JOURNAL OF
MATERIALS PROCESSING
&CHARACTERIZATION

The Effect of Clay Addition on the Mechanical Strength of Unsaturated Polyester Hybrid Composite Reinforced with Woven Agel Leaf Fiber/Glass Fiber

O. D. Setiawan*
Kusmono
Jamasri

Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada. Jl. Grafika 2, Yogyakarta 55281, Indonesia

Email:
*orisantodarmasetiawan@gmail.com

Keywords
woven agel leaf fiber, chemical treatment, unsaturated polyester, clay, mechanical testing.

Abstract

In the field of material technology, natural fiber materials are candidates for reinforcement in the production of lightweight, high-strength, environment-friendly, economical composites. Hybrid composites are comprised of a variety of reinforcement, fillers, and polymers. The objective of this research was to figure out the effect of clay addition on the mechanical properties of hybrid composites reinforced with woven agel leaf fiber/glass fiber. The materials used included woven agel leaf fiber, glass fiber, clay, Yukalac BQTN 157 type unsaturated polyester resin, and methyl-ethyl ketone peroxide catalyst. Firstly, the woven agel leaf fiber was given an alkaline treatment by submersion in a 4% NaOH solution for 1 hour, then rinsed with clean water and dried in the open air for 48 hours. The composite manufacture process employed 3 sheets of woven agel leaf fiber and 4 sheets of glass fiber sized 25 cm × 20 cm with unsaturated polyester matrix. The manufacture method used was the vacuum bagging method with a suction pressure of –70 cmHg. The mechanical tests carried out consisted of tensile test (based on the ASTM D638 standard), bending test (based on the ASTM D790 standard), and impact test (based on the ASTM D5942 standard). The results show that an addition of 1 wt% clay was able to increase the tensile strength, bending strength, and impact strength of the hybrid composite reinforced with woven agel leaf fiber/glass fiber by 7.26%, 30.85%, and 36.25%, respectively.

Volume 1 Number 2, 2020 64-70
DOI: 10.22146/jmpc.v%vi%i.68280
e-ISSN: 2716-1285, ISSN: 2714-9722

1. Introduction

In the field of material technology, natural fiber materials are candidates for reinforcement in the production of lightweight, high-strength, environment-friendly, economical composites. The community, especially in Kulon Progo, Special Region of Yogyakarta (DIY), has been well-acquainted with agel (*Corypha gebanga*) fiber for decades. While in the past agel leaves were used as rod and *bagor* (sack) material, today they are used in their fiber form as raw material for a wide array of craftworks. In modern days, the use of natural fibers as composite reinforcement in place of synthetic ones has been well-developed. One of the natural fibers potential to use as a reinforcing material is agel leaf fiber. It was reported by Hestiawan et al. (2018) that after alkaline treatment, agel leaf fiber demonstrated fairly high tensile strength, namely 816 MPa, thus highly potential to use as polymer composite reinforcement.

Figure 1. Gebang palm

According to Callister (2007), to meet the lightweight, lower-volume, lower-cost material requirement, a composite made of more than one reinforcement material named hybrid composite is developed. A hybrid composite is composed of multiple reinforcing materials and a polymer. The advantage of hybrid composites is that they carry better properties than those with only one type of reinforcement. The reinforcing layers in hybrid composites may be comprised of two or more dissimilar reinforcing materials.

Of late, the development of natural-fiber-reinforced composites gains much interest. Natural fibers possess a wide range of advantages, including environment-friendliness, low density, biodegradability, recyclability, low cost, non-toxicity, low energy consumption, high specific mechanical properties, non-abrasive properties, and good heat resistance (Mohanty et al., 2002). However, they also come with a couple of shortcomings, namely high humidity, water resistance, and non-uniform size variation (Baillie, 2005).

With increasingly scarce metal materials available on Earth, lower-cost, lighter natural fiber composites development is now growing in popularity (Joshi et al., 2004). Natural-fiber-reinforced polymer composites are highly prospective to expand in a developing country like Indonesia. The success in natural fiber composite development is hoped to boost the technological and economic values of natural fibers (Jamasri, 2008).

Composites reinforced with natural fibers and glass fibers have been vastly studied, usually with results showing that high mechanical properties are achieved at volume fraction of around 20–30%. Clay addition as reinforcement is recommended to reduce the fiber amount. Montmorillonite clay is a proven nanocomposite reinforcing material, in that, with only a little bit of clay addition, the polymer mechanical properties were found to be significantly improved. The reason for this is that clay owns high aspect ratio and nanometer-scale size allowing it to build strong bonding with matrix (Riedel, 1999). Yet, research specifically studying hybrid composites reinforced with woven agel leaf fiber, glass fiber, and clay is still rare, causing it necessary to conduct a study on this topic.

