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Research Article

Mechanical Properties of Sandwich Composite with Polyurethane Core Reinforced by Biaxial Geogrid and Carbon-Glass Fiber/Polyester as Skin

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ABSTRACT

The development of sandwich panels as structural materials is increasingly driven by the diversification of constituent materials. In this study, carbon-glass/polyester fibers were selected for the outer skins due to their high strength-to-density ratio, while polyurethane foam was used as the core for its lightweight characteristics despite its relatively low mechanical strength. To enhance the core's performance, two-way geogrid reinforcement was incorporated. The primary objective of this research is to investigate the effect of geogrid reinforcement and the influence of core thickness on the mechanical properties of the resulting sandwich composite, with particular emphasis on identifying the optimal geogrid configuration and core thickness that yield the highest structural performance. The novelty of this research is the addition of a geogrid used as a sandwich composite reinforcement. Variations in the number of geogrid layers and core thickness were examined. The composite sandwich panels undergo flexural and compressive tests. The results indicated that the composite with a core thickness of 50 mm and five layers of geogrid reinforcement exhibited the highest performance, achieving a flexural strength of 47.59 MPa and a shear stress of 1856.68 MPa. In contrast, one layer of geogrid achieved a flexural strength of 45.46 MPa and a shear stress of 1768.60 MPa. Similar results were observed in the composite compression tests, where the composite with five geogrid layers achieved a compressive strength of 0.18 MPa, significantly higher than the 0.12 MPa achieved with a single layer of geogrid. The decreasing distance between geogrid layers increases the core density, thus enhancing resistance to compressive loads. This material can be used as a structural material to withstand vibrations such as earthquakes.

1. Introduction

Sandwich panels as structural class composites have high rigidity and strength [1]. The constituent material, consisting of two surface sheets glued between the thicker cores, makes the sandwich panel lighter in weight than other composites. Skins are usually made of strong and rigid materials such as aluminum, steel, plywood, or fiber-reinforced resin. Several skin modifications have been made to increase the flexural strength of the sandwich panels [2]. This is due to the fact that when a sandwich structure undergoes bending, maximum stress occurs on its upper and lower surfaces. Therefore, high-strength skins are on the upper

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and lower layers of the sandwich. Conversely, the core material is characterized by a low elastic modulus and inherently low density [3]. The core material is usually wood, foam, or honeycomb [4].

This research uses a carbon-glass/polyester composite as a skin sandwich panel. The CGF/polyester composite was chosen due to the fact that the skin, which can withstand tensile and compressive loads, must be able to withstand the applied load [5]. The intentional incorporation of these two distinct fibers yields a composite material demonstrating a greater load-bearing capacity [6]. Moreover, the resulting material possesses a lower modulus of elasticity (or is less rigid) when contrasted with conventional engineering metals such as iron and aluminum [7, 8]. In comparison to plywood or fiber-reinforced resin systems, carbon-glass/polyester composites demonstrate a greater capacity to withstand applied loads. Carbon and glass fibers, as synthetic fibers, clearly have a higher tensile strength than other fibers [9]. The fiber used must have a low density because, as a construction panel, it requires a lightweight material. The core used is a medium-density foam, namely polyurethane [10, 11]. The choice of polyurethane as the core is because it considers the maximum shear force that occurs in the center of the sandwich panel during loading [12]. The selection of polyurethane foam cores also has advantages in terms of weight and stiffness of the sandwich panels. The materials used give sandwich panels the advantages of strength, safety, weight, durability, corrosion resistance, dent and puncture resistance, weather resistance, and cost [13]. From these advantages, polyurethane foam is widely used as an insulating material for furniture, cooling and freezing systems, house construction, etc., because it has trucyural flexibility.

