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The Mechanical Properties Of E-Glass/Epoxy, E-Glass/Polyester, And Sisal/Polyester Polymer Composites

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Abstract: E-Glass fiber reinforced polymer matrix composites have been widely employed as a substitute material in car and aerospace applications due to its light weight and superior mechanical capabilities. The vacuum bagging procedure for preparing the specimen is described in this study. Tensile, hardness, and impact strength qualities are characterized through investigation in accordance with ASTM standards. E-glass fibers are accessible in a variety of configurations; in the current study, E glass woven fabric is used as a reinforcing material, and Polyester resin is used as a matrix material. The synthetic glass fiber was chosen for its outstanding mechanical strength, while the polyester resin making for its greater qualities. Tests were carried out for a 60%,65% and 70% volume fraction of E-glass woven fabric reinforcement polymer matrix composites. Obtained results evident that 70% of woven roving mat (E-glass fiber) has good mechanical properties compare to 60% volume fraction reinforced polymer matrix composites

Keywords - Synthetic glass, polymer matrix composites, vacuum bagging process:

I. INTRODUCTION

Polymer matrix composites have emerged as the vital & most promised materials for a larger category of application because of their excellent mechanical, physical, and chemical properties. The modern years, a considerable growth in the interest of the development of multifunctional polymer matrix composites that can offer not only mechanical properties but also additional functionalities such as thermal, electrical, and sensing properties. Polyethylene (PE) fibers have been extensively studied because of their good mechanical Property, lower density,and lesser cost prices. The **Fig. 1** provides the types & categories of polymer material[1].The developing of multifunctional polyethylene fibre type of reinforced polymers matrix composite requires the integration of functional materials into the polymer matrix. The functional materials can be added to the polymer matrix in different forms such as nano-particles, fibers, or sheets. Adding of these composite material could improve the thermal and, electrical based conductivity of the composites, making them suitable for different applications, thermal management and electromagnetic type of shielding's. Developing a number of multifunctional polyethylene fibre reinforced polymer's matrix composite also requires the optimization of the processing techniques. The processing parameters such as pressure, time, and temperatures can significantly which could affect the different property of the composites [2]. Multifunctional polyethylene (PE) fibres based reinforced polymer matrix composite is advanced material that consists of PE fibers as reinforced materials and a polymer matrix as the binding material. In recent years, the use of fibre-reinforced composites has been on the rise due to their lower production costs, lightweight nature, high fracture toughness, and improved control over thermomechanical properties. For instance, they are being considered for the fuselage structures of commercial aircraft [3]. The design of hinge-less & bearing less helicopter rotor hubs also employs laminated composite materials, which experience both centrifugal loads and bending in the flapping flexure region. In order to meet the demand for improved performance of these structural materials, it becomes necessary to evaluate them under multi-axial loading[4]. There have been numerous researchers who have worked on the topic of design and development of multifunctional polyethylene (PE) fibres based reinforced polymer matrix composites, and the field is continuously expanding.

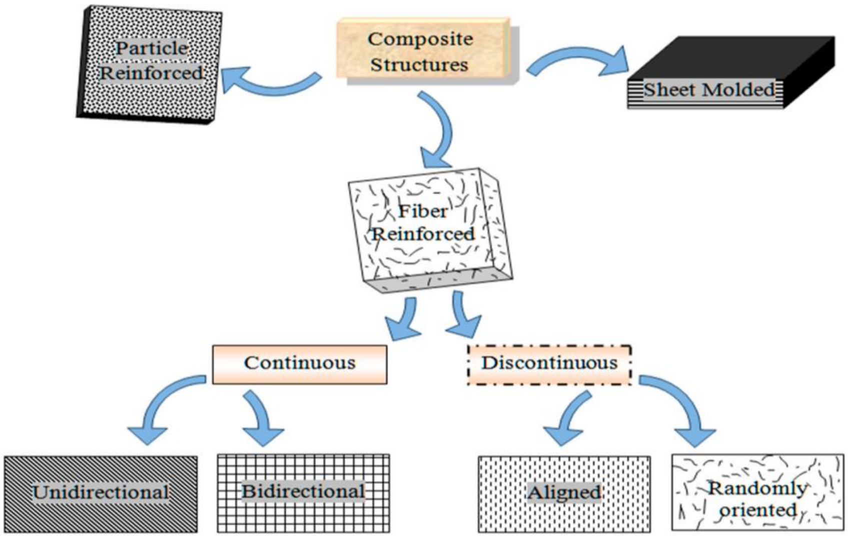


Fig.1: Classification and types of polymer material

The polymer matrix provides the binding material that will hold the fibers in tandem & will transfer the loads b/w the different fiber. Modern engineering applications often necessitate materials with unique and specialized property that can't be fulfilled with traditional metal alloy, ceramic, or polymers. For instance, aircraft engineers demand structural materials that are lightweight yet robust, rigid yet resistant to impact damage, among other attributes [5]. Unfortunately, materials with high strength often possess high density, and attempts to enhance strength or stiffness usually results in a reduction of impact resistance. As a result, engineers worldwide have been persistently seeking new materials with optimal combinations of properties to satisfy diverse application requirements [6]. The surface based treatment of the reinforcement fibers play a crucial part to improve the inter-facial bonding b/w the fiber & the matrices. Physical modification involves altering the fiber surface by mechanical means, such as roughening, etching, or sandblasting, which improves the mechanical inter-lockings b/w the matrix and fiber. Among the available options, Aluminum Metal matrix composites can offer the desired characteristics [7]. Several formation mechanisms for hot cracks have been proposed in the literature for continuously casting and the shape type of casting processes, while there has been comparatively little research on cold cracks in recent years. Cold cracks occur the continual process of cooling of the solidified metal with a temp range of around 100s of degrees, making it difficult to understand their formation conditions due to the radical changes in the mechanical property of composite metal as ultimate strengths, fractured strains, stress, and modulus. The main aim of the research work carried out as development of an improvised polymer type of composite materials, which is more effective than the current polymer based composite materials in many aspects such as durability, ductility, performance-wise, cost, reliability [8]. The fabricated samples of fiber reinforced polymer composites would be subjected to ignition, void content and chemical resistance tests as per prevailing ASTM standards.

II.LITERATURE REVIEW

The reason for the conduction of a literature survey is for identifying the existing knowledge, research/s, and advancements in the field, as well as to identify any gaps or limitations that can be addressed through the proposed study. In the case of the development of multifunctional PE fibers reinforced polymer matrix composites, the literature survey would typically begin with a review of the basic concepts and principles related to composites, such as the types of composites, their properties, and their manufacturing processes. For instance, they are being considered for the fuselage structures of commercial aircraft [9],[10]. The design of hinge-less & bearing-less helicopter rotor hubs also employs laminated composite materials, which experience both centrifugal loads and bending in the flapping flexural region. In order to meet the demand for improved performance of these structural materials, it becomes necessary to evaluate them under multi-axial loading [11]. They worked extensively on the research in the area of polymer composites. Her research interests include the design and development of multifunctional composites using various reinforcement materials, including polyethylene fibers [12]. He has conducted research on the design and fabrication of multifunctional composites using various reinforcement materials, including polyethylene fibers. His research has focused on the development of composites with enhanced mechanical and thermal properties. They carried out the research on the design and fabrication of multifunctional composites using polyethylene fibers as the reinforcement material [13]. His research has focused on developing of the composite material considering improvised electrical & thermal property. His research focuses on the integration of functional materials into polymer matrices to achieve tailored properties, including the utilization of polyethylene fibers as material for reinforcement structures [14],[15]. The extracted fibers are then subjected to drying under sunlight for ten hours to eliminate residual moisture. The fibers which are extracted will be then dried & washed under broad sunlight for removing the excess moisture. A metal brush was used to comb the surface of the fibre for the removal of the waste particles [16]. Researchers conducted a study to compare the mechanical properties of polyester-based composites reinforced with short abaca fibers and glass fibers. The study investigated the effects of fiber length, fiber content, and surface treatment on the mechanical properties of the composites. The results demonstrated that fiber length and surface treatment significantly impacted the mechanical properties of the composites [17]. Jute fibers were used as reinforcing agents in the fabrication of composites with polyester and epoxy resins at 25:90 weight percentages. The mechanical properties of the fabricated composites, including tensile strength, flexural strength, impact strength, and hardness, were examined, and it was found that the jute-reinforced polyester composite exhibited superior mechanical properties compared to the jute-epoxy composite [18]. The study also explored the effect of resin penetration into fiber lumens on the mechanical and water-absorption properties of composites. The results showed that as the amount of resin inside the fiber lumens increased, the mechanical properties of the composites improved due to changes in the fracture modes. E-glass/epoxy composites were also studied for their combined effects of load, moisture, and temperature [19]. Results showed that short-duration immersion in distilled water led to a decrease in modulus and an increase in strength and strain to failure. At a higher temperature of 75°C for a longer duration, the strength decreased by 32% and the modulus decreased by 30%, while the strain to failure increased by 4%. The reduction in strength was not significant due to the replacement of chemical bonds with physical bonds, which maintained good stress transfer at the inter-phase [20]. The tensile test failure resulted in massive fiber non-bonding, indicating that at higher temperatures, moisture penetrates the fiber/matrix inter-phase.

