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An Assessment of The Mechanical Properties of a Composite Material Composed of Natural Fibres and Reinforced with Polymer

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Abstract

Composites are essential in contemporary engineering and production, providing a flexible and effective solution for various applications that demand lightweight materials with exceptional performance. Natural composites provide adaptable and eco-friendly solutions for various sectors and applications, promoting environmental sustainability and the preservation of resources. Further advancements in research and development in this discipline are anticipated to enhance the utilization of natural composites across several industries. For this investigation, two types of composite materials are created: synthetic composites and Hybrid composites. The materials picked for the fabrication of synthetic composite were basalt, coconut coir and glass fibre. For the hybrid composite, basalt, coconut coir, and kenaf fibre were chosen. The mechanical properties of the composite materials were evaluated by analyzing the data obtained from several tests, including tensile, compression, flexural, and impact tests. From the test results, the synthetic composite exhibited a 21% increase in tensile strength, 44% increase in compression load, 137% increase in flexural strength and 83% increase in impact strength over the hybrid composites.

Keywords: Composites, synthetic composites, hybrid composites, fabrication, mechanical properties

INTRODUCTION

Composite materials are a unique combination of multiple substances that have exceptional capabilities, leading to significant advancements in fields such as aerospace and automotive engineering. Composite materials have become a fundamental aspect of contemporary engineering, utilising the distinct capabilities of each component to attain exceptional performance qualities. Composites provide a customised solution to satisfy the requirements of various applications by merging multiple materials with different characteristics. Composites have surpassed the constraints of traditional materials, offering lightweight structures that can survive harsh environments and adaptable components that improve efficiency and durability [1].

Composites possess a wide range of favourable attributes due to the distinctive combination of matrix and reinforcing materials. Prominent characteristics include a high ratio of strength to weight, remarkable rigidity, resistance to corrosion, and stability in terms of heat. Composites can have significantly enhanced properties by effectively utilising the complementary characteristics of their constituent materials [2].

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The fabrication of composite materials involves a wide variety of manufacturing methods, each designed to accommodate specific material compositions and desired characteristics. Common methods encompass lay-up, filament winding, pultrusion, and injection moulding, among other processes. These technologies provide versatility in design and production, allowing for the fabrication of intricate shapes and structures while minimising material waste. In addition, progress in additive manufacturing has enabled the quick creation of prototypes and the customisation of composite components, thereby broadening the range of businesses that can benefit from these materials [3,4].

Hybrid composites and synthetic composites are two different types of materials that are becoming more and more important in modern engineering. Although each have distinct benefits, it is necessary to closely analyse their variations in composition, features, and uses. Hybrid composites are defined by their varied composition, which includes different types of reinforcements, such as fibres, particles, or laminates, combined inside a single matrix material. This allows for the optimisation of mechanical, thermal, and electrical properties by utilising the distinctive characteristics of each reinforcement material. On the other hand, synthetic composites are made up of a uniform mixture of only one kind of reinforcement material, usually fibres or particles, embedded in a matrix material [5-8]. Hybrid composites offer adaptability and customisation by combining various reinforcement elements, whereas synthetic composites ensure uniformity and consistency in attributes.

The composition and processing procedures of hybrid composites and synthetic composites have a significant impact on their qualities. Hybrid composites possess a blend of characteristics obtained from each reinforcing material, leading to improved strength, rigidity, and longevity in comparison to conventional composites. The combined impacts of various reinforcements enable the customisation of characteristics to meet precise application demands. In contrast, synthetic composites provide consistent and standardised properties that are determined by the specific characteristics of the individual reinforcement material. Although synthetic composites may not possess the same level of diversity as hybrid composites, they do offer a high degree of consistency and reliability in terms of performance [9,10].

