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Mechanical and Morphological Properties of Waste *Eurycoma longifolia* Fiber/Montmorillonite Reinforced Poly(vinyl chloride) Hybrid Composites

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ABSTRACT: Hybrid composites are currently spearheading in polymer composites field with the promising ability in improving polymer properties. The influence of *Eurycoma longifolia* (EL)/montmorillonite (MMT) hybrid fillers loading on the mechanical properties of poly(vinyl chloride) (PVC) hybrid composites has been investigated. PVC resin and various additives were first dry-blended using a laboratory blender before being milled into sheets using two-roll mills at 165°C and hot pressed at 180°C and 120 kgm^{-2}. The mechanical properties of PVC hybrid composites were determined using Izod impact, tensile, and flexural test. The incorporation of EL fiber into PVC matrix improved the flexural modulus, tensile modulus of PVC composites, whereas the tensile strength and impact strength decreased with increasing EL fiber content. The addition of MMT into EL-filled PVC composites has significantly increased the flexural modulus, tensile modulus of PVC hybrid composite compared to PVC composites. However, MMT decreased the flexural strength and impact strength of PVC hybrid composites. © 2012 Wiley Periodicals, Inc. J. Appl. Polym. Sci. 000: 000–000, 2012

KEYWORDS: poly(vinyl chloride); composites; mechanical properties; morphology

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INTRODUCTION

Polymer nanocomposites is popular nowadays because they have potential to high-performance characteristics and exhibit multifunctional only by adding together with small quantity of nanoparticle into polymer matrix.[1] PVC has an important role worldwide due to its special properties and it's useful and produced on an industrial scale. PVC is normally plasticized, which allows using a wide variety of product made from rigid and hard through to rubber-elastic and soft. For developing PVC to increase the properties and cost advantage, several researches have been done on PVC/nanofillers.[2]

There is great upsurge in research on polymer-nanoclay in past decade, because these materials can enhance fire resistance and mechanical properties compared with traditional composites. Many of researches have been done on variety of thermoplastic and thermoset polymer such as polyolefin and epoxy resins.[3,4] MMT is considered as reinforcement filler, which can effect on properties of thermoset and thermoplastic polymer. Based on previous research, the optimum value for MMT for PVC is 4 PPH according to mechanical properties, especially on tensile strength of PVC and MMT, which in comparison with different concentrations of EL on PVC can increase the mechanical properties of PVC/MMT.[5] Based on Madaleno et al.,[6] the mechanical properties of the PVC/MMT nanocomposites were greatly improved compared to pure PVC. Nanocomposites by 2 and 5 phr of MMT have demonstrated effect in tensile strength and elongation, Young's modulus.

Wan et al.[4] reported that PVC/MMT can enhance mechanical properties due to small stacks of 2–10 layers homogenously dispersed through the PVC matrix, which were actually necessary to create a material with improved mechanical properties rather than complete exfoliation structures. Based on a research of PVC/bagasse fiber (BF) that the mechanical properties of the PVC/BF, such as tensile strength and elongation at break, tensile modules and impact strength affected are by adding different amounts of BF to PVC. There is significant increase in strength and tensile modulus when BF is added to PVC; however impact strength and elongation at break slightly decrease by increasing BF to PVC.[7]

PVC/*Eurycoma longifolia* (EL)/MMT hybrid composites, where EL and MMT are used as reinforcing agent in the PVC matrix. Because EL plant is native to Indonesia, Malaysia, and, to a lesser extent, Thailand, Vietnam, and Laos, utilizing of EL will be beneficial. So it can be used with MMT to develop new PVC composites. It is an alternative to use hybrid fillers to improve overall performance yet cost less than using MMT alone.

