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The effect of fabrication methods on the physical properties of Sumberejo kenaf fiber - Polyurethane foam core sandwich composite for sustainable building construction

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ABSTRACT

Sandwich composites made of natural fibers are currently being investigated for use in buildings. Kenaf fiber is an environmentally friendly material that is widely used in cement and polymer composites owing to its strength and support. The purpose of this study was to investigate the fabrication method and physical properties of a Sumberejo kenaf fiber-polyurethane foam core sandwich composite (KF/EP-PU foam) for sustainable building construction. Sumberejo kenaf/epoxy laminate composites (KF/EP) were used as the skin layer in sandwich composites, with polyurethane foam (PU foam) as the core of the sandwich composites. Sandwich composites were fabricated using two methods: cold press and vacuum-assisted resin infusion (VARI). The water absorption, burning rate, and sound absorption coefficient of the sandwich composite production process were investigated. The results demonstrated that sandwich composites employing the VARI method had a lower percentage of water absorption (3.95 ± 0.38 %) than cold press method (7.21 ± 0.67 %). This indicates a more effective epoxy resin wetting procedure for covering the kenaf and polyurethane foam. The horizontal burning test showed no significant difference between the KF/EP-PU foam VARI (18.5 ± 1.3 mm/min) and KF/EP-PU foam cold press (18.9 ± 0.4 mm/min). The highest peak sound absorption coefficient of the KF/EP-PU foam cold press was 0.168 at 1000 Hz, whereas KF/EP-PU foam VARI sample had a sound absorption coefficient of 0.169 at 1128 Hz. It is recommended to consider the use of suitable fabrication methods for building application. The fiber and matrix weight fractions also need to be explored further.

1. Introduction

The development of composite technologies is becoming faster and more dynamic. Many researchers have started to modify composites in terms of material selection and structure to obtain the desired material strength characteristics. Currently, reinforcing materials in composites have shifted from the use of synthetic fibers to natural fibers because they are not detrimental to humans and the environment [1,2]. Ashraf et al. [3], reported that sandwich composites with a hybrid flax/glass skin layer were more resistant to bending loads than non-hybrid flax skin layers. This was an opportunity for researchers to further investigate the performance of natural fibers in sandwich composites. Natural fibers are easy to renew, find, and economical. Mixing natural fibers such as coir, kenaf, sisal, jute, flax, abaca, and coconut with a matrix such as epoxy resin or polypropylene results in good physical and mechanical properties [4,5]. Epoxy resin is a good material to use as an adhesive between the skin and core layers because of its water-resistant properties, good temperature, and dimensional stability also has a short working time [6,7]. Researchers have also examined the utilization of natural fibers as reinforcements in epoxy composites [8,9].

Kenaf fiber is one of the most effective natural fibers, compared to other natural fibers, in terms of properties [10,11]. Kenaf fiber (Hibiscus cannabinus, L.) is a natural fiber used in the stems of kenaf plants. Kenaf is a known source of cellulose compounds with economic and ecological benefits [12]. The cellulose compound content in kenaf fiber is 45–72 % [10,12]. Kenaf fibers also contain non-cellulosic substances that easily

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bind water molecules, which can affect the physical and mechanical properties of a natural fiber composite [7]. This can be minimized by alkalization treatment by soaking natural fibers in NaOH solution at a certain concentration and period, which aims to reduce non-cellulosic substances such as lignin and pectin. Hamidon et al. [13], reported that chemical treatment on kenaf fiber such as, alkaline-silane, alkaline-heat, and alkaline-bleaching can increase the interface adhesion between fiber and matrix and reduce the water absorption of fibers. Firdausi et al. [14], reported that Sumberejo kenaf fibers experienced a loss of hemicellulose, lignin, and pectin compounds when alkalized. Viore et al. [15], confirmed that alkali treatment can increase the adhesive strength at the interface between the matrix and fiber, thereby increasing the stress transfer.

Researchers have investigated sandwich natural fiber composites that exhibit potential for use in construction applications, providing enhanced performance and sustainability to reduce energy consumption and mitigate environmental pollution [16–20]. Sandwich composites are lightweight materials with two layers of skin a core in between the skins. The conventional core types that are widely used are the honeycomb core and polymeric foam core. Light polyurethane foam is suitable for applications in the automotive, aerospace, and building construction industries [21]. The use of polyurethane is very good for dampening vibrations in the energy absorption process. Globally, the use of PU as a foam material reached 67 % in 2016 [21,22]. PU foam has been widely used as a core layer in sandwich composites [23,24].

In addition, determining the fabrication method is useful for investigating and studying more deeply its influence on the characteristics of sandwich composites. Researchers have used several fabrication methods such as compression molding [16], hand lay-up [25], and vacuum assisted resin transfer molding (VARTM) [24]. The vacuum infusion method has been widely used by researchers because it has advantages such as reduced resin waste, a clean process, consistency in resin use, uniform thickness, and fast curing time [26]. VARI is a fabrication technique that uses a vacuum method. This method is a composite fabrication process that can produce aircraft fuselages and wings at an economical cost [27]. In addition, the VARI method has a higher ultimate tensile strength than the hand lay-up method and vacuum bagging [28,29]. However, the VARI method is widely used in the fabrication of laminate composites and is not often used in the fabrication of natural fiber sandwich composites with foam cores.

