. Moreover, epoxy materials also have really strong resistance to solvents, chemical attacks, and climatic aging. The presented features confirm the fact that there is a constant interest of scientists in the modification of resins and understanding its mechanisms, as well as in the development of these materials to obtain systems with the required properties. Most of the recent studies in the literature are focused on green fillers such as post-agricultural waste powder (cashew nuts powder, coconut shell powder, rice husks, date seed), grass fiber (bamboo fibers), bast/leaf fiber (hemp fibers, banana bark fibers, pineapple leaf), and other natural fibers (waste tea fibers, palm ash) as reinforcement for epoxy resins rather than traditional non-biodegradable fillers due to their sustainability, low cost, wide availability, and the use of waste, which is environmentally friendly. Furthermore, the advantages of natural fillers over traditional fillers are acceptable specific strength and modulus, lightweight, and good biodegradability, which is very desirable nowadays. Therefore, the development and progress of "green products" based on epoxy resin and natural fillers as reinforcements have been increasing. Many uses of natural plant-derived fillers include many plant wastes, such as banana bark, coconut shell, and waste peanut shell, can be found in the literature. Partially biodegradable polymers obtained by using natural fillers and epoxy polymers can successfully reduce the undesirable epoxy and synthetic fiber waste. Additionally, partially biopolymers based on epoxy resins, which will be presented in the paper, are more useful than commercial polymers due to the low cost and improved good thermomechanical properties.

[20] A comparative study on the effect produced by fillers specifics on the dynamic mechanical and dielectric properties of natural rubber-based composites

This paper presents the results on the effect of specific characteristics of three completely different carbon black upon the dynamic mechanical and dielectric thermal properties of natural rubber-based composites. It has been found that the size of carbon black particles, its specific surface area, respectively, as well as the ability of carbon black particles to formvarious aggregates and agglomerates affect both the dynamic mechanical and dielectric properties of the prepared composites. At the same concentration of all fillers studied the dynamic mechanical properties of the composites filled with high structure carbon black having super high specific surface area are much better than those of the composites filled with conventional carbon black. The same is valid for their dielectric permittivity values which are of about two-three orders higher.

[21] Comparison on mechanical properties of lignocellulosic flour epoxy composites prepared by using coconut shell, rice husk and teakwood as fillers

The objective of this work was to investigate the feasibility of using lignocellulosic fillers (coconut shell, rice husk and teakwood) as alternative reinforcement for expensive non-renewable fillers used in conventional composites. Various concentrations of epoxy-based bio-fillers composites were prepared and the influences of filler size (75–105 and 106–180 m) and mass concentration (2.5 and 4.5 wt%) on the mechanical properties were investigated. Properties such as deformability, stiffness, elasticity and strain energy absorption ability of each material combination were determined using single indentation load control, single indentation displacement control and multi-cyclic indentation tests. The results showed that parameters such as filler size, volume content, filler type (chemical composition and shape) dispersion influenced these properties. It was revealed that high lignin content increased the stiffness whereas high cellulose content with high impregnation ability favoured deformability. High cellulose content and surface roughness supported better adhesion due to a large number of hydrogen bonds and high mechanical interlocking, respectively.

[22] The Effect of Silica Filler Source on the Mechanical Properties of Composite Rubber

Rubber composite is a high molecular weight polymer, produced from natural or synthetic rubber with sulfur as its common crosslinking agent. To improve the mechanical properties of rubber, filler with high silica content was usually added. Hence in this experiment, due to their high silica content, Risk husk ash (RHA), along with chemizil and zeosil were used as the composite filler. Sulfur was chosen as the crosslinking agent of a rubber mixture that consists of polyisoprene rubber (IR), acrylonitrile butadiene rubber (KNB), and polybutadiene rubber (BR). The composition of the other component was fixed at Per Hundred Rubber (PHR) of 51.43. During mixing, the temperature and mixing time were kept constant at 60-70ºC and 6 minutes. The properties of rubber composite were characterized based on their physical and mechanical properties. Based on the rheological test, RHA has a faster vulcanization time compared to chemisil and zeosil. Improvement of the mechanical properties of the RHA rubber mixture was also observed, with 300% modulus, elongation, and tear at 42 kg/cm^2, 867%, and 51 kg/cm^2. Meanwhile, insignificance differences in tensile strength, hardness, and specific gravity of RHA compared to chemisil and zeosil, were observed.

[23] Fillers for polymer composite materials

For the production of building products made of PVC, compositions are used that, along with the polymer, include additives: plasticizers, stabilizers, modifiers. This leads to a decrease in the chlorine content in the composition and increases the flammability of the productitself. Therefore, nanoparticles of various fillers are added into the compositions. Fillers inPVC compositions (more often inorganic, less often organic substances) are solid additives that differ from the polymer matrix in chemical composition and structure.In most cases, the main function of fillers is to reduce flammability and cut costs of the products obtained, in some cases they serve to impart or improve the following properties: reducing plasticizer absorption, changing in dielectric properties, increasing rigidity and hardness, reducing noise transmission, reducing toxicity of combustion products. Fillers are classified according to various criteria. According to the state of aggregation, they are divided into gaseous, liquid and solid. By their nature, they are divided into organic and inorganic; according to the source of receipt – reinforcing, strengthening, reinforcing, neutral; bythe size, particle shape and structure – into 4 main types: dispersed (powder); fibrous (fibers, threads, bundles, etc.); sheet (film) with a given structure (fabrics, paper, tapes, sheets, films, nets); volumetric (framework) with a continuous three-dimensional structure (bulk fabrics, felt, skeletal and porous frameworks). The most commonly used solid fillers, which are also called dispersed. The introduction of dispersed fillers into polymer composite materials (PCM) is more appropriate for creating mass-produced materials, more technologically advanced, with a low level of strength characteristics. Dispersed fillers are introduced into thermoplastics with high fracture energy to reduce their cost, increase stiffness and compressive strength, and improve their technological characteristics during processing. At the same time, their tensile strength and impact strength decrease due to reduction in the proportion of polymer in the filled composition. The introduction of solid and hard particles leads to an increase in the elastic modulus (E); and soft, elastic or gaseous fillers – to its decrease. According to the mechanism of action, dispersed fillers can be divided into inert ones, which do not affect the properties of the matrix and are introduced into its composition to reduce the cost of the composition, and active ones. Dispersed fillers are divided into mineral, organic and metal. The commonest of those are minerals. Thus, at present, there are a large number of substances and materials used as fillers and making it possible to obtain PCM with low shrinkage and shape stability of products, high mechanical properties and the necessary set of special properties. Due to fillers, PCM can compete with other materials such as glass, ceramics and even metal in most areas of human activity.

[24] Effect of moringa and bagasse ash filler particles on basalt/epoxy composites

This study evaluated the effect of moringa and nano ash filler particles on mechanical, chemical corrosion and moisture absorption of basalt fiber/epoxy composites. Epoxy resin and Araldite HY951 hardener was used as matrix along with the inclusion of filler particles while the bi-directional woven basalt fiber mat was used as the reinforcement in fabricating composites using hand layup technique. Three different composites i.e. Plain BF + matrix with no filler particles, BF + matrix with 10 wt, % moringa ash and BF + matrix with 10 wt, % bagasse ash were fabricated and tested according to the ASTM standards to determine the mechanical properties and chemical corrosion resistance. According to the experimental test results, the composites with moringa ash inclusion showed better properties than the bagasse ash inclusion and with no filler added composites.

