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# Evaluation of properties of hybrid laminated composites with different fiber layers based on Coir/$Al_2O_3$ reinforced composites for structural application

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A R T I C L E I N F O

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A B S T R A C T

Hybrid composites produced using natural and synthetic fibers are sustainable alternative materials for different structural applications. Therefore, this study aimed to incorporate coir fiber, E-glass, synthetic fabric, and rubber sheet into epoxy matrix by adding alumina filler to the coir composite. The hand layup method was used to manufacture a hybrid laminates composite of coir/E-glass/synthetic fabric/rubber sheet with different stacking sequences. The tensile, flexural, impact, hardness properties, water absorption, and thickness swelling of the products were evaluated. Scanning electron microscopy was used to study the morphology of the fractured surfaces. The results showed that the hybridization fiber and filler can enhance the tensile properties of the products up to 280% as well as improve the water absorption performance and thickness swelling to 78%. The flexural properties decreased after the incorporation of the fiber layer to the coir/alumina composite. An increase was also observed in the flexural and impact properties after the synthetic fabric was replaced with a rubber sheet. This study revealed that the incorporation of fibers layers into a coir composite led to higher hardness resistance. Furthermore, SEM image and macroscopic fractography showed fiber breakage on the matrix, a brittle fracture of composites, and delamination failure between the rubber sheet and matrix during the bending test. Based on the results, coir/E-glass/synthetic fabric/rubber sheet hybrid composites with different layering sequences were appropriate for various structures applications.

## 1. Introduction

The world currently requires environmentally friendly materials for various applications. Consequently, several studies developed polymer composites based on natural fibers and combined them with synthetic fibers as a sustainable alternative material for various structural applications in engineering [1,2]. Natural fiber composites have been used for various purposes due to their advantages over the synthetic type, such as low density, low cost, biodegradability, minimum waste disposal problems, and environmental friendliness [3]. However, they have some disadvantages in their practical applications, including high moisture absorption, poor compatibility characteristics, as well as low mechanical properties, durability, and thermal stability at higher temperatures. Hybridizing natural and synthetic fibers within the same matrix is one of the promising strategies that can be used to overcome these problems [4]. Synthetic fibers have excellent mechanical and physical properties, as well as compatibility with polymer matrices. They are also very effective at mitigating the drawbacks of the natural type [5]. Several studies reported the use of synthetic fibers, such as kevlar, aramid, and glass in combination with natural variants, including basalt, ramie, and jute, for layering sequence as well as to improve the mechanical properties [6,7].

Over the past few years, several studies explored the effect of hybridization on the mechanical and physical properties of hybrid laminated composites. Hybrid laminated composites provide different ways of designing materials with superior mechanical properties, lightweight, moisture resistance, and cost-reduction advantages [8,9]. Previous studies also published some of these products, such as sisal/jute/glass [10,11], bagasse/jute [7,12], jute/ramie [13], PALF/kevlar/hemp/glass [14], cotton/bamboo [15], flax/basalt/glass [16,17], and rayon textile [18]. Although there are still no alternative materials to replace conventional fibers in real-time applications, hybridization of

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natural/synthetic variants can reduce the body weight of the material, and the costs. Therefore, the optimization approach is very important for the production of hybrid laminated composites, which involves optimizing the design variables, objective functions, constraints, and algorithms [19].

Apart from being influenced by fiber type and hybridization of natural/synthetic fibers, the characteristics of polymer composites are also affected by fillers. Several studies revealed that the addition of appropriate fillers can increase the matrix's effectiveness. Arpitha et al. [20] developed polymer composites by combining natural and synthetic fibers with the addition of silicon carbide. The results showed that silicon carbide fillers can reduce voids and improve the product's physical properties. Furthermore, several studies explored the addition of fillers to fiber composites. The mechanical, physical, tribological, thermal, and dimensional stability properties of the products have been widely investigated [21–25]. Previous studies also carried out experimental tests on the characteristics of hybrid composites with various types of fillers, such as the inorganic types for applications in high-performance materials [26], the effect of alumina nanofiller in basalt/epoxy composites [25], and influence of graphene powder on banyan aerial root fibers reinforced epoxy composites [27]. Other studies included the development of hybrid composites containing carbon fiber, natural fiber, and fish bone nanofiller for different application [28], as well as production of jute fiber polyester composites with eggshell powder/nano clay as fillers [29]. The results showed that the addition of nanofillers can affect mechanical properties, improve physical qualities and dimensional stability, increase wear resistance, and delay thermal degradation.