Previously, several studies on Sumberejo kenaf fiber laminate composites and Sumberejo sandwich composites were conducted. From the previous study by Zahrotin and co-researchers [30], indicates that the KF/EP-PU foam cold press has superior mechanical properties in terms of tensile and flexural strengths, with values of (0.220 ± 0.031) MPa and (7.564 ± 0.816) MPa, respectively. The compressive strengths of the KF/EP-PU foam cold press and KF/EP-PU foam VARI has were not significantly difference, with values of (0.331 ± 0.032) MPa and (0.393 ± 0.004) MPa respectively. The mechanical and physical properties of the four-layer woven Sumberejo kenaf fiber laminate composite with unidirectional orientation were also tested. In a journal written by Afkari et al. [4], stated that the Sumberejo epoxy laminate/kenaf fiber composite with a unidirectional fiber had higher tensile strength, tensile modulus, flexural strength, flexural modulus, compressive strength, and compressive modulus than the composite with a bidirectional fiber arrangement, with respective values of (96.61 ± 10.18) MPa, (7.58 ± 1.22) GPa, (131.01 ± 6.60) MPa, (8.70 ± 1.18) GPa, (71.96 ± 5.50) MPa, and (1.61 ± 0.37) GPa. All fibers are arranged parallel to the direction of loading, resulting in a high strength and stiffness of the composite. Zahrotin et al. [31], also investigated a Sumberejo epoxy laminate/kenaf fiber composite with unidirectional fiber arrangement with water content and swelling values of (4.34 ± 0.18 %) and (4.07 ± 0.50 %), respectively. This laminate composite meets SNI 01-4449-2006. Therefore, this study aims to compare the physical characteristics (water absorption, burning rate, and sound absorption coefficient) of Sumberejo kenaf fiber-polyurethane foam core sandwich composites fabricated using cold press and VARI. A comparison of the two methods is presented in this study.

2. Materials and methods

2.1. Materials

The skin layer is a laminate composite consisting of Sumberejo kenaf fiber as the reinforcement and epoxy resin as the matrix. Neat Sumberejo kenaf fiber is obtained from the retting process starting from soaking kenaf plant stems into fiber, washing and drying the fiber. This fiber was obtained from Balittas (Badan Penelitian Tanaman Pemanis dan Serat) (Malang, Indonesia). The type of variety fiber used was Kenaf 1 Agribun. Pre-treatment was carried out on kenaf fiber with an alkalization process using sodium hydroxide (NaOH) pellets and aqua-bidestilization at a ration of 1 : 20. The NaOH pellets were obtained from Merck (DKI Jakarta, Indonesia). The matrix used was an EPR 174 epoxy resin mixed with an EPH 555 hardener in a ratio of 2:1, obtained from PT. Justus Kimiaraya (DKI Jakarta, Indonesia). The core layer is polyurethane foam (PU foam) with a density of 0.04 g/cm^3 and a thickness of 20 mm obtained from Arta Mitra Supplier (Bekasi, Indonesia).

2.2. Preparation of Sumberejo kenaf fiber

Material preparation consisted of alkalizing and weaving the Sumberejo kenaf fibers. The alkalization process began by cutting the kenaf fiber 45 cm and soaking the kenaf fiber in 5 % NaOH solution for 24 h at room temperature (23 ± 1 °C). After that, the fibers were rinsed using water until the washing water looks clean. Subsequently, two stages of drying were carried out, those were drying at room temperature (23 ± 1 °C) for 48 h and drying using an oven (60 ± 1 °C) for 24 h. Fig. 1 shows the alkalization process of kenaf fibers. After that, the kenaf fibers were woven using a thin two-layer cotton yarn (Ne 40/2) with dimensions of woven fiber are 30 cm × 30 cm which was done at Ridaka Supplier (Pekalongan, Central Java, Indonesia). The cotton yarn percentage was less than 5 wt%. Therefore, it did not affect the mechanical characteristics of the composite [32]. Fig. 2 shows the process of weaving Sumberejo kenaf fiber.

2.3. Fabrication methods of sandwich composite

The sandwich composite fabrication process was carried out by combining three materials, namely Sumberejo kenaf fiber as reinforcement, epoxy resin as a matrix in the skin layer and adhesive between the skin and core layers, and polyurethane foam as the core layer in the sandwich composite. The total weight fraction of the epoxy resin was ±60 wt% in one sandwich composite panel. Four layers of woven kenaf fibers were arranged unidirectionally. The arrangement of the fibers and PU foam is shown in Fig. 3, with the green layer being the Sumberejo kenaf fiber sheet and the yellow layer being the PU foam. This study investigated the different characterizations of sandwich composite-based Sumberejo kenaf fiber and PU foam using two methods: cold press and VARI. Fig. 4 shows a schematic of the VARI and cold press fabrication methods.

The VARI method was carried out on a table with a glass surface to facilitate sample removal and produce samples with good results. VARI fabrication begins by applying release wax to the glass surface so that the composite can be easily removed. Sealant tape and vacuum plastic were used to maintain the vacuum state. Sealing tape was attached to the glass surface surrounding the sample. Sealant tape was used as an adhesive between the vacuum plastic and the glass surface. Before attaching the vacuum plastic with sealant tape, four sheets of woven kenaf fiber with dimensions of 300 mm × 300 mm were arranged on the top and bottom sides sandwiching the PU foam. Then, on top of the kenaf fiber layers and PU foam were covered by a peel ply, release film, infusion mesh, and vacuum bag. The edge of the vacuum bag was glued

