

ABSTRAK

Kajian ini adalah tentang penggunaan 'Nanoclay' sebagai pengisi kepada Poly (Lactic Acid) dan Polybutylene Succinate sebagai matrik untuk Serat Daun Nenas (PALF) sebagai asas komposit. Tujuan kajian ini adalah untuk mengoptimumkan pengisian 'Nanoclay' terhadap sifat-sifat mekanik polimer 'Poly (Lactic Acid)', (PLA) dan 'Polybutylene Succinate' (PBS), untuk mengkaji kesan 'Nanoclay' terhadap sifat termal PLA dan untuk menilai pengaruh 'Nanoclay' pada sifat-sifat mekanik komposit polimer Serat Daun Nenas (PALF). Pertamanya, 'Nanoclay' dirawat menggunakan ultrasonik untuk memastikan penyebaran 'Nanoclay' yang baik. Kemudian 'Nanoclay' digunakan sebagai pengisi pada 0.5, 1, 3, 5, dan 7wt. % untuk menghasilkan komposit menggunakan kaedah 'solvent casting' dan mesin 'compression moulding'. Ciri-ciri termal PLA dengan pemuatan 'Nanoclay' yang dianalisis menggunakan 'Differential Scanning Calorimetry'. Manakala, pemuatan optimum Nanoclay akan diteruskan dengan proses 'pre-pregging' untuk menghasilkan bahan 'pre-preg' 'Nanoclay-PLA/PALF' dan 'Nanoclay-PLA/PBS/PALF'. Selepas itu, komposit telah dihasilkan menggunakan mesin 'compression moulding'. Selepas ujian dijalankan, pemuatan optimum 'Nanoclay' yang dicapai adalah pada 1 wt.%. Ini disokong oleh hasil ujian tegangan dan analisis 'SEM' yang menunjukkan peningkatan nilai sifat tegangan dan permukaan patah yang serata pada komposit. Manakala sifat termal didapati bertambah baik dengan kehadiran 3 wt.% 'Nanoclay', T_g meningkat dari 56.4°C ke 59.22°C. Manakala, T_m telah meningkat dari 151.20°C ke 152.62°C. Hasilnya membuktikan bahawa dengan kehadiran 'Nanoclay', sifat termal bertambah baik dari segi T_g dan T_m yang meningkat berbanding dengan PLA tulen. Sifat mekanikal menunjukkan peningkatan 'Nanoclay-PLA/PBS/PALF' dari segi kemuluran dengan nilai 'Elongation at Break' pada 5.07% yang meningkat 5 kali ganda berbanding dengan PLA tulen/PALF. Kekuatan tegangan 'Nanoclay-PLA/PALF' juga meningkat ke 148.93 MPa iaitu 4% meningkat berbanding PLA tulen/PALF kerana kehadiran 'Nanoclay'. Sekaligus menyarankan 1 wt % 'Nanoclay' dijadikan calon yang terbaik untuk digunapakai didalam pembuatan komposit PLA/PALF.

ABSTRACT

The study is about the utilization of Nanoclay as filler for Poly (Lactic Acid) and Polybutylene Succinate as matrix for Pineapple Leaf Fibre based composite. The aim of this study is to optimize the filler loading of Nanoclay with respect to mechanical properties of the Poly (Lactic Acid), (PLA) and Polybutylene Succinate (PBS) polymers, to investigate the effect of Nanoclay onto the thermal properties of the PLA and to evaluate the influence of the Nanoclay on the mechanical properties of the Pineapple Leaf Fibre (PALF)-polymer composite. Firstly, the Nanoclay is being treated using ultrasonic probe to ensure a well dispersion of Nanoclay. Then the Nanoclay is being used as filler loading at 0.5, 1, 3, 5, and 7 wt% to produce the composite using solvent casting method and compression moulding machine. The thermal properties of PLA with different loading of Nanoclay are being analysed using Differential Scanning Calorimetry due to the main matrix for the composite. Then, optimum loading of Nanoclay is proceed with pre-pregging process to produce Nanoclay-PLA/PALF and Nanoclay-PLA/PBS/PALF. The optimum loading of Nanoclay is at 1 wt.%. This is supported by the result of tensile testing and SEM analysis which showed the increased value of tensile properties and the homogenous fracture surface of the composite. The result proved that with the presence of Nanoclay, the thermal properties improved with 3 wt.% of Nanoclay, the presence of Nanoclay has increased the T_g from 56.4°C to 59.22°C and T_m has increased to 151.20°C to 152.62°C. The mechanical properties of Nanoclay-PLA/PBS/PALF showed improvement in terms of ductility with value of Elongation at Break at 5.07% which increased 5 times compared to pure PLA/PALF. Ultimate tensile strength of Nanoclay-PLA/PALF also improved 4% at 148.93 MPa compared to pure PLA/PALF due to the presence of Nanoclay. Therefore, 1 wt % of Nanoclay loading reinforced PLA/PALF has been selected as the best candidate for composite in term of strength and ductility.

