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Mechanical Properties of Sandwich Composite using Glass Fiber Reinforced Polymer as A Skin and 3D Printed Polylactic Acid as A Core

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Muhammad Ridlwan[1], Faisal Arif Nurgesang[1], Rahmat Riza[1] and Nur Muhammad Syafi'i[1]

[1]Department of Mechanical Engineering, Islamic University of Indonesia, Indonesia

Corresponding author:
Muhammad Ridlwan
Department of Mechanical Engineering, Islamic University of Indonesia, Indonesia
Email: ridlwanm@uii.ac.id

Abstract

Recently, 3D printing technology has become a practical method to realize products rapidly. It is suitable for making small quantities of products. Although it is capable of printing with a high level of geometric complexity, there is a lack of tensile strength due to its process where the products are printed layer by layer. However, this technology is potentially to be combined in a composite manufacturing process. Mostly, a composite product is made by using a mold. This mold is relatively expensive and can only create a product with less complexity. Nevertheless, the composite product has main advantages such as light, strong, and flexible. Therefore, combining these two technologies is a new breakthrough in realizing products with high complexity, light, strong, and flexible. This study aims to determine the mechanical properties of sandwich composite filled with 3D printed product as a core. Several parameters were varied including core thickness and skin thickness. The skin material was a Glass Fiber Reinforced Polymer (GFRP) while the core material was 3D printed Polylactic Acid (PLA). The tensile and bending tests have been done in accordance with ASTM D638 and ASTM D790. The results showed that the addition of GFRP skin on the sandwich composite could significantly increase the tensile strength but did not have an impact on the flexural strength. The highest flexural strength of 50.36 MPa was achieved at 3 layers of GFRP skin while a remarkable tensile strength of 55.74 MPa was obtained at 4 layers GFRP skin. Moreover, the addition of core thickness also does not have an impact on flexural strength. The flexural strength of the 3D printed core was around 20 MPa for all thickness. However, when 2 layers of GFRP skin were used, a remarkable flexural strength of 57.67 MPa was obtained but the flexural strength was then decreased when using 10 and 15 mm cores.

Keywords: *3D printing, composite, sandwich composite*

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INTRODUCTION

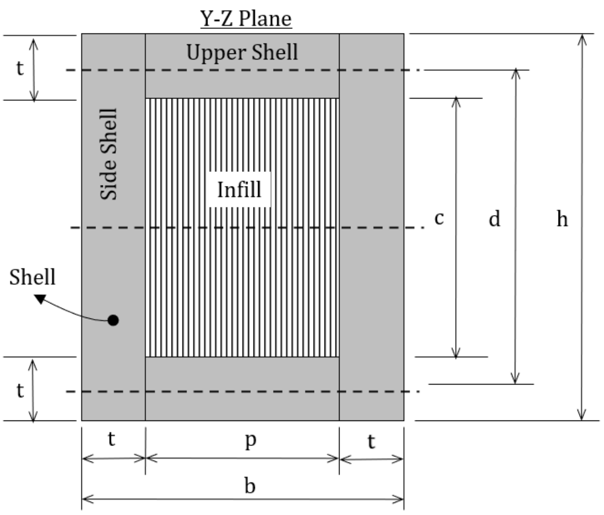
3D printing is a new promising technology that can create products rapidly [1-4]. Compared to other manufacturing processes, 3D printing is more suitable for making small quantities of products. It can fabricate products with a high level of geometric complexity. One of the most widely used 3D printing technologies is Fused Deposition Modeling (FDM) which uses various polymeric materials as filaments such as Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polyethylene Terephthalate (PET), Nylon, and Polycarbonate (PC) [5-6]. Currently, there are 16 kinds of filament materials that can be used in the FDM process which provides flexibility in making products [5]. However, the value of tensile and bending strength is still relatively low compared to other engineering material products [8-9]. To date, 3D printing products have not been widely used directly in mechanical products. They are still limited to visualizing models or prototypes [1]. However, some work has been carried out to improve the strength of 3D printing product by combining different types of filaments in one product and using nanoparticle technology in the filament itself [5].