II. MATERIALS & EXPERIMENTAL PROCEDURE

The new experimental procedures and materials specification of the properties of composite materials reinforced with glass fibers. As a solution, natural fibers are increasingly being used due to their low cost, biodegradable nature, availability, and renew-ability. The present study fabricates hybrid composite laminates is to used sisal & fibers made of glass that too being reinforced using polyester & epoxy material for studying the mechanical and physical property [21]. The stacking sequence and weight %age of matrix & fibre were varied to fabricate the composite laminates.

Synthetic Materials

Fiber reinforced polymer composites are often made with glass fibers due to their low cost, high tensile strength, chemical resistance, and insulating properties. There are two types of glass fibers commonly used in the industry: S-glass and E-glass. S-glass is known for its high tensile strength, greater modulus, and higher elongation at failure, and was originally developed for use in missile casings, aircraft components, and helicopter blades. However, it is more expensive due to its compositional difference and higher manufacturing cost. E-glass, on the other hand, is the least expensive reinforcing fiber available, and is therefore widely used in the FRP industry. For the purposes of this research, E-glass fibers were chosen to create Glass-Sisal hybrid composites. Plain woven fabric form was used to achieve uniform fiber distribution, minimize void formation, and ensure uniform laminate thickness [22]. The E-glass fiber fabric used was in plain woven form and is shown in **Fig.2**, which depict the natural fibers. The fabric was supplied by Suntech Fiber Pvt. Ltd. in Bangalore, India.

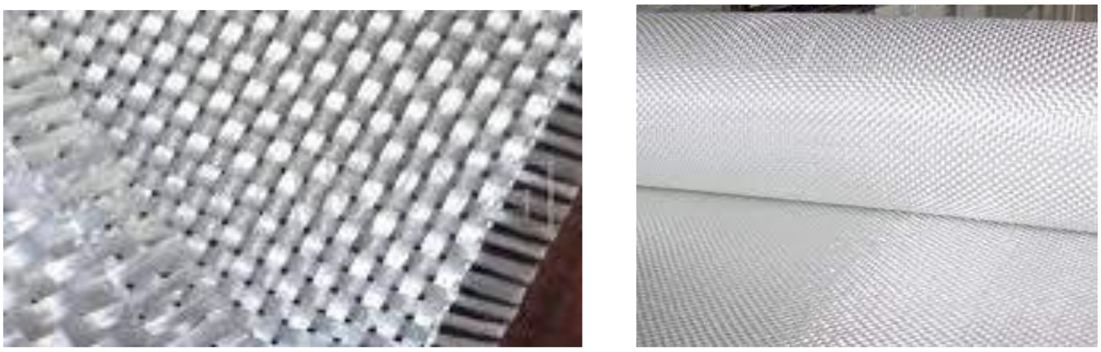


Fig.2: E-Glass fiber fabric sheet

Fig.3: Brown fabric sisal material & Organic based sisal material

According to the literature, sisal fibers offer several advantages, such as high tensile strength, load-carrying capacity, durability, and low maintenance, making them an attractive option among natural fibers. A typical sisal plant has a rosette of sword-shaped leaves, each measuring approximately 1.75 to 3 meters in length, and every plant can yield around 200 to 250 leaves, with each leaf containing 1200 to 1300 fibers. To improve inter-facial adhesion between fiber and matrix, natural fibers are usually subjected to appropriate chemical treatment prior to use. In this study, alkali treatment was applied to plain woven sisal fabric to fabricate Glass-Sisal hybrid composites [23]. To ensure a uniform distribution of fibers, minimize void formation, and achieve uniform laminate thickness, plain woven fabric form was used. The sisal fabric in plain woven form is depicted in **Fig.3** and was supplied by Sri Ramesh Chandili Groups & Exports and Imports, located in Bangalore, Karnataka, India.

Table.1: Properties of epoxy and polyester resins

Properties	Polyesters Resins	Epoxy's Resin
Densities (gm/cm^3)	1.3 – 1.6	1.2 – 1.5
Young"s moduli (G Pa)	2.5 – 4.57	3.3 – 6.3
Tensile strength (MPa)	50 – 100	30 – 110
Compression strengths (M Pa)	80 – 200	101 – 201
Tensile elongations for breaks in %	2.0 – 3.0	1.0 – 6.0
Cure shrinkage (%)	4.5 – 8.5	1.1– 22
Absorbing of water in 24 hours at 25˚C	0.15 – 0.35	0.2 – 0.5

Polyester & epoxy mats are particularly popular due to their excellent electrical & mechanical properties, resistance to heat & adhesion characteristics. The work carried out here utilizes epoxy type & isophthalic polyester resins for fabricating the sisal-glass fiber type of RF hybrid type of composites. Epoxy resin Araldite LY556 and hardener K6 and isophthalic polyester resin, accelerator, and catalyst are used in the preparation of the matrix system [24]. **Table.1** provides the different characteristics of various types of resins used in fabrication of composite laminates.

Fabrication of composite laminates

The hybrid composite laminate measuring (300 × 300 × 3) mm was manufactured using a vacuum bagging technique and plain woven Glass-Sisal fiber fabric with epoxy/polyester resin. The laminate was composed of alternating layers of glass and sisal fabrics arranged in a specific stacking sequence to achieve a thickness of 3 mm [25]. **Table.2** presents the different weights and weight fractions of the fibers and matrix. For a dimension of (300 × 300 × 3) mm, the wt. of the glass based fabric (w_g) was 36 ± 2 gm and the wt. of the sisals fabric (w_s) was 15 ± 1 gms.

$$W_f = \frac{w_f}{(w_f + w_m)} \ \& \ W_m = \frac{w_m}{(w_f + w_m)} \quad (1)$$

W_f, W_m, W_g, W_s are the Fiber Wight fraction (%), Matrix weight fraction (%), Glass fiber weight fraction (%),and the Sisal fiber weight fraction (%).

Table.2: Laminate designation as per stacking sequence

Laminates	Designations
L1	G + G + G + G + G (Epoxy)
L2	G + G + G + G + G (Polyester)
L3	S + S + S + S + S (Epoxy)
L4	S + S + S + S + S (Polyester)
L5	G + S + S + S + G (Epoxy)
L6	G + S + S + S + G (Polyester)
L7	G + S + G + S + G (Epoxy)
L8	G + S + G + S + G (Polyester)

The laminates which are renamed depending on the variety of the matrix material that is being utilized, weight percentages of glass and sisal fabric, and the number of layers used. L1 consisted of only glass fabric (wt.% of 37.5) of five layers with epoxy as the matrix material (wt.% of 62.5). L2 was made up of only glass fabric (wt.% of 37.5) of five layers with polyester as the matrix material (wt.% of 62.5). L3 contained only sisal fabric (wt.% of 27.28) of five layers with epoxy as the matrix material (wt.% of 72.72), while L4 contained only sisal fabric (wt.% of 27.28) of five layers with polyester as the matrix material (wt.% of 72.72). L5 was composed of glass fabric (wt.% of 22.36) on outer layers and three intermediate layers of sisal fabric (wt.% of 15.25) with epoxy matrix (wt.% of 68.12) [26]. L6 had glass fabric (wt.% of 22.36) on outer layers and three intermediate layers of sisal fabric (wt.% of 15.25) with polyester matrix (wt.% of 68.12). L7 had alternative layers of glass (wt.% of 28.19) and sisal fabric (wt.% of 9.83) (glass fabric on outer layers) with epoxy matrix (wt.% of 66.59), while L8 had alternative layers of glass (wt.% of 28.19) and sisal fabric (wt.% of 9.83) (glass fabric on outer layers) with polyester matrix (wt.% of 66.59).