[25] quasi-static indentation behavior of gfrp with milled glass fiber filler monitored by acoustic emission

This paper aims at investigating the influence of the addition of milled glass fibers upon quasi-static indentation (QSI) properties of glass/epoxy composite laminates. The QSI behavior was experimentally studied by evaluating indentation force, residual dent depth, energy absorbed and size of the damaged area for different indentation depths. Following the QSI tests, the filler-loaded glass/epoxy samples were subjected to three-point bending tests in order to measure residual flexural strength, and the results were compared with the baseline glass/epoxy samples. Both tests were performed with online acoustic emission monitoring in order to observe damage progression and characterize different fracture mechanisms associated with loading. The results show that the filler-loaded laminates exhibit a substantial improvement in the peak force and contact stiffness, with a reduced permanent damage both in terms of depth and of area, in comparison with the baseline ones. It is found that the filler presence offers greater stiffness and higher energy dissipation through toughening mechanisms such as filler debonding/pullout and filler bridging/interlocking.

[26] A Brief Review on Effect of Nano fillers on Performance of Composites

The utilization of nano materials creates a huge impact on today's scenario in development of various products. One such type of nano material developing concept is the usage of nano fillers for making composite product. This review briefs about the development of various nano fillers and its types followed by the fabrication of various composite combinations along with various nano fillers also discussed in detail. The addition of these nano fillers as a reinforcement or matrix for the composite making creates a significant impact in the mechanical properties of the composites. Special focus is given in such a way that the nano filler dispersion in which way enhances the mechanical properties. Better bonding between the matrix and reinforcement only improves the property how the nano fillers behave in that aspect also discussed in this review. The dispersion of nano fillers in various polymer matrix composites also presented in the review. Tensile, Flexural and Impact property of the composites decides its usage in various structural applications and this review presents briefly how these properties varying with respect to various nano fillers. Further the nano filler performance on the thermal properties as well as its impact in various sectors such as automobile, biomedical, sports, and aerospace applications etc., also presented in this review paper.

[27] Mechanical and Morphological Properties of Nano Filler Polyester Composites

This research is focusing on mechanical and morphological properties of unsaturated polyester (UP) reinforced with two different types of filler which is nano size clay Cloisite 30B (C30B) and Carbon Black (CB). Samples were fabricated via hand lay-up and open molding technique. Percentages of Cloisite 30B & Carbon Black (CB) used vary from 0, 2, 4, 6, 8 and 10 wt%. The mechanical properties were evaluated by impact, flexural and hardness testing. Result shows that the mechanical strength of C30B was better compare to CB filled composite. The combination of UP with C30B helps to improve the properties due to the high surface area of nanosize filler in the matrix. The result shows that increasing of filler content had increased mechanical properties of composites. Optimum percentage represent good mechanical properties are 4% for both fillers. SEM images showed that rough surface image indicate to agglomeration of filler in the matrix for CB sample and smooth surface image on C30B sample indicate to homogenous blending between filler and matrix polyester. SEM images proved that mechanical properties result indicate that C30B polyester composite is a good reinforcement compare to CB polyester composite.

[28] Effects of fibers and fillers on mechanical properties of thermoplastic composites

Thermoplastic copolyester elastomer (TCE) and Polyoxymethylene (POM) filled polytetrafluroethylene (PTFE) composite, reinforced with short glass fiber (SGF) and different shape microfillers such as short carbon fiber (SCF), silicon carbide (SiC) and alumina (Al2O3) were prepared by melt mixing method using twin screw extruder followed by injection moulding. Mechanical properties such as tensile, flexural and impact strengths were studied. The mechanical properties test results show that short glass fiber obviously improves the strength of TCE and POM filled PTFE composites and different shape ceramic fillers decreases the tensile and bending properties of TCE filled PTFE composite, but different shape microfillers exhibits a synergistic effect on tensile and bending properties of POM with PTFE simultaneously. Hybrid composites have shown lower tensile strength and strain with increase in fiber/filler content. POM composites exhibited better tensile (strength of 75.78 and modulus of 1769.1 MPa respectively) and flexural (strength of 116.2 and modulus of 5697 MPa respectively) properties. TCE composites showed moderate elongation at break and better impact strength as high as 80 J/m (with 20 wt% glass fiber content) compared to POM composites.

[29] Computational and Experimental Investigation & Analysis on the Effect of Milled Basalt Fibre Fillers on Static Flexural Properties of the Natural Fibre Composites for Aerospace and Automobile Industrial Applications

Academic and industry researchers are focused on developing a material that satisfies various parameters such as durability, manufacturability, low cost, lightweight, adaptability, high strength, bio-degradability, etc. to meet the current day trends across aerospace and automotive industries. In engineering and technology, fiber-reinforced matrix composites and their applications are extensive. The addition of fillers (both natural and synthetic) along with matrix and fibers is considered to be a better option to increase the efficiency and performance of the composite materials. Recently, researchers have focussed on adding fillers along with matrix and its hybridization to lift the composite properties and applications. This research paper describes the computational and experimental investigation & analysis on the effect of milled basalt fibre fillers on static flexural properties of the natural fibre composites for aerospace and automobile applications. As a first step, an optimized milled filler percentage is examined by incorporating the basalt milled filler into the epoxy laminates from 0.5% to 3% weight percentages concerning epoxy laminates. Finally, the 1% filler incorporated epoxy laminates showed better results than the base samples. Then, the 1% milled basalt filler material was incorporated into basalt fiber and areca fiber with epoxy resin and hardener to make the composite laminates for static testing. The static testing was carried out with the help of a Universal Testing Machine (UTM) i.e. the three-point bending test. The filler-incorporated basalt and areca nut epoxy composite laminates show higher flexural properties than the base samples with 0% filler material. The project work was also carried out with the help of ANSYS software with proper filler material and epoxy composite laminates for static testing. The flexural properties of the filler-incorporated composite laminates show higher properties than the base samples. Results reveal that the flexural properties of the composite laminates from experimental testing and software analysis are of less error percentage difference.

From the literature surveys, it is clear that the influence of mechanical properties of the composite material with the addition of fillers (natural and synthetic fiber milled). The addition of optimum composition of fillers enhances the mechanical properties of composite materials. To satisfy the current trends of a wholesome material, the addition of fillers with matrix is considered to be a better option. Thus, the produced composite materials and structures are better suited for the application of aerospace and automotive industries.

III. EXPERIMENTAL PROCEDURE

3.1 Fillers and Chemicals Used

3.1.1 Basalt Filler

Figure 2: Basalt Uni-Directional Fibre (left), Powdered Basalt Filler (right)

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Milled fibers are a short form of Basalt fibers, typically approximately 100µm in length, used as a reinforcing material in the composites industry. Milled fillers manufactured from recycled fibers are used in a wide range of applications when there is a need for improving mechanical properties like tensile strength and modulus. Basalt fibers can be applied in a wide range of application areas, i.e. thermal and acoustic insulation, pipelines, beams, fabrics, structural synthetic materials, various car parts, reinforced concrete, insulating synthetic material, or friction material to name a few. Basalt is a natural quality raw material, which is not harmful to the environment. In contrast to many conventionally used fibers, basalt does not produce any toxic emissions during production and processing.

3.1.2 Areca Nut Filler

The husk fiber of the Areca nut is used as a lightweight, economically reinforcing material in industries such as construction, vehicle manufacturing, and aircraft manufacturing. The husk fiber is also used in the preparation of hard boards, paper boards, cushions, and non-woven fabrics. Milled Arecanut fibers are used as fillers in composite laminates to check their effect on the mechanical properties of composites such as Flexural properties.

