Effect of Organo-Modified Nanoclay on the Mechanical Properties of Sugar Palm Fiber-reinforced Polyester Composites

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The aim of this study was to investigate the effect of nanoclay on the mechanical properties of sugar palm fiber-reinforced polyester composites. Organo-modified nanoclay (OMMT) was dispersed in unsaturated polyester resin at various weight contents from 1% to 5% using a mechanical stirrer. Naturally woven sugar palm fibers were reinforced in the nanoclay-modified resin, which were then hot compressed to form the composites. The effect of the OMMT weight content on the tensile, flexural, and impact properties of the composites were analyzed. The addition of OMMT resulted in a noticeable improvement in all of the investigated properties, until a certain weight percentage. The tensile properties showed the best improvements at a 2% nanoclay content. However, the 4% nanoclay content resulted in the best enhancements to the flexural and impact properties.

Keywords: Sugar palm fibers; Polyester; Nanoclay; Nanocomposites; Mechanical properties

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INTRODUCTION

With such rapid progress in research and technology, there is a need to satisfy the constantly increasing material requirements of these advancements. Composite materials have become an engineering necessity to cater to these needs. Composites are formed by the combination of different materials, which provides a wide range of properties to better suit specific requirements. A polymer matrix composite consists mainly of two components, a polymeric matrix/binder and reinforcements/fibers. The matrix helps to bind the fibers together and protects them from the environment. Reinforcements help to enhance the mechanical properties of the matrix because they are typically stronger, stiffer, and tougher than the binder (Razak and Kalam 2012). An increasing awareness of the environmental impacts from using typical composites, which are derived from non-renewable resources, has shifted the focus to research and production of composites that use materials acquired from renewable sources. This has resulted in an increased use of natural fibers as reinforcements in polymer matrix composites. Various biodegradable waste materials, such as wood chips, plant fibers, newspaper, *etc*., are now utilized as reinforcements. This also helps reduce the need for synthetic raw materials and mitigate waste management problems (Saba *et al*. 2016c). Natural fibers offer a wide range of advantages, including a low density, less wearing from tools, better thermal properties, acoustic insulation, lower cost, and biodegradability (Haameem *et al*. 2016).

A key advantage of using sugar palm fiber (SPF) as reinforcement in composites is that it exists in a naturally woven state (Ishak *et al*. 2013), which greatly reduces the time, effort, and cost required to transform them into usable reinforcements for composites. Figure 1 shows naturally existing woven SPFs. These fibers grow around a tree and can be extracted without cutting down the tree (Ticoalu *et al*. 2013), which caters to the preservation needs of sugar palm plants. In the past decade, a number of studies have been performed to explore the potential use of SPF in composites. Sugar palm fibers have been observed to have competitive mechanical and physical properties compared with other natural fibers, such as palmyra, kenaf, and coconut fibers (Sanyang *et al*. 2016). Sugar palm fibers have extensively been used as a conventional roofing material in Indonesia and Malaysia. However, the difficulty of maintenance, water seepage, high degradability, susceptibility to fungal infections calls for an improvement in the conventional roofing system. Reinforcing the sugar palm fibers in polymers can help to solve the problems as stated above and utilize the abundantly available fibers as well. This is a preliminary study to enhance the mechanical properties of sugar palm reinforced composites for its application as an alternate roofing materials.

Fig. 1. Sugar palm tree and extracted naturally woven fibers (Ishak 2009)

There are some disadvantages when using natural fiber reinforcements, such as weak fiber-matrix bonding characteristics and a tendency towards high water absorption by the natural fibers (Chandrasekar *et al*. 2017). These attributes can affect the mechanical and thermal properties of natural fiber-based composites. These properties can be improved by either various fiber treatments or adding additives to the polymer to meet the desired requirements. The topic of interest in this work was improving the mechanical properties of a composite by mixing an additive with the polymer. Advanced additives such as nano-fillers have been used effectively as nano-additives to further refine the properties of a polymer. For the past two decades, nano-science has been a popular topic amongst researchers, who are trying to better understand its benefits and applications (Saba *et al*. 2016a). A few commercially available nano-fillers include carbon-nanotubes (CNT), layered silicates, polyoctahedral silsesquioxane, and graphite nanoflakes (Saba *et al*. 2017). To be classified as nano-sized, the filler must have at least one of its dimensions be equal to or less than 100 nm (Saba *et al*. 2016c).