Vacuum bagging hand lay-up and autoclave processes

Initially, the required number of layers of glass and sisal fiber fabrics are marked and cut according to the required dimensions. The calculated amount of matrix, hardener, and accelerator are mixed in a 10:1 ratio for epoxy and 100:10:1 for isophthalic polyester resin. The 1st glass fiber layer is kept on a plain surface which is being cleaned with a liquid named as 'acetone' & further coating carried out using a resin layer with the help of variety of brushes. This procedure is repeated until the desired laminate thickness is achieved. To expedite the process curings, the laminate is placed in an auto-clave m for ab/c for out 4 hours while maintaining a constant temperature of approximately 80ºC. The **Fig.4** illustrates the post-curing of composite laminates in the autoclave machine [27]. After complete curing, the laminates are removed from the autoclave machine. The fabricated composite laminates are presented in **Fig.5 to Fig.6**. A similar procedure was followed to fabricate the different composite laminates according to the stacking sequence.

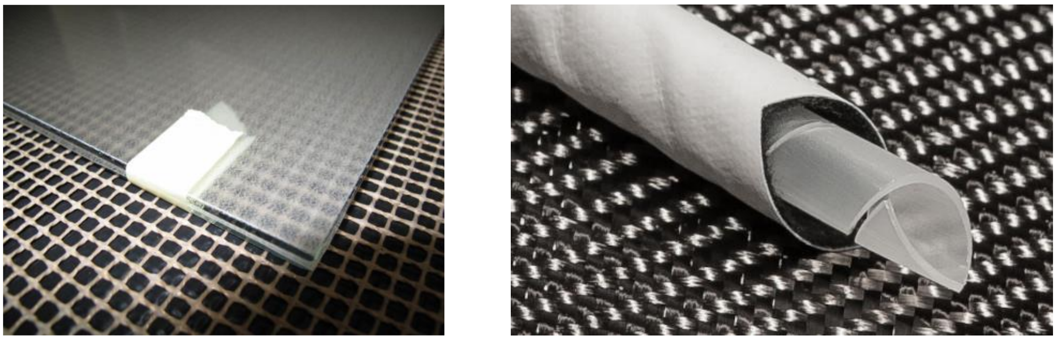


Fig.4: Stages of vacuum bagging hand lay-up processes

Fig. 5: Autoclave machine – post curing the laminates

Fig.6: The developed reinforced based laminates in the workshop

Preparation of the specimens

The m/c operates in a identical manner to a sawmill, with the blade which is moving in a vertical fashion along a flat type of working table. When the position and laminate moving concept is considered, the specimens were cut with greater precision [28]. Tensile strengths, flexural strengths hardness strengths, impact strengths and water absorption strengths of the specimens are cut utilizing the band knife cutting machine, in accordance with various ASTM standards. The remaining portions of the fabricated laminates after cutting the specimens are shown in **Fig.7** Finally, after modifications, the **Fig.8**provides the sisal type glass hybridized composite laminated material.

Experimental procedures

In the current study, we examined the physical and mechanical property of composite laminates manufactured from the Sisal – Glass reinforcement and epoxy and polyester matrix, in accordance with ASTM standards. Several test was performed as per the standards of ASTM in order to assess the diverse properties.

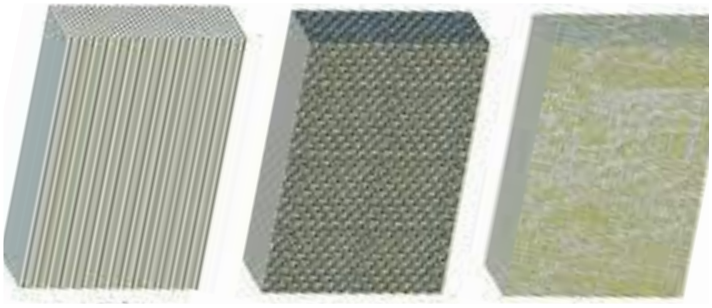


Fig. 7: Glass reinforced composite laminated material development

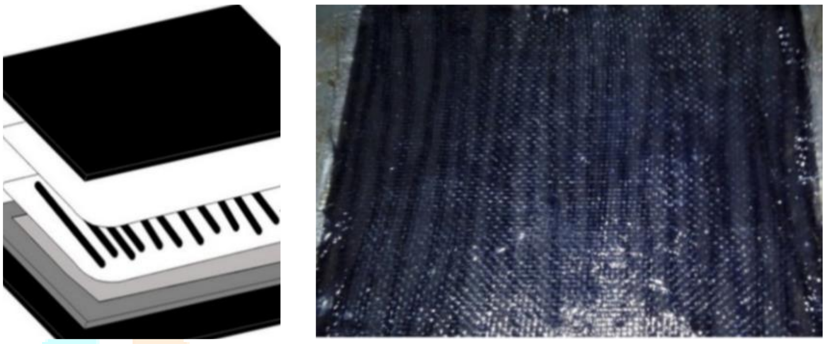


Fig. 8: Sisal type glass hybridized composite laminated material

Conduction of the tensile strength test

When performing the tensile strength test, it is important to take the following factors into consideration. Tensile strength measures a composites material ability to resist force which will pull it apart and its ability to stretch prior to failure. The dog bone category specimen, as depicted in the **Fig.9**, is commonly used for tensile testing. A uni-axial load is applied to both ends of the specimen during the test. Tensile test are carried out on a 1000 KN Kalpaak computerized UTM, as shown in **Fig.10**, in line with the standards of ASTM D638 standards. The tests were conducted at the room temp. using a cross-head speed of 10 mms per min. The testing machine used for the experiment is manufactured by Kalpaak Instrument & Control (manufactured in Pune, Model: KIC2-1000C) with a maximum load capacities of 100 KN was used for the test [29].

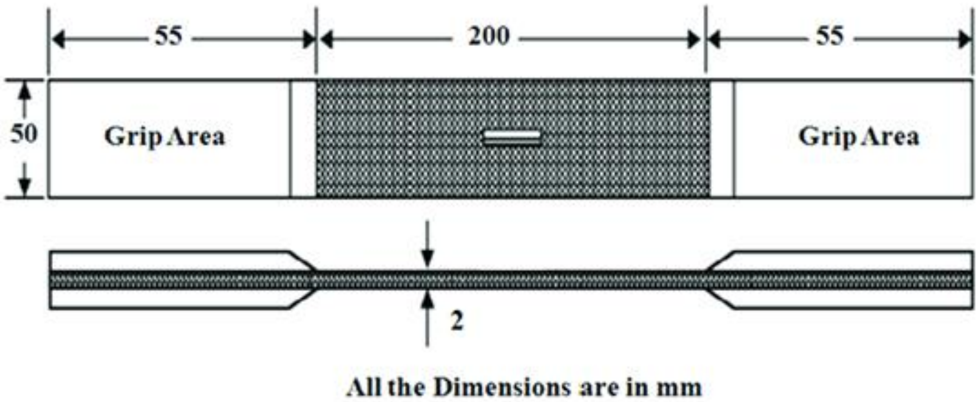


Fig. 9: Tensile test specimen developed

Inter-laminar shear strengths – ILSS tests

The maximum shear stresses that occurs b/w the layer of a laminated materials is known as the inter-laminar shear strengths (ILSS), which is a crucial parameter that needs to be estimated to resist de-lamination in the matrix-fibers interfaces. De-lamination caused using the absence of ILSS at the interface can significantly reduce the strengths of the composites materials. The ILSS of composite laminates is actually depending on the stacked sequences of the fiber fabric material & the type of matrix used.