Coir is a natural fiber, which can serve as an alternative for synthetic fibers to reinforcement in composites. Similar with other natural fibers, it has several advantages over the synthetic variants, such as low density, low cost, high degree of flexibility, non-toxic, biodegradable, and recyclable [30]. Previous studies also investigated the mechanical and physical properties of the coir/synthetic fiber-reinforced hybrid laminated composites. The construction of the products was also evaluated, such as the amount and layering sequence of fibers affecting their properties. Mittal et al. [31], evaluated the mechanical and physical properties of 3-layer hyrid laminated composite coir/glass. The results showed that the product exhibited resistance to the water molecules and it had a higher impact strength than PALF/glass composite. Silva et al. [32], produced three hybrid laminated reinforcements, namely sisal/glass, luffa/glass, and coir/glass. The products were made of a five-layer laminate with two layers of natural fibers, such as sisal, coir, or Luffa sponge in between the three layers of E-glass. Coir/glass composites have higher tensile strength than hybrid luffa/glass. Wei et al. [33], investigated the mechanical performance of coir/rubber-reinforced hybrid laminated composites, which were compressed under a pressure of 15 MPa for 20 min. Subsequently, the tensile strength was evaluated under a temperature range of 130 °C–160 °C. The results showed that there were only slight changes in the tensile properties from 138.8 to 145.3 MPa. This indicates that it was not affected by the change in temperature.

Several studies focused mainly on using natural and glass fibers as well as the stacking sequences of the fiber mat. However, no study examined the mechanical and physical properties of hybrid laminated composites reinforced with coir/glass fiber/synthetic fabrics/rubber sheets. It is important to review the use of synthetic fabrics and rubber sheets as additional reinforcement because they can improve these characteristics. In this study, the hybrid laminated composites were made of coir + alumina/glass fiber/synthetic fabric/rubber sheet to evaluate their physical and mechanical properties. The product was manufactured with different numbers of layers and stacking. Various analyses were also carried out to evaluate the tensile strength, flexural properties, impact strength, hardness, water absorption, thickness swelling properties, and fracture behavior.

## 2. Materials and methods

### 2.1. Materials

In this study, the hybrid laminated composites were reinforced with coir, E-glass, and rubber sheet, while epoxy resin served as the matrix. The coir fiber was collected from the agricultural field of Aceh, Indonesia, while the rubber sheets and fabric were bought from the local market. Furthermore, E-glass (chopped strand mat) were supplied by Euro Chemo-Pharma Sdn. Bhd, Penang, Malaysia. The epoxy resin Eposchon A (Bisphenol A-epichlorohhydrin) and epoxy hardener Eposchon B (polyaminoamide) were provided by Justus Kimia Raya-Medan, Indonesia. The alumina powder ($Al_2O_3$) used as filler were bought from Labchem Sdn. Bhd, Selangor, Malaysia. Properties of coir, E-glass, fabric, rubber, and alumina are presented in Table 1.

### 2.2. Pretreatment of coir fiber

The characterization of natural fibers for producing composite structures depends on the preparation and processing methods. Furthermore, the appropriate use of suitable chemical and surface treatment can improve their characteristics [37,38]. Several studies used NaOH to modify natural fibers, and the results showed increased interfacial bonding with the matrix [39–41]. In this study, the coir fiber pre-treatment began with selection and cutting of the samples into diameter and length of <0.5 mm and 10–20 mm, respectively. The sample was pretreated by boiling in a 5% NaOH solution at 80 °C for 10 min. The fibrillation process was then semi-mechanically carried out using a high-speed blender. The coir fiber was blended at 20000 rpm for 10 min to reduce the diameter. The fibrillated fibers were then washed with distilled water and dried for three days before fabrication of the samples [42].

### 2.3. Production of hybrid laminated composites

The hand lay-up technique followed by static load compression was used to produce the hybrid laminated composites. The molding (250 × 250 × 14 mm) was used to manufacture composites of a matrix, reinforcement, and filler material. Two control, namely C1 and C2 as well as three different types of hybrid laminated composite were produced, as shown in Table 2. The first type, namely HL-1, consists of 3 layers, including coir + alumina + epoxy, E-glass, and rubber sheet, sequentially. The second type, HL-2 contains 3 layers, namely coir + alumina + epoxy, E-glass, and synthetic fabric. Furthermore, the third type, HL-3, consists of 4 layers, including coir + alumina + epoxy, E-glass, synthetic fabric, and rubber sheet. The first layer of the composites, namely coir fiber + alumina + epoxy, contains coir and epoxy in a ratio of 30:70 as well as alumina filler, which is equivalent to 5% of the epoxy weight. The matrix was produced by mixing epoxy resin and amine hardener in a ratio of 2:1. The hybrid composite layering sequences are shown in Fig. 1.

### 2.4. Physical testings

#### 2.4.1. Density testing

The density of the hybrid laminated composites was determined using the ASTM D792 standard [43]. The specimens were cut with a dimension of 50 × 50xt mm squares, after which all the specimens were pre-conditioned until they reached a constant mass before being tested at 25$^{O}$C. A total of five specimens of each variant composites were prepared and then tested. Furthermore, the density was calculated using the formula in Equation (1).

