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Flexural and Compressive Properties of Hybrid Kenaf/Silica Nanoparticles in Epoxy Composite

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Abstract

Kenaf fiber like other natural fibers is used as a sustainable form of material to fabricate composite. But natural fibers are generally weaker than synthetic fibers due to the porosity of the fibers making them grow weaker mechanically and physically as time passes. To improve the quality of kenaf reinforced composite, silica nanoparticles was introduced as a filler material. 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 fibers. The results shows that generally the inclusion of hydrophobic silica nanoparticles had a detrimental effect on the mechanical properties. However, composites with 2 vol% silica had the best mechanical properties of specimens with silica nanoparticles included at 43.8 MPa and 3.05 GPa for flexural strength and flexural modulus, and 40.0 MPa and 1.15 GPa for compressive strength and compressive modulus, respectively.

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1. Introduction

The usage of natural fiber as a reinforcing or filler material in the fabrication of composites steadily increasing as there is an environmental awareness towards the usage of sustainable materials to replace materials derived from fossil fuels[1]. Natural fibers 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

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allowing high filling levels[1, 2]. However, natural fibers still fall behind in term of mechanical strength to synthetic fibers. They require various chemical treatments, hybridization by combining natural and synthetic fibers, weaving in different orientations to achieve comparable strength to those of synthetic fibers[3].

In the ecological point of view, kenaf (Hybiscus cannabinus 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]. Weaving pattern and hybridization of kenaf/banana hybrid composite shows that kenaf/banana reinforced composite had the highest increase in tensile strength due to minimal stress developed at the interface of the composite[3]. Alkalization effect on the flexural strength of unidirectional kenaf fiber reinforced epoxy (KFRE) shows 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[6]. Processing condition of kenaf fiber reinforced polyester fabricated using resin transfer molding was found to have little effect on the mechanical performance of the composite[7]. However the use of pressurized mold increased the flexural strength of the laminates by 15-20% compared to other laminates 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 and compressive 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]. A silica nanoparticle-multiwalled carbon nanotube (MWCNT) complex prepared by multi-step functionalization was used to fill the glass fiber reinforced epoxy based composites with 0.5 wt% silica nanoparticle-MWCNT having an optimum mechanical properties and the increment of the nanoparticle-MWCNT loading subsequently reduced the properties linearly[10].

Although the close mold resin infusion system is similar to resin transfer molding, there is a difference in which the resin transfer molding used two-parts rigid mold while the vacuum infusion use one part rigid mold sealed with a vacuum bag[11]. An 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]. The process is gaining acknowledgement because it is a cost effective process to produce lightweight large composites and significantly reduce the volatile organic compounds produced by the matrix due to it being a close mold system[13].

2 Methodology

2.1 Materials

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 fibers originating from the Kelantan state of Malaysia. The orientation of the fibers were random in the mat form. Silica nanoparticles used was hydrophobic 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 and compressive tests respectively. 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 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 Fig. 1. The composites fabricated had 50 vol% of kenaf mat with silica nanoparticles inclusion of 0, 0.5, 2, 3 and 4 vol%. It should be noted that the nanoparticles were additions implying that the amount of epoxy used for every specimens was the same.

Fig. 1. Prepared 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.

2.3 Flexural Properties

The turbine blade of a windmill will experience a multiple direction forces in which the blade will not be pulled in one direction like that of a tensile test. Thus the flexural test, in which the specimen will experience a compressive and pulling forces at the same time is considered. Furthermore, compared to tensile test, flexural test require specimen of a smaller size. In this work, the 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 × 3.2 mm. The support span was set with the span-to-depth ratio of 16:1. The specimen's 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 5 specimens tested.

2.4 Compressive Properties

The specimens required for compressive tests are small and can be taken from the extra part of the whole plate fabricated. Even so it can provide an insight on the mechanical properties of the fabricated specimen. Compressive tests were conducted under ASTM D695 using Instron 3365 Universal Testing System with the specimens conditioned into the size of 10 mm × 10 mm × 3.2 mm. The specimens were place in the middle of the jig with the smaller part of the specimen touching the lower part of jig and the upper section of the specimen almost touching the upper jig. The compressing rate was 2 mm/min. Compressive strength is reported as the maximum strength before the stress drop suddenly and the compressive modulus is reported as the slope of the linear part of the stress strain curve. A repetition of 5 times per loading was conducted and the average was taken.

3. Results

Due to the dense nature of random orientated compressed kenaf mat, the resin flow during the vacuum infusion process was extremely slow in that it requires approximately 45 minutes for the whole fiber to be infused with resin. Furthermore, the inclusion of silica nanoparticles increased the viscosity of the resin further slowing the resin flow into the fiber. A method to increase the resin flow is by introducing outside force to force the resin to impregnate the fiber like that of resin transfer infusion process.

