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IMPACT PROPERTIES OF HEMP NATURAL – GLASS FIBERS HYBRID POLYPROPYLENE SANDWICH COMPOSITES

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ABSTRACT

One way to improve the mechanical properties of composite structures is by hybridizing natural and synthetic fibers. Besides that, combined with sandwich structure composites consists of two relatively strong, thin, and stiff faces separated by a core, for example, balsa, foam, and honeycomb, a relatively thick lightweight. This research develops sandwich composites for structures that have able to withstand high loads and modulus-to-weight ratios but can absorb impacts through impact tests by utilizing the raw material of jute natural fiber, which is abundant in Indonesia so that this research study can predict the effect of variations in the hybridization of hemp natural fiber and the combination of hemp natural fiber with e-glass using polypropylene core sandwich composites by using hand lay-up and vacuum bagging methods. The current impact test results show that the hemp natural-e-glass fibers hybrid sandwich composites get a higher impact strength with a value of 0,019 J/mm² than the hemp-PP honeycomb hybrid sandwich composite with a value of 0,013 J/mm². It shows that by combining e-glass fiber in the composite, it can increase its impact strength and can be a lightweight structural material as being a new alternative material of jute and e-glass natural fiber hybrid sandwich composites with polypropylene cores to substitute conventional materials such as metals which is potential for applications in the automotive, building, and unmanned aerial vehicle industries.

1. INTRODUCTION

To improve the properties of the composite, at least two reinforcement elements are combined into a matrix to produce hybrid composite materials. The components' morphology, composition, and orientation significantly impact how composites respond to solicitations. The properties of the composite's constituent elements, which control its internal structures, are closely linked to the composite's characteristics (Bouhfid et al., 2019). A matrix with at least two different types of reinforcements is typically identified as a "hybrid composite" (Swolfs et al., 2014).

A Sandwich-Structured Composite is a particular class of composite materials fabricated by attaching two thin but stiff skins to a lightweight but thick core. The essential characteristics of sandwich composites are high stiffness-to-weight ratio (Ramakrishnan et al., 2018). Due to sandwich structures constructed of various polymeric materials, there are many opportunities for specific items with various characteristics (Biron, 2018). Two face sheets (skins) and a core structure compose the sandwich structures. The core structure, which supports the face sheets, connects them. The core structure's significant objective is to increase the sandwich structure's flexural stiffness while contributing only a tiny amount of weight. However, applying a core material with a relatively low density affects stiffness and strength properties, increasing the possibility that the composite sandwich structure would completely fail (Fazzolari, 2017). The choice of the core is critical to the performance of the sandwich, as the core properties control the energy absorption and magnitude of the force transfer through the structure. Commonly used cores comprise metallic and nonmetallic honeycombs, cellular foams, balsa wood, truss, and lattice structures (Reddy & Madhu, 2017).

This study uses the easily obtainable jute natural fiber from Indonesia as a raw material; this research develops sandwich composites for structures that can withstand high loads and modulus-to-weight ratios while absorbing impacts through impact tests. This research study can predict the effects of variations in the hybridization of hemp natural fiber and the combination of hemp natural fiber with e-glass using polypropylene core sandwich composites, a combination of natural fibers and synthetic fibers was used as reinforcement in the sandwich composite structure. Natural fibers have attracted the interest of engineers, researchers, professionals, and scientists all over the world as an alternative reinforcement for fiber-reinforced polymer composites because of their superior properties such as high specific strength, low weight, low cost, reasonably good mechanical properties, non-abrasive, eco-friendly and bio-degradable characteristics (Sanjay et al., 2015). Hybridization of natural/glass fiber-reinforced polymer composites has been developed to build their applications in the field of engineering and technology (Sanjay & Yogesha, 2017). Glass fiber Reinforced Polymers are mixed with natural fibers to increase Engineering and Technology applications (Sanjay et al., 2015).

