PROPERTIES OF MONTMORILLONITE FILLED EPOXY /ACRYLATED EPOXIDIZED PALM OIL HYBRID KENAF/GLASS FIBER COMPOSITES

ROHANI BINTI MUSTAPHA

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School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

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DEDICATION

'This thesis is dedicated to my beloved parents, sisters and brothers'

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Bismillahirrahmanirrahim...

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ABSTRACT

In recent years, due to growing environmental and ecological concerns, many studies have focused on the use of renewable resources as a starting material or blending component in the polymer resin formation. To tap to the mass production of palm oil in Malaysia, this study focuses on developing a novel hybrid glass/kenaf fiber reinforced epoxy composites from acrylated epoxidized palm oil (AEPO) filled organo modified montmorrillonite nanoclay (OMMT) and cured with bio-based hardener. The effects of AEPO and OMMT loading on mechanical and thermal properties, morphology as well as water absorption properties of epoxy/AEPO nanocomposites were investigated. The amounts of AEPO in epoxy resin were varied at 10, 20 and 30 wt% and the OMMT loadings were varied at 1, 1.5 and 2 phr. The results revealed that the impact strength and ductility properties of epoxy/AEPO resin improved with AEPO loading. The highest improvement of impact strength was indicated by epoxy/AEPO resin with 30 wt% AEPO loading, representing 57.8% higher than the neat epoxy resin. However, the strength and modulus of epoxy/AEPO resins were reduced with increasing of AEPO content. The addition of OMMT improved the modulus and thermal stability of nanocomposites with the optimum balanced properties at 10 wt% AEPO and 1.5 phr OMMT nanoclay loading. At this loading, tensile modulus of epoxy resin with 10 wt% AEPO loading improved 45.6 % higher than the neat epoxy/AEPO resin. The thermogravimetric analysis and dynamic mechanical analysis results also revealed that the thermal stability and glass transition temperature of epoxy/AEPO nanocomposites improved with the addition of OMMT up to 1.5 phr OMMT loading. The hybrid glass/kenaf fiber composites were fabricated using hand lay-up technique. The moisture absorption behaviour and its effects on the flexural properties of hybrid glass/kenaf fiber composites were investigated. The water absorption studies showed that the hybridization between glass and kenaf fibers significantly affected the water absorption and flexural strength of the composites. The alternated layering sequence of GKKG (where, G and K stands for glass and kenaf fiber, respectively) gave the best flexural properties of the resulted hybrid kenaf/glass fiber reinforced epoxy/AEPO filled OMMT composites. The overall results showed that montmorrilonite filled epoxy/AEPO hybrid kenaf/glass fiber composites are potential materials which could be utilized for applications in automotive panels, wall or floor panels, furniture, and housing construction materials.