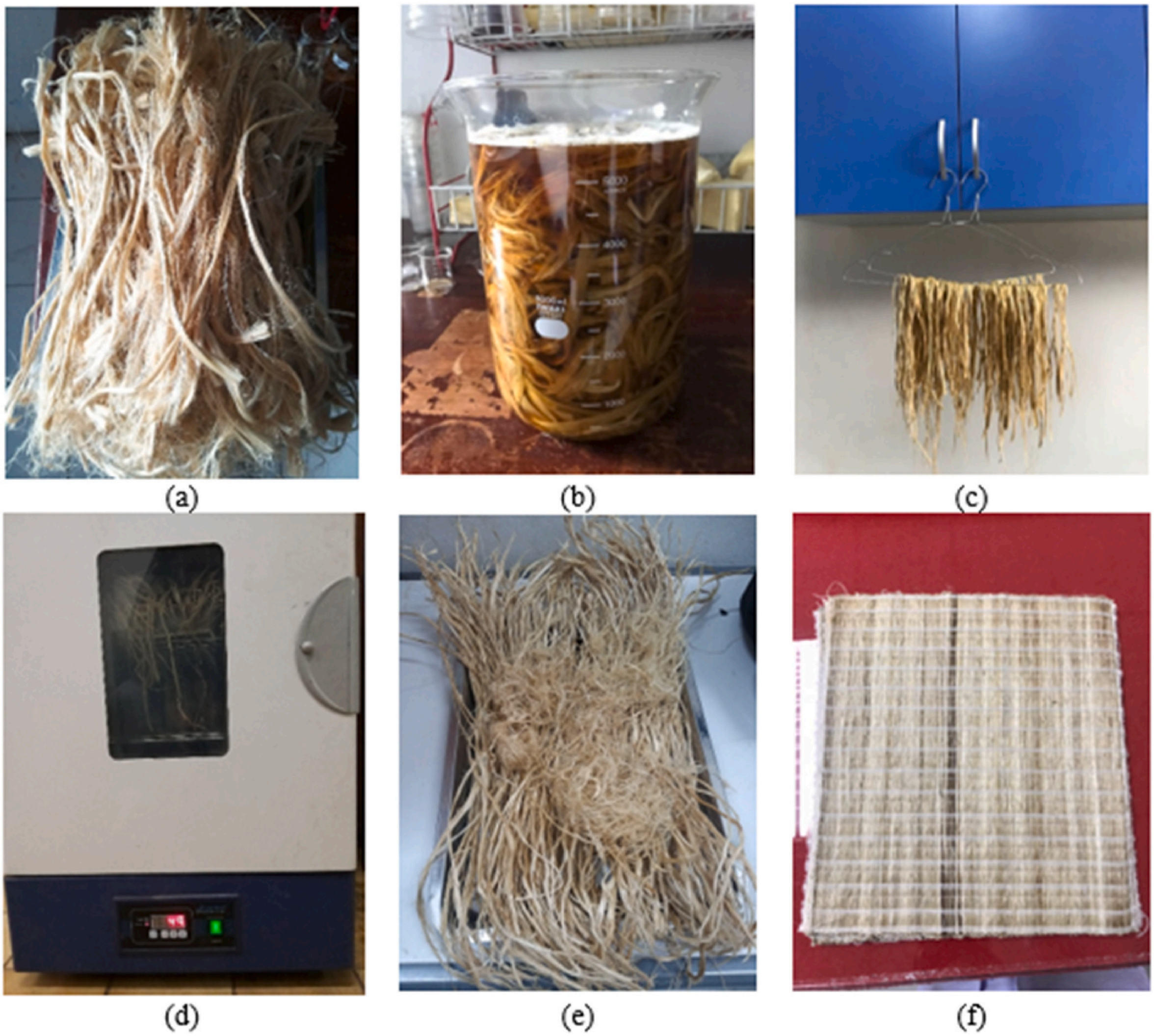

Fig. 1. The alkalization process of Sumberejo kenaf fiber from (a–f): (a) Sumberejo kenaf fiber before alkalization, (b) soaking kenaf fiber into 5 % NaOH solution for 24 h, (c) Drying in room temperature for 48 h, (d) Drying in oven (60 ± 1 °C) for 24 h, (e) Kenaf fiber after alkalization, (f) Woven kenaf fiber.

to a sealant tape to maintain the sample in a vacuum condition at a pressure of 60 cmHg. After ensuring that there was no air in the vacuum bag, the resin was immediately infused until the epoxy resin spread evenly. After that, The samples was kept in a vacuum condition at room temperature (23 ± 1 °C) for 24 h. The results of the fabrication method are labeled as KF/EP-PU foam VARI.

Meanwhile, the cold press method was performed by coating the epoxy resin between the skin layer (epoxy laminate composite reinforced with kenaf fiber) and the core layer (PU foam) using a brush or roller. Then, It was cold pressed at 2040 Pa in room temperature (±23 ± 1 °C) for 24 h. The laminate composite fabrication was carried out using the same vacuum technique as the VARI fabrication method previously described. The laminate composite consisted of four layers of 40 wt% kenaf fiber and 60 wt% epoxy resin. The detailed procedure followed that in the previous study [30]. The results of the fabrication method are labeled as KF/EP-PU foam cold press. Fig. 5 shows the cold press and VARI fabrication processes.

2.4. Testings

Physical testing was performed to determine the characteristics of the sandwich composites under environmental influences. Several researchers have investigated the influence of the environment on the characteristics of sandwich composites, including the water absorption properties, burning rate properties, and sound absorption coefficient. In this study, the testings were carried out on sandwich composites, KF/EP laminate composites, and PU foam.

2.4.1. Water absorption test

The water absorption test was performed according to ASTM C 272M – 12 [33]. The specimen size required for the sandwich composite was 75 mm × 75 mm x 28 mm, the KF/EP laminate composite is 75 mm × 75 mm x 4 mm, and the PU foam is 75 mm × 75 mm x 20 mm, with five specimens for each sample. This test was performed by comparing the weight of the specimen before and after immersion in water. Equation (1) shows the formula used to calculate water absorption (%); with W is the weight of the specimen after immersion (grams), D is the weight of the specimen before immersion (g), and V is the specimen volume (length x width x height) (cm^3). The immersion depth of the specimens was 25 mm below the water surface. Soaking is carried out at room temperature (23 ± 1 °C) until the specimen weight reached a constant weight [33,34]. Fig. 6 shows the process of immersing the specimen in water using a mesh such that the specimen does not float on the water.

$$\text{Water absorption } (\%) = \frac{W - D}{D} \times 100 \quad (1)$$

Fig. 2. The weaving process of Sumberejo kenaf fiber.