DEDICATION

To my dearest Abah, Saiffuddin Ramli,
my beloved Mak, Sharifah Noor Mah Syed Ismail,
my Meors and Puteri siblings and families.

Thank you for the moral and financial support, understanding and prayers.

Untuk arwah Abah yang tersayang, Saiffuddin bin Ramli,
Untuk Mak yang tercinta, Sharifah Noor Mah binti Syed Ismail,
Adik beradik Meor dan Puteri, serta keluarga besarku.

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LIST OF ABBREVIATIONS

PLA	-	Poly Lactic Acid
PBS	-	Polybutylene Succinate
PALF	-	Pineapple Leaf Fibre
KF	-	Kenaf
WF	-	Wood flour
O-MMT	-	Organo-Montmorillonite (OMMT)
PP	-	Polypropylene
PE	-	Polyethylene
PS	-	Polystrene
PET	-	Poly (Ethylene Terephthalate)
PVC	-	Poly (Vinyl Chloride)
MOE	-	Modulus of Elasticity

LIST OF SYMBOLS

Wt.%	-	Weight Percentage
Vol.%	-	Volume Percentage
MPa	-	Mega Pascal
GPa	-	Giga Pascal
T_m	-	Melting Temperature
T_g	-	Glass Transition Temperature
T_c	-	Cold Crystallization Temperature
$^{\circ}\text{C}$	-	Degree Celcius
J/g	-	Joule per Gram
%	-	Percentage
mm	-	Millimeter
X_c	-	Crystallinity

CHAPTER 1

INTRODUCTION

1.1 Research Background

Manufactured polymers have turned out to be mechanically noteworthy since the 1940s and bundling is one industry that has been changed by polymers, for example, polyethylene (PE), polypropylene (PP), polystyrene (PS), poly (ethylene terephthalate) (PET) and poly (vinyl chloride) (PVC). The flexibility of plastic enables it to be utilized as a part of everything from the basic part, to complicated parts. The purpose for multi utilization of plastics is the ability in the one of a kind approach to be fabricated which to meet the detail of the utilitarian requirements for shoppers. Plastics likewise have been discovered helpful in life which including from transportation, building, bundling and medicinal machines, agribusinesses and correspondence (Steve, 2002).

Engineered plastics, for example, polyethylene and polypropylene have a low water vapor transmission rate so that, they are non-biodegradable, and subsequently prompt natural contamination, which posture genuine environmental issues. There has been an expanded enthusiasm for upgrading the engineered plastics to biodegradable plastics. However, biodegradable plastic has their own weakness which should be overcome.

Composites are one of materials that have been generally utilized worldwide as the substitute for the other material for the example, metal and woods. Composites are materials that joined at least two components of material in one unit to deliver the preferable materials with better properties over the past materials. By utilizing filler or fibre as reinforcing agent in composite, properties of composite will vary.

Filler and natural fibre obtained from renewable resources which is safer than inorganic filler. It has many points of interest which incorporate ease, bottomless supply, and natural harmony. Along these lines, it demonstrates that nanofiller and natural fibre has an awesome potential to be delivered into biodegradable polymer. In way to enhance properties of nanofiller, it should be treated with some process due to its poor characteristics.

1.2 Problem Statement

These days, plastic has been utilized broadly in industry. This is because the versatility of the plastic itself. In other case, there are huge amounts of waste has been delivered in the production line and it happens basically because of the residual cut from the non-degradable plastic. Large amount of plastic waste accumulation giving bad impact to our earth. Other than that, agricultural waste also has been distributed around the country.