Recently, interest in using natural fibers as reinforcement for composite materials has increased, primarily due to environmental concerns, governmental regulations, and technological developments. Due to its excellent mechanical characteristics, hemp is one of the most widely utilized natural fibers used as reinforcement in polymers. Currently, hemp fibers are gaining the interest of design engineers worldwide to develop composites with wide-ranging uses in the automotive, electrical, construction, and packaging industries. Natural fiber-reinforced polymer composites' primary problem is improper fiber matrix adherence at the interface, which can result in poor mechanical characteristics in the finished product. In order to make the most of the potential of natural fiber composites, excellent bonding at the fiber-matrix interface remains important (Deshmukh, 2022).

Natural fibers have some disadvantages when combined with polymers, which have a high moisture content and poor compatibility. On the composite surface, brittle matrices with significant moisture absorption and swelling are more likely to crack. Their surface characteristics must be appropriately modified to enhance interfacial interactions and offer desired properties. One solution to get around these problems is to apply alkali treatment to the fiber surface (Rafiqah et al., 2023). Meanwhile, the tensile and bending strength of the composite filled with fibers treated with 6% NaOH solution was lower than that of composites etched with 2% and 4% NaOH solutions. A large number of the tested properties of the produced biocomposites for each filler of the plant-origin and polymer matrix improved with an increase in the alkalizing solution concentration in the case of biocomposites filled with hemp fibers to enhance the distinct characteristics of biocomposites. The fiber alkalization treatment should be explicitly selected, and the removal of waxes and fatty acids that may adversely affect interfacial bonds (Frącz et al., 2021).

A study conducted concerning sandwich hybrid composites by Mataram and Besi (2019) shows that the composite structures of kenaf fiber reinforced fiberglass hybrid composite with core senton laut sawdust/epoxy by using a hand lay-up method has an impact energy value of 0,00907 J/mm2. Furthermore, the composite sandwich carbon fiber reinforced/epoxy with core balsa has an impact energy value of 0.027 J/mm2 (Banowati et al., 2022), and the composite sandwich agave fiber reinforced/polyester with particle wood core has a value of 0,012 J/mm2 (Yudhanto, 2015). Other research related to the hybrid composites of natural and synthetic fibers with their respective impact strengths are as follows: the flax/glass fibers reinforced polypropylene hybrid composites have a value of 0.07 J/mm2 (Ghasemzadeh-Barvarz et al., 2015), and the two hybrid biocomposites with the combination of sisal and glass fiber were blended with polypropylene via extrusion and injection molding process has value of 0,18 J/mm2.

Based on the results of previous research shows that there has been research on the impact strength of sandwich hybrid composites kenaf-glass fiber reinforcement with sea sengon sawdust core and carbon fiber reinforced with balsa core, both types of sandwich hybrid composites using epoxy resin, while agave fiber reinforced with core particle wood core using polyester resin. Besides that, there is also research that concerns the hybrid composites of flax-glass and sisal-glass fiber reinforcement, both types the hybrid composites using polypropylene resin. The difference with the current research is the sandwich hybrid composites using hemp-glass fiber reinforcement with epoxy resin and honeycomb polypropylene as the core, which has novelty in this research. Therefore, this research used the epoxy resin as a matrix mixed with hemp fiber with NaOH alkaline treatment and e-glass fibers as reinforcement and a honeycomb polypropylene core in the sandwich hybrid composite structure. The composite manufacturing method used is hand lay-up and vacuum bagging. The produced specimens were prepared for the impact tests according to ASTM D 6110-04 standards (ASTM D6110-10, 2018)

2. METHODS

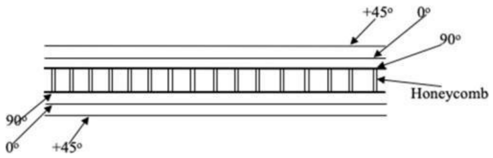
2.1. Materials

The first step is the treatment process of hemp fiber alkali (Figure 1), which is soaked using 5% NaOH solution for 2 hours, then washed the fiber with clean water and dried under the sun at 29° C for 8 hours.