On the other hand, composite technology is a manufacturing process which can produce a lightweight and strong product. These advantages can easily be achieved by adjusting the type of matrix and reinforcement agent such as glass fiber, carbon fiber, and Kevlar [9-11]. These reinforcing agents are increasingly being used in modern products. In some cases particularly composite products with a large size, in order to increase flexural rigidity, a core such as honeycomb or lantor soric was used [12-13]. This kind of composite is called a sandwich composite [14]. The combination of these two technologies provides an opportunity that the geometry and mechanical properties of the product can be designed more flexibly according to its use in mechanical systems. However, mechanical properties of this composite depend on many factors such as number of skin layers, the bond between the skin and the core, infill type and type of filament. In this study, these factors were investigated. Some works have been reported that the impact strength of sandwich composites depends on the mechanical properties of the skin composite sheet and the bond between the skin and the core. This skin sheet significantly absorbs impact energy [8]. The bonding between the skin and the core using adhesive bonding also has the advantages of easier adhesion, weight reduction, lower stress concentration and more homogeneous stress distribution [15]. Moreover, a study on the mechanical properties of sandwich composite prepared using 30% infill was reported. It uses PLA filament as the core with various infill types. They have shown that the full honeycomb was the highest flexural strength compared to other infill types. Nevertheless, when using 20% infill, the modulus of elasticity still increases [16]. Another study also reported that a re-entrant honeycomb has better ability to absorb the energy compared to truss and conventional honeycomb. They have concluded that the core structure design can be used to increase the bending stiffness properties and estimate the failure mechanism of sandwich composites [17]. In its application to engineering, sandwich composites are subjected to various mechanical loads, such as compressive, tensile, flexural, shear, and torsional loads. Sometimes, the mechanical load experienced by this material exceeds its design load causing the sandwich composite to fail. The types of failure that can occur in sandwich composites such as face yield, face wrinkling, debonding, core crushing, core shearing, and core tearing [18].

In composite production, there are various methods to realize it. One of the easiest ways to produce the composite is the hand lay-up method. This method is inexpensive and simple. But there is still a weakness where some pores can obviously be seen. A better method in making composite is a Vacuum Infusion Process (VIP). This method uses vacuum to infuse the resin into the matrix. The vacuum process can eliminate the pores so a higher strength can be achieved. A study was reported that using the vacuum process gains a higher strength than that of the hand lay-up method [19]. Therefore, this study aims to investigate the mechanical properties of composite sandwich using 3D printing product as a core produced using Vacuum Infusion Process (VIP).

MATERIALS AND METHODS

Materials used in this study were Polylactic Acid (PLA) filament with diameter of 1.75 mm, Glass Fiber Reinforced Polymer, Resin Polyester, and Catalyst. The sandwich



$A_{shell} = (b \times h) - (p \times c)$

$A_{infill} = \rho_{infill} \times p \times c$

$A_{3DP\ Core} = A_{shell} + A_{infill}$

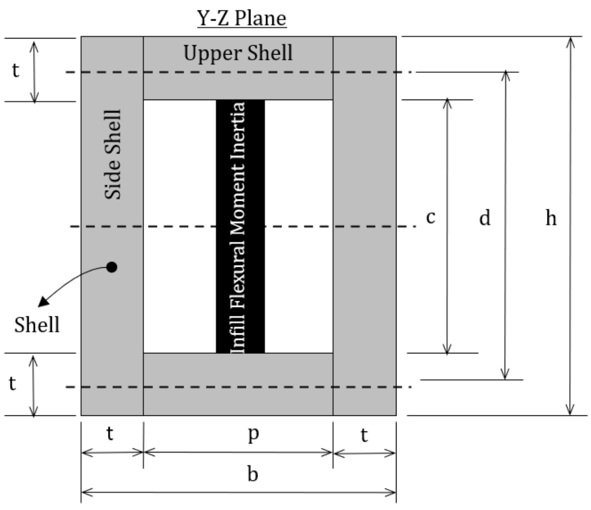
$p = b - 2 \times t$

$c = h - 2 \times t$

h = 3DP core thickness

b = 3DP core width

t = 3DP core shell thickness



$$I_{3DP\ Core} = 2 \times I_{upper\ shell} + 2 \times I_{side\ shell} + I_{infill}$$

