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FLEXURAL PROPERTIES OF HYBRID HYDROPHILIC SILICA NANOPARTICLES/KENAF REINFORCED EPOXY COMPOSITES

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ABSTRACT

With the promoting of sustainable material usage, natural fibres such as kenaf has gained recognition as a reinforcing materials. But natural fibres are generally weaker than synthetic fibres and the porosity of the fibres make them grow weaker as time passes. As such, to counter the weakness of the natural fibre, the addition of hydrophilic silica nanoparticles is studied. Silica nanoparticle is a material with high surface area contributing to its high interfacial interaction with the matrix resulting in the improvement of the matrix. In this work, the composites were fabricated via vacuum infusion process by creating a system in which the compressed randomly orientated kenaf mat are laid in. The silica nanoparticles are dispersed into the epoxy using a homogenizer at 3000 rpm for 10 minutes before being infused into the fibres. With the inclusion of 1 vol% silica nanoparticles, even though most composite had a decreased strength, the composite with 60 vol% kenaf had shown an increment in strength at 27% making it kenaf reinforced epoxy with the highest flexural strength and modulus.

Keywords: hybrid composites, silica nanoparticles/aerogel, kenaf natural fibre, flexural properties, vacuum infusion.

1. INTRODUCTION

The usage of natural fibre as a reinforcing or filler material in the fabrication of composites has been gaining momentum steadily as there is an environmental awareness towards the usage of sustainable materials to replace materials derived from fossil fuels [1]. Natural fibres possess desirable properties such as being low cost, renewable, having high specific strength and modulus due to its low density, and easy processing which is contributed by its nonabrasive nature allowing high filling levels [1, 2]. However, natural fibres still fall behind in term of mechanical strength to synthetic fibres. They require various chemical treatments, hybridization by combining natural and synthetic fibres, weaving in different orientations to achieve comparable strength to those of synthetic fibres [3].

In the ecological point of view, kenaf (*Hybiscuscannabinus* L.) is an attractive choice for composite reinforcing as it is a crop with a rapid growth maturing in 5-6 months with height of 4-5 m [4]. Another favourable factor of cultivating kenaf is its high ability to fixate carbon dioxide at 1.4 times its own weight and its photosynthesis rate is three times than that of the usual plant [5]. An example of weaving pattern and hybridization effect on composite reinforcement is by comparing the mechanical properties of plain and twill woven hybrid banana and kenaf fibre reinforce polyester [3]. Hybrid kenaf/banana reinforced composite had the highest increase in tensile strength indicating that minimal stress was developed at the interface of the composite due to the distribution of load transfer along the fibre direction. One of the chemical treatments of natural fibre is alkalization. A research has been made to investigate the effect of alkali treatment on the flexural strength of unidirectional kenaf fibre reinforced epoxy (KFRE) by immersing the fibre into sodium hydroxide (NaOH) for 24

h [6]. It was found that the flexural strength of the NaOH treated KFRE was the strongest at 36% higher than the pure matrix while the untreated KFRE was 20% stronger than pure epoxy. Processing condition of kenaf fibre reinforced polyester fabricated using resin transfer moulding was found to have little effect on the mechanical performance of the composite [7]. However, even though no significance effect to the composite performance can be seen by changing the temperature of the mould, the use of pressurized mould increased the flexural strength of the laminates by 15-20% compared to other laminates. This is attributed to the reduction of the voids size resulting from the pressure applied after injection.