But the polyurethane core has strength only in that range of 2-3,03 MPa [14, 15]. Reinforcement such as banana fiber is also not sufficient to withstand the load properly, with the highest yield of 11.21 MPa [16]. This problem causes sandwich panels to lack high strength. In another study, cellular wood and plywood are quite able to withstand the load, but the weight tends to be higher [17]. The addition of nanoclay to sandwich composites can increase flexural strength by up to 34% and shear strength by up to 51% [18]. This can be overcome by using reinforcements in the polyurethane core, such as polyester strimin [9]. Geogrids, as polymer products formed from intersecting rib connections, have strong potential as reinforcement for sandwich composite cores [19]. Between the intersecting ribs formed an open space measuring one inch. The materials used in geogrids are usually polypropylene (PP), high-density polyethylene (HDPE), and polyester (PET) [20]. Geogrids have been commonly used as highway reinforcement to stabilize asphalt or casting. Geogrid has a high tensile strength in the longitudinal and transverse directions. Therefore, the geogrid has strong and stable mechanical performance. Geogrids have the potential to be reinforcements in sandwich composites based on their properties and capabilities. So this study uses geogrids as reinforcements for sandwich composites. The good ability of geogrids can be utilized to withstand loads on sandwich composites.

This study aims to enhance the performance of sandwich composites by reinforcing the polyurethane core with biaxial geogrids. The research hypothesis posits that the incorporation of geogrids will improve flexural strength and inhibit crack propagation within the composite core. Additionally, the researchers intend to examine the effects of core thickness and the spacing between geogrids on the mechanical properties of the composite. Specifically, this study will analyze how the addition and strategic placement of geogrids can optimize stress distribution within the composite and increase its load resistance. Consequently, this research is expected to contribute to the development of stronger, lighter, and more durable sandwich composite materials for various industrial applications

2. Materials and Methods

2.1. Materials

The research began by preparing the equipment and materials used. Polyester Yukalac 157 and Polyurethane were obtained from Justus Kimiaraya Indonesia. Carbon Fiber and Glass Fiber from PT Karyatama Indonesia. While Geogrid was obtained from PT Nusa Indonesia. The skin is made of carbon fiber and glass with a Yukalac Polyester 157 matrix. The core uses Tosoh Millionate foam, which is printed by mixing PU A (Millionate MR-200), namely polyisocyanate, and PU BB (JKR-7631L), namely polyether, in a ratio of 3: 2. The skin and core are combined by gluing on both sides of the skin. Gluing uses Sikaflexx 255 FC to better glue the skin interface. Material Properties of Sikaflexx 255 FC are presented in Table 1.

2.2. Manufacturing Process

The skin is manufactured using the hand lay-up method with 1 layer of woven carbon fiber and glass fiber. Combined with polyester, this results in a skin thickness of 2 mm. While the manufacture of the core begins by installing a biaxial geogrid on the mold with the number according to Table 2. The geogrid is installed in various ways to see the effect of the addition to the scheme in Figure 1(a). The biaxial geogrid uses PP material with the specifications described in Table 1. Figure 1(b) shows the Biaxial Geogrid used as a polyurethane reinforcement [9]. After bonding, the sandwich composite was cut according to the C393 test standard. The results of the sandwich composite ready for testing are shown in Figures 1(c) and (d). Figure 1(c) shows samples for flexural testing with different polyurethane core thicknesses. Meanwhile, Figure 1(d) shows samples for compression testing.

Table 1. Properties of Skin, Core, Geogrid, and Bond

Properties	Skin	Core	Geogrid	Bond
Material	Carbon/Glass Polyester	Polyurethane	Polypropylene	Polyurethane
Ultimate Tensile Strength (kN/m)	55	2.5	20	5
Peak Strain (%)	1.2		13	50
Load at 2% Strain (kN/m)			7	
Density	1.6 (g/cm^3)	0.068 (g/m^3)	230 (g/m^3)	1.31 (kg/l)
Flexural Rigidity (mg-cm)			1090000	
Aperture Stability (m-N/deg)			0.7	

Table 1. Core Thickness Variation Code in Sandwich Composites

Sample Code	Skin Thickness (mm)	Number of Geogrid	Core Thickness (mm)
S1	2	0	50
S2	2	1	50
S3	2	3	50
S4	2	5	50
S5	2	5	75
S6	2	5	100