$$I_{upper\ shell} = \frac{p \times t^3}{12} + \frac{p \times t \times d^2}{4}.$$

$$I_{side\ shell} = \frac{t \times h^3}{12}$$

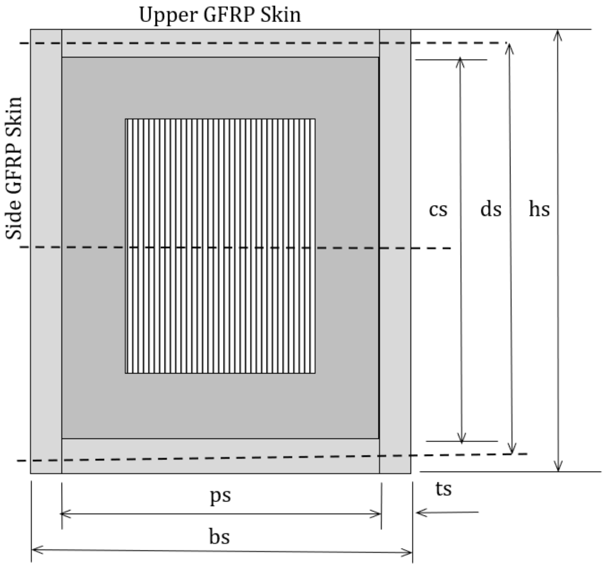
$$I_{infill} = \frac{\rho_{infill} \times p \times c^3}{12}$$

$p = b - 2 \times t$

$c = h - 2 \times t$

$d = h - t$

Figure 1. Proposed approach of calculating the effective area and moment inertia of the core



$A_{sandwich} = A_{skin} + A_{3DP\ core}$

$A_{skin} = (bs \times hs) - (ps \times cs)$

$ps = bs - 2 \times ts$

$cs = hs - 2 \times ts$

$ds = hs - ts$

hs = Sandwich composite thickness

bs = Sandwich composite width

ts = GFRP skin

$ts = (hs - h)/2$

$I_{sandwich} = 2 \times I_{upper\ skin} + 2 \times I_{side\ skin} + I_{3DP\ Core}$

$$I_{upper\ skin} = \frac{ps \times ts^3}{12} + \frac{ps \times ts \times ds^2}{4}.$$

$$I_{side\ shell} = \frac{ts \times hs^3}{12}$$

Figure 2. Proposed approach of calculating the effective area and moment inertia of the sandwich composite

composite was made using the Vacuum Infusion Process (VIP) where the design of the experiment is shown Table 1. The cores were printed using a 3D printer (Prusa i3 model). The infill type of the cores was honeycomb. The specimens were tested in compliance with ASTM D790 for bending test and ASTM D638 for tensile test. These tests were done using a Universal Testing Machine (UTM) and there are three repetitions for each parameter.

Table 1. Design of experiment of sandwich composite made using VIP method

Method	**Parameters**					
	GFRP Layer Skin Thickness (mm)	Core Thickness (mm)	Core Infill (%)	Printing Speed (mm/s)	Layer Height (mm)	Extruder Temperature (°C)
VIP	0, 2, 3, 4	5, 10, 15	20	50	0,2	200

Sandwich composite is slightly different in terms of effective area and moment inertia compared to solid bodies. To calculate the effective area and moment inertia of sandwich composite accurately, an approach was proposed as illustrated in Figure 1 and Figure 2. This approach was then used to calculate flexural strength of the core and the sandwich composites.