Figure 3: Areca Nut Filler

3.1.3 Epoxy and Hardener

Epoxy resin Araldite LY556 is extensively used as a reinforcing material due to its medium viscosity and chemical resistivity. The 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 molding, filament winding, and so on. This resin is known for its exceptional mechanical, good fiber impregnation, and thermal and dynamic properties. Also, epoxy resin LY556 has a low tendency to crystallize and hence it is preferred for aircraft and aerospace adhesives. Hardener Aradur HY951 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 starts a chemical reaction that produces heat- an exothermic reaction. It is claimed that after curing the bond is impervious to boiling water and all common organic solvents.

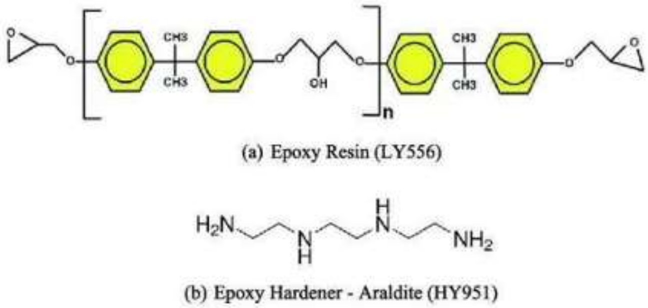

Figure 4: Chemical Composition of Epoxy Resin and Hardener

3.2 Ball Milling of Fibres

A ball mill is a type of grinder, that is a cylindrical device used in grinding (or mixing) materials like ores, chemicals, ceramic raw materials, and paints. Ball mills rotate around a horizontal axis, partially filled with the material to be ground plus the grinding medium. It works on the principle of impact and attrition: size reduction is done by impact as the balls drop from near the top of the shell. A ball mill consists of a hollow cylindrical shell rotating about its axis. The axis of the shell may be either horizontal or at a small angle to the horizontal. It is partially filled with balls. The grinding media are the balls, which may be made of steel (chrome steel), stainless steel, ceramic, or rubber, depending on the requirements.

Figure 5: Planetary Ball Mill Setup

Here, for my project purpose, I used a planetary ball mill, to grind the fibres into fine powders (fillers). The fiber is first cut into small pieces, and ground in the home appliance before putting it into the ball milling vile, for efficient milling.

Figure 6: Home Blended Basalt Fibres and Steel Balls

From literature surveys, the duration of grinding, ball to fibers ratio to be used, and Speed of rotation of the jars are found, which are as follows:

Fibres to balls wt. ratio :	**1:10**
Weight of fibre per run:	**20g**
Weight of Steel Balls:	**200g**
Ball Milling speed:	**732 rpm**
Ball Milling Duration:	**4hrs**

Hence, the milling was done with the above conditions, to get the desired powder with a size in the range of micrometers, which can then be used as fillers.

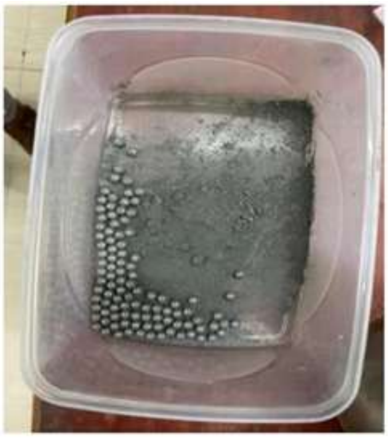

Figure 7: Milled Basalt Fibre Filler

3.3 Fabrication of Epoxy Laminates

A silicone mold 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 identical dimensions, the mold's impressions are created. For static flexural testing, the sample is estimated to be 150 mm x 25 mm x 4.5mm in size. The process of 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. First, the virgin epoxy sample is made without any filler added to it for comparison. Further in a similar fashion, the epoxy is added with fillers in weight fractions of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% respectively. In each weight percentage, five samples have been fabricated and tested for more accurate results. So, a total of 35 samples have been made with different weight percentages of milled basalt fillers. The milled Basalt fibers are combined with the epoxy resin using a magnetic stirrer. Using a magnetic stirrer, the epoxy resin and milled filler mixture are blended for 2 hours at 60-degree temperature. The magnetic stirrer ensures that the fibers and epoxy resin are mixed uniformly, creating uniform dispersion without any air bubbles or voids.

Figure 8: Magnetic Stirrer

The stirring in a magnetic stirrer 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. The epoxy resin and milled fiber mixture are stirred for 32 minutes using this magnetic stirrer.

Figure 9: Sonicator

The mixture is now allowed to cool for some time, and the hardener is added in the ratio of 1:10 hardener to mixture ratio. The mixture is now stirred using a stick, manually, and carefully so that no air bubbles are formed, and until the hardener disperses well into the mixture. This mixture is then poured into silicone molds where they are allowed to cure for 24 hours.

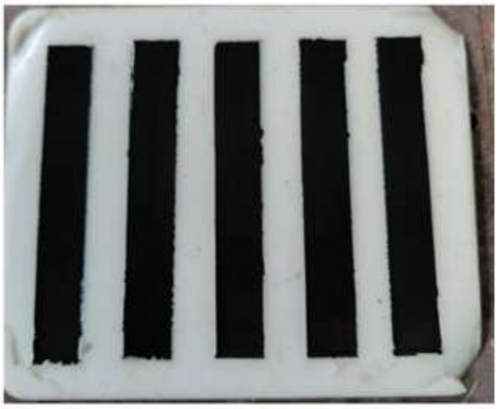

Figure 10: Mixture Poured into Silicone Mould for Curing

Before the mixture is cured fully, it is taken from the mold within 24 hours, to perform post curing process, in which the samples are left in the temperature chamber for two hours at 90°C. This post-curing in the temperature chamber ensures the breakage of the O-H bond of epoxy, and the necessary chemical bonding to take place between the epoxy and filler materials.

Figure 11: Temperature Chamber

The milled basalt fillers utilized have weight percentages of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%, respectively. In the same manner, five samples in each weight percentage have been created and evaluated to ensure more precise findings. So, 35 samples in all have been created using various weight ratios of milled Basalt fillers. 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 the fabrication of composite samples, with Basalt fiber and epoxy resin as fiber and matrix materials respectively, where the optimal weight percentage of milled basalt filler is added to the epoxy resin.

Composition of the sample	**Epoxy samples**	**Total no. of samples**
Base sample without filler	05	05
Sample with 0.5% milled Basalt fillers	05	
Sample with 1% milled Basalt fillers	05	
Sample with 1.5% milled Basalt fillers	05	
Sample with 2% milled Basalt fillers	05	
Sample with 2.5% milled Basalt fillers	05	30
Sample with 3% milled Basalt fillers	05	
Total no of epoxy samples		**35**

Table 1: Quantity of Epoxy Samples Fabricated for Static Testing and their Filler Composition

3.4 Procedure for Flexural Testing

Pure epoxy, and 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%, milled basalt 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. 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.

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 2: Specifications of Universal Testing Machine (UTM)

Figure 12: Virgin Epoxy Samples before Testing

Figure 13: Epoxy Samples with Milled Basalt Fillers 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.

IV. RESULTS AND DISCUSSIONS

For the investigation of flexural properties, plain epoxy samples are compared to milled basalt filler concentrations of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%, weight fractions. The samples are examined for flexural characteristics using the Universal Testing machine (UTM).

Figure 14: 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 (Flexural Testing)

It is very well known that cured pure epoxy is brittle 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.