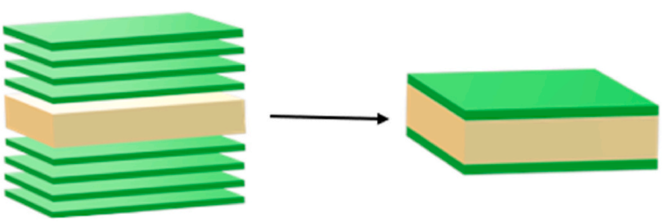

Fig. 3. The arrangement of sandwich composite KF/EP-PU foam.

2.4.2. Burning test

The standard procedure for burning test was UL94 Horizontal Burning from The UL Thermoplastics Testing Center [35], with test specimen dimensions of 125 mm × 13 mm x 4 mm (for the KF/EP laminate composite), 125 mm × 13 mm x 20 mm (for the PU foam), and 125 mm × 13 mm x 28 mm (for the sandwich composite), with three specimens for each sample. Specimens were marked at distances of 25 mm and 100 mm from the tip of the specimen. The tip of the specimen was burned using a burner with a flame tilt of 45°. The first burning step was performed for 30 s. The calculation of the burning time started when the flame touched the 25 mm mark. A schematic and process of the Horizontal Burning (HB) method are shown in Fig. 7 [35]. Equation (2) is the formula for calculating the burning rate of a material, with V is the burning rate (mm/min), L is the length of the burning specimen (mm), and t is burning time (s).

$$V = \frac{60L}{t} \tag{2}$$

2.4.3. Sound absorption test

Sound absorption testing was carried out using Kundt's tube from Brüel & Kjær. The measurement was conducted in accordance to ASTM E1050-19 [36]. The specimen size required for sandwich composites is 99 mm × 99 mm x 28 mm, KF/EP laminate composites are 99 mm × 99 mm x 4 mm, and PU foam is 99 mm × 99 mm x 20 mm, with one specimen for each sample [49]. This test was performed in the frequency range 50–1600 Hz. The test was carried out by preparing an impedance tube that included an amplifier, loudspeaker, and two microphones. The specimen was placed in a holder at the end of the impedance tube and a loudspeaker at the other end emitted sound waves that were then be transferred to the specimen. The reflected signal was captured using a microphone attached to an impedance tube. Therefore, the data can be processed using PULSE LabShop software. Fig. 8 shows a schematic and the process for the sound absorption test. Equation (3) was used to determine the sound absorption coefficient [36]. α_n indicates the ability of material to absorb energy at various frequencies and R is the sound reflection coefficient.

$$\alpha_n = 1 - |R|^2 \tag{3}$$

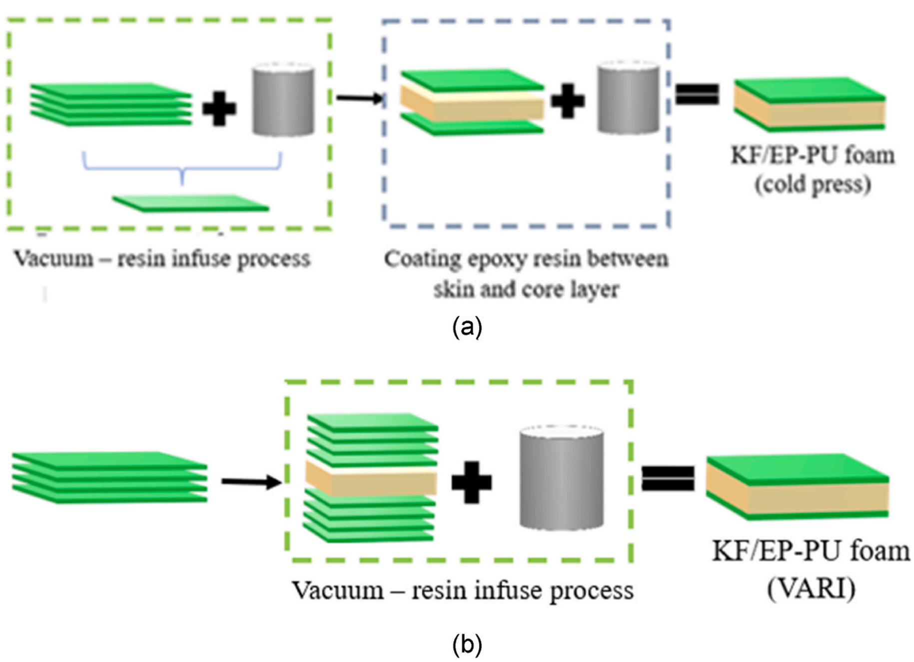

Fig. 4. The schematic of (a) cold press and (b) VARI fabrication methods.

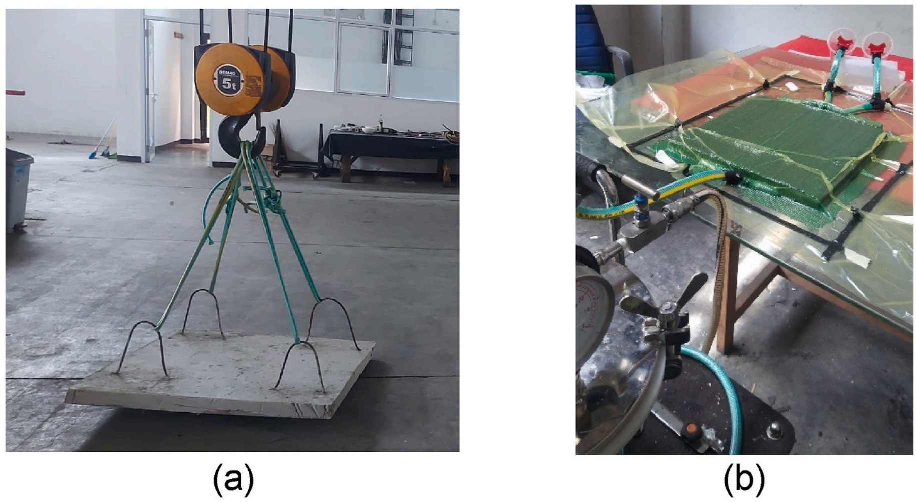

Fig. 5. The fabrication process of KF/EP-PU foam using (a) cold press and (b) VARI methods.