This research was aimed to find out the effect of clay addition on the tensile strength, bending strength, and impact strength of a hybrid composite reinforced with woven agel fiber/glass fiber.

Composite Mechanical Properties Testing

1. Tensile Test

The equation for computing tensile strength and modulus of elasticity according to ASTM D638-02 (2002) is as follows:

$$\sigma c = \frac{P}{A}, E = \frac{\Delta\sigma}{\Delta\varepsilon}, \varepsilon = \frac{\Delta L}{L_0} \quad (1)$$

where

σ_c	=	composite stress (MPa),
P	=	load (N),
A	=	initial cross-section area (mm^2),
E	=	composite elasticity modulus (MPa),
ε	=	composite strain,
ΔL	=	elongation (mm),
L	=	measuring length after fracture (mm), and
L_0	=	measuring initial length (mm).

2. Bending Test

Bending testing was performed using three-point bending according to the ASTM D790 method.

The equation for computing the composite bending strength is as follows:

$$\sigma b = \frac{\frac{PL}{4} \times \frac{d}{2}}{b \times \frac{d^3}{12}}, \sigma b = \frac{3PL}{2bd^2} \quad (2)$$

where:

P	=	load (N),
L	=	distance between supports (mm),
b	=	specimen width (mm), and
d	=	specimen thickness (mm).

3. Impact Test

Impact testing was performed to figure out the toughness of the composite. This testing was aimed to find out the material's ability to absorb energy before fracture. The impact testing was carried out in accordance with the ASTM D5942-96 standard using the Charpy method.

The equation for computing the energy absorbed by the materials is as follows:

$$W = G \times R (\cos\beta - \cos\alpha) \quad (3)$$

where

W	=	energy absorbed by specimen (J),
G	=	pendulum weight (N),
R	=	pendulum distance from center of rotation (m),
β	=	pendulum angle after collision with specimen (°), and
α	=	pendulum angle without specimen (°).

The impact strength of the specimen was calculated using the following equation:

$$\text{Impact strength} = \frac{W}{b_i \times h_i} \quad (4)$$

where

W	=	energy absorbed by specimen (J),
b_i	=	specimen width (mm), and
h_i	=	specimen thickness (mm).

2. Materials and Methods

This research was conducted at the Engineering Materials Laboratory of the Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada.

The hybrid composite manufacturing employed 7 fiber sheets, consisting of 3 sheets of woven agel leaf fiber (ALF) and 4 sheets of glass fiber (FG), arranged during the manufacture process in the order FG-ALF-FG-ALF-FG-ALF-FG as presented in Figure 2 with UP matrix and clay as filler.

FG
ALF
FG
ALF
FG
ALF
FG

Figure 2. Hybrid composite fibers order

The weaving of dried fibers was conducted using a traditional weaving tool by a natural fiber craftman in Sentolo, Kulonprogo, Yogyakarta. The woven agel leaf fiber was then cut to meet the composite manufacturing need. The woven agel leaf fiber and glass fiber were cut 250 mm × 200 mm in size, and weighing was performed on each.

Clay was first heated for 5–6 hours at 80 ºC in an oven before mixed with UP to reduce its water content. UP and clay were weighed to adjust to the material composition as variations of the composite to be made. UP and clay were mixed in a mixing cylinder, then stirred using a mechanical stirrer at 80 ºC for 3 hours at 800 rpm. The mixture was cooled for 20 minutes. Mepoxe was added to the UP/clay mixture at a ratio of 1:100 (v/v). The UP/clay mixture preparation is presented in Figure 3. The mixture was then stirred for 5 minutes before being poured onto the woven agel leaf fiber and glass fiber sheets.

Figure 3. UP/clay mixture preparation

The composite manufacturing process was undertaken using the vacuum bagging method. While the UP/clay mixture preparation was underway, the equipment for vacuum bagging must also be prepared. The composite was manufactured with a composition of 7 layers of fibers wetted with resin to the last layer, which was then covered with a release film and a piece of breather fabric for resin absorption before the vacuum process was started. The vacuum bagging equipment is shown in Figure 4.

Figure 4. Vacuum bagging equipment

The composite was made into 2 variations, namely clay-less composite and composite with 1% clay. The woven agel leaf fiber is shown in Figure 5.

Figure 5. Woven agel leaf fiber

Then, the composite was cut into several specimens, namely tensile test specimen based on ASTM D638 (Figure 6), bending test specimen based on ASTM D790 (Figure 7), and impact test specimen based on ASTM D5942 (Figure 8). The three tests were conducted at the Engineering Materials Laboratory of the Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada. The tensile testing used the Simadzu EFH-EB20-40L Servopulser machine with a 2,000 kg load cell at a tensile speed of 10 mm/minute. The bending testing used the Torsees Universal bending testing machine with a 500 kg load cell at a loading speed of 10 mm/minute. The impact testing used the Charpy impact testing machine with a load of 1 kg.