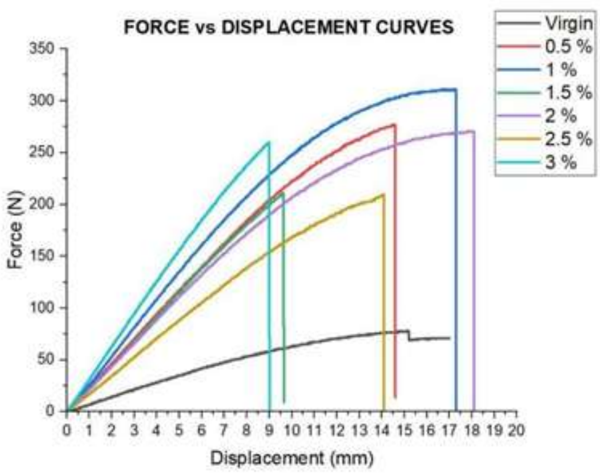

Figure 15: Load Vs Displacement Graph of Epoxy Samples with Basalt Fillers

Also, from the graphs, it can be noted that up to a particular weight concentration, the ultimate yield force increases with an increase in weight percentage. After a certain weight fraction of fillers in epoxy laminate, the ultimate yield force decreases with an 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 analyzed. For samples with milled Basalt fibers, the maximum ultimate yield force is obtained for 1% weight percentage. Flexural strength, flexural toughness, and flexural modulus are the properties that are being analyzed. For this purpose, these values are being plotted against the weight percentage of milled fillers to get the required values.

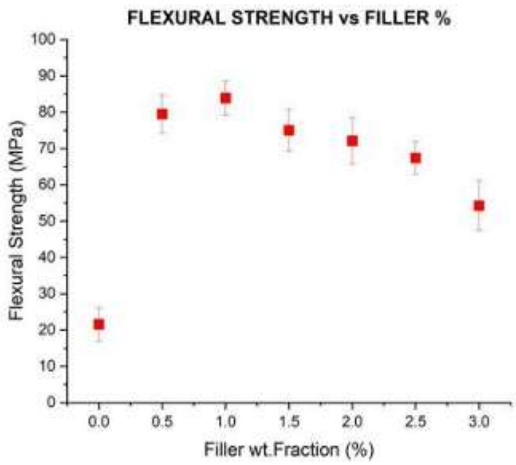

Figure 16: Flexural Strength Vs Weight Concentration Graph for Epoxy Samples with Milled Basalt Fillers

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 Basalt fillers, the maximum flexural strength is obtained for samples with 1% milled Basalt fillers which is 81.884 MPa.

$$\sigma = \frac{3FL}{2bd^2}$$

Where, σ = Flexural Strength (MPa)

F = Ultimate load (N)

L = Effective span of sample (m)

b, d = Breadth and Depth of the sample (m)

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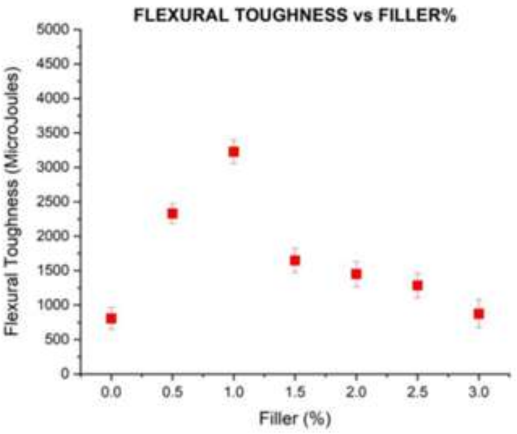

Figure 17: Flexural Toughness Vs Weight Concentration Graph for Epoxy Samples with Milled Basalt Fillers

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 1% of milled Basalt fibers have a higher flexural toughness value of 3227.4106 MPa compared to Epoxy samples with other weight percentages. 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.

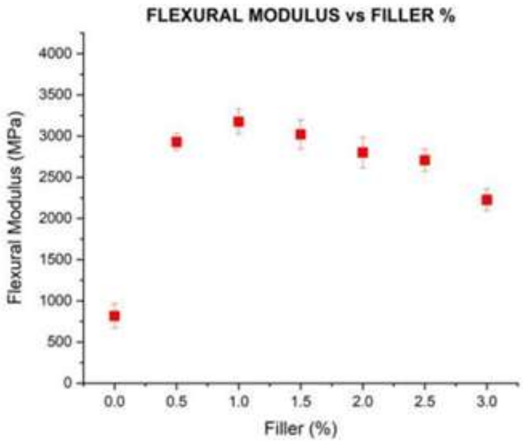

Figure 18: Flexural Modulus Vs Weight Concentration Graph for Epoxy Samples with Milled Basalt Fillers

Flexural modulus or bending modulus is defined as the ratio of stress to strain in flexural deformation, or the tendency for a material to resist bending. It is determined from the slope of a stress-strain curve produced by a flexural test. In the case of flexural modulus too, Epoxy samples with 1% of milled Basalt fillers have a higher flexural toughness value of 3175 MPa compared to Epoxy samples with other weight percentages of milled Basalt fillers. From the graphs above plotted, it is evident that all three flexural properties are higher for 1% weight percentage of milled Basalt fillers.

These properties are being compared with the base sample of epoxy resin without any milled fillers which is being tabulated below.

Properties	Base Sample (MPa)	Sample with 1% milled Basalt fibers (MPa)	Percentage increase (%)
Ultimate yield stress	25.7	99.7	287.93
Flexural Strength	21.578	81.888	279.49
Flexural Toughness	807.31	3227.41	299.71
Flexural Modulus	817.187	3175	288.52

Table 3: Comparison of Properties of Base Epoxy Samples ans Samples with 1% Milled Basalt Fibre Fillers

4.2 Basalt/Epoxy Samples (Flexural Testing)

Following the optimization of the weight percentage of milled Basalt fillers in epoxy resin to be used, I move ahead with manufacturing composite laminate with Basalt as fiber and epoxy as resin. A base sample without filler is being manufactured, followed by making 1% milled basalt filler incorporated sample. A hand layup process was used to make the laminate with proper precautions. 16 layers of Basalt UD fibre were cut each having dimensions of 200 x 200 mm. The resin-to-hardener ratio taken was 10:1. Following the layup process, the composite laminate was placed in a compression molding chamber to speed up the curing process. Compression molding was performed for 15 minutes at around 90 degrees Celsius.

Figure 19: Hand Lay Up of Basalt/Epoxy Composite Laminate

4 samples each were taken in both Base and filler incorporated Basalt/Epoxy composites, after cutting to proper ASTM standard dimensions., and tested until the failure point in the Universal Testing Machine.

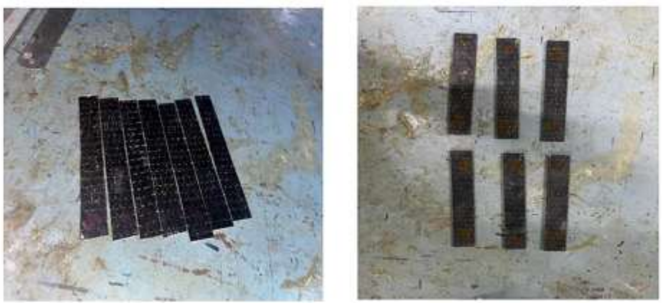

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Figure 20: Base Basalt/Epoxy Samples (Left); Basalt/Epoxy + Filler Samples (Right)

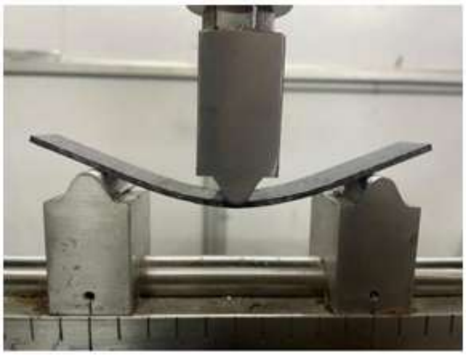

Figure 21: Three Point Bending Test being done in UTM

The load versus displacement graphs is plotted for Basalt fiber composite samples with 1% milled Basalt fillers and also for composite samples without any fillers.