Malaysia is one of the pineapple producer countries. Due to the extraction of pineapple plant is mainly for its fruits purpose so that PALF is still an under-utilised natural resources which can be used to create the job opportunity and incomes. The proper extraction and processing of PALF will make it able to develop its application in construction, mechanical, automotive, naval, aeronautical and space industries (Leo et al., 2015).

By using degradable plastic such as Poly Lactic Acid it will help to reduce the plastic waste. However, PLA itself do not promising a competitive strength and low in ductility. By utilizing the agricultural waste which is pineapple leaf fibre (PALF) and nanoclay as nanofiller, the properties can be enhanced.

Polybutylene Succinate (PBS) which is also degradable polymer can also be used in the fabrication of composite to improve the ductility of the composite due to the properties of PBS itself which is better in ductility compared to PLA. By the blending of PLA and PBS, it should improve the properties of PLA/PBS in term of ductility.

Nanofiller that can be utilized is Organo-Montmorillonite (OMMT) which is type of nanoclay. Nanoclays are environment friendly and low cost of chemical substances. In addition to these application, nanoclays stated that it is helpful in order to protect the environment and also remediation. (Nazir *et. al* 2016)

1.3 Objective

The objectives of the project are as follows: -

- a) To optimize the filler loading of Nanoclay with respect to mechanical properties of the PLA and PBS polymers
- b) To investigate the effect of Nanoclay onto the thermal properties of the PLA.
- c) To evaluate the influence of the Nanoclay on the mechanical properties of the natural fibre – polymer composite.

1.4 Scope of Research

The scopes of research are mainly focused on the Nanoclay which are commercial Organo-Montmorillonite (O-MMT) filled thermoplastic and pineapple leaf fibre (PALF) as a composite. The thermoplastic used in this research are Poly Lactic Acid (PLA) and Polybutylene Succinate (PBS). The fibre used is pineapple leaf fibre (PALF) with fibre loading at 40 wt.% which to be used to produce composite with the optimum loading of Nanoclay. The filler and fibre loading of the composites is the main factor that influenced the characters of the composites. The composite is compounded into six compounding. Each compounding has 0, 0.5, 1, 3, 5 and 7 wt. % of Nanoclay as filler. The composites and thermoplastic is characterized by using thermal analysis, tensile testing, and morphological evaluation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Plastic is divided into two class in term of degradability which is degradable and non-degradable. Degradable plastic is plastic that can be degraded by natural way. However degradable plastic such as Poly Lactic Acid itself do not promising a competitive strength of plastic. Therefore, composite is the best way to improve the properties of the material. Composite is a combination of two or more materials. It can be made specifically made based on the properties or requirement.

2.2 Nanocomposite

As reported by A. Vaia (2005), the nano-scale and related to nanoscience and technology promising unique opportunities to create combination of material revolutionary. All of these materials will help to improve the classic material performance by accessing new characteristics. One of the way is by exploiting nanotechnology to enhance and also improved the properties of existing classes of materials. For example, is polymer composites which have been a good in demand to give a high-performance aircraft for many years. It offers desirable and tailorable properties such as high strength and stiffness, dimensional and also thermal stability. The existing of application for nanotechnology has made the polymer composite become more interesting and also attractive. Polymer composite is already well-known in industry since 25 years ago. Therefore, polymer nanocomposite will usher in this new era of material development.

A. Vaia (2005) also added, by the reinforcement of polymers by using fillers either organic or inorganic fillers is a norm in the fabrication of modern plastic. Polymeric nanocomposite or known as polymer nanostructured materials has represented a great alternative to the conventional filled polymers or called as polymer blend. Comparison to conventional systems which the reinforcement is on the order of microns. While polymeric nanocomposite is exemplified by discrete constituents on the order of a few nanometres which are 10,000 times finer than a human hair.

2.3 Nanoclay

A study was conducted by Rethon (2002) about nanoclay. He reported that the sedimentation of silicates was separated into thin crystalline plates with very thin thickness and several hundred nanoclay ratios. Composite hardness and high heat output, while only a few percent load. It also has gas-barrier properties and is reportedly highly fire resistant. Delamination of the crystals is generally carried out using chemicals. The most suitable clay for the purpose is 2:1 clay, such as montmorillonite. The type of Nanoclay is octahedrally aluminum sandwiched between two sheets of tetrahedral silica. Some research has made using aluminum substitution with positive ions such as magnesium. This would result in a net negative charge, which is balanced by hydrogen, and carbon dioxide, in a space called the gallery between layers. If the cations are large, the spacing between the layers will increase to the point where they can be separated by some physical means (such as etching). Four ammonium compounds are especially useful for this purpose. Extensive processing often involves the production of these clays due to the need for high purification and edema.

