FMDB ***Transactions on Sustainable Environmental Sciences***

Experimental Investigation of Sustainable Hybrid Composite Material for Marine Application

Gnaneswari Gnanaguru[1,*], G. Agalya[2], D. Kerana Hanirex[3], V. Poornima[4], G. Padmapriya[5], Amarilys González García[6]

[1]Department of Computer Applications, CMR Institute of Technology, Bengaluru, Karnataka, India.
[2]Department of Petroleum Engineering, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.
[3]Department of Computer Science, Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu, India.
[4]Department of Computer Science, Vels Institute of Science, Technology and Advanced Studies, Chennai, Tamil Nadu, India.
[5]Department of Chemistry, Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu, India.
[6]Department of Research and Development, Placental Histotherapy Center, Havana, Cuba.
gnaneswari@yahoo.com[1], agalya@dhaanishcollege.in[2], keranahanirex.cse@bharathuniv.ac.in[3], poornimasudhaagar@gmail.com[4], ppstminex@gmail.com[5], agonzalez@miyares-cao.cu[6]

Abstract: In the newer developments in technology in making materials, composite materials are proving to be a sufficient replacement for traditional materials because of improved properties. Composites are produced by bringing two or more materials into contact to create new materials with the desired performance features like strength, hardness, and elasticity. They are primarily synthetic and natural, with different properties and uses. Three to four tonnes of animal hair fibre are lost annually in India. Interestingly, we have a reinforced polymeric composite mixed with the waste fibre and resin. We have developed a hybrid composite material by K29 and animal hair fibres for our project. The composite was then reinforced with different binding agents, i.e., Epoxy resin-556, polyester, and PVC, using the hand layup technique under load conditions. Samples were conditioned after composite preparation according to ASTM testing standards. The tensile strength of the composite was explored, and the microstructure was examined using a SEM. Results revealed that epoxy-reinforced hybrid composite showed increased tensile strength and good interfacial adhesion between hair fibres and Kevlar. The new composite material can also be used in marine construction and shipbuilding bulkhead lining where strength and toughness are needed.

Keywords: Hybrid Composite; Hand Layup Technique; Mechanical Strength; Marine Application and Kevlar (K29); Scanning Electron Microscope (SEM); Polymeric Composite Material; Epoxy Resin-556; ASTM Standards Specimen.

Received on: 05/03/2024, **Revised on:** 11/05/2024, **Accepted on:** 22/06/2024, **Published on:** 07/09/2024

Journal Homepage: https://www.fmdbpub.com/user/journals/details/FTSESS

DOI: https://doi.org/10.69888/FTSESS.2024.000301

Cite as: G. Gnanaguru, G. Agalya, D. K. Hanirex, V. Poornima, G. Padmapriya, and A. G. García, "Experimental Investigation of Sustainable Hybrid Composite Material for Marine Application," *FMDB Transactions on Sustainable Environmental Sciences*., vol. 1, no. 3, pp. 149–160, 2024.

1. Introduction

*Corresponding author.

Composite materials are specially treated materials made up of two or more constituent materials whose physical or chemical properties differ widely. The constituents are not blended into a third one at the macro level of the final product. The unlike materials complement each other in providing special features to the composite that do not exist in individual components. However, in composites, the materials never merge, and it is generally simple to separate the various parts. They are added to these new materials since they are better in all respects, e.g., stronger, lighter, or cheaper than the regular materials. Composites are generally made up of two phases: the first one, the matrix material, and the second one, which is called the reinforcement material. The matrix material imparts the overall shape to the composite, acts as a continuous phase capable of transmitting induced stress to the reinforcement phase, and commonly surrounds and encloses other phases, e.g., utilized by other researchers [1]. The strengthening phase, typically harder than the matrix phase, strengthens the composite and its mechanical properties since the work of others designates it [2].

Composites are classified depending on the matrix material, either polymer, metal, or ceramic. Polymer matrix composites (PMCs) are made of a thermoset matrix made of epoxy or unsaturated polyester or a thermoplastic matrix made of polycarbonate or nylon reinforced by glass, carbon, or Kevlar fibres, as some innovators [3] have. Metal matrix composites (MMCs) are metal matrices such as aluminium or copper reinforced with a metal or ceramic phase and are used by most manufacturers [4]. Ceramic matrix composites (CMCs) are ceramic matrices reinforced with an alternate phase of ceramic fibre, such as aluminium oxide or silicon carbide, as per research by others [5]. The merits of composite materials are that they are light in weight, stiff, vibration-absorbing, heat transfer, and environmentally friendly, employed by designers in many industries [6]. They are generally employed in product forms such as aircraft and missile components, car wheels, engine blocks, cycles, medical equipment, etc., as in many applications [7].

Polymer matrix composites (PMCs) consist of extremely high amounts of continuous or short fibres reinforced in an organic polymer matrix. The role of the matrix in PMCs is to keep the fibres in contact and transfer loads from one fibre to another, which are utilized by various groups of engineers [8]. The composites are classified into reinforced plastics and advanced composites. Reinforced plastics have low-stiffness glass fibres and polyester resins, whereas advanced composites consist of combinations of higher strength and stiffness matrices and fibres, as seen from research studies [9]. The fibres normally comprise approximately 60% by volume in PMCs, with some common materials used being aramid fibres, fibreglass, and graphite, as seen from research studies conducted by researchers [10]. The mechanical properties of reinforcing fibres are highest in their directions, and fibres are aligned in different shapes and directions to impart distinctive physical properties depending on the application, as reflected by methods developed by engineers [11].