Table I. Different Concentration of PVC and EL Fiber

	S1	S2	S3	S4	S5	S6	S7	S8	S9
MMT	0	0	0	0	0	4	4	4	4
Eurycoma longifolia	0	10	20	30	40	10	20	30	40

EXPERIMENTAL

Materials and Methods

PVC used in this study was suspension PVC with *K* value 66 produced by IRM Sdn. Bhd MMT, Nanomer 1.42E purchased from Nanocor, USA and the waste EL is local plant in Malaysia. Constant amount of PVC (100 phr) is mixed with different additives (Tin stabilizer, calcium Stearate, Stearic acid, acrylic polymer, and titanium oxide) with constant concentration (2, 0.5, 0.6, 1.5, and 4 phr). Then the mixture was mixed with different concentrations of EL fiber and MMT as in Table I.

The PVC composites blend formulations as shown in Table I were dry blended using a laboratory mixer for 10 min for homogenizing process. Each blended formulation was then mill sheeted with a laboratory tow-roll mill at 160°C for 10 min. Later, the milled sheets were placed into the mold and then hot pressed at pressure and temperature of 12 kgm^{-2} and 180°C, respectively, for 5 min preheating and 6 min heating. The molding was cooled for 10 min before the specimens are being removed and used for testing. The fiber used in this research was treated with NaOH with 5 phr with 5 kg of water and stirring for 2 h by using high speed stirrer.

CHARACTERIZATION

The notch Izod impact strength was measured according to ASTM D256-93. The flexural test was conducted according to the ASTM D790-86 by using the Instron machine model 5567. The tensile test was carried out by using the Instron machine, of model os 5567 under the ASTM D 638. The morphologies (SEM) of the fractured surface of all samples were observed using JEOL model JSM-6301 F SEM. A small portion of sample was mounted on the copper stub and sputter-coated with thin layer of gold to avoid electronic charging during examination.

RESULT AND DISSCUTION

Mechanical Properties

Flexural Strength. The capacity of the material to withstand bending force applied perpendicular to its longitudinal force is called flexural strength. Figure 1 illustrates the effect of EL on the flexural strength of PVC and PVC/MMT hybrid composites. It can be seen that the flexural strength of PVC increased by increasing the amount of EL. The pure PVC flexural strength is around 81 MPa. The result of flexural strength increased by adding EL shows that the fiber can affect on flexural strength of PVC. Adding 10 phr EL to PVC can increase flexural strength for 2 MPa and followed by 5 MPa by using 20 phr PVC. It is interesting to note the flexural strength of PVC with 30 phr of EL composite was significantly higher than all PVC/EL composites. However, for PVC with 40 phr of EL there was a significant decrease in flexural strength. PVC was unable to wet the EL fiber at 40 phr due to the increase of fibers agglomerations that decreased the fiber–matrix interaction. Rozman et al.[8] and Bakar et al.[9] had reported similar results of this test.

PVC/MMT hybrid composite flexural strength decreased by adding 10 phr EL fiber. In this result, it can be summarized that for 10 phr EL the flexural decreased by 27 MPa. By increasing the fiber content to 20 phr, the flexural strength increased by 2 MPa. The optimum value of EL fiber for flexural strength was achieved at 30 phr, which is 60 MPa. The dramatically decreasing in flexural strength between PVC/EL composite and PVC/EL/MMT hybrid composite might be because of the softening effect of MMT as the plasticizer.

Montmorillonite layers dispersed in PVC matrix may act as a plasticizer by increasing the distance between PVC chains and thus decreasing the intermolecular interaction between PVC chains and increasing the energy absorption of PVC hybrid composite that can lower the flexural strength. Apart from this, it can also be caused by agglomeration of MMT content in PVC hybrid composite. Tungjitpornkull and Sombatsompop had same results with this opinion.[10]