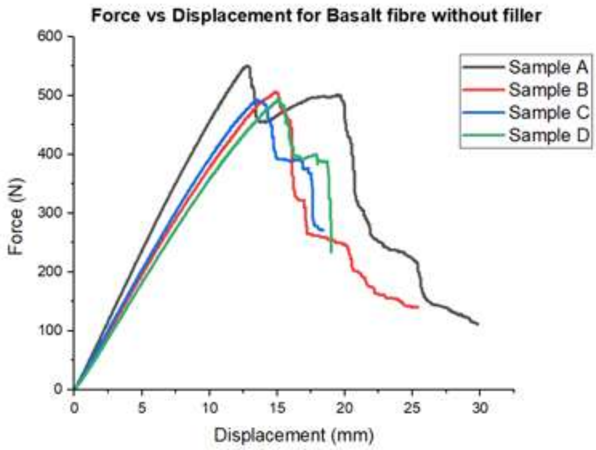

Figure 22: Load Vs Displacement Graph for Basalt Fiber Composite Sample without Fillers (Base Samples)

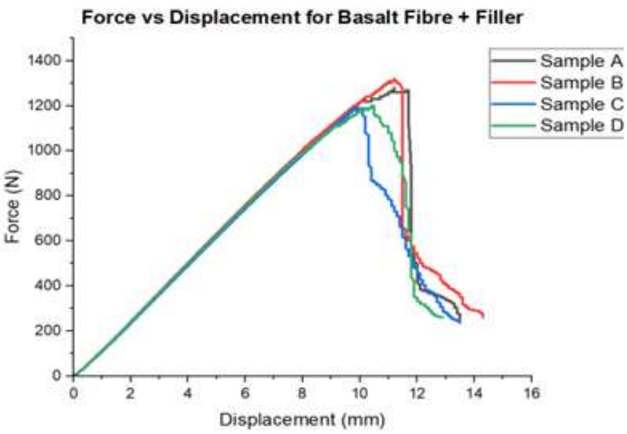

Figure 23: Load Vs Displacement Graph for Basalt Fiber Composite Sample with Milled Basalt Fillers

With the above load versus displacement graphs, it is possible to compare and analyze the load-carrying capacity of Basalt/Epoxy composites with and without filler.

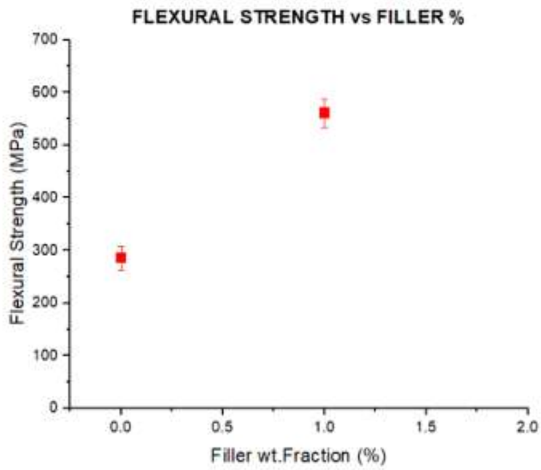

Figure 24: Comparison of Flexural Strength Vs Filler Weight Percentage Graph for Basalt/Epoxy Composite Samples

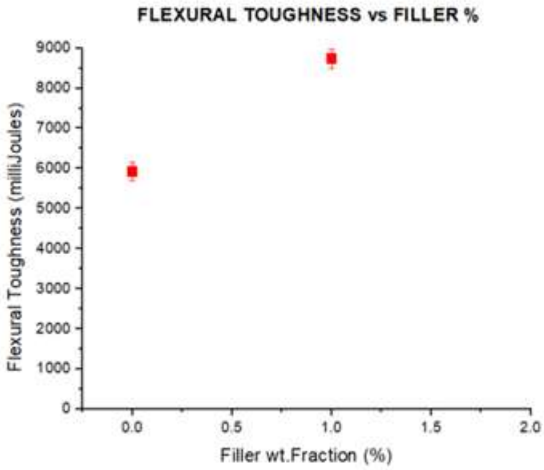

Figure 25: Comparison of Flexural Toughness Vs Filler Weight Percentage Graph for Basalt/Epoxy Composite Samples

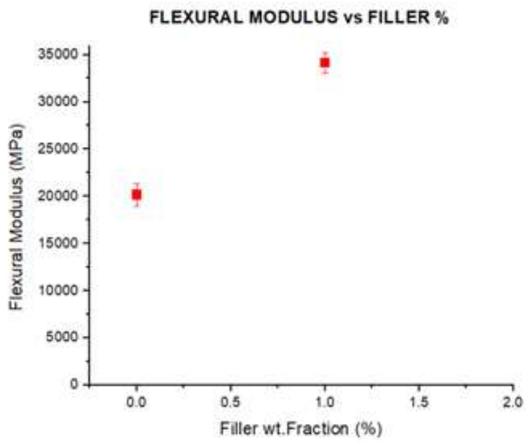

Figure 26: Comparison of Flexural Modulus Vs Filler Weight Percentage Graph for Basalt/Epoxy Composite Samples

The three aforementioned graphs demonstrate how the flexural properties depend on the filler weight percentage. It is evident that when compared to the base composite sample, the filled incorporated Basalt/Epoxy composite sample with 1% milled fillers exhibits higher values for flexural properties. Furthermore, the load-carrying capacity improves.

Properties	Base sample (MPa)	Sample with 1% milled Basalt fibers (MPa)	% increase of property from base sample
Ultimate Load (N)	507.535	1246.712	145.64%
Flexural strength	285.488	561.0206	96.51%
Flexural Toughness (mJ)	5919.39	8738.64	47.67%
Flexural Modulus	20,175	34,125	69.14%

Table 4: Comparison of Properties of Base Basalt/Epoxy Composite Sample and Sample with Milled Fibres