The matrix phase in PMCs has a major influence on determining the chemical attack, impact damage resistance, water absorption, and high-temperature creep resistance of the composite, as highlighted in recent literature [12]. The matrix is predominantly the weakest part of the composite, as determined by most material scientists [13]. PMCs are thermosetting or thermoplastic resins, but the latter forms are used to a larger extent because their properties are better used by most companies [14]. PMCs have numerous advantages, such as a comparatively lower cost, ease, and ecologically friendly advantage in less use of wood-based materials as targeted by most industrial processes [15]. They also have a few drawbacks in environmental degradation and water uptake followed by polymer swelling, particularly at comparatively higher temperatures, as discovered by other scientists through experiments. Polymer processing is a broad term for production processing involving converting raw polymeric material to the desired form, end products, and characteristics.

Some processes used in polymer processing are injection moulding, compression moulding, spray coating, and hand layup, as seen in the industry. Injection moulding is a process where elements are formed by liquid injection into a mould. Many companies apply this process to materials such as metals, elastomers, and plastics for manufacturing purposes. Compression moulding is loading a preheated moulding material into a hot open mould cavity and adding heat and pressure to take the desired form, which composite firms apply. The spray layup method develops the hand layup method, where resin and reinforcement are sprayed onto a mould, and the air is evacuated by passing a roller over the material before curing, employed by producers in mass production. It is applied in applications such as truck fairings and caravan bodies, observed in different production lines. The most common and least costly open-mould process is hand layup, in which the reinforcement fibre is manually put into a mould, and resin is brushed or rolled and applied to many industries to create products such as aeroplane skin, park benches, and port-a-potties. These different composite materials and production processes allow for a wide variety of long-life and high-performance aerospace, automotive, medical, and construction products, as seen in recent commercial usage. The production and processing of composite materials are still full of potential to provide even greater improvement in material performance, weight saving, and cost savings and are, therefore, a basic part of modern production, as attested by recent developments and activity in the area.

1.1. Problem Identification

- Less bonding strength

- They didn't mention ASTM standard dimensions for making a sample composite.
- They used unidirectional Kevlar, which has less tensile strength.
- The composition of resins should have the correct mixing ratio.
- Hair fibre not treated in acetone solution.
- Hair fibre is not formed as a mat.
- They used small lengths of hair to form a composite.
- Constant load is not applied.

1.2. Objectives of Research

- Improve the mechanical properties of hair fibre composite materials and structures by optimizing integrated synthetic fibre like Kevlar fibre and reducing the composite material's weight.
- Test the specimens for conducting various mechanical tests from the collected hair materials.
- It is to be used to apply marine (or) submarine parts.
- In our project, we will examine the chemical composition of the chemicals used.
- The above literature reviews used only one resin to prepare a sample composite, so that we will use three resins: Epoxy resin, polyester resin, and PVC.

2. Literature Review

Composite materials are custom-made materials consisting of two or more different constituent materials, historically using synthetic and natural fibres to develop the desired properties. They are produced to provide new mechanical strengths, including increased tensile, flexural, and impact strengths, that cannot be realized through the individual components. One commonly applied method of composite material production is reinforcing a polymer matrix with natural fibres like human hair, jute, or palm fibres and synthetic fibres like Kevlar. These fibres are then bonded with a range of resins, such as epoxy and Araldite, which are of prime importance in enhancing the general mechanical properties of the composite, as one can observe from work carried out by authors [2]. The process of manufacture normally involves compression moulding or hand layup methods, which are of the highest benefit in making high-strength materials for applications involving dynamic loads, particularly in the aerospace and automotive industries. Natural fibres in the polymer matrices offer a series of benefits such as cost-effectiveness and environmental sustainability and lower the environmental impact of production, as shown by the work accomplished by several authors [1].

The reinforcing filaments, such as human hair, are of high tensile strength, and the presence of these filaments within the matrix greatly improves the mechanical properties of the composite [5]. The hand layup method, commonly employed to manufacture these composite specimens, has been found sufficient enough to acquire a material of an acceptable quality that could fulfil industry requirements of tensile and bending strength [4]. In addition, matrix material and fibre interaction are also accountable for the ultimate performance of the composite, and fibre volume fraction and fibre length are significant factors in determining the ultimate properties of the composite [3]. Research on the tensile properties of such composites indicates that more fibre content produces higher strength, along with their enhanced use in dynamic applications [2]. Their environmental friendliness with waste products like human hair and fly ash also adds to their growing production demand [3]. Blending natural fibres with thermoset resins has also been researched to minimize dependence on synthetic components at the expense of desirable mechanical characteristics [5].

The impacts of various manufacturing processes, such as compression moulding and spray layup, have been extensively studied to identify the most efficient processes utilized to produce high-performance composite products. The manufacturing processes are responsible for setting the final properties of composites, which are utilized in various applications, from automotive components to aircraft parts. Compression moulding, for example, is an old technology of high-strength composite production because it involves preheated material fed into an open mould where the material is compressed under pressure to achieve a desired shape. Utilizing heat and pressure during compression moulding assures proper curing of the matrix, thereby contributing towards enhanced mechanical properties of the composite, such as tensile strength and flexural rigidity. This is especially valuable in the production of large numbers of complex parts, and its capability to make composites of consistent properties makes it suitable for high-performance parts such as automobile body panels or aircraft structural parts, as indicated by various researchers [6].

Alternatively, spray layup is another highly prevalent composite manufacturing process, particularly where high-speed and high-volume production of relatively intricate parts is required. Spray layup is a technique where the resin-reinforcement composite is sprayed onto a mould and hardened to form a solid composite. Spray layup is also widely used in those applications where intricate designs or higher surface areas must be quickly and efficiently coated. It is a cost-effective process that conserves materials and allows for quick turnaround. Hence, it is best suited for producing large numbers of components like truck fairings, boat hulls, and even some parts for aircraft. The ability of spray layup in terms of the variety of materials that can be utilized and its moderate expense make it the best option for those applications where cost-effectiveness and high performance are essential, according to research conducted by other researchers [7].