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}\left(\frac{\text{g}}{\text{cm}^3}\right) \tag{1}$$

**Table 1**
Properties of hybrid laminate composite reinforcement fibers.

| Description | Epoxy | Coir [34] | E-glass [35] | Rubber | Synthetic Fabric | $Al_2O_3$ [36] |
|---|---|---|---|---|---|---|
| Density (kg/m$^3$) | 1100–1160 | 1250–1500 | 2560 | 925–975 | 820 | 3950 |
| Tensile strength (MPa) | 26,44–27.24 | 105–175 | 1700–3500 | 2–4 | 20 | 660 |
| Elastic Modulus (GPa) | 0.8–1.1 | 4–6 | 66–72 | 0.01–0.03 | 0.185 | 380 |

**Table 2**
Configuration of manufactured hybrid laminated composites.

| Type | Laminated configuration |
|---|---|
| C1 | Epoxy matrix |
| C2 | coir + $Al_2O_3$+epoxy |
| HL1 | (coir + alumina + epoxy) + E-glass + rubber sheet |
| HL2 | (coir + alumina + epoxy) + E-glass + synthetic fabric |
| HL3 | (coir + alumina + epoxy) + E-glass + synthetic fabric + rubber sheet |

#### *2.4.2. Water absorption and thickness swelling testing*

The water absorption (WA) and thickness swelling (TS) test for hybrid laminate composites was carried out using the standard test method of ASTM D570-98 [44]. The five prepared samples of each hybrid laminated composite were cut into dimensions of 20 mm × 20 mm × 10 mm, followed by drying in the oven at 50 °C for 30 min. Before immersion, they were weighed, and then soaked in water for 30 days. Every five days, the samples were taken out, and water was wiped off the surface, followed by weighing. The weight of the samples was continually measured until the saturation threshold absorption was attained. The percentage of absorbed water was calculated using Equation (2).

$$\text{Water absorption }(\%) = \left(\frac{\text{wet weight} - \text{conditioned weight}}{\text{conditioned weight}}\right) \tag{2}$$

The influence of water absorption on the dimensional changes of the composite samples while they are submerged in water for a specified period was studied using the thickness swelling test. The sample for the water absorption test was also used, and it was measured every five days up to 30 days. The percentage of thickness swelling was calculated using Equation (3).

$$\text{Thickness swelling }\quad(\%) = \left(\frac{\text{wet thickness} - \text{conditioned thickness}}{\text{conditioned thickness}}\right) \tag{3}$$

### *2.5. Mechanical testings*

#### *2.5.1. Tensile testing*

The tensile properties of hybrid laminated composites were determined based on tensile strength. The sample was cut into rectangular strips using the ASTM standard D3039 [45] with a dimension of 250 × 25 mm x actual thickness for each type of composite. Tensile tests were carried out in a Tensilon Universal Testing Instrument Model RTF 1350 (Japan) at a crosshead speed of 2 mm/min. The five samples were prepared for each variant, after which the average breaking load and ultimate tensile strength were recorded. Tensile tests were performed at room temperature with a humidity level of 50–60%.

#### *2.5.2. Flexural testing*

The flexural characteristics of the hybrid laminated composites were tested using the 3-point bending method using ASTM D790 [46] with the Tensilon Universal Testing Instrument Model RTF 1350 (Japan). The five samples with dimension of 165 × 12.7 × 10 mm were used for each hybrid laminate composite type. Furthermore, the span used was 120 mm with a crosshead displacement rate of 2 mm/min, and tests were carried out at room temperature. The MOR of the hybrid laminated composites was determined using Equation (4).

$$\text{MOR (MPa)} = \frac{3PL}{2bd^2} \tag{4}$$

where P is the load, L is the support load, b is the width, and d is the depth of samples.

#### *2.5.3. Impact testing*

The impact test was performed using the Pendulum Impact Charpy Testers Model Matest (in Italy). The Charpy impact test was carried out using the ASTM D6110-02 standard [47]. The five samples of each type of hybrid laminate composite were prepared with a dimension of 125 × 12.7 × 12.7 mm, with 2 mm V-notch depth and an angle of 45°. The energy taken to break the samples and the toughness of the composites can be recorded.

#### *2.5.4. Hardness testing*

The hardness tests were carried out using Digital Durometers Shore D Hardness Tester (China) by pressing a cone indentor into a sample of hybrid laminated composite. The testing was performed by following ISO 868 [48] and ASTM D2240 [49]. Each sample has six test sites on both sides and it was carried out at regular intervals at 10 mm from the edge of the specimen.

### *2.6. Morphological characterization*

The morphological characterization of hybrid laminated composites was identified using a scanning electron microscope (SEM) model Quanta FEG 650, Germany. Furthermore, the morphological micrographs were obtained under conventional secondary electron imaging conditions using 15 kV of acceleration tension and magnification of 200×. The samples were coated with gold by sputtering and then mounted on aluminum holders using double-sided before SEM analysis.