Hybrid composites and synthetic composites are utilised in several industries such as aerospace, automotive, marine, and sporting goods [11-13]. Hybrid composites are ideal for applications that necessitate customised features such as lightweight constructions, impact resistance, or thermal stability. Synthetic composites are frequently employed in situations where maintaining uniformity and consistency in attributes is of utmost importance, such as in structural components or high-performance materials. Comprehending the comparative advantages and drawbacks of each composite type is crucial in order to choose the most suitable material for specific purposes.

Whilst both synthetic and hybrid composites are materials designed to have particular qualities, their compositions and production methods are different. hybrid composites are made up of two or more different kinds of materials. Usually, a matrix material, such epoxy or polyester resin, is combined with fibres, like carbon, glass, or aramid. The materials' combination produces a synergistic effect in which every constituent adds special qualities to the composite. Synthetic composites are predominantly composed of polymers or ceramics, which are synthetic materials. While they may incorporate components such as aramid fibres, carbon fibre reinforced polymers (CFRP), or fibreglass, they do not comprise a blend of dissimilar materials as is the case with hybrid composites.

Two categories of composite materials are produced for this current investigation: synthetic composites and Hybrid composites. The chosen materials for constructing the synthetic composite were basalt, coconut coir, and glass fibre. The hybrid composite consists of basalt, coconut coir, and kenaf fibre. Though various methods are available for the production of composites, hand lay-up technique is used to manufacture the specimens for mechanical testing [14]. The hand lay-up technique offers flexibility, simplicity, and affordability, making it suitable for prototyping, custom fabrication, and low-volume production of composite components.

Various mechanical tests, including tensile, compression, flexural, and impact tests, are performed to evaluate the mechanical properties and response of composite materials under different types of loads. The results were compared to determine the optimal outcome.

MATERIALS AND METHODS

Materials

The favourable mechanical qualities and environmental benefits of basalt fibres have attracted attention in composite applications. Some of the notable properties of Basalt fibre are 2.75 g/cm^3 as density, 5.5x10^{-6} co efficient of linear expansion, 600-700ºC as operating temperature range and 0.035 W/mK as Thermal conductivity. Owing of their great tensile strength, basalt fibres can be used to reinforce composite structures. It also contributes to the overall stiffness of composite constructions by providing good stiffness properties. Because of their exceptional resistance to corrosive materials, they can be used in abrasive situations like the chemical processing or maritime sectors [15]. Additionally, it has outstanding thermal stability, meaning that even at high temperatures, its mechanical qualities are retained.

Coconut coir, obtained from the fibrous outer shell of coconuts, has garnered interest as an environmentally-friendly resource for strengthening composites. Coconut coir consists of lengthy, lignocellulosic fibres that provide excellent tensile strength and stiffness. The chemical composition of coconut coir such as Lignin as 45.84%, cellulose 43.44%, Hemi-Cellulose as 0.25%, Pectin as 3.00% and remaining water soluble 5.25% makes the coconut coir to be avialble with desirable properties for composite applications. It possesses notable characteristics such as exceptional durability, low mass, and effortless biodegradability. Coconut coir fibres can be mixed with many types of matrix materials, including thermoset resins like epoxy and polyester, as well as thermoplastic resins, to create composite materials. Coconut coir is a favourable option for enhancing composite materials, offering a blend of favourable mechanical characteristics, sustainability, and cost-efficiency.

Glass fibres are manufactured using many types of glass, including E-glass (electrically insulating glass), S-glass (glass with great strength), and other varieties. These fibres are commonly created by extruding liquefied glass through minuscule apertures to generate uninterrupted strands. The following are the ideal characteristics of glass fibres. These materials have great strength, low density, chemical resistance, and good thermal stability. Some of the notable properties of glass fibres are density as 2.44 g/cm^3, tensile strength of 3300 MPa and elongation percentage as 4.8. Various techniques, including hand layup, filament winding, pultrusion, and resin infusion, can be used to manufacture glass fibres. Glass fibres are a highly adaptable and extensively utilised material for reinforcing composites in manufacturing. They provide a blend of exceptional strength, low weight, and cost efficiency, making them suitable for a wide range of sectors.

