POLYPROPYLENE REINFORCED WITH NANOCLAY CLOISITE® 30B: STUDY ON MECHANICAL PROPERTIES.

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BORANG PENGESAHAN STATUS TESIS♦

JUDUL : POLYPROPYLENE REINFORCED WITH NANOCLAY CLOISITE® 30B: STUDY ON THE MECHANICAL PROPERTIES.

SESI PENGAJIAN : 2010/2011

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POLYPROPYLENE REINFORCED WITH NANOCLAY CLOISITE® 30B: STUDY ON MECHANICAL PROPERTIES.

MUHAMMAD FIRDAUS BIN HARON

A thesis submitted in fulfillment
of the requirements for the award of the Degree of
Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
University of Malaysia Pahang

NOVEMBER 2010

"I hereby declare that I have read this thesis and in my/our opinion this thesis has fulfilled the qualities and requirements for the award of Degree of Bachelor of Chemical Engineering"

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Name of Supervisor	:	Dr. Kamal Yusoh
Date	:	2 December 2010

I declare that this thesis entitled *"Polypropylene Reinforce With Nanoclay Cloisite® 30B: Study On Mechanical Properties"* is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

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Date : 2 December 2010

Dedication to

My beloved family
My thoughtful teachers and lecturers
My dearest friends
My only one

Thank you…

ACKNOWLEDGEMENT

With the name of the Almighty, Alhamdulillah Praise Allah S.W.T. for His helps and guidance that I finally able to complete this Projek Sarjana Muda (PSM).

First of all, I would like to take this opportunity to convey my gratitude towards my parents, En. Haron Md. Noh and Pn. Kamisah Bandan, for their prayers, supports and love that can make my dreams to become a successful person become reality. I appreciate their sacrifice, patient and morale support throughout my research and my studies.

I would like to thank my supervisor Dr. Kamal Yusoh for his supervision and unflinching support almost over a year. I am deeply grateful for his inspiration and guidance in helping me to understand the concepts of environmental research. I thank him for his patience in reviewing my work that helped me to improve my research contributions. I appreciate his help in guiding me to overcome my research and other problems.

I grateful acknowledge the Faculty of Chemical and Natural Resources Engineering for the supports which enabled this work to be carried out. Thank all the technicians and staff in the Chemical and Natural Resources Engineering Laboratory for their help in completing my research.

I sincerely thanks to my dear friends and my dearest one for their helps and moral supports, and encouragement.

ABSTRACT

Polymer had been widely use nowadays in many field. Their properties make them useful in much industrial activity, such as coating, packaging labels and etc. The escalating of world technology requires improvement in the existing polymer. Hence, polymer composites had been invented to fulfil the need. Polymer nanocomposites are one of the latest technologies invented to enhance the targeted polymer in many site such as mechanical properties, thermal properties, electricity conductivity and etc. In this study, polypropylene (PP) had been chosen to be modifying by adding 30B organoclay to increase its mechanical properties. By using melt intercalation method, twin screw extruder has been used to prepare the sample. The sample differentiates each other by their amount of nanofiller. Starting with the pure PP, and three other sample (1wt%, 3wt% and 5wt% of nanofiller) were prepared by the same method. The introduction of 30B organoclay in PP had shown the increment of its properties in their mechanical properties. In testing its hardness, Rockwell-Brinell hardness test had been performed. The test uses the indentation value to show its hardness. The result showed that the hardness had been increase up to 32.9%. The tensile strength of produced composite also had been test to see the differences between the pure polymer and the nanocomposites. The tensile strength analysis applied stress to the sample until its maximum load. The results indicate that its strength had been improved up to 207% with addition of nanofiller. To ensure the improvement of the sample is because of the nanofiller, FTIR analysis had been run to show the existence of the nanofiller itself. The introduction of nanofiller in the polymer nanocomposites had proved a significant improvement in the mechanical properties.

ABSTRAK

Polimer telah digunakan secara meluas saat ini dalam pelbagai bidang. Sifat mereka membuatkan mereka berguna dalam pelbagai kegiatan industri, seperti penyadur, label bungkusan dan lain-lain. Peningkatan teknologi dunia memerlukan penambahbaikan dalam polimer yang sedia ada. Oleh kerana itu, komposit polimer telah dicipta untuk memenuhi keperluan tersebut. Polimer nanokomposit adalah salah satu teknologi terkini dicipta untuk meningkatkan polimer yang diberi tumpuan dalam pelbagai aspek merangkumi sifat mekanik, sifat terma, konduktiviti elektrik dan lain-lain. Dalam kajian ini, 'polypropylene' (PP) telah dipilih untuk menjadi subjek dengan menambah 'organoclay 30B' untuk meningkatkan sifat mekanikalnya. Dengan menggunakan kaedah pencairan interkalasi, skru ekstruder berkembar telah digunakan untuk menghasilkan sampel. Sampel membezakan antara satu sama lain dengan jumlah 'nanofiller' mereka. Dimulai dengan PP asli, dan tiga sampel lain (1wt%, 3wt% dan 5wt% 'nanofiller') dihasilkan dengan kaedah yang sama. Pengenalan '30B organoclay' dalam PP telah menunjukkan peningkatan dalam sifat mekanik mereka. Dalam ujian kekerasannya, 'Rockwell-Brinell' ujian kekerasan telah dilakukan. Ujian menggunakan nilai lekukan untuk menunjukkan kekerasan itu. Keputusan kajian menunjukkan bahawa kekerasan telah meningkat hingga 32,9%. Kekuatan tarik komposit yang dihasilkan juga telah diuji untuk melihat perbezaan antara polimer asli dan nanokomposit. Analisis kekuatan tarik diterapkan tekanan ke atas sampel sehingga beban maksimum. Keputusan kajian menunjukkan bahawa kekuatan sampel telah meningkat sehingga 207% dengan penambahan 'nanofiller'. Untuk memastikan peningkatan sampel adalah kerana nanofiller, analisis FTIR telah dijalankan untuk menunjukkan kewujudan nanofiller tersebut. Pengenalan nanofiller dalam polimer nanocomposites telah membuktikan peningkatan yang signifikan dalam sifat mekanik.