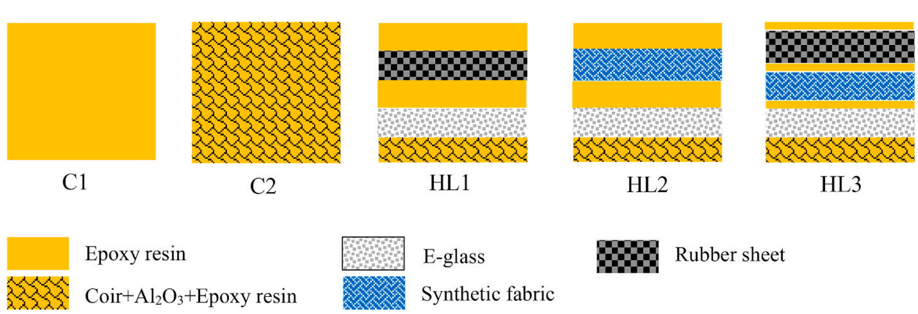


**Fig. 1.** Illustration of hybrid laminated composites configuration.

## 3. Result and discussion

### 3.1. Density of hybrid laminated composites

Table 3 shows the density of hybrid laminated composites compared to the control sample, namely pure epoxy resin and coir composite with alumina filler. The result showed that the products have a higher density compared to the control. The density of the composite ranged from 1090 to 1190 kg/cm$^3$, where the highest and lowest were obtained from HL3 and C1, respectively.

The difference in the density of the raw materials affected hybrid laminated composites. The number of fiber layers also influenced the value obtained for the product. The density of hybrid laminated composites improved as the number of fiber layers increased, and it was also affected by the type of fiber used [50]. The hybridization of different types of fibers and the composition of the layers inside a matrix provided a more acceptable degree of customization of the product qualities. These findings helped in the selection of materials for construction in composite technology.

### 3.2. Water absorption and thickness swelling properties

Water absorption can affect the fiber-matrix interface and the composites' structure. It also correlates with bulk properties, such as dimensional stability and mechanical properties. Fig. 2 shows the percentage of water absorbed by pure epoxy and hybrid laminated composites after immersion for 30 days. The water absorption in the samples increased significantly from day 1–5, followed by a gradual approach to the saturation point on day 10, after which no water was absorbed until 30 days. The HL3 sample of hybrid laminated composites has a higher absorption capacity, while the C1 sample had the lowest. The composites absorbed 2.05%–2.35% water after being immersed for ten days, namely HL3 (2.35%) > HL2 (2.25%) > HL1 (2.05%) > C2 (1.99%) > C1 (1.84%).

A similar trend was obtained by previous studies, which measured water absorption on laminated epoxy composites woven jute/ramie [13]. However, the results of this study showed better water resistance performance using natural fiber layers. This indicates that the content of natural fiber made the water penetration easier in the composite due to its hydrophilic nature.

The hybrid laminated composites showed a greater tendency for water absorption than the pure epoxy variant. This study revealed that the water uptake of the products increased with the number of fiber layers. As the reinforcing layer increases, the number of fibers exposed to water due to specimen cutting also increases, thereby leading to more uptake. This can also be attributed to the layer's poor structure, where the fiber layer–matrix interfacial bonding led to the formation of microchannels. Furthermore, the performance absorption of the HL2 sample with synthetic fabric loading was higher than HL1 with rubber sheet, at 0.20%. This finding indicates that synthetic fabric has more absorption performance than rubber sheets.

The thickness swelling performance is related to the dimensional stability properties of the hybrid laminated composites. For a certain period of immersion, it was affected by the amount of absorbed water. Fig. 2 shows that the thickness swelling of the products increased with water absorption. However, its effect was lower compared to the weight

**Table 3**
Physical properties of hybrid laminate composites.

| Type Composites | Density (kg/m$^3$) | $WA_{Saturation}$ (%) | $TS_{Saturation}$ (%) |
|---|---|---|---|
| C1 | 1090 | 1.84 | 0.70 |
| C2 | 1120 | 1.99 | 0.73 |
| HL1 | 1150 | 2.05 | 0.75 |
| HL2 | 1140 | 2.25 | 0.83 |
| HL3 | 1190 | 2.35 | 0.93 |

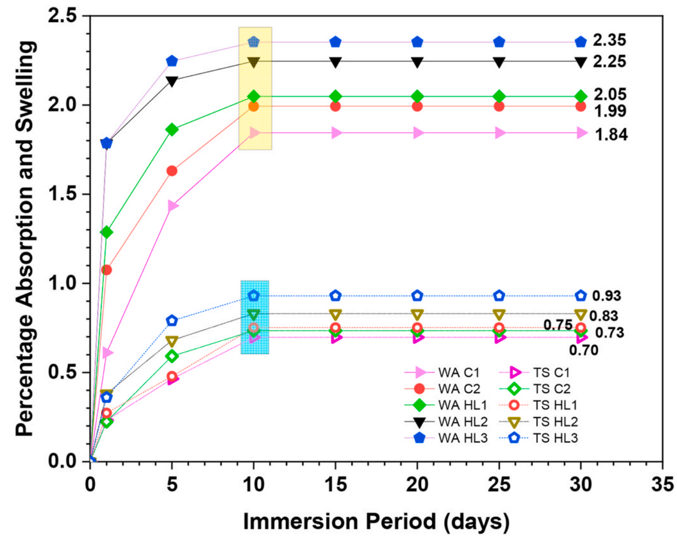


**Fig. 2.** WS and TS of hybrid laminated composites with different type.

increment due to moisture uptake. Low thickness swelling can be attributed to the softening impact of water molecules, which decreases the stiffness of the fiber structure. The samples of hybrid laminated composites expand in the horizontal and vertical direction when immersed in water [51]. Water can act as a plasticizer, and its absorption by fiber can affect the composites' mechanical properties.