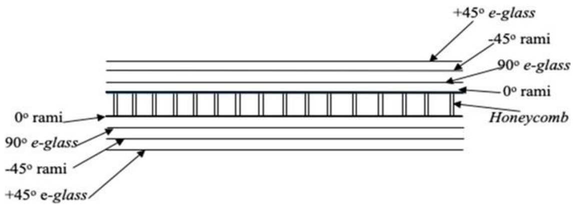
a b c

Figure 1 Hemp Fiber Alkali Treatment Process: a. Hemp fiber before alkali treatment, b. Alkali treatment of hemp fibers, c. Drying the hemp fibers

The fiber was carefully arranged to eventually will produce ±45º, 0°, and 90° balanced symmetry fiber orientation for both hemp and hybrid hemp-e-glass fiber, respectively, as skin and polypropylene (PP) honeycomb as core (Figure 2) measured in order to achieve 50% fiber volume fraction, then placed into the molding were mixed with epoxy using hand lay-up and vacuum bagging method (Figure 3).



a



b

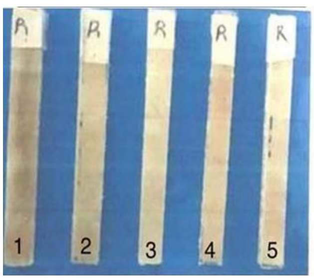
Figure 2 Fiber Orientation of Hybrid Sandwich Composite: a. Hemp- PP honeycomb, b. Hybrid hemp-e-glass- PP honeycomb

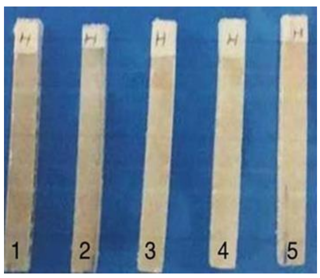
a b

Figure 3 Hand Lay-up and Vacuum Bagging Method: a. Hand lay-up composite, b. Composite vacuum bagging

2.2. Specimen Test

The final specimen for the impact test according to ASTM D 6110 – 04 standard is as follows(Figure 4):





a b

Figure 4 Specimen for the Impact Test Sandwich Composite: a. Hemp- PP honeycomb, b. Hybrid hemp-e-glass-PP honeycomb

Table 1 Impact strengths of hemp-PP honeycomb and hemp-e-glass- PP honeycomb hybrid sandwich composite

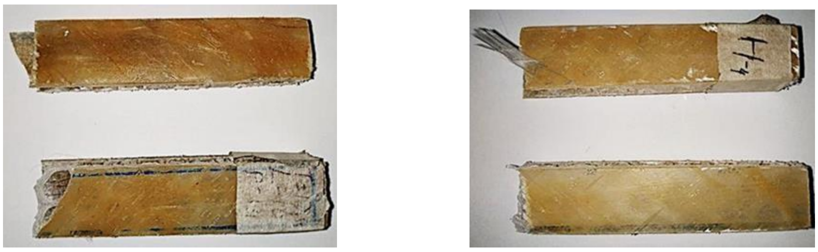
Specimen	Impact strength (J/mm²)	
	Hemp-PP honeycomb hybrid sandwich composite	Hemp-e-glass-PP honeycomb hybrid sandwich composite
1	0.017	0.018
2	0.017	0.019
3	0.010	0.018
4	0,009	0.019
5	0,011	0,019
Average	0.013	0.020

In Table 1 above, the impact strength value for the hemp-e-glass-PP honeycomb hybrid sandwich composite specimen is higher with a value of 0,019 J/mm² than hemp-PP honeycomb hybrid sandwich composite with a value of 0,013 J/mm². It shows that combining e-glass fiber in the composite can increase its impact strength. In accordance with the objectives of this study that the hybridization of natural fibers with synthetic fibers was able to increase the impact strength of composites. The comparison of the results of the density test is as follows (Table 2).