Fig. 10: UTM -Interfaced with PC

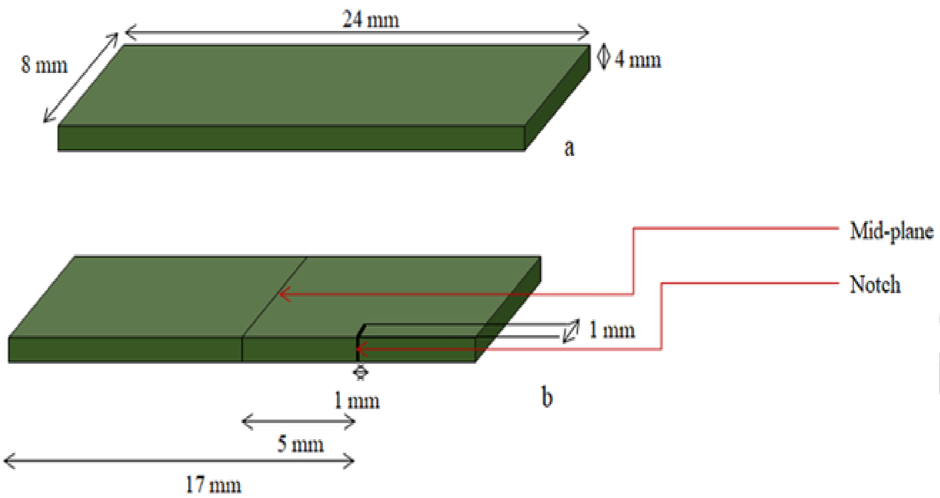


Fig.11: Inter-laminar Shear Strengths ILSS Tests specimen

Several formation mechanisms for hot cracks have been proposed in the literature for continuously casting and the shape type of casting processes, while there has been comparatively little research on cold cracks in recent years. Cold cracks occur the continual process of cooling of the solidified metal with a temp range of around 100s of degrees, making it difficult to understand their formation conditions due to the radical changes in the mechanical property of composite metal as ultimate strengths, fractured strains, stress, and modulus. As a solution, natural fibers are increasingly being used due to their low cost, biodegradable nature, availability, and renew-ability. The present study fabricates hybrid composite laminates is to used sisal & fibers made of glass that too being reinforced using polyester & epoxy material for studying the mechanical and physical property [21]. The stacking sequence and weight %age of matrix & fibre were varied to fabricate the composite laminates

Fig.12: Machine used for conduction of the Inter-laminar Shear Strengths ILSS Tests

To determine the ILSS, tests are carried out on a UTM (KIC-2-1000-C) w.r.t. the ASTM D2344 standard. Then, the ILSS tests specimen with dimensions is shown in **Fig.11 to Fig.12.** The specimen was placed between two supports, 40 mm apart, and loaded at a constant rate of 1.5 mm per min.

Conduction of the hardness tests

To measure the hardness of both reinforced and non-reinforced rigid plastics, Shore-D, Barcol, and Vickers's micro hardness tests were performed, all of which measure the resistance of FRP composites to uniform pressure. In this study, the Matsuzawa Make-MMT-X7A Vickers's micro hardness based testers is employed for measuring the hardness value of the laminates in line with the standards of ASTM D 2583. During the tests, a gradual load - 10 KGF to 100 KGF is applied to the surface of the samples. An indentation mark created by a diamond indenter can be seen in **Fig.13**. Composite laminates fabricated according to the stacking sequence were utilized to estimate the hardness strength [30]. The test specimen utilized for hardness tests will be in line with the standards of ASTM D 2583 & were visually examined. The hardness tests specimen for different wt.% of fiber and matrix after the test was also observed. **Fig.14** shows the set-up in lab for conduction of micro Vicker's hardness test on the specimen.

Fig.13: Set-up in lab for conduction of micro Vicker's hardness test on the specimen

Fig. 14: Specimen showing the indentation markings

$$\text{Hardness} = 1.854 \times \left(\frac{F}{d^2}\right) \quad (4)$$

Here, F is the loads in kg-f & 'd' is the arithmetic means of the 2 diagonal of d_1 and d_2 respectively. To estimate the hardness strength of the composites laminate, those developed according to the stacked sequence. For the hardness tests, specimen is prepared in line with the standards of ASTM & their appearance was visually inspected [31]. The test specimens were made of different weight percentages of fiber and matrix, and their hardness strength after the test was observed. The Shore-D, Barcol, and Vickers's micro hardness tests were used to measure the hardness of both reinforced and non-reinforced rigid plastics by applying uniform pressure, with a load ranging from 10 kgf to 100 kgf. In this study, a Matsuzawa Make-MMT-X7.

Conduction of the impact strength test

The ASTM D256 standards were followed to conduct the Izod impact tests for evaluating the impact strength of the composite laminates. The Izod type of impact tests are widely used to evaluate the abilities of materials for resisting sudden loading. The test specimen was prepared as per the dimensions is observed in **Fig.15** using the machine shown in the **Fig. 16.** Impact tests are conducted utilizing a pendulum-type impact tester at room temperature. The stacking sequence of the fiber fabric material and type of matrix. The results of the test were used for estimating the impact strengths of the composites laminates [32]. Then, the impact tests specimens for different wt.% of fiber and matrix after failure were also examined. **Fig. 17** gives the variety of Izod impact test specimens that could be used for a host of test samples.

Fig.15: Izod impact testing set-up used for conducting the test

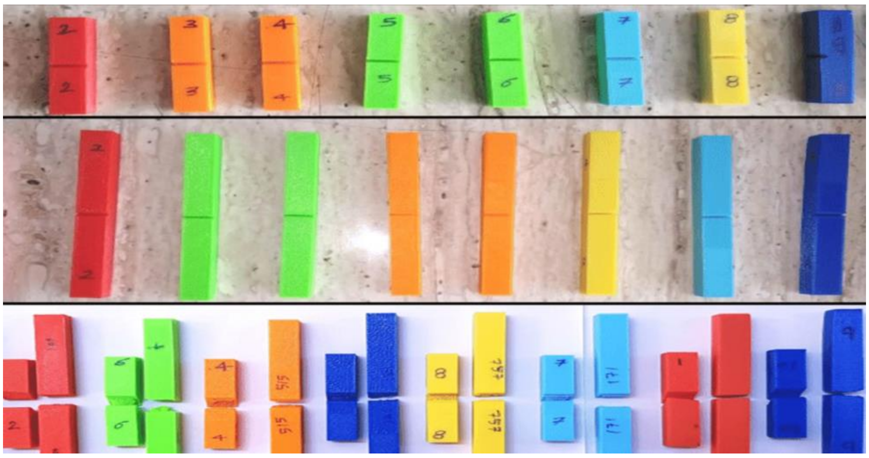


Fig.16: Izod impact test specimens

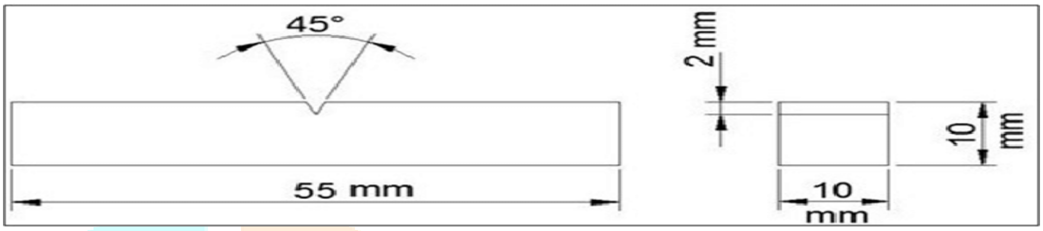


Fig.17: Izod impact test specimen with dimensions

H_2O absorption type of tests

For the investigation of the amalgamation behavior, a H_2O based absorption tests was conducted on Sisal-Glass fiber RF hybrid composites using variable wt. fractions according to the ASTM D570-98 standard. The test specimens, which had dimension of (40 × 30 × 2) mms, are initially dried in a hot air oven to eliminate any moisture & then the cooling is done at the room temp [33]. Before testing, each sample was precisely weighed to 0.0001 grams. Subsequently, the samples were immersed in normal water and were taken out every 24 hours to remove any moisture on the surface. They were then weighed again. **Fig. 18** gives the H_2O absorption test sample specimens that could be used for the experimentation purposes.

$$R = 100 \times \left(\frac{W_a - W_b}{W_b}\right) \quad (5)$$

Here, W_a represents the wt. of the tablet after the H_2O absorption & W_b represents the wt. of the tablet before H_2O absorption.