Kenaf fibres consist of cellulose, hemicellulose, lignin, and pectin. The fibres are obtained from the outer bark (bast) of the kenaf plant, which is principally cultivated for its fibres. In addition, they exhibit characteristics such as moderate strength, lightweight, low density, and easy biodegradability. Kenaf fibres can be treated using analogous procedures to those employed for other natural fibre composites. The mechanical properties of kenaf are density as 1.4 g/cm^3, tensile strength ranges from 283 to 800 MPa, elongation at failure 1.6%. It also possesses a moisture absorption percentage of 18. Kenaf fibres present a favourable option for strengthening composite materials, offering a blend of satisfactory mechanical characteristics, sustainability, and cost-efficiency.

Epoxy resin is a desirable option for many industrial and commercial applications due to its exceptional adhesion, mechanical strength, chemical resistance, durability, and adaptability. In this current work, epoxy resin is used for the production both synthetic and hybrid composites. Epoxy resins are generally long-lasting, very stable fluids on their own. They are only able to go through the necessary chemical reaction to cure effectively when combined with an epoxy hardener. If the resin was put to a floor without a hardener, it would stay almost liquid forever and not solidify into a long-lasting flooring system [16]. Figure 1 shows the different fibres used for the production of composites for the current investigation.

Methods

The hand layup method is versatile and suitable for producing a wide range of composite parts, from simple flat panels to complex contoured shapes. It offers flexibility in design, low equipment investment, and ease of process control, making it a popular choice for prototyping, small-scale production, and custom fabrication. The hand layup method of producing composite includes the following processes. preparing the mould, cutting the reinforcing fibres, laying them out, using the release agent, applying the resin, consolidation, curing, demoulding, and lastly trimming and finishing. Figure 2 shows the different steps involved in hand layup method. The hybrid composite is made using fibres such as Basalt, Coir, and Kenaf, while the synthetic composite is formed using Basalt, Coir, and Glass Fibre. Figure 3 shows the hybrid and synthetic composite specimens for mechanical testing of the composite materials.

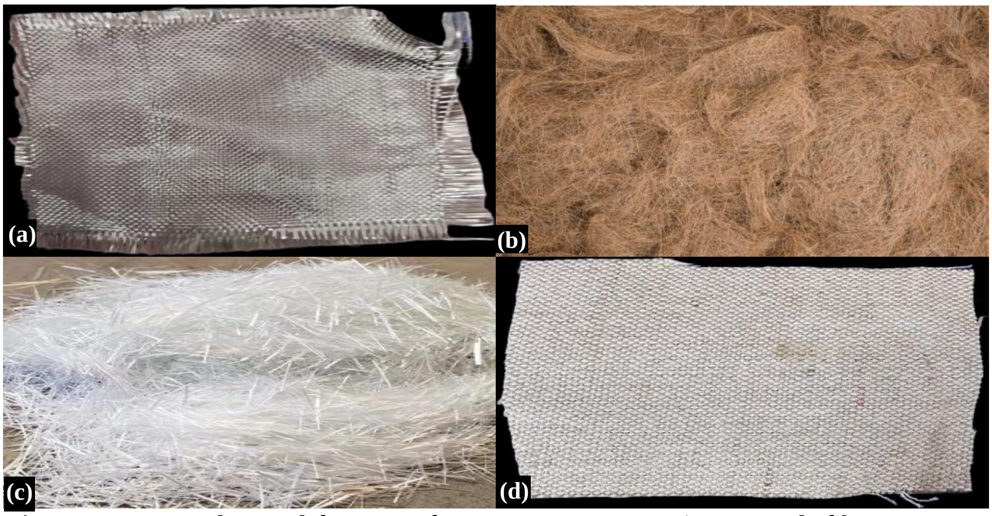

Figure 1. Materials Used for Manufacturing Composite (A – Basalt fibre B – Coconut coir C- Glass fibre D – Kenaf fibre sheet).