Fig. 2 shows that the thickness swelling of pure and hybrid laminated composites increased significantly between day 1 and 10, after which it flattened from day 10. This study revealed that the highest value of 0.93% was obtained from the HL3 sample. The difference in the number of layers and the type of fiber affected the value obtained. Hybrid laminated composites with less fiber layer content can reduce thickness swelling. The lowest dimension change rate of the pure epoxy sample occurred during immersion. This is because epoxy is hydrophobic, which makes it resistant to water. This study's results showed that increasing the number of reinforcing layers affected the water resistance and dimensions of hybrid laminated composites, where the resin was not efficient in completely covering the fiber. This further led to the formation of cavities within the composites. The composite laminate hybrid produced better water absorption resistance and thickness swelling compared to the glass/jute fiber reinforced hybrid composite [52].

### 3.3. Mechanical properties

#### 3.3.1. Tensile and flexural properties

Fig. 3a and b shows the typical load vs displacement curves of hybrid laminated composites' tensile and flexural properties. The loads to the tensile were greater, while the displacement of flexural was higher. Furthermore, the tensile and flexural strength properties of pure epoxy and hybrid laminated composites were evaluated in this study. Both properties were determined based on the maximum stress the sample can withstand until failure occurs.

The tensile and flexural strength of hybrid laminated composites with different layering sequences were shown in Fig. 4. The HL3 sample had the highest tensile strength of 76.03 MPa, followed by HL2, HL1, and C2 with values of 64.56, 60.47, and 53.70 MPa, respectively. Compared to hybrid laminated composites, the value obtained for pure epoxy composites was lower at 26.84 MPa due to the lack of reinforcement. The tensile strength of C2, 53.70 MPa, was better than that of the coir-reinforced hybrid composite with an epoxy matrix, namely 28.7 MPa [53].

Furthermore, increasing the number of fiber layers in the matrix improved the tensile properties of the composites. In this study, 3-layer