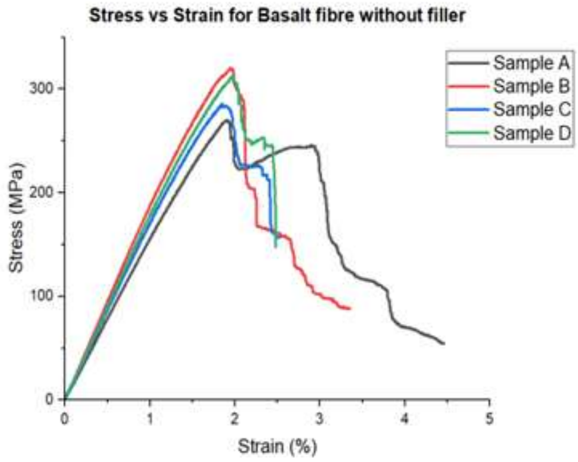

Figure 27: Stress Vs Strain Graph for Basalt Fiber Composite without Filler

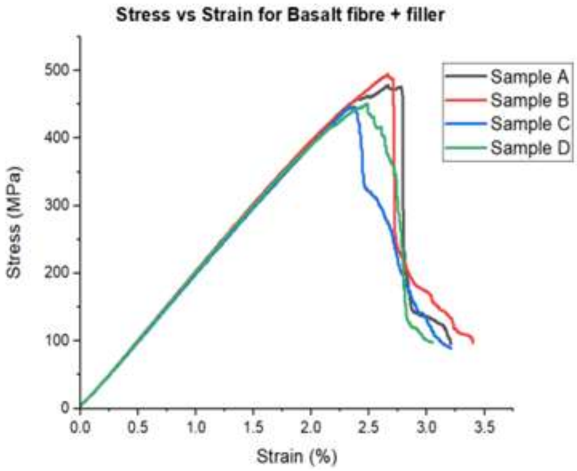

Figure 28: Stress Vs Strain Graph for Basalt Fiber Composite with Filler

4.3 ArecaNut/Epoxy Samples (Flexural Testing)

Following the static testing of Basalt/Epoxy laminate with and without filler being added, I move ahead with manufacturing composite laminate with Arecanut as fiber and epoxy as resin. A base sample without filler is being manufactured, followed by making 1% milled basalt filler incorporated Arecanut/Epoxy sample. A hand layup process was used to make the laminate with proper precautions. 4 layers of Arecanut UD fibre were cut each having dimensions of 200 x 200 mm. The resin-to-hardener ratio taken was 10:1. Following the layup process, the composite laminate was placed in a compression molding chamber to speed up the curing process. Compression molding was performed for 15 minutes at around 90 degrees Celsius.

Figure 29: Hand Lay Up of Areca Nut/Epoxy Composite Laminate

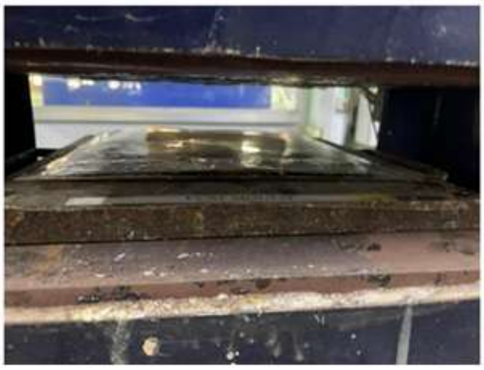

Figure 30: Compression Moulding in the Moulding Chamber

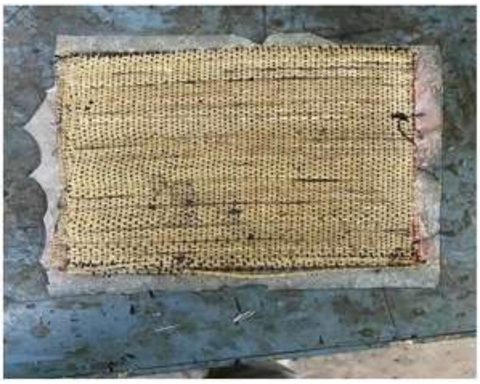

Figure 31: Areca Nut/Epoxy Sample Post Compression Moulding

4 samples each were taken in both Base and filler incorporated Arecanut/Epoxy composites, after cutting to proper ASTM standard dimensions., and tested until the failure point in a Universal Testing Machine.

Figure 32: Base ArecaNut/Epoxy Samples

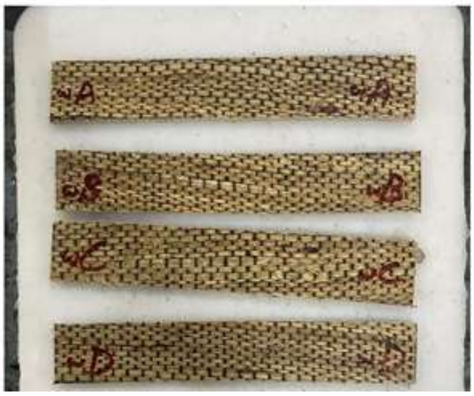

Figure 33: ArecaNut/Epoxy Samples added with Milled Basalt Filler

The load versus displacement graphs is plotted for Arecanut fiber composite samples with 1% milled Basalt fillers and also for composite samples without any fillers.

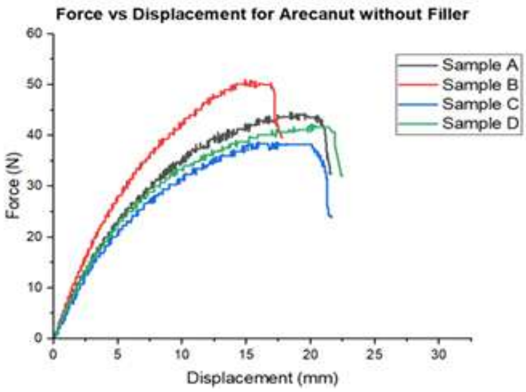

Figure 34: Load Vs Displacement Graph for ArecaNut Fiber Composite Sample without Fillers (Base Samples)

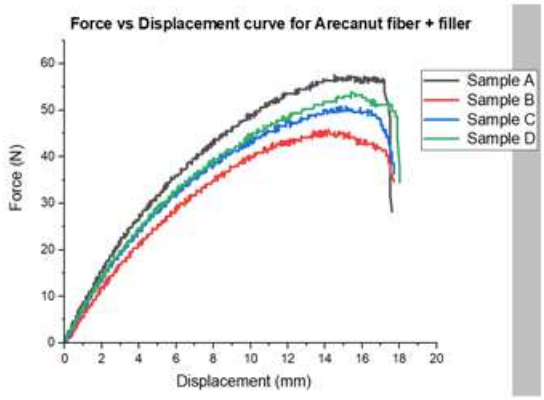

Figure 35: Load Vs Displacement Graph for ArecaNut Fiber Composite Sample with Milled Basalt Fillers

With the above load versus displacement graphs, it is possible to compare and analyze the load-carrying capacity of Arecanut/Epoxy composites with and without filler.

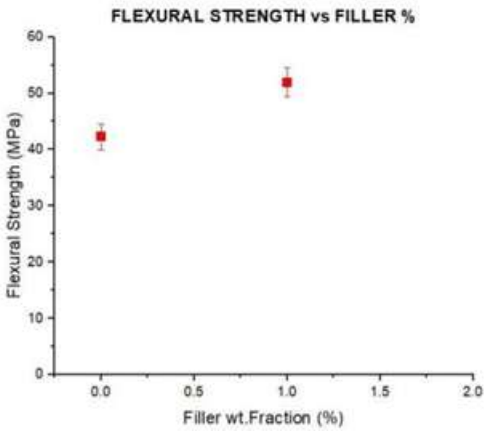

Figure 36: Comparison of Flexural Strength Vs Filler Weight Percentage Graph for ArecaNut/Epoxy Composite Samples

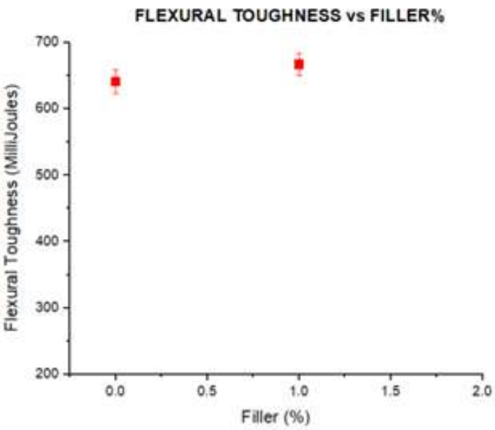

Figure 37: Comparison of Flexural Toughness Vs Filler Weight Percentage Graph for ArecaNut/Epoxy Composite Samples

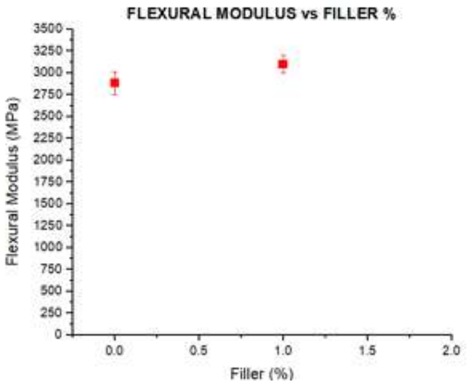

Figure 38: Comparison of Flexural Modulus Vs Filler Weight Percentage Graph for ArecaNut/Epoxy Composite Samples

The three aforementioned graphs demonstrate how the flexural properties depend on the filler weight percentage. It is evident that when compared to the base composite sample, the filled incorporated Arecanut/Epoxy composite sample with 1% milled fillers exhibits higher values for flexural properties. Furthermore, the load-carrying capacity improves.