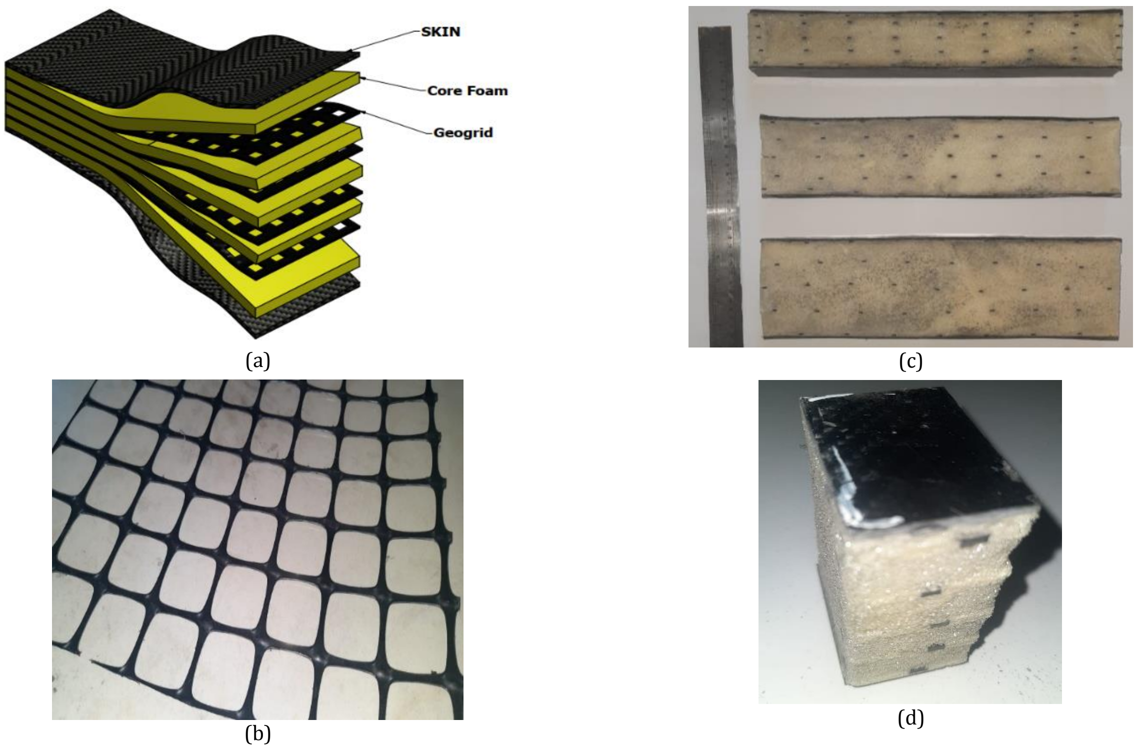


Fig. 1. Sandwich Composite Material with (a) geogrid installation diagram; (b) two-way geogrid image; (c) sample for flexural testing; (d) sample for compression testing.

2.3. Experiment Setup

The carbon fiber polyester sandwich composite with a polyurethane core was tested to determine its mechanical properties. Composite testing in the form of flexural test and compressive test. The bending test refers to the ASTM C393 test standard for sandwich panels. The flexural strength, shear stress, and bending moment of the sandwich composite are calculated by the formula :

$$\sigma_b = \frac{PL}{2t(d+c)b} \quad (1)$$

$$\tau = \frac{P}{(d+c)b} \quad (2)$$

$$M = \frac{PL}{4} \quad (3)$$

where σ_b : sandwich flexural strength (MPa); τ : sandwich shear stress (MPa); M: bending moment (N · mm); P: load (N); L: span length (mm); b: width (mm); c: core thickness (mm); d: thickness (mm); t: skin thickness (mm). Figure 2 shows the dimensions of the test specimens.