Clay-based nano fillers are used to enhance the properties of composites. Clay minerals can be described as aluminosilicates, which are essentially hydrous phyllosilicates (Rautureau *et al*. 2017). Smectite can be classified as a group of clay minerals with hydrated exchangeable cations and a 2:1 tetrahedral to octahedral sheet arrangement (Mackenzie 1959). Some of the clay species included in the smectite group are saponite, hectorite, stevensite, montmorillonite (MMT), beidellite, and nontronite (Kloprogge *et al*. 1999). Of these species, MMT nanoclay is the most widely studied and is used in manufacturing composites because of its good tendency for cation exchange, high aspect ratio, and good swelling characteristics (Ganguly *et al*. 2011). Principally, the structure of MMT is comprised of a central aluminum hydroxide octahedral layer between two silicon oxide tetrahedral layers. The isomorphous substitution of Al^{3+} with Mg^{2+} within these layers creates an overall negative charge on the MMT crystal, which is balanced by exchangeable counter ions, such as Na^{+}, K^{+}, and Ca^{2+} (Nguyen and Baird 2006). These inorganic hydrated cations promote the hydrophilic tendencies of MMT. To enhance the miscibility of MMT in organic polymers, the surface structure of MMT is modified. Inorganic cations present within the layers of MMT are replaced with organic ones, creating more hydrophobic organo-modified MMT (OMMT) and increasing the compatibility with polymer composites (Floody *et al*. 2009). Nanoclay-dependent enhancements of the mechanical and thermal properties of various thermoset-based composites reinforced by natural fibers has been well documented in previous studies (Kushwaha and Kumar 2011; Mohan and Kanny 2016; Hasan *et al*. 2018).

It has been observed that the optimum performance varies from material to material based on the amount of nanoclay used. However, it has been established that at an optimum filler content, which usually lies between 1% and 5%, most polyester-based composites show improvements in the thermal, physical, and mechanical properties (Rajini *et al*. 2012, 2013a,b; Saba *et al*. 2016b). The enhancement behavior may vary based on several factors, including the source and process for obtaining the nano reinforcements, which can cause variations in the aspect ratio, morphology, and crystallinity of the filler (Mohan and Kanny 2016). The scope of this study was to investigate the effectiveness of nanoclay on the sugar palm fiber reinforced polyester composites. As of now, there has been no published study with similar scope on sugar palm reinforced composites. Addition of additives to improve the mechanical properties of natural fiber reinforced composites is one of the most popular techniques to enhance the various properties of composite, and this will open a new dimension in sugar palm composites where significant enhancements can be achieved without going through the process of chemically modifying the fibers. Modification of polymer using additives is a much more controlled procedure in contrast with modification of natural fibers. So obtaining similar or better results with filler addition can be rated as a significant accomplishment in comparison to the alternate modification procedure. This paper focused on determining the variations in the tensile, flexural, and impact properties of sugar palm/polyester composites after adding various weight percentages of nanoclay. Based on the results from this study, the optimum percentage of nanoclay for all three of the investigated characteristics of sugar palm/polyester composites were determined.

EXPERIMENTAL

Materials

In this study, commercially available organoclay (MMT modified with 15 wt.% to 35 wt.% octadecylamine and 0.5 wt.% to 5 wt.% aminopropyltriethoxysilane; Nanomer®1.31 PS, (Sigma-Aldrich, St. Louis, MO, USA) was used. The nanoclay was provided in an off-white powder form with a density ranging from 200 kg/m^3 to 500 kg/m^3. The OMMT was used as supplied and without any further modification. Sugar palm fibers were collected from the trunk of sugar palm trees, where they occur in a naturally woven state known as ijuk, in Kuala Jempol, Negeri Sembilan, Malaysia. The mechanical and physical properties of the sugar palm ijuk fibers are given in Table 1.

Table 1. Properties of the Sugar Palm Ijuk Fiber

Property	SPF - Ijuk
Density (g/cm^3)	1.20
Tensile Strength (MPa)	276.60
Tensile Modulus (GPa)	5.90
Elongation at Break (%)	22.30

Data taken from Ganguly *et al*. (2011)

General purpose orthophthalic polyester resin with the trade name Reversol P9509 supplied by Berjaya Bintang Timur Sdn Bhd, Kuala Lumpur, Malaysia, was used to prepare the composite. A constant concentration of 1% (w/w) methyl ethyl ketone peroxide (MEKP) was used as a curing agent for the unsaturated polyester resin. The gel time of the polyester resin at 1% MEKP was 18 min to 23 min. The typical properties of the Reversol P9509 polyester resin are given in Table 2.