Flexural Modulus. The assimilation of different concentrations of EL loading to PVC and PVC/MMT hybrid composite are shown in Figure 2. It shows that the flexural modulus was significantly increased with amount of EL loading from 0 to 40 phr. As can be seen in Figure 2, the flexural modulus of pure PVC is around 2800 MPa. By adding 10 phr EL fiber for 10 phr to PVC as reinforcement, the modules increased significantly around 3400 MPa. It is followed by 3700 MPa for 20 phr. For 30 phr EL and 40 phr the flexural modulus are 3900 and 4300 MPa. This shows that the stiffness of PVC composite increased by adding EL fiber to PVC. The enhancement of modulus is dependent on several factors like fiber aspect ratio, but it is more related to fiber content and fiber modulus. The similar result is also reported by other researchers.[9,11]

Furthermore, adding MMT as filler to PVC/EL composite increased the flexural modulus. As seen in Figure 2, for PVC/10 phr EL/4 phr MMT the flexural modulus is almost 4000 MPa

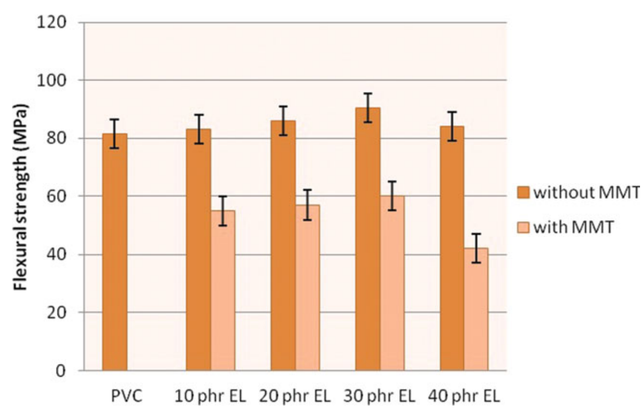

Figure 1. Effect of different concentrations of EL on flexural strength of PVC and PVC/MMT hybrid composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

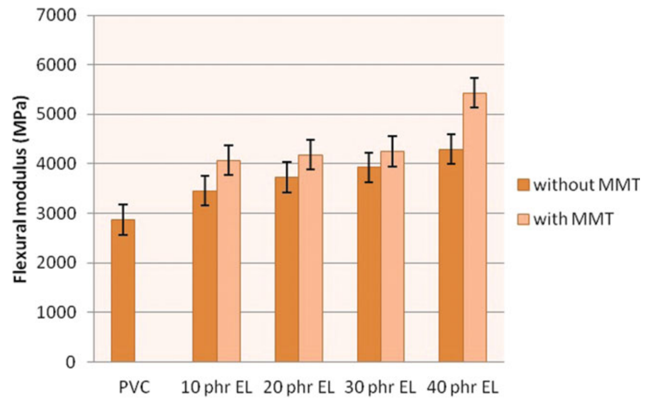

Figure 2. Effect of different concentrations of EL on flexural modulus of PVC and PVC/MMT hybrid composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

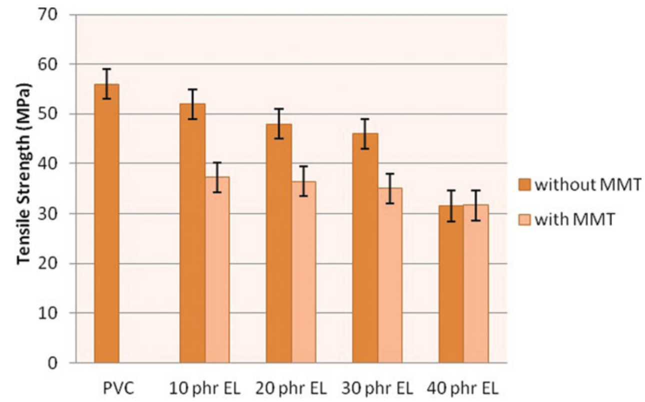

Figure 4. Effect of different concentrations of EL on tensile strength of PVC and PVC/MMT hybrid composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

and for 20 phr EL with 4 phr MMT, it is around 4200. For 30 and 40 phr with 4 phr MMT the flexural modulus are 4300 and 5200 MPa. It proved that the flexural modules of PVC/MMT/EL composites are higher than PVC/EL composite modulus. This is because of the MMT behavior, which is homogenously dispersing in PVC matrix and higher interaction between the matrix and reinforcement.[4]

