STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 2, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Development of Robot Arm Fingers with Polymer Soft Materials

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Abstract

Lightweight soft material applications have attracted attention to Basalt Fiber Reinforced Polymer (BFRP) laminates because of their impressive mechanical characteristics. The impact response and stress-strain behavior of epoxy resin laminates armored with basalt fiber and banana fiber are investigated during this project using computational and experimental approaches. The hand lay-up method was employed to create laminates with a thickness of 3 mm, dimensions of 300x300 mm², and a layout of 5-3/2 layers. Water jet machining was used to accurately prepare specimens for several mechanical tests, including impact, flexural, hardness, shear, and tensile tests, in accordance with defined testing protocols. A 10-ton capacity servo ball screw mechanism Universal Testing Machine (UTM) was utilized to collect tensile and flexural stress-strain responses, while a Charpy testing machine was used to analyze impact reactions. The scanning electron microscopy (SEM) analysis of fracture surfaces from flexural, impact, and tensile specimens provided a comprehensive examination of the failure mechanisms. The thorough examination of experimental data and computational models sheds light on the physical characteristics and reasons for failure of these laminates, drawing attention to their possible use as a soft material in medical robot fingers.

Keywords: VARTM, Soft material, fracture surface, mechanical characteristics, teratology

INTRODUCTION

Combining two or more foreign elements into a shared host matrix is a common way to generate hybrid nanocomposites [1,2]. Increased elasticity, ductility, decreased weight, and enhanced fire resistance are just a few of the novel and improved material qualities that emerge from this synergistic combination of components.A variety of large-scale technological applications, including building, airplane constructions, vehicle production, marine vessels, sporting products, and more, make use of carbon fibers because of their inherent qualities.[3-5]. Given the information provided, it is critical to find fibers that can be used to make hybrid composites that are strong, but also lightweight, long-lasting, and affordable. Many of the organic and inorganic fibers available today are either too costly for modest weights or don't have enough structural strength or durability. Basalt fiber has quickly become the material of choice due to its many desirable properties, including its inorganic composition, high modulus, strength, strain resistance, high-temperature endurance, stability, chemical resistance, processing ease, lack of toxicity, natural origin, eco-friendliness, and affordability I have read [6-7] It was possible to create a composite material by mechanically cutting basalt fibers and then putting them into a mixture of polypropylene and clay. Thanks to this innovative

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Received Date: October 23, 2024
Accepted Date: November 18, 2024
Published Date: February 15, 2025

Citation: J. Srinivas, Ravindran.S, Jenaris D. S, N. Ramanan Development of Robot Arm Fingers with Polymer Soft Materials. Journal of Polymer & Composites. 2025; 13(Special Issue 2): S432–S439p.

process, the composite's yield strength and elastic modulus were both enhanced. Basalt reinforcement may be included in a number of forms other than standard fibers because to its plasticity and ductility. This effectively makes use of shapes such as rods, bars, and textile materials, which increases the variety of potential uses.These sources: [8-10]—This effectively makes use of shapes such as rods, bars, and textile materials, which increases the variety of potential uses.

An experimental study was conducted to forecast the impact properties of thermosetting composites when subjected to falling weight. The model successfully foretold the the forces that come into touch with one another and the most severe distortion of the composites, despite its inherent complexity. A largely biodegradable vinyl ester resin was used to manufacture the composites. Reinforcements such as flax and basalt were added using resin infusion and hand layup processes. The composites were then cured in an autoclave with controlled heat and pressure. In order to gather information about the development and characteristics of the damage, tests were conducted on the tensile and flexible characteristics, as well as on the impact with falling weight at different energy levels up to 40 J. Using layers of flax fiber as a core material between basalt fibers greatly increased the tensile performance. The eleventh Research looked at how water absorption affected the interlaminar fracture toughness of flax and flax/basalt hybrid materials, as well as vinyl ester-based composites. These composites were meticulously prepared using the vacuum-assisted resin infusion process [11]. Composite laminates' delamination morphology and fracture shear failure patterns were examined using scanning electron microscopy and X-ray micro-computed tomography. Composites reinforced with flax fibers showed markedly enhanced durability and water resistance after being hybridized with basalt fibers, according to the test findings. In terms of improved resistance to water absorption and general durability, this study highlights the advantages of combining these materials [12-13].

Hand laying of composites composed of kenaf epoxy and hybrid basalt was done. Hybrid composites with three sack layers and individual composites made of basalt and kenaf with three sack layers were among the four sequence combinations that were built and thoroughly examined. We used tensile and flexural tests to look at the composites' mechanical properties. The fracture surfaces and failure causes were investigated using scanning electron microscopy (SEM). In the mechanical test, the hybrid basalt/kenaf composites did very well, with a flexural strength of 283.9 MPa and a tensile strength of 111 MPa. These investigations showcase the remarkable strength qualities of this hybrid composite material and emphasize its potential [14-15].