Properties	Base Arecanut/Epoxy sample (MPa)	Sample with 1% milled Basalt fillers (MPa)	% increase of property from base sample
Ultimate Load (N)	46.445	54.056	16.38%
Flexural strength	42.263	51.894	22.78%
Flexural Toughness (mJ)	640.688	666.387	4.01%
Flexural Modulus	2885	3100	7.45%

Table 5: Comparison of Properties of Base ArecaNut/Epoxy Composite Sample and Sample with Milled Fibers

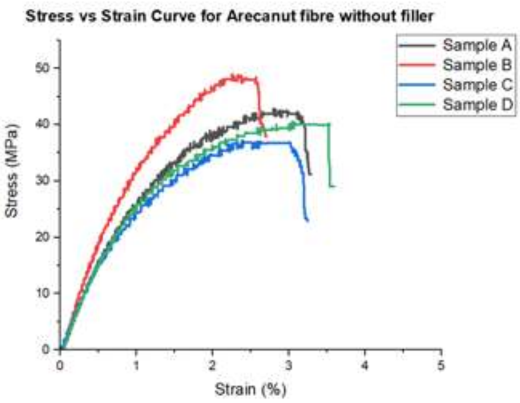

Figure 39: Stress Vs Strain Graph for ArecaNut Fiber Composite without Filler

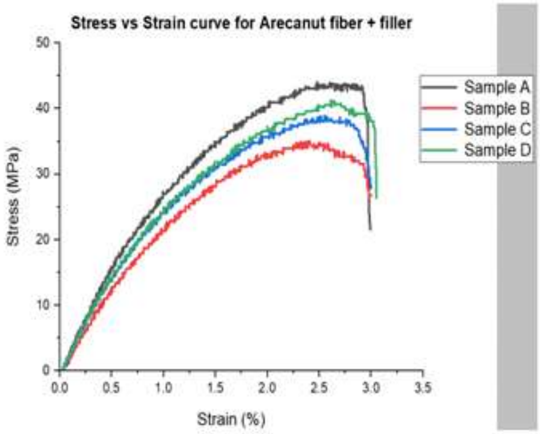

Figure 40: Stress Vs Strain Graph for ArecaNut Fiber Composite with Filler

V. CONCLUSIONS

5.1 Resin Study (Optimization of Filler%)

The resin study of the samples with milled basalt fillers is analyzed for further fabrication of the composite with the optimum weight percentage of the milled fillers showing the desired results. Using milled fibers as fillers shows promising results in terms of flexural properties as well as the load-carrying capacity of the resin samples.

As I proceeded from 0.5 % filler to 3% filler incorporated epoxy samples, I observed that I got maximum flexural properties such as Flexural Strength, Flexural Toughness, and Flexural Modulus, at a 1% weight fraction of Basalt filler in epoxy sample. The properties increase because, the addition of filler enhances the fracture toughness behavior of the matrix, resulting in more efficient load transfer by arresting and diverting the crack. The fillers in the resin arrest crack propagation by preventing the expansion of matrix micro-cracking. Micro cracks forming in the matrix due to the load are better dissipated as the filler is dispersed equally in the matrix, the milled fibers tend to form bridges between the cracks and hold together the matrix increasing flexural properties.

However, after 1% concentration, an increase in the concentration of the milled fibers causes a decrease in the ultimate yield stress. So consequently, a decrease in the flexural properties is also noted for an increase in the weight percentage after this optimum weight concentration. This happens due to agglomeration of the milled fibers taking place due to Vander Waals attraction between the molecules of the milled fibers, at higher weight percentages.

Hence, I have used this ideal weight fraction of 1% milled Basalt filler in the composite laminates to be made with Basalt and Arecanut fibers and epoxy as resin, which has been done further, and necessary flexural testing has been carried out to determine their mechanical properties. These properties have been compared with their respective base composite samples, which are not added with milled fiber filler.

5.2 Basalt/Epoxy Composite – Flexural Testing

At the end of the static testing of both base and filler incorporated samples, I found a significant enhancement of flexural properties such as Flexural strength, modulus, and toughness.

1. Maximum Ultimate force of 1246.712 N was observed for Basalt/Epoxy sample with 1% Milled filler incorporated sample. Hence, increase in Ultimate force value from that of Base Composite (Basalt/Epoxy) sample is: 2.46 times (145.64%)

2. Maximum Flexural Strength of 561.0206 MPa was observed for Epoxy sample with 1% Milled filler incorporated sample. Hence, increase in Flexural Strength value from that of Base Composite (Basalt/Epoxy) sample is: 1.96 times (96.51%)

3. Maximum Flexural Toughness of 8.738 Joules was observed for Epoxy sample with 1% Milled filler incorporated sample. Hence, increase in Flexural Toughness value from that of Base Composite (Basalt/Epoxy) sample is: 1.476 times (47.62%)

4. Maximum Flexural Modulus of 34.125 MPa was observed for 1% Milled filler incorporated sample. Hence, increase in Flexural Modulus value from that of Base Composite (Basalt/Epoxy) sample is: 1.69 times. (69.14%)

The increase in the flexural properties in the filler-loaded sample, compared to the base sample can be attributed to the fact that ball milling leads to roughening of the surface of the fiber, the rough surface of the fiber helps in better interfacial bonding with the matrix and also prevents pull-out of the fiber due to increased friction, hence leading to an improvement in properties. Moreover, the filler enhances the adhesion between the fiber and the matrix, reducing the scope of delamination. Transverse matrix cracking and fiber-matrix interface debonding are reduced by improving the interlaminar properties of brittle epoxy matrix by incorporation of fillers.

5.3 ArecaNut/Epoxy Composite – Flexural Testing

Similarly, at the end of the static testing of both base and filler incorporated samples, of Arecanut/Epoxy composite, I have found an enhancement of flexural properties, but of lower significance when compared with that of Basalt/Epoxy laminate.

1. Maximum Ultimate force of 54.056 N was observed for 1% Milled Basalt filler incorporated sample. Hence, % increase in Ultimate force value from that of Base Composite (Arecanut/Epoxy) sample is: 16.38 %

2. Maximum Flexural Strength of 51.894 MPa was observed for 1% Milled Basalt filler incorporated sample. Hence, increase in Flexural Strength value from that of Base Composite (Arecanut/Epoxy) sample is: 22.78 %

3. Maximum Flexural Toughness of 0.66 Joules was observed for 1% Milled Basalt filler incorporated sample. Hence, % increase in Flexural Toughness value from that of Base Composite (Arecanut/Epoxy) sample is: 4.01 %.

4. Maximum Flexural Modulus of 3100 MPa was observed for 1% Milled Basalt filler incorporated sample. Hence, increase in Flexural Modulus value from that of Base Composite (Arecanut/Epoxy) sample is: 7.45 %.