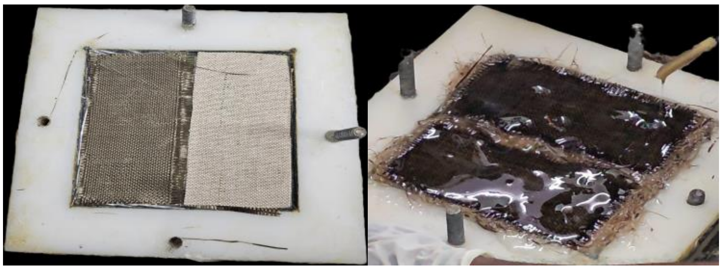

Figure 2. Production of composite by hand layup method.

Figure 3. Hybrid and synthetic composite specimens for mechanical testing.

Tensile, flexural, and impact tests were performed on composite specimens of both types, and the results were compared. The mechanical tests were performed in accordance with the ASTM norms [17-21]. The tensile test was performed according to the ASTM D3039 standard, compression test in ASTM E9, while the flexural test was conducted in accordance with the ASTM D7264 standard. The Izod impact test was carried out following the ASTM D256 standard.

RESULTS AND DISCUSSION

Tensile Test Results

The tensile test was conducted using an FTE universal testing machine, following the ASTM D039 test procedure. The sample had a thickness of 1.6 mm and an initial gauge length of 25 mm. The test findings are organised and presented in Table 1 and in figure 4, which includes data on the ultimate tensile strength and yield stress. After conducting a tensile test on three distinct specimens, the average ultimate tensile strength of the hybrid composite was found to be 23 MPa, whereas the synthetic composite had an average ultimate tensile strength of 27.96 MPa. Therefore, the use of synthetic composite results in a significant improvement of 21.56% in the ultimate tensile strength, surpassing other materials.

Table. 1. Mechanical Test Results.

Materials used	Sample no	Ultimate tensile strength in MPa	Yield Stress in MPa	Compression load in KN	Flexural strength in mPa	Impact strength in kJ/m^2
Hybrid Composite (Basalt + Coconut Coir + Kenaf)	1	23.4	11.6	1.6	41.3	49.7
	2	22.5	10.9	1.9	40.8	45.3
	3	23.1	11.7	1.8	39.7	43.6
Synthetic Composite (Basalt + Coconut Coir + Glass)	1	28.7	15.1	2.3	95.8	81.6
	2	27.5	14.6	2.7	96.7	88.9
	3	27.7	14.3	2.6	97.2	83.4