The objective of this work is to improve the flexural properties of kenaf reinforced epoxy with the inclusion of silica nanoparticles. Silica nanoparticles is a material characterized with small structure contributing to its high interface area, active function, and high interfacial interaction with the matrix, resulting in their ability to improve the mechanical, physical and optical properties of the matrix while providing resistance to the environmental stress caused cracking and aging [8]. The dispersion of silica nanoparticles into epoxy by ultrasonication and magnetic stir bar proves that the nanoparticles improve the mechanical properties of the epoxy with consistent strength up to 10 wt% of silica nanoparticles [9]. At 20 wt% the composites were significantly brittle with slightly reduced strength but the tensile modulus increased monotonically. A silica nanoparticle-multiwalled carbon nanotube (MWCNT) complex prepared by multi-step functionalization was used to fill the glass fibre reinforced epoxy based composites [10]. The inclusion of 0.5 wt% silica nanoparticle-MWCNT had the optimum mechanical properties and the increment of the nanoparticle-MWCNT loading subsequently cause reduction in the properties linearly. This is attributed to strong interfacial adhesion

and effective stress transfer produced due to the generation of chemically bonded nanoscale interfacial area between the glass fibre and epoxy bridged by the fillers.

Although the close mould resin infusion system is similar to resin transfer moulding, there is a difference in which the resin transfer moulding used two-parts rigid mould while the vacuum infusion use one part rigid mould sealed with a vacuum bag [11]. The basic important aspect in fabricating using the vacuum infusion is to have a completely airtight system. If this condition is not met, the vacuum will not be generated effectively and the resulting composites will be poorly produced with parts that include dry spots and/or entrapped air [12]. Vacuum infusion process is gaining acknowledgement because it is a cost effective process to produce lightweight large scale composites and significantly reduce the volatile organic compounds produced by the matrix due to it being a close mould system [13].

2. EXPERIMENTAL

2.1 Materials

In this work the matrix used for fabrication was epoxy resin of Epoxamite 100 with 103 SLOW Hardener. The epoxy's resin to hardener ratio is 100:28.4 by weight with the pot life of 55 min and curing time of 20-24 hours. The kenaf used was provided by *Zkk* with the fibres originating from the Kelantan state of Malaysia. The orientation of the fibres were random in the mat form. Silica nanoparticles used was hydrophilic silica nanoparticles provided by *Maerotech*.

2.2 Composite fabrication

The composites were fabricated into 150 mm × 150 mm plates to be cut into the size required for the flexural tests. Thus, the kenaf mat was cut into the said dimension before being weighted and stacked with one another to accommodate the weight needed for the loading intended. The stacked kenaf mats were then compressed in between two metal plates with one fixed and one lifted using a 20 tonne hydraulic jack. While the mats were left in between the plates, silica nanoparticles was dispersed into epoxy without the hardener using a homogenizer at 3000 rpm for 10 minutes. The epoxy/silica nanoparticles solution was then casted into a vacuum environment with a vacuum oven to remove the micro bubbles produced during the homogenizing process.

The preparation for vacuum infusion was done next. A completely airtight system was made with the only connection to outside environment were from two tubes named inlet and outlet respectively. One of them was used to infuse resin (inlet) and one of them was connected to vacmobile 20/2 vacuum system to produce the vacuum pressure used in the infusion process (outlet). Silicon tape was pasted on a glass table in a rectangular shape larger than the cut kenaf mats' dimension. The glass surface inside the area of pasted silicon tape was waxed before the compressed kenaf mats were extracted from the metal plates and put in the middle of the silicon taped area. One spiral tubes were laid at one side of the kenaf mat and

another was laid on the opposite side. The spiral tubes each were connected to another tube and one of them was assigned as inlet while the other as outlet. The outlet was connected to the vacmobile. Peel ply for excess resin removal and resin mesh for smoother infusion process were laid in the order written. Lastly, a vacuum bag was used to cover the whole system. The bag and glass table connection with the silicon tape was checked to make sure there was no leakage. The airtightness of the system was verified by bringing the pressure to 0 MPa and sealing the inlet and outlet, if the pressure remained at 0 MPa even after the vacmobile was switched off, the system is considered airtight. The final condition of the vacuum infusion preparation procedure before the resin was infused is shown on Figure-1.

Figure-1. Vacuum infusion system.

After the preparation of the vacuum infusion was completed, the dispersed silica nanoparticles/epoxy solution was extracted from the vacuum oven and the hardener was mixed. The mixed resin was then infused into the system prepared until the whole kenaf mat was wet. Next, the inlet and outlet was sealed and the whole system was left for 24 hours before being removed. The post curing of the plate was done next under the temperature of 80 °C for 2 hours.