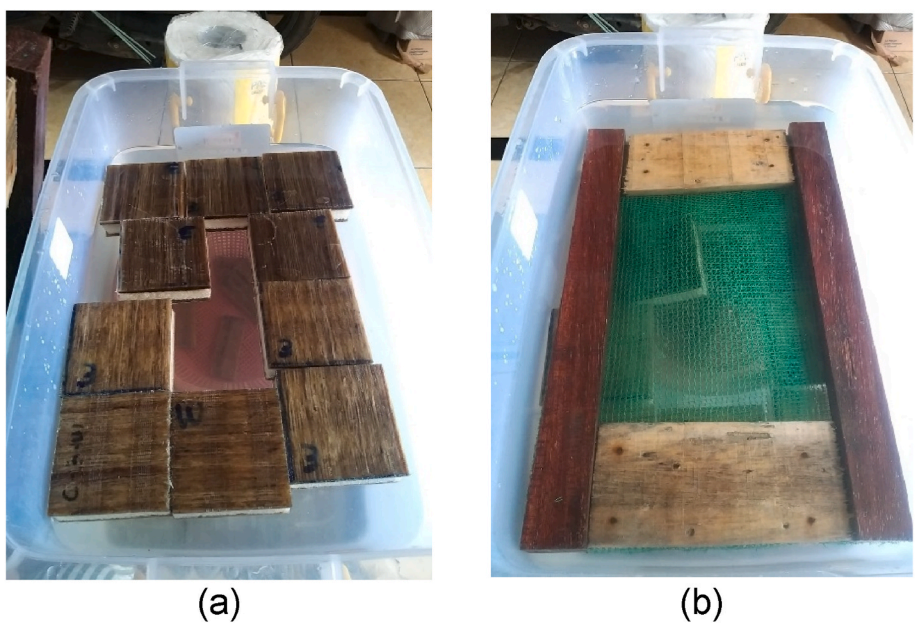

Fig. 6. The process of water absorption test: (a) the specimen floated without using a mesh, (b) the specimen immersed under water surface used a mesh.

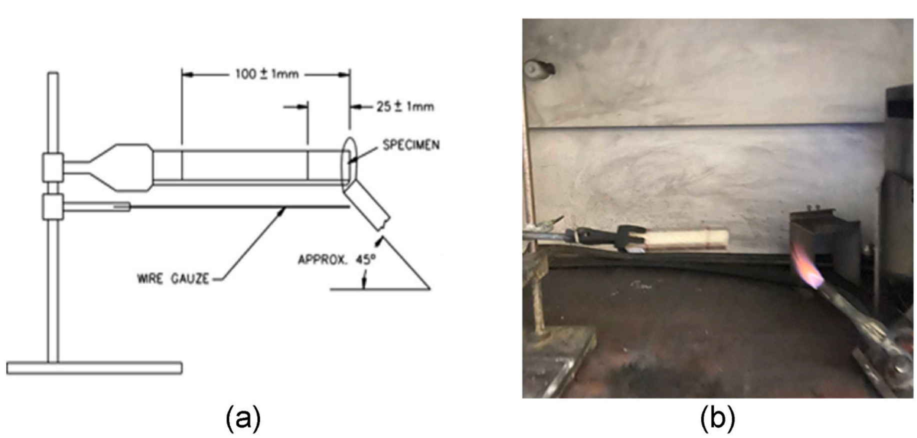

Fig. 7. (a) The schematic burning test of composite; (b) The process of Horizontal Burning (HB) test of composite KF/EP-PU foam.

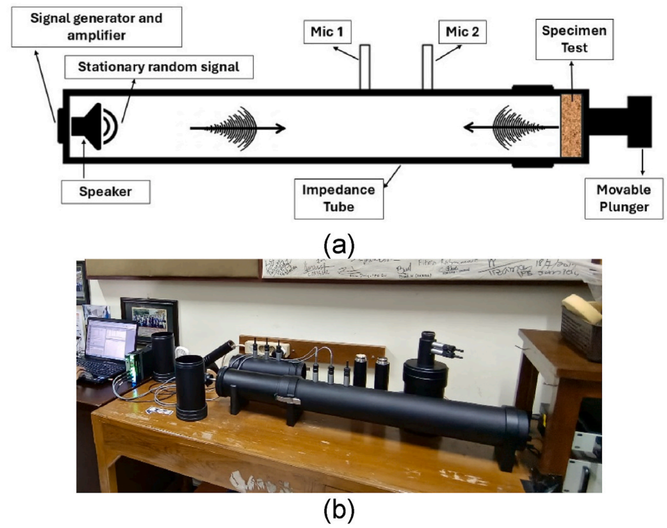

Fig. 8. (a) The schematic of sound absorption test; (b) The process of the sound absorption test on KF/EP-PU foam composite.

3. Result and discussions

3.1. Water absorption properties

Water absorption tests were carried out on the KF/EP-PU foam cold press and VARI samples to analyze the differences in characteristics between the two fabrication methods. In addition, it was tested on KF/EP laminate composite layers and PU foam to determine the characteristics of the layers that formed the sandwich composite. The test was conducted for 50 h until the water absorption value increased and reached a constant value. A graph of water absorption versus time is shown in Fig. 9. The water absorption value is directly proportional to the soaking time. Dhakal et al. [37], stated that the percentage of water absorption in the non-woven flax/film PLA and cork as core sandwich composites increased linearly at the beginning of soaking, continued to increase with increasing soaking time (hours) and reached saturation at 1200 h. The percentage of water absorption in the synthetic foam composite with kenaf/glass as the skin layer also increases with increasing soaking time [38].