In addition to process-specific advantages in both, hybrid composites—a blend of natural fibres like human hair, jute, and synthetic fibres—were tougher and are consequently in great demand in adverse environments. Hybrid composites were also more tolerant of environmental factors like moisture, UV degradation, and thermal cycling, which are common problems for materials utilized in aerospace and automotive technologies [9]. For example, it has been confirmed that incorporating jute and human hair fibres in epoxy resin systems increases the toughness and fracture resistance of the composites as a whole to make them best suited for application to impact loading conditions when use of the traditional material alone would yield a detrimental effect. These improved durability characteristics have added the appeal of hybrid composites on components exposed to abrasive conditions, such as engine parts, automobile structural supports, and even medical implants, such as prostheses or orthotic appliances. The initiatives of various research work [3] in studying the mechanical characteristics of hybrid composites have indicated the potential of the material to give excellent performance but be affordable and eco-friendly [5].

The range of possible properties with composite materials is not restricted to mechanical response. Another of the key reasons for the increasing application of composites in a broad cross-section of industries is that they are cheap and easy to make. Blending natural fibres such as jute and human hair with synthetic resins and polymers provides an affordable yet eco-friendly solution to all the problems associated with working with conventional materials. Not only are natural fibres cheap and renewable, but they are light in weight and cheap to manufacture, and thus very desirable as opposed to working with synthetic fibres in most situations. Composite processing techniques like compression moulding and spray layup are also simple and readily scalable, lowering production costs. This has made composites a viable option for industries like the manufacture of automobiles, where less weight and less fuel usage are the key concerns, and in the medical field, where what is required is light material but one that is durable enough to provide prosthetics and medical equipment, say researchers [13].

Blending natural fibres with composite materials also has several environmental advantages. Utilization of renewable resources such as jute and human hair reduces the use of petrochemical-based synthetic fibre, which is energy-intensive to produce and pollutes the environment. Waste material depolymerization, in this scenario, human hair, also decreases landfill disposal and promotes recycling, resulting in a circular economy. This inherent benefit, coupled with the lower cost of production, has made hybrid composites an effective alternative for businesses that desire to enhance their sustainability process without sacrificing high performance, as per various research studies of industry professionals [1]. /In most instances, combining natural fibres such as human hair, jute, and artificial fibres and resins produces composite materials with better mechanical properties, enhanced durability, and significant cost savings. Employing simple but effective manufacturing techniques such as compression moulding and spray layup also increases the worth of such composites. It suits them best for various applications, from the automotive to the medical field. All of the research these researchers have conducted has pointed to the potential of hybrid composites in meeting the growing need for green, high-performance materials and being a viable and affordable alternative to traditional materials for manufacturers. Mixing fibres derived from nature with artificial materials represents a groundbreaking path to the science of material and the pivotal first step towards adopting greener and more efficient ways of producing in current times.

3. Research Methodology

Composite preparation is done by a procedure that starts with washing hair fibres in hot and cold water and drying. After drying, the fibres are washed with acetone and dried. In the meantime, a mosaic stone is chosen and acetone-cleaned. Kevlar-K29 fibres of the specified sizes are positioned on the mosaic stone, rolled out gently to remove wrinkles, and hair material of various compositions is added above the Kevlar layer. The hand layup transfers resin to the hair fibres, and a frame is positioned over the material. A load is imposed for 20-24 hours to fix the composite material. This process is performed for various compositions of the materials.

The samples, once dried, are taken out from the mosaic and mechanically tested as per ASTM standards, with results plotted for analysis. Sample materials prepared are Kevlar fibre, human hair, epoxy resin, polyester resin, and polyvinyl chloride (PVC). Kevlar is a heat-resistant synthetic fibre with a high tensile strength-to-weight ratio, making it resistant to abrasion and impact. It is widely used in protective equipment, such as bulletproof vests and combat footwear. The high interchain bonding of the material gives it a special set of physical properties, such as good cut and chemical resistance. Human hair, which is mostly made up of alpha-keratin, is a fibrous protein with outstanding mechanical characteristics, primarily owing to the very organized cortex structure that makes it resistant to elongation and elasticity. Its physical characteristics result from hair diameter and race (e.g., Caucasian, Asian, or Afro hair). Epoxy resin is tough, adhesive, and chemically resistant. It is used in high-strength composite applications and has better mechanical properties and flexibility. Polyester resin, an unsaturated synthetic resin generated by the reaction between dibasic acids and polyhydric alcohols, is largely used in applying fibreglass-reinforced plastic (FRP). Polyester resin is resistant to chemicals, water, and ageing but possesses a very pungent smell when cured. PVC, the third most mass-produced synthetic plastic polymer, occurs in rigid and flexible types. It is employed in anything ranging from pipes and window profiles to flooring and signages.