Table 2. Properties of the Polyester Resin

Property	Unsaturated Polyester
Density (g/cm^3)	1.2 to 1.5
Young's Modulus (GPa)	2 to 4.5
Tensile Strength (MPa)	40 to 90
Compressive Strength (MPa)	90 to 250
Tensile Elongation at Break (%)	2
Cure Shrinkage (%)	4 to 8
Water Absorption 24 h at 20 °C	0.1 to 0.3

Data taken from Ishak (2009)

Fabrication Process

Naturally woven SPFs were washed thoroughly with water to remove as much dirt and impurities as possible. The washed fibers were left to dry for 24 h at room temperature. These washed and dried fibers were then measured and cut according to the desired dimensions to form equally sized woven sheets. The SPF sheets were then stacked together to achieve the required weight for fabrication. As the fibers were in their natural state, the resulting sheets possessed a high overall thickness because of the fiber turning characteristics and trapped air, which gives them a fluffy structure. This characteristic is a hinderance in a proper hand layup procedure. To overcome this limitation, the fibers were hot pressed at 80 °C for 10 min to form compressed fiber mats, which made them easier to use in the hand layup process. This process can also help to remove moisture and trapped air from within the fibers and allows resin to seep through easily. After the fibers cooled down, they were ready for fabrication. Nanoclay was mixed with polyester, using a mechanical stirrer (HS 30D, Wisestir, Selangor, Malaysia) at 500 rpm for 60 min. After mixing, the mixture was left to settle for 30 min to remove air bubbles. Next, 1% MEKP, which acts as a hardener, was added to the mixture and manually stirred for 30 s using a wooden stirrer. A thin aluminum sheet was used to cover the base and top plate of the mold. A lubricant was sprayed on both the plates and mold for easy removal of the samples. Mild steel stoppers were placed on the base plate, so that the resulting samples would have the dimensions of approximately 300 mm × 300 mm × 3 mm. A thin layer of resin was poured into the mold. Next, the prepared fiber mat was placed in the mold, and the remaining resin was slowly poured and rolled evenly on the fibers. The mold was closed using the top plate. It was left undisturbed for approximately 5 min so that the resin could settle and air bubbles could be removed. Next, the mold was placed in a 40-ton hydraulic hot press machine (40 HC-B, Technopress, Selangor, Malaysia) at 80 °C for 30 min. The mold was removed from the hot press after 30 min and cooled in a hydraulic cold press (40 HC-B, Technopress, Selangor, Malaysia) for 2 min. Following the cooling of the mold, the samples were removed from the mold and left under nominal pressure to further cure for 48 h at room temperature. A band saw (LB1200F, Makita, Selangor, Malaysia) was used to cut the specimens according to the dimensional requirements of the standards used for testing.

Characterization

All of the samples were conditioned at 22 °C and 50% humidity for at least 2 d prior to the tensile, flexural, and impact tests.

Tensile testing

The tensile properties were examined by performing tensile tests in accordance with ASTM D3039 (2017). Test specimens with the dimensions of 120 mm × 20 mm × 3 mm were prepared. Tests were performed on a 5 KN Blue hill INSTRON universal testing machine (Selangor, Malaysia). The average results from five specimens per configuration were reported. The tests were performed at a constant head speed of 2 mm/min for all of the samples.

Flexural testing

The specimens for the flexural test were cut to the dimensions of 127 mm × 12.7 mm × 3 mm. The test was performed in accordance with ASTM D790 (2017). The tests were performed on the 5 KN Blue hill INSTRON universal testing machine. The average results from five specimens per configuration were reported. The cross-head speed was calculated using the following equation (Eq. 1):

$$R = (ZL^2) / (6d) \tag{1}$$

where R is the cross-head speed (mm/min), L is the support span length (mm), d is the depth of the beam (mm), and Z is the straining rate of the outer fiber (mm/mm/min). The variable Z was equal to 0.01.

Impact testing

The Charpy impact test was performed to determine the impact strength of the composites. Specimens with the dimensions 55 mm × 10 mm × 3 mm were tested, and the average results of five specimens were reported. The test was performed according to ASTM D6110 (2018). The impact strength was calculated using the following equation,

$$I = E / A \tag{2}$$

where I is the impact strength (kJ/m^2), E is the impact energy (kJ), and A is the area under the notch (m^2)

Scanning electron microscopy

The surface morphology of the fractured specimens from the impact strength tests was observed with scanning electron microscopy (SEM), which was performed on a HITACHI S-3400N (Selangor, Malaysia). The investigated surface was sputtered with gold prior to analysis. This observation was performed to analyze the change in the fracture mechanism of the composites with the addition of nanoclay.

RESULTS AND DISCUSSION

Tensile Properties

Tensile tests were performed on composites with and without nanoclay content (NC). The effect of the nanoclay weight percentage on the tensile properties was investigated, and the results are shown in Fig. 2.