MMT is extracted from the bentonite by a process of sedimentation in water (Kornmann *et al.*, 1998), and then activated by sodium ions (Na^+) to improve clays swelling. It is then possible to insert organic cations, such as silanes (Fu & Qutubuddin (2004), ammonium bromides as studied by Kornmann *et al.* (1998) or known as ammonium chlorides. These ions reduce the surface energy of clay, making it more organophilic, thus facilitating access between the layers of monomers and polymers with different polarities. Nowadays, pre-modified MMT are often used and commercially available (Closite, Garamite, and others). (Marquis *et al.*, 2005).

2.3.1 Nanoclay as Nanofiller

Nanoclay, untreated and treated montmorillonite were incorporated to improve the strength of resin concrete (containing 11% polyester resin and 89% of mineral fillings (sand and limestone)) were combined (Jo *et al.* 2008). Only the treated montmorillonite improves the strength and coefficient in the concrete pressure with a 20% improvement in mechanical properties at a rate of 5% to 7%. Without the process of surface treatment, performance can be compared to those unfilled with nanofiller and exfoliation is supposed to explain differences. The incorporation of montmorillonite-layered silicates in a thermoplastic matrix needs the exchangeable cations or alkaline earth from the clay to be replaced by organophilic cations. The common organophilic cations used are quaternary ammoniums. The aim of the process is to obtain interaction between the nanofiller and the matrix at the nano scale. The insulated structure is the main objective when dealing with nanoclays. Apophyllite (Phyllosilicate of $KFCa_4 [Si_8O_{20}], 8H_2O$) can be used through the syllilation reaction as reported by Dean *et al.* (2007). The superior apophils (n - Octylsiloxy apophyllite) can be applied in polyester resins or vinyl ester. As reported by Dean *et al.* (2007), the effect of nano or epoxy compound on improving compound properties using different methods of dispersion (mechanical or ultrasonic) and different concentrations of nano (mass masses 0, 1, 2.5 and 5%). (Marques *et al.*, 2005)

2.3.2 Chemical Structure of Nanoclay

The Nanoclay structure may have an effect on the matrix. As mentioned by Nazir *et al.* (2016), MMT is a two-channel octahedral channel with a layer 2: 1 link. They are the optimum reinforcement filler and their reinforcement potential is well known in literature. Study has revealed that the larger surface area and the large elevation ratio are the salient features responsible for the reinforcements also supported by Arora, Padua (2010) and Azeredo (2009). Besides enhancing the effect of MMT, it is also seen as a rigid and non-permeable filler. It creates a large structure when dispersed in polymers, forcing the moving gases /vapors to follow a twisted path, and ultimately reduces the rate of penetration. Each individual MMT layer has side dimensions of 200-600 nm and a few nm thickness consisting of two quadrilateral pages and an octahedral sheet.

All layers are linked one by one in a way that involves SiO₄ in 3 out of 4 oxygen atoms with the central octahedral plates as shown in Figure 2.1. MMT layers in its pristine regulate themselves from each other where platelets are stacked with different levels of stacking within clay minerals. Depending on the level of stacking, the primary particles or aggregates can be layered (fine aggregates and gravel). During the interlocking substitution of Al + 3 by Fe + 2 or Mg + 2; and Mg + 2 by Li + 1 in the layer structure, the difference in equivalence leads to a total negative charge on each layer of three layers. The various metal cations (Na + 1, Ca + 2) are present in all classes of layers / galleries that exhibit imbalance, thus increasing the water character (Bordes *et al.*, 2009; Paul and Robeson 2008; Pavlidou and Papaspyrides 2008). Because of these hydrolitic properties, MMT moisturizing affects the galleries for expansion and clay in bloating. In addition, pure clay is dispersed in hydrolitic polymers such as vinyl alcohol and ethylene oxide. Na + 1 in clay fairs with organic cations, such as alkylammonium or alkyphosphonium / ion ions, can also be changed to eliminate the hydrophilic properties and improve the compatibility of Nanoclay with water-resistant polymers. Murray (2000) reported that the equilibrium imbalance, called the CEC exchange capacity in the thicket, was about 0.66 per unit cell because of the equalization of the shape. The CEC depends on the interlocking nature of the alternatives and varies from layer to layer, thus taking into account the average total amount of crystal (Alexander and Dubois 2000). It is expressed as mequiv / 100 g (meq / 100 g) and also in the range of 80 to 150 mequiv / 100 g for the sapatite (Pavlidou and Papaspyrides 2008).