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LIST OF ABBREVIATION

PP	-	Polypropylene
PNC	-	Polymer Nanocomposite
FTIR	-	Fourier-transformed infrared spectrophotometry
kgf	-	Kilogram Force
N	-	Newton
kN	-	Kilonewton
mm	-	Millimeter
PVC	-	Polyvinyl Chloride
EPDM	-	Ethylene Propylene Rubber
PP	-	Polypropylene
LLDPE	-	Linear Low-Density Polyethylene
MDPE	-	Medium-Density Polyethylene
HDPE	-	High- Density Polyethylene
AAS	-	Atomic Absorption Spectroscopy
XRF	-	X-Ray Fluorescence Radioisotope
Ca	-	Calcium
EDTA	-	Ethylene-Diamine-Tetra-Acetic
FLAA	-	Flame Atomic Absorption Spectrometry
GFAA	-	Graphite Furnace Atomic Absorption
ICP-AES	-	Inductively Coupled Plasma Atomic Emission Spectrometry
ICP-MS	-	Inductively Coupled Plasma Atomic Emission Spectrometry
ppm	-	Part Per Million

Chapter 1

INTRODUCTION

1.1 Research Background

Polypropylene is one of the common polymers used nowadays in almost all industrial fields such as automotive technology, food industry and etc. The useful properties possessed by this polymer are the main reason for its popularity in the industrial field. Low molecular weight, low density, cheap, easily produce and its resistance to corrosion is a few reason for polypropylene to be widely use in those industrial field.

Polypropylene is one of the thermoplastic which produced by its linked chain of its monomer, propene. The structure can be classified into two types, which are isotactic and syndiotactic. These two arrangements in the polypropylene backbone tend to coil and form the helical shape is what brings the desire mechanical properties by the world technology. As for the strong bond between its monomer, polypropylene did not dissolve in water, hence bring the effect of water proof. The low density it possessed make the structure made out of it light yet durable. The corrosion resistance ability is very helpful in coating industry. In general, the chemical property it has is very handy and make it the priority in the industrial field. Due to the low manufacturing cost, it adds up every reason for industrial site to choose this polymer.

When the world extends its technology, the need for better polymer arises. Polypropylene is one of the polymers that are subjected to have upgrade and modification. By using composite technology, polypropylene received improvement in its chemical and mechanical properties. Addition of fiber in different of type, reinforce its properties.

As the world keeps moving forward in technology, polymer composite becomes conventional polymer that commonly use. New finding have been made and polymer nanocomposite have been given birth. This nanocomposite is the new breath in the world of polymer. Many intelligent researchers have gather and share their intelligence in producing nanocomposite with variety of nanofiller, which improve the polymer in different ways. Until today, nanocomposite still being study and new founding keep appearing.

Polymer nanocomposite had given a significant improvement compare to the conventional polymer. The improvement in microstructure improves the polymer nanocomposite properties down to the micro scale. The addition of nanofiller such as clay particle and carbon nano tube, improve the properties more than 50%. Despite of its significant improvement, its low density, low weight, and acceptable cost are the reasons why its been popular day by day. The polymer nanocomposite also has widen the area of it application. Now, it can be use in microstructure which applied in modern equipment.

In this study, polypropylene-clay nanocomposite is subjected to be the interest to focus on. There is much reason on why polypropylene had been chosen. Among them are because of it low cost and widely use in many industrial field. From previous study, the tensile strength of polypropylene had been boosted with the reinforcement of nanoclay. The nanocomposite arrangement of polymer matrix between the clay layer form interaction between them. The strong hydrogen bond between them make the polymer tensile properties increase (Thac KimN et al.,2006, Saminathan K. et al., 2008).

The arrangement of nanocomposite can be distinguish into three types. There are intercalated nanocomposites, flocculated nanocomposites, and exfoliated nanocomposites (Wypych and Satyanarayana, 2005; Ray and Okamoto, 2003). Each of them brings different effect on the properties improvement. The arrangement of the nanocomposite can be achieved by using different type of method in producing the particular polymer (Sharma et. al, 2004).

There are three main method use in producing the polymer nanocomposite which are intercalation of polymer or pre-polymer from solution, in situ intercalative polymerization method and melt intercalation method. Each of the method will bring different type of nanocomposite arrangement. Out of the three methods, the interested one that will be use in this study is the melt intercalation method. The method is the simplest, low cost, widely use in industrial field and nature friendly.

Previous study on the propylene-clay nanocomposite showed significant improvement in the mechanical properties. The improvement is up to 50% in the mechanical properties. This is a significant value and need to look further into consideration in the clay content in the nanocomposite.

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1.2 Objective

The aim of this research is to study the mechanical properties of Polypropylene-clay nanocomposite and comparing it to the pure Polypropylene.

1.3 Scope of Study

To achieve the objective of the study, a number of scopes have been drawn to be fulfilled:

1. To produce Polypropylene and Polypropylene organoclay nanocomposite using melt intercalation method using the twin screw extruder.
2. To characterize the properties and morphology of Polypropylene organoclay nanocomposite using Fourier Transform Infra Red (FTIR) and Scanning Electron Microscopy (SEM).
3. To study the mechanical properties which are tensile strength and hardness of the polypropylene organoclay nanocomposite.

1.4 Problem statement

The world won't stop stepping forward in advancing its technology. In developing the overall technology, polymer industry also need to be modernize to balance the growth. This is because polymer is one of the incredible founding mankind ever made and it's needed in almost every other technology. When there is a need, a solution for the particular need have to solve. The latest technology in polymer industries would be the polymer nancomposite where it is proven to have significant advantages compared to the pure polymer, ready to gear up the technology growth once again.

A lot research had been done on this topic, but not all of them able to produce the desire product. The composition of the composite had to be study to have a perfect blend. The morphology of the polymer also needs to be taken care as it affects the properties later. By changing intercalation and exfoliation of filler had already brought significant differences in the properties. The composition and the method in producing the polymer nanocomposite must be in the first priority in producing the desire product.

1.5 Rationale and significant

This study is designed to enhance the properties of Polypropylene which reinforced by the existence of the organoclay 30B. With the new polymer produced, much benefit can be obtained by the food industry, agriculture, construction and even automotive industry. With the outstanding performance of the new polymer, the other industry can receive its benefit and continue in stepping ahead.

In producing the PP/organoclay nanocomposite, organoclay will be consumed. Although the filler comes with high price, but it is still manageable because we only need a small portion of it. Considering the improvement it brings, we can say that producing this PP/organoclay is still economical.

CHAPTER 2

THE PHYSICAL AND CHEMICAL PROPERTIES OF POLYPROPYLENE AND POLYPROPYLENE-CLAY NANOCOMPOSITES

2.1 Introduction

Polymer is one of the materials in this world that would not stop in development. They keep improving in structure as well as their properties. From basic based polymer, they have been improved into polymer composite. In the world of polymer composite, the enhancement in structure goes to the macro-scale only. As their structure improves, the properties they possessed also improve to a certain level.

As technology keep advancing, polymer now required in micro-scale application. The problem with this need is polymer composite is not ready to be used in micro-scale technology. The macro-structure of polymer composite is the main reason for this failure. Basic polymer could be use, but it does not fulfil the requirement in their properties. Intelligent researcher had gather and come with a solution, which is to produce polymer nanocomposite. As for it title, nanocomposite use nanofiller to make make them polymer nanocomposite. With this solution, improvement in microstructure can be achieved. The improvement in their properties also down to the microturcture of the particular polymer.