RESULTS AND DISCUSSIONS

Effect of GFRP skin layer on the flexural strength of sandwich composite prepared using 10 mm 3D printed product as a core is presented in Figure 3. It is showed that with the use of 20% infill, 10 mm of a core without any GFRP layer, the flexural strength was only 24.44 MPa. An increase of flexural strength of 33.66 MPa was obtained when using 2 layers of GFRP skin while the highest flexural strength as high as 50.36 MPa was achieved at 3 layers of GFRP skin. In these sandwich composites, a failure mode in the 3D printed core was core shearing. At 2 layers of GFRP skin, the failure on the core was obviously seen compared to 3 layers of GFRP skin as depicted in Figure 4(a) and Figure 4(b). However, sandwich composite with 4 layers of GFRP skin, the flexural strength decreased drastically to 18.11 MPa. This decrease occurs because the skin was too stiff so that the bending load received by the core was quite large. The 3D printed core experienced a core crushing failure, which then spread to the interface between the core and the bottom composite skin, resulting in rapid debonding as can be seen in Figure 4(c).

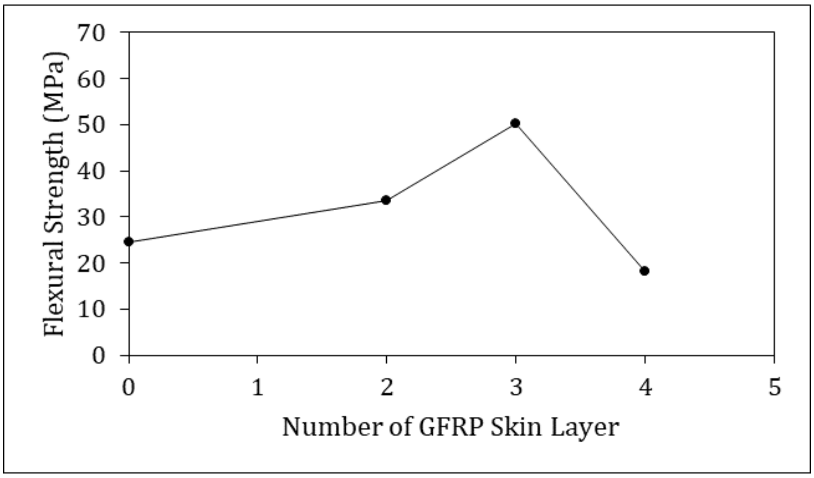


Figure 3. Flexural strength of sandwich composite produced with different layer of GFRP skin

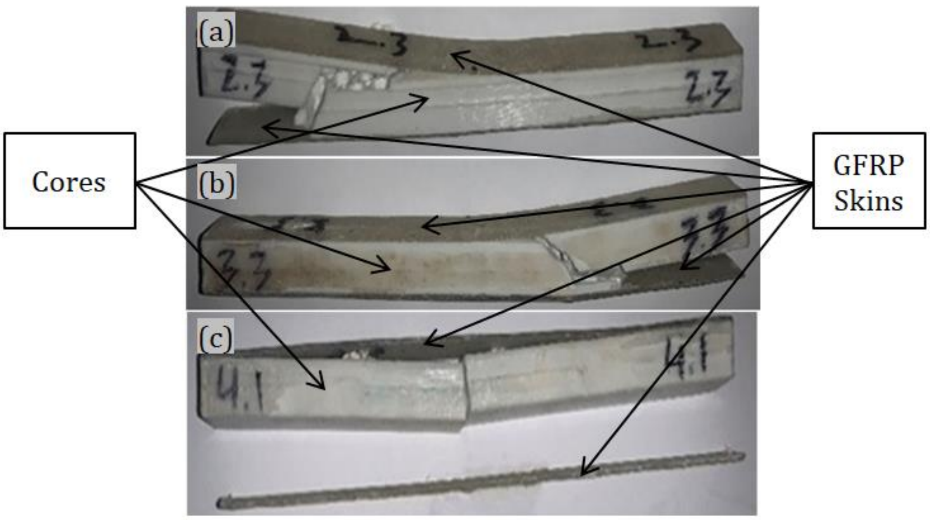


Figure 4. Failure mode of sandwich composite after subjected to bending load with variation of GFRP skin for a) 2 layers, b) 3 layers, and c) 4 layers