The data calculation using Equation (1), determined KF/EP laminate composite and PU foam have maximum water absorption values of (25.87 ± 1.40 %) and (64.85 ± 10.07 %), respectively. Meanwhile, the water absorption values for the KF/EP-PU foam cold press and KF/EP-PU foam VARI were (7.21 ± 0.67 %) and (3.95 ± 0.38 %), respectively. From these results, it can be stated that combining the KF/EP laminate composite and PU foam into a sandwich composite structure can reduce the water absorption value of its constituent materials (KF/EP laminate composite and PU foam). This also occurred in the research conducted by Naveen et al. [39], where the water absorption value of a jute/glass sandwich composite with a cork core was smaller than that of the jute fiber laminate composite.

Fig. 10 shows an enlargement of the graph compared to that in Fig. 9 to see the details of the water absorption curve of the KF/EP-PU foam cold press and VARI. It is known that the water absorption of the two types of sandwich composites begins to remain constant at soaking times greater than 30 h. The characteristic differences between the KF/EP-PU foam cold press and VARI are also known. The water molecule diffusion process in the KF/EP-PU foam cold press and VARI composites were influenced by several factors, such as fiber weight fraction, skin surface layer, density, and fabrication process [40]. Table 1 shows a comparison of the fiber weight fractions of the KF/EP-PU foam cold press and VARI. Natural fibers have hygroscopic properties that allow them to easily absorb water molecules around them [41]. Thus, the influence of the weight fraction of natural fibers in a composite also affects the water absorption value (%) [14]. The KF/EP-PU foam cold press had a higher kenaf fiber percentage than KF/EP-PU foam VARI. This supports the water absorption value (%) of the KF/EP-PU foam cold press being higher than that of VARI. This was also observed by Sanjeevi et al. [42], who found that the weight fraction of biduri stem fiber and areca nut of 45 wt% had a higher water absorption value than the fiber weight fraction of 25 wt% and 35 wt%.

In addition, the composite fabrication process in this study also affected the water absorption flow in the KF/EP-PU foam. The differences in the appearance of the skin surface between the two types of KF/EP-PU foam samples are shown in Fig. 11. The surface of the skin on the KF/EP-PU foam cold press appeared uneven owing to the epoxy resin, in contrast to the skin surface on the KF/EP-PU foam VARI, in which the epoxy resin spread evenly. Thus, water molecules that diffuse from the radial direction (skin surface) and are trapped in the micro-cracks of the matrix in the KF/EP-PU foam cold press is higher than that in the KF/EP-PU foam VARI sample. Dhakal et al. [37], also stated that the

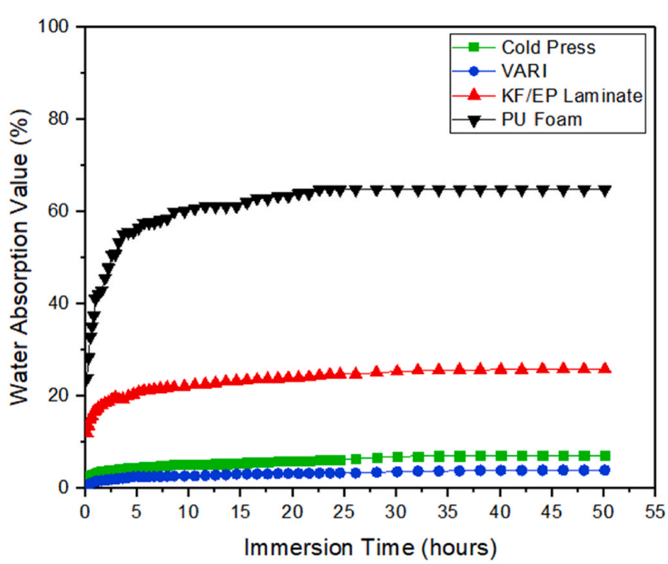

Fig. 9. Immersion time (h) vs percentage water absorption value (%) of KF/EP-PU foam Cold Press and VARI also constituent materials (KF/EP laminate and PU foam).

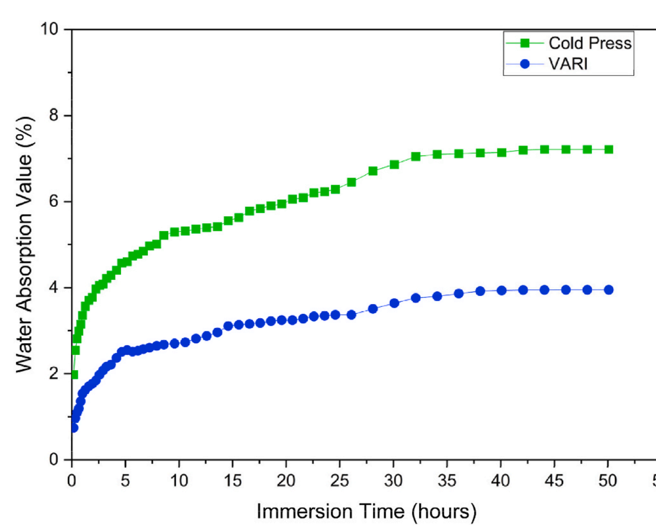

Fig. 10. Immersion time (h) vs percentage water absorption value (%) of KF/EP-PU foam Cold Press and VARI.

Table 1
Comparison of weight percentages of KF/EP-PU foam constituent materials.