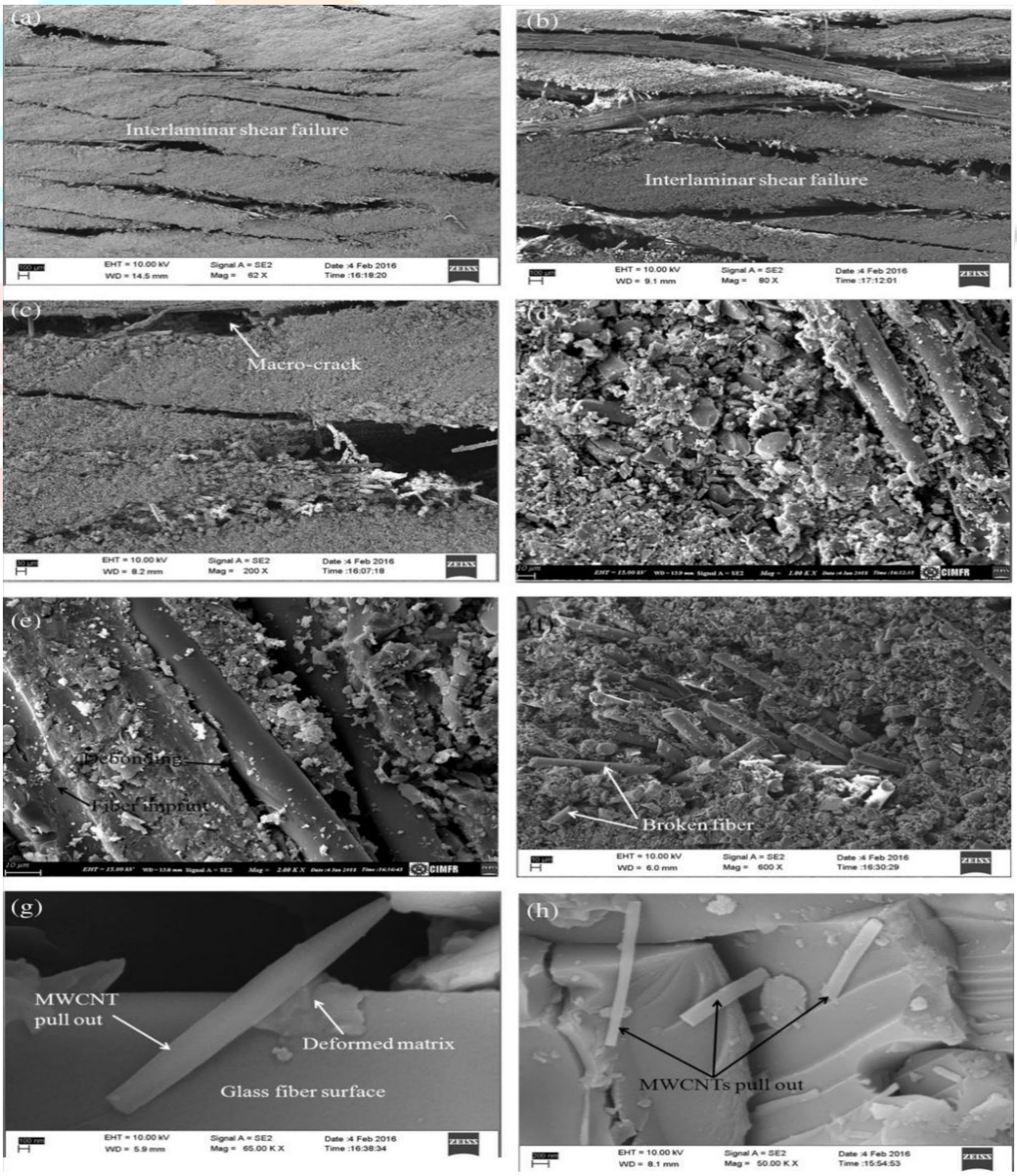
Fig.18: H_2O absorption test sample specimens

III. RESULTS & DISCUSSION

The study also explored the effect of resin penetration into fiber lumens on the mechanical and water-absorption properties of composites. The results showed that as the amount of resin inside the fiber lumens increased, the mechanical properties of the composites improved due to changes in the fracture modes. E-glass/epoxy composites were also studied for their combined effects of load, moisture, and temperature. Results showed that short-duration immersion in distilled water led to a decrease in modulus and an increase in strength and strain to failures.

Micro-structure analysis

Scanning electron microscopy (SEM) can be a powerful tool in developing of the multifunctional polyethylene fiber RF polymer based matrix composite. By utilizing SEM, researchers can analyze the micro structure of the composite material to identify any potential defects or areas of weakness that may affect its performance [34],[35]. Furthermore, SEM could also be utilized to investigate the electrical, thermal, and other functional properties of the composite, providing insight into its potential for use in applications such as energy storage, sensing, and actuation. Overall, the use of SEM in developing of the multifunctional polyethylene fiber RF polymer's matrix composite can help researchers optimize the material's properties and tailor it to specific applications, resulting in more advanced and efficient composite materials. The SEM, or Scanning Electron Microscope, uses a concentrated light of very high value of energy based electron beam for producing a range of signal on the outer layer of the test specimen, providing insight into its texture, crystalline structure, and orientation in the **Fig.19.**



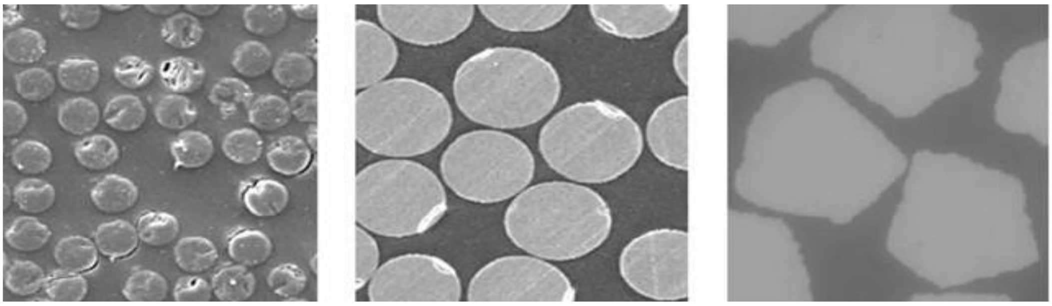


Fig.19: SEM results / micro-images

Effect of tensile strength

To conclude the tensile type of tests results, tensile strengths of composite laminates were found out according to the ASTM standards to evaluate their tensile characteristics. The result are indicated that the polyester-glass L2 type of composites laminates showed superior tensile strength compared to the other composite laminates. This improvement in tensile strengths can be attributed to the good bonding, adhesion & an uniform dispersion of the fibers in the composite matrices [36],[37]. Composites laminate made solely of sisal L3 & L4 exhibited lesser tensile strengths because of the presence of pore @ the interface b/w the matrix & the fibers, thus resulting a in a very very weak type of inter-facial adhesion's. Furthermore, the hybrid composite laminates L5 and L6 demonstrated better tensile strength than L3 & L4 due to the adding of glass fibers along with sisal fibers enhanced bonding & adhesion @ the composite's interface. Laminates L7 & L8 exhibited superior tensile property in comparison to L3 L4 L5 & L6 laminate due to further adding of the glass fibers. The use of natural - sisal fibers in combination with glass synthetic fibers improves the mechanical property, biodegradability & the disposal ease @ the end of the service life of the composite materials. **Fig.20** presents the graph of displacement in mms versus the load in newton for 4 sample specimens, while the Table.5 provides its quantitative results of loads with different samples from L1 to L4.