Table 2 The comparison of the results of the density test

Specimen	Density (gr/cm^3)
Hemp-PP honeycomb hybrid sandwich composite	0.78
Hemp-e-glass-PP honeycomb hybrid sandwich composite	0.91

Table 2 shows that the density value for the hemp-e-glass-PP honeycomb hybrid sandwich composite specimen is lower with a value of 0,78 gr/cm3 than the hemp-PP honeycomb hybrid sandwich composite with a 0,91 gr/cm3 value. It shows a difference in the density value of the two composites. The figure below shows the failure mode that occurs in the composite impact test results (Figure 5) and (Figure 6) as follows:



a b

Figure 5 Failure Mode Impact Strength of Sandwich Composite: a. Angled gage middle that occurs in hemp-PP honeycomb, b. Fiber breaking that occurs in hemp-e-glass-PP honeycomb

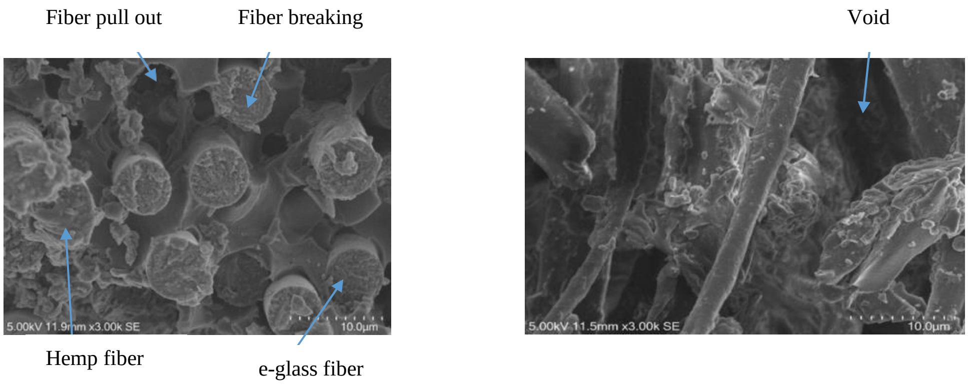
In Figure 5, the failure mode impact strength of the sandwich composite, whereas in hemp- PP honeycomb composites, the form of failure that occurs is angled gage middle a failure mode of the specimen, according to the direction of the fibers placed on the top and bottom lamina surface of each composite at 45 degrees. Whereas in hemp-e-glass-PP honeycomb composites, the form of failure that occurs is fiber breaking which shows that the bond between the fiber and matrix interface is good enough.

a b

Figure 6 Failure Mode Impact Strength of Sandwich Composite Other Unbroken: a. Delamination age middle, b. Failure in core

As seen in Figure 6, the failure mode impact strength of the sandwich composite other unbroken is delamination and failure in the core. Whereas the delamination gage middle is a delamination failure in the middle in the form of peeling on the surface of the gage, which often occurs in reinforced structures due to lack of adhesive layer, failures in mix making, chemical reactions, and overloading.

Figure 7 shows the SEM (Scanning Electron Microscopy) conducted to see the morphological structure of the surface with 1000x magnification.



a b

Figure 7 SEM Results of Sandwich Composite with 1000x magnification: a. Transverse direction, b. Longitudinal direction

In Figure 7, the SEM result of the sandwich composite with 1000x magnification for transverse direction shows that failure starts with the fiber breaking at the weakest cross-section of the fiber. Meanwhile, for the longitudinal direction, some voids are air bubbles trapped in the matrix that cannot be avoided during the composite lamination process.