Research is focused on developing safer, lighter, and more fuel-efficient bumpers for automobiles. In comparison to the previous steel bumper, the new Basalt composite one is 49% lighter, 56% cheaper, and performs better overall. The Basalt composite bumper provides better safety margins according to the finite element analysis since it has a higher Factor of Safety and a 47.6% higher impact strength. Also, with improved energy absorption in collisions and a deformation capacity that is 51% higher at 32 mm, it offers an affordable, high-performance option for automotive applications [16]. Safe, common, and exceptionally strong and long-lasting, basalt rock is an ideal building material. The raw resources needed to make it are cheap. Basalt, a kind of solidified volcanic lava, is very durable and heat-resistant; it finds great use as an insulator for vehicle interiors and engine parts. Studies looked at several composites that combined basalt with jute fibers and polyester resin. While jute-reinforced composites did better in impact tests, pure basalt-fiber composites were clearly the winners in flexural and tensile tests [17]. Although they are structural components, automobile body panels are not often designed to increase a vehicle's crashworthiness or protect occupants from harm in frontal, side, or rear crashes [18]. Modern automotive companies are concentrating on developing lightweight, fuel-efficient, and resource-efficient materials. To that aim, we are always innovating our production techniques, our materials, and our design concepts [19]. A hybrid material that combines basalt fiber, aluminum fiber, and glass fiber is the target of this study. The objective is to produce a laminated composite with better qualities by combining the qualities of these current materials. Finding and contrasting the new composite's distinctive properties with those of its constituent parts is the primary

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

goal of this research. Making a bumper that works as intended—with a tensile strength of 38 MPa and a deformation range of 0.017378 m to 0.03114 m—is a primary goal. The composite is practical for use in everyday life since it can endure stresses up to 242.4 MPa [20].

Among the hybrid composites tested, the one consisting of Kevlar, Aloe vera, palm, and epoxy showed the best mechanical qualities. In particular, there was a 50% rise in tensile strength, a 14% boost in flexural strength, and a 54% boost in load-bearing capacity. The increased properties of the fracture surface provided more evidence of the composite's superior performance [21].

The use of synthetic fibers is gradually dwindling in several industries. Because of its inexpensive cost, simple availability, and exceptional mechanical qualities, Ananas Comosus leaf was selected for investigation among the numerous natural fibers that were accessible. The three materials that were tested showed improved mechanical qualities, as measured by tear strength, tensile strength, and cure time [22].

More and more people are hoping that technology will drive the advancement of generations to come. That being said, there needs to be an efficient and cost-effective way to build a high-quality product that meets customer expectations, all the while staying ahead of the competition. In order to address the demands of the current environment, engineering industries rely heavily on material selection for new product development. Aiming for quality while being cost-effective and receptive to criticism is crucial in meeting current requirements. The widespread use of composites in recent years is indicative of the remarkable advancements in material science. All industries rely on these materials, and their effects are far-reaching. Their manufacturing processes have advanced greatly since they demonstrated the capacity to merge the inherent strengths of reinforcement and matrix materials, making stronger materials than the sum of their parts. Lightweight Ness, stability, environmental friendliness, corrosion resistance, and other desirable properties are the main targets of hybrid structures.

MATERIALS AND METHODS

The manual lay-up method is commonly used to make BFRPs by layering different types of metal and fiber/prepreg in a mold. Afterwards, the construction is autoclaved or cured at the specified temperature and pressure. There is a significant risk of blow holes or bonding failures with this technology, and the production procedure is costly and only works for a limited number of specimens. We used the VARTM technique, which is available at the Manufacturing Technology Lab at Anna University, to prepare our specimens in order to keep bonding accuracy high while keeping costs down.

In this project, we utilized three identical layers of basalt fiber and 300x300 mm fiber-drilled sheets. The layers were arranged in such a way that the top and bottom are made of aramid, with banana fiber alternating between them. Using a 1:10 ratio of polyester resin to HY5/3 hardener, VARTM was able to obtain the necessary BFRC using a cold mold setup. The aforementioned mixture was pushed into the stacked dies using a vacuum gun at a pressure of 5 bar and left to cure for about a day.

The necessary test specimens were cut from the acquired plate using abrasive water jet machining in accordance with ASTM guidelines. After that, we verified and evaluated the various cut testing samples.

TESTING RESULTS

Tensile Test

One of the most basic forms of mechanical testing done on materials is a tensile test, sometimes called a tension test. Full standardization, low cost, and ease of administration characterize tensile testing. It is possible to rapidly ascertain the material's response to tension forces by pulling on a specimen. The elongation and strength of the material may be assessed as it is being pulled. The ultimate strength of the manufactured specimen is ascertained by the test, which aids in ascertaining the most force that the material can endure without breaking.