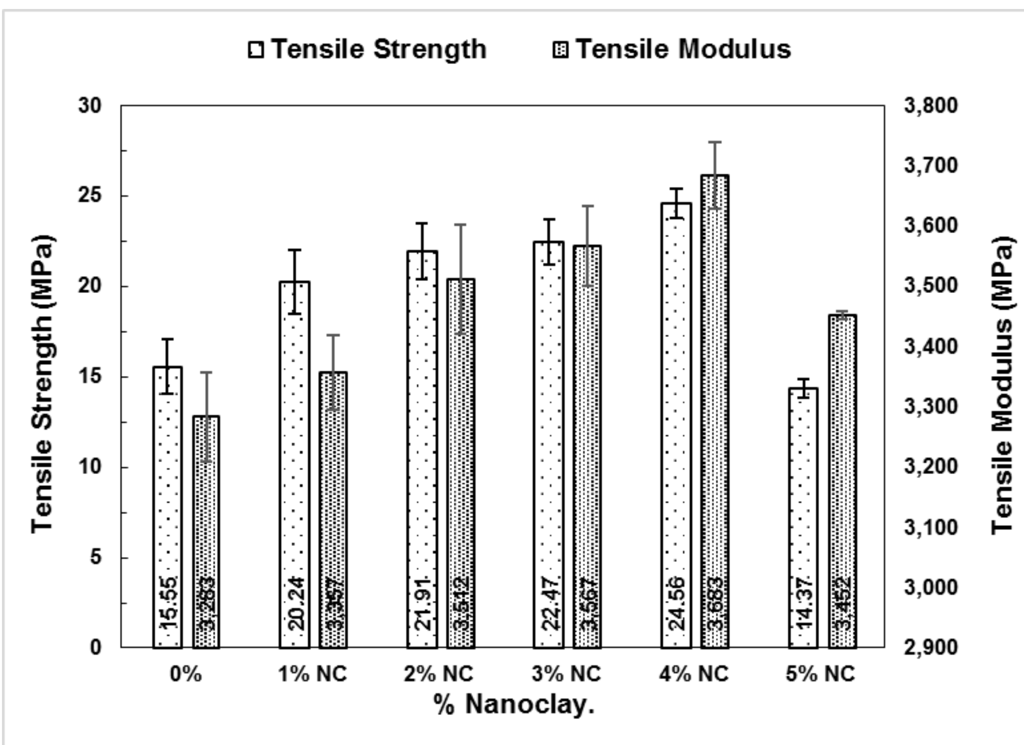


Fig. 2. Effect of the nanoclay on the tensile properties of the sugar palm/polyester composites

It was observed that the addition of nanoclay had a noticeable effect on the tensile properties of the composites. Overall, all of the nanoclay-incorporated composites showed improvement in the tensile strength and modulus, except at a 5% NC, which deteriorated the tensile strength slightly.

The tensile strength of the sample without nanoclay (0% NC) was 15.55 MPa, which increased remarkably after the addition of up to 4% nanoclay and decreased suddenly at a 5% NC. At 1% NC, the tensile strength increased to 20.24 MPa, which was almost a 30% increase compared with the composite without nanoclay. A higher NC caused a gradual increase in the tensile strength, until it reached its highest value (24.56 MPa) at a 4% NC. At this point, there was an overall increase in the tensile strength of 58%. This increase in the tensile strength could have been because of the higher interfacial contact between the matrix and nano filler, which facilitated better adhesion characteristics in the composite (Teja *et al*. 2017). When the NC was 5%, the tensile strength showed a 7.6% reduction compared with that of the 0% NC composite. This was attributed to the formation of agglomerates because of high number of nano particles and increased van der Waals forces between the nano filler. A high surface area to volume ratio is one of the main advantages of nano fillers, which is reduced by agglomeration and thereby reduces the surface energy of the nanoclay for interfacial bonding with the matrix. Teja *et al*. (2017) showed a similar effect of nanoclay on banana fiber/polyester composites. It was reported that there was a gradual increase in the tensile strength with the addition of nanoclay until 4% and then a sudden decrease with the further addition of nanoclay.

The tensile modulus for all of the samples with nanoclay showed higher values compared with that of the composite without nanoclay. This indicated that the stiffness of the composites increased with the addition of nanoclay, which has an inherently high stiffness (Ray and Okamoto 2003). A steady increase in the modulus was observed for the 1% and 2% NC composites. The maximum tensile modulus was achieved in the 4% NC composite. The tensile modulus increased by almost 12% after adding a 4% NC to the composite.