ABSTRAK

Dalam tahun-tahun kebelakangan ini, disebabkan oleh kebimbangan alam sekitar dan ekologi yang semakin meningkat, banyak kajian telah memberi tumpuan kepada penggunaan sumber yang boleh diperbaharui sebagai bahan permulaan atau komponen campuran dalam pembentukan resin polimer. Untuk memanfaatkan lambakan minyak kelapa sawit di Malaysia, kajian ini memberi tumpuan untuk membangunkan satu komposit baharu gentian kaca/kenaf hibrid bertetulang epoksi dari minyak kelapa sawit terepoksi terakrilasi (AEPO) terisi tanah liat montmorilonit yang diubahsuai organo (OMMT) dan diawet menggunakan pengeras berasaskan bio. Kesan pemuatan AEPO dan OMMT kepada sifat mekanikal dan haba, morfologi serta sifat penyerapan air bagi komposit nano epoksi/AEPO telah dikaji. Jumlah AEPO dalam resin epoksi diubah pada 10, 20 dan 30% berat dan muatan OMMT diubah pada 1, 1.5 dan 2 phr. Hasil kajian menunjukkan bahawa sifat kekuatan hentaman dan kemuluran resin epoksi/AEPO bertambah baik dengan peningkatan muatan AEPO. Peningkatan kekuatan hentaman tertinggi ditunjukkan oleh resin epoksi/AEPO dengan muatan 30% berat AEPO, mewakili 57.8% lebih tinggi daripada resin epoksi asli. Walau bagaimanapun, kekuatan tegangan dan modulus resin epoksi/AEPO dikurangkan dengan peningkatan kandungan AEPO. Penambahan OMMT meningkatkan modulus dan kestabilan haba komposit nano dengan sifat-sifat keseimbangan optimum pada 10% berat AEPO dan 1.5 phr OMMT tanah liat nano. Pada muatan ini, modulus tegangan bagi resin epoksi dengan muatan 10 % berat AEPO dipertingkat sekitar 45.6% lebih tinggi daripada resin epoksi/AEPO asli. Keputusan analisis termogravimetrik dan analisis mekanikal dinamik juga menunjukkan bahawa kestabilan haba dan suhu peralihan kaca epoksi/AEPO komposit nano bertambah baik dengan penambahan muatan OMMT sehingga 1.5 phr. Komposit gentian kaca/kenaf hibrid telah disediakan menggunakan teknik bengkalai tangan. Tingkah laku penyerapan kelembapan dan kesannya terhadap sifat lenturan bagi komposit gentian kaca/kenaf hibrid dikaji. Kajian penyerapan air menunjukkan bahawa hibridisasi antara gentian kaca dan kenaf memberi kesan yang ketara kepada penyerapan air dan kekuatan lenturan komposit. Urutan berlapis berganti GKKG (di mana, G dan K masing-masing bermaksud gentian kaca dan kenaf) memberikan sifat lentur yang terbaik daripada keputusan komposit gentian kaca/kenaf hibrid bertetulang epoksi/AEPO terisi OMMT. Keputusan keseluruhan menunjukkan bahawa komposit montmorilonit terisi epoksi/AEPO gentian kenaf/kaca hibrid adalah bahan berpotensi yang boleh digunakan untuk aplikasi dalam panel automotif, dinding atau lantai, perabot, dan bahan pembinaan rumah.

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LIST OF ABBREVIATIONS

AEPO	-	Acrylated epoxidized palm oil
AESO	-	Acrylated epoxidized soybean oil
AEVO	-	Acrylated epoxidized vegetable oil
ASTM	-	American Society for Testing and Materials
BPA	-	Bisphenol-A
CNSL	-	Cashew nut shell liquid
DETA	-	Diethylenetriamine
DGEBA	-	diglycidyl ether of bisphenol A
DMA	-	Dynamic mechanical analysis
DSC	-	Dynamic scanning calirometry
DTG	-	Derivative thermogravimetric
ECO	-	Epoxidized castor oil
EPO	-	Epoxidized palm oil
EVO	-	Epoxidation of vegetable oil
EPCH	-	Epichlorohydrin
ESO	-	Epoxidized soybean oil
EVO	-	Epoxidized vegetable oil
EPO	-	Epoxidized palm oil
FRP	-	Fiber reinforced polymer
FTIR	-	Fourier transform infrared spectroscopy
FWHM	-	Full width half maximum
GPE	-	Glycerol polyglycidyl ether
HT	-	Hydrotalcite-type
HDPE	-	High density polyethylene
IPDA	-	Isophoronediamine
LENR	-	Liquid epoxidised natural rubber
LDH’S	-	Layered double hydroxides
MDA	-	Methylene- dianiline
MFC	-	Microfibrillated cellulose
MMT	-	Montmorillonite nanoclay

MPA	-	Maleopimaric acid
MT	-	Metric tons
NaOH	-	Sodium hydroxide
NFRP	-	Natural fiber reinforced polymer composites
OMMT	-	Organo modified montmorrillonite nanoclay
phr	-	Part per hundred resin
PP	-	Polypropylene
PVC	-	Poly(vinyl chloride)
RTM	-	Resin transfer molding
SEM	-	Scanning electron microscope
SPE	-	Sorbitol polyglycidyl ether
TA	-	Tannic acid
TEA	-	Triethylamine
TEM	-	Transmission electron microscopy
TETA	-	Triethytlene tetramine
TMA	-	Terpene maleic anhydride
UPE	-	Unsaturated polyester
VO	-	Vegetable oil
XRD	-	X-ray diffraction