Flexural Test

Materials' responses to straightforward beam loading may be evaluated using the flexure test procedure. A transverse beam test is another name for it when applied to certain materials. A stress-strain diagram is used to display the maximum fiber stress and strain for each load increment. When measured at the specimen's convex or tension side surface, flexural strength is the greatest stress in the outermost fiber.

An easy way to determine a specimen's flexural strength is to weight it at one or two spots along its length while it sits on two supports. Both bulk ceramics and ceramic-matrix composites are excellent candidates for this test. The stress condition in a flexural test is not pure nor uniform; it changes from tension on one surface to compression on the other, with shear also present. Consequently, this sort of testing is ideal for composite materials.

Impact Test

A pendulum hammer is used to cause a standard-sized notched specimen to be fractured with a single hit in an impact test, such the Charpy test. The test measures the amount of energy absorbed during fracture to determine the material's tensile strength and its capacity to bear rapid stress.

Particularly in the Charpy test, a tiny beam is subjected to a three-point flexural impact force by means of a swinging pendulum. The standard dimensions of the beam are 55 mm (2.17 inches) in length and 10 mm (0.39 inches) in width. The test specimen has a 45-degree included angle in its notching. On the tensile side of the specimen is placed the notch, which is 2 mm (0.079 inches) deep, in order to cause failure at that specific spot during the test.

Units of foot-pounds or kilojoules are used to quantify the findings of the Charpy test, which determine the toughness and energy absorption capacity of the material under impact circumstances.20

Fracture Surface

Due in large part to the persistent miniaturization of materials utilised in a wide range of applications, scanning electron microscopes (SEMs) have recently developed into robust and flexible instruments for material characterisation. Electron microscopy (SEM) uses electrons for imaging, just like a light microscope uses visible light. To create a picture, these microscopes pick up electrons that are reflected off or dispersed close to a sample's surface. Transmission electron microscopes (TEMs) catch electrons as they go through a thin object, however this is not the case.

SEMs offer superior resolution compared to light microscopes because electrons have a much shorter wavelength than visible light. This capability allows SEMs to visualize fine details and structures at the nanoscale, making them invaluable for studying materials with high precision and depth.

Wear Testing

The purpose of a wear test is to determine the wear mechanism and to make predictions about the wear performance. A pin-on-disc wear tester describes a circular wear path by pressing a pin on a flat spinning disk specimen. This apparatus is useful for testing materials' friction and wear characteristics in a pure sliding environment. A specimen can be either a disk or a pin. The wear test is conducted using ASTM G99-04A in this case. Samples undergo a wear test.21

RESULT AND DISCUSSION

Mechanical Characteristics

The data from the mechanical characteristics tests conducted on samples of coconut fiber are summarized in Table 1. These tests focused on many important parameters, including ultimate tensile strength (N/mm²), ultimate flexural strength (N/mm²), double shear average displacement (mm), impact test results (joules), and hardness test (HRL). Taken as a whole, these parameters define the mechanical

Journal of Polymer & Composites
Volume 13, Special Issue 2
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

properties of the coconut fiber samples, illuminating their hardness, shear resistance, impact resistance, flexibility, and strength. Sample 1 stands out with its exceptional mechanical performance, as seen by its greatest Ultimate Tensile Strength and Ultimate Flexural Strength. A thorough assessment of the mechanical characteristics of the coconut fiber is crucial for determining its acceptability for different applications, and each measure adds to that evaluation.

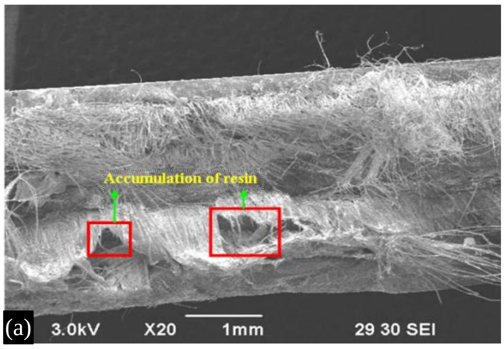
Fracture Surface

The material's interior surface properties were investigated by morphological inspection utilizing a Scanning Electron Microscope (SEM). Using an ion-sputter coater, we coated each test sample with a 15 to 20 nm coating of gold after it had dried. Afterwards, scanning electron microscopy was used to examine the samples. The SEM pictures that were produced offer strong proof of the matrix and fiber adherence at the interface.