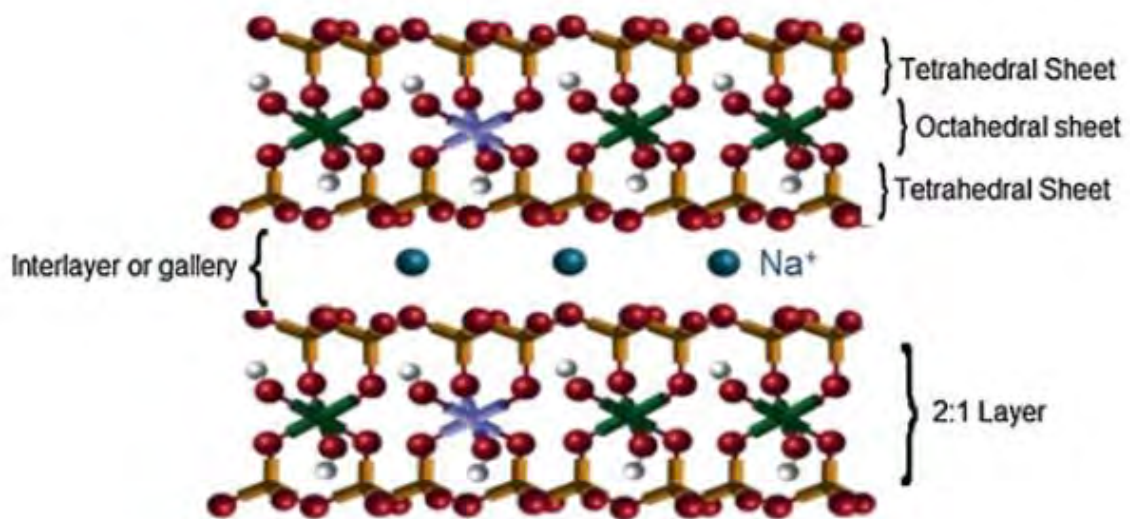


Figure 2.1: Structure of Na-MMT (Paul and Robeson 2008)

2.4 Surface Modification of Nanoclay

As reported in by Hamid and Osman (2018), clay that used in the research was an organically modified montmorillonite (OMMT). The surface modification is process has been made by using distilled water as the ultrasonication medium to allow swelling of OMMT. The OMMTs were prepared in suspension from using different ratio of OMMT and distilled water. The suspensions were homogenized by using ultrasonic probe at 20 kHz amplitude for five minutes. Then, the resulting gel-like suspensions is placed in the oven for 48 hours until it fully dried. The result achieved stated that the properties of thermal is thermally stable and has obtained swelled clay powder. Disruption in platelets ordering upon the ultrasonication process resulted in tactoid with smaller size and the packed OMMT platelets more loosely.

2.5 Polymer Matrix based Composite

Polymer matrix composite material is the one that used organic polymer as matrix and fiber as reinforcing agent. However, there the matrix material must have great bond properties which will firmly bond fibers together. At the same time, the matrix material can function well and will uniformly distribute the applied load, and exchange the loads to fiber. Over addition, some properties about composite materials primarily rely on upon the strength of the matrix material. Therefore, in composite materials, the performance of matrix, fiber and the interface between both of element have given a big impact on the performance of composite material. The prominent advantages of polymer matrix composite materials are their high specific modulus and strength. The specific strength is the ratio of density and strength and the specific modulus is the ratio of density and modulus, and the dimensions or units are both length. Under the premise of equal weight, they are indices of measuring bearing capacity and stiffness properties of the material (Wang et al. 2011).

2.6 Poly Lactic Acid as Thermoplastic Matrix

Poly (lactic acid) (PLA) have gain a vast significant attention in the biomedical applications. It is widely used in the clinical, dentistry and pharmacy, etc., mainly due to it bio-compatibility and biodegradability (Auras *et al.*, 2011). PLA is a biodegradable thermoplastic polymer and it is obtained from lactic acid and which can degrade through hydrolysis process into water (H₂O) and carbon dioxide (CO₂). Lactic acid can be formed by fermentation of sugars from sugarcane which is natural organic acid. Hence, it is an environmental and user friendly material.