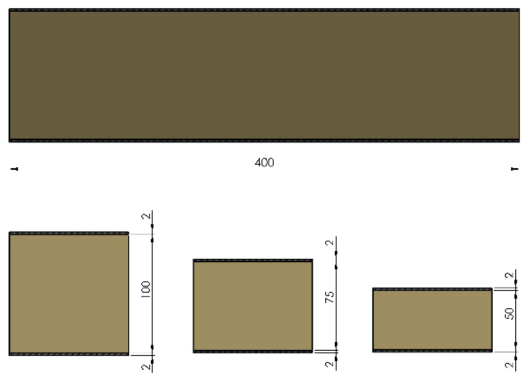


Fig 2. Test Specimen Size ASTM C393-06

Sandwich composite compression test by following the ASTM C365 test standard. The test uses a universal testing machine with a small cube-shaped sample. Tests were carried out to determine the compressive strength and modulus of elasticity of the sandwich composite structural design. Each specimen is placed under the loading plate to ensure uniform load distribution. All specimens were tested under displacement control at a constant speed of 0.5 mm/min. The test was conducted by repeating each variation on five specimens to minimize errors and ensure the accuracy of the results.

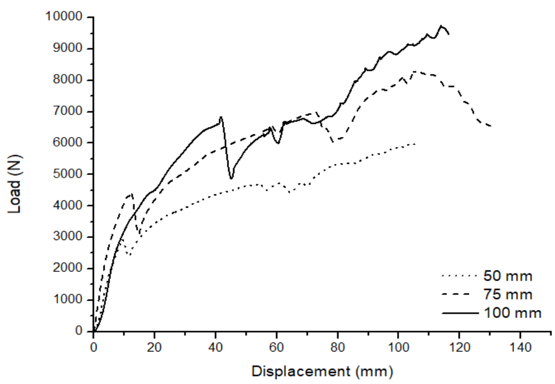
3. Results and Discussion

3.1. Flexural Strength of Sandwich Composite

The results of the sandwich composite flexural testing are shown in Figure 3. The flexural testing graph is shown in Figure 3 (a), which shows that a greater core thickness is able to withstand a greater load. This is in accordance with the research by Ardiyanto et al. (2015), which shows that a thicker core increases resistance to loads. The results of the sandwich composite testing with varying thicknesses are presented in Figure 3 (a) with a core thickness of 50 mm, Figure 3 (b) with a core thickness of 75 mm, and Figure 3 (c) with a core thickness of 100 mm.

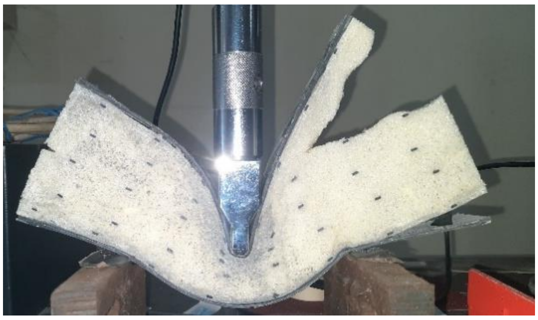
The flexural strength test graph shows several peaks. In all thickness variations, the first peak indicates cracking in the top layer due to compressive stress. This is caused by the inability of the skin layer to withstand the stress it receives due to insufficient strength. In the 50 mm and 75 mm thickness variations, the second peak occurs due to cracking in the bottom layer due to tensile stress. The continuous pressure received by the sample causes failure in the bottom skin layer [22]. At a thickness of 100 mm, there is delamination caused by lateral stress. This can be seen in Figure 3(c), which shows skin wrinkling failure.

The difference in core thickness causes different failure phenomena. In the 100 mm core, delamination failure occurred at the beginning of the response to the load received. Delamination between the core and the skin shows that the small core thickness value causes the interface to be unable to receive shear loads. A larger core thickness is still able to withstand the shear test specimens received [21].



(a)

(b)



(c)

(d)

Fig. 3. (a) Load-Displacement Graph with core thicknesses of (b) 25 mm, (c) 50 mm, and (d) 100 mm.