LIST OF SYMBOLS

wt%	-	Weight percent
Td	-	Thermal decomposition temperature (°C)
Tg	-	Glass transition temperature
i.e.	-	That is
ºC	-	Degree celsius
mm/min	-	Millimetre per minute
h	-	hour
M	-	Molarity
phr	-	Parts per hundred parts of resin
rpm	-	Revolution per Minute
cm	-	Centimetre
nm	-	Nanometer
%	-	Percent
˚C/min	-	Degree celsius per minute
MPa	-	Mega pascal
mg	-	Milligram
J	-	Joule
kV	-	Kilovolts
ρ	-	Density
E’	-	Storage modulus
E’’	-	Loss modulus
GPa	-	Giga pascal
J/m	-	Joule per meter
J/m^2	-	Joule per meter square
min	-	Minutes
mm	-	Milimeter
N	-	Newton
s	-	Second
tan δ	-	Tan delta
m^2	-	Meter square

kg	-	kilogram
R	-	Gas constant (8.314 J/K.mol)
E	-	Young modulus
P	-	pressure
g/eq	-	Equivalent weight
T_{max}	-	Maximum degradation temperature
IS	-	Impact strength
kg/L	-	Kilogram per liter
KOH/g	-	Potassium hydroxide (KOH) per gram
g cm^{-3}	-	Gram per cubic centimeter
μm	-	Micrometer
mm2	-	Milimeter square
Mmol/kg	-	Millimoles per kilogram
mPa.s	-	Millipascal-seconds
g/ml	-	Gram per mililiter
ppm	-	Part per million

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In recent years, increasing environmental awareness and growing global concerns towards the depletion of non-renewable resources, as well as concerns over the threat of global warming, have created a groundswell of interest in products compatible with the environment. Therefore, attention is being given to developing bio-based polymer resins using renewable feedstocks as a starting materials or blending component in the polymer resin formation as an alternative to replace the existing thermoset petroleum-based polymer resins such as epoxies, polyester, and polyurethanes. Bio-based polymers are polymer derived from natural resources such as sugars, polysaccharides, vegetable oils, lignin, lipids, proteins, or other monomers. Bio-based polymers have received a great deal of interest in their ability to replace petroleum based polymers in both research and industrial applications. This is due to their renewability, biodegradability properties, and low cost (Karak, 2012).

Among these, vegetable oils (VOs) represent as the most important and promising options because of their versatility, availability, renewability and biodegradability properties (Saurabh et al., 2008). VOs consist of various chemical structure and composition which enable them to be activated for condensation polymerization with the addition of curing agent or with the addition of latent catalyst (Sharma and Kundu, 2008). Furthermore, global production of VOs has increased every year, making them a valuable source to produce VO-based resins, which can substitute for petroleum-based polymer resins. Using renewable materials to produce VO-based polymer can contribute to environmental sustainability.

Vegetable oils (VOs) have diverse chemical structure and compositions that enable them to be used as a starting materials in the production of VO-based polymer resins. There are several types of vegetable oils have used to produced VO-based resins, which are soybean oil, linseed oil, sunflower oil, jathropa oil, canola oil, and corn oil (Adekunle et al. , 2012; Alsagayar et al 2015; Roudsari, Mohanty and Misra, 2014; Supanchaiyamat, 2012). The global production of most vegetable oil has increased every year. Based on data from the Food and Agriculture Organization of the United Nation, palm oils have the largest oil production volume and consumption of all vegetable oils (Food and Agriculture Organization of the United Nation, 2018). For example, in 2017/2018, the global production of palm oil was around 70.5 million metric tons. Malaysia is one of the greatest producers of palm oil in the world. Palm oil is primarily used for cooking in the form of cooking oil, shortening, and margarine as well as industrial feedstocks in the form of biodiesel fuels, paints, candles, cosmetics, and soap (Mba, Dumont and Ngadi, 2015). However, the potential of palm oil to produce VO-based resins is underreported compared to other vegetable oils such as soybean oil and linseed oil. Expanding palm oil applications is expected to increase profit returns in the agricultural sector while reducing the burden from petroleum-based products. Therefore, it is beneficial to use palm oil to produce VO-based polymer resins.

Epoxidized palm oil (EPO) is a potential candidates as a substitution for petrochemical-based resin. A study on the blending epoxidized palm oil (EPO) with epoxy resin has been conducted by Alsagayar and his co-workers (2015). The authors used synthetic epoxy resin mixed with EPO and cured with synthetic amine hardener. Their findings show that the incorporation of EPO into epoxy resin increased the ductility and toughness properties, however decreased the thermal, tensile and flexural properties of the epoxy/EPO resin. Therefore, to facilitate more cross-linked structures between the palm oil and the polymer matrix, further modification of EPO is required. Acrylation is a common method used to further modify epoxidized vegetable oil to increase its reactivity and introduces more polymerizable functionalities such as acrylate and hydroxyl groups. Some studies have reported that the incorporation of acrylated epoxidized vegetable oil into polymer resin exhibited better mechanical and thermal properties than epoxidized vegetable oil polymer resin (Paluvai, Mohanty and Nayak, 2015; Saithai et al., 2013).