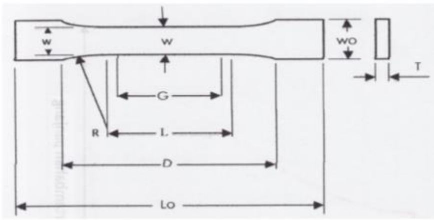

Figure 6. ASTM D638 tensile test specimen

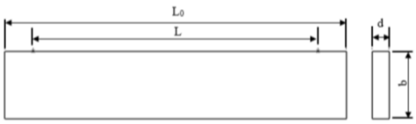

Figure 7. ASTM D790 bending test specimen

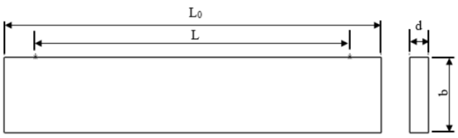

Figure 8. ASTM D5942 impact test specimen

3. Results and Discussion

Figure 9 displays the tensile strengths of the woven agel leaf fiber/glass fiber hybrid composite without clay and that with 1 wt% clay. The tensile strength of the clay-less hybrid composite was 90.11 MPa, while that of the hybrid composite with 1 wt% clay was 96.65 MPa. This suggests that the addition of 1 wt% clay was able to increase the hybrid composite tensile strength by 7.26%. This increase was presumably caused by the formation of an exfoliation structure within the hybrid composite that was added with 1 wt% clay. Within the exfoliation structure, the 1-nm-thick silicate layer of the clay was spread evenly in the polymer matrix with a high aspect ratio, resulting in increased contact surface area and stronger adhesion with the polymer molecular chain of the matrix. The evenly distributed nanoclay in the polymer matrix then served as an efficient stress transmitter, thus increased hybrid composite tensile strength (Parija et al., 2004). Clay-induced increases in hybrid composites were also reported by previous researchers (Haq et al., 2008; Karippal et al., 2011; Kusmono et al., 2013). Haq et al. (2008) reported that clay addition caused improvements in mechanical properties, including the tensile strength and modulus of elasticity of phenolic resin matrix. These increases were resulted because nanoclay dispersion provided a strong bond interaction at the interface with polymer matrix which caused a great restriction to the mobility of the matrix polymer chain at the polymer-clay interface. Other researchers, Karippal et al. (2011) reported that clay addition until 5 wt% to an epoxy/glass fiber hybrid composite had improved the tensile strength, but addition over 5 wt% rendered the opposite result. Kusmono et al. (2013a) reported that the optimal clay content was 2 wt% at which the highest tensile strength was achieved in a polyester/glass fiber hybrid composite. Additions of over 2 wt% clay would lower the tensile strength, instead, due to clay agglomeration at which stress was concentrated and the onset of crack.

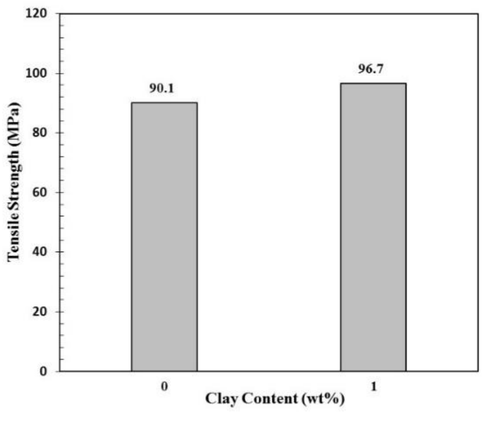

Figure 9. Tensile strength-clay use chart

The bending strengths of the hybrid composites without clay and with 1 wt% clay are shown in Figure 10. From Figure 10 it can be observed that the presence of 1 wt% clay in the polyester/woven agel leaf fiber/glass fiber hybrid composite was able to quite significantly increase the bending strength by

30.85%. This increase was linked to nanoclay dispersion and interface adhesion between polyester matrix and nanoclay, which placed restriction to polymer matrix chain mobility due to bending load, allowing transfer of higher stress to the glass fiber or the agel leaf fiber and in turn increased bending strength (Lin et al., 2006). Similar results were also reported by Karippal et al. (2011) and Kusmono et al. (2013a). According to Karippal et al. (2011), addition of clay until 5 wt% caused the bending strength to rise, but addition over 6 wt% caused the opposite. The optimal clay content in an unsaturated polyester/glass fiber/clay hybrid composite was 2 wt% because this level generated the highest bending strength, but further addition beyond 2 wt% provided the reverse effect (Kusmono et al., 2013a).