Tensile Modulus. Figure 3 shows the effect of EL with different concentrations on PVC and PVC/MMT hybrid composite in terms of tensile modulus. As shown in Figure 3, by increasing the EL fiber, the tensile modulus increased. For pure PVC tensile modulus is around 3200 MPa. By adding fiber for 10 phr to PVC, the tensile modulus increased up to 3800 MPa. The tensile modulus increased by adding fiber content to PVC up to 30 phr of EL. The tensile modulus for PVC with 30 phr EL is around 5200 MPa. Apparently, this behavior is in agreement with previous studies that by increasing the fiber to PVC the tensile modulus increased because of the interaction between fiber and matrix in composite. Different researchers had similar results in this test.[9,12] However, by adding more fiber to PVC composite, the tensile modulus significantly decreased. This behavior is because of the decrease in wetting of fiber by matrix, and by

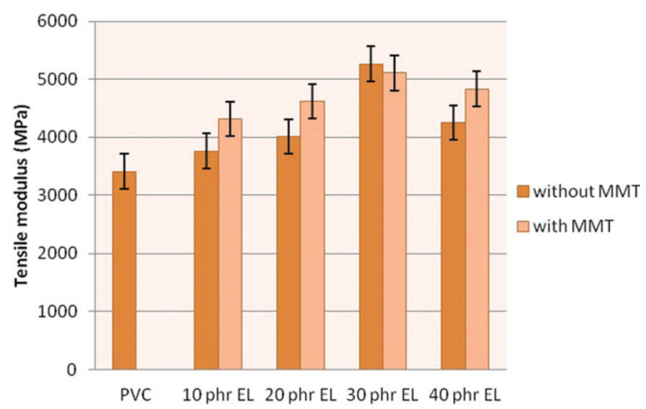

Figure 3. Effect of different concentrations of EL on tensile modulus of PVC and PVC/MMT hybrid composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

changing the fiber phase to matrix phase Rozman et al.[8] had similar result.

The same result in tensile modulus happened when the EL added to PVC/MMT of which the tensile modulus increased significantly by increasing the EL. For PVC with 10 phr EL adding to 4 phr MMT, the tensile modulus is higher than without MMT which is around 4100 MPa. Even for 20 and 30 phr of EL adding to PVC/MMT composite, the tensile modulus have significantly increased compared to composites without MMT filler. This is because by adding EL and MMT as hybrid filler the mobility of PVC chain was restricted due to the block off of EL, MMT in PVC matrix. Abu Bakar et al.[9] reported that fiber can impart a drastic improvement in stiffness by hindering the movement of PVC molecules.

Tensile Strength. Figure 4 shows the effect of EL on PVC in terms of tensile strength. As shown in Figure 4, for pure PVC, the tensile strength is around 56 MPa. By adding EL as fiber for 10 phr, tensile strength decreased for almost 5 MPa, and for 20 and 30 phr, tensile strength decreased more for 57 and 55 MPa, respectively. It can be concluded that because of poor miscibility between EL and PVC, which caused PVC composite unable to absorb stress transfer. Madaleno et al.[6] reported that the decrease in tensile strength probably caused by some agglomerates that may exist within the nanocomposites.