At thicknesses of 50 mm and 75 mm, cracks were observed on the sides, indicating failure of the polyurethane core shear. Biaxial geogrid reinforcement is strong enough to withstand the load received by the sample so that the applied stress in the polyurethane does not cause damage. The failure occurred in the sample due to the lack of strong interfacial bonding of the skin and core, which caused the skin to peel off [23]. The flexural test results are presented in Figure 3 (b), which shows several cracks visible due to the load received by the sandwich composite. This failure phenomenon differs from sandwich composites with polypropylene honeycomb cores and polypropylene-glass fiber skins, which exhibit bending failure in composites [24].

The test results of sandwich composites reinforced with geogrid reinforcement are shown in Table 2. The test results show that geogrid reinforcement is proven to be able to increase the flexural strength of sandwich composites by 63.4%, with the highest yield of 47.59 MPa. This result was followed by an increase in shear stress and bending moment, which increased 63.4% and 64% of sandwich composites that did not use geogrid reinforcement.

The modification did not result in a substantial enhancement of the panel's bending stiffness. This is due to the relatively similar size of the specimens, resulting in almost identical composite sandwich stiffness values. This result is higher than that of sandwich panel composite with strimin polyester reinforcement, which has the highest bending strength value of 39.07 MPa [9]. The test results are higher than those of unreinforced composites, which show resistance to loads up to 5750 N. In addition, unreinforced composites show fracture failure in the middle due to stress that is not supported by the reinforcement [12].

However, even though the load-bearing resistance is higher, the flexural strength of the sandwich panels tends to decrease with thicker cores. Table 3 shows that the flexural strength of the composite decreased from 47.59 MPa to 32.53 MPa. This is due to the higher dimensions of the sandwich panels. High dimensions will increase the bending moment of the sandwich panel, which is inversely proportional to the flexural strength. This result is similar to that of Dhaliwal and Newaz (2020), which shows that increasing the dimensions of the sandwich composite can increase the material's resistance to withstand loads. This is evidenced by an increase in the bending moment of 41.6%. This increase indicates that the sample becomes stiffer. This is reinforced by the results of testing on the panel bending stiffness, which has increased by 574.15%.

Table 3. Flexural Properties of Composite Sandwich

Specimens code	Flexural Strength (MPa)	Shear Stress Core (Mpa)	Bending Moment (N.mm)	Panel Bending Stiffness (N.mm2 x 106)
S1	29.11	1136.22	139.90	315.13
S2	45.46	1768.60	218.11	315.16
S3	45.71	1790.71	220.10	315.13
S4	47.59	1856.68	228.68	315.13
S5	38.95	1516.38	274.95	949.71
S6	32.53	1274.13	304.07	2124.46

3.2. Compressive Strength of Sandwich Composite

The tests were carried out until the load-displacement curve showed a collapsed structure with very high deformation. The results of the sandwich composite compressive strength test are presented in Figure 4. The first part of the graph, it shows that the loading is still linear up to a displacement deformation of 35 mm. After that, the collapse of the sample causes density in the polyurethane core. The number of 5-layer geogrids shows a sudden and very high increase. This is due to an increase in foam density as the load increases [25]. Foam that can no longer accept the compressive load causes the load to increase. At higher core thickness, the displacement increases due to a greater distance in loading until the core density increases. This causes the deformation of the composite to increase [26].

Based on the test results, the composite with 5 layers of geogrid has a higher resistance to compressive loads than other variations. This is related to the greater amount of geogrid reinforcement in the composite. The number of geogrid reinforcements will have an impact on the distance between geogrids. The smaller distance between geogrids causes the density of the polyurethane core to increase. However, for the number of geogrids 0, 1, and 3, the distance between the geogrid reinforcements is greater, so that the resistance to withstand the load becomes low. Conversely, an increase in core thickness corresponds directly to a greater separation distance between the geogrid reinforcements. This makes resistance to load lower. This result is similar to previous research that tested the amount of reinforcement in sandwich composite cores. The smaller amount of geogrid causes density in the core, so that the material's resistance to receiving high loads [9].