2.2 Polypropylene (PP)

Polypropylene (PP) or well known as polypropene, is actually a type of thermoplastic polymer. Most commercial PP is isotactic and has an intermediate level of crystallinity between that of low-density polyethylene (LDPE) and high-density polyethylene (HDPE). It is widely use in many application included laboratory equipment, packaging, textile and etc.

Polypropylene is first polymerized by Giulio Natta and his coworkers in March 1954 in form of crystalline isotactic polymer **(**Peter J. T. Morris, 2005). This polymer is a linked chain of its methyl group, propene. The important concept in polymerized PP is the link between the structure of polypropylene and its properties is tacticity. The relative orientation of each methyl group (CH_3) relative to the methyl groups in neighboring monomer units has a strong effect on the polymer's ability to form crystals. There are two types of orientation of methyl group in the polymer, isotactic and syndiotactic. In isotactic orientation, all the methyl group neighboring aligns at the same side with respect of the polymer backbone of the polymer chain. Such isotactic macromolecules will coil into helical shape. These helices shape line up to one another to form crystal and give PP most of its desire properties. The syndiotactic orientation has the methyl group alternately at the polymer’s backbone. Same as the isotactic form, the chain will coil into helical shape and line up to be crystalline material.

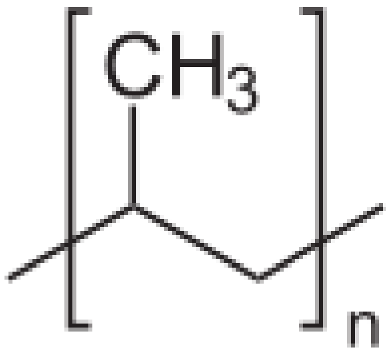

Figure 2.1: Methyl Group

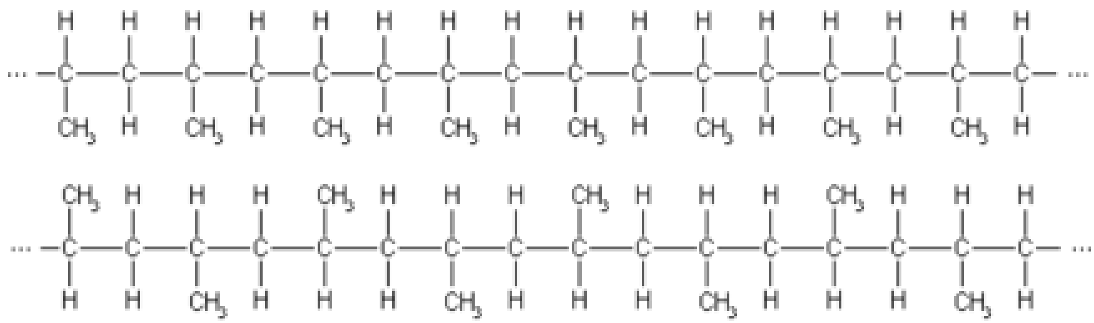

Figure 2.2: Isotactic and syndiotic orientation

2.3 Nanocomposite

In the world of composites, the particular material having two or more distinct phases such that a better combination of properties is achieved. Before go any further about nanocomposite, Let review what is composite really are. Composite materials are materials having two or more distinct phases such that a better combination of properties is achieved. The constituents must be chemically and physically dissimilar and separated by a distinct interface. The composite consists of a matrix, which is continuous and surrounds the filler, which provides the reinforcement such that the resulting composite property is a function of the properties of both the matrix and filler. The constituents will retain their identities; they do not dissolve or merge completely into one another although they act as one.

The components can be physically identified and show an interface between one another. So, for a nanocomposite material, it is still a composite but despite of the macroscale mentioned before, it comes in a size of below than 100 nm.

The mechanical, electrical, thermal, optical, electrochemical, catalytic properties of the nanocomposite will differ markedly from that of the component materials.

Size limits for these effects have been proposed:

Effect	Size limit (nm)
Catalytic activity	< 5
Hard magnetic material to soft material	< 20
Refractive index changes	< 50
Achieving superparamagnetism / mechanical strengthening / matrix dislocation movement	< 100

The following is the most common techniques for the synthesis of polymer nanocomposite:

1. *In situ polymerization*; where the fillers are initially dispersed in the monomer, followed by the polymerization of the monomer within the fillers gallery.
2. *Melt intercalation*; where the polymer molecules, intercalate the fillers layers during the melt processing.
3. *Intercalation in polymer solution*; where the fillers is dispersed in a polymer solution, following by the evaporation of the solvent.

2.4 Nanoclay (Cloisite® 30B)

Cloisite® and Nanofil® additives consist of organically modified nanometer scale which layered by magnesium aluminum silicate platelets. The silicate platelets that the additives are derived from are 1 nanometer thick and 70 – 150 nanometers across. The platelets which are originally normal clay are surface modified with an organic chemistry to allow them to complete dispersion into and provide miscibility with the thermoplastic systems for which they were targeted to improve. The additives have been proven to reinforce thermoplastics by enhancing flexural and tensile modulus. The additives have also been proven to be effective at improving gas barrier properties of thermoplastic systems. The surface char formation and flame retardance of thermoplastic systems have also been improved by incorporating the nanoparticles into the structure. There are some unique application areas where the additives have been proven to improve the physical properties of the plastic products. Cloisite® and Nanofil® additives have been shown to improve the properties of injection molded pieces for the automotive industry, of flexible and rigid packaging such as films, bottles, trays, and blister packs, and also of electronics plastics such as wire and cable coatings.

Figure 2.3: SEM graphic focusing on nanoclay particle.

2.5 Polymer Nanocomposite

2.5.1 Introduction

Polymer which had been used for generation beholds a great potential to be improve. Previously, intelligent researcher had found the way to strengthen them by turning them into composite. By adding fillers such as fiber manages to improve their mechanical or chemical properties or both. Nowadays, there is a new way found to improve polymer properties, by using nanofiller to make them nanocomposite.

Main feature of polymeric nanocomposite, which differ it with the conventional composite, lies in the reinforcement on the order of nanometer which greatly affected to the final macroscopic properties. Polymeric nanocomposites can be produce with different particle nanosize, nature and shape:

- Clay/Polymer Nanocomposites
- Metal/Polymer Nanocomposites
- Carbon Nanotubes Nanocomposites

There are three main material constituents in any composite: the matrix, the reinforcement (filler), and the so-called interfacial region. The interfacial region is responsible for communication between the matrix and filler and is conventionally ascribed properties different from the bulk matrix because of its proximity to the surface of the filler (Vaia and Wagner, 2004).

