

Fabrication of Epoxy Nanocomposites from Oil Palm Nano Filler: Mechanical and Morphological Properties

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The aim of this research was to fabricate epoxy nanocomposites by utilizing the developed nano filler from oil palm mills agricultural wastes oil palm empty fruit bunch (OPEFB) fibers for advanced applications. Epoxy-based polymer nanocomposites were prepared by dispersing 1, 3, and 5 wt. % nano OPEFB filler by using a high speed mechanical stirrer through hand lay-up technique. The mechanical (tensile and impact) properties and morphological properties of nano OPEFB/epoxy nanocomposites were examined and compared. Morphological properties were analyzed by transmission electron microscopy (TEM) and scanning electron microscopy (SEM) to look at the dispersion of the nano OPEFB filler in the epoxy matrix. The tensile and impact properties of nanocomposites increased until 3% nano filler loading, but beyond 3% they decreased. Overall mechanical properties reached maximum values for 3% loading, due to better stress transfer owing to homogenous dispersion of nano OPEFB filler within epoxy matrix. The observed results were also confirmed by SEM and TEM micrographs.

Keywords: Epoxy; Oil Palm empty fruit bunch fiber; Nano filler; Nanocomposites; Mechanical properties; Morphological properties

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INTRODUCTION

Nanocomposites are the advanced engineered solid materials where at least one of the phases has a dimension in the nanometer range (1 nm to 100 nm), and are regarded as promising alternatives to overcome the drawbacks of polymer matrix, micro- and macro-conventional composites (Saba *et al.* 2014). Nanocomposites at lower filler contents can deliver superior mechanical/thermal properties, gas permeability, and flame retardancy compared with traditional materials (Saba *et al.* 2016b). The nanocomposites possess specific and remarkable properties that are critically required for different applications such as automotive, construction and buildings, food packaging, and electronics industries (Sun and Yao 2011; Saba *et al.* 2016c).

Epoxy resins based on bisphenol A diglycidyl ether (DGEBA) are widely used in thermosetting engineered polymeric materials in the fields of electronic encapsulation, heavy equipment, dielectric materials, blending, composites, and nanocomposites (Mohan 2013; Saba *et al.* 2015b). Epoxy resins are leading the modern industries toward the development of high performance materials because of their thermal stability, mechanical properties, optically transparent properties, easy processing abilities, high stiffness, and

relatively high absence of byproducts or volatiles (Azeez *et al.* 2013; Mohan 2013; Saba *et al.* 2015b;). However, the mechanical properties (modulus, strength, and toughness) of cured epoxy resin are not adequate for certain end-use applications. These limitations are primarily due to their delamination, low impact resistance, inherent brittleness, and fracture toughness behavior (Abdellaoui *et al.* 2015). Thus, there is a need to modify the epoxy resin to improve its physical and mechanical properties (Saba *et al.* 2014), by inducing various fracture mechanisms with only 1% to 10% additives (in mass to resin) (Han and Fina 2011; Ayandele *et al.* 2012). Currently, modified epoxies are the subject of interest in research to extend its applications in civil infrastructure and the transportation sector.

Nano fillers have the potential to increase stiffness, strength, impact resistance, and thermal stability (Saba *et al.* 2015a). However, the interfacial strength between filler and polymer play a crucial role in development of nano filler/polymer nanocomposites. Researchers have described the effects of different nano filler loading particle size, aspect ratio, matrix-filler interactions, and filler-filler attractions parameters on the mechanical, morphological and thermal properties of the polymer composites (Bhat and Khalil 2011; Abdul Khalil *et al.* 2013a). The inclusion of 1 wt.% organo-clay platelets in recycled cellulose fibers (RCF) in epoxy composites considerably increases the flexural strength and modulus, as well as the impact strength and toughness of composites (Alamri *et al.* 2012).

The use of cellulosic solid waste materials as nano filler in polymer composites is a new step in managing bio-agricultural wastes. Recently, researchers utilized bio-agricultural oil palm ash (OPA) waste as nano filler in polypropylene polymer matrix. They observed that both the tensile strength and impact properties were better than polypropylene composites (Bhat and Khalil 2011). Bio-waste OPA has also been used as a reinforcement in epoxy matrix to fabricate epoxy nanocomposites (Khalil *et al.* 2013), with maximum tensile and flexural strength when the OPA filler loading was only 3% (Khalil *et al.* 2013a).

In other interesting work, the carbon black (CB) derived from bamboo stems (BS-CB), oil palm and empty fruit bunch (OPEFB-CB), and coconut shells (CNS-CB) have been used to modify epoxy composites. The CB-filled epoxy composites show better mechanical properties than epoxy composites. Among all CB-filled epoxy composites, the OPEFB-CB displayed better tensile strength, modulus, and elongation at break than the CNS-CB and BS-CB filled epoxy composites (Abdul Khalil *et al.* 2013a).

The positive results prompted this study to develop sustainable and environmentally friendly nano-based materials along with cost-effective waste management. The incorporation of OPEFB bio-waste as nano filler in epoxy matrix will open new alternative way to utilize locally available biomass for advance applications. From literature review, it is evident that no work reported on the utilization of nano OPEFB filler to enhance the mechanical (tensile and impact) properties of the neat epoxy matrix. In our previous work, the development and characterization of nano filler from OPEFB fibers through cryogenizer and high energy ball milling (HEBM) technique are well reported (Saba *et al.* 2015a). The present research work deals with the incorporation of developed nano OPEFB filler in epoxy resin to enhance the overall mechanical and morphological properties. The effect of different nano OPEFB filler loading (1%, 3%, and 5%) content on the mechanical (tensile and impact) properties and morphological (SEM and TEM) properties of the epoxy composites were investigated in order to provide a new step to utilize the green nano filler for renewable and sustainable structural products.