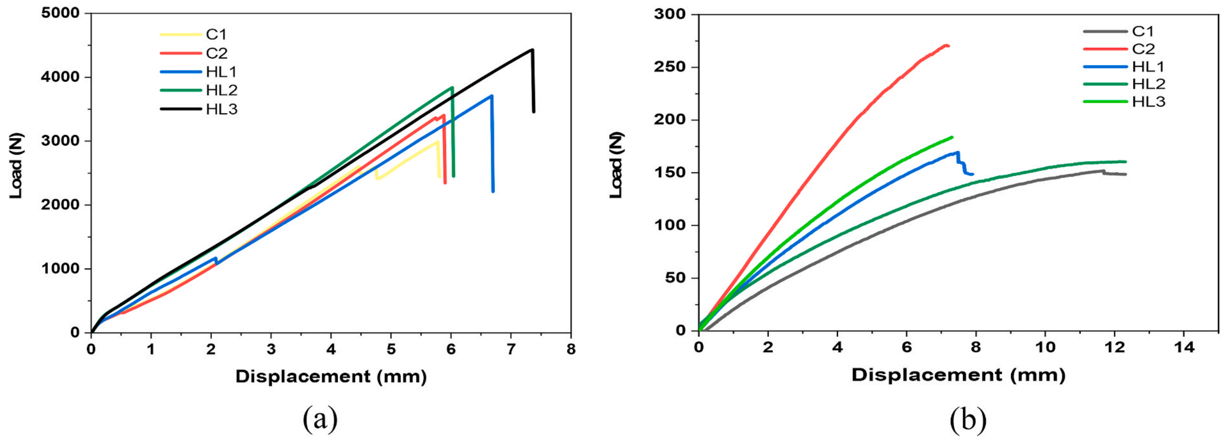


**Fig. 3.** Load vs diplacement of hybrid laminated composite
(a) Tensile test and (b) Flexural test.

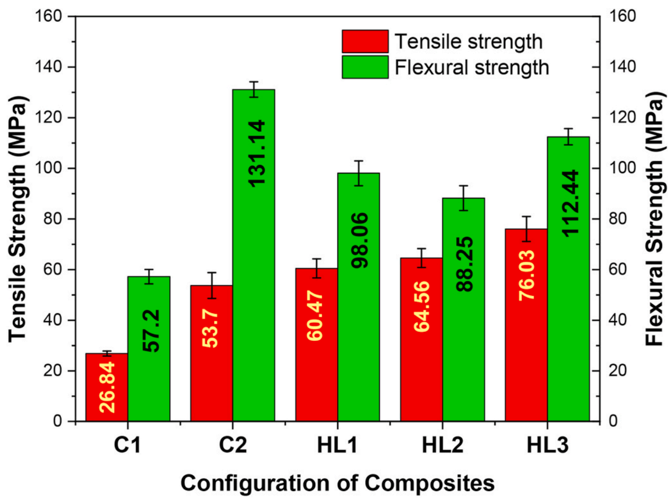


**Fig. 4.** Tensile and flexural strength of hybrid laminated composite laminates.

and 4-layer composites with different fiber content were evaluated. Based on the result, the average tensile strength of the 4-layer sample (HL3) was higher than the 3-layer (HL2 and HL1). This finding showed that the type and number of layering also plays an essential role in influencing the tensile strength. The higher value obtained in the 4-layer sample was due to the incorporation of synthetic and rubber layers, which led to better reinforcement. The large number of fiber layers helps to absorb stresses and distribute them evenly. When it was compared to the proposed hybrid laminated composite, the results were better than the composites containing coir/synthetic fiber 5-layers [31,32], and their tensile strength were 52.00 MPa and 48.9 MPa, respectively.

The flexural characteristic test was carried out to determine the ability of the hybrid laminated composites to withstand bending forces by measuring flexural strength. Fig. 4 shows the mean flexural strength for the various hybrid laminated and pure epoxy composites. In this study, the C1 sample had the lowest value of 57.20 MPa, while the coir/alumina composites, namely C2 had the highest of 131.14 MPa. The fiber layer in the hybrid laminated composites is expected to increase crack propagation due to higher interlayer delamination.

The hybridization of E-glass, synthetic fabric, and rubber sheets with coir/alumina hybrid laminated composite (HL3) performed better than the E-glass/synthetic fabrics or E-glass/rubber sheet with coir/alumina composites (HL1 and HL2). The HL1 and HL2 samples had an average flexural strength of 98.06 MPa and 88.25 MPa, respectively, while a value of 112.44 MPa was recorded for HL3. These results indicate that the number of fiber layers positively increased the flexural strength performance of the hybrid laminated composite. Furthermore, incorporating high-strength and elastic fibers into the composite layer gave better flexural and impact resistance [16]. The type, sequence, and number of fiber layers also play an important role as the main load-carrying element of the sample.

Fig. 5 shows the tensile and flexural modulus of the hybrid laminated composite laminates, where the highest values were 2.82 GPa (HL3 sample) and 7.61 GPa (C2 sample), respectively. The results showed that the use of some fiber layers improved tensile modulus properties, while flexural modulus decreased when a synthetic fabric was used to replace the rubber layer. Furthermore, the alumina filler can have a positive effect on enhancing the both parameters. Similar findings were obtained from a previous study [25], where the basalt/epoxy composite's flexural properties improved after the addition of alumina nanofillers with a small percentage.

### 3.3.2. Charpy impact properties

A Charpy impact test was carried out to investigate the energy absorption capability of the hybrid laminated composites reinforced with different fiber layers. The impact strength was calculated by dividing the recorded absorbed impact energy by the cross-section area. The HL3 sample had the highest value of 58.02 kJ/m$^2$, followed by HL1 and HL2 with 50.62 and 41.13 kJ/m$^2$, respectively. C2 had an impact strength of 18.43 kJ/m$^2$, and the pure epoxy sample, namely C1 had the lowest of

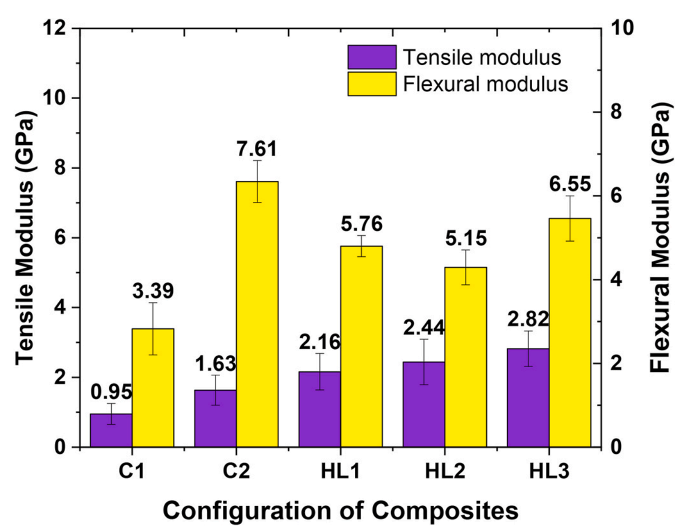


**Fig. 5.** Tensile and flexural modulus of hybrid laminated composite.

10.09 kJ/m$^2$. The hybridization of fiber layers significantly increased the impact strength of the composite by 50%. Fibers play a significant role in impact resistance, as they interact with the formation of cracks within the matrix and serve as stress transfer mechanisms. These findings have a better impact strength of up to 58.02 kJ/m$^2$, which is relative to coir/carbon/epoxy resin composites [34].