In mechanical view, nanocomposites differ themselves from conventional composite materials due to their high surface to volume ratio of the reinforcing phase. The reinforcing material can be made up of particles, sheets, or fibers. The area of the interface between the matrix and reinforcement phase(s) is typically an order of magnitude greater than for conventional composite materials. The matrix material properties are significantly affected in the vicinity of the reinforcement. Local chemistry, polymer chain mobility and polymer chain conformation is what basically affected the polymer nanocomposites properties. The degree of polymer chain ordering can all vary significantly and continuously from the interface with the reinforcement into the bulk of the matrix.

Polymer nanocomposite represents a radical alternative to conventional filled polymers or polymer blends – a staple of the modern plastics industry. In contrast to conventional composites, where the reinforcement is on the order of microns, PNCs are exemplified by discrete constituents on the order of a few nanometers. The value of PNC technology is not solely based on the mechanical enhancement of the neat resin nor the direct replacement of current filler or blend technology. Rather, its importance comes from providing value-added properties not present in the neat resin, without sacrificing the resin's inherent processibility and mechanical properties, or by adding excessive weight. PNCs contain substantially less filler (1-5 vol %) and thus enabling greater retention of the inherent processibility and toughness of the neat resin (Vaia and Wagner, 2004).

2.5.2 Polymer nanocomposite characterization

Polymer/layered nanocomposites in general, can be classified into three different types, namely intercalated nanocomposites, flocculated nanocomposites, and exfoliated nanocomposites (Wypych and Satyanarayana, 2005; Ray and Okamoto, 2003).

Each of the nanocomposite type has their own identity that distinguishes them from each other as such:

- Intercalated nanocomposites:

  Polymer chains are inserted into layered structures such as clays, which occurs in acrystallographically regular fashion, with a few nanometers repeat distance, irrespective of the ratio ofpolymer to layered structure.

- Flocculated nanocomposites:

  Flocculation of intercalated and stacked layers to some extent takes place due to the hydroxylated edge–edge interactions of the clay layers.

- Exfoliated nanocomposites

  Separation of the individual layers in the polymer matrix occurs in the third type by average distances that depend only on the loading of layered material such as clay.

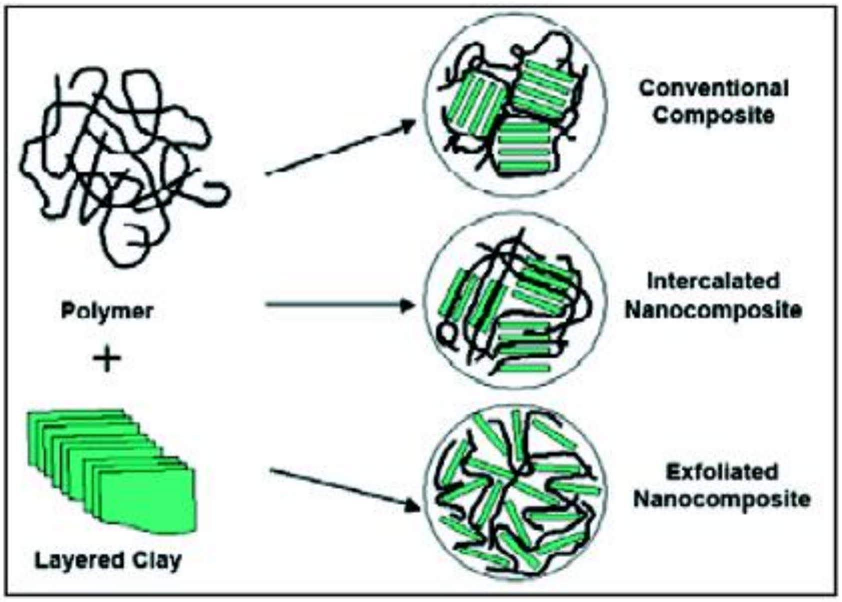

Figure 2.4: Polymer-layered nanocomposites (Denault and Labrecque, 2004).

There is a general agreement in the literature that exfoliated systems lead to better mechanical properties, particularly higher modulus, than intercalated nanocomposites (Jordan et. al, 2005). Figure shows an ideal picture how polymers surface active agents favor in a subsequent separation of the platelets from each other forming finally the matrix material with homogeneously dispersed platelets (molecular composites) (Fischer, 2003).

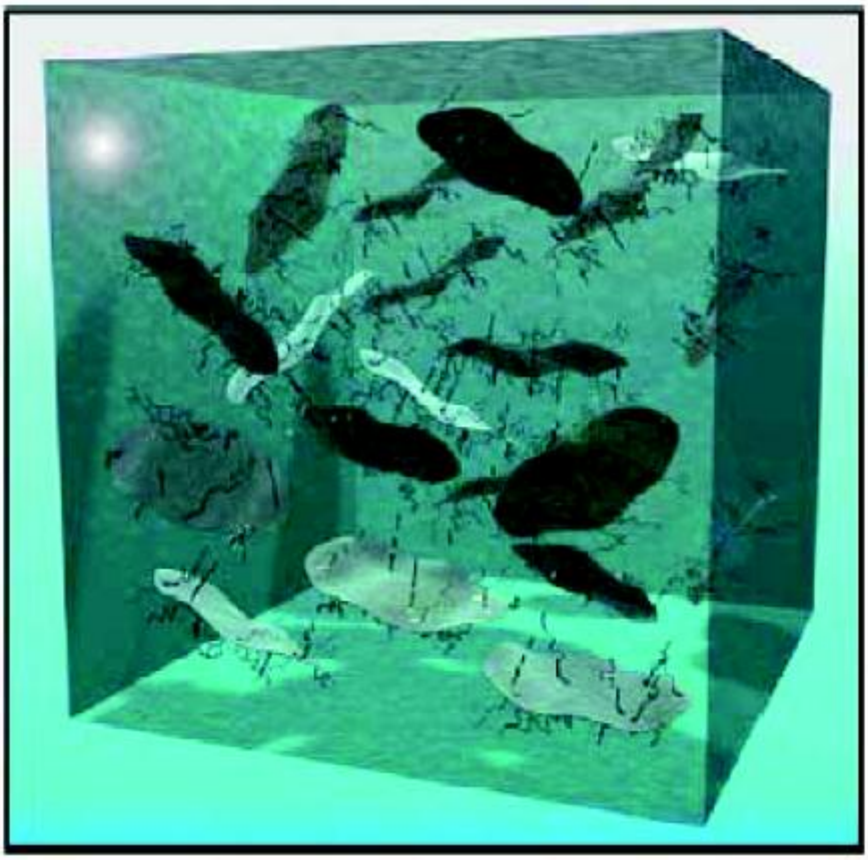

Figure 2.5: Schematic picture of a polymer-clay nanocomposite material with completely exfoliated (molecular dispersed) clay sheets within the polymer matrix material (Fischer, 2003).