EXPERIMENTAL

Materials

The OPEFB fiber was obtained from MPOB, Bangi-Selangor, Malaysia. The physical, mechanical, and chemical composition of OPEFB fiber is shown in Table 1. The epoxy resin D.E.R 331 is a clear liquid resin based on diglycidyl ether of bisphenol A (DGEBA) and was obtained from Dow Chemical Pacific Singapore (Table 2). The curing agent, epoxy hardener Jointmine (905-3S), is a transparent liquid. It is a modified cycloaliphatic amine supplied by Epochemie International Pte Ltd., Singapore. It is less volatile than linear aliphatic amines and possesses chemical resistance, hardness besides good elevated temperature performance (Table 3).

Table 1. Physical and Mechanical Properties of OPEFB fiber (Saba *et al.* 2016c; Rosamah *et al.* 2016)

Properties	OPEFB fiber
Density (g/cm ³)	0.7-1.55
Tensile Strength (MPa)	50-400
Young's modulus (GPa)	1-9
Elongation at break (%)	8-18
Cellulose content (%)	43.7
Hemicellulose (%)	29.02
Lignin content (%)	13.33
Microfibril angle (deg)	42-46
Lumen width (μm)	6.90

Table 2. Typical Properties of Epoxy Resin D.E.R 331 (Saba *et al.* 2016c)

Characteristics	Description
Epoxide Equivalent Weight	182 – 192
Viscosity @ 25 °C	11000 – 14000
Color	Water-white to yellow
Hydrolyzable Cl	0-500
Epichlorohydrin	5.0 Max
Water Content	700 Max
Density (25 °C, g/cm ³)	1.16
Flash Point (Cooled Cup °C)	255
S.P.I. Skin rating	2

Table 3. Properties of Epoxy Hardener (Jointmine 905-3S) (Saba *et al.* 2016c)

Characteristics	Description
Type	Modified cycloaliphatic amine
Color	< 2
Viscosity (poise @ 25 °C)	200-400
Amine Value (mg KOH/gm)	280-320
Pot Life (100g @ 25 °C)	75 min
Thin Film Set Time (@ 25 °C)	5 h
Hardness (Shore D)	85
Equivalent weight per Active-H	95
Recommended Usage Rate (phr)	50

All purchased chemicals were used without any further purification. The silicone spray used was procured from Dow Chemical Pacific Singapore, Singapore. Teflon sheets were procured from NR Medicare Sdn. Bhd., Selangor, Malaysia.

Methods

Fabrication of composites

The nano OPEFB filler was dried at 60 °C for 12 h and then kept in a desiccator to cool and prevent humidity until it was used for fabrication. Dried nano OPEFB filler (1%, 3%, and 5%) was added into the epoxy resin using a high speed mechanical stirrer. The stoichiometric ratio (2:1) of the epoxy and hardener was maintained. The mixture was mechanically stirred for at least 20 min at room temperature. The mixture was then poured into a stainless steel mould and cured for 24 h at room temperature. Silicone spray release agent was used in the mould to facilitate the removal of the composite samples.

Characterization

Tensile test

The tensile strength, modulus, and elongation at break of the nano OPEFB/epoxy nanocomposites and epoxy composites were measured with a universal testing machine (Instron 5567, Shakopee, USA). The composite samples were cut to 120x20x3mm with a band saw machine prior to commence tensile testing. All samples were prepared as per the specifications in ASTM D 3039 (2014). A standard head displacement was applied at 5 mm/min. For each composites sample, six replicate specimens were tested, and the average tensile strength, modulus and elongation at break were calculated.

Impact test

The impact strength of nano OPEFB/epoxy nanocomposites was measured with a CEAST 9050 impact testing machine (Instron, Norwood, USA). Before impact testing, V-notches were made on all eight replicates of each composites sample by using NOTCHVIS. The V-notched specimens were then tested according to the ASTM D256 (2010) specifications. The composite samples were cut to 70x15x3 mm with a band saw machine. Appropriate pendulum hammers were mounted with the speed 10 kJ, and the machine was calibrated for energy and for accurate determination of the exact amount of impact energy (J/m) involved in the tests. The energy needed to break the composite sample, its toughness and average impact energy was then analyzed.

Transmission electron microscopy (TEM)

The morphology and size distribution of nano OPEFB filler in the nano OPEFB/epoxy nanocomposites sample were studied by transmission electron microscopy (TEM; Hitachi 7100, Tokyo, Japan). The dried epoxy nanocomposite samples were dissolved in acetone and dispersed thoroughly by sonication with an ultrasonicator (JP SELECTA 3000512) for 30 min. Next, a drop of the colloidal dispersion containing nanocomposite powder was transferred onto a carbon-coated 300 mesh copper grid, which was dried at room temperature before TEM.

Scanning electron microscopy (SEM)

The microstructure and surface morphology characteristics of tensile fractured samples of epoxy composites and nanocomposites were performed by scanning electronic microscopy (SEM), after gold coating with EMITECH K575X sputter coater (Quorum Technologies, Ashford, UK). Micrographs were captured with a NOVA NANO SEM 230 (FEI, Hillsboro, USA) field emission instrument.

RESULTS AND DISCUSSION

Tensile Properties

Figure 1 shows the effect of different nano OPEFB filler loading on the tensile strength of epoxy composites. The tensile strength of the neat epoxy matrix enhanced with the loading of nano OPEFB filler (1%, 3%, and 5%). The nanocomposites developed by incorporating nano OPEFB filler were relatively stiffer and tougher than epoxy composites as the filler are harder and stiffer particles. From Figure 1 it is evident that the incorporation of 1% and 3% nano OPEFB filler in the epoxy resin primarily increased the tensile strength. However, when the filler loading allowed increasing from 3% to 5%, tensile strength was decreased. The obtained results were quite similar to oil palm ash/epoxy nanocomposites, where the loading of nano oil palm ash filler beyond 3% reduces the mechanical properties of nanocomposites (Khalil *et al.* 2013).

The considerable increase in tensile strength with the incorporation of nano OPEFB filler up to 3% (29.01 MPa) was attributed to better homogeneous dispersion and remarkable enhancements in the interaction between the nano filler and the epoxy matrix within the nanocomposites. The improved interaction allows better transfer of applied longitudinal stress between the nano filler particles and the epoxy matrix, and thus consequences the enhancement in tensile strength of the epoxy nanocomposites.