In addition, specific flexural rigidity of sandwich composite produced with different layers of GFRP skin is presented in Figure 5. It shows that the flexural rigidity increases when the core is layered with GFRP skin. However, at 4 layers of GFRP skin, the specific flexural rigidity was lower compared to 2 and 3 layers of GRFP skin. This is caused by the thickness of the GFRP skin. It was too thick so the sandwich composite became rigid.

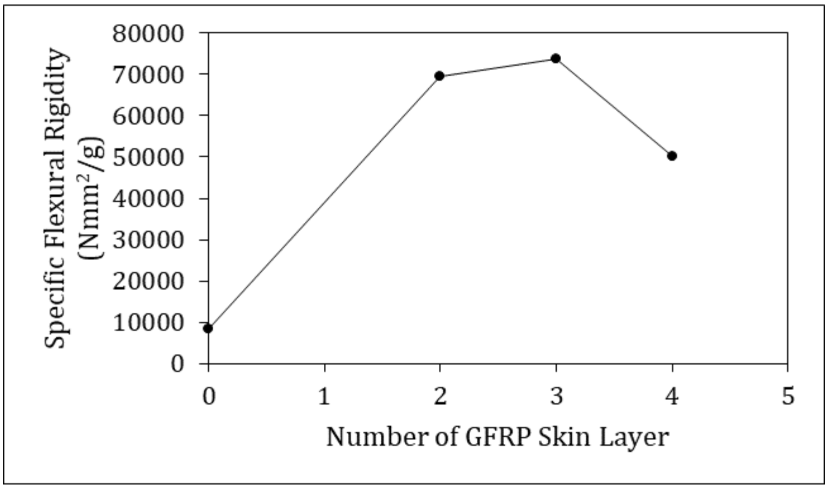


Figure 5. Specific flexural rigidity of sandwich composite produced with different layer of GFRP skin

Tensile strength of sandwich composite shows an increase as the number of GFRP skin layers increases (see Figure 6). Tensile strength of the core without GFRP skin was only 21.83 MPa. An escalation of strength was seen at 2, 3, and 4 layers of GFRP skin where the tensile strength was 39.75, 44.57, and 55.74 MPa respectively. Number of GFRP skin layers plays an important role in tensile load. When the sandwich composite is subjected to the tensile load, GFRP skin restrains the load so that its tensile strength can be increased. Therefore, it can be concluded that the number of GFRP skin strengthen the sandwich composite for tensile strength but not the flexural strength particularly at 4 layers of GFRP skin.