PLA consist of three stereoisomer formation which are shown in Table 2.1 and has varies from the structural formula of PLA monomers (Figure 2.2). The advantages and disadvantages of the PLA is summarized in the Table 2.2.

Table 2.1: Types of poly (lactic acid) and their abbreviation

Types of poly (lactic acid)	Abbreviation
Poly (L-lactide)	PLLA
Poly (D-lactide)	PDLA
Poly (DL-lactide)	PDLLA

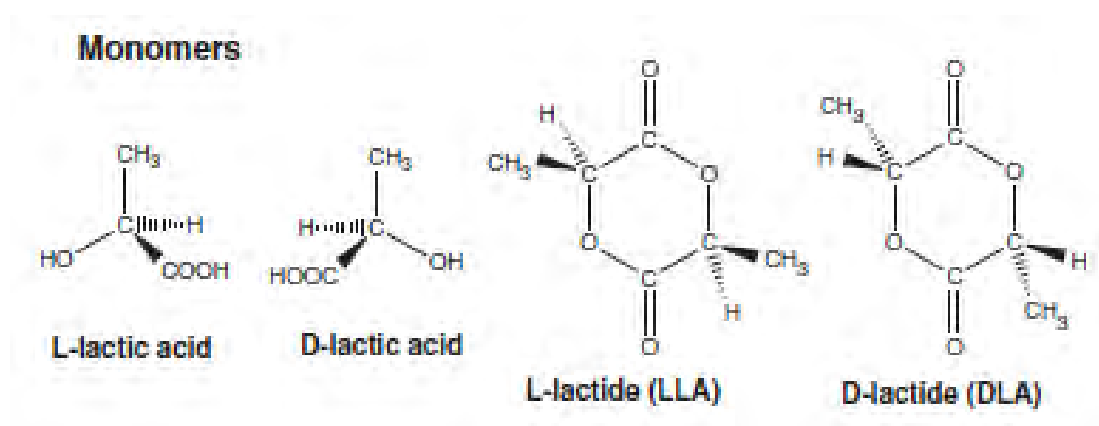


Figure 2.2: Types structural formula of PLA monomers (Auras *et al.*, 2011)

Table 2.2: Advantages and disadvantages of PLA (Tsuji, 2011)

Advantages	Disadvantages
Eco-friendly	Poor toughness
Biocompatibility	Slow degradation rate
Processibility	Hydrophobicity
Energy savings	Lack of reactive side-chain groups

2.6.1 Mechanical Properties

Mechanical properties of PLA are among the best between the other degradable polymer. As reported by Ahuja et al., (2018), Poly Lactic Acid is well known for brittle and tensile strength. Tensile strength has been decreased with the addition value of wt.% of wood flour composition with constant composition of PLA and PBS at 70/30. With the composition of 70/30/5 has achieved the tensile property at highest value at 47.66 MPa. The results also confirmed that pure PLA shows rigidity of 3.2 GPA and 68 MPa of tensile strength. They added that with addition of PBS into the blends, it has changed the properties of poly lactic acid. As the result, PBS ductility improved to 30-35% compared to pure PLA but the rigidity and yield stress of PBS decreased.

While Kamthai and Magaraphan (2015) stated that the average values and standard deviation of the mechanical properties of the plasticized PLA/CMCB composites are reported in Table 2.3. As expected, the addition of plasticizer caused substantial decrease in tensile strength and Young's modulus of PLA/CMCB composites, which ranged from 30.1-46.5 MPa and 1,336.6-2,474.4 MPa, respectively. Interestingly, tensile strength and Young's modulus of the 5-10%wt plasticized PLA/CMCB composites had higher values than those of PLA and PLA/CMCB composite. It infers that the distribution of CMCB granules in PLA matrix is good. Conversely, the elongation at break tended to increase with the plasticizer content. The result showed significant increase in elongation at break at 15-20%wt isosorbide diesters concentration. This showed that isosorbide diesters enhances the molecular mobility of PLA chains and improved the ability of plastic deformation. The dramatic change in elongation at break may cause by the plasticizer. The optimum content of isosorbide diesters for PLA/1 wt% CMCB composite which soft, less rigid and tougher is 15 wt%.