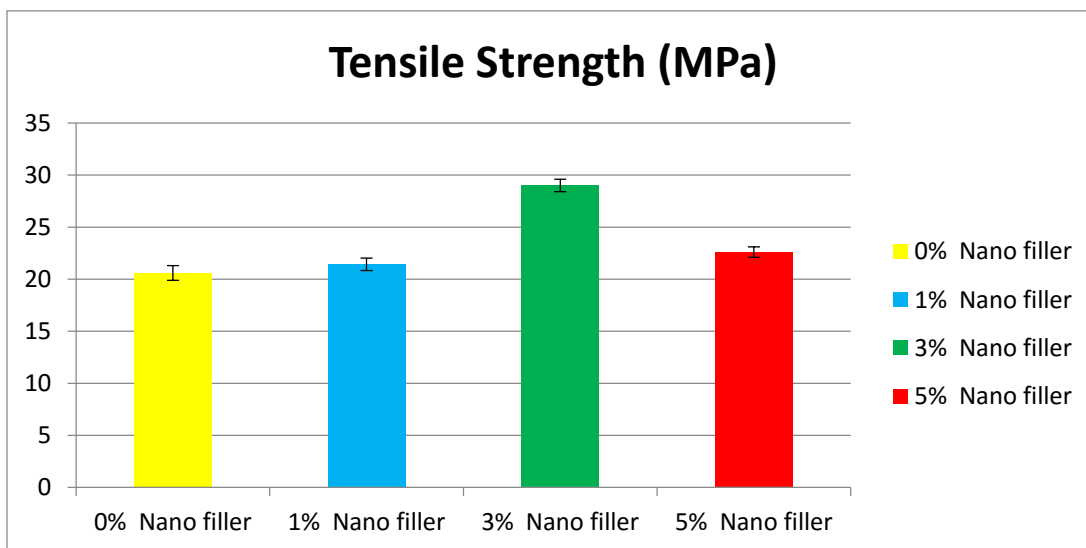


Fig. 1. Effect of nano OPEFB filler loading on tensile strength of epoxy composites

Epoxy nanocomposites with 5% nano OPEFB filler loading displayed lower tensile strength compared to 3% nano OPEFB/epoxy nanocomposites. It can be explained by the fact that principally all nano particles possess strong tendency of agglomeration in order to minimize their high surface energy (Zare 2016a; Machrafi *et al.* 2016). Besides, the addition of a higher number of discrete nano filler particles within the polymer matrix increase the filler volume fraction and concentration and thereby leads to considerable increase in inter-particles interaction within epoxy matrix. This might affect the percolation parameter of nano filler, as in the case of 5% nano OPEFB/epoxy nanocomposites, where nano filler are much stiffer than the epoxy matrix. Analogous explanations were also reported by other researchers (Brecht *et al.* 2001; Cassagnau 2013; Dorigato *et al.* 2013).

The increase in number or concentrations of nano filler particles increases the density, which is attributed to the clustering mechanism or agglomeration of nano OPEFB filler under the driving force of their Brownian motion with a weak flow within the epoxy matrix. Agglomeration of nano OPEFB filler particles ultimately results in the formation of microvoids, which thereby decreases the effectiveness of nano OPEFB particles in the epoxy matrix. Additionally, an inefficient stress transfer from epoxy matrix to nano OPEFB filler particles in the case of 5% occurs, resulting in an early rupture or failure followed by poor mechanical properties in terms of tensile strength of the nanocomposites compared to 3% nano OPEFB filler loading. Comparable arguments were reported in the literature by other researchers (Hubbe *et al.* 2008; Zare 2016a, b). Accordingly, when the load was perfectly transferred from fragile and brittle matrix to rigid/tougher/stiffer nano OPEFB filler, the composites were strengthened under tensile loading as in the case of 3% nano OPEFB/epoxy nanocomposites. Several researchers reported a similar trend of mechanical property behaviors when there was a higher loading of nano filler in polymer matrix beyond a certain level (Bhat and Khalil 2011; Galpaya 2012; Abdul Khalil *et al.* 2013b). Furthermore, the observed results are also in line with other research findings, where fibers (jute, sisal) are reinforced in polymer composites. They reported that when the bonding between matrix and fibers was improved, the tensile strength of a polymer composites also was increased compared to their neat epoxy matrix (Boopalan *et al.* 2012; Jawaid *et al.* 2013).

Figure 2 shows the effect of nano OPEFB filler loading on the tensile modulus of epoxy composites. It is evident from Fig. 2 that the tensile modulus followed a trend similar to tensile strength (Fig. 1). The addition of nano filler increased the tensile modulus value with respect to epoxy composites. Commencing from 1% to 5% nano OPEFB filler loading, the maximum value of the tensile modulus was observed at 3% loading. However, when the percentage of nano OPEFB filler loading increased beyond 3%, reductions in tensile modulus values were noticed.