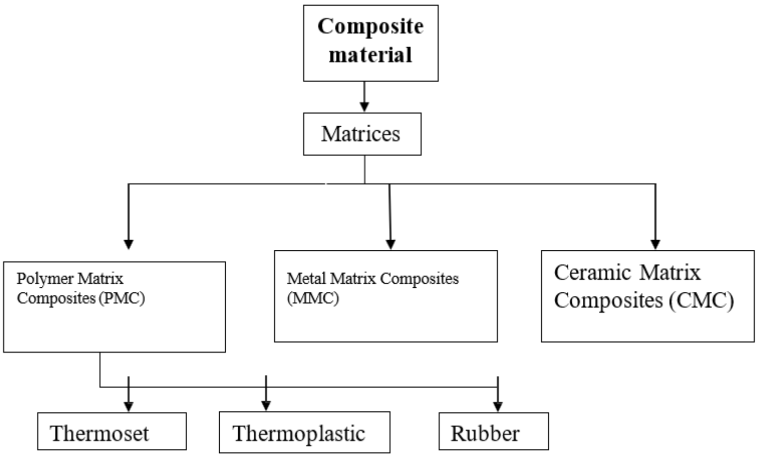

Figure 1: Classification of Composite based on Matrices

Figure 1 shows the categorization of composite materials according to their matrices. Composite materials are mainly categorized into three types: Polymer Matrix Composites (PMC), Metal Matrix Composites (MMC), and Ceramic Matrix Composites (CMC). These are categorized according to the matrix material. PMCs are again categorized into three types according to the polymer matrix type: thermoset, thermoplastic, and rubber. Thermoset polymers are cured and hardened, whereas thermoplastic polymers can be remelted and reshaped when heated to facilitate flexibility. Rubber matrices have better impact resistance and elasticity. Also, MMCs employ a metal as the matrix material, having high thermal stability and strength, and thus are best suited to high-performance areas such as aerospace and automobile components. CMCs, however, employ ceramic matrices and possess higher heat and wear resistance, which is appropriate for application in extreme temperature conditions. The above definition shows differences in composite material types, each possessing unique properties and applications based on matrix materials.

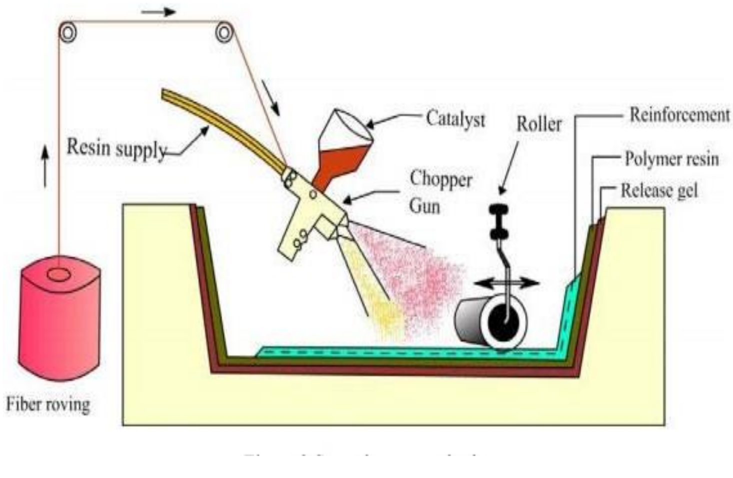

Figure 2: Spray Layup Method for Composite Fabrication

Hand layup is used to produce the composite. This low-volume, labour-intensive process involves manually placing reinforcing mats or fabrics into an open mould. The release gel is applied to the mould to prevent sticking, and plastic sheets are placed at the top and bottom to achieve a smooth surface finish. The fibres are cut to size and placed in the mould, and the resin is brushed or rolled on. The fibres and resin are added alternately until the required layers are obtained. When cured, the composite is removed from the mould for subsequent processing. Sample preparation is done using various pairs of materials. For Sample I, human hair and Kevlar fibre are used as the matrix material, and epoxy resin is used as the reinforcing material. Sample II substitutes epoxy resin with polyvinyl chloride resin, and Sample III uses polyester resin. For Sample II preparation, the substrate material is waxed first, followed by applying and rolling off Kevlar fibre to avoid folding. Human hair fibres are then loaded in a vertical axis following the application of resin, and resin is again applied. A new layer of human hair and Kevlar is loaded on a horizontal axis, and resin is applied again. The composite is allowed to cure for 24-28 hours and then removed. This is done for Sample III as well, but with the use of polyester resin rather than PVC resin.

Figure 2 illustrates the spray layup process, a composite material fabrication process employing a spray of resin and reinforcing fibres and applying it on a mould. The source of the fibre roving is from the spool, which sprays in the direction of movement under constant run. The catalyst and resin supply blend was mixed and sprayed using a chopper gun on the mould. The gun also breaks the resin-coated fibres into fragments and sprays the mixture onto the mould surface. The polymer resin and reinforcement are covered with a uniform layer. A roller compacts and presses out air bubbles and continues depositing fibre and resin on the mould in an even layer. It is also the application of a release gel coat onto the mould surface before the process to prevent the polymer from sticking to the mould. It is well suited for manufacturing large and complex shapes and is extensively used for manufacturing aerospace, automobile, and shipping components. It is a low-waste process with reusable material attributes and is cost-effective. The main elements of the spray layup process are shown in the diagram and consist of the fibre rovings, resin feed, chopper gun, roller, and release gel, all of which contribute to effective composite material fabrication.

Material testing comprises various mechanical tests. Tensile testing is applied to measure such properties as yield strength, elongation, and ultimate tensile strength by subjecting the test sample to controlled tension until the Sample fails. Water immersion testing examines leaks and measures the material water resistance by testing the Sample by submerging it in pressurized water. It checks for sample leaks, which is extremely valuable information regarding the Sample's withstanding water conditions. Scanning electron microscopy (SEM) determines the composite surface and structure. The SEM employs a focused beam of electrons to scan the sample surface, detecting the secondary electrons to create high-resolution images of the sample topography and composition. SEM is useful in viewing the Sample at different magnifications and detecting structural characteristics like cracks or surface irregularities of the material. In short, the experimental process of the composite material involves the intentional mixing of different fibres and resins concerning proper layering, application of resins, and curing time. The chosen materials, such as Kevlar, human hair, epoxy resin, polyester resin, and PVC, provide a wide range of properties that collectively enhance the composite's strength, durability, and performance. The hand layup method enables the compounding of the materials by hand, and the test procedures yield useful information about the mechanical and physical properties of the composite materials, confirming their appropriateness for diverse applications.