Figure 4 also shows the tensile strength of PVC/MMT hybrid composites. The overall result is similar with PVC/EL composite but the rate of dropping is different for PVC/EL/MMT. The dropping in tensile strength is dramatically in comparing with PVC/EL composite. For PVC with 10 phr EL and 4 phr MMT the tensile strength is around 33 MPa, which is around 20% less than PVC and 10 phr EL. Similar results were obtain by adding 20 and 30 phr in PVC/MMT composite. This difference could be because of availability of MMT in PVC/EL hybrid composite. It can be also mentioned that the possibility of creating more stress point in hybrid composite as availability of MMT was incorporated in the system. This can be brought about by the increase of incapability in the interfacial region between the matrix and the filler. Also because of tensile strength is controlled by dispersion of filler and fiber, any inhomogeneous dispersion

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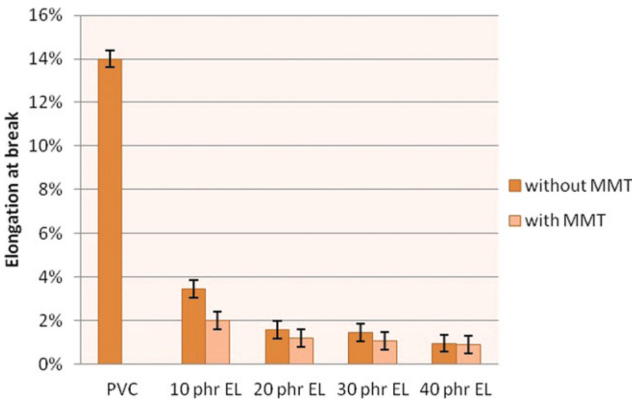

Figure 5. Effect of EL on elongation at break of PVC/EL and PVC/EL/MMT hybrid composite. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Figure 7. SEM micrograph of pure PVC.

in the composites can decrease the tensile strength. Other factors which effect the tensile strength is fiber loading; wetting problem, facial adhesion, and better tendency to consolidation in hot press play an important role in reducing the tensile strength.[8,9]

Elongation at Break. The effect of the EL loadings on the elongation at breaks of PVC and PVC/MMT hybrid composites is shown in Figure 5. Figure 5 indicates that the content of EL was the main factor affecting the elongation at break. As seen in Figure 5 the elongation at break for pure PVC is 14%.The elongation at break decreased significantly which is almost 3.8% when 10 phr EL fiber incorporated in PVC. With the increase of fiber loading at 20 and 30 phr, the elongation at break decreased to 1.9 and 1.8%, respectively. It shows that the elongation at break decreased with increasing fiber loading. The decrease of elongation at break may be due to the contribution of EL stiffness that transforms the ductile to the brittle failure of the composites. Zheng et al.[7] have similar results with this work.

Figure 5 shows that by adding EL fiber to PVC/MMT hybrid composites, the elongation at break was decreased. Beside that the percentage of elongation at break of the PVC/EL/MMT hybrid composites is lower than PVC/EL composites. These results show that the addition of MMT has increased the degree of fiber and filler agglomerates in the matrix, which reduced the interfacial interaction between matrix and filers and fibers.[7]

Impact Strength. Figure 6 shows the relationship between EL loading and impact strength. The impact strength of PVC is 31.5 J m^{-2}. The impact strength of PVC/EL composites gradually decreased with increasing of EL fiber loading from 10 to 40 phr. This is due to the poor interfacial interaction between EL and PVC matrix caused by the fiber agglomeration, which resulted in the PVC/EL unable to absorb more energy during fracture.

Figure 6 also shows that the impact strength of PVC/EL/MMT hybrid composites decreased with the addition of MMT loading and their valves are lower than PVC/EL composite. This is because of the availability of MMT in the PVC/EL/MMT hybrid composite, which creates more stress point in hybrid composite. This can be brought about by the increase of incapability in the interfacial region between the matrix and filler. As mention in

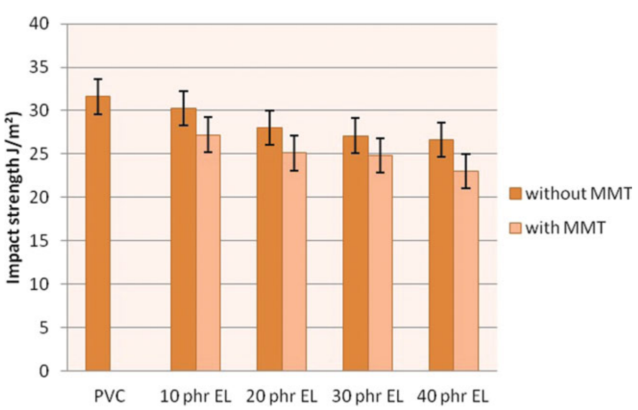

Figure 6. Effect of EL on impact strength on PVC and PVC/MMT hybrid composite. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