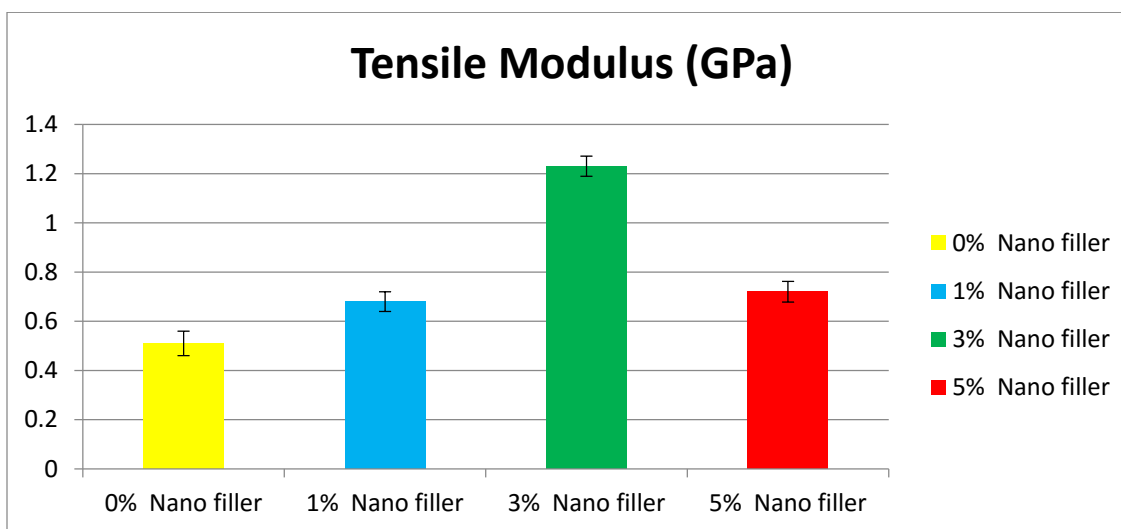


Fig. 2. Effect of nano OPEFB filler loading on tensile modulus of epoxy composites

The higher tensile modulus value of epoxy nanocomposites for 3% nano OPEFB filler loading was attributed to homogenous dispersion along with better interfacial interaction between nano OPEFB filler particles and epoxy matrix. This resulted in the

effectiveness of nano OPEFB filler particles within the epoxy matrix. The existence of agglomerates and voids in the case of 5% nano OPEFB/epoxy nanocomposites favors the lower tensile modulus with respect to 3% nano OPEFB/epoxy nanocomposites. A similar observation was also reported in the literature by other researchers (Schaefer and Justice 2007; Hubbe *et al.* 2008). The considerable decrease in the tensile modulus value for 5% nano OPEFB/epoxy nanocomposites were ascribed to higher degree of agglomeration of added filler particles. The observed result was in agreement with many research studies reported in the literature (Mochalin *et al.* 2011; Neitzel *et al.* 2011; Ayatollahi *et al.* 2012). Observed from our experiment, decreases in the composites performance in the case of 5% nano OPEFB filler loading are due to agglomeration of particles and micro-voids that act as preferential sites for crack initiation and failure. However, when nano filler get uniformly dispersed in the matrix as in the case of 3% nano OPEFB filler loading, a strong interfacial interaction between the epoxy matrix and dispersed filler exists and thus the applied stress can be transferred easily to the stiffer nano filler. Consequently, the 3% nano OPEFB/epoxy nanocomposites can endure or tolerate more loads and display higher values of tensile modulus, among the rest epoxy nanocomposites.

Figure 3 illustrates the elongation at break values when longitudinal stress/load was applied to the composites. The obtained data was similar to the results obtained for tensile strength and tensile modulus. The elongation at break values increased at 1% and for 3% nano OPEFB filler loading, but decreased on loading 5% nano OPEFB filler to the epoxy matrix. This can be explained on account of higher tensile strength value offered by 3% nano OPEFB filler loading in epoxy composites with respect to 1% and 5% nano OPEFB loading in epoxy composites.

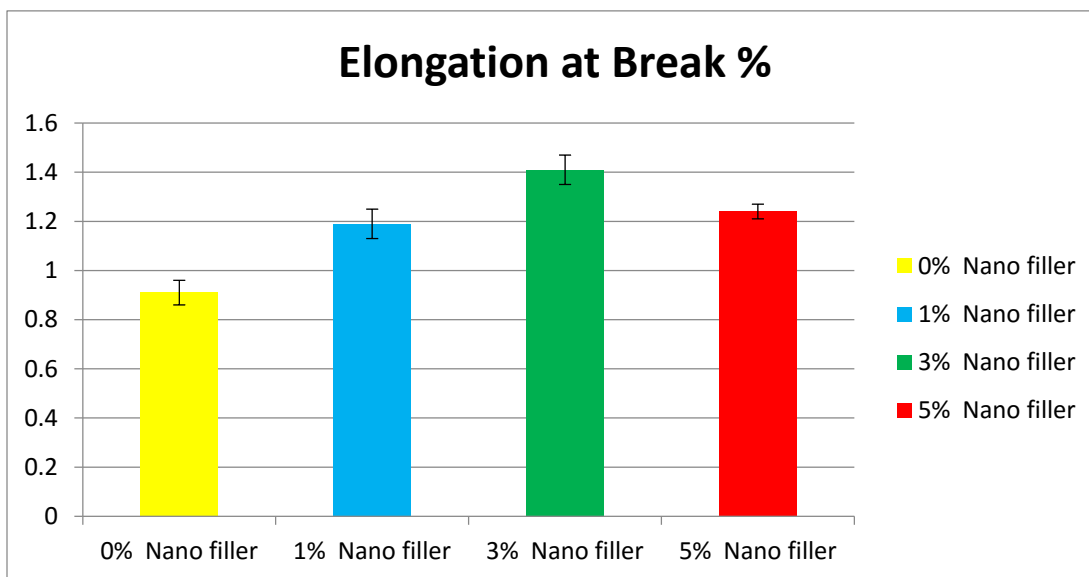


Fig. 3. Effect of nano OPEFB filler loading on elongation at break of epoxy composites

Impact Properties

Figure 4 displays the impact strength of the epoxy composites and the 1%, 3%, and 5% nano OPEFB/epoxy nanocomposites. The epoxy composites showed the lowest impact properties; however a noticeable increase in the impact strength was realized by the incorporation of nano OPEFB filler. A marked increase in impact properties was evident when the filler loading was increased from 1% to 3%. The result was attributed to better interfacial interaction and hence bonding of the nano filler particles with the epoxy matrix to resist the high impact stress/load. However, when the loading was increased from 3% to 5%, there was a considerable decrease in impact properties. Similar results were evident in the case of nano oil palm ash/polypropylene nanocomposites. The addition of 3% nano oil palm ash displayed better impact properties as compared with 1% and 5% nano filler loading (Bhat and Khalil 2011).