4. Result and Discussions

Experimental research on sea composite hybrid material has yielded important information about mechanical behaviours and the future potential of the material under harsh conditions. Composite mixing was investigated by researching Kevlar fibre, human being's hair, and other different resins like epoxy, polyester, and polyvinyl chloride. The composites' tensile strength and water absorption characteristics were examined to determine if and how they might be utilized in marine environments where maximum tensile strength and resistance to water are needed. The greatest tensile strength was achieved by Sample I, which was composed of Kevlar fibre and human hair reinforced with epoxy resin. The epoxy resin created a hard bonding matrix, which significantly increased the mechanical properties of the fibres, creating a high-strength and elongation-resistant composite material. The composite material also resists water absorption, a crucial aspect in marine applications where the materials are subjected to continuous water. The strong resin-fibres adhesion in Sample I was responsible for the close surface packing that resisted water infiltration and improved the overall strength of the composite. Sample I was, therefore, the best material to use under marine conditions, particularly for parts that needed high mechanical performance under adverse conditions. A generalized stress-strain relationship is given below:

$$\sigma = C \cdot \varepsilon \tag{1}$$

where σ is the stress vector, C is the stiffness matrix (which depends on the material properties and the orientation of the composite fibres), and ε is the strain vector. Stress in a composite laminate is:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_6 \end{Bmatrix} = \begin{Bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{Bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix} \tag{2}$$

where Q_{ij} Are the elements of the stiffness matrix for an orthotropic material and ε_1, ε_2, γ_{12} are the normal strains and shear strains. The rule of mixtures for hybrid composites is:

$$E_{composite} = V_f \cdot E_f + V_m \cdot E_m \quad (3)$$

where $E_{co/nposite}$ Is the effective modulus of the composite, E_f and E_n Are the moduli of the fibre and matrix materials and y_f and y_n Are the volume fractions of the fibre and matrix? Fatigue life prediction for composites in math form is:

$$\sigma_{\max} \cdot N_f^b = C \quad (4)$$

where σ_{nax} Is the maximum stress, N_f It is the number of cycles to failure, b is the fatigue exponent, and C is a material constant. The damage evolution equation in hybrid composites is given below:

$$D = 1 - (1 - \frac{\sigma}{\sigma_{\max}})^n \quad (5)$$

Where D is the damage parameter, σ is the applied stress, σ_{nax} Is the maximum stress at failure, and n is the damage exponent.

To which human hair and polyvinyl chloride resin were added, Sample II had a moderate tensile strength and took up more water than Sample I. Polyvinyl chloride resin did not bond well with the fibres to form the less stiff composite material. Higher water absorption in Sample II is explained by poor bonding, where the water can diffuse more freely in the material. Where tensile strength was adequate for certain applications, high water absorption ensured that this composite would not be compatible with wet conditions over long periods and, hence, was less compatible with high-risk marine applications. Sample III, composed of polyester resin, human hair mat, and Kevlar fibre, had excellent tensile strength but failed in Sample I. Sample III's failure could be attributed to poor bonding between the fibres and polyester resin, and it weakened its water absorption resistance. Though strong enough for certain applications, Sample III's medium water uptake was not ideal for applications with high durability and water resistance demand. The tensile and water absorption tests were very conclusive that Sample I has superior mechanical characteristics and water resistance, which are very much required under marine conditions. SEM micrographs of the composites further revealed further information regarding bonding mechanisms within the materials. Effective resin distribution throughout the composite and interfacial Kevlar fibre bonding to epoxy resin was established through SEM observation of Sample I.

Human hair fibre surface topography provided evidence of effective fibre/resin matrix integration, resulting in increased mechanical strength and water resistance. The SEM morphology of Sample II and Sample III was less uniform in resin distribution and weaker resin adhesion to the fibres, consistent with their higher water absorption and lower tensile strength. The improved performance of Sample I indicates that hybrid composites of human hair, Kevlar fibre, and epoxy resin are best suited to apply in the marine environment, particularly in areas where as much strength and durability as possible are required by conditions such as water. The finding of this study warrants using these hybrid composites aboard where light-weight strong material and resistance to water cannot be avoided. Such composites' resistance to corrosive marine atmospheric environments, such as seawater exposure, humidity, and mechanical loading, makes them suitable for most applications, from boat hulls to marine structures and other water-exposed parts with long-term water immersion. The experimental results show the ability of hybrid composite materials to offer cost-effective, high-performance alternatives to conventional materials employed in marine applications with improved sustainability and mechanical performance. Further investigation of the experiment results is recommended to optimize the fibre-matrix interface and study long-term material properties against seawater exposure, specifically resistance to UV radiation, saltwater corrosion, and long-term fatigue Table 1.

Table 1: Tensile strength of given specimens

Tensile strength of given specimens	Tensile stress in MPa
S-1A	28.75 MPa
S-1B	54.73 MPa
S-1C	52.37 MPa
S-2A	37.34 MPa
S-2B	25.83 MPa
S-2C	26.49 MPa
S-3A	14.34 MPa
S-2B	25.32 MPa
S-3C	29.40 MPa

Sample 1: As per the case of sample 1, the composite was prepared with materials like Kevlar fibre, Hair fibre, and Epoxy resin. Thus, the combination of Epoxy resin and Hair fibre gives good tensile strength, constant elongation, and less brittleness.