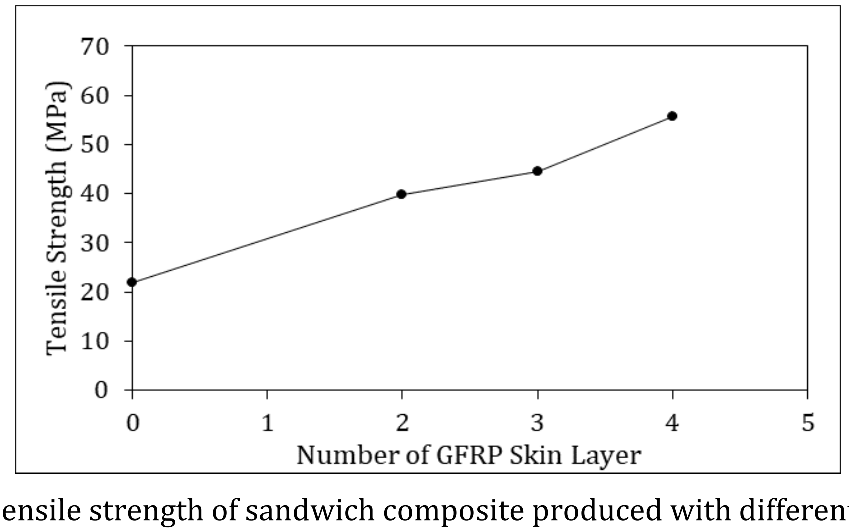


Figure 6. Tensile strength of sandwich composite produced with different layer of GFRP skin

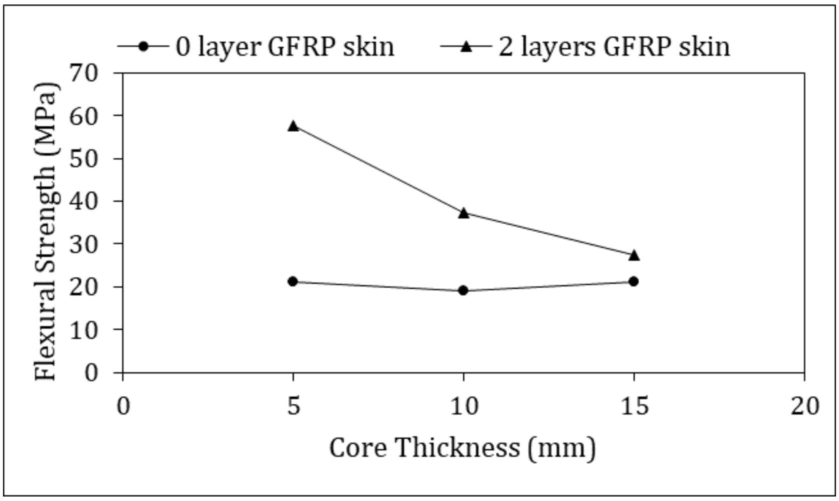


Figure 7. Flexural strength of sandwich composite produced with different core thickness

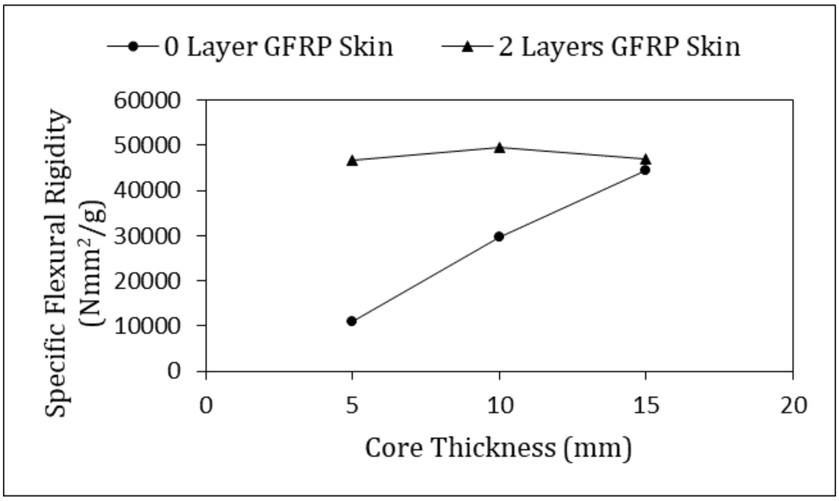


Figure 8. Specific flexural rigidity of sandwich composite produced with different core thickness

Effect of core thickness on flexural strength of sandwich composite is presented in Figure 7. It shows that the flexural strength of sandwich composite with 0 layer GFRP skin was around 20 MPa for all thickness. To the contrary, when 2 layers of GFRP skin were used, a remarkable flexural strength of 57.67 MPa was obtained. However, the flexural strength was then decreased when using 10 and 15 mm cores. The decrease in flexural strength with the increase in core thickness is caused by the core itself. When the thickness of the core increases, the cross-sectional area of the cavities also increases, resulting in lower flexural strength. The addition of core thickness can withstand bending loads much stronger. This is caused by the value of bending moment inertia of the cross section (I) of the sandwich composite increases. The stiffer core can support the upper skin so that it is not easily deflected and transmit the bending load to the lower skin where the bending load is divided into compressive loads on the upper skin, shear loads on the core, and tensile loads on the lower skin.