The increase in flexural properties of the filler-loaded sample to that of the base sample can be explained in a similar way as done for basalt/epoxy composites. However, here the % increase in properties is not as significant as compared with basalt/epoxy composites. This may be because, the milled filler is of basalt and the fiber material is areca nut here, so the adhesion between matrix and fiber might not be as strong as in the case of basalt/epoxy composite, where the filler and fiber both are of same material (Basalt). However, this conclusion is not based on any literature surveys.

Flexural Properties	**% Increment of properties of Filler + Basalt/Epoxy composite from Base sample**	**% Increment of properties of Filler + Arecanut/Epoxy composite from Base sample**
Ultimate Load (N)	145.64 %	16.38 %
Flexural strength (MPa)	96.51 %	22.78 %
Flexural Toughness (mJ)	47.62 %	4.01 %
Flexural Modulus (MPa)	69.14 %	7.45 %

Table 6: Comparison of properties enhancement in both Basalt and ArecaNut Samples

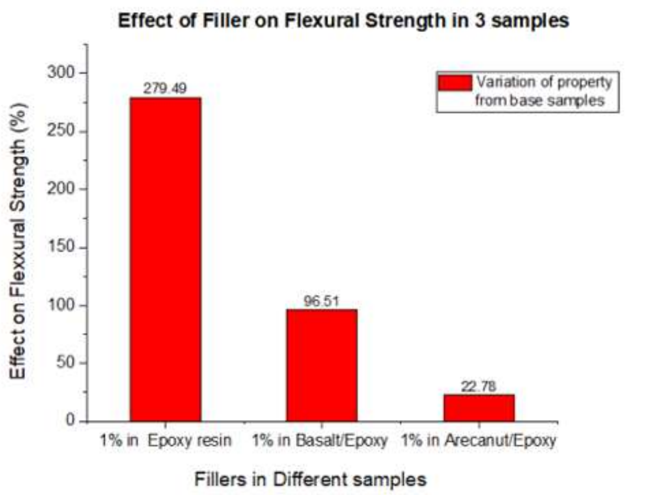

Figure 41: Effect of Filler on Flexural Strength of Samples with Fillers in Comparison with their base samples

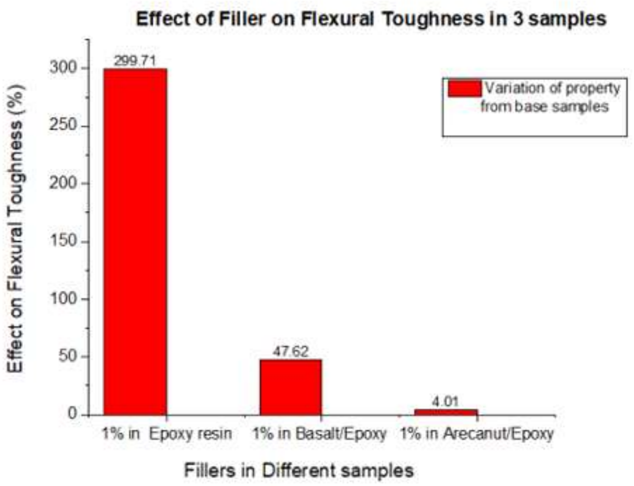

Figure 42: Effect of Filler on Flexural Toughness of Samples with Fillers in Comparison with their base samples

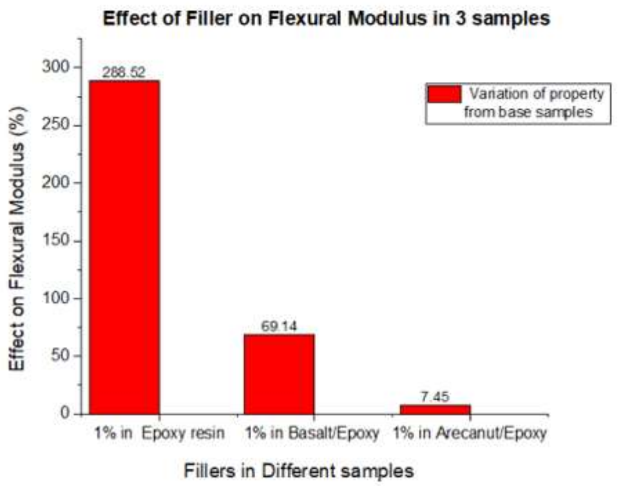

Figure 43: Effect of Filler on Flexural Modulus of Samples with Fillers in Comparison with their base samples

Figure 44: SEM Micrographs of fractured surfaces after flexural testing of (a) baseline basalt/epoxy samples (b) 1% wt. basalt filler modified basalt/epoxy samples. To the right, two insets of (b) showing close-up of the marked regions.

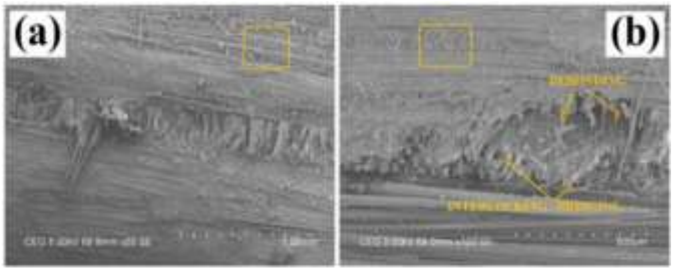

Figure 45: Effect of basalt filler distribution in 1 wt.% basalt/epoxy composite at different magnifications: (a) 50x, (b) 100x

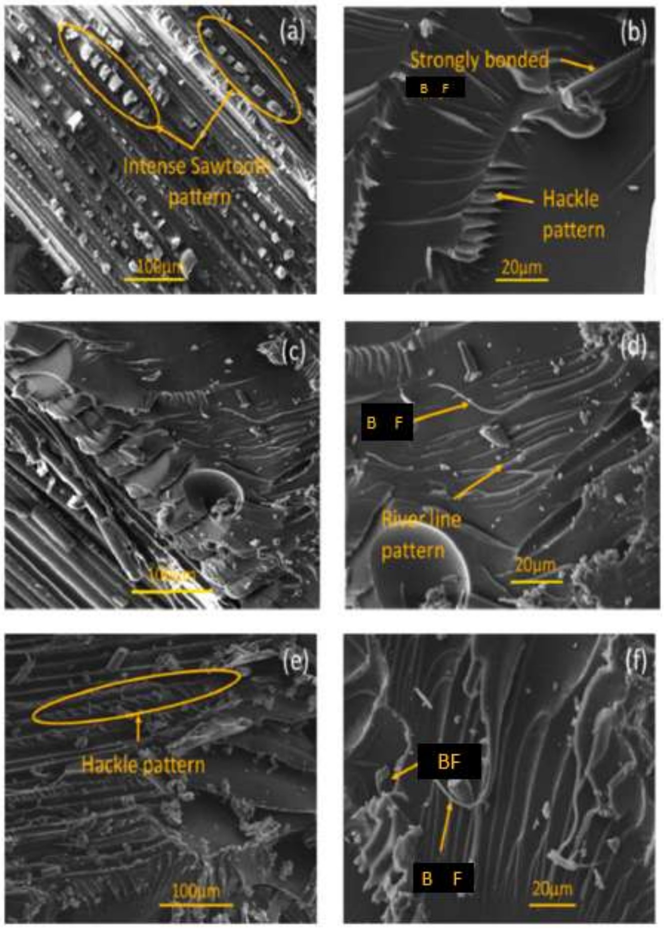

Figure 46: SEM Micrographs of fractured surfaces after flexural testing (a-f) 1% wt. basalt filler incorporated arecanut/epoxy composite samples

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