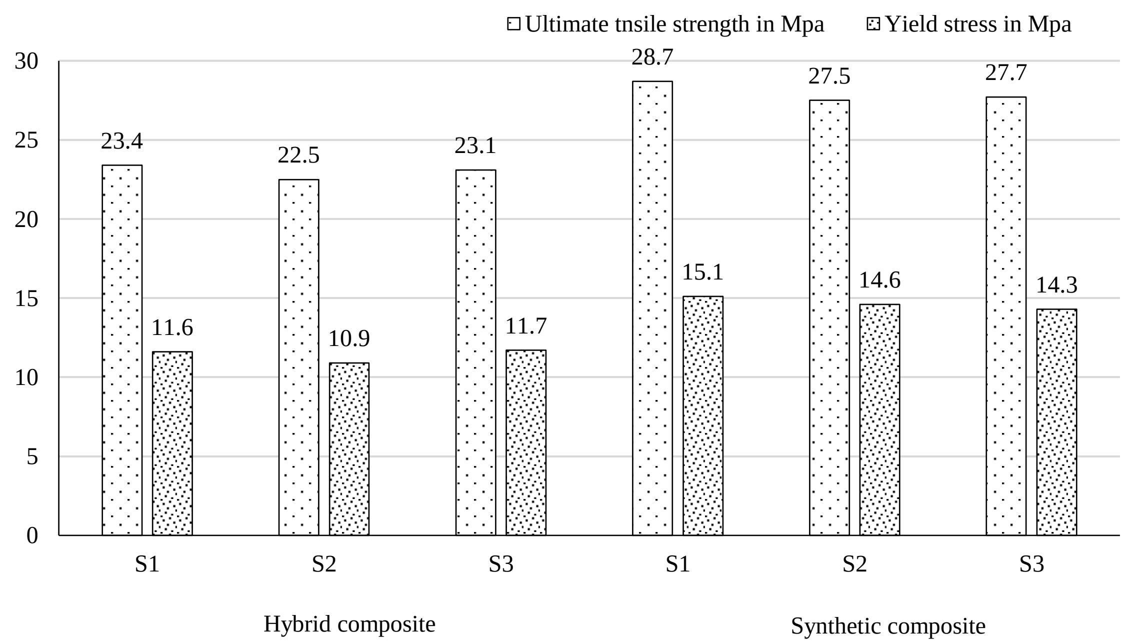

Figure 4. Tensile test results.

Compression Test Results

The compression test was conducted using the same Universal Testing Machine (UTM) and followed the ASTM E9 test procedure. The sample had a thickness of 1.6mm and a gauge length of 50mm. The test results are tabulated in table 1 and shown in Figure 5.

The mean compressive load for hybrid composite is 1.76 kN, while for synthetic composite it is 2.53 kN. The synthetic composite exhibits a superior compression load value of 43.76%.

Flexural Test Results

The flexural strength was measured in accordance with the ASTM D7264 norms and the results are tabulated in Table 1. As shown in Figure 6, the hybrid composite has an average flexural strength of 40.6 MPa, while the synthetic composite has an average flexural strength of 96.56 MPa. The synthetic composite demonstrates significantly greater performance, with a remarkable 137% increase in flexural property.

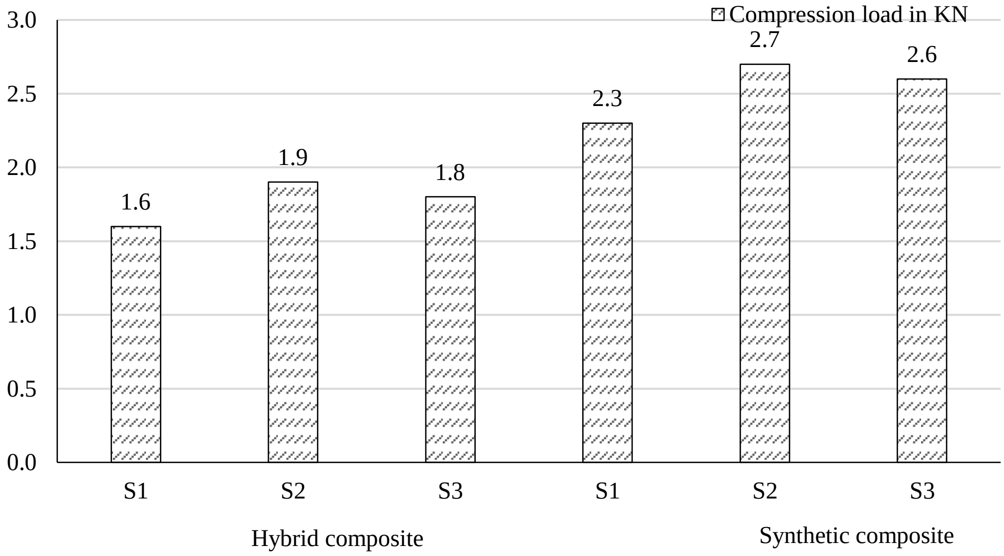

Figure 5. Compression test results.