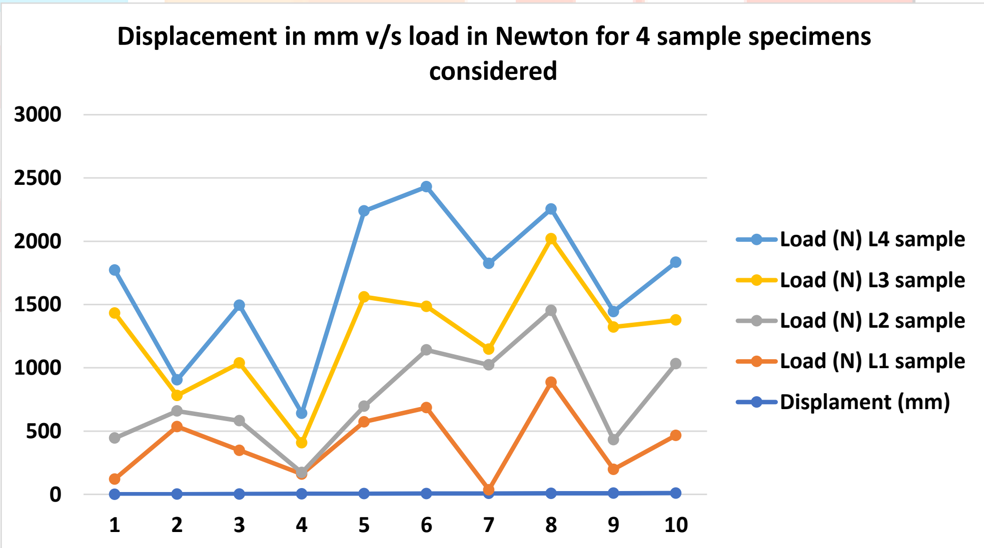


Fig.20: Displacement in mms versus the load in newton for 4 sample specimens

Effect of inter-laminar shear strength

In conclusion, regarding the inter-laminar shear strength results, it is observed that composite laminate L2 exhibits a higher inter-laminar shear strength compared to other laminates due to improved bonding and adhesion at the matrix-fiber interfaces. However, laminates L3 & L4 have a lower inter-laminar shear strengths due to poor matrix dispersion resulting in void in composites laminate developed with natural sisal fibers. The presence of pore in natural fibers also enhances bonding strength during fabrications, leading to enhanced inter-laminar shear strengths in L5 & L6 in comparison to L7 & L8, thus minimizing the de-lamination of the fiber-matrix interface. **Fig. 21** gives the graph of inter-laminar shear strengths of the reinforced composite fibers.

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In conclusion, regarding the inter-laminar shear strength results, it is observed that composite laminate L2 exhibits a higher inter-laminar shear strength compared to other laminates due to improved bonding and adhesion at the matrix-fibre interfaces. However, laminates L3 & L4 have a lower inter-laminar shear strengths due to poor matrix dispersion resulting in void in composites laminate developed with natural sisal fibers [38],[39]. The presence of pore in natural fibers also enhances bonding strength during fabrications, leading to enhanced inter-laminar shear strengths in L5 & L6 in comparison to L7 & L8, thus minimizing the de-lamination of the fiber-matrix interface. **Fig. 22** gives the graph of inter-laminar shear strengths of the reinforced composite fiber.

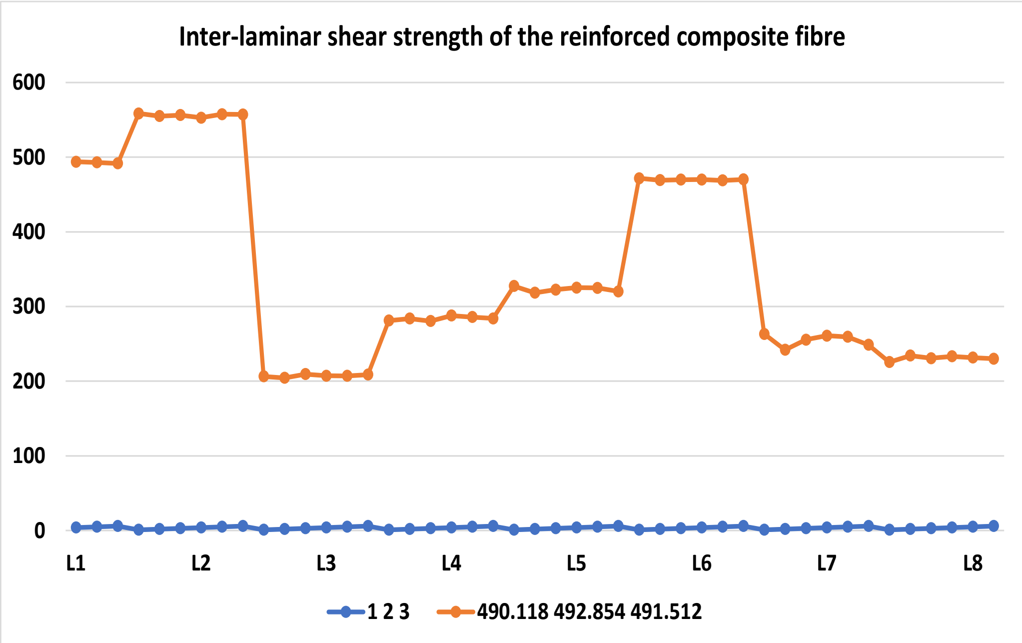

Fig. 21: Graph of inter-laminar shear strengths of the reinforced composite fiber

Effect of hardness strength

To conclude the micro-hardness test, the consideration of the void parameters in the composites laminate L3 & L4 caused by the lumens in the cellular structure of sisal fibers, leads to lower hardness as compared to other laminates. However, the addition of glass fibers to sisal fibers (L7 and L8) results in better hardness compared to L3, L4, L5, and L6 due to hybridization [40]. Therefore, the developed glass-sisal-polyester (L8) composite laminate demonstrates comparable and superior mechanical properties to the glass-epoxy composite laminate L1 (**See Fig.22**). Results showed that short-duration immersion in distilled water led to a decrease in modulus and an increase in strength and strain to failure. At a higher temperature of 75°C for a longer duration, the strength decreased by 32% and the modulus decreased by 30%, while the strain to failure increased by 4%. The reduction in strength was not significant due to the replacement of chemical bonds with physical bonds, which maintained good stress transfer at the inter-phase [20]. The tensile test failure resulted in massive fiber non-bonding, indicating that at higher temperatures, moisture penetrates the fiber/matrix inter-phase. Results showed that short-duration immersion in distilled water led to a decrease in modulus and an increase in strength and strain to failure. At a higher temperature of 75°C for a longer duration, the strength decreased by 32% and the modulus decreased by 30%, while the strain to failure increased by 4%. The reduction in strength was not significant due to the replacement of chemical bonds with physical bonds, which maintained good stress transfer at the inter-phase [20]. The tensile test failure resulted in massive fiber non-bonding, indicating that at higher temperatures, moisture penetrates the fiber/matrix inter-phase.

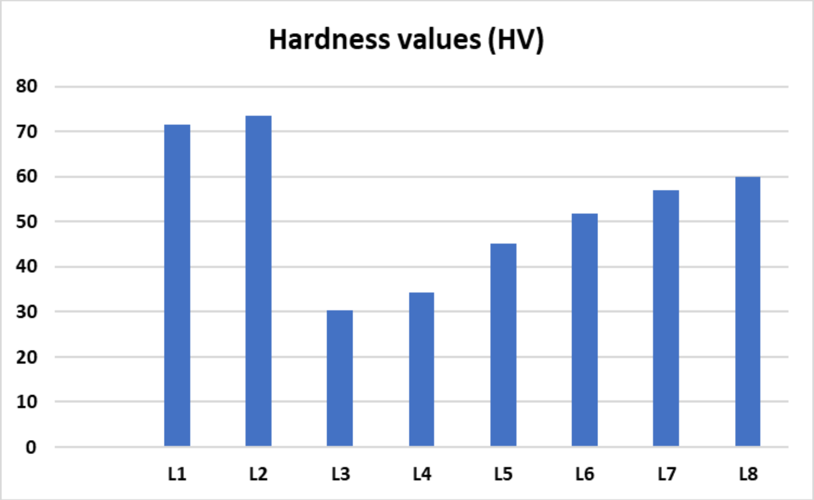

Fig.22: Graph of hardness values v/s samples

Effect of impact strength

In conclusion, the impact test results reveal that the enhanced impact strengths observed in composite laminates L-2 can be attributed to better bonding, adhesion, and uniform dispersion of the fiber in the matrix. Conversely, laminates L3 and L4 exhibit lower impact strength due to the presence of more voids. Additionally, the results demonstrate that the hybridization of glass and sisal fibers consistently leads to improved impact strength in L5, L6, L7, and L8 composite laminates. If the **Fig.23** gives the graph of avg. impact strengths v/s samples [41].