There are two main methods for producing VO-based polymer resins: the direct synthesis of VO and blending VO with polymer resin. The direct synthesize of VOs is more challenging and thus satisfactory results have not yet been reached because of its relatively low strength compared to petroleum-based epoxy resins that limits its applications (Mohanty, Misra and Drzal, 2005; Stemmelen et al., 2011; Takahashi et al., 2008). Several authors have reported on the blending of petroleum-based epoxy resins with VOs (Gogoi, Boruah and Dolui, 2015; Paluvai, Mohanty and Nayak, 2015; Sarwono, Man and Bustam, 2012). The partial replacement of petroleum-based epoxy resin with functionalized VO may produce materials with acceptable properties and a low overall cost with improved processability. There are many researchers that have reported on the blending of VOs with polymer resins such as epoxy, polyester, polyurethane, and poly(lactic acid) (Alsagayar et al., 2015; Auvergne et al., 2014; Bordes, Pollet and Averous, 2009; Chaudhari et al., 2013; Chieng et al., 2014; Pfister, Xia, and Larock, 2011; Roudsari et al., 2014; Stemmelen et al., 2011).

Epoxy resin is the most commonly used thermoset in the polymer industry and has widely used in high performance applications in the aerospace, marine, automotive, and building industry (Bao et al., 2011; Jaillet et al., 2013; Mohanty et al., 2005). This is due to its unique chemical and physical properties such as good mechanical properties, good electrical and heat resistance, excellent chemical resistance, high stiffness, low shrinkage, and excellent fiber-matrix adhesion to many substrates(Bao et al., 2011; Jaillet et al., 2013; Norhakim et al., 2014). However, it has disadvantages such as brittleness and low impact strength (Mohanty et al., 2005). Previous studies have proved that the incorporation of vegetable oils into epoxy resins may lead to a substantial improvement in toughness and brittleness properties (Norhakim et al., 2014; Tan and Chow, 2010; Tayde and Thorat, 2015). Higher amounts of VO can result in higher impact energy absorption in VO/polymer resins. However, the addition of VO decreases resin stiffness and thermal properties of resins (Sarwono et al., 2012a; Silverajah et al., 2012; Tan and Chow, 2010a). Therefore, some fillers need to be added to balance the toughness and stiffness performance of the VO/epoxy resin.

There are several types of nanomaterials that have been used as reinforcing filler for VO/polymer nanocomposites such as nanoclays, graphene, carbon nanotube, silica and alumina. Among these, organo modified montmorillonite nanoclay platelets (OMMT) is the most commonly used reinforcement fillers for polymer nanocomposites. This is because OMMT is natural mineral that is inexpensive and has a higher aspect ratio and large surface area that can provide sufficient interface interaction with polymer resin (Wang, 2014a). In nature, clays are hydrophilic and are not compatible with hydrophobic polymers. In this case, pre-treatment of clays using amino acids, organic ammonium salts, or tetra organic phosphonium is necessary. The well dispersed intercalated or exfoliated forms of nanolayer silicates for modified clays in vegetable oil-based polymer resin were reported allowing a slightly enhancement in stiffness and thermal properties at low level loadings. Therefore, this led to improve stiffness-toughness balance of vegetable oil/polymer resin comparable to commercially available synthetic neat epoxy resins (Miyagawa et al., 2004; Wang, 2014a).

VO/epoxy resins may be reinforced with natural or synthetic fibers to produce partially or fully green composites. Glass fibers are the most commonly used reinforcement for fiber reinforced polymer composites. Glass fibers possess excellent strength with less varied properties and have been extensively used in many high performance applications such as in the structural and marine industries. Glass fibers are inexpensive compared to other synthetic fibers such as carbon and aramid fibers and are compatible with many different materials. However, the main disadvantages of glass fibers is that they are produced from petroleum-based products, which are not a renewable resource and are not environmentally friendly.