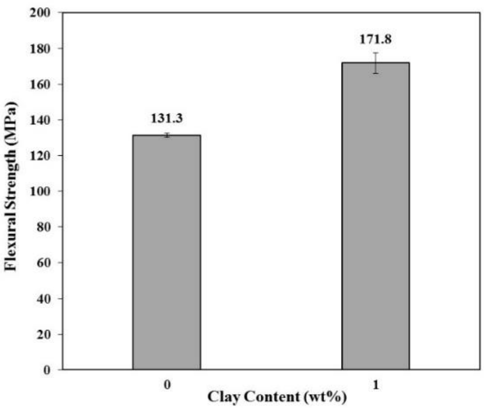

Figure 10. Bending strength-clay use chart

Figure 11 presents the impact strength of the hybrid composite with 1 wt% clay and without clay. It can be clearly observed that the impact strength of the composite with 1 wt% clay was 4.4 kJ/m2, while the impact strength of the clay-less composite was 3.2 kJ/m2. The presence of 1 wt% clay had raised the impact strength of the hybrid composite by 37.5%. This indicates that the clay addition of 1 wt% was able to improve the hybrid composite toughness. The exfoliation structure occurring in the hybrid composite with 1 wt% was believed to be the source of such impact strength increase. In the exfoliation structure, the 1 nanometer silicate layer in clay was dispersed individually and evenly within the polyester matrix and later functioned as an inhibitor of crack propagation resulting in a winding crack propagation path, thus eventually improving the hybrid composite toughness (Inceoglu and Yilmazer, 2003). Increased toughness induced by clay presence in polymer composites was similarly reported by earlier researchers (Manfredi et al., 2008; Kusmono et al., 2013a; Kusmono et al., 2013b). Manfredi et al. (2008) reported that the impact strength of an epoxy/glass fiber composite increased with clay presence. The rise in impact strength brought about by clay addition up to 4 wt% to a polyester/glass fiber hybrid composite was also reported by Kusmono et al. (2013a). Yet, clay addition in excess of 4 wt% led to the reverse. A similar finding was reported by Kusmono et al. (2013b), where a clay addition of 3 wt% to epoxy resin produced the highest strength value, while the addition over that level resulted in a decrease. The exfoliation structure formed in the epoxy composite with 3 wt% clay was presumed to have caused the impact strength increase, while the clay agglomeration structure was believed to cause the toughness decrease in the clay content of beyond 3 wt%.

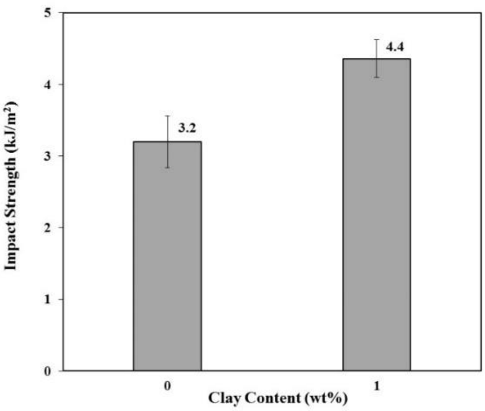

Figure 11. Impact strength-clay use chart

4. Conclusion

From this research's results, it can be concluded that a clay addition of 1 wt% to a woven agel leaf fiber/glass fiber hybrid composite was able to improve the tensile strength, bending strength, and impact strength of the hybrid composite by 7.26%, 30.85%, and 36.25%, respectively.

5. Acknowledgements

This research was supported by the Research Grant of the Postgraduate Team (Contract No. 1792 / UN1 / DITLIT / DIT-LIT / LT / 2018). Acknowledgements are also addressed to the staff of the Engineering Materials Laboratory of the Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta.

6. References

Baillie, C., 2005. Green Composites: Polymer Composites and the Environment Caroline Baillie, ed., CRC Press, Taylor & Francis Group.

Callister, W.D., 2007," Materials Science And Engineering", John Wiley & Sons, Inc, United States of America.

Jamasri, 2008," Prospek Pengembangan Komposit Serat Alam di Indonesia", Pidato Pengukuhan Jabatan Guru Besar pada Fakultas Teknik Universitas Gadjah Mada, Yogyakarta.

Joshi, S. V et al., 2004. Are natural fiber composites environmentally superior to glass fiber reinforced composites ? Composites Part A, 35, pp.371–376.

Mohanty, A.K., Misra, M. & Drzal, L.T., 2002. Sustainable Bio-Composites from Renewable Resources : Opportunities and Challenges in the Green Materials World., 10(April), pp.19–26.

Riedel, U., 1999. Natural fibre-reinforced biopolymers as construction materials – new discoveries. Die Angewandte Makromolekulare Chemie, 272(4756), pp.34–40.