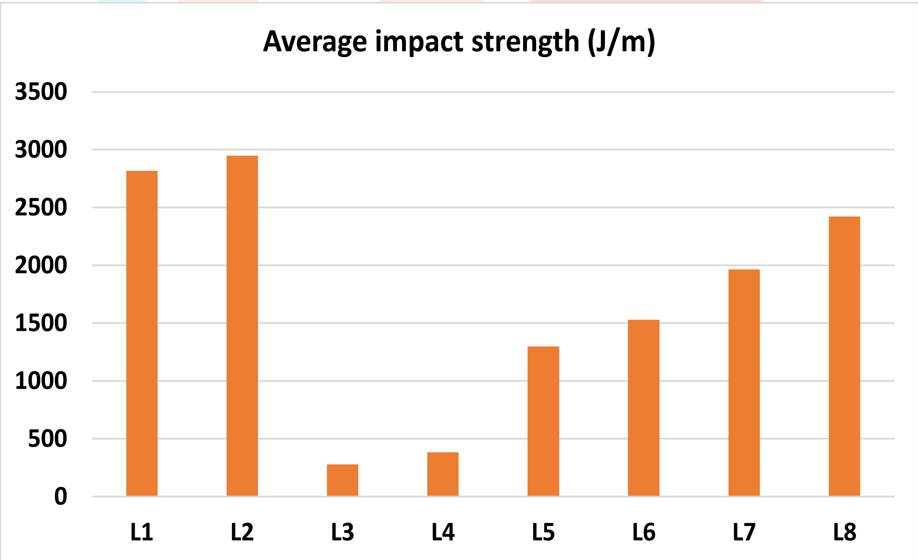

Fig. 23: Graph of avg. impact strengths v/s samples

Effect of H_2O absorption

This process was repeated at 48, 72, 96, 120, 144, 168, 192, 216, and 240 hrs. Moisture absorptions is found out by measuring the wt. diff. of the specimens, and the wt. gain %age is determined using a mathematical model[42],[43],[44],[45]. The results of composite laminates fabricated according to the stacking sequence are tabulated and were used to find the %age of H_2O absorption in the specimens. The test specimens for the water absorbing tests are carried out as per the standards of the ASTM D570-98 & are illustrated in the form of a diagram, and the test setup is also presented (**See Fig.24**)

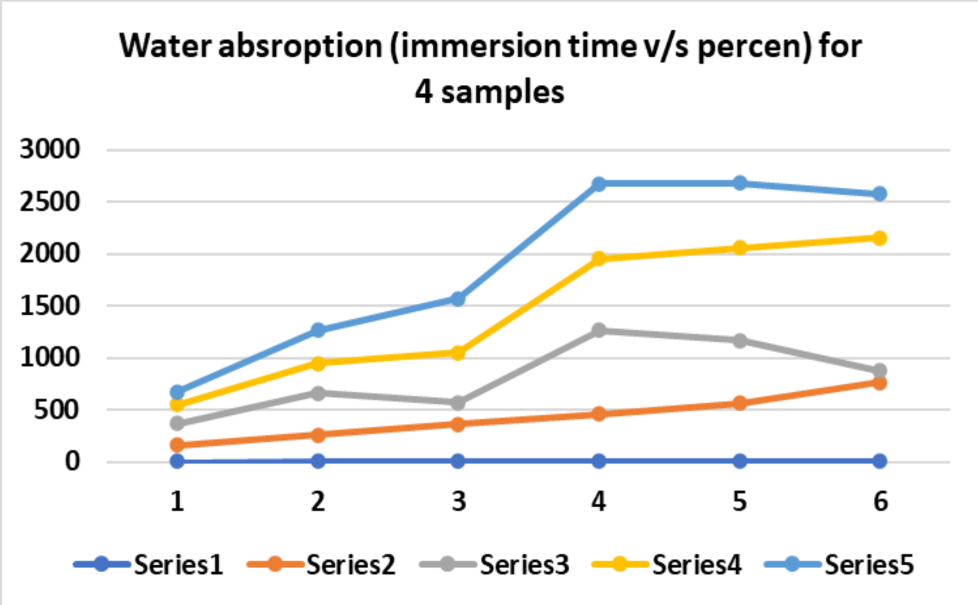

Fig.24: H_2O absorptions (immersions times v/s percentage) for 4 samples

V.CONCLUSION

The new experimental procedures and materials specification of the properties of composite materials reinforced with glass fibers. As a solution, natural fibers are increasingly being used due to their low cost, biodegradable nature, availability, and renew-ability [46],[47],[48].The present study fabricates hybrid composite laminates is to used sisal & fibers made of glass that too being reinforced using polyester & epoxy material for studying the mechanical and physical property. The stacking sequence and weight %age of matrix & fibre were varied to fabricate the composite laminates.

- In contrast, hybrid composite laminates demonstrated better interracial bonding between fiber and matrix interfaces, leading to fiber breakage rather than de-lamination.
- The SEM images also revealed that glass fibers absorbed maximum load in the vertical direction, leading to the pullout of glass fibers and the breakage of sisal fibers, thereby affecting the mechanical property of the laminates.
- The impact test results reveal that the enhanced impact strengths observed in composite laminates L-2 can be attributed to better bonding, adhesion, and uniform dispersion of the fiber in the matrix.
- Conversely, laminates L3 and L4 exhibit lower impact strength due to the presence of more voids. Additionally, the results demonstrate that the hybridization of glass and sisal fibers consistently leads to improved impact strength in L5, L6, L7, and L8 composite laminates.
- However, the addition of glass fibers to sisal fibers (L7 and L8) results in better hardness compared to L3, L4, L5, and L6 due to hybridization.
- The presence of pore in natural fibers also enhances bonding strength during fabrications, leading to enhanced inter-laminar shear strengths in L5 & L6 in comparison to L7 & L8, thus minimizing the de-lamination of the fiber-matrix interface.

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REFERENCES

[1]. Ashby M.F. and Jones David.R.H., “Engineering Materials 2: An Introduction to Microstructures, Processing and Design”, Elsevier, Amsterdam, pp. 239-306, 1998.

[2]. Verma D., Gope P.C., Shandilya A., Gupta A. and Maheshwari M.K., “Coir Fibre Reinforcement and Application in Polymer Composites: A Review”, Journal of Materials and Environmental Science, vol. 4, pp. 263-276, 2013.

[3]. Alagarsamy S., Sagayaraj A. and Vignesh S., “Investigating the Mechanical Behaviour of Coconut Coir—Chicken Feather Reinforced Hybrid Composite”, International Journal of Science, Engineering and Technology Research, 4, 4215-4221, 2015..

[4]. Bazan P., Nosal P., Kozub B. and Kuciel S., “Biobased Polyethylene Hybrid Composites with Natural Fiber: Mechanical, Thermal Properties, and Micromechanics”, Materials, vol. 13, Article 2967, 2020.

[5]. Natsa S., Akindapo J. and Garba D., “Development of a Military Helmet Using Coconut Fiber”, European Journal of Engineering and Technology, vol. 3, pp. 55-65, 2015.

[6]. Jimoh Y.A. and Kolo S.S., “Dissolved Pure Water Sachet as a Modifier of Optimum Binder Content in Asphalt Mixes”, Epistemics in Science, Engineering and Technology, vol. 1, pp. 176-184, 2011.

[7]. PrakashReddy B., Satish S. and Thomasrenald C.J., “Investigation on Tensile and Flexural Properties of Coir Fiber Reinforced Isophthalic Polyester Composites”, International Journal of Current Engineering and Technology, vol. 2, pp. 220-225, 2014.

[8]. Hammajam A.A., El-Jummah A.M. and Ismarrubie Z.N., “The Green Composites: Millet Husk Fiber (MHF) Filled Poly Lactic Acid (PLA) and Degradability Effects on Environment”, Open Journal of Composite Materials, vol. 9, pp. 300-311, 2019.

[9]. Amulah C.N., El-Jummah A.M. and Modu Tela B., “Development and Characterization of a Composite Material Based on the Mixture of Gypsum Plaster and Rice Husk Ash”, Continental Journal of Engineering Sciences, vol. 14, pp. 15-33, 2019.