Rozman *et al*. (2011) conducted a study to investigate the size of natural fiber and the effect of nanoclay concentration on the tensile properties of kenaf/polyester composite. The authors concluded that the smaller the size of fiber the lower the tensile strength and modulus. The study indicated that difference in tensile strength of composites with different fiber length was increased with addition of nanoclay. This showed that with addition of nanoclay, the tensile strength of composites with longer fibers improved to a higher degree. SPF used in this study are long and woven fibers. The length as well as the weave nature of the fibers further helped in enhancing the effectiveness of nanoclay and resulted in a higher percentage increase in tensile strength than the previous study. Previous studies on addition of nanoclay in natural fiber reinforced polyester composites showed that percentage improvement in tensile strength and modulus usually ranges from 15% to 30% and 10% to 15% respectively (Haq *et al.* 2008; Rozman *et al.* 2011; Prasad *et al.* 2015; Teja *et al.* 2017; Shuvo *et al.* 2015). In this study, SPF/UPE composite displayed an improvement of almost 58% and 12% in tensile strength and modulus, with addition of nanoclay. The higher rate of improvement in tensile strength can be attributed to better compatibility of nanoclay infused polyester with sugar palm fibres due to its unique facial microstructure. Previous study on microstructure of SPF revealed that the surface of SPF contains a number of microscopic pores (Bachtiar *et al.* 2010), which is a distinctive feature compared to natural fibres used in above literature such as kenaf, jute, hemp, and grasses, *etc.* The inclusion of nano-reinforcement in the resin results in increased usability of these sites for effective bonding and better stress transferability. The acquisition of these sites on a nano-scale provides a higher net fibre-matrix contact area, which leads to a comparatively higher rate of improvement in strength. The modified rough structure of matrix as shown in Fig. 6b also plays a part in providing additional hinderance and support in these particular sites. The tensile results showed that the 4% NC resulted in the optimum characteristics in the composite for transmitting and distributing stress.

Flexural Properties

Figure 3 shows the flexural strength and modulus for the various quantities of NC in the sugar palm/polyester composites. Generally, the NC was seen to affect the flexural behavior of the composites. The trend of enhancement depended on the amount of nanoclay added to the composite.

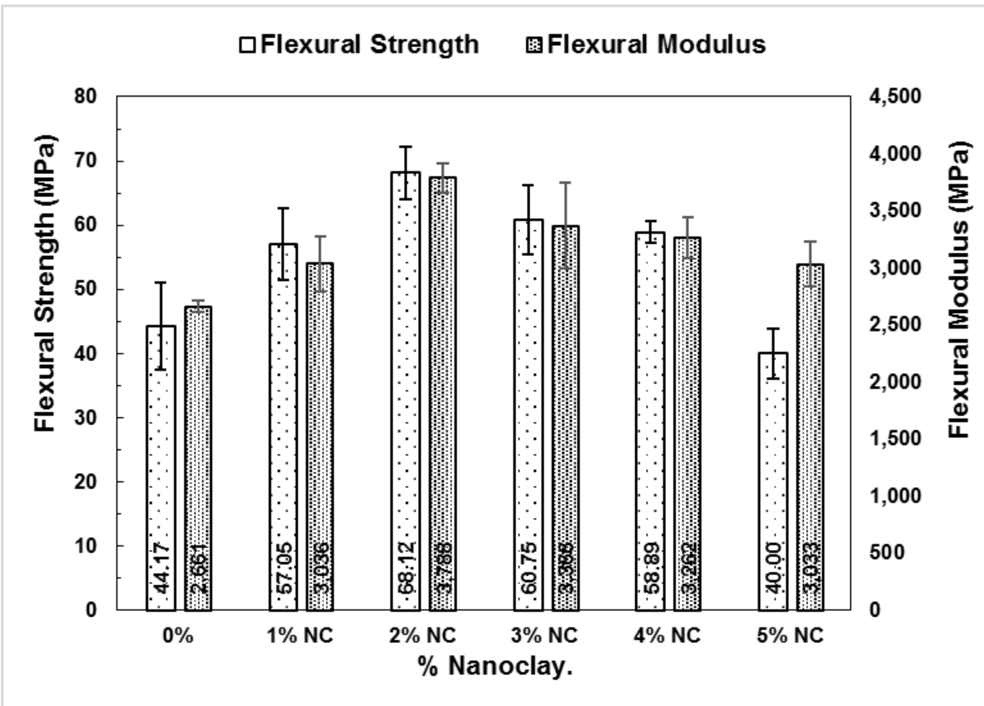


Fig. 3. Effect of the nanoclay on the flexural properties of the sugar palm/polyester composites

A positive effect on the flexural strength was observed immediately after the introduction of a 1% NC to the composite. This effect was observed in the composite until a 2% NC was added to the composite. At this NC, the composite was observed to have an increased flexural strength, which was almost 54% higher compared with that of the composite without nanoclay. This improvement was attributed to good dispersion and exfoliation between the nanoclay and polyester resin at the low nano filler concentrations (Haq *et al*. 2009). This characteristic maintained the high resulting aspect ratio of the nanoclay and produced better interfacial bonding, which prevented the formation and propagation of cracks within the composite. With the further addition of 3% to 5% nanoclay, the flexural strength was observed to decrease. At a 5% NC, the flexural strength showed the lowest value and was 10% lower compared with that of the composite without nanoclay. This could have been the result of agglomeration of the nano filler, which causes composites to deteriorate mechanically.