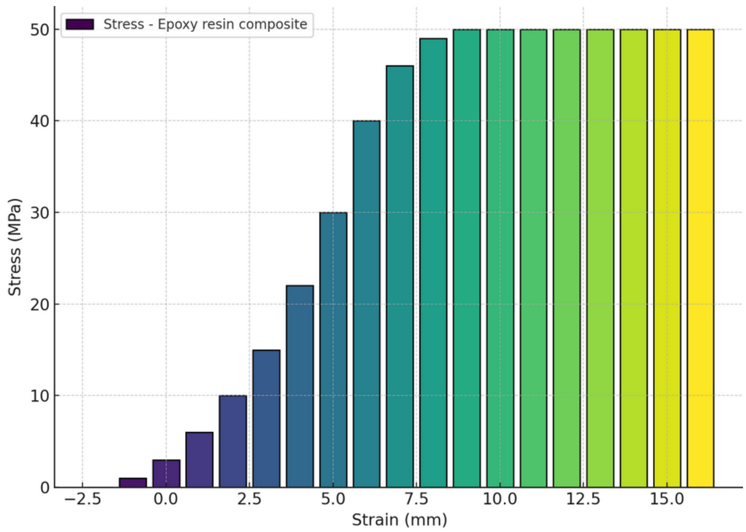

Figure 3: Stress-strain graph for sample 1

Figure 3 represents a composite material epoxy resin's stress-strain diagram in which every bar of the bar graph is labelled based on stress in MPa if there is any amount of strain (in mm). Gradating tints in dark purple on descending bars make their representation clearer in the direction of maximum rise in strain to its higher value stress level. A linear trend is observable from the graph as the strain value rises, leading to stress, a parameter measuring the material's resistance to deformation by tensile loading. Low stress is observed when there are extremely small initial strains (-2.5 mm to 2 mm), and the bars start around zero and rise step by step. When the stress keeps escalating to and past a value of 5 mm, stress levels continue to climb enormously to a stage of 50 MPa, where strain is practically a value of 16 mm. That is the route that shows the tension behaviour of the composite, whereby the initial step is an elastic distortion to a stage where plastic deformation begins as the stress levels peak. The lack of abrupt drop-off or point failure of the graph implies that the composite can withstand increasing strain without compromising integrity, a testament to its improved bonding and structural integrity. This type of stress-strain behaviour is typical of epoxy-based composites, whose stress capacity before failure has been established long ago. In general, the figure qualitatively describes the composite's better performance in both strength and deformation behaviour when loaded in tension.

Sample 2: As per the case of sample 1, the composite was prepared with materials like Kevlar fibre, hair fibre, and Polyvinyl chloride resin. Thus, combining Polyvinyl chloride and Hair fibre gives better tensile strength and shows medium elongation and sudden breaking point.

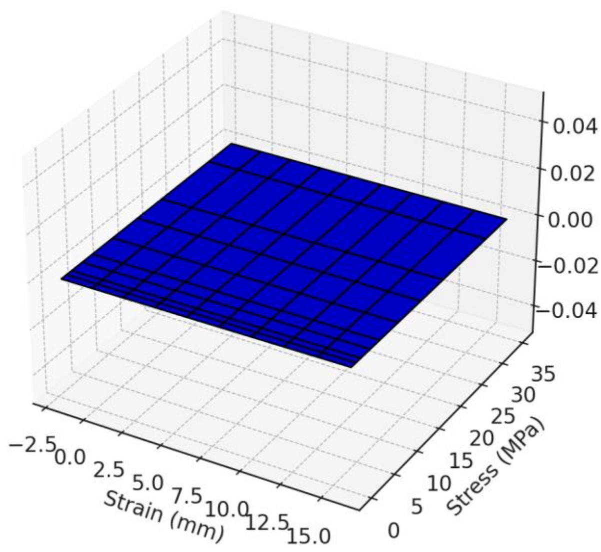

Figure 4: Relationship between strain and stress for PVC-reinforced composite material

Figure 4 is a three-dimensional stress (y-axis), strain (x-axis), and corresponding value (z-axis) plot of a PVC-reinforced composite material. The plot is linearly directly proportional between stress and strain, as in most materials deforming under load. Stress rises highly with a rise in strain, i.e., the material plastic deforms upon attaining a specific critical strain. The lower part of the plot (low values of strain) corresponds to low stress levels, corresponding to the initial elastic region where the material is still linear and very recoverable. As the strain values increase, the material is already under higher stress levels, and this could mean that the composite is at a non-linear stage where the material can start to exhibit yielding or failure behaviour. The trend in the graph shows that the PVC composite reinforced material resists deformation at lower resistance strain values but is more prone to more stresses, with higher strain values producing larger stresses, ultimately leading toward material failure or damage. Z-values of axes are unequal but show the line of deduction between experiment points for stress and strain. This kind of visualization is critical in establishing the composite's behaviour under different load conditions and the position of stress and strain criticality, and it can be utilized in areas of need for tension or load material integrity.

Sample-3: As per the case of sample 1, the composite was prepared with Kevlar fibre, hair fibre, and Polyester resin. Thus, the combination of polyester resin and Hair fibre gives the medium tensile strength and shows the medium elongation with high brittleness.

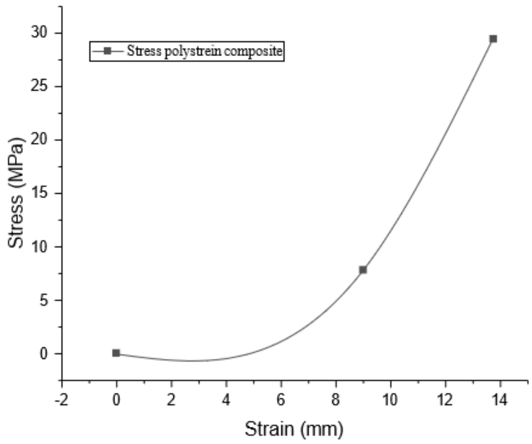

Figure 5: Stress-strain graph for sample 3

Water Absorption Test: This is done for all the three samples. This test was done to determine the water absorption capacity of the samples.

