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Research paper

Flexural Behaviour of Nanoclay filled Chopped Basalt and Glass Fibres Composites

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Abstract

Natural fibres have attracted researcher's attention due to their advantages such as abundance of resources, good mechanical properties and low density. In order to increase the usage of natural fibre, lots of researches have been conducted on natural fibres as reinforcement to polymer matrix. In this study, natural and synthetic fibres were used in order to determine and compare the properties of these materials in terms of their flexural strength, modulus and failure strain. Chopped natural mineral based fibre namely basalt and synthetic fibre namely glass of 5 mm length were used. Epoxy resin was used as the polymer where the drawback of this material is its brittleness. In order to overcome this weakness, nanoclay filler of 1, 3, 5 wt% was used to increase the stiffness of the epoxy resin. Therefore, the aim of this study is to evaluate the effect of nanofillers content on different types of chopped fibres reinforced polymer composites. The flexural tests were conducted according to ASTM D790 with specimen size of 4mm thickness, 10 mm width and 78mm length with 60mm support span. The results indicated that nanoclay filled-chopped GFRP exhibited the highest flexural properties at 5wt% nanoclay while, nanoclay filled-chopped BFRP showed the best flexural properties at 3 wt% nanoclay.

Keywords*: Flexural properties; Basalt fibre composites, Glass fibre composites, Short Fiber composites; Nanoclay*

1. Introduction

A composite material is a mixture or combination of two or more different materials that results in superior properties than those of their constituent materials. Composite materials consist of three main different elements of materials or phase, i.e. reinforcement, matrix and filler to form the fiber reinforcement polymer (FRP) composites. Nowadays, due to environment concern it is encouraged to develop a new material based on natural fibers which has certain properties and capability to withstand external forces [1]. Fibers are usually used as one of the main components in composites and known as the reinforcement. Fibers are commonly made of stiffer and stronger materials. It can be classified into two categories which are natural fiber and synthetic fiber and can be in the form of chopped fiber or long fiber. In this study, natural fibers used are basalt fibers, meanwhile glass fibers are used as the synthetic ones.

Natural fibers usually have low density, low energy consumption, low-cost and provide predictable reinforcement composite than synthetic fibers [2]. Synthetic fibers are made from chemical processes; usually through extrusions and they can contribute half of all fiber usage with applications in every field [3]. Basalt fiber is produced by melting the volcanic rock and rapid cooling before carrying the pultrusion process [5]. FRP is a composite made by combination of a strong reinforcing fibers with polymer resin matrix. Short or chopped fiber reinforced in the polymer shows their advantages such as cheaper and easier manufacturing process compare to long fiber reinforcement which made them easier to be used in wide applications such automobile and other industries. Usually epoxy was used in the industries as the polymer matrix to develop the FRP composite and applied into many applications such as in aerospace, automotive, marine and construction industries owing to their versatility [6].

Epoxy matrix with low compressive strength and low compressive strain was added to provide the environmental protection to the fiber, while reinforcing fiber provides the mechanical properties such as strength and stiffness of the FRP composite [7]. Basically, nanofiller was added into a polymer to increase modulus and improve the strength of the FRP composite such as silica, clay and carbon nanotube. The addition of nanofiller i.e. nanoclay could increase the stiffness of the matrix and enhance the flexural modulus and strength [8].

In engineering field, flexural resistance is the one of the important mechanical properties in designing the composite material to be a new class of modern materials. Flexural properties of a material are crucial in order to ensure safety applications, especially in structural applications. Due to previous study by Amir *et. al* [9], the flexural strength of 5 wt% nanoclay specimen exhibits the tremendous improvement with 80% increment compared to neat GFRP composites. Agarwal *et. al* [10] studied the flexural behaviour of short and bi-directional CFRP epoxy composites. It was found that the mechanical properties of bi-directional CFRP/epoxy composites shows enhancement with increment in fiber loading compared to short fiber reinforced epoxy composite. However, in case of hardness, the chopped carbon fiber reinforced composites exhibits better results. Md Ekramul Islam *et. al* [11] studied the CFRP composites modified with 0.3 wt% MWCNT and 2 wt% nanoclay. The results analysis was compared with unmodified carbon/epoxy composites under flexural testing. It is found that the flexural strength and flexural modulus of all composites increase if the nanoparticle were incorporated and the enhancement were almost similar.

It is known that carbon fiber offers the highest specific modulus and highest specific strength of all reinforcing fibers. Glass fibers definitely have their own feature such as lightweight, extremely strong, and robust material. However, for the sustainability of the environment, natural fibers have attracted broad attention due to their potential as alternative material to synthetic fiber. Natural fiber is called as environment friendly material due to its biodegradability and recyclability. Therefore, the number of study of comparison between natural fibers and synthetic fiber increase substantially from year to year [12].