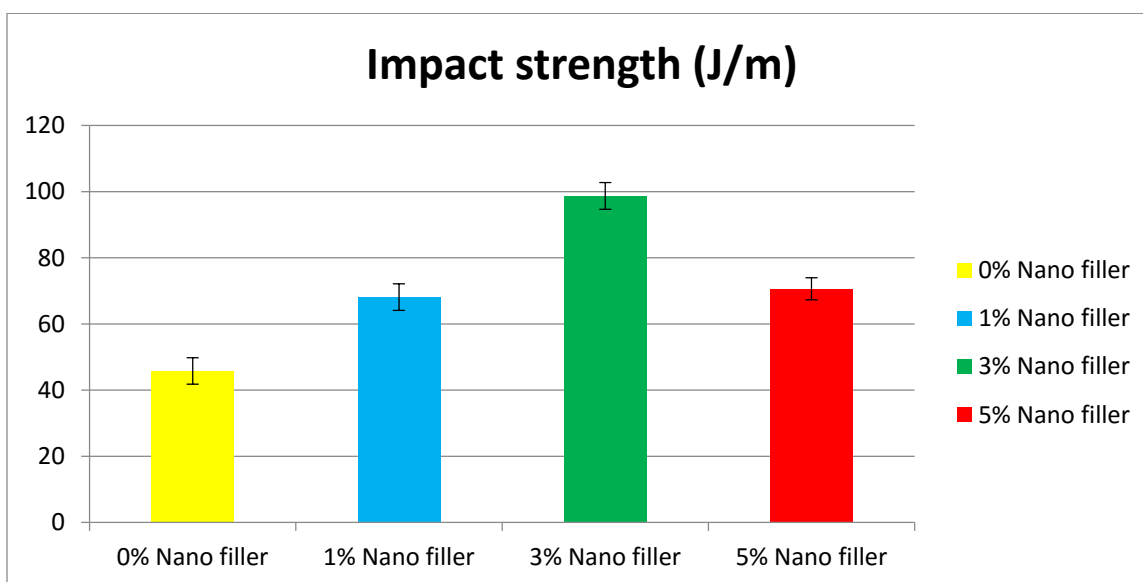


Fig. 4. Effect of nano OPEFB filler loading on impact strength of epoxy composites

Transmission Electron Microscopy (TEM)

TEM is a straightforward and valuable tool to visualize nanoparticle size, and dispersion within the polymer matrix as well as the impact on mechanical properties (Rozenberg and Tenne 2008; Bilbao-Sainz *et al.* 2011). TEM also has been used to investigate the morphology of nano filler particles in the matrix governing the improved thermal, mechanical, and physical properties of the nanocomposites (Saba *et al.* 2016c).

Figure 5 shows TEM micrographs of 1%, 3%, and 5% nano OPEFB/epoxy nanocomposites. From Fig. 5(a) it is evident that the dispersion of 1% nano OPEFB filler particles in epoxy composites was good. Figure 5(b) displayed the TEM images of 3% nano OPEFB filler loading in the epoxy matrix. From the Figure, it can be clearly observed that 3% nano OPEFB filler loading in the epoxy matrix had perfect and uniform dispersion of the nano particles within the epoxy matrix. Interestingly, the well-dispersed and uniform nano OPEFB filler presents large surface area for better interfacial bonding, which ultimately improves the interfacial attraction and finally the mechanical properties. However, when the filler loading was increased from 3% to 5%, the result was quite different (Fig. 5c, d), as poor dispersion of the nano filler in the epoxy matrix are noticed.

The reduction in mechanical (both tensile and impact) properties for 5% nano OPEFB/epoxy nanocomposites with respect to 3% loading can be ascribed due to the poor and inhomogeneous dispersion of nano OPEFB filler within the epoxy matrix.