The 4-layer sample, namely HL3 had a higher impact strength than the 3-layer, HL1 and HL2. In the 3-layer composite, the sample with a rubber sheet had better impact properties than the sample with the synthetic fabric layer. This was because rubber sheets have a higher ductility than synthetic fabric. This study's result showed that the impact properties of hybrid laminated composite materials were influenced by the structure of the constituent materials, the stacking, and the number of layers. Fig. 6 depicts how impact strength relates to the composites' tensile and flexural strength. The impact strength performance of hybrid laminated composites was directly proportional to the tensile strength, but not to the flexural properties.

#### 3.3.3. Shore-D hardness

The hardness test showed that HL3 had the highest shore-D hardness of 84.90, followed by HL2, HL1, C2, and epoxy with values of 84.62, 83.10, 81.70, and 78.20, respectively. In this study, the shore-D hardness performance of composites epoxy increased linearly with the tensile strength of hybrid laminated products. This result showed that hybridization affected the hardness value. The relationship between shore-D hardness and tensile strength is presented in Fig. 7. This product has a better shore-D hardness compared to the banyan aerial root fibers epoxy composite with graphene powder as a filler [27]. Furthermore, when hybrid laminated composites are compared with some product applications, they are categorized in the extra hard level, as shown in Fig. 8.

### 3.4. Fractography analysis

Fig. 9 shows an SEM image and macroscopic fractography of hybrid laminated composites. Meanwhile, Fig. 9a shows an SEM image of a fractography of coir fiber/epoxy hybrid composite with alumina filler after mechanical testing. The results showed that the coir fibers broke from the matrix, which indicates a good fiber-matrix interface bonding. The fiber–matrix interface affects the mechanical properties of composites. A good stress transfer between fibers and matrix can lead to higher mechanical properties of the product [9]. Fig. 9b shows the image of the fractured cross-section of hybrid laminated composites after the tensile test. The image was characterized by matrix failure and a break of

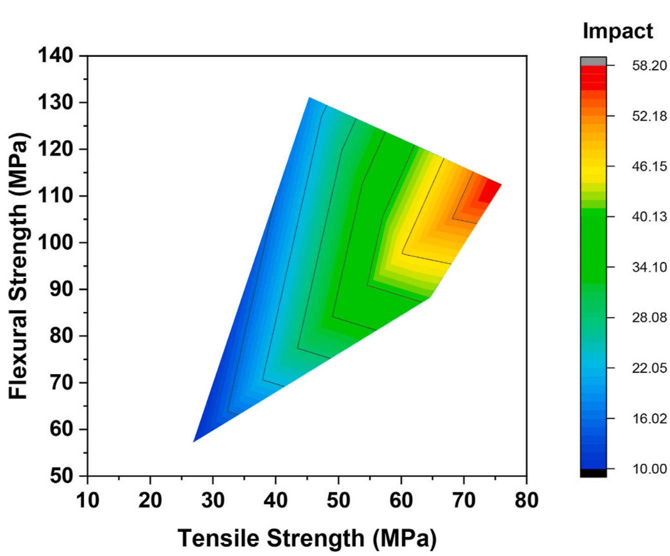


**Fig. 6.** Relationship impact strengths, tensile and flexural strength of hybrid laminated composites.

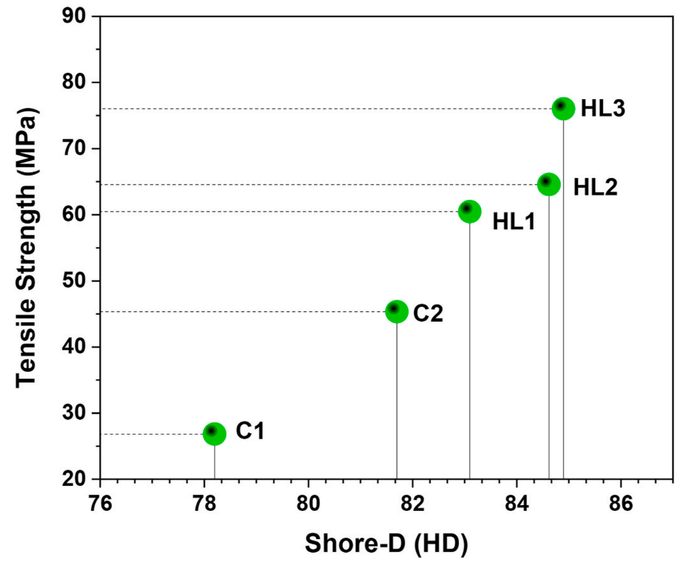


**Fig. 7.** Correspondence hardness and tensile strength of hybrid laminated composites.

the E-glass and synthetic fibers. Based on the fracture type, the hybrid laminated composite has a brittle behavior. Furthermore, Fig. 9c shows the brittle behavior and delamination of the product, which was visible between the matrix and the rubber layer. The delamination and cracking on the surfaces indicated poor interfacial bonding between the epoxy and rubber sheets. During impact testing, brittle fracture behavior was also observed in the hybrid laminated composite. This characteristic is comparable to the tensile test, as shown in Fig. 9d.