One of the drawback of using natural fiber into the polymer matrix is different polarity that leads to low adhesion between the interfaces [13]. Other than that, pure epoxy resins is obviously brittle, fragile, and have low resistance to the propagation of cracks due to high crosslinking density of its structure that may reduce the mechanical properties of the composite. This problem is solved by combining epoxy resin with nanoparticle such as nanoclay and carbon nanotube to enhance the strength of epoxy resin [13][14]. There are a number of previous reports about the long fiber reinforced polymer but there is still limited information about the effect of the nanoclay and CNT on flexural properties of short fiber composites. Therefore, this study concentrates on evaluating the flexural properties of nanoclay and CNT filled chopped-Kenaf FRP, carbon FRP, Basalt FRP and glass FRP composites. Hence, the flexural properties and behaviour of neat and modified FRP are analysed and discussed.

2. Materials and Method

In this study, two types of chopped fiber were used: (i) glass fiber and (ii) basalt fiber. 10 wt.% of fiber were mixed with epoxy resin to produce the Fiber reinforced polymer (FRP) composite. For nano-modified composite, the filler used are nanoclay. The desired weight percentage for nanofiller used are 1wt%, 3wt% and 5wt% of nanoclay. All main materials selected for this study are tabulated in Table 1 below.

Table 1: Materials used for specimen fabrication

Materials selected	Descriptions
Basalt fiber and glass fiber	Chopped fiber with of 4-5 mm length (using Crusher Machine)
Epoxy	Miracast 1517 Part A
Hardener	Miracast 1517 Part B
Nanoclay	MMT nanomer I 30

MIRACAST 1517 Part A and B of epoxy resin and hardener were used with ratio 100:30. Epoxy resin was stirred manually with 10wt% of fiber to produce unmodified FRP. Then, the mixtures were poured into a silicon mould (4 x 10 x 78mm) for the testing process. The mould was left for 24 hours at room temperature for the curing process. The preparation of nanofiller filled epoxy polymer involved the use of mechanical stirrer and three roll mill machine to disperse the nanofiller in the epoxy resin. The desired weight percentages of nanoclay used in this study are 1.0wt%, 3.0wt% and 5.0wt%. The desired weight percentage of nanofiller was mixed together with epoxy resin in beaker before stirred using mechanical stirrer at 400 rpm speed and 80 °C.

The mixture was then milled using a three roll mill machine. The milling process was carried out at 60 °C temperature by pouring the nanofiller-epoxy mixtures in between the feed and the center rollers. The whole cycle was repeated for three times to ensure that the nanofiller platelets form exfoliated structure. After that, the mixture of epoxy resin and nanofiller were mixed together with chopped fiber before hardener is added in order to harden the mixture. Then, the mixture was poured into a designed mould. The mould was placed on a flat surface before a load was put on top of the mould to ensure flat surface and to ensure epoxy flow evenly through all the fibers and the mould was left for 24-hours for curing process before can be used for testing. Fig. 1 shows the fabrication of BFRP samples.

Fig. 1: Fabrication of BFRP samples

The flexural tests was conducted according to ASTM D790 with the size of 4mm thickness, 10 mm width and length is 20% longer than the support span of 60 mm (distance between two supporting pins). A 100kN INSTRON 3382 Universal Testing Machine was used to run the flexural test using Bluehill 2 testing software. From the flexural load and deflection obtained from the test, flexural stress and strain were calculated for each specimen. These values were used to plot the stress-strain curve in order to obtain flexural modulus of the specimens.

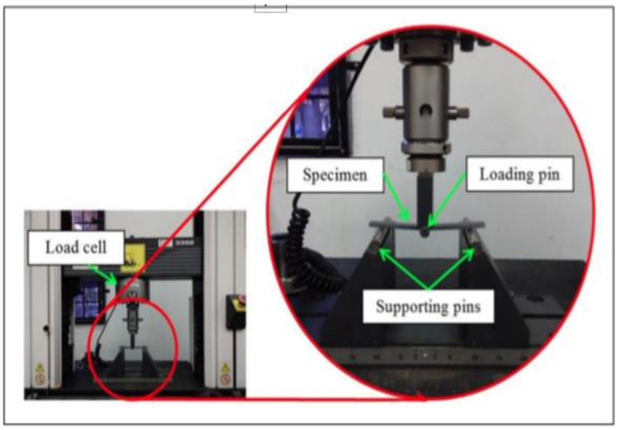

Fig. 2: Three-point bending flexural test setup using Instron 3382 Universal Testing Machine

