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EFFECT OF NANOCLAY CONTENT ON FLEXURAL PROPERTIES OF GLASS FIBER REINFORCED POLYMER (GFRP) COMPOSITES

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Widia Wahyuni Amir, Aidah Jumahat*, Jamaluddin Mahmud

Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

*Corresponding author
aidahjumahat@salam.uitm.edu.my

Graphical abstract

Abstract

This paper presents a study on the flexural properties of glass fiber reinforced polymer composites. The epoxy-nanoclay resin was milled using a three roll mill machine to produce exfoliated structure nanocomposites. The fiber laminates specimens were manufactured by vacuum bagging system. These specimens were tested in the three point bend configuration following the ASTM D7264. The flexural modulus, flexural strength and strain to failure were then determined based on the flexural test results. The results showed that flexural modulus and flexural strength increases when a certain amount of nanoclay was included in the resin system. A maximum of 80% and 37% improvement of flexural strength and flexural modulus, respectively, were found at 5 wt% nanoclay content when compared to the neat GFRP composite. The improved properties of GFRP composites were achieved mostly due to an increase on the interfacial surface areas as well as a well-dispersion of nanoclay in the GFRP composite system. The fracture surfaces of specimens after flexural test were observed under FESEM. The results showed that the compressive failure region in the fiber was a dominant failure mechanism of the specimens due to a large compressive area on the fracture surface.

Keywords: Flexural properties, nanoclay, epoxy, GFRP, fracture.

1.0 INTRODUCTION

Fiber Reinforced Polymer (FRP) is a composite material made of a polymer matrix reinforced with fibers. The most widely fiber used are glass, carbon, aramid and Kevlar. Over the recent years, FRP composites have become attractive for structural applications such as aerospace, marine, automobile and construction industries due to their high mechanical performance. In the aerospace industry, applications range from wall and floor panels to the fuselage [1, 2]. Glass fiber is by far the most widely used reinforcement fiber and is the lowest in cost [3, 4]. The glass fibers have a lower strength and modulus but a higher density when compared to carbon and aramid fibers [3-5]. There are many types of glass fiber such as E-Glass, S-glass, and C-Glass. Among them E-Glass is generally used as a reinforcing material due to its good mechanical and electrical properties [6].

Epoxy resins are extensively used in FRP composites as a matrix material due to their superior thermal, mechanical, and electrical properties [7]. The widespread use of the epoxy resins, however, is limited in many high-performance applications because of their inherent brittleness properties. The development of improved high performance composites based on epoxy resins can only be achieved by simultaneously improving matrix composites, fiber and interface properties. So that, the inclusion of nanoparticle into matrix composites leads to new enhancements of composites properties compared to conventional composites [8, 9].

Amongst the potential nanoparticle, nano layered silicate or nanoclay have received much attention as reinforcing fillers for polymer because of their potentially high aspect ratio and unique intercalation/exfoliation characteristics. Nanoclay having thickness around 1 nm and lateral dimensions in the order of few microns, have a very high aspect ratio and specific surface area (around 657 m^2/g) . The nanoclay is expected to strengthen the mechanical properties of FRP when nanoclay is well dispersed in epoxy resin system [10].

A number of research studies have been carried out to determine mechanical behavior of FRP using nanoclay filler. Mechanical characterization like tensile, flexural and, impact test are performed to quantify the significance of nanoclay on the mechanical properties of the composites. The presence of exfoliated nanoclay platelets substantially increased both the tensile strength and modulus. Significant enhancement was observed at nanoclay loadings less than 10% by weight of epoxy. However, it was reported that brittle behavior was also observed with high nanoclay content because of the presence of agglomeration of nanoparticle in the matrix resin.