2.5.3 Polymer nanocomposite improvement

Clay-reinforced nanocomposites have received considerable attention in recent years. A number of polymers, such as PC, PAN, PP, etc. were used as the matrix. Shelley et al. (2001) examined a polyamide-6 system with clay platelets. The platelets constituted 2% and 5% weight fraction and were 1 nm×10 nm×10 nm in size. Good interaction was found between the matrix and inclusions. With this setup, the elastic modulus was found to improve for both the 2% and 5 % samples. For the smaller weight fraction (2%), the increase in effective elastic modulus was 40% over the modulus of the pure polymer system. The larger weight fraction (5%) improved the effective modulus by a factor of two as compared to that of pure polymer. These results were for tensile specimens cut in both longitudinal and transverse directions. In addition, the yield stress also improved for both weight fractions, with the greatest improvement found for the higher concentration of inclusions. The other property studied was the strain-to-failure. The 2% system was found to give higher strain-to-failure than the pure system in the longitudinal direction but close to that in the pure system in the transverse direction. The higher filler content resulted in a decline in strain-to-failure from the pure system in both directions (William Gacitua E et al.,2005).

2.6 Polypropylene-clay (pp-clay) nanocomposite

Polypropylene-clay nanocomposite comes from basic polymer of polypropylene. The nanofiller, as for its name would be the nanoclay. Lots of study had been run on pp-clay nanocomposite on the physical properties, as well as the chemical properties. Previous study had proof that pp-clay nanocomposite showed significant improvement in both properties. As part of polymer nanocomposite family, pp-clay nanocomposite do have the same arrangement as other polymer. It is either intercalated nanocomposites, flocculated nanocomposites, or exfoliated nanocomposites. The arrangement of the nanocomposite can be achieve by the selected method used to synthesis the particular polymer. Figure showing the TEM micrograph of polypropylene-layered silicate. The arrangement of pp-clay nanocomposite have a similar arrangement to polypropylene-layered silicate.

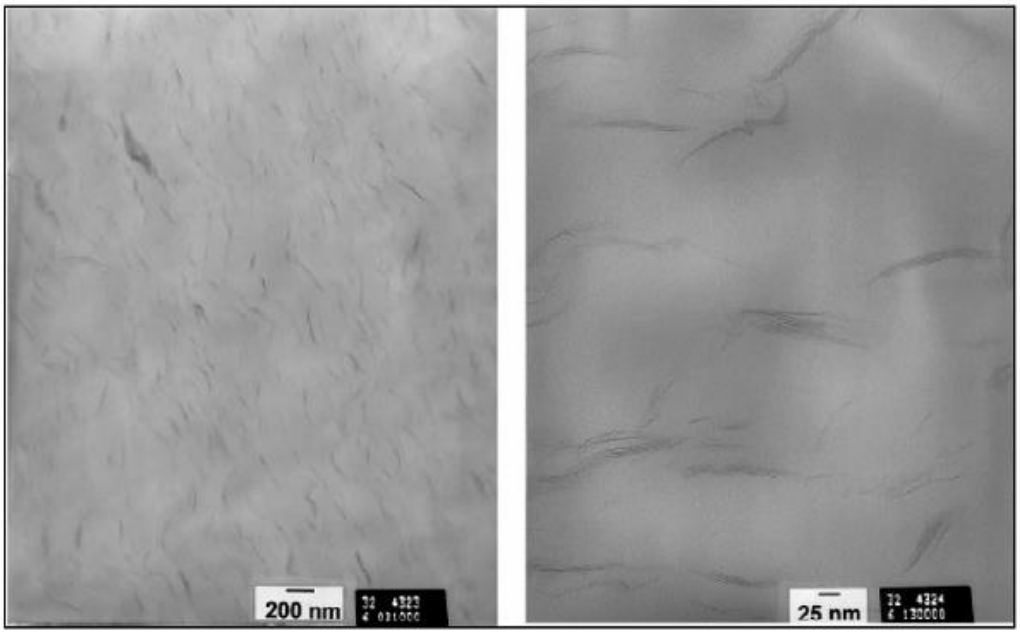

Figure 2.6: TEM micrographs of the PP nanocomposites (Ellis and D'Angelo, 2003).

Nowadays, pp-clay nanocomposite had been widely used in the industrial field. Because of it improve mechanical properties, along with the lower manufacturing cost; pp-clay nanocomposite is one of the favourable choice. Pp-clay nanocomposite even can be used in micro-scale technology as it fit the requirement in its physical properties.

It has been proposed that properties such as elastic modulus, tensile strength, and yield strength decrease in nanocomposites with polypropylene matrix due to the change in nucleation caused by the nanoparticles. The nanoparticles produce a much larger number of nucleating sites but, in turn, greatly reduce the size of these spherulites. In their experimental work, no spherulites were found in the nanocomposites by SEM indicating that either none were present or they were reduced to such a small size that SEM could not detect them. It was further proposed that there was another mechanism which was causing these same properties to increase. The increase occurred when there was a strong interaction between the polymer and filler. This interaction had larger impact in nanocomposites due to the large interfacial area between the filler particles and the matrix. Jordan et al. (2005) stated that for most systems, density is proportional to elastic modulus, so the region directly surrounding the inclusions will be a region of high modulus. If the particles are densely packed, then the boundary layer of polymer at the interface will comprise a large percentage of the matrix and can create a system where there is no space for a low modulus region to form (Chan et al. 2002).

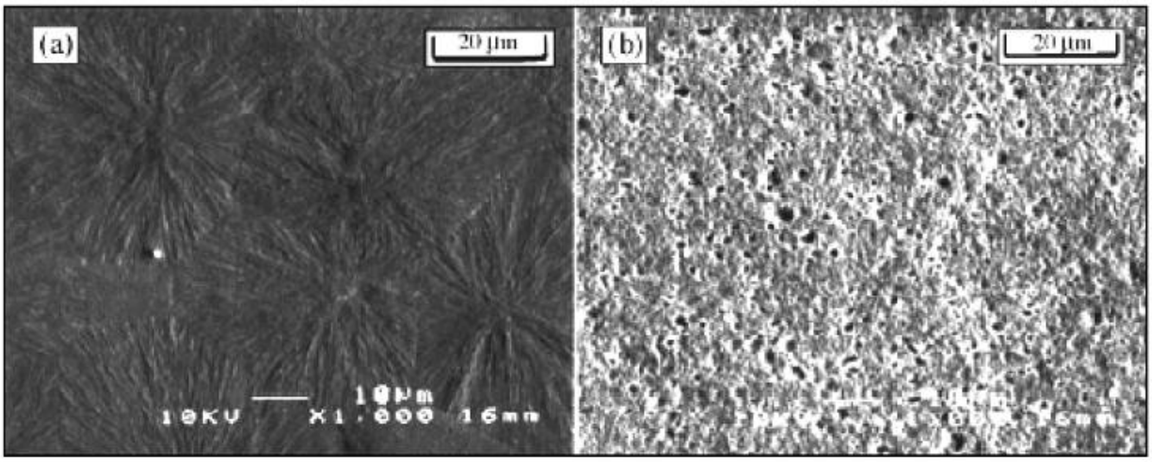

Figure 2.7: (a) Pure polypropylene and (b) polypropylene with 9.2% volume filler (Chan et al. 2002).