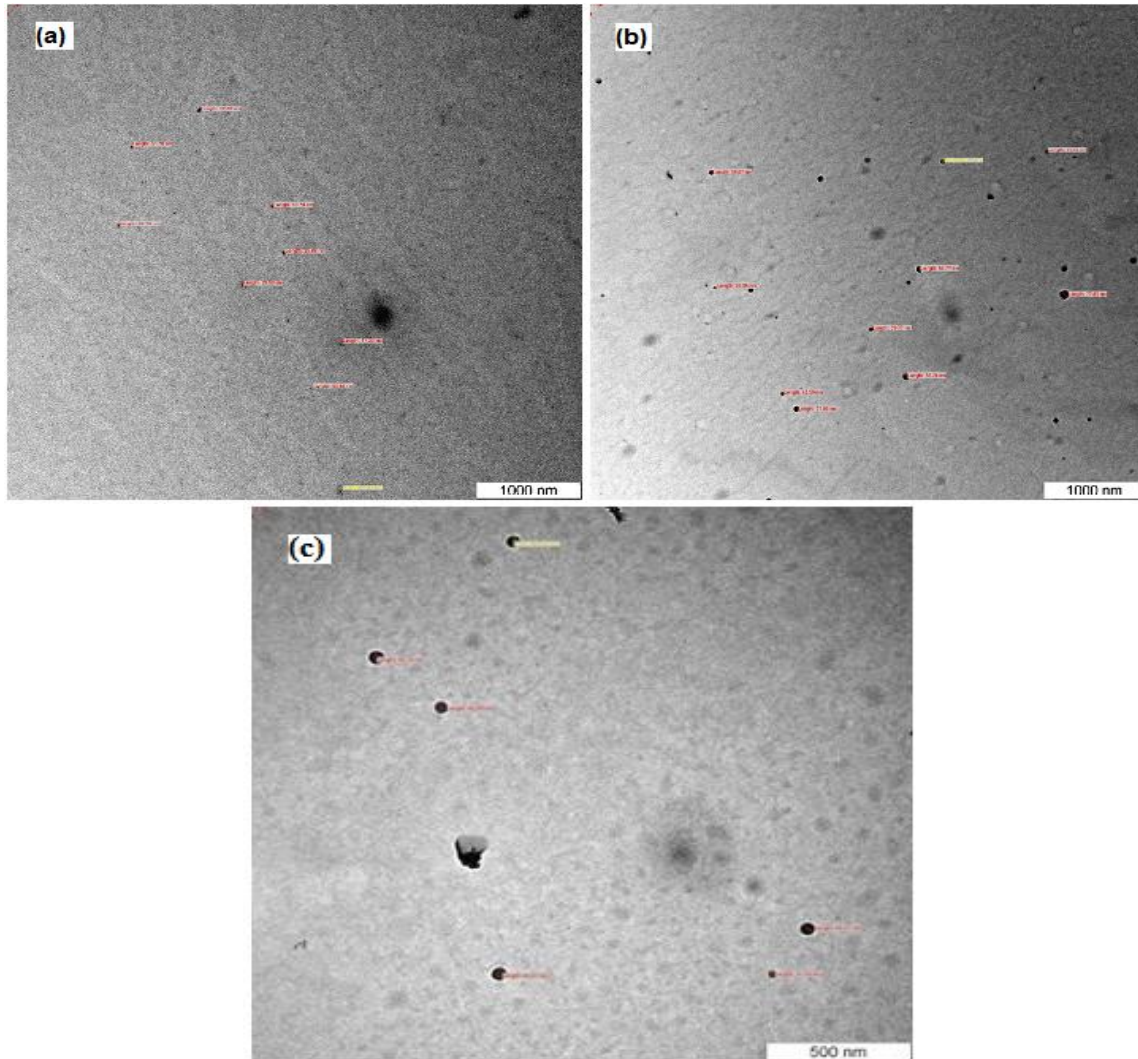


Fig. 5. TEM micrograph for (a) 1%, (b) 3%, and (c) 5% nano OPEFB/ epoxy nanocomposites

Scanning Electron Microscopy (SEM)

The primary goal of SEM is to determine the particle dispersion and to investigate the variations or modifications occurred in the surface structure (morphology) of the polymer matrix. The SEM studies in this research were made to analyze the surface morphologies and interfacial adhesion between the incorporated nano OPEFB filler and the epoxy matrix of the tensile fractured samples of nanocomposites. Figure 6 shows the SEM of the tensile fractured samples of highly cross-linked epoxy composites.

The micrograph of epoxy composites (Fig. 6a) offered a smooth and glassy exterior with numerous wavy or stream-like cracks. The cracks pattern of epoxy composite surface clearly revealed its typical brittle plastic nature. Furthermore the direction of crack propagation was from “upper left up” to “lower right” and in different planes. The wavy

and brittle nature indicates that resistance towards cracking or rupturing and its propagation was considerably lesser in epoxy composites. Thus relatively less energy required during tensile fracturing of epoxy composites. A similar SEM micrograph image for epoxy composites was also reported by other researchers (Dadfar and Ghadami 2013; Quan and Ivankovic 2015).

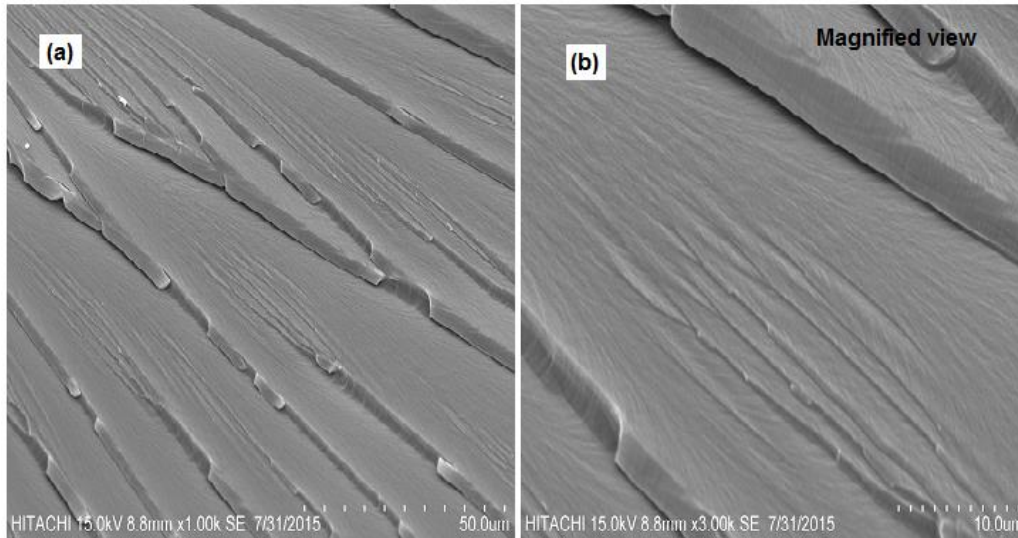


Fig. 6. SEM micrographs of tensile fractured images of epoxy composites. (a) 1000x and (b) 3000x magnification

The SEM micrographs of 1%, 3%, and 5% nano OPEFB/epoxy nanocomposites are shown in Figs. 7 to 9. From the figures it is evident that the SEM morphology of 1%, 3%, and 5% nano OPEFB/epoxy nanocomposites was quite similar, but are relatively different than epoxy composites. The irregular and jagged fracture surface of all nano OPEFB/epoxy nanocomposites displayed relatively less brittle and ductile failure nature of the epoxy matrix (Lee *et al.* 2010; Yang *et al.* 2011). The incorporation of nano OPEFB filler in the brittle, soft and smooth epoxy material reduces the number of crack lines and made the surface coarser, thus leading to matrix deformation and finally to the deflection of cracks. Consequently, fluctuations in the crack propagation pathway from straight, conventional and unruffled growth were observed in the epoxy nanocomposites. Comparative results were also reported in the literature, where incorporation of nano oil palm ash particles in the epoxy matrix displayed similar SEM images (Abdul Khalil *et al.* 2010). Figure 7 shows the tensile fractured surface of 1% nano OPEFB/epoxy nanocomposites having the crack propagation from up to down. Tensile fractured surface of 1% nano OPEFB/epoxy nanocomposites shows a slightly rougher and jagged texture compare to tensile fracture surfaces of epoxy composites, with no particle clumping.