A total of 12 type of loadings were fabricated including separately made neat matrix specimens. This is shown in Table-1.

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Table-1. List of fabricated specimens.

Specimen name	Kenaf's loading (vol%)	Nanoparticles' loading (vol%)
000(Neat Epoxy)	0	0
200	20	0
201	20	1
300	30	0
301	30	1
400	40	0
401	40	1
500	50	0
501	50	1
600	60	0
601	60	1

2.3 Flexural test

3-point bending flexural tests were executed under ASTM D790 using Instron 3365 Universal Testing System. The dimension of the specimens were 125 mm × 12.7 mm. The support span was set with the span-to-depth ratio of 16:1. The specimen straining rate was 0.01 mm/mm/min. Flexural strength is the maximum stress in the stress-strain curve while flexural modulus is the slope of the linear region. For each loading, the results are taken from the average of 10 specimens tested.

3. RESULTS

Figure-2 represents the average value of flexural strength of each loading fabricated. In general, at 78.8 MPa the neat epoxy was stronger than the kenaf reinforced epoxy. It is interesting to note that in other work [14], the flexural properties of the woven kenaf reinforced epoxy were lower than that of neat epoxy. However, for kenaf reinforced epoxy without silica nanoparticles, the increment of kenaf's loading increases the strength of the kenaf reinforced improved slightly with the maximum strength at the loading of 50 vol% before the strength decrease once more with 60 vol% kenaf's loading. Epoxy with the addition of kenaf had the flexural strength of 40-49 MPa. The optimum kenaf's reinforced epoxy without any silica nanoparticles included was 37% lower than the neat epoxy.

With the addition of 1 vol% silica nanoparticles, as can be seen in Figure-2, except 60 vol% kenaf reinforced epoxy, the strength of the composite decreased slightly with 50 vol% kenaf's loading decreasing the most at 37%. The addition of 1 vol% silica nanoparticles only had miniscule effect on 40 vol% kenaf reinforced epoxy but improved the strength of 60 vol% kenaf reinforced epoxy by 27% when compared to the composite with the same kenaf's loading surpassing the 50 vol% kenaf reinforced epoxywitout silica nanoparticles. Hydrophilic silica nanoparticle is a lightweight porous material. The inclusion of silica nanoparticle induce a higher porosity

specimens. It has been reported that high porosity materials have lower mechanical performance than the ones with lower porosity [15]. Thus the inclusion of 1 vol% silica nanoparticles may reduce the flexural strength of the composites.
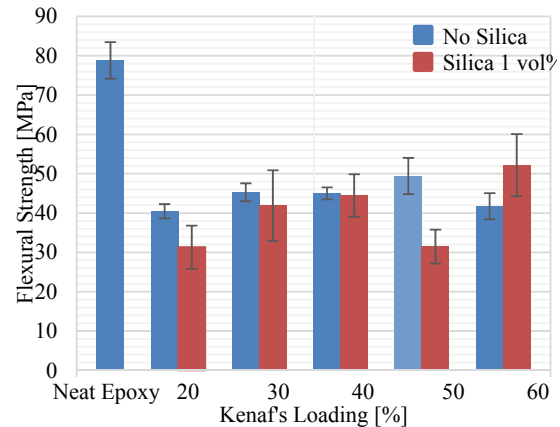
Figure-2. Flexural strength of fabricated composites.

For flexural modulus of the random orientated kenaf mat reinforced epoxy, a similar pattern can be seen as shown in Figure-3. However this time the flexural modulus of the neat epoxy was lower than the kenaf reinforced epoxy without silica nanoparticles. This is an indication that the kenaf reinforced epoxy composites are stiff materials. They require high amount of load to be bent elastically but cannot withstand a high degree of deformation before being ruptured.

