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Effect of Silica Nanoparticles in Kenaf Reinforced Epoxy: Flexural and Compressive Properties

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ABSTRACT

Kenaf natural fibre is used as a sustainable form of material to reinforce polymeric composite. However, natural fibres usually do not perform as well as synthetic fibres. Silica nanoparticle is a material with high surface area and its high interfacial interaction with the matrix results in its improvement. In this research, silica nanoparticles were introduced into epoxy resin as a filler material to improve the mechanical properties of the kenaf-reinforced epoxy. They were dispersed into the epoxy using a homogeniser at 3000 rpm for 10 minutes. The composites were fabricated by spreading the silica filled epoxy evenly onto the kenaf mat before hot pressing the resin wet kenaf mat. The results show for flexural properties, composites with higher fibre and silica volume content generally had better properties with specimen 601 (60 vol% kenaf and1 vol% silica) having the highest strength at 68.9 MPa. Compressive properties were erratic with specimen 201 (20 vol% kenaf and 1 vol% silica) having the highest strength at 53.6 MPa.

Keywords: Compressive, flexural, kenaf, nanoparticles, nanosilica

INTRODUCTION

Natural plant fibres such as kenaf have been extensively studied as an environmentally sustainable replacement to synthetic fibres such as glass and carbon fibres (Ochi, 2008; Xue et al., 2009). This is due to the natural fibre's biodegradability, resistance, reduced dermal and respiratory irritation, low cost, renewability, low density which contributes to its high specific strength and non-abrasive nature making the natural fibre easy to be processed and filled (Akil et al., 2011; Lee et al., 2009; Marques et al., 2015). Natural fibres have also garnered attention in the automotive world

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(Asumani et al., 2012; Xue et al., 2009). Compared with other natural fibres, kenaf (*Hibiscus cannabinus* L.) has a significantly high ability to fixate CO_2 and is able to absorb CO_2 1.4 times its weight (Serizawa et al., 2006). It can be easily grown and adapts to different climate. Kenaf has a high growth rate, reaching up to three metres in height within three months and is considered mature between five and six months of age (Nishino et al., 2003; Sallih et al., 2014; Summerscales et al., 2013).

Using natural fibre as a reinforcing material has challenges, namely the incompatibility between hydrophilic natural fibre and hydrophobic matric which reduces the interfacial adhesion. This causes stress transfer between the materials ultimately reducing their mechanical properties of the composites (Lee et al., 2009). Thus, in order to improve surface compatibility between fibres and matrices, surface treatment such as alkalisation (Meon et al., 2012), silane coupling agent treatment (Herrera-Franco & Valadez-Gonzalez, 2005) and silance treatment with pre-impregnation process of the HDPE/xylene solution. The presence of Si-O-cellulose and Si-O-Si bonds on the lignocellulosic surface confirmed that the silane coupling agent was efficiently held on the fibres surface through both condensation with cellulose hydroxyl groups and self-condensation between silanol groups. The fiber-matrix interface shear strength were examined (Asumani et al., 2012). Alkali treatment increases the surface roughness of the fibre to improve mechanical bonding while silane treatment improves the degree of cross-linking in the interface area and increases the fibre surface area (Asumani et al., 2012). While improving the properties of the composite, the total cost of the composite production may increase. Addition of silica nanoparticle as filler which is derived from cheap source of rice husk ash is an alternative material to improve composite properties. It is highly porous and due to the small porous structure, it has high surface area of about 1500 m^2/g, which have active function and high interfacial interaction with resin (Bajuri et al., 2016; Basri et al., 2015). With such properties, it has ability to enhance a composite's mechanical, physical and optical properties while being able to protect against environmental stress such as cracking and aging (Zayed et al., 2014). Moreover, inclusion of nanoparticles may improve the toughness and other mechanical properties of a composite by enhancing the energy crack propagation, the increment of hard-particle interactions or by changing the properties of the polymer nearby the particle surface (Chen et al., 2008). Due to their large surface area to volume ratio, the area of contact between the nanoparticles and matrix will increase and in turn, the stress concentration around the filler will be reduced (Gendre et al., 2015). This study has achieved its objective to show the importance of silica nanoparticles as filler materials. to improve the flexural and compressive properties of kenaf-reinforced epoxy.