3. RESULT AND DISCUSSION

According to previous research, the combination of basalt and glass fiber improves the strength and modulus of ramie fiber composites by increasing the load-bearing capability of the hybrids by including advanced fiber at their outer layers (Kapila et al., 2021). Based on the research results, it is appropriate and proven that the composite can improve its impact strength by including e-glass fibers. According to the goals of this research, hemp natural and e-glass synthetic fibers could be combined to increase the impact strength of composite materials because e-glass synthetic fiber has greater tensile strength and density with a value of 2000 - 4000 MPa and 2,55 g/cm3 when compared to hemp natural fiber with a value of 400-500 MPa and 1.4 – 1.6 g/cm3 respectively, while polypropylene has a density of 0.9 – 1.6 g/cm3 (Liu et al., 2017). Another goal to be achieved with the sandwich composite system using polypropylene honeycomb core can produce lightweight material properties when compared with composites without the use of sandwich systems such as hemp/PP composites which has a density of 1.534 g/cm3 (Sathish et al., 2021). Following the research results, the density of the hemp-PP honeycomb hybrid sandwich composite has a lower value with a value of when compared to the hemp-e-glass-PP honeycomb hybrid sandwich composite. Hybrid sandwich composite material properties have high impact strength and are lightweight; the results of the current study compared with the similar impact strength of natural fibers and natural fiber-e-glass hybrid sandwich composites available in the literature (Table 3).

Table 3 Comparison with other natural-glass fiber and hybrid sandwich composite systems

Material	Impact strength (J/mm²)
Kenaf fiber reinforced fiberglass hybrid composite withcore sengon laut sawdust (Agung M. et al., 2019)	0.009
Agave particle wood core sandwich composite (YudhantoF., 2015)	0.012
PP-glass-Aluminum sandwich composite (Ahmad A.,2015)	0.018
Hemp -Agave -Carbon - silicone rubber composite (Widi K.A. et al., 2021)	0.020

Therefore, based on Table 3, shows that hemp-e-glass-PP honeycomb hybrid sandwich composite has higher impact strength than other natural-glass fiber and hybrid sandwich composite systems unless hemp -agave -carbon - silicone rubber composite has equivalent values where each composite has a value of 0.020 J/mm². Besides that, the hemp-PP honeycomb hybrid sandwich composite and hemp-e-glass-PP honeycomb hybrid sandwich composite has a lower density value and will be an alternative material as a complement to pre-existing and conventional composite materials such as aluminum, plastic, and other composites and will be a new composite sandwich material so that it has the potential to be applied as a lightweight structural material that has good impact strength in the automotive, buildings, especially unmanned aerial vehicle industry. Besides that, it became more economical because hemp fibers were abundantly available, and these hemp fibers were cheaper in Indonesia.

The failure mode impact strength of sandwich composite in hemp-PP honeycomb composites, the form of failure that occurs is angled gage middle. This failure is usually caused by shear loads and uneven loading that occurs in the hemp-PP honeycomb composite specimen, which is first received by the matrix as a fiber protector and then distributed throughout the fiber surface in a 45-degree direction on the laminated upper and lower surfaces of the composite resulting in the occurrence of angled gage middle. Failure mechanisms in fiber composites are a function of the constituent properties, lamination geometry, and lamina level (uni-directional composite) according to the direction of the fibers placed on each composite's top and bottom surface layers at 45 degrees direction. Following research conducted by Weijermars (2016) shows that the balsa panels' core has some form of defect, probably delamination or debonding. Due to the balsa's out-of-plane shearing action, the core and skin appear to debond, and delaminations are produced by matrix cracks, which create the initial damage.

Delaminations may reduce the material's stiffness and the associated structure's stiffness. It could cause the structure to fracture catastrophically under impact load loading (Melaibari et al., 2022) for balanced angle-ply and angle-ply laminates. Failure Modes in Angle-Ply Laminates, the first ply failure is easily predictable at a 45-degree direction. The overall behavior of the composite laminate is intimately related to the internal stress distributions and load transfer between the constituent matrix and fibers. The fundamental failure modes include compressive or shear fracture of the matrix, bond failure at the fiber-matrix interface, and tensile or compressive failure of the fibers. These modes are not isolated or independent but can interact and trigger each other. Failures on the microscopic level within one ply can cause interplay failures (delaminations) and through-the-thickness total laminate failure. The second failure in the form of cracks parallel to the fibers of a ply occurs when the strain limit of the weakest ply (usually the one at 90-degree fiber direction).