Again, with the exception of 60 vol% kenaf reinforced composite, the inclusion of 1 vol% silica nanoparticles cause a reduction in the flexural modulus like that of flexural strength. Only 20 vol% kenaf reinforced epoxy had a modulus lower than neat epoxy at 22% lower than the 20 vol% kenaf reinforced epoxy without the silica nanoparticles.
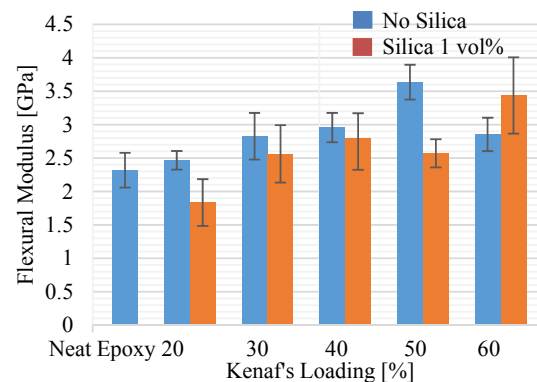

Figure-3. Flexural modulus of fabricated composites.

Figure-4 represents the common stress-strain curve for the flexural tests done. For most specimens, with the increase of strain the stress will increase too. In the

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beginning, the increment of stress was linear but it will start to curve. The specimens usually yield slightly after reaching maximum stress before breaking. As can be seen from the figure, the stress at break point did not fall in a perfecly verticel manner. This is attributed to the uneven stress distribution due to the fibre random orientation and the uneven resin distribution into the fibre.
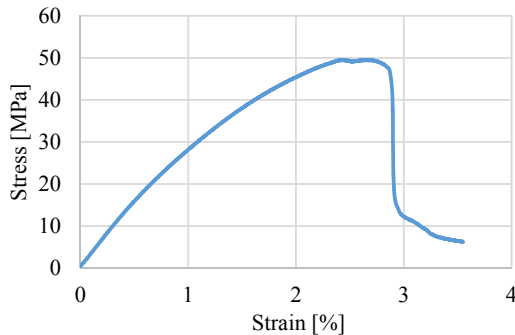

Figure-4. Common stress-strain curve.

For specimens with high fibre volume fraction such as specimen 600, sometimes stress-strain curve like that of Figure-5 occur. After breaking, the stress dropped for a certain degree before reaching an almost constant rate with the increment of strain. Then the stress dropped again in a breaking manner. This is due to the presence of voids in between the layer of kenaf mat causing delamination to occur in between the layer of mats making the stress distribution in between the layers not properly distributed. After the breaking of the first layer of the kenaf mat, instead of propagating vertically, the cracks due to breaking stopped at the location where the delamination occur. Then the stress is distributed into the layers above the broken kenaf mat causing the stress to hit an almost constant rate before the above layers are broken too.
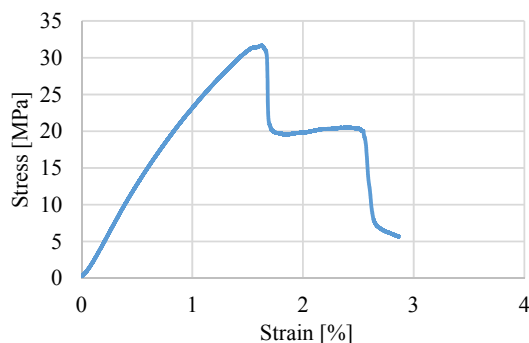

Figure-5. Uncommon stress-strain curve for specimen with high kenaf volume fraction.

4. CONCLUSIONS

The fabrication of hybrid hydrophilic silica nanoparticles/kenaf reinforced epoxy has been done. Without the silica, 50 vol% kenaf reinforced epoxy had the highest flexural strength and flexural modulus at 49.4 MPa and 3.64 GPa respectively. The inclusion of 1 vol% silica nanoparticles had a detrimental effect on the flexural properties generally but for 60 vol% kenaf reinforced epoxy, the strength improved and surpassed that of 50 vol% kenaf reinforced epoxy at 52.2 MPa making it the kenaf reinforced epoxy with highest flexural strength.

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