METHODOLOGY

Materials

The resin used for fabrication was Epoxamite 100 with 103 SLOW Hardener, manufactured by Smooth-On. The resin-to-hardener ratio was 100:28.4 by weight as suggested by the manufacturer. Pot life and curing time of the epoxy were 55 minutes and 20~24 hours respectively. The kenaf mat used provided by Zkk Sdn Bhd. The fibre's orientation was

random with the fibres compressed into mat form. Hydrophilic silica nanoparticles, derived from rice husk ash, were used as filler and provided by Maerotech Sdn. Bhd., Malaysia. The average diameter of the silica nanoparticle was 324 nm as determined by particle size analyser.

Material Preparations

Specimens with loading of 20 to 60 vol % of kenaf were prepared. 1 and 5 vol % of silica were also prepared to be added into the epoxy/kenaf. Table 1 lists all the composition of kenaf, epoxy and silica nanoparticle in making composite. For the specimen name, the first two numbers indicate kenaf's loading and the last number indicates silica nanoparticles' loading. As an example, specimen 405 is the specimen with 40% vol kenaf, 60% vol epoxy and an extra 5% vol silica nanoparticles from kenaf and epoxy's total volume percentages. The mat-like fibres were cut into 150 mm × 150 mm. They were used by combining the mats until the desired amount is reached.

Table 1
List of specimens fabricated

Specimen Name	Kenaf's Loading [vol%]	Epoxy's Loading [vol%]	Silica Nanoparticles' Loading [vol%]
200	20	80	0
300	30	70	0
400	40	60	0
500	50	50	0
600	60	40	0
201	20	80	1
301	30	70	1
401	40	60	1
501	50	50	1
601	60	40	1
205	20	80	5
305	30	70	5
405	40	60	5
505	50	50	5
605	60	40	5

Specimen Fabrication

Silica nanoparticles were dispersed into epoxy using a homogeniser at 3000 rpm for 10 minutes. The hardener was then added into the mixture before it is applied evenly onto kenaf layers using a paint brush. The resin wet kenaf layers were then placed inside a 150 mm × 150 mm × 3 mm mould and hot pressed for 20 minutes at 80˚C under 40 tonne pressure. Further cold press for five minutes under 40 tonne pressure was applied onto the specimens. The specimens were left for 24 hours to be cured before being post-cured at 80˚C for two hours. Finally, the specimens were conditioned into respective dimensions needed for each test using a composite cutter.

Flexural Test

A 3-point-bending test was conducted using 5 kN INSTRON Universal Testing Machine according to ASTM D790-03. The samples were conditioned into 125 mm × 12.7 in length and width. As the composites fabricated used mat type fibres, even after being compressed, the thickness of specimens with different loading varied. The thickness variation of samples with the same loading rate was miniscule. A total of 10 samples per loading were tested. The loading rate (R) in mm/min used is written in [1] where Z is the straining rate, L is the support span and d is the depth of the specimen.

$$\mathrm{R} = {}^{ZL^2}/_{6d} \qquad [1]$$

Here, a straining rate of 0.01 mm/mm/min and a support span-to-depth ratio of 16:1 were used. Flexural strength is the maximum stress obtained from the stress strain curve while flexural modulus is the slope of the linear section of the same curve.

Compressive Test

The compressive tests were done according to ASTM D695-02a using 5 kN INSTRON Universal Testing Machine. The samples' length and width were 1.275 mm × 1.275 mm. A total of 5 samples per loading were tested. The loading rate used was 2 mm/min. The specimen was placed on top of the compressive jig with the thickness sections of the specimen lightly touching the jig before pressure is applied. The compressive strength and compressive modulus will be discussed in the report.