In contrast, the 0-degree fiber direction can better withstand impact loads because it is perpendicular to the direction of the applied loading. These results follow research conducted by Sathyanarayana V. et al. (2016) which shows that due to the low resistance of a tape lamina to transverse cracking, the orientation of the 90° layer, which is the first ply in the ramped face sheet, against the core facilitates the beginning of failure. Verifying whether changing the ply orientation to 45° or 0° would cause higher failure loads would be interesting (Sathyanarayana V. et al., 2016).

Further, in hemp-e-glass-PP honeycomb, the failure mode of fiber breaking occurs in hemp-e- glass composite specimens. It shows the occurrence of good fiber and resin interfacial bonding in the composites. The tensile strength of natural fiber after hemp fiber after treatment NaOH 5% for 2 hours occurs due to increased fiber stiffness because of increased cellulose content and reduced content of other elements such as hemicellulose and lignin. As a result, the fiber-polymeric matrix's effective surface contact area increased in composites, resulting in appropriate interfacial adhesion across the interface through improved wetting, mechanical interlocking, and later chemical bonding between fiber and matrix resin (Shahril et al., 2022).

The failure mode impact strength of sandwich composite other unbroken is delamination and failure in the core that occurs because the center of the specimen receives the highest impact load, which results in peeling or delamination in the center of the specimen.

While the figure shows that failure mode to the composite core is damage that commonly occurs in sandwich structure composites when given an impact load, the failure usually occurs in the center of the specimen because it is the part subjected to the highest impact load. It is recognized that the overall behavior of the composite laminate is intimately related to the internal stress distributions and load transfer between the constituent matrix and fibers. The fundamental failure modes include tensile, compressive, or shear fracture of the matrix, bond failure at the fiber-matrix interface, and tensile or compressive failure of the fibers. These modes can interact and activate one another and are neither isolated nor independent. Failures inside a single ply can cause interplay failures (delaminations) and through-the-thickness total laminate failure. According to an earlier study, most energy during an impact event is absorbed by deflection and delaminations. The energy is also absorbed by matrix cracking, delamination, and fiber breakage (Fatima et al., 2021).

SEM result of the sandwich composite with 1000x magnification for the transverse direction that failure starts with the fiber breaking at the weakest cross-section of the fiber, which is the weakest, resulting in uneven fiber breaking. Only a small amount of matrix is attached to the fiber only a small amount of matrix adheres to the fiber. There are some fiber pull-outs; however, many fibers are still embedded in the epoxy matrix. It shows that the interfacial bonding between the fiber and the epoxy matrix is good enough. As for longitudinal direction, there are voids that are air bubbles trapped in the matrix. In other words, voids resulting from imperfections in the manufacturing process are seen as undesirable as they can reduce the mechanical properties and therefore reduce the lifetime of the finished composite. As defects, they can act as crack nucleation sites and, upon propagation of such cracks, can lead to unpredictable behavior and even catastrophic failure of the composite. Previous research shows that for sandwiches involving only carbon fibers, fiber breakage occurs on the compression side due to the low compressive strength of these fibers, and around them, some delaminations occur. The damage mechanism for the hybrid sandwiches is relatively similar, but it is considerably more restricted to the impactor/composite contact zone. As was already indicated, the deterioration starts at the top ply. It spreads to the lower layers, but because of the cork core, it is anticipated to stop at the composite/cork interface and cause significant delaminations above (Balogun et al., 2022).

4. CONCLUSION

The present study concludes that hemp natural- e-glass fibers hybrid sandwich/epoxy composites have a greater impact strength than hemp natural fibers hybrid sandwich/epoxy composites. However, the hemp natural fibers hybrid sandwich /epoxy composites have a lower density value when compared to hemp natural-e-glass fibers hybrid sandwich /epoxy composites. Therefore, by combining e-glass fiber, the composite can increase its impact strength. It can be a lightweight structural material as it is a new alternative material of hemp and e- glass natural fiber hybrid sandwich composites with polypropylene cores. Both sandwich hybrid composites have excellent mechanical properties compared with other natural-glass fiber hybrid composite systems. After that, both composites have an excellent potential to be developed further for application in the automotive, building, and crewless aerial vehicles industries.

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