Another previous study shows the flexural properties of the as-moulded PP and the NC-2 nanocomposites with 3, 7, and 10 wt% nanoclay. Both the elastic modulus and the maximum stress increase substantially as the clay content increases. At 10 wt% nanoclay, the modulus and maximum stress increase by factors of about 2 and 1.5 respectively with respect to neat PP. However, it should be noted that the most significant improvement is obtained between 0 and 3 wt% nanoclay content. This can be explained by the fact that at lower nanoclay loadings, somewhat better intercalation/exfoliation can be expected. At higher loadings, where there is a higher proportion of unintercalated clay, the material behaves more like a microcomposite. The role of the clay as a reinforcing agent in the polypropylene matrix is clearly evident. Similar results have been reported in the recent literature (Manias E et al., 2001, Zhang Q, 2000). According to Kojima et al. (Kojima Y et al., 1993), a region where the polymer chains are restricted in mobility contributes to the improvement of some mechanical properties of a polymereclay hybrid, and the elastic modulus would be one of them. Results obtained by Manias et al. (Manias E et al., 2000) support these observations and confirm that such improvement is caused by the volume constrained by the platelets of the clay particles. Moreover, these authors have suggested that to optimize the increase of these properties, the degree of dispersion must be optimized to maximize the degree of matrix/filler interaction. The work presented by Hasegawa et al. (Hasegawa et al., 1993) on PP nanocomposites, inwhich addingmaleic anhydride (MA) to the matrix changed the degree of filler dispersion, supports these hypotheses. Increasing the clay content in the polymer matrix should therefore continuously constrain the polymer chains' mobility in the polymer matrix and some mechanical properties of the nanocomposite materials should be improved. The results confirm this tendency. Such an improvement in the elastic modulus and the maximum stress by the increase of the clay content is accompanied by a decrease of the degree of strain at the maximum stress. This decrease could be explained by the same reasoning discussed above and it is due to the decrease of the mobility of the polymer chains as the clay loading in the nanocomposites increases.

2.7 Tensile strength

Tensile properties are showing how the material reacts to the forces which being applied in tension. A tensile test is a test where a sample, which in this case, polypropylene/nanoclay is loaded with a controlled value of pressure while measuring the applied load and the elongation of the specimen over some distance. With tensile tests, modulus of elasticity, elastic limit, elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength and other tensile properties can be analyze and obtained.

The main result of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Since both the stress and the strain are obtained by dividing the load and elongation by constant values (specimen geometry information), the load-elongation curve will have the same shape as the engineering stress-strain curve. The stress-strain curve relates the applied stress to the resulting strain and each material has its own unique stress-strain curve. From the stress versus strain graph, the tensile modulus can be obtained by calculating the slope of the graph without the deformation value. The tensile modulus is a dimensionless value that indicates the ratio of stress over strain. Basically, the higher number of tensile modulus, the better the material is.

2.8 Hardness Test

Hardness test start with the revolutionary of indentation test which started by professor Paul Ludwik in his book *Die Kegelprobe* (crudely, "the cone trial") in 1908 as the differential depth hardness measurement (G.L. Kehl, 1949). The differential-depth method subtracted out the errors associated with the mechanical imperfections of the system, such as backlash and surface imperfections. To overcome the problem in previous founding, The Brinell hardness test, invented in Sweden, was developed earlier in 1900 but it was slow, not useful on fully hardened steel, and left too large an impression to be considered nondestructive. In overcoming those problem, Hugh M. Rockwell (1890–1957) and Stanley P. Rockwell (1886–1940) take the initiative to improvise and invented The Rockwell hardness tester which is still a differential-depth machine. The machine kept been improvise until 1993.

Until today, the Rockwell hardness had been developing into a common usage, to measure the indentation on the material. The Rockwell scale is a hardness scale based on the indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload (E.L. Tobolski & A. Fee, 2000). The indentation hardness correlates linearly with the tensile strength of the particular sample (E.J. Pavlina and C.J. Van Tyne, 2008). The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load, and then noting the depth of penetration, vis a vis, hardness value directly from a dial, in which a harder material gives a higher number. The main advantage of Rockwell hardness is its ability to display hardness values directly, thus obviating tedious calculations involved in other hardness measurement techniques. This test commonly use in engineering and metallurgy.

There are several alternative scales; the most commonly used being the "B" and "C" scales. Both express hardness as an arbitrary dimensionless number (Smith, William F.; Hashemi, Javad, 2001).

Scale	Abbreviation	Load	Indenter	Use
A	HRA	60 kgf	120° diamond cone†	Tungsten carbide
B	HRB	100 kgf	1⁄16-inch-diameter (1.6 mm) steel sphere	Aluminium, brass, and soft steels
C	HRC	150 kgf	120° diamond cone	Harder steels
D	HRD	100 kgf	120° diamond cone	
E	HRE	100 kgf	1⁄8-inch-diameter (3.2 mm) steel sphere	
F	HRF	60 kgf	1⁄16-inch-diameter (1.6 mm) steel sphere	
G	HRG	150 kgf	1⁄16-inch-diameter (1.6 mm) steel sphere	
†Also called a *brale indenter*				

Table 2.1: Various Rockwell Scale

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this study, polypropylene was used as the targeted polymer that decides to reinforce with nanoclay. The polypropylene use in this study is the common commercial pp which can be obtained in palette form. As for the filler, nanoclay cloisite 30B had been chosen as the interested additives. The particular nanoclay lies in the industrial grade where can be purchase from Southern Clay co. The nanoclay obtained in solid and powder form.

3.2 Material

Pure polypropylene palette, nanoclay cloisite 30B supplied by Southern Clay Co. obtained with the cooperation of laboratory of Faculty of Chemical Engineering and Natural Resources of Universiti Malaysia Pahang.