RESULTS AND DISCUSSIONS

Flexural Properties

Figure 1 shows the mean flexural strength while Figure 2 shows the mean flexural modulus of kenaf reinforced epoxy (KRE) and silica nanoparticles infused kenaf reinforced epoxy (SIKRE). It can be seen that by increasing the fibre volume fraction, the flexural strength of the KREs increased too. For each kenaf's loading the flexural strength increased too with the

inclusion of silica nanoparticles, except for specimen 201 as its strength is lower than specimen 200. Furthermore, other than specimens with 60% vol kenaf, generally, the inclusion of 5% vol silica nanoparticles had specimens with better strength. Specimen 601 had the highest flexural strength at 68.9 MPa, 1~33% stronger than other specimens. From Figure 2 similar trend can be seen for flexural modulus of every loading. However, it is interesting to note that although specimen 601 had the highest strength when compared with other specimens with the same fibre content, its flexural modulus is not the highest. This indicates that although specimen 601 was strongest in term of strength it is not the stiffest specimen and can withstand less deformation than some other specimens such as specimen 405, 501, 505, 600, and 605 before breaking. Specimen 605 had the highest modulus at 4.35 GPa, 4~49% higher than other specimens. Overall, generally it can be seen that the inclusion of silica nanoparticles improved the flexural properties of the KREs. Inclusion of silica nanoparticles caused some volume of matrix surrounding the nanoparticles to become immobilised due to the binding of the matrix with the particles' surface which caused the matrix to be stiffer (Zhang et al., 2003). Hence, improving the elastic property of the KREs.