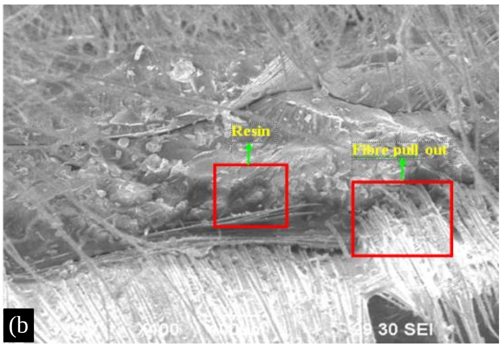
Inadequate dispersion and insufficient amalgamation of the hardener and resin are possible causes of the resin buildup seen in the specimens, as shown in Figure 1. Preventing this from happening in laminates that are under load requires extreme caution when choosing the mixture ratio and curing period. Fiberpullout, as seen in Figure 1.b, occurs when the composite materials do not have enough fiber packing. Figure 1.a and 1.c shows that the composites' tensile strength and mechanical characteristics were negatively affected due to fiber breakage, which occurred as a result of insufficient fiber treatment. Adherence to correct production procedures and efficient fiber treatment processes can solve these problems.

Table 1. Observations of mechanical properties testing.

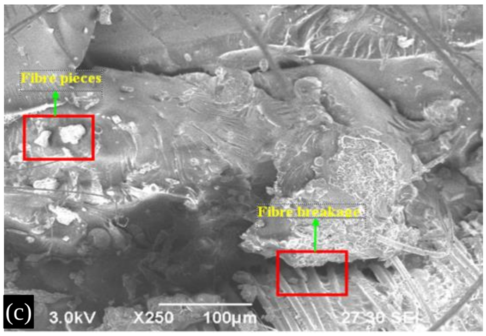
BFRP	Ultimate tensile strength (N/mm^2)	Ultimate flexural strength (N/mm^2)	Impact test in joule
Sample 1	39	90.05	6
Sample 2	27	85.21	5
Sample 3	34	86.32	3
Sample 4	36	84.42	5
Sample 5	36	87.23	7



Tensile fracture



Flextural fracture



Impact fracture

Figure 1. SEM microstructure of the fractured regions

Figure 2. Wear calculations graph.

Wear Test Results

Wear calculations

Frictional Coefficient =frictionfactor/loadinN
Changing Length=3.14 x diameter x discspeed x slidingtime
Rate of Wear = weight loss/time in (sec)
Changing Length =3.14x100x764x5=1200m
Rate of wear for Sample1:Rate of wear =(0.0121/300)=0.0000403g/s
Rate of wear for Sample2: Rate of wear = (0.0094/300)=0.0000313g/s
Rate of wear for Sample3: Rate of wear = (0.0085/300)=0.0000283g/s

As can be seen in Figure 2, the degree of wear can vary substantially based on the particular time period. It has been determined that the maximum level of wear has been obtained at the time of 235 seconds. The weight was set at 5 kilograms, the disc speed was set at 764 revolutions per minute, and the sliding time was set at 5 minutes. All of these components were taken into consideration. Table 2 is a list that provides a summary of the weight loss that occurred for three separate specimens. A correlation between the wear rate and the coefficient of friction is also included in Table 3, which may be seen here.

Table 2. Deterioration-related mass loss.

S N.	Load in Kg	Disc speed in RPM	Time for sliding in Min	Before weight in g	After weight in g	Weight loosing
1	0.5	764	5	29.9947	29.9826	0.0121
2	0.5	764	5	29.2358	29.2264	0.0094
3	0.5	764	5	33.4395	33.4310	0.0085

Table3. Sample Friction Coefficient and Rate of Wear.

S N.	Load in Kg	Disc speed in RPM	Time for sliding in Min	Before weight in G	After weight in g	Weight losing	Wear rate(g/s)	COF
1	0.5	764	5	29.9947	29.9826	0.0121	0.0000403	0.00621
2	0.5	764	5	29.2358	29.2264	0.0094	0.0000313	0.00551
3	0.5	764	5	33.4395	33.4310	0.0085	0.0000283	0.067052

CONCLUSION

The basalt fiber reinforced polymer (BFRP) and banana fiber laminates have strong mechanical qualities that make them good for uses involving soft materials, such the fingers of medical robots, according to both experimental and computational data. Charpy testing revealed that these laminates can bear abrupt loads successfully based on their impact response. In addition, their stress-strain behavior under tensile and flexural loads, as measured by a Universal Testing Machine, highlights its durability and appropriateness for uses that need both strength and flexibility. The failure causes may be better understood by scanning electron microscopy (SEM) study of fracture surfaces, which is essential for future design and material selection optimization. Taken together, these results provide credence to the idea that BFRP and banana fiber laminates might be great materials for medical robots' need for lightweight, mechanically strong components.

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