The flexural modulus of the composite followed almost the same trend as that of the flexural strength after the addition of nanoclay. The flexural modulus increased from 0% to 2% nanoclay and gradually decreased with the further addition of 3% to 5% nanoclay. The flexural modulus of the composite without nanoclay was 2.66 GPa, which increased by 14% in the composite with a 1% NC. The maximum flexural modulus occurred in the composite with a 2% NC, which was 3.79 GPa (approximately 42% increase from that of the 0% NC composite). As was discussed above, this improvement was achieved primarily because of the high modulus of the nanoclay and smooth distribution of nanoclay in the polyester. With a further increase in the nanoclay, the flexural modulus decreased to 3.37 GPa, 3.26 GPa, and 3.03 GPa for the 3%, 4%, and 5% NC~~s~~, respectively. It was observed that, with an increase in the NC above 2%, the flexural strength deteriorated at a faster rate compared with the flexural modulus. This behavior could have occurred because the free volume for nano particles, which permitted it to evenly disperse in the matrix, decreased with the addition of a higher nano filler. This created a high stress region and facilitated early crack formation during bending, and thereby decreased the strength at a higher nano fiber loading. The modulus, which is a low deformation property, is affected to a lesser extent by this behavior (Dewan *et al*. 2013).

With the addition of 2% nanoclay, the flexural strength and the modulus of SPF/UPE increased by 54% and 42% respectively. Previous studies on effect of nanoclay on natural fibre reinforced polyester composites showed that the enhancement ranges between 10% to 20% for both the flexural strength and modulus (Dewan *et al.* 2013; Rajini *et al.* 2013b; Venkatram *et al.* 2016; Teja *et al.* 2017). A comparatively higher rate of nanoclay effectiveness in SPF/UPE can be attributed to the structural features of SPF and improved SPF-matrix compatibility with addition of nanoclay. The morphological changes in polyester due to addition of nanoclay resulted in higher resistance to bending while the improved fibre-matrix adhesion provided means for better strength distribution throughout the composite.

Impact Properties

The performance of a material upon impact and its potential to behave in a brittle or elastic way can be determined by performing an impact test (Saba *et al*. 2016c). The results can help to better understand the overall strength of a material. The results are represented in a bar chart in Fig. 4. It was observed that the addition of nanoclay had both positive and negative effects on the impact properties of the composites.

The impact strength improved slightly with the addition of 1% nanoclay in the sugar palm/polyester composite. This trend continued for the 2% NC composite and declined with the further addition of nanoclay. A noticeable improvement of 23% was observed at a 2% NC compared with that of the composite with a 0% NC. This indicated that the composite was more durable and could withstand a higher impact energy.

The decrease in the impact property was almost linear from the 3% to 5% NC. According to Hosseini (2017), a higher NC may cause higher levels of un-exfoliated clay structures, which results in a decrease in the impact strength. This could have explained the low impact performance of the composites with the 3% to 5% NC. The decrease in the impact strength revealed that the composite became increasingly brittle with an increasing nanoclay weight percentage.

Previous researchers have shown varying results with addition of nanoclay, with some showing decrease in impact properties (Haq *et al.* 2008; Kushwaha and Kumar 2011) while others showing improvements (Rozman *et al.* 2010; Venkatram *et al.* 2016). In the case of SPF/UPE composite, the enhancing factors of SPF as discussed in earlier sections, contributed to improved impact strength with the addition of nanoclay. Another unique feature of the SPF, as visible from Fig. 5b, is the circular hollow nature of microfibrils (Ishak 2009). The incorporation of nanoclay improved the interfacial adhesion between the reinforcements and matrix, as discussed in the earlier sections. Both of these aspects jointly contributed to enhanced energy absorption properties of the composites. Better interfacial bonding, due to incorporation of nanoclay, facilitated efficient distribution of impact energy throughout the fibres and the hollow structure of microfibrils further provided a distinctive shock-absorbing characteristic to the composite. This resulted in good impact properties of SPF/UPE composite at 2% nanoclay concentration.