3. Results and discussion

Fig. 3 shows the flexural stress-strain curves of neat epoxy polymer and nanoclay-filled epoxy polymer. Table 2 shows the summary of the flexural properties of nanocomposite specimen. The stress-strain curve shows that specimens fail into brittle fracture manner. Nanoclay-filled epoxy polymer with 5 wt% nanoclay shows the highest flexural strength when compared to neat epoxy with 29% enhancement, followed by 3wt% and 1 wt% of nanoclay with 16% and 10% increased, respectively. It showed that the slope of stress-strain curve increase with increasing in content of nanoclay. However, the flexural strain of 5 wt% nanoclay- modified epoxy plotted the lowest value, followed by 3 wt% and 1 wt% compared to neat epoxy which fails prematurely may be due to several imperfections of the fabricated specimen. In general, the incorporation of nanoclay into epoxy matrix led to a modest enhancement in flexural strength for all nanocomposite [15].

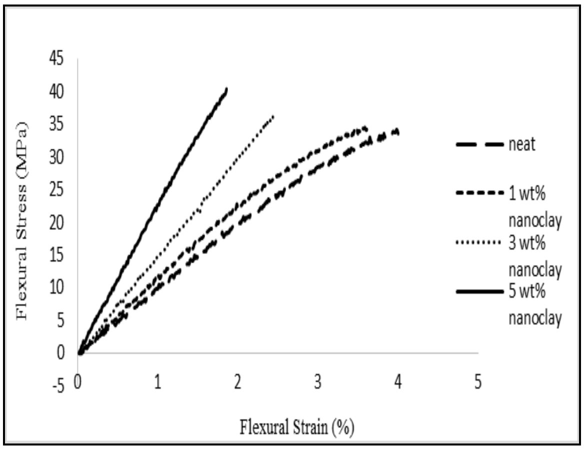

Fig. 3: Flexural stress-strain curves of nanoclay modified epoxy polymer compared to neat polymer

Table 2: Flexural properties of the neat and modified epoxy polymer

Nanoclay content (wt%)	Nanoclay-filled Epoxy Composites		
	Flexural Strength, σ_f (MPa)	Flexural strain, ε_f (%)	Flexural Modulus, E_f (GPa)
Neat	31.381 ± 0.701	4.275 ± 0.254	0.943 ± 0.0902
1wt%	34.476 ± 0.729	3.410 ± 0.722	1.144 ± 0.059
3wt%	36.392 ± 0.745	2.441 ± 0.357	1.385 ± 0.074
5wt%	40.413 ± 0.854	1.858 ± 0.620	2.228 ± 0.558

Flexural behavior of neat BFRP and nanoclay-filled BFRP composites as shown in Table 3. From the graph in Fig. 4, it shows the comparison between neat BFRP and nanoclay-filled BFRP composites. The flexural strength of nanoclay-filled BFRP composite contain 3 wt% nanoclay shows the best performance about 39MPa with 58% increasing, followed by 1 wt% nanoclay achieved 37MPa with 53% increasing compared to neat BFRP. The increment nanoclay content embedded in epoxy resin, flexural strength of specimen also increased. However, the flexural strength start to decrease when 5 wt% nanoclay is added due to intercalated structure of the nanoclay at high weigh percentage as in Fig. 3. The flexural strain increase with increment of nanoclay of 1 wt%, 3 wt% and 5 wt% nanoclay that shows the significant improvement with 2%, 27% and 46% increasing compared to neat BFRP composite. This shows that there is a strong interfacial adhesion between the matrix and fiber which contributes to the extent of matrix deformation.

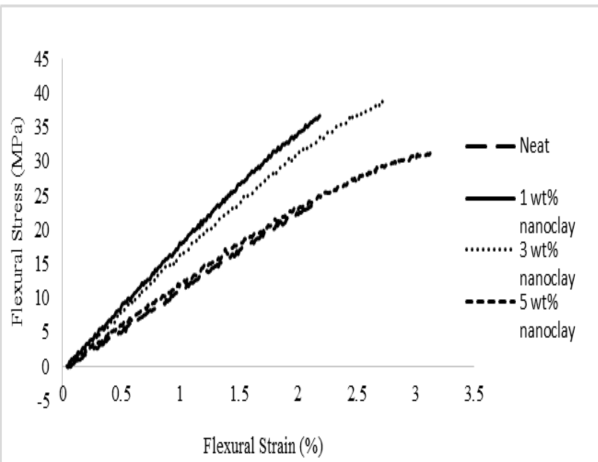

Fig.4: Flexural stress-strain curves of nanoclay filled BFRP composites compared to neat BFRP