Table 2.3: Tensile properties of composite (Kamthai and Magaraphan, 2015)

Sample	Tensile strength (MPa)	Elongation at break (%)	Young's Modulus (MPa)
PLA	41.83 ± 0.63	4.07 ± 0.37	2004.33 ± 62.9
PC1	38.57 ± 3.02	5.40 ± 0.53	2013.33 ± 54.2
PC1S5	46.85 ± 1.76	3.36 ± 0.35	2395.42 ± 70.2
PC1S10	46.84 ± 2.41	3.16 ± 0.18	2474.39 ± 70.5
PC1S15	32.13 ± 1.57	120.11 ± 2.66	1377.72 ± 15.7
PC1S20	30.10 ± 2.01	247.06 ± 0.93	1336.62 ± 45.7

Another study by Liu et al. (2013) on the mechanical properties of PLA / Nanoclay modified Woodflour (WF). The increased value of the Nanoclay concentration initially improved the tensile properties and then decreased after reaching a maximum value of 1% in all three types of WF / PLA. In general, it was associated with two factors, namely, the static barrier caused by dispersion of padding and long fibers. The larger WF can interfere with the molecular chains of the PLA and then fix the PLA matrix, while the smaller WF is distributed in the PLA matrix in a more symmetric manner and improves the compatibility between the WF and the matrix. When nanoclay concentration was more than 1%, much of the clay was aggregated on the surface of the WF and led to interaction with weak bonding in WF / PLA compounds. Composite materials with 0.5% nanoclay modified WF performance better than other concentrations. In addition, this enhancement was even more important in WF. As a result, the highest tensile strength of 55.36 MPa and 4.87 GPa was achieved in the WF_a-0.5% / PLA group, which increased by 28.7% and 14.6% compared with WF_a / PLA control, respectively. g for the Sectate (Pavledo and Papaspyrides 2008).

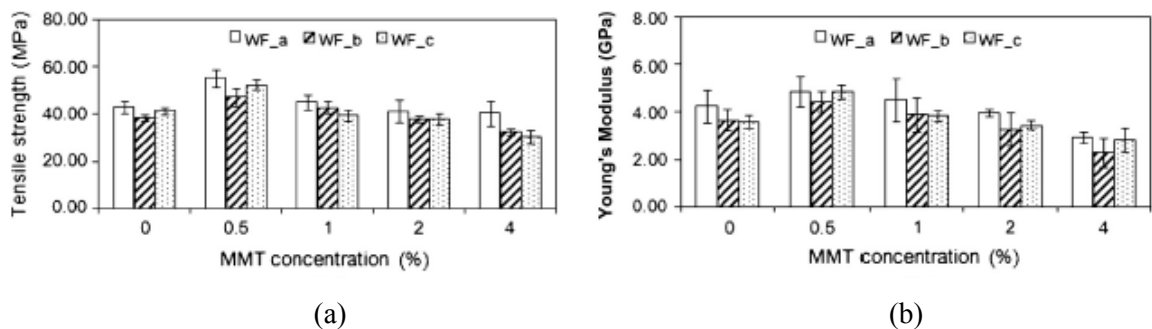


Figure 2.3: (a) The mechanical properties of PLA/modified WF composite. (b) The mechanical properties of PLA/ unmodified WF composite (Liu et. al 2013)

Another study by Talbamrung *et al.* (2016) on PLA / NBR. Figure 2.4 (a) illustrates the behaviour of stress and strain curves of PLA / NBR mixtures. With the addition of 5-10% NBR, it has improved the ductility of the PLA. The bleaching occurred during the strain on the yield in the NBR mix of 5 to 10%. However, limitations related to permanent deformation were observed during the research. With NBR content of 15 to 30% in PLA, stress and behaviour curves show poor behaviour. This resulted from phase separation and large NBR molecules in mixtures. Figure 2.4 (b) shows the tensile strength and tensile strength of the PLA / NBR mixtures. It has been shown that tensile strength has been consistently decreasing with NBR content. While tensile elongation of PLA / NBR TPV was achieved in NBR content of 10-20%, the PLA was improved by 500 to 1000%. The small sparse NBR particles and the interconnection between PLA and NBR were responsible for the rigidity and ability of the compound to elongate. Also with the TPV was clear compliance. This occurs because of cross-linking between NBR and polymerization between NBR and PLA in the interface. With NBR content of 25 to 30%, a reduction in tensile elongation was achieved, but still better than the pure PLA. In the high NBR content, the rubber caused the aggregation and was greater than 5 to 20% of NBR content. NBR tangle and cross-polymerization is still NBR with PLA in the interface occurred. This affects the properties of higher elongation stress compounds associated with high NBR in the TPV.