3.1 Flexural Properties

Fig. 2. shows the average of the flexural strength and flexural modulus for each loadings. As can be seen, when silica nanoparticles are infused together with epoxy, the flexural strength of the specimens generally decreased. However, at 2 vol% hydrophobic silica nanoparticles' loading, at 43.8 MPa the flexural strength was similar to as the specimens without any silica nanoparticles included, which is 45.7 MPa. For, flexural modulus, a similar pattern can be seen from the curve with the inclusion of 2 vol% silica nanoparticles inducing the highest modulus of the specimens with nanoparticles inclusion. Increment of nanoparticles' loading of more than 2 vol% reduced the strength and modulus even further. This can be explained by the high porosity of nanoparticles in general. It has been reported that high porosity materials have lower mechanical performance than the ones with lower porosity[14]. Hydrophobic silica nanoparticle is a lightweight porous material. The inclusion of silica nanoparticle induce a higher porosity specimens. Furthermore, the more silica nanoparticles included, the higher percentage of the nanoparticles will agglomerate instead of spreading homogeneously throughout the resin. Agglomerated nanoparticles will not have a good interaction with the resin causing the fabricated specimen to be more brittle due to ineffective stress transfer[9].

3.2 Compressive Properties

Closely imitating the flexural properties, both compressive strength and compressive modulus of the fabricated specimens show a similar trend as can be seen from Fig. 3. One of the differences when compared to flexural properties is, for compressive strength, at 0.5 vol% of silica nanoparticles' loading had the minimum value at 20.0 MPa. And for compressive modulus, the inclusion of 2 vol% hydrophobic silica nanoparticles had highest value even more than the specimens without nanoparticles at 1.15 GPa. Further increment of nanoparticles' loading again, reduced the compressive strength and compressive modulus. Like that of flexural properties, the increment of silica nanoparticles will increase the porosity of the specimen meaning that there will be more voids where stresses applied to the specimen will not be able to be transferred effectively. This will cause the specimen to lose its integrity at a lower stress level. Strong interfacial adhesion and effective stress transfer can be produced by the generation of chemically bonded nanoscale interfacial area between the fibre and epoxy bridged by the fillers[10]. However, this might not occur due to the incompatibility between natural fibres and synthetic epoxy and silica nanoparticles. To investigate the interaction between the kenaf fibres and nanoparticles mixed with epoxy further test such as SEM is required.

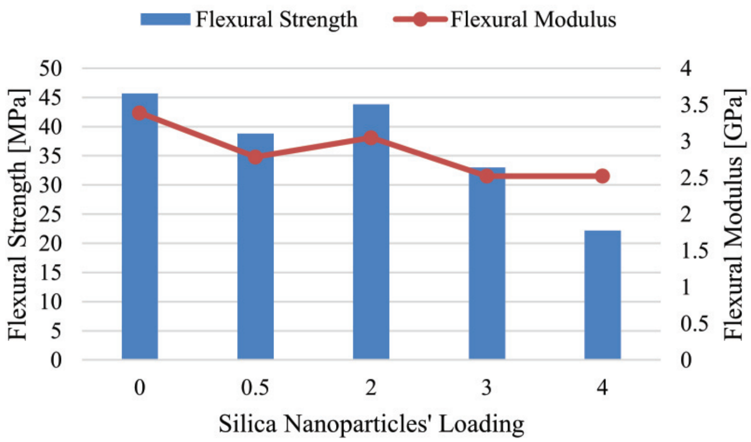

Fig. 2. Flexural properties of fabricated specimens

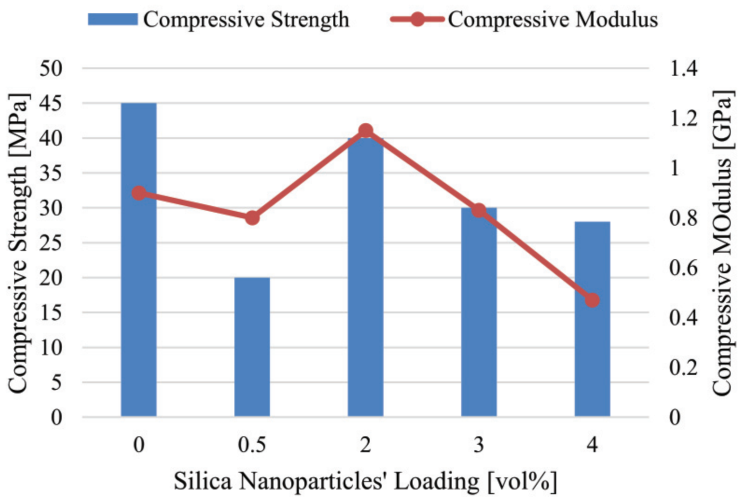

Fig. 3. Compressive properties of fabricated specimens

4. Conclusion

Except for compressive modulus, generally the inclusion of hydrophobic silica nanoparticles had a detrimental effect on the mechanical properties. However, composites with 2 vol% silica had the best mechanical properties of specimens with silica nanoparticles included at 43.8 MPa and 3.05 GPa for flexural strength and flexural modulus, and 40.0 MPa and 1.15 GPa for compressive strength and compressive modulus, respectively.

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