Figure 8 shows the SEM micrographs of tensile fractured surface of 3% nano OPEFB/epoxy nanocomposites. The SEM images clearly displayed the rapid crack proliferation, indicating that cracks followed more twisting paths in well dispersed 3% nano OPEFB/epoxy nanocomposites. This made the surface coarser and rougher as no transverse river line or wavy marking was observed. Noticeably, 1% and 3% nano OPEFB filler loading displayed cloudy and irregular tensile fractured surfaces with no obvious agglomeration within the epoxy matrix. This indicates that relatively higher amounts of energy were consumed to break the 3% nano OPEFB/epoxy nanocomposites sample as the

dispersed nano filler particles hindered the crack propagation path. Consequently the increase in tensile and impact properties of 3% nano OPEFB/epoxy nanocomposites also correspond to crack deflections process. This statement are also in agreement with other research findings (Liu *et al.* 2011). The 3% nano OPEFB/epoxy nanocomposites displayed better resistance toward crack propagation due to the deflection of cracks under tensile stress conditions.

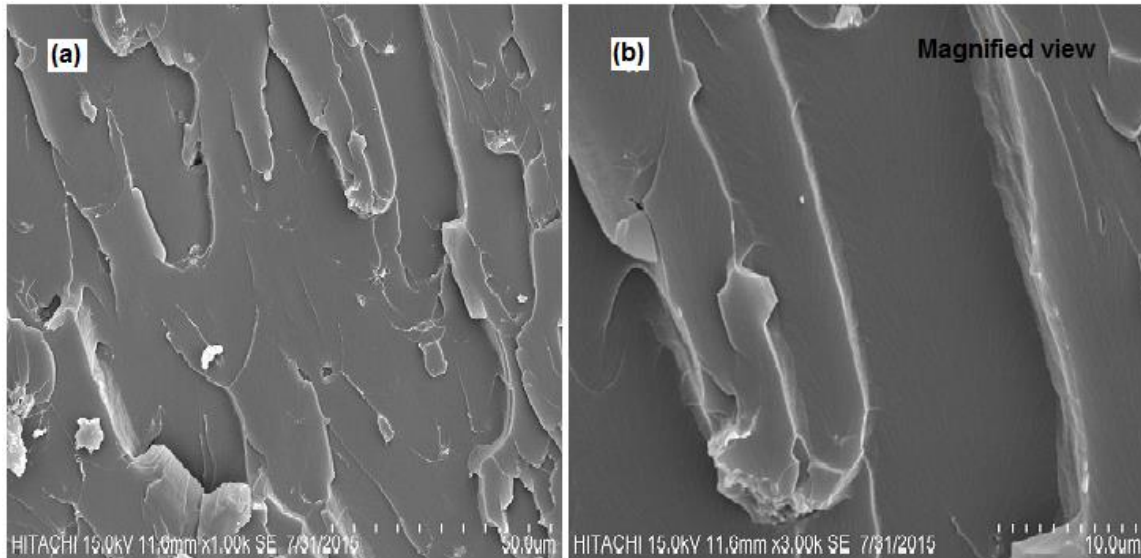


Fig. 7. SEM micrographs of the tensile fracture texture of 1% nano OPEFB filler loading. (a) 1000x and (b) 3000x magnification

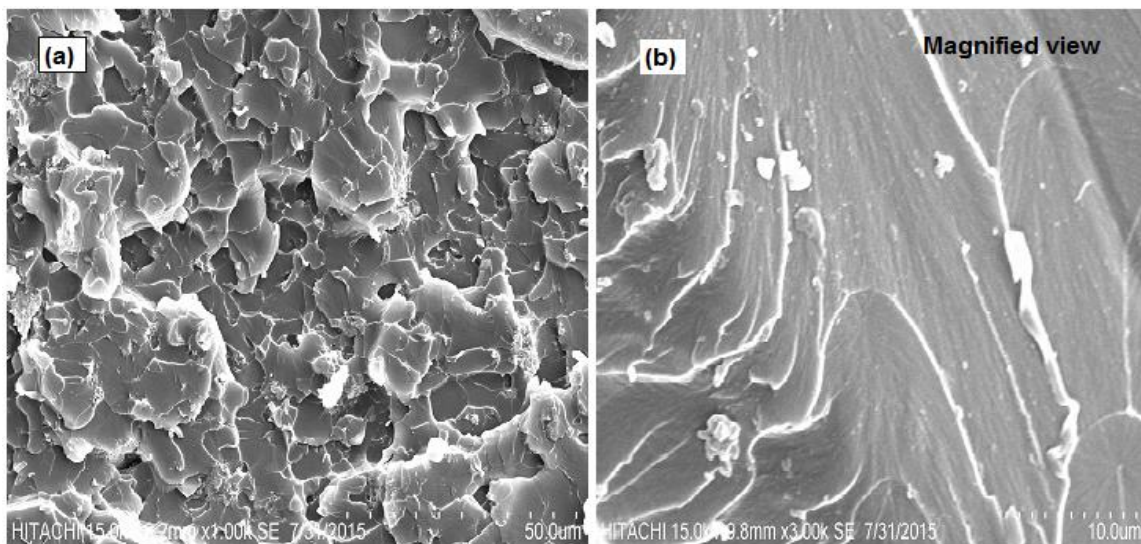


Fig. 8. SEM micrographs of tensile fractured sample of 3% nano OPEFB filler loading. (a) 1000x and (b) 3000x magnification

The 5% nano OPEFB/epoxy nanocomposites displayed higher roughness in certain spaces, but had no wavy or river line marking of the kind seen in the 3% nano OPEFB/epoxy nanocomposites (Fig. 9). The presence of agglomerations leads to a reduction in effective interaction volume as well as large continuous interfacial zones in added nano OPEFB filler of 5% nano OPEFB/epoxy nanocomposites are clearly visible in