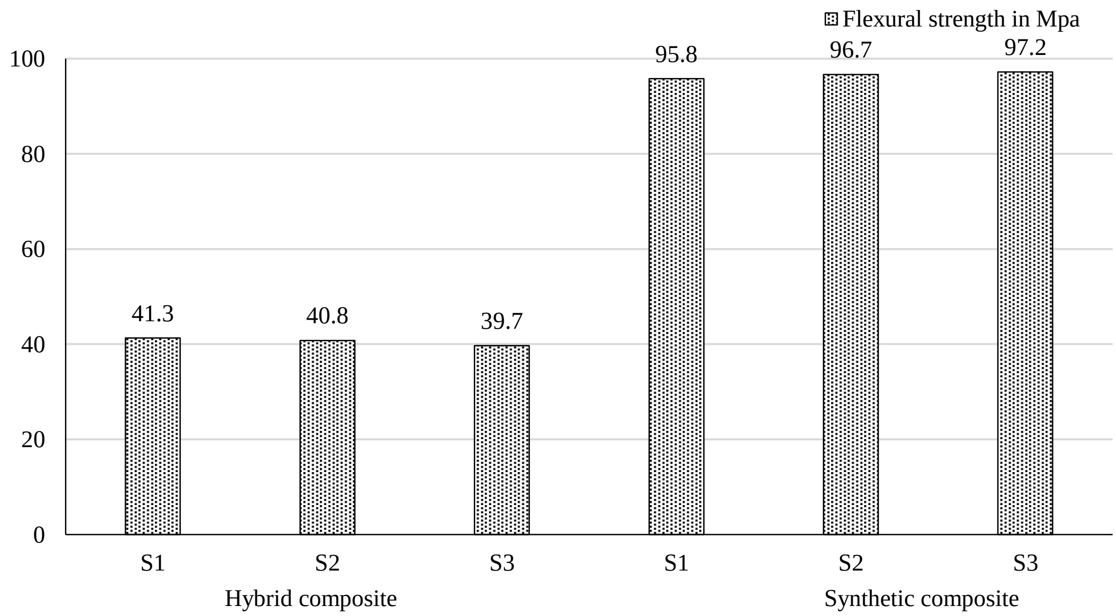

Figure 6. Flexural test results.

Impact Test Results

The impact test was experimented in a MCS make pendulum type impact testing machine model MIT-30 in ASTM D256 standard. The impact strength of the various specimens is tabulated in table 1. From figure 7, the mean impact strength of the hybrid composite is 46.2 MPa, while that of the synthetic composite is 84.64 MPa. Similar to the previous test findings, the synthetic composite exhibited an overall increase of 83% in impact strength.

Microscopic Examination

Figure 8 depicts the microscopic image of synthetic composite material. The resolution of the microscopic images was taken in 100X magnification. It is evident that the fiber distribution is uniform and consistent orientation is observed. There is no porosity or voids observed due to the thorough mixing of resin, resulting in good adhesion at the interface of the matrix and reinforcement materials. Figure 9 shows the microscopic image of hybrid composite material. It is clear that the homogeneity of the polymer is achieved through uniform dispersion of reinforcements. This is due to the rich resin areas at the interface of the matrix material and the reinforcements, which helps to eliminate localized stress concentrations and influences the mechanical properties [22-24]. No delamination or layer misalignment is observed, resulting in good bonding between the matrix and the reinforcement.