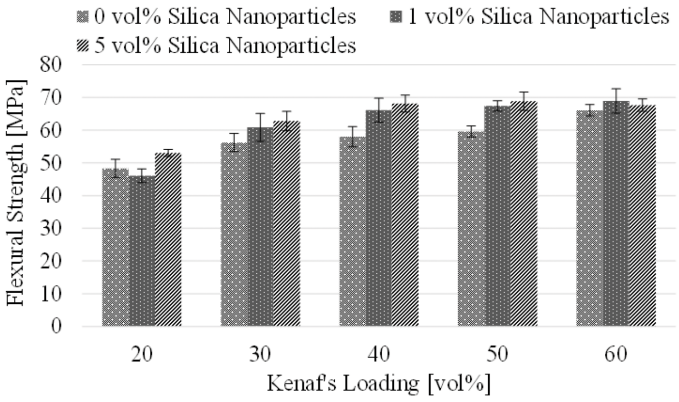

Figure 1. Flexural strength of SIKRE

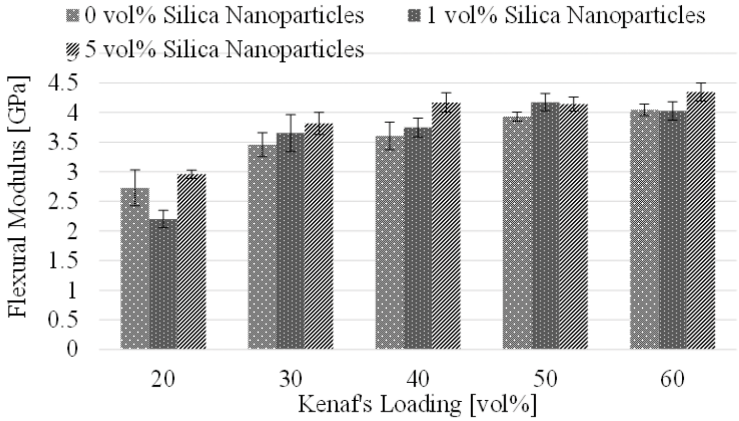

Figure 2. Flexural modulus of SIKRE

Compressive Properties

For compressive strength, contrary to flexural strength, specimens with 20% vol kenaf had the highest strengths with specimen 201 being the best (Figure 3). Specimen 201's compressive strength was 53.6 MPa, 5~34% stronger than other specimens. However, from the same figure it can be seen that if we ignore specimens 200, 201 and 205, the results are similar to those of flexural strength results as discussed in the previous section. Fibres are strong in the direction they are pulled but they do not provide much support in the opposite direction, like the case in compressive test. This may be the reason why specimens with 20% vol kenaf were stronger than other specimens. The fibre's volume content was low enough that instead of relying on kenaf, the specimens rely mostly on the epoxy matrix instead for support. From 30% vol onward, the fibre content was high enough to affect the overall compressive strength. The increment of fibre content also means that the fibres will be more compressed inside the composite. The compressed kenaf in turn will provide support to the whole composite increasing its strength as kenaf's load is increased. The inclusion of silica nanoparticles did not seem to have a significant effect, with some specimen's strength increased and some lowered when compared with specimens without silica nanoparticles. For compressive modulus, based on Figure 4, other than specimens with 20% and 30% vol kenaf, the results are quite erratic. However, specimen 201 has the highest modulus. It is interesting to note, the results showed low standard deviation; however, the results for compressive modulus had high deviations. The behaviour of the compressive modulus indicates that different sections of the same plate that was fabricated possess different level of stiffness. This may be due to the usage of randomly orientated kenaf mat. Due to the random nature of the fibre, there is a possibility that the parts used for the test may be of different length and orientation which has an effect on how the specimen behaves. It has to be noted that the specimen size for the compressive tests were small. The fibre might be aligned to an orientation which provides better properties at some parts of the plate.

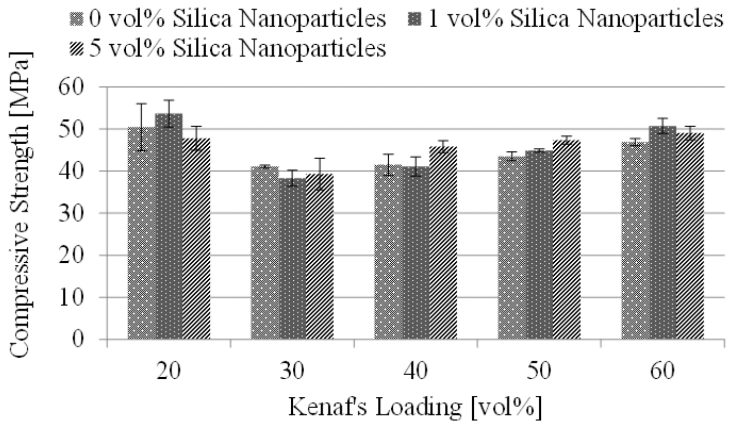

Figure 3. Compressive strength of SIKRE

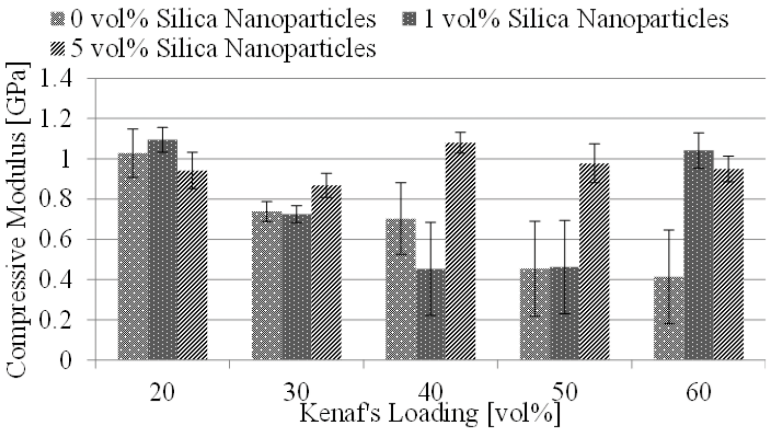

Figure 4. Compressive modulus of SIKRE

CONCLUSIONS

The findings of this study indicate that for flexural properties, increase in kenaf fibre volume content increased the specimen strength and modulus while increase in silica nanoparticles also generally improved the properties, except for specimen 201 and 605. For compressive strength, other than specimens with 20% vol (having the highest strength) kenaf, increase in fibre volume content had a positive impact. Inclusion of silica nanoparticles did not produce much difference compared with KREs without the nanoparticles. For compressive modulus, the results were erratic. As a whole, the inclusion of silica nanoparticles had a positive impact in terms of improving the mechanical properties of KREs.

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