Moreover, specific flexural rigidity of sandwich composite produced with different core thickness is presented in Figure 8. It shows that the flexural rigidity of the 3D printed core (0 layer GFRP skin) increases as the thickness increases. Nevertheless, the flexural rigidity of sandwich composite produced with 2 layers of GFRP skin was almost the same around 46.000 Nmm^2/g.

Failure mode of composite sandwich produced with several variation of core thickness is presented in Figure 9. It showed that the failure mode of sandwich composite is mostly core shearing followed by debonding. The debonding is the failure of the bond between the interface of the skin and the core. The upper and the lower skins have high tensile strength and stiffness, so the bending load in the form of vertical shear stress held by the core is quite large. Moreover, it was reported from previous work that the core thickness affects the failure mode. The thicker the core, the failure mode changes to core crushing [18].

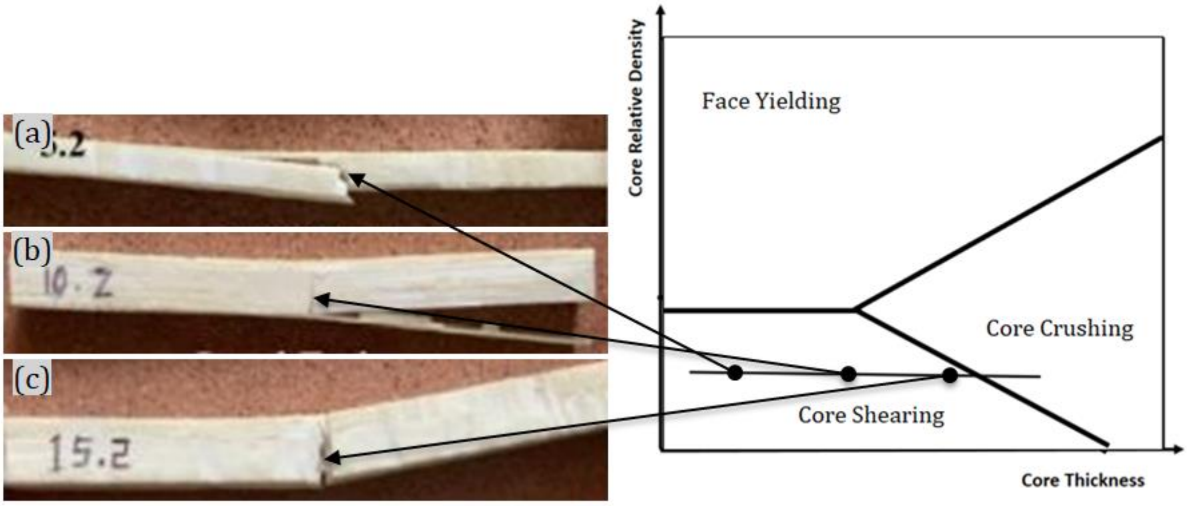


Figure 9. Failure mode of sandwich composite after subjected to bending load with variation of core thickness; a) 5 mm, b) 10 mm, and c) 15 mm