Weight Fraction (wt.%)		
Constituent Materials	Cold Press	VARI
Sumberejo Kenaf Fiber	32	31
Epoxy Resin	59	61
PU Foam	8	7

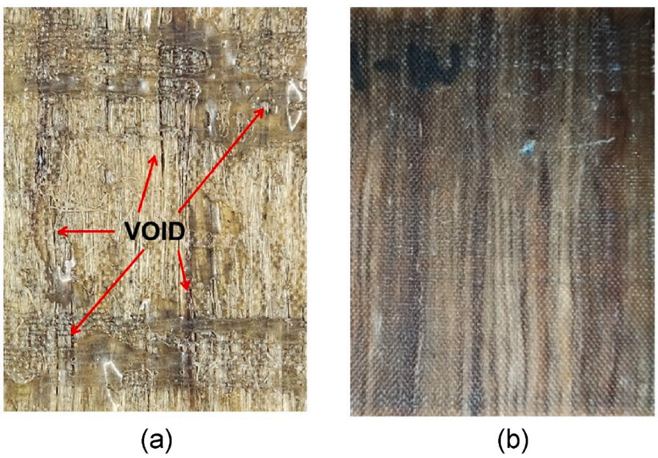

Fig. 11. Skin surface of sandwich composite (a) KF/EP-PU foam cold press (b) KF/EP-PU foam VARI.

degradation of the surface of the skin on the Hemp/PLA – cork composite can cause high water absorption. Water absorption is also influenced by the porosity of the composite, such as the presence of pores or voids in the matrix, the interface between the fiber and matrix, and internal voids in the fiber [43].

3.2. Burning rate properties

The burning rate was calculated using Equation (2). Comparison of the burning rate for the KF/EP-PU foam cold press and KF/EP-PU foam VARI shown in Fig. 12. There is an insignificant difference of 3.07 % between the two types of composites, with a KF/EP-PU foam cold press value of (18.9 ± 0.4 mm/min) and KF/EP-PU foam VARI of (18.5 ± 1.3 mm/min). The KF/EP-PU foam cold press specimen is 2 mm thicker than the KF/EP-PU foam VARI which has a slight influence on the difference result of burning rate. Murillo et al. [44], also stated that variations in the thickness of the PIR foam sandwich composite did not have a significant impact on the fire reaction. In this KF/EP-PU foam, the lower skin layer was affected more by the flame and then spread to the PU foam and upper skin from the start of burning. The constituent materials, KF/EP laminate composite, had a burning rate of (15.8 ± 0.6 mm/min). According to Aulia et al. [45], the presence of kenaf fiber as reinforcement in epoxy laminate composites can reduce the burning rate of composites. From their research, the epoxy burning rate value was obtained at (19.5 ± 0.3 mm/min), while the value for the KF/EP laminate composite with unidirectional fiber direction in the study was (16.6 ± 0.5 mm/min). In addition, it was also obtained from another reference, which was a laminate composite of 50 wt% kenaf fiber with a phenolic matrix had a burning rate of 15 mm/min [46]. Research by Xu et al. [47], obtained a horizontal burning rate value for carbon/epoxy laminate composites of 16.6 mm/min. The PU foam was also investigated in this study. The burning rate was 0 mm/min. This occurred because the fire was extinguished within 2 s after the PU foam was burned with the burner. Therefore, it can be concluded that the PU foam used was non-flammable material. The non-flammable PU foam could not withstand the fire rate from both parts of the skin. This is because the position of the PU foam is between the two KF/EP laminate composite, which have a higher burn rate than PU foam.

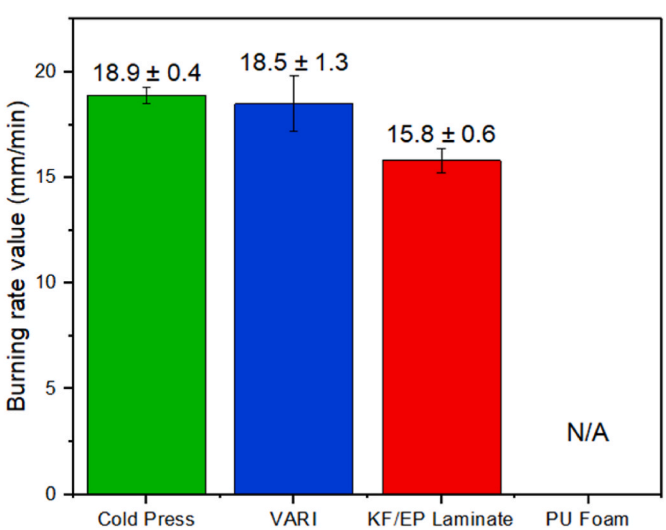

Fig. 12. Horizontal burning test results of KF/EP-PU foam Cold Press and VARI also constituent materials (KF/EP laminate and PU foam).

Fig. 13 shows the pictures of the KF/EP-PU foam, KF/EP laminate composite and PU foam after testing. This result, indicated that by combining PU foam and KF/EP laminate composite into a sandwich composite structure, the burning rate of the KF/EP-PU foam sandwich composite increases and the difference between the cold press and VARI fabrication methods does not affect the KF/EP-PU foam burning rate value.

3.3. Sound absorption properties

Fig. 14 shows the sound absorption characteristics of the KF/EP laminate composites, PU foam, KF/EP-PU foam cold press, and KF/EP-PU foam VARI in the frequency ranges of 400–1000 Hz (low frequency) and 1000–1600 Hz (middle frequency). The results were obtained using Equation (3). In the frequency range 1000–1600 Hz, there is a critical value/peak that shows the sound absorption coefficient of the sample. In this range, the KF/EP laminate composite had a sound absorption coefficient of 0.094 at a frequency of 1028 Hz. At frequency 1600 Hz, the sound absorption coefficient of the KF/EP laminate composite is 0.314. PU foam has sound absorption value in the low-frequency and middle-frequency ranges of 0.116 at 600 Hz and 0.506 at 1600 Hz, respectively. The same phenomenon also occurred in the research of Lyes Dib et al. who stated that the sound absorption coefficient of closed-cell PU foam was in the low-frequency and high-frequency ranges [48]. The addition of a core layer to the sandwich composite in the form of foam with skin in the form of a laminate composite can optimize the sound absorption coefficient of the laminate composite [49].