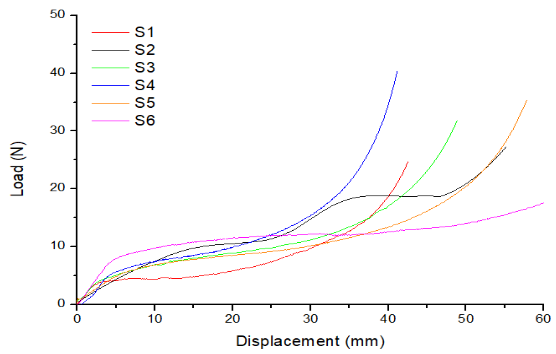


Fig. 4. Load-Displacement Compressive Test of Sandwich Composite

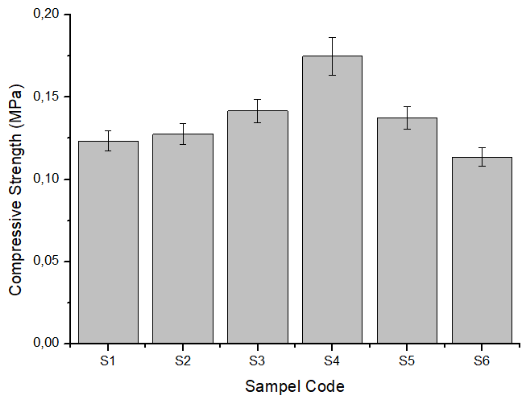


Fig. 5. Compressive Strength of Sandwich Composite

The results of the compressive strength of the sandwich composite are presented in Figure 5. Based on the graph, it can be seen that the highest yield occurred in samples with a 5-layer geogrid. Sample S4 shows compressive strength up to 0.17 MPa. This is related to the large number of geogrids. Samples that do not use geogrids only have a compressive strength of 0.123 MPa.

These results indicate that the number of geogrids with a low core thickness causes the distance between geogrids to become smaller, which has an impact on the density and ductility of the composite. Meanwhile, at a higher core thickness, the compressive strength decreased to 0.113 MPa. This is due to the fact that, with the same number of geogrids but greater thickness, the distance between geogrids becomes greater. Figure 6a shows a sample that has not received a compressive load.

After the compressive load is applied to the sample, it can be seen in Figure 6b that there is a buckling failure. This is influenced by the increase in thickness and number of geogrids. The greater the thickness of the foam, the higher the deformation of the material [2].

This indicates that there is deformation due to compressive loads, which causes the sample to fail to bend. The failure in Figure 6b occurs at a displacement of 35 mm to 40 mm. This buckling failure resulted in the sample collapsing and compacting.

The use of geogrids in sandwich composites is an innovation that can provide a solution to increase the strength of sandwich panels. The results show that the strength of sandwich composites increases with the addition of geogrids. The increase is much higher compared to polyester strimin reinforcement [9].

(a)

(b)

Fig. 6. The Composite (a) before compressive test and (b) deformed under compressive test

4. Conclusions

This study addresses the main challenge of polyurethane-based sandwich composites, namely, low mechanical strength despite their light weight. Test results show that reinforcement with biaxial geogrid significantly increases flexural strength (up to 47.59 MPa with 5 layers of geogrid), shear resistance, and composite stiffness. This improvement in performance stems from the geogrid's ability to distribute loads evenly and reinforce the core, while delaying failure due to delamination, the main mechanism of damage in sandwich composites. Scientifically, these findings show that geogrids not only function as passive reinforcements but also transform the polyurethane core into an active structural component. This composite has the potential to be used as wall panels or non-structural elements in earthquake-resistant construction, thanks to its combination of lightness, strength, and energy absorption capabilities. The addition of an optimal biaxial geogrid overcomes the strength limitations of the polyurethane core, making this sandwich composite suitable for earthquake-resistant building applications that require lightweight yet durable materials.

Nomenclature

σ_b	Sandwich composite flexural strength
P	Load
L	Span length
t	Skin thickness
d	Thickness
c	Core thickness
b	Width
τ	Sandwich composite shear stress
M	Bending Moment

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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