[10]. Nam T.H., Ogihara S., Tung N.H. and Kobayashi S., “Mechanical and Thermal Properties of Short Coir Fibre Reinforced Poly (Butylene Succinate) Biodegradable Composites”, Journal of Solid Mechanics and Materials Engg., vol. 5, pp. 251-262, 2011.

[11]. Han, S.O., Lee, S.M., Park, W.H. and Cho, D. (2006) Mechanical and Thermal Properties of Waste Silk Fiber-Reinforced Poly (Butylene Succinate) Biocomposites. Journal of Applied Polymer Science, 100, 4972-4980.

[12]. Karthik, S. and Arunachalam, V.P. (2020) Investigation on the Tensile and Flexural Behavior of Coconut Inflorescence Fiber Reinforced Unsaturated Polyester Resin Composites. Materials Research Express, 7, Article ID: 015345.

[13]. Bsuo M.J. Jekabsons N. Varna J. “An evaluation of different, odds for prediction of elastic properties of woven composites”, Journal of composite materials part B, vol 31, pp 7-20, 2000.

[14]. Alurri G.B., O’Brien T.K., Rousseau C.Q., “Fatigue life methodology for tapered composite flexbeam laminates”, American Helicopter Society Inc.,1997.

[15]. Mum G.B., Schaff J.R., Dobyns A.L., “Fatigue and damage tolerance analysis of a hybrid composite tapered flexbeam”, American Helicopter Society Inc., 2001.

[16]. Palmer S.O., Nellies A.T. Jr., “An experimental study of a stitched composite with a notch subjected to combined bending and tension loading”, NASA report no. NASAITM-1, pp. 999-2095, National technical information service, 1999.

[17]. Heger J., “Combined tensile bending load simulation of laminate composite”, 2000.

[18]. Krueger R., Cvitkovich M.C., Brein T.K., Minguet P.J., “Testing and analysis of composite skin / stringer debonding under multiaxial”, Journal of composite materials, vol. 34, pp. 1263-300, 2000.

[19]. Lin W.P., Hu H.T., “Parametric study on the failure of fiber reinforced composite laminates under bi-axial tensile load”, Journal of composite materials, vol 36, issue 12, pp. 481-503, 2002.

[20]. Lee C.S., Hwang W., Park H.C., Han K.S., “Fatigue failure model for composite laminates under multi-axial cyclic loading”, Key engineering materials, pp. 183-187:945-50, 2000.

[21]. Khashaba U.A., Ali-Eldin S., "Behaviour of unidirectional GFRI epoxy composites under tension-torsion biaxial loading", Proceedings of the seventh international conference on production engineering, design and control, vol. 3. Egypt: Alexendria University, pp. 1977-93, 2001.

[22]. EI-Assal A.M., Khashaba U.A., "Combined torsional and bending fatigue of unidirectional GFRP composites, "Proceedings of the second international conference on mechanical engineering" Advanced technology for industrial production, vol. 1, Egypt: Assiut university pp. 206-16, 1999.

[23]. Wisnom M.R., "The relationship between tensile and flexural strength of unidirectional composites". Journal of composite materials, vol. 26, issue 8, pp. 1173-80, 1992.

[24]. Khashaba U.A., "Tensile and flexural properties of randomly oriented GFRP composites", Proceedings of the 1st International Conference on Mechanical Engineering adv tech for Indus prod, vol. 1, Egypt: Assiut University, pp. 43-46, 1994.

[25]. Bosia F., Facchini M., Botsis J., "Through-the –thickness distribution of strains in laminated composite plates subjected to bending", Journal of composite science technology, vol. 64, pp. 71-82, 2004.

[26]. Murri G.B., Schaff J.R., Dobyns A.L., "Fatigue life analysis of tapered hybrid composite flexbeams", 2003.

[27]. Young W.C., Budynas R.G., "Roark's formulas for stress and strain", 7th edn. McGraw-Hill, Table 8.9, 2002.

[28]. Fer R.T., "Mechanics of solids. Blackwell scientific publications", (see pages 322, 435,440), 1989.

[29]. Chajes A., "Principles of structural stability theory", Prentice-Hall, Section 12: Eccentrically loaded columns, pp. 32-34, 1974.

[30]. Mohammed Bukar A., Mohammed El-Jummah A. and Hammajam A., "Development and Evaluation of the Mechanical Properties of Coconut Fibre Reinforced Low Density Polyethylene Composite", Open Journal of Composite Materials, Vol. 12, pp. 83-97, 2022.

[31]. The Seven Ages of Materials E&T Magazine, Engineering & Technology, 2019, July 2020

[32]. R.-M. Wang, S.-R. Zheng, and Y.-P. Zheng, "Introduction to polymer matrix composites," in Polymer Matrix Composites and Technology, pp. 1–548, Woodhead Publishing, 2011.

[33]. "Polymer matrix composites: properties and applications - matmatch," August 2020.

[34]. V. V. Kumar, G. Balaganesan, J. K. Y. Lee, R. E. Neisiany, S. Surendran, and S. Ramakrishna, "A review of recent advances in nanoengineered polymer composites," Polymers, vol. 11, no. 4, p. 644, 2019.

[35]. F. L. Matthews and R. D. Rawlings, "Polymer-matrix composites," in Composite Materials, pp. 168–205, Woodhead Publishing, 1999.

[36]. "Polymer matrix composites applications in many industries," August 2020.

[37]. G. Neşer, "Polymer based composites in marine use: history and future trends," Procedia Engineering, vol. 194, pp. 19–24, 2017.

[38]. J. S. Binoj, R. E. Raj, S. A. Hassan, M. Mariatti, S. Siengchin, and M. R. Sanjay, "Characterization of discarded fruit waste as substitute for harmful synthetic fiber-reinforced polymer composites," Journal of Materials Science, vol. 55, no. 20, pp. 8513–8525, 2020.

[39]. S. Vigneshwaran, R. Sundarakannan, K. M. John et al., "Recent advancement in the natural fiber polymer composites: a comprehensive review," Journal of Cleaner Production, vol. 277, article 124109, 2020.

[40]. Q. T. H. Shubhra, A. K. M. M. Alam, M. A. Gafur et al., "Characterization of plant and animal based natural fibers reinforced polypropylene composites and their comparative study," Fibers and Polymers, vol. 11, no. 5, pp. 725–731, 2010.

[41]. T. G. Yashas Gowda, M. R. Sanjay, K. Subrahmanya Bhat, P. Madhu, P. Senthamaraikannan, and B. Yogesha, "Polymer matrix-natural fiber composites: an overview," Cogent Engineering, vol. 5, no. 1, 2018.

[42]. E. Reashad, B. Kabir, and E. N. Ferdous, “Kevlar-the super tough fiber,” International Journal of Textile Science, vol. 1, no. 6, pp. 78–83, 2012.

[43]. S. Feroz, N. Muhammad, J. Ratnayake, and G. Dias, “Keratin - based materials for biomedical applications,” Bioactive Materials, vol. 5, no. 3, pp. 496–509, 2020.

[44]. D. Rajak, D. Pagar, P. Menezes, and E. Linul, “Fiber-reinforced polymer composites: manufacturing, properties, and applications,” Polymers, vol. 11, no. 10, p. 1667, 2019.

[45]. K. Prabhakar, S. Debnath, R. Ganesan, and K. Palanikumar, “A review of mechanical and tribological behaviour of polymer composite materials,” IOP Conference Series: Materials Science and Engineerin, vol. 344, no. 1, article 012015, 2018.

[46]. K. Friedrich, “Polymer composites for tribological applications,” Advanced Industrial and Engineering Polymer Research, vol. 1, no. 1, pp. 3–39, 2018.

[47]. A. Ali and A. Andriyana, “Properties of multifunctional composite materials based on nanomaterials: a review,” RSC Advances, vol. 10, no. 28, pp. 16390–16403, 2020.

[48]. A. S. Singha and V. K. Thakur, “Synthesis, characterisation and analysis of hibiscus sabdariffa fibre reinforced polymer matrix based composites,” Polymers and Polymer Composites, vol. 17, no. 3, pp. 189–194, 2018.