Recent years have witnessed a huge interest in developing other types of reinforcement with natural origin as an alternative to traditional synthetic fibers in polymer composite systems. Kenaf fibers are a commonly used natural fibers reinforcement for most VO-based or green polymer composites. They are inexpensive and have excellent characteristics such as good tensile and modulus properties compared to other natural fibers (Nishino, Hirao and Kotera, 2006). Kenaf fibers have received extra attention over man-made fibers such as aramid or carbon because they are renewable, low density, non-toxic, non-abrasive, cheap, completely or partially recyclable, and biodegradable (Aji et al., 2009). However, natural fiber composites are still limited to the structural applications, owing to their poor durability, high water absorption, and low fire resistance properties than synthetic fiber composites (Muhammad et al., 2016; Ramesh, Palanikumar and Reddy, 2016). Therefore, this study focused to develop hybrid composites with two or more types reinforcing fibers in a single matrix**.**

The hybridization of kenaf and glass fibers composites has received significant attention over single reinforcing fiber composites such as natural fiber composites or glass fiber composites. The inclusion of hybrid fibers in polymer composites offers a good compromise in terms of mechanical and thermal properties in addition to a low cost and reduced environmental impact (Ghani et al., 2012; Muhammad et al., 2016; Salleh et al., 2012). Moreover, the addition of glass fiber and natural fiber to polymer composites increases the mechanical properties and significantly decreases the water uptake of the composites (Akil et al., 2014; Silva et al., 2016).

The moisture absorption characteristics of natural fiber are very important to producing good hybrid composites. The water absorption of polymer composites has a deleterious effect on their mechanical performance. As a result, it is essential to understand the moisture diffusion behaviour of polymer composites to predict long-term performance and optimize structural design. Therefore, in this study, the effect of acrylated epoxidized palm oil (AEPO) and OMMT contents on the mechanical and thermal properties of VO/epoxy resin and its morphology were analysed. The mechanical, thermal, and morphological properties as well as water absorption behaviour of hybrid kenaf/glass fiber reinforced epoxy/AEPO filled OMMT composites were also investigated. It is expected the output of this research study can produce new composite materials that is suitable for automotive and housing construction applications.

1.2 Problem Statement

Epoxy resin is a popular thermoset resins due to its good mechanical and thermal properties, excellent adhesion, low shrinkage upon curing, and its ability to be processed under a variety of conditions. Epoxy resin has wide applications in the automotive, marine, construction, and aircraft industries. However, it is produced from petrochemical products, which are not sustainable or eco-friendly. Continued reliance on this material might result in diminishing petroleum resources in the future. Therefore, to preserve the environment the study of VO/epoxy resin is necessary.

There are numerous studies on the development of VO/epoxy resin. Vegetable oil (VO) has been reported as the most promising option for the production of VO/epoxy resin. However, the direct synthesis of epoxy resins from VO does not offer satisfactory properties due to the low strength and higher moisture absorption of the produced resins, which limit their applications. Therefore, blending epoxy with vegetable oil is required. Nevertheless, there has been no study conducted on the blending of epoxy resin with acrylated epoxidized palm oil (AEPO). Therefore, in this study the blending of epoxy resin with AEPO was studied.

The blending of epoxy with VO has been reported on by many researchers (Pin, Sbirrazzuoli, and Mija, 2015; Sarwono, Man, and Bustam, 2012b; Tayde and Thorat, 2015). They found that that the incorporation of VO into epoxy resins enhanced epoxy resin toughness properties and indirectly overcame the major limitations of epoxy resins, which are brittleness and low impact strength. However, the addition of VO reduces the stiffness performance of the resulting VO/epoxy resin. Therefore, the addition of a fiber or filler such as organo modified montmorrillonite nanoclay (OMMT) is required to balance the toughness and stiffness properties of the VO/epoxy resin. In this study, the effect of OMMT loading on the mechanical and thermal properties, morphology as well as water absorption of epoxy/AEPO nanocomposites were investigated.

In order to produce green composites from a VO/polymer resin, it is necessary to use natural fibers as reinforcement. Kenaf fiber is the most common reinforcing fiber used to reinforce VO/polymer composites. This is due to its lower cost and high specific mechanical and biodegradability properties. However, kenaf fiber exhibits lower mechanical and thermal properties as well as lower moisture absorption resistance than synthetic fiber composites. Therefore, it is important to investigate materials with enhanced durability properties and good thermo-mechanical performance.