This paper aims is to synthesize highly exfoliated epoxy-clay nanocomposites using three roll mill machines. Furthermore, the nanomodified GFRP composites were fabricated using vacuum bagging technique to develop high performance composites. It is worth mentioning, if mechanical properties are improved, the life-span of composites should be improved. From this overview, the flexural test has been performed in this study to determine the effect of nanoclay on mechanical properties of nanoclay incorporated GFRP composites. A possible fracture mechanism on specimens fracture surface occur during testing was obtained based on FESEM observations

2.0 EXPERIMENTAL

There are several factors which must be considered while selecting materials for a composite structure. The most important factors are nanoclay and resin chemistry, dispersion of the nanoclay in resin, compatibility of fiber and resin, matrix formulation, processing parameters and curing conditions. The epoxy resin used in this study is a commercially available Morcrete BJC 39 epoxy obtained from Morstrong Industries Sdn. Bhd. This polymer system comprises of a three to one ratio of resin to hardener. MMT clays type nanomer I.28 was used as nanofiller. This type of nanoclay is commercially available and supplied by Nanocor Inc. There are various types of nanoclay available and have been commercialized including I.28 that are compatible with epoxy resin. The surface of the MMT clay is modified with 25–30 wt% of trimethyl stearyl ammonium to produce nanomer I.28. Nanomers I.28 are supplied as a white powder that has a mean dry particle size of 8 – 10 μm and density of 1.9 g/cm^3. The plain weave type of E-glass fibre has been used as reinforcement. E-glass fiber is high strength glass fiber for structural applications and offers unique combinations of properties: strength, impact resistance, stiffness, temperature resistance, fatigue resistance etc. The modified epoxy with nanoclay content then reinforced with glass fiber to develop advanced FRP composites.

The required weight fraction of clay particles was pre-dispersed into the resin by hand-stir for 15 minutes. Due to the presence of the clay particles the epoxy resin became opaque and viscous, the mixture was then milled using three roll mill machines to produce exfoliated structure nanocomposites. The milling process was carried out at 60°C temperature by pouring the nanoclay-epoxy mixtures in between the feed and the center rollers. The material was collected and fed back into the feed and center rollers because the three roll mill machine was not a continuous process. The material was then poured into the hopper feeder.

Then, the fiber laminates specimens were produced using vacuum bagging system. The fiber was then cut into size 300 mm x 250 mm in preparing laminates. A series of nanomodified GFRP composites was fabricated using 1 wt%, 3 wt% and 5 wt% nanoclay content. The nanomodified resin and hardener were mixed at weight ratio of 3:1 as a matrix material. The plastic film was used to cover the specimens to ensure the laminate can be easily removed and smooth surface finish. The flatness of the laminate without any air bubbles was ensured by placing a 10kN load on top of the laminate and applying vacuum pressure to the laminate using a vacuum bagging system. The laminate was cured at room temperature for 24 hours.

Flexural test was conducted to determine the flexural properties of nanomodified-GFRP composites according to ASTM D7264. The test specimens of 80 mm lengths x 13 mm width x 4 mm thickness were bent under three-point bend configuration.

3.0 RESULTS AND DISCUSSION

3.1 Flexural Test

Figure 1 shows the typical flexural stress-strain curves of neat and nanoclay-filled GFRP composite systems. The graphs show that the addition of nanoclay improved the flexural properties of the GFRP composite. The flexural properties of GFRP composites are summarised in Table 1. Flexural modulus is the ratio of stress to strain within the elastic limit and this property was used to indicate the bending stiffness of the material while flexural strength shows the ability of the material to resist deformation under load. As can be seen, the nanoclay-filled GFRP composites improved flexural strength and flexural modulus but slightly reduced the failure strain at maximum flexure load when compared to the neat GFRP composites. The flexural strength of 5 wt% nanoclay specimen exhibits the tremendous improvement with 80% increasing compared to neat GFRP composites. In addition, the flexural strength of 1 wt% and 3 wt% nanoclay was increased to 27% and 71%, respectively. It was shown that the strong bonding between glass fiber and matrix results in increases the ability of the glass fiber to sustain the stress.

In addition, the flexural modulus of 5 wt% nanoclay displayed the highest flexural modulus of approximately 25GPa with 37% improvement compared to neat GFRP composites. The flexural modulus for 1 wt% and 3 wt% nanoclay also exhibit significant enhancement with 26% and 35%, respectively. It is worth noting that the improvement of flexural modulus value is contributed by the presence of nanoparticles in the epoxy matrix that interact strongly with the polymer chain and limit the ability of the polymer chain to move thus increasing the flexural modulus considerably.

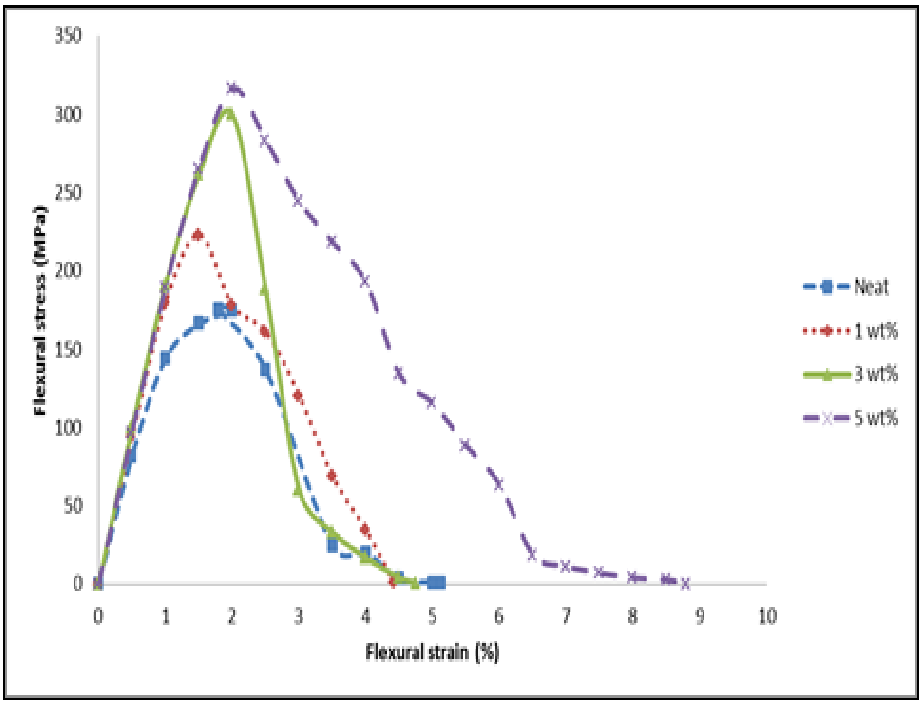

Figure 1 Typical flexural stress-strain curves of nanomodified (GFRP) composites system

Table 1 Flexural properties of the GFRP composites with various of nanoclay content

GFRP system	Flexural Strength, σ_f (MPa)	Flexure strain at Maximum Flexure load, ε_f (%)	Flexural Modulus, E_f (Gpa)
Neat	175.34±16.84	2.05±0.87	20.64±1.87
1wt%	222.84±16.79	1.51±0.64	22.53±1.25
3 wt%	299.67±12.93	2.02±0.69	24.25±2.68
5 wt%	316.05±17.35	2.11±0.81	24.31±1.64

3.2 Fracture Surface

The fracture surfaces of GFRP composites system after flexural test are shown in Figure 2. The fiber breakage indicates that there is some fragmentation of fiber bundles, evidence of extensive fiber debonding, delamination and extensive matrix cracking. The neat GFRP composites (Figure 2(a)) shows the fracture occurred along the bonding interface between fiber and epoxy resin. The nanomodified-filled GFRP composites (Figure 2(b,c and d)) shows a crack extension along the fiber-matrix interface with the absence of appreciable matrix deformation, which is reminiscent of brittle fracture behavior. Nanoclays is observed to adhere in the epoxy matrix providing significant resistance to crack propagation. This showed that by adding nanoclay into epoxy matrix, the shear load is effectively transferred from the matrix to the glass fiber to improve the strength of fiber laminates composites. On other hand, for neat GFRP system without nanoclay filler (Fig. 2(a)) the fracture occurred along the bonding interface between fiber and epoxy resin showing a poor adhesion of fiber to the matrix.

The example of closer inspection of fracture surface GFRP composite specimen as observed under FESEM as shown in Figure 3. The micrograph was taken in order to provide an insight on damage mechanisms of fracture surface. The compressive failures are the most common damage mechanisms under flexural loading. The presences of splitting and buckled fiber are clearly seen at the compressive surface. The tensile failures are also observed at the tension side of the specimens. This appears due to the brittle failure or fiber pullout. The laminate failed in compression after applied flexural loading due to the strong tensile properties of the glass fiber.

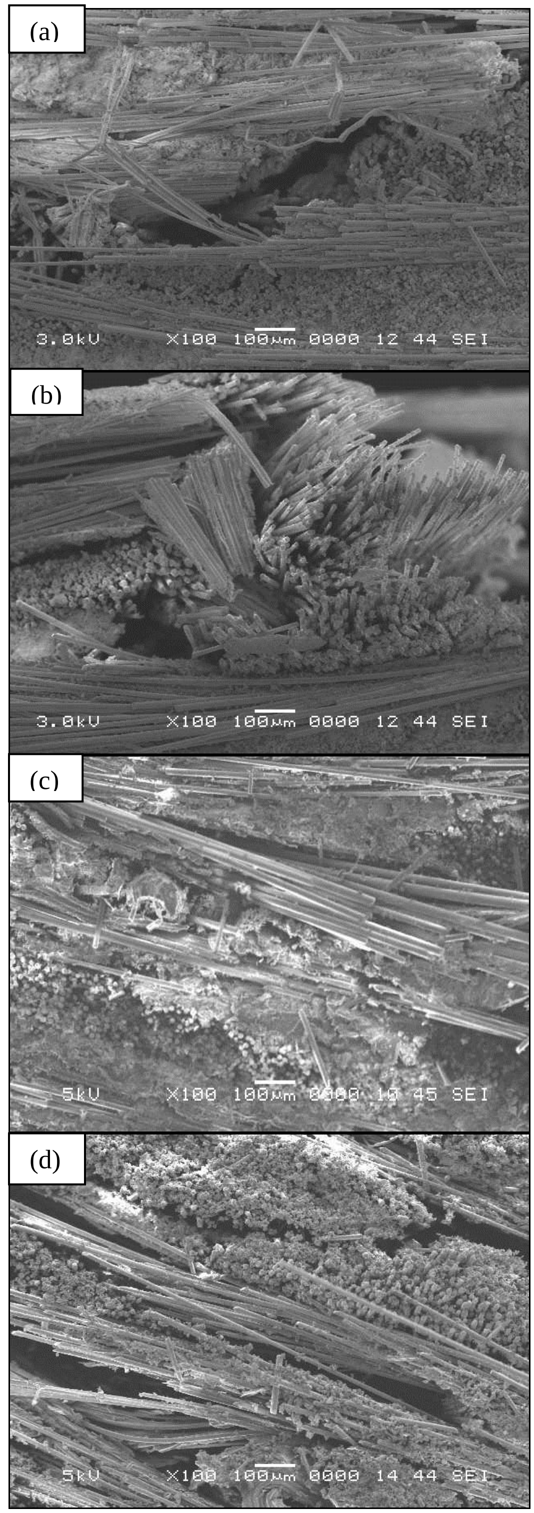

Figure 2 FESEM examination on fracture surface of GFRP (a) neat system; (b) 1 wt% nanoclay; (c) 3 wt% nanoclay; (d) 5 wt% nanoclay

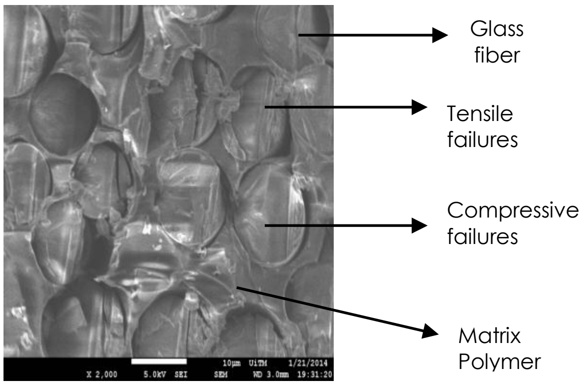

Figure 3 FESEM microstructure showing crack propagation of nanomodified GFRP composites observed under 2000x magnification.

4.0 CONCLUSION

The nanomodified GFRP composites with nanoclay filler were successfully developed using vacuum bagging system. Based on the experimental results, it was found that the milling technique using three roll mill machine was an effective technique to infuse nanoclay into epoxy matrix due to the improvement of flexural properties of glass fibre laminates. The GFRP composites fabricated with 5 wt% nanoclay inclusion showed a significant improvement in the flexural properties possibly due to several factors such as: (1) well interaction between the matrix, clay and fibers, (2) enhancement of matrix-fiber adhesion with inclusion of nanoclay and (3) better stiffness properties of the matrix.

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