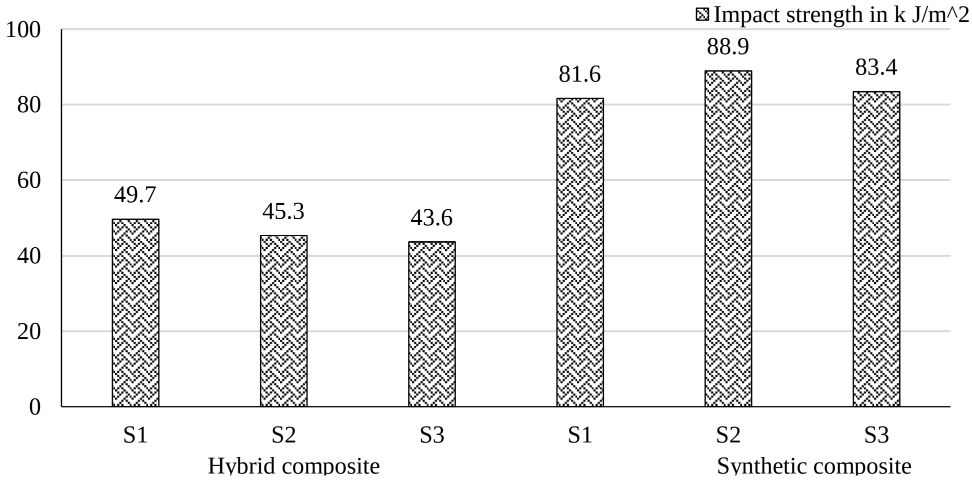

Figure 7. Impact test results.

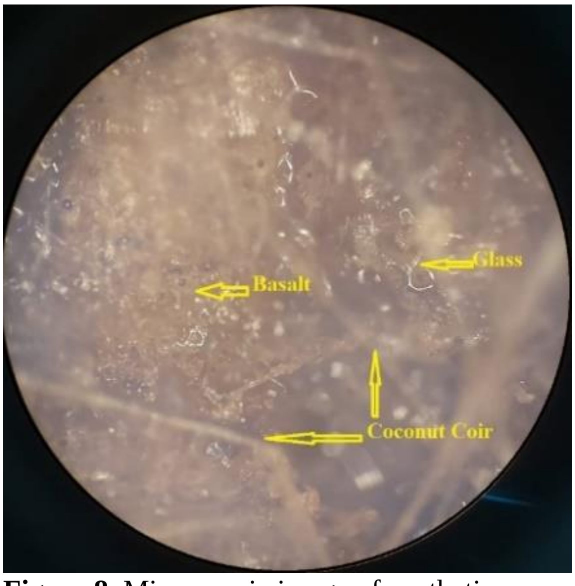

Figure 8. Microscopic image of synthetic composite material.

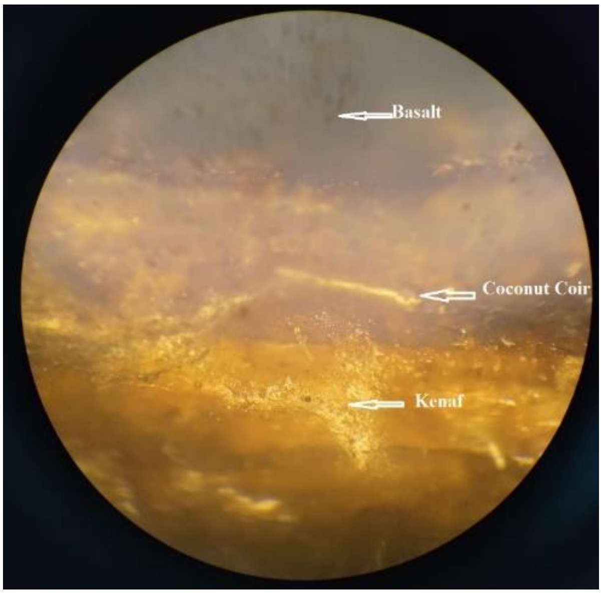

Figure 9. Microscopic image of Hybrid composite material.

CONCLUSIONS

Our investigations indicates that synthetic composite materials provide superior performance compared to hybrid composites in several mechanical tests, such as tensile, compression, flexural, and impact strength. The synthetic composite exhibits significant improvement of 21.56% in the ultimate tensile strength, greater compression load value of 43.76%, a notable 137% increase in flexural property, overall increase of 83% in impact strength. This demonstrates that synthetic composites have superior mechanical properties overall when compared to hybrid composites. The ramifications of these studies are substantial for a range of businesses, especially in the fields of engineering and materials science, where the creation of high-performance materials is of utmost importance. Additional research is necessary to examine the precise structural and compositional elements that contribute to the observed variations. This will help improve the design and use of synthetic composites in various real-life situations. The superiority of synthetic composites highlights its capacity to propel developments in materials engineering and enable the development of more long-lasting, efficient, and groundbreaking goods.

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