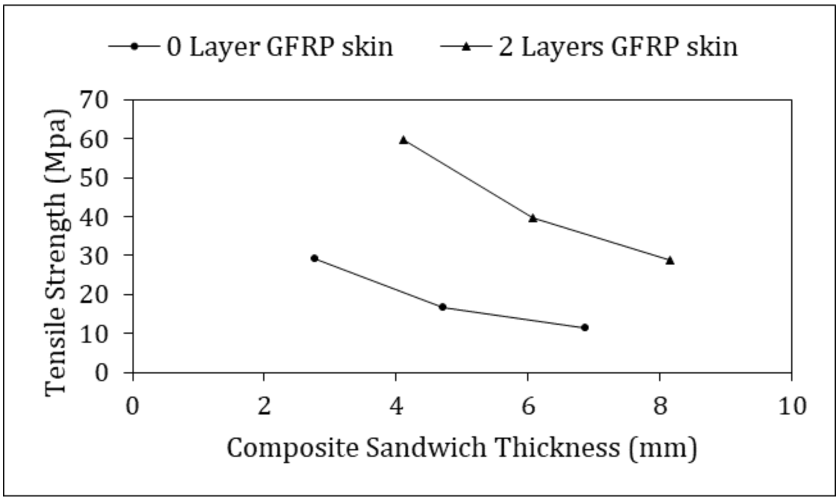


Figure 10. Tensile strength of sandwich composite produced with different core thickness

Tensile strength of sandwich composite made with different core thickness is presented in Figure 10. The tensile strength of 3D printed core only (0 layer GFRP skin) decreases as the thickness increases. The hollow shape of the honeycomb infill and the low interlaminar layer shear strength are the factors that make the tensile strength were low. Thus, the addition of core thickness does not increase the tensile strength. This trend was also seen in composite sandwiches produced with 2 layers of GFRP skin. However, the tensile strength was 2 times higher compared to that of a 3D printed core only. The GFRP skin increases the ability to withstand the tensile loads.

Based on the results of bending and tensile tests that have been done, parameters that affect the mechanical properties of sandwich composites with 3D printing product and GFRP skins is illustrated in Figure 11.

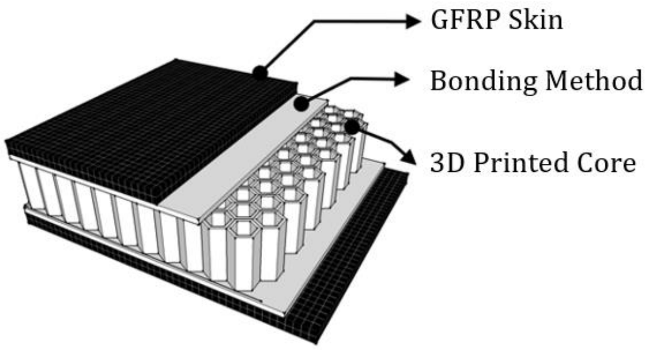


Figure 11. Parameters that affect the mechanical properties of sandwich composites

The tensile strength of sandwich composites is significantly affected by the strength of the skin while the bending strength of sandwich composites is influenced by the role of the stiffness of the core. Another parameter that influences on mechanical properties is bonding method. When using Vacuum Infusion Process (VIP) in making sandwich composite, the bonding between 3D printed core and the GFRP skin was strong enough. It plays important role in reducing debonding between the core and GRFP skin.

CONCLUSIONS

Research to investigate the mechanical properties of sandwich composite using 3D printing products as the core has been done. Based on the results, the addition of GFRP skin can significantly increase the tensile strength of sandwich composite. A remarkable tensile strength of 55.74 MPa was obtained when using 4 layers of GFRP skin. However, the addition of GFRP skin thickness did not have an impact on the bending strength of the sandwich composite. In these sandwich composites, a failure mode in the 3D printed core was core shearing and core crushing. Moreover, the addition of core thickness also does not have an impact on flexural strength. The flexural strength of 3D printed core was around 20 MPa for all thickness. However, when 2 layers of GFRP skin were used, a remarkable flexural strength of 57.67 MPa was obtained but the flexural strength was then decreased when using 10 and 15 mm cores. The decrement in flexural strength with the increase in core thickness is caused by the core itself. When the thickness of the core increases, the cross-sectional area of the cavities also increases resulting lower flexural strength.

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DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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