Table 3: Flexural properties of the neat and nanoclay filled BFRP composites

Nanoclay content (wt%)	Nanoclay-filled BFRP Composites		
	Flexural Strength, σ_f (MPa)	Flexural strain, ε_f (%)	Flexural Modulus, E_f (GPa)
Neat	24.293 ± 2.800	2.138 ± 0.668	1.123 ± 0.072
1wt%	37.171 ± 6.852	2.201 ± 0.249	2.042 ± 0.304
3wt%	38.593 ± 5.267	2.721 ± 3.461	2.006 ± 0.258
5wt%	33.745 ± 3.300	3.127 ± 0.061	2.188 ± 0.113

The flexural properties of neat GFRP and nanoclay-filled GFRP composite are listed in Table 4. Fig. 5 indicates the influence of nanoclay on flexural stress and flexural strain responses of GFRP composites compared to unmodified neat GFRP composites. As can be seen from graph in Fig. 5, the increment of nanoclay content increase the slope of the stress-strain curves. The flexural strength of nanoclay-filled GFRP composite contains 5 wt% of nanoclay displayed the highest flexural strength with 53% increasing, followed by 3 wt% and 1 wt% with 25% and 21% increasing compared to neat GFRP composite. The nanoclay-filled GFRP composites present fewer deflections compared to neat GFRP composite when the flexural load increase. Nanoclay-filled GFRP composites endure more loads compared to neat GFRP at the constant flexure strain. For instance, the flexural strain of 1 wt%, 3 wt% and 5 wt% nanoclay GFRP composites show significant improvement with 10%, 16% and 50%. In addition, nanoclay content helped nanoclay filled-GFRP composites to improve their stiffness. It is significant that flexural strength of the epoxy was improved after addition of nanoclay without decline the flexural strain and this conclusion also supported by previous study from literature [12].

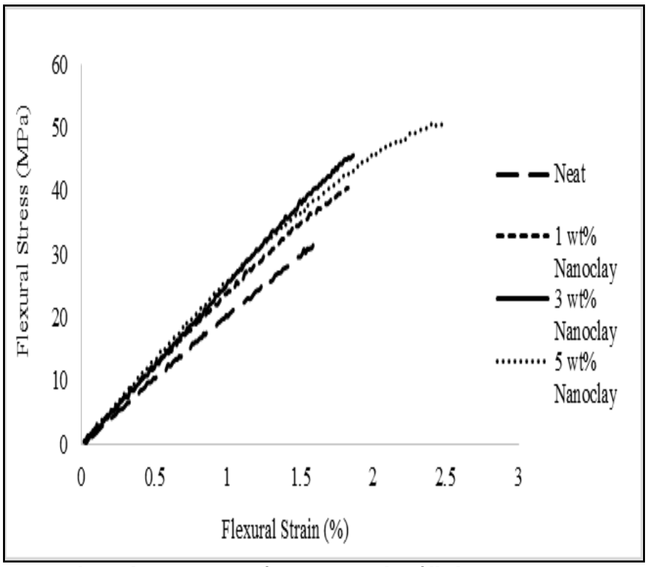

Fig. 5: Flexural stress-strain of curves nanoclay filled GFRP composites compared to neat GFRP

Table 4: Flexural properties of the neat and nanoclay filled GFRP composites

Nanoclay content (wt%)	Nanoclay-filled GFRP Composite		
	Flexural Strength, σ_f (MPa)	Flexural strain, ε_f (%)	Flexural Modulus, E_f (Gpa)
Neat	28.421 ± 5.453	1.963 ± 0.320	1.636 ± 0.090
1wt%	34.300 ± 6.553	2.357 ± 0.593	1.987 ± 0.243
3wt%	35.325 ± 6.711	2.393 ± 0.592	2.128 ± 0.245
5wt%	43.712 ±1.102	2.429 ± 0.755	2.314 ± 0.222

4. Conclusion

Flexural test was successfully conducted on two different FRP with three different ratio of nanoclay (1,3 and 5wt.%) according to ASTM D790. As the conclusion, addition of nanoclay to Basalt fiber and glass fiber reinforced polymer has improved the flexural strength, flexural and flexural modulus. These result proved that nanoclay shows better mechanical properties. The well-dispersed of nanoclay in epoxy resin and strong interfacial adhesion between matrix and fiber contributes to improvement of the flexural properties.

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