3.3 Preparation of PP/nanoclay nanocomposite

3.3.1 PP/nanoclay nanocomposites synthesis.

3.3.1.1 Introduction

There are several ways to produce polymer nanocomposite. The most popular methods would be Intercalation of polymer or pre-polymer from solution, In situ intercalative polymerization method and Melt intercalation method. As for those three methods, each of the method brings certain significant in operation and final product based on the properties of the polymer itself. The method use also will determine the nanocomposite arrangement inside the polymer matrix. Therefore, to select the suitable method, the particular polymer properties and the desired product must be taken into consideration. As for the method listed before, each of them has their own identity in synthesizing the polymer nanocomposite, as such:

Intercalation of polymer or pre-polymer from solution:

This is based on a solvent system in which the polymer or pre-polymer is soluble and the silicate layers are swellable. The layered silicate is first swollen in a solvent, such as water, chloroform, or toluene. When the polymer and layered silicate solutions are mixed, the polymer chains intercalate and displace the solvent within the interlayer of the silicate. Upon solvent removal, the intercalated structure remains, result-ing in PLS nanocomposite.

In situ intercalative polymerization method:

In this method, the layered silicate is swollen within the liquid monomer or a monomer solution so the polymer formation can occur between the intercalated sheets. Polymerization can be initiated either by heat or radiation, by the diffusion of a suitable initiator, or by an organic initiator or catalyst fixed through cation exchange inside the interlayer before the swelling step.

Melt intercalation method:

This method involves annealing, statically or under shear, a mixture of the polymer and OMLS above the softening point of the polymer. This method has great advantages over either in situ intercalative polymerization or polymer solution intercalation. First, this method is environmentally benign due to the absence of organic solvents. Second, it is compatible with current industrial process, such as extrusion and injection molding. The melt intercalation method allows the use of polymers which were previously not suitable for in situ polymerization or solution intercalation.

3.3.1.2 Intercalation of polymer or pre-polymer from solution

Usually, this method works on Water-soluble polymers, such as PEO (Aranda P et al., 1992), PVA (Greenland DJ., 1963), PVP (Francis CW., 1973),and PEVA (Zhao X et al.,1989), have been intercalated into the clay galleries using this method. Examples from non-aqueous solvents are nanocomposites of PCL/clay (Jimenez G et al., 1997) and PLA/clay (Sinha Ray S, Biswas M., 1999) in chloroform as a co-solvent, and high-density poly- ethylene (HDPE) with xylene and benzonitrile (Jeon HG, 1998). Nematic liquid crystal PLS nanocomposites have also been prepared using this method in various organic solvents, such as toluene and DMF (Kawasumi M et al., 1998).

For the overall process, in which polymer is exchanged with the previously intercalated solvent in the gallery, a negative variation in the Gibbs free energy is required. The driving force for the polymer intercalation into layered silicate from solution is the entropy gained by desorption of solvent molecules, which compensates for the decreased entropy of the confined, intercalated chains (Vaia RA, Giannelis EP, 1997). Using this method, intercalation only occurs for certain polymer/solvent pairs. This method is good for the intercalation of polymers with little or no polarity into layered structures, and facilitates production of thin films with polymer-oriented clay intercalated layers. However, from commercial point of view, this method involves the copious use of organic solvents, which is usually environmentally unfriendly and economically prohibitive (Suprakas Sinha Ray, Masami Okamoto, 2003).

3.3.1.3 In situ intercalative polymerization method

This method generally requires the introduction of the nanofiller in the first step in growing the polymer chain. The interested filler was inserting while forming the monomer chain to be the desire polymer. Although inter-lamellar polymerization techniques using appropriately modified layered silicate or synthetic layered silicates (Blumstein A, 1965, Theng BKG, 1979) have long been known, the field of PLS nanocomposites gained momentum recently due to the report of a N6/MMT nanocomposite from the Toyota research group (Okada A, 1990), where very small amounts of layered silicate loadings resulted in pronounced improvements in thermal and mechanical properties. Recently, Wang and Pinnavaia (Wang Z, Pinnavaia TJ, 1998) reported the preparation of polyurethane–MMT nanocomposites using a direct in situ intercalative polymerization technique (Wang Z, Pinnavaia TJ, 1998).WAXD analyses of these nanocomposites established the formation of intercalated structure. More recently, Yao et al. (Yao KJ, 2002) reported the preparation of a novel kind of PU/MMT nanocomposite using a mixture of modified 4,40 -di-phenymethylate diisocyanate (M- MDI) modified polyether polyol (MPP) and Naþ- MMT. In a typical synthetic route, a known amount of Naþ-MMT was first mixed with 100 ml of MPP and then stirred at 50 8C for 72 h. Then, the mixture of MPP and Naþ-MMT was blended with a known amount of M-MDI and stirred for 30 s at 20 8C, and finally cured at 78 8C for 168 h. As for the outcome, this method manages to intercalate the polymer matrix between the clay layers, even though in some cases, the arrangement tends to move into exfoliatiated nanocomposites arrangement (Suprakas Sinha Ray, Masami Okamoto, 2003).

3.3.1.4 Melt intercalation

Recently, the melt intercalation technique has become the standard for the preparation of PLS nanocomposites. During polymer intercalation from solution, a relatively large number of solvent molecules have to be desorbed from the host to accommodate the incoming polymer chains. The desorbed solvent molecules gain one translational degree of freedom, and the resulting entropic gain compensates for the decrease in conformational entropy of the confined polymer chains. Therefore, there are many advantages to direct melt intercalation over solution intercalation. For example, direct melt intercalation is highly specific for the polymer, leading to new hybrids that were previously inaccessible. In addition, the absence of a solvent makes direct melt intercalation an environmentally sound and an economically favorable method for industries from a waste perspective.

This process involves annealing a mixture of the polymer and OMLS above the softening point of the polymer, statically or under shear. While annealing, the polymer chains diffuse from the bulk polymer melt into the galleries between the silicate layers. A range of nanocomposites with structures from intercalated to exfoliate can be obtained, depending on the degree of penetration of the polymer chains into the silicate galleries. So far, experimental results indicate that the outcome of polymer intercalation depends critically on silicate functionalization and constituent interactions. The present authors observe that (a) an optimal interlayer structure on the OMLS, with respect to the number per unit area and size of surfactant chains, is most favorable for nanocomposite formation, and (b) polymer intercalation depends on the existence of polar interactions between the OMLS and the polymer matrix (Suprakas Sinha Ray, Masami Okamoto, 2003).