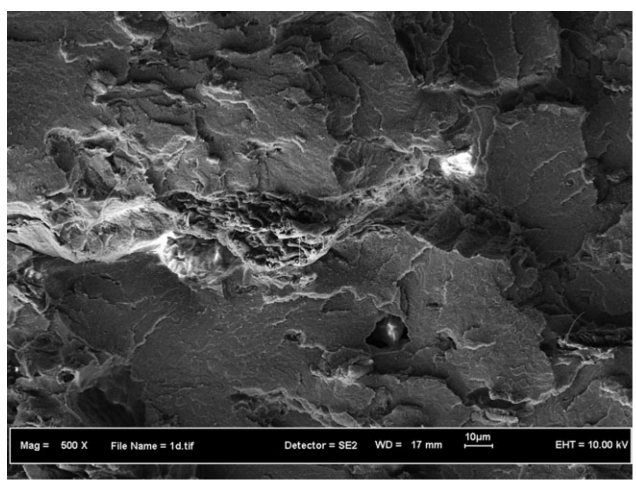

Figure 8. SEM micrograph of PVC/30 phr EL composite.

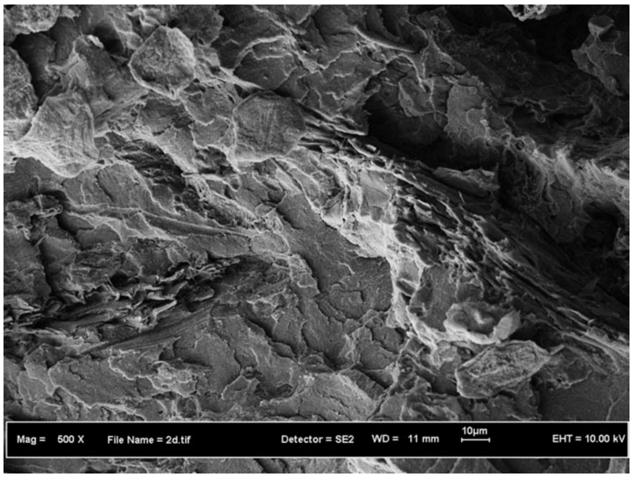

Figure 9. SEM micrograph of PVC/40 phr EL composite.

tensile strength, it can be related to dispersion of MMT on matrix and also less wetting by matrix phase of composite.[8]

Scanning Electron Microscopy (SEM)

Figure 7 illustrates the SEM micrographs of PVC and PVC composites filled with EL fiber and MMT filler. According to Figure 7, pure PVC was found to contain some small particles which were evenly dispersed in the PVC matrix. The particle size of these small particles was smaller than 0.5 μm and believed to be the unfused particles of the PVC resin. Some researchers had similar results.[13,14] The PVC resin did not melt and fuse fully during milling and compounding. The presence of voids was also observed at the interface between the unfused PVC particles and PVC matrix.

Figure 8 shows the SEM of 30 phr EL/PVC composite and PVC/40 phr EL. As seen in Figure 9, there is a good interaction between PVC and EL fiber, which can effect on some properties such as flexural modulus, tensile modulus, and flexural strength, which can be related to the interaction between fiber and matrix, and also to aspect ratio of fiber.[9] However, there is some