Previous studies have shown that the hybridization of natural fiber and synthetic fiber can be used to produce composites with balanced properties that could not be attained with a mono-fiber composites. Thus, in this study, kenaf fiber was hybridized with glass fiber. Glass fiber was chosen because it is relatively inexpensive compared to other synthetic fibers such as Kevlar and carbon fiber and it has excellent tensile strength, stiffness, and good corrosion resistance. In literatures, the fibers layer sequences have also been reported to have an important effect on the mechanical performance of hybrid composites. The different laminate fiber-stacking sequence is assumed could increase the strength, stiffness and water retention properties of the composites. Thus, the effect of different layering sequences of kenaf and glass fibers were investigated in this study.

Nevertheless, the mechanical properties of hybrid natural fiber and synthetic fiber composites can be affected by moisture humidity uptake. Durability is the main issue for polymer composites that are used as structural materials. In order to develop composites that have good long term performance, it is essential to provide a basis for their structural design in specific environmental conditions. Hence, the study of the water absorption behaviour of polymer composites in distilled and salt water are necessary to facilitate the optimum design and fabrication of composite structures.

In this study, the potential use of acrylated epoxidized palm oil (AEPO) as part of an epoxy resin in hybrid kenaf/glass fiber reinforced composites was investigated. To date, there has been no study on the hybrid kenaf/glass fiber reinforced epoxy/AEPO filled OMMT composites reported in the literature.

1.3 Research Objectives

The overall objective of this study was to produce a new composite with least amount of synthetic materials toward green product based on acrylated epoxidized palm oil (AEPO) blend with synthetic epoxy resin, organo modified montmorrillonite nanoclay (OMMT) as nanofiller and kenaf and glass fibers as reinforcement. The detail of the objectives are:

1. To examine the effect of acrylated epoxidized palm oil (AEPO) loading on the mechanical and thermal properties, morphology, as well as water absorption of epoxy/AEPO resins.

2. To investigate the effects of organo modified montmorrillonite nanoclay (OMMT) loadings on the mechanical and thermal properties, morphology as well as water absorption of epoxy/AEPO nanocomposites.

3. To study moisture absorption behaviour and its effects on the flexural properties of hybrid kenaf/glass fiber reinforced epoxy/AEPO filled OMMT composites as a function of different layering sequences and different environments (in distilled and salt water).

1.4 Scopes of the Study

To achieve the research objectives, the study scopes are as follows:

1. Preparation of acrylated epoxidized palm oil (AEPO) in accordance to the method reported by Habib and Bajpai (2011). The functional groups present in AEPO were characterized by using fourier transform infrared spectroscopy (FTIR).

2. Preparation of epoxy/AEPO resin by direct mixing of AEPO with epoxy resin. Amounts of AEPO added into epoxy resin were varies at 10, 20 and 30 wt%. The

effects of AEPO loading on mechanical properties of epoxy/AEPO resin were investigated by determining tensile, flexural, impact properties. The thermal, thermophysical, morphology and water absorption of epoxy/AEPO resin were characterized by using TGA, DMA, scanning electron microscope (SEM) and water absorption test.

3. Preparation of epoxy/AEPO/OMMT nanocomposites by adding various amounts of OMMT content at 1, 1.5, and 2 phr. The effects of organo modified montmorrillonite nanoclay (OMMT) loadings on mechanical properties of epoxy/AEPO/OMMT nanocomposites were evaluated by determining tensile, flexural, impact properties. The thermal, thermophysical, morphology and water absorption of epoxy/AEPO/OMMT nanocomposites were characterized by using TGA, DMA, TEM and water absorption test. The formulation of OMMT/AEPO/epoxy resin with the best stiffness-toughness balance was chosen for composite preparation.

4. Preparation of hybrid kenaf/glass fiber reinforced epoxy/AEPO filled OMMT composites by using hand lay-up technique. Kenaf fiber mat and chopped strand mat glass fibers were arranged in different laminate layers configurations for composite fabrication. The moisture absorption behaviour of hybrid composites were determined by water absorption. Two different types of water solutions were used: distilled water and salt water (3.5% NaCl solution). The effects of water absorption on flexural properties of hybrid composites as a function of different layering sequences and different environments (in distilled and salt water) were evaluated. The morphology of hybrid composites was characterized by using SEM.

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