Fig. 9a. Presence of agglomeration, created blank spaces or voids (Fig. 9b) within the polymer matrix, reflecting poor particle dispersion. After the initial tensile impact, the crack propagated in the direction of the tension, proceeding to the weak interfaces, where there were comparatively lesser nano filler ultimately leading to the failure or damage to the composites material. The presence of dispersed nano OPEFB filler particles acted as obstacles to premature cracks or ruptures, but there were still many places where there are no particles present in order to resist the crack propagation, as displayed in (Fig. 9c). The presence of voids and agglomerated structures of the nano OPEFB filler particles within epoxy matrix act as stress concentration sites to initiate cracking by the applied stress. The cracks penetrate the material, while the aggregates act as weak points that initiate the preliminary rupture or failure of the nanocomposites on exposure to mechanical testing (Montazeri and Chitsazzadeh 2014). Thus, the 5% nano OPEFB/epoxy nanocomposites had reduced mechanical properties, especially tensile strength, compared to 3% nano OPEFB/epoxy nanocomposites.

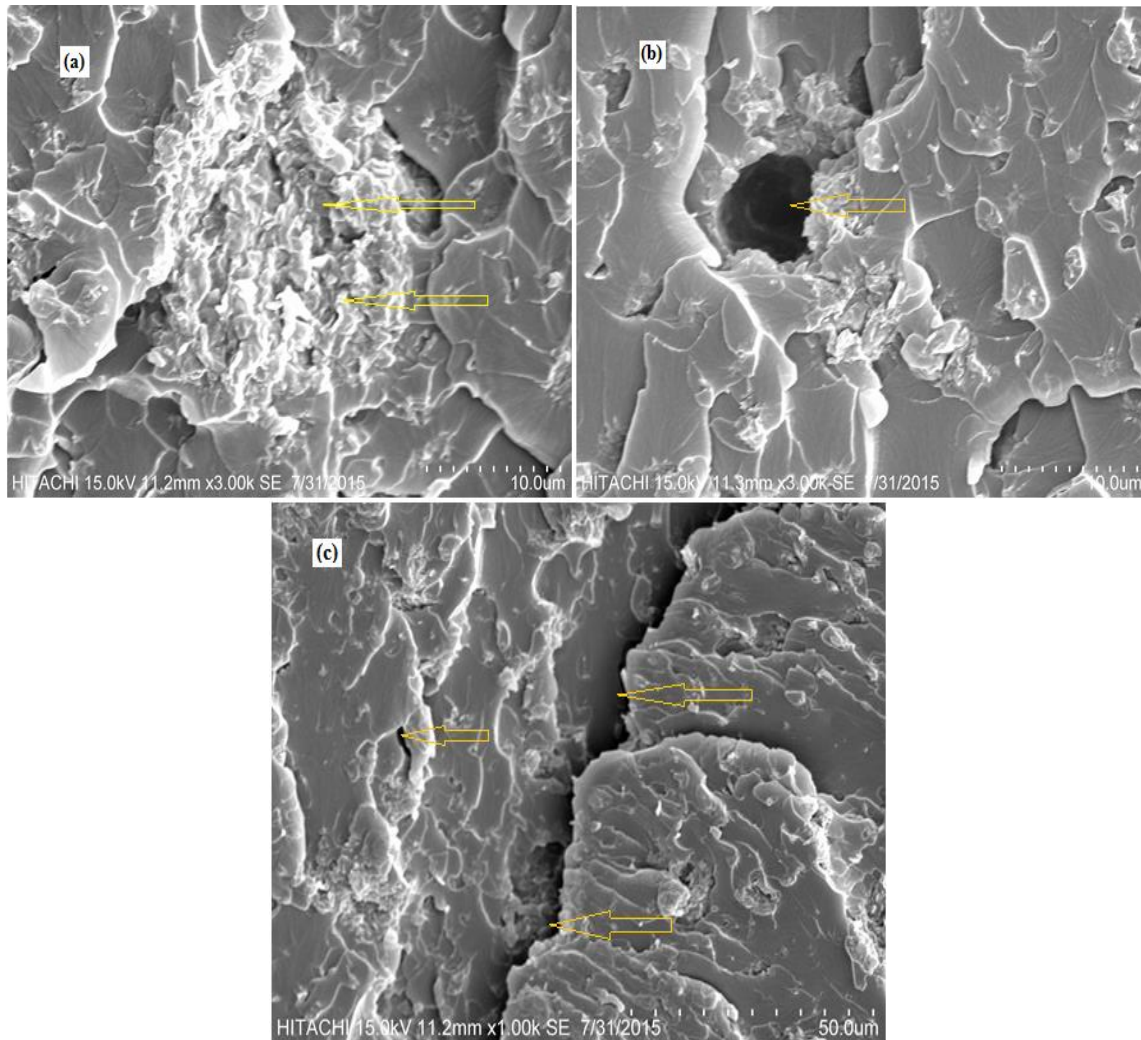


Fig. 9. SEM micrographs of the tensile fracture texture showing (a) agglomerations, (b) void, and (c) deep fracture in 5% nano OPEFB filler loading. (a) 3000x (b) 3000x and (c) 1000x magnification

CONCLUSIONS

1. The 3% nano OPEFB/epoxy nanocomposites displayed better tensile and impact properties relative to the other epoxy nanocomposites and neat epoxy in this study. Considerably higher Brownian motion of the dispersed nano OPEFB filler within epoxy matrix and better interfacial interaction between 3% nano OPEFB filler and epoxy matrix results in an efficient stress transfer in 3% nano OPEFB/epoxy nanocomposites with respect to the 1% and 5% nanocomposites.
2. TEM analysis confirmed that 3% nano OPEFB filler loading resulted in good/uniform distribution and dispersion of particles with no evidence of agglomerations and voids content in the space. In contrast to 3% filler loading, the 5% displayed poor dispersion of the nano filler in the epoxy matrix.
3. SEM results were in agreement with the TEM and mechanical properties results.
4. Overall, the incorporation of 3% nano OPEFB filler loading into the epoxy matrix showed optimum, reasonable, and better mechanical properties.

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