The results are tabulated as shown below:

Table 2: Day absorption

Days	Sample-1 Weight (Grams)	Sample-2 Weight (Grams)	Sample-3 Weight (Grams)
Day-1	13	15	14.2
Day-2	13	15	14.2
Day-3	13	15.2	14..2
Day-4	13	15.3	14.3
Day-5	13.1	15.3	14.3
Day-6	13.1	15.5	14.3
Day-7	13.1	15.6	14.4
Day-8	13.1	15.6	14.4
Day-9	13.1	15.7	14.5
Day-10	13.2	15.9	14.5
Day-11	13.2	15.9	14.5
Day-12	13.3	16	14.5
Day-13	13.3	16	14.6
Day-14	13.3	16	14.6

Table 2 It is absorbed that the water absorption in samples gradually increases day by day due to low bonding capacity. In sample-1, the absorption of water increases by 0.3 grams, and in sample-2, the absorption of water increases by 1 gram. In sample 3, the absorption of water increases by 0.4 grams. At the end of water absorption, sample-1 has higher water resistance than other samples Figure 5.

Morphological Analysis: The prepared samples are tested in SEM to determine each Sample's bonding strength**.** The analyzed images are given below.

Sem Image of Sample 1

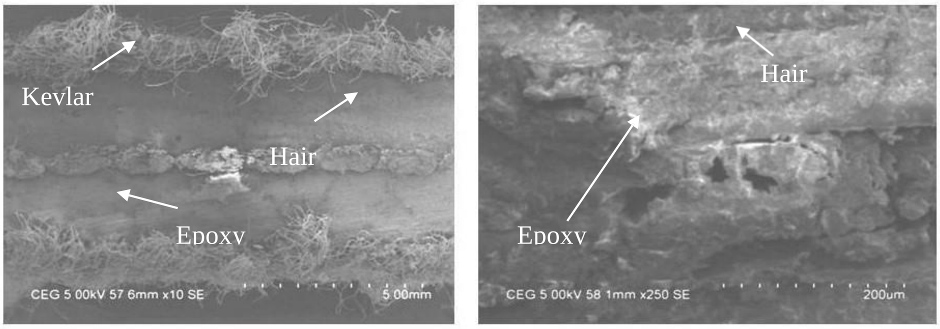

Figure 6: SEM Image of Hair fibre and Epoxy resin

Figure 6 In the first image, we can see the surface topography of Kevlar fibre, Hair fibre, and epoxy resin at the magnification of 500mm. The second image shows the same Sample at the magnification of 200 um. Both images have good bonding strength. Correct composition resins give better bonding strength.

Sem Image of Sample 2

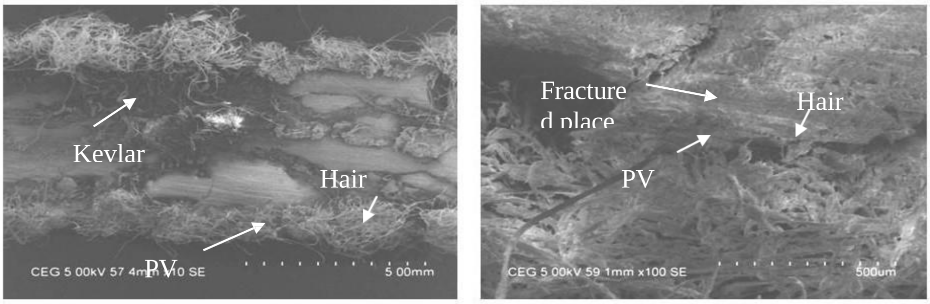

Figure 7: SEM Image of Hair fibre and polyvinyl chloride resin

Sem Image of Sample 3

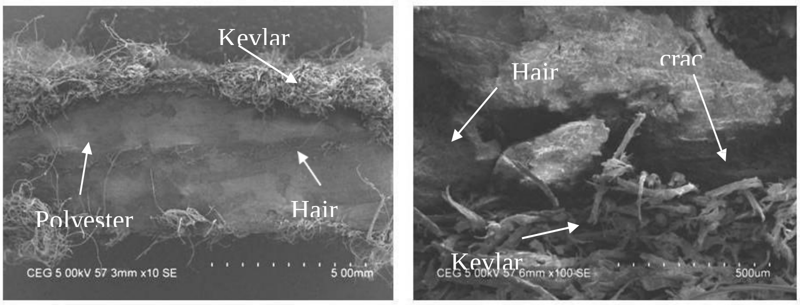

Figure 8: SEM Image of Hair Fibre and Polyester Resin

Figure 7 In the first image, we can see the surface topography of Kevlar fibre, human hair, and Polyester resin at a magnification of 500mm. The second image shows the same resin and hair fibre bonding magnification sample. We can see the hair fibre fractured inside the Sample and the polyester resin layer in the second image Figure 8.

5. Conclusion

The greatest deviations are the three composite samples' tensile strength and water absorption capacity. The Sample, which consists of Kevlar, human hair, and epoxy resin, possesses the highest tensile strength compared to all the samples. The same composite has the lowest water absorption capacity because of the rigid interlocking of hair fibres with epoxy resin. The most pronounced bonding feature of the epoxy resin is that it provides an extremely high reinforcement to the fibres and, therefore, the overall tensile strength of the Sample. Sample II, which is made from Kevlar, human hair, and polyvinyl chloride (PVC), is of medium tensile strength compared to the other two samples. This Sample has a larger water absorption capacity because of the weak interfibre and resin-fibre bonds, corresponding to lower reinforcement. Sample III, containing Kevlar, human hair mat, and polyester resin, yields a low resistance tensile strength, as opposed to Sample I. Polyester resin does not bond well to fibres in an attempt to possess an intermediate water absorption capacity. As an elongation and tensile strength, Sample I is superior to the remaining samples with the lowest elongation and highest tensile strength. The water absorption test also confirms that Sample I possesses a very close surface and the lowest water absorption. SEM images also confirm the same by showing successful material reinforcement in the matrix. SEM micrographs indicate material adhesion, surface topography of hair fibres, and resin distribution, confirming excellent adhesion strength for Sample I. Such composites, particularly Sample I, have their use in aerospace and naval applications in which tensile strength is satisfactory, water absorption is minimal, and durability is essential.