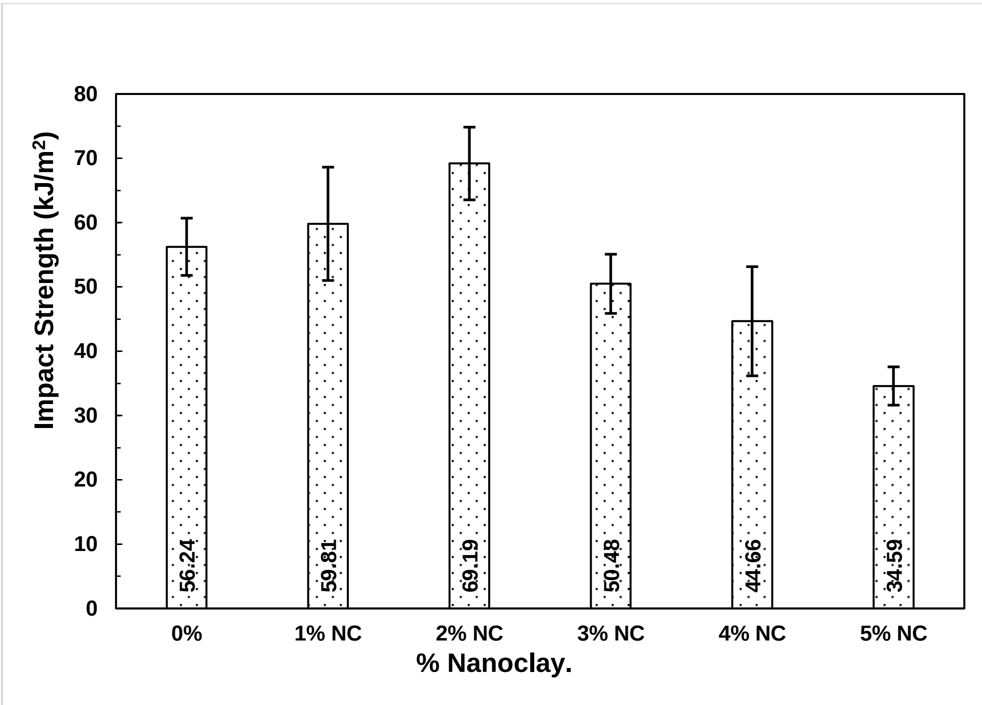
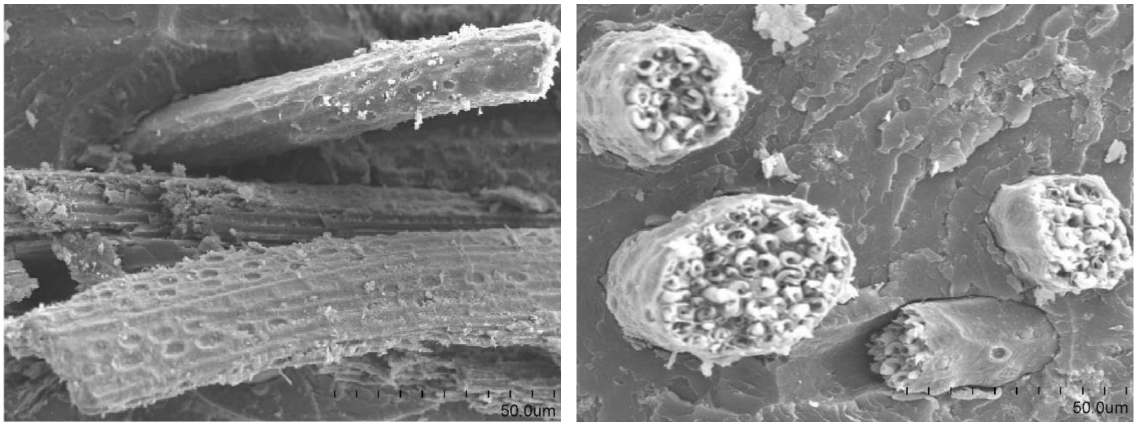


Fig. 4. Effect of the nanoclay on the impact properties of the sugar palm/polyester composites

Scanning Electron Microscopy Analysis

The surface morphology of the composites that fractured during the impact testing was examined with SEM analysis. Figure 5 shows the SEM micrographs of the fractured surfaces of the composites with and without nanoclay. Figure 6 shows a magnified view of the resinous regions within the fractured surface of the composites with and without nanoclay.