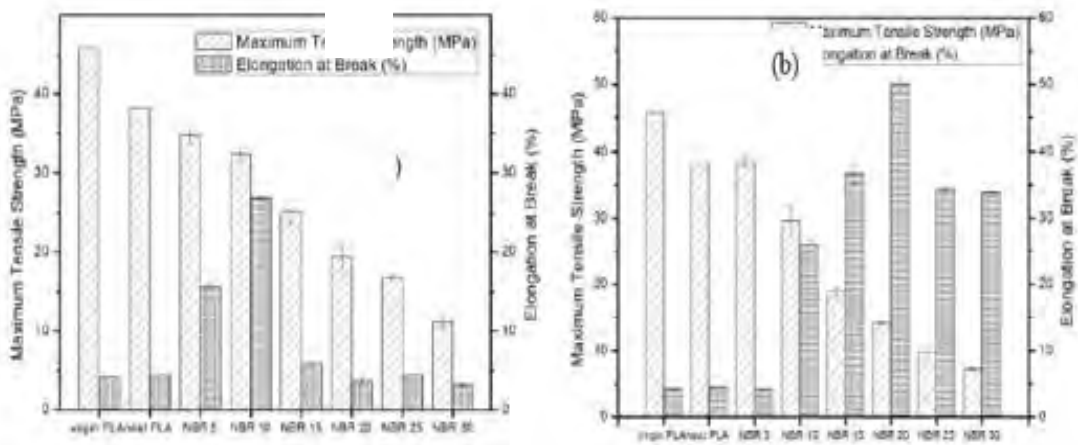


Figure 2.4: (a) The mechanical properties with Cloisite 30 loading. (b) The mechanical properties without Cloisite 30 loading (Talbamrung *et al.*, 2016)

Another study was conducted to study the effect of nanoclay in PLA polymer. As stated by Phua *et al.*, (2011) shows the resistance of PLA / PCL / clay compounds in Figure 2.5. Addition 1% clay Montmorillonite K10 and PGV Nanomer in mixtures, it increased tensile strength about 13.82% (52.29MPa) and 16.89% (55.14MPa), respectively, compared with pure PLA / PCL mixtures (45.74MPa). On the other hand, when more clay is added to the mixtures, the tensile strength gradually decreases. By addition of small amount of clay to a polymer matrix, Nanoclay is located in the intersection phase between the matrix and the dispersed phase. In addition, the integration of clay increases interstitial adhesion, thus achieving compatibility at the molecular level by the matrix and mud, which improves the transfer of stress within the transfer and then becomes the main reason for increasing the value of tensile strength. However, with the addition of additional clay content, Xc% in the PBS phase improved the tensile strength of PLA40 with the addition of NPCC at 1.0 phr slightly compared with the non-filled ones. PLA / PBS gave 60/40% by weight with NPCC of 1.0 PHR higher. For SB, with the addition of SB in the polymer blends may have an effect on the lower elongation, especially in the PLA40. The result was also due to higher nucleation crystallization in the PLA matrix producing continuous joint phases with higher fragility.

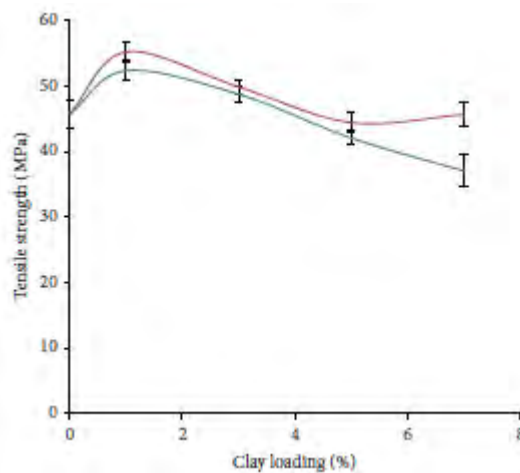


Figure 2.5: Tensile strength of PLA/PCL/Clay (Phua, et al., 2011)