5.1. Limitations

Experimental work on marine hybrid composite material has some limitations. For example, external conditions such as temperature, humidity, and salt exposure can influence the material response, which cannot be perfectly replicated in the laboratory. Experimental test specimens in studies are usually small relative to real marine structures, which can impact extrapolation. In addition, the durability of hybrid composites under long-term cyclic loading, UV weathering, and resistance to marine biofouling have not been well examined, thus impacting prediction in life under harsh marine conditions. Variability when homogenously blending the materials and quality control throughout the manufacturing process can also lead to non-homogeneous products. Lastly, although the primary mechanical properties researched in hybrid composites are their mechanical properties, repairability, recyclability, and environmental impact of manufacturing, these are also less researched.

5.2. Future Scope

Enhancing the life of hybrid composites by subjecting them to the performance test under actual marine conditions, such as long-term exposure in seawater and temperature variation exposure, can be addressed in future research. Future research into nanotechnology and 3D printing technology would be undertaken to determine the properties of the materials at a reduced manufacturing cost. Also, long-term environmental stressor impacts and hybrid composite fatigue information must be considered in order to continue using them in ocean systems. Developing green and sustainable hybrid composite formulations and new recycling techniques will further augment their use. Material scientists, naval engineers, and ecologists must work together and develop tomorrow's composites for use in the sea.

Acknowledgement: We gratefully acknowledge CMR Institute of Technology, Dhaanish Ahmed College of Engineering, Bharath Institute of Higher Education and Research, Vels Institute of Science, Technology and Advanced Studies, and the Placental Histotherapy Center for their invaluable support and collaboration. Their contributions were instrumental in the successful completion of this work.

Data Availability Statement: Data is available upon request from the corresponding author.

Funding Statement: This research received no financial support.

Conflicts of Interest Statement: No conflicts of interest were declared; all references were appropriately cited.

Ethics and Consent Statement: The research adhered to ethical guidelines, with informed consent and confidentiality ensured.

Reference

1. M.K. Egbo, “A fundamental review on composite materials and some of their applications in biomedical engineering,” J. King Saud Univ. Eng. Sci., vol. 33, no. 8, pp. 557–568, 2021.
2. A. Karimi, D. Rahmatabadi, and M. Baghani, “Various FDM mechanisms used in the fabrication of continuous-fibre reinforced composites: A review,” Polymers, vol. 16, no. 6, pp. 1-28, 2024.

3. X.-S. Yi, “An Introduction to Composite Materials,” in Composite Materials Engineering, Volume 1: Fundamentals of Composite Materials, X.-S. Yi, S. Du, and L. Zhang, pp. 1–61, Springer, Singapore, 2018.
4. K.O. Iwuozor, T.T. Micheal, K.T. Micheal, S.S. Emmanuel, E.C. Emenike, and A.G. Adeniyi, “Plant biomass-based composites in the maritime industry: A review,” Mar. Struct., vol. 96, no. 3, p. 103609, 2024.
5. A.D. Nugraha, M.I. Nuryanta, L. Sean, K. Budiman, M. Kusni, and M.A. Muflikhun, “Recent progress on natural fibres mixed with CFRP and GFRP: Properties, characteristics, and failure behaviour,” Polymers, vol. 14, no. 23, pp. 1-37, 2022.
6. D. Rahmatabadi, E. Soleyman, M.F.M. Bashi, M. Aberoumand, K. Soltanmohammadi, I. Ghasemi, M. Baniassadi, K. Abrinia, M. Bodaghi, and M. Baghani, “4D printing and annealing of PETG composites reinforced with short carbon fibres,” Phys. Scr., vol. 99, no. 5, pp. 1-14, 2024.
7. S. Acharya, S.S. Rumi, Y. Hu, and N. Abidi, “Microfibres from synthetic textiles as a major source of microplastics in the environment: A review,” Text. Res. J., vol. 91, no. 17, pp. 2136–2156, 2021.
8. R. Bhanupratap, “Study of tensile behaviour by variation of Kevlar to the jute fibre epoxy hybrid composites,” vol. 7, no. 6, pp. 1039-1043, 2017.
9. G.D. Gautam, G. Norkey, and A.K. Pandey, “Mechanical Characterization of Kevlar-29 Fibre Reinforced Polymer Composite,” ELK Asia Pacific Journals, Presented at ARIMPIE-2017, ITS Engineering College, Noida, Uttar Pradesh, India, 2017.
10. I. Al-Mosawi, “Mechanical Properties of Composite Material Reinforcing by Natural-Synthetic fibres,” Academic Research International, vol. 3, no. 3, pp. 108-111, 2012.
11. S. Rajesh and B. Vijaya Ramnath, “Investigation of Tensile Behaviour of Kevlar Composite,” Science Direct, Materials Today, vol. 5, no. 1, pp. 1156–1161, 2018.
12. Z. Yu, “Carbon Fibre Reinforced Epoxy Resin Matrix Composites. Yonglian Tang, School of Materials Science and Engineering,” Carbon Fibre Reinforced Epoxy Resin Matrix Composites, vol. 1, no. 1, pp. 1–6, 2017.
13. A. Nazeer, “To Study the mechanical properties of coconut coir fibre reinforced with epoxy resin AW,” International Journal of Modern Engineering Research, vol. 4, no. 7, pp. 38-47, 2014.
14. V. Vatsal, S. Shamveel, “Fabrication and Analysis of Human Hair Based Hybrid Epoxy Composite for Mechanical Properties,” vol. 2, no. 7, pp. 459-465, 2017.
15. M. Yasaswi, “Experimental Analysis of Coir-fibre Reinforced polymer composite material,” Int. J. Mech. Eng. & Rob. Res., vol. 2, no. 1, pp. 10-18, 2013.