Fig. 14 shows that the sound absorption coefficient between the two types of sandwich composite samples, namely the KF/EP-PU foam cold press and VARI, does not exhibit a significant difference in the frequency range of 1000–1600 Hz. The highest peak sound absorption of the KF/EP-PU foam cold press was 0.168 at 1000 Hz, whereas the KF/EP-PU foam VARI had a sound absorption coefficient of 0.169 at 1128 Hz. The differences between the cold press and VARI were due to the coating of epoxy resin between the KF/EP laminate composite and PU foam, which provided a denser structure at the interface between the skin and the core. The epoxy resin layer preven sound waves from entering the PU foam [50]. A comparison of the sound absorption values of KF/EP-PU foam and bricks, which are commonly used in commercial buildings, showed that the sound absorption coefficient of KF/EP-PU foam is better

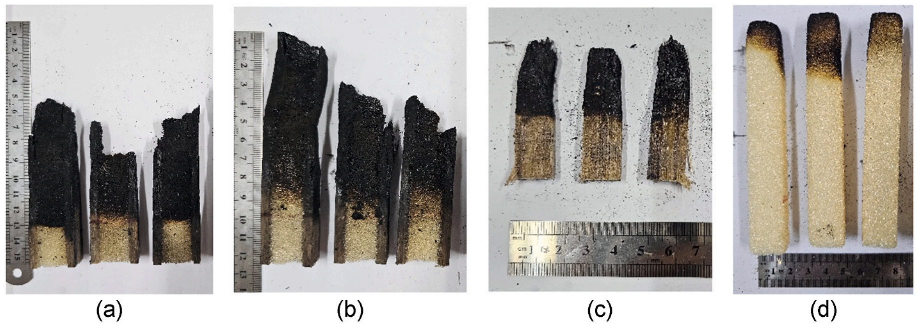

Fig. 13. Specimen condition after horizontal burning test (a) KF/EP-PU foam cold press, (b) KF/EP-PU foam VARI, (c) Laminate composite KF/EP, (d) PU foam.

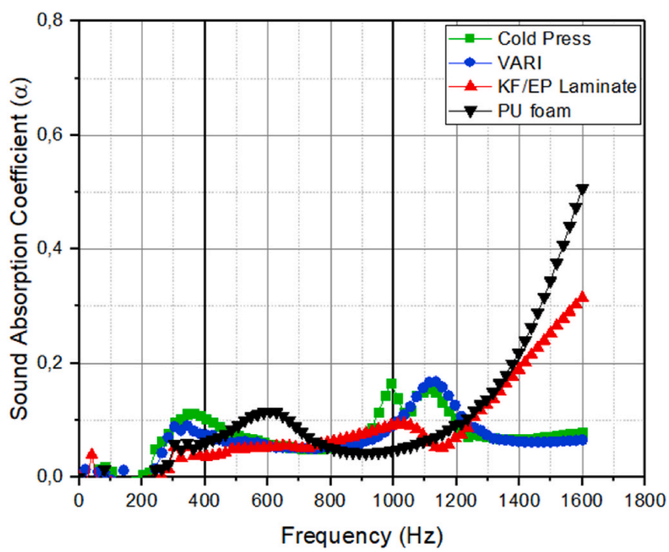

Fig. 14. Sound absorption coefficient of KF/EP-PU foam Cold Press, VARI, and constituent materials (KF/EP laminate and PU foam).

than that of bricks. Bricks have a sound absorption coefficient of 0.020 at a frequency of 1000 Hz [51]. Based on this research, KF/EP-PU foam is classified as a sound-absorbing material type E with a coefficient value of 0.15–0.25 based on ISO 11654 [52].

As of result and discussion of this research. The burn rate and sound absorption properties are nearly identical between the cold press and VARI methods, indicating that both fabrication methods yield similar performances. but VARI method provides a material that is more water-resistant, which could be a deciding factor depending on the intended use of the composite.

The interrelationship of these test results shows that the fabrication method impacts properties water absorption. But overall material performance (in terms of sound absorption and burn rate) remains very similar between the two methods cold press and VARI.

4. Conclusion

A Sumberejo epoxy/kenaf fiber sandwich composite with polyurethane foam core (KF/EP-PU foam) was fabricated using two different methods, namely, cold press and VARI method. Physical tests were carried out to determine the characteristics of the sandwich composites according to the type of fabrication. The KF/EP-PU foam VARI has superior water absorption properties with a lower absorption value, (3.95 ± 0.38 %). The burn rate and sound test results between KF/EP-PU foam cold press and KF/EP-PU foam VARI are not significantly different from the following values: burn rate value of KF/EP-PU foam cold press (18.9 ± 0.4) mm/minute and KF/EP-PU foam VARI of (18.5 ± 1.3) mm/minute; The sound absorption coefficient of KF/EP-PU foam cold press is 0.168 at 1000 Hz and KF/EP-PU foam VARI is 0.169 at 1128 Hz. These sandwich composites are classified as a sound-absorbing material type E with a coefficient value of 0.15–0.25 based on ISO 11654.

This research shows that the VARI method produces a KF/EP-PU foam sandwich composite that is better in water absorption resistance properties without considering the burning rate and sound absorption properties. In addition, in building construction applications, composite resistance is required from various environmental conditions to understand the material's performance. Therefore, it is recommended to consider the use of suitable fabrication methods in the production of sandwich composites. The amount of fiber and matrix weight fractions also need to be explored further.

CRediT authorship contribution statement

Ilva Zahrotin: Writing – original draft, Investigation, Formal analysis. **Ariadne L. Juwono:** Supervision, Project administration, Funding acquisition. **Januar P. Siregar:** Writing – review & editing, Validation. **Seto Roseno:** Validation, Formal analysis. **Saeful Rohman:** Project administration, Investigation. **Eryanti Kalembang:** Project administration, Investigation.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All author have read and agreed to the published version of the manuscript.

Availability of data and materials

We ensure that all data are contained within the article.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ariadne L. Juwono reports financial support was provided by Universitas Indonesia. Ariadne L. Juwono reports a relationship with University of Indonesia that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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