## 4. Conclusions

The physical and mechanical properties, such as hardness, water absorption, thickness swelling, as well as tensile, flexural, and impact strength of hybrid laminated composites with coir/E-glass/synthetic fabric/rubber sheet as the reinforcement were evaluated in this study. Combining synthetic, rubber, and glass fiber layers in coir epoxy composites can enhance mechanical properties. Furthermore, the HL3 sample had higher tensile strength of 76.03 MPa compared to HL2 and HL1. The C2 sample also exhibited higher flexural properties (131.14 MPa) than others. HL3 sample showed the highest impact strength of 58.02 kJ/m$^2$, followed by HL1 and HL2, while C1 had the lowest. The shore-D hardness value of hybrid laminated composites correlated linearly with the tensile properties. The water absorption performance ranged from 1.84 to 2.35%, while pure epoxy composites performed better than the hybrid laminated variant. The products showed brittle behavior with the failure patterns of delamination and fiber breakage. Delamination between the rubber sheet and matrix epoxy was the dominant failure mechanism during bending. This indicated the existence of poor interfacial bonding in these composites. The products developed can be used as an alternative to pure natural or synthetic fiber composites for various structural applications.

## Credit author statement

Iskandar Hasanuddin: Data Curation, Writing-Reviewing Draft. Indra Mawardi: Conceptualization, Methodology, Writing-Original Draft Preparation, Supervision. Nurdin: Visualization, Investigation. Ramadhansyah Putra Jaya: Writing-Reviewing, Validation, and Editing.

## Declaration of competing interest

The authors declare that they have no known competing financial

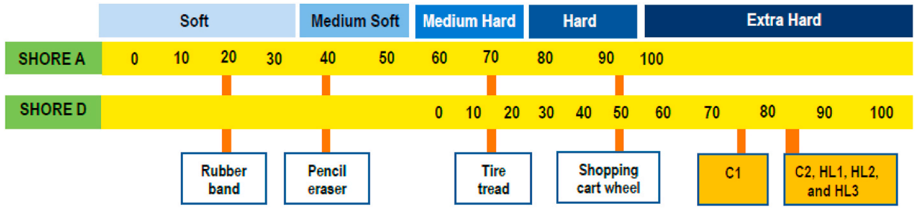


**Fig. 8.** Comparison hardness of hybrid laminated composites and application product.

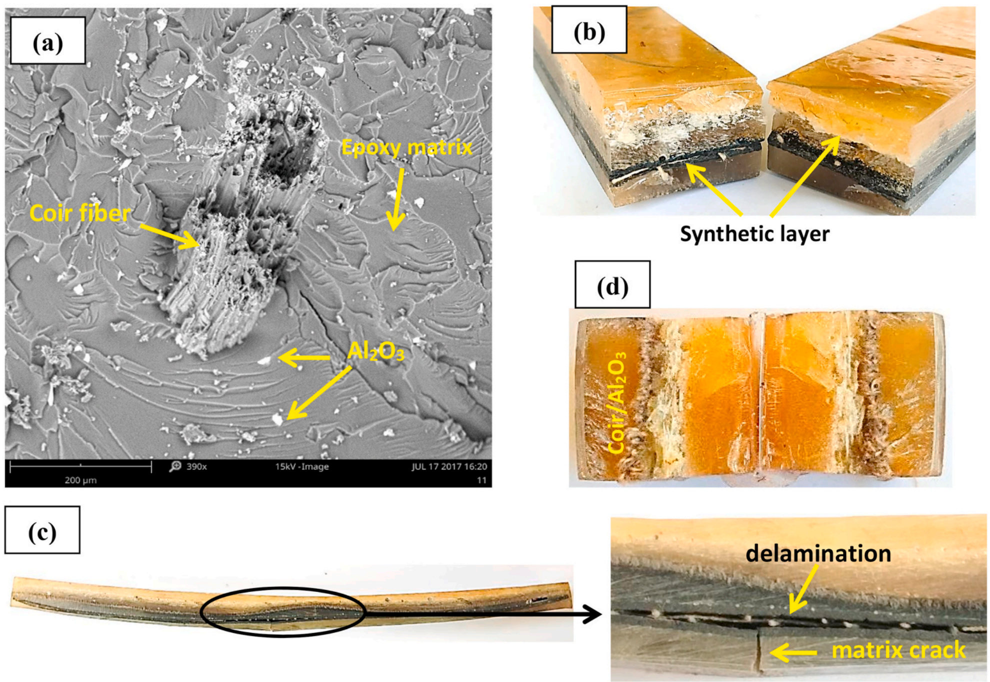


**Fig. 9.** SEM image and macroscopic fractography of hybrid laminated composites.

interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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