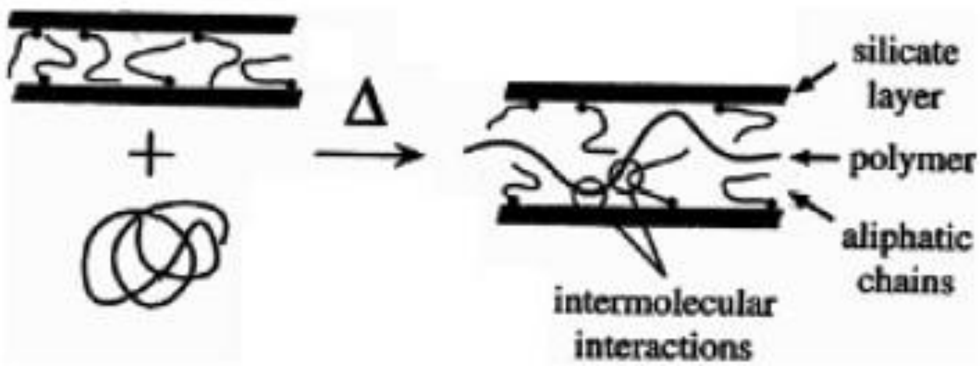

Figure 3.1: Schematic depicting the intercalation process between a polymer melt and an OMLS

Vaia et al. (Vaia et al., 1997, Vaia et al., 1997) applied a mean-field statistical lattice model, reporting that calculations based on the mean field theory agree well with experimental results. Details regarding this model and explanation are presented in Vaia et al. study. Although there is entropy loss associated with the confinement of a polymer melt with nanocomposite formation, this process is allowed because there is an entropy gain associated with the layer separation, resulting in a net entropy change near to zero. Thus, from the theoretical model, the outcome of nanocomposite formation via polymer melt intercalation depends primarily on energetic factors, which may be determined from the surface energies of the polymer and OMLS. Based on the Vaia et al. (Vaia et al., 1997) study and the construction of product maps, general guidelines may be established for selecting potentially compatible polymer/OMLS systems. Initially, the interlayer structure of the OMLS should be optimized in order to maximize the configurational freedom of the functionalizing chains upon layer separation, and to maximize potential interaction sites at the interlayer surface. For these systems, the optimal structures exhibit a slightly more extensive chain arrangement than with a pseudobilayer. Polymers containing polar groups capable of associative interactions, such as Lewis-acid/base interactions or hydrogen bonding, lead to intercalation. The greater the polarizability or hydrophilicity of the polymer, the shorter the functional groups in the OMLS should be in order to minimize unfavorable interactions between the aliphatic chains and the polymer.

3.3.1.6 Method selection

The interested method to be used in this study is the third method which is the melt intercalation method. By using this method, the targeted polymer, polypropylene-clay nanocomposite can be well produce. The operation in producing the polymer nanocomposite is rather easier compared to the other method, but still giving the promising outcome. Beside this method have it own popularity among the polymer industrial field, this method is suitable as it is nature friendly.

3.3.1.7 Melt mixing operation

To begin the production process, the moisture among the polypropylene palettes needs to eliminate to prevent H2O disturbance in the pp-clay nanocomposite. To do so, the polypropylene palettes were heated in an oven up to 70^{o}C for two hours. After moisture elimination, the palette was kept in a tight dry glass bottle to prevent any moisture to reappear. After that, the polypropylene has been weight using the analytical scale to the value needed to add with nanoclay corresponding to the desire nanoclay content. Both of polypropylene and the nanoclay had been mixed together in a plastic container and the container been shake to have a well mix material. The nanoclay was ensured to well distribute among the polypropylene palette.

Clay content	Polypropylene (g)	Nanoclay (g)
0%	200	0
1%	198	2
3%	194	6
5%	190	10

Table 3.1: The composition for each sample.

Before the sample being mold with screw extruder, the machine first needs to be flushed away using pure PP to ensure there are no foreign materials inside the barrel. After the cleaning process, the samples were mold with a few constant parameters, which are the temperature (160^{o}C) and the speed at 80 rpm. By this method, the polypropelene and the nanoclay were believed to mix well among each other. During the extrude process, polypropylene melted hence blend in the nanoclay finely between its matrix. The twin screw spinning mechanism, giving the mix additional kinetic energy, agitated the movement of the nanoclay particle within the melted polypropylene. At the end of the extruder, the product will in strip shape, cooled with water then being palletized by cutter.

After the palletized PP/nanoclay had been formed, each sample needs to be molded into dog-bone shape so that they can undergo the mechanical test. The palletized samples were molded using the hot press equipment. The temperature and pressure for this process would be 160^{o}C and 8 bar. To minimize the bubble formation in the sample, the palletized sample had to be dried inside an oven for 2 hours at 70^{o}C. During the hot press process, the samples were let inside the equipment for 15-20 minutes. This is to let the palette to melt entirely, and not too long to have they burn. After the time range, the metal plate holding the pp-clay nanocomposite in dog bone shape was drawn out and let cooled. This is an important procedure to prevent any damage to the sample. After the plate had been entirely cooled, the pp-clay nanocomposite was retrieve carefully from the mold. This is to prevent any damage or cracking to appear on the pp-clay nanocomposite in the process. For this entire process, 6 samples were made for each composition.

3.4 PP/nanoclay composite mechanical test

3.4.1 Tensile test

Tensile test is crucial in analyzing the strength of the particular material. The test takes the maximum load reading until the material start to failure, in this case deform or break. The maximum load then is divided with the material area to have the stress value. The stress value indicate how the material withstand the load, before it failure. There are several method commonly used to run the tensile test. One of them is the universal testing machine which is common equipment in polymer technology. The testing can be set to show various parameters (Jordan et. al, 2005).

Each composition tensile test was run using the universal testing machine. The sample was place into the machine, with the main load of 50kN. The outcome parameter had been set to receive the desire result, such as:

- **Tensile modulus (Pa)**
- **Load at yield (kN)**
- **Tensile stress at yield (Pa)**
- **Tensile stress at maximum load (Pa)**
- **Tensile stress at break (Pa)**

The test continues until the sample failure, in this case, break. Each composition was test three times. The results obtained were calculated to have the average reading. Graph were plotted to see the trend of tensile strength and the tensile modulus corresponding to the clay content.

3.4.2 Rockwell Hardness test

In this test series, the indentation value when a load applied on the material surface is measured. The indentation value indicates the hardness of the material itself. The testing can be run by various equipment such as Rockwell Brinell Hardness tester, Vickers hardness tester and etc. Each of the available equipment did a different scale in their testing, regarding the desire range of result. In this study, as for equipment availability and range desire, Rockwell hardness tester had been selected to use.

For this test, the most smooth and flat sample had to be selected from the product for each composition to have a very accurate result. From each composition, three samples was selected and tested with Rockwell Hardness testing machine. The machine had been set to HR15-T scale to test the polymer. With this scale, the minor load would be 3kgf while the major load would be 15kgf. The indenter would be ball shape with the size of 1/16 inch. Each of the result will sum up to find the average reading.

3.5 Precaution

Along the production of pp-clay nanocomposites and the testing, there several precautions step that needs to be considered to prevent any casualties to self, sample and the equipment.

- **Wear mask all the time during handling with nanoclay particle.**
- **Do not touch the outer layer