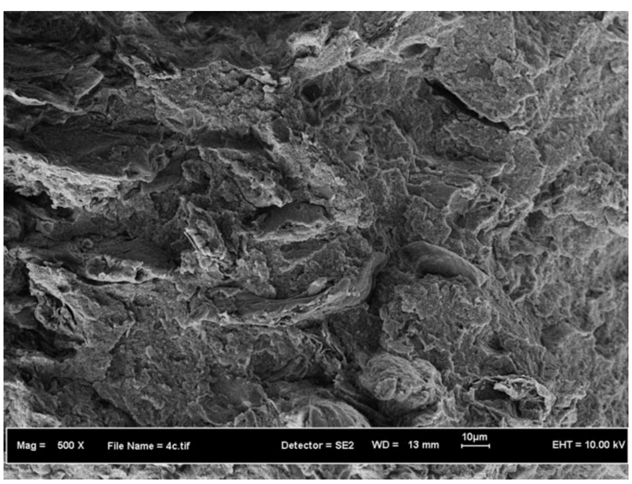

Figure 10. SEM micrograph of PVC/30 phr EL/4 phr MMT hybrid composite.

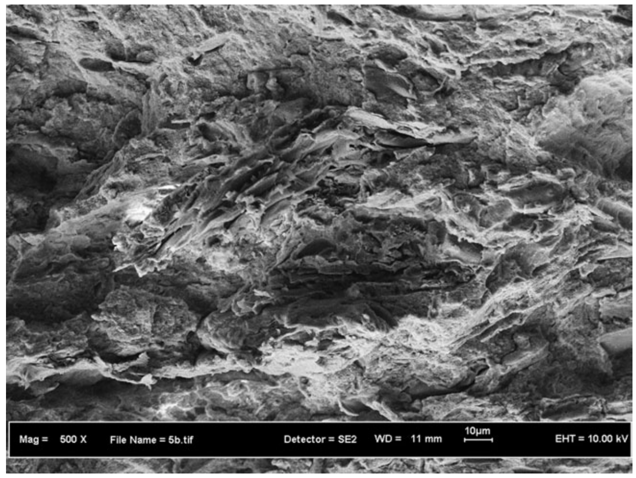

Figure 11. SEM micrograph of PVC/40 phr EL/4 phr MMT hybrid composite.

applomirates which can effect on the tensile strength. It can create some stress point; even this decreasing can be discussed in terms of miscibility and less interfacial between fiber and matrix.[6,8,9] Based on Figure 9, the interaction is high but the agglomeration is >30 phr EL/PVC composite, which the mechanical properties behavior is same but lower than PVC/30 phr EL composite. And it might be because agglomeration is higher and less wetting of fiber by matrix and changing the matrix by fiber.

Figures 10 and 11 show the SEM for PVC/30 phr EL/4 phr MMT and PVC/EL40 phr/4 phr MMT. As seen in Figures 10 and 11, the surface of PVC hybrid is rougher than the PVC/EL composite, which is because of ability of MMT as nanofiber. It shows that the MMT caused the roughness in PVC composite. Nevertheless, Figures 10 and 11 also shows the interaction between the PVC and EL fiber, which is high but still the agglomeration is available. The availability of MMT can effect on some of the mechanical properties like flexural strength by decreasing it. It might be because of softening effect of MMT as plasticizer, which can increase the energy absorption of PVC hybrid composites. Furthermore, homogeneous dispersion of MMT in PVC matrix and hindering the movement of PVC molecule can increase flexural and tensile modulus of PVC/EL/MMT hybrid, but however, adding MMT can increase the creation of stress point and it can decrease the tensile strength.[4,9]

CONCLUSIONS

In conclusion, by adding EL as natural fiber reinforcement can affect the mechanical properties of PVC/EL composites. From the results of this study, the flexural modulus, tensile modulus of PVC composites increased whereas the tensile strength and impact strength decreased with increasing EL fiber content. The addition of MMT significantly increased the flexural modulus, tensile modulus of PVC hybrid composite compared with PVC composites. The addition of MMT has decreased the flexural strength, and impact strength of PVC hybrid composites, which is lower than PVC/EL composites.

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