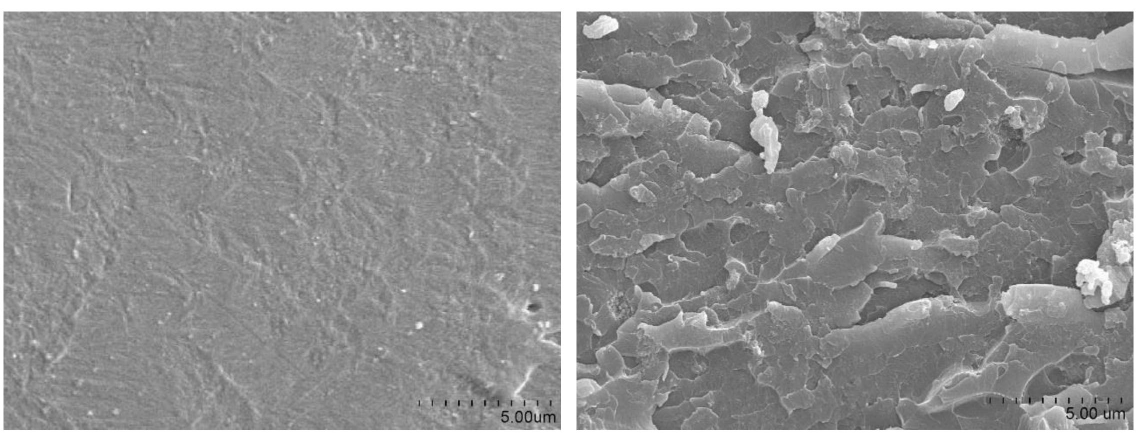
Figure 5a shows the fractured surface of the SPF/polyester composite without any additive. The impact energy applied to the composite caused the fibers to pull out from the composite before breaking at an excess of applied strength, which revealed poor interfacial bonding of the SPFs with the polyester. Figure 5b shows the fractured surfaces of the composite infused with a 2% NC.



(a) (b)

Fig. 5. SEM images of the (a) 0% NC and (b) 2% NC composites

The physical characteristics of SPF such as micropores on the surface of SPF and the structure of microfibrils can be seen in the image. A visible difference in the enhanced fiber bonding was observed in the composite filled with nanoclay. It was seen that in the composite with the additive, fiber breakage occurred at a smaller length, which indicated that the fibers were in good contact with the resin and avoided slipping and pulling out at a higher degree. This was attributed to an improved stress transferability from the resin to the reinforcement and resulted in enhanced mechanical characteristics of the composite, as was concluded from the results earlier. In contrast, the composite without additives showed higher fiber lengths, which was attributed to the inability of the polyester to keep the fibers intact and thus resulted in lower mechanical properties for this composite. Hossen *et al*. (2016) reported better fiber matrix adhesion with the addition of nanoclay and attributed this behavior to similar characteristics.



(a) (b)

Fig. 6. Magnified SEM images of the resinous region in the (a) 0% NC and (b) 2% NC composites

Figure 6a shows that the resinous regions in the composite without nanoclay had a much smoother surface compared with that of the composite with additives. The flat surface showed the brittleness of the composite, while the roughness indicated a decrease in the brittleness with composite fracturing. This was confirmed by the results obtained from the impact tests for these composites. Binu *et al*. (2016) reported similar behavior and morphology with the addition of nanoclay in glass fiber-reinforced composites. The rougher surface texture exhibited by the composites with nanoclay, as shown in Fig. 6b, indicates that the fracture was forced to follow a more distorted path as guided by the positioning of the nano reinforcements in the matrix. This behavior of crack propagation resulted in increased surface area of the fracture and required a greater amount of energy to overcome the enlarged surface area of the fracture (Kornmann *et al.* 1998). The random orientation of these layers was attributed to the exfoliated dispersion of the nanoclay within the matrix. Hence, the roughness on the surface seen with the addition of nanoclay was attributed to the enhanced adhesion within the matrix, which resisted breakage. This surface morphology of the matrix with nanoclay also helped to create a higher fiber resistance, which prevented them from slipping out.

CONCLUSIONS

1. This study investigated the effect of various concentrations of nanoclay (NC) on the mechanical properties of polyester composites that also contained sugar palm fibers (SPF). It was established that the addition of nanoclay generally improved the mechanical properties of the composites.
2. The results indicated that the composite with a 4% NC had the best tensile properties.
3. The best flexural properties were obtained with the 2% nanoclay-infused composite.
4. The impact study showed that the impact strength was enhanced with the addition of up to 2% nanoclay, and the impact strength deteriorated with a further addition of nanoclay to the composites.
5. The SEM images showed a rough and fractured surface morphology of the composite with the addition of nanoclay, which was consistent with the enhanced mechanical properties. The micropores and the microfibrils in the structure of SPF are also visible in SEM images, which contributed to better nanoclay effectiveness.

The results from this study indicated considerable increase in the mechanical properties at optimum concentrations of nanoclay in SPF/UPE composites. The future work will focus on exploring other related properties such as thermal, physical and weathering studies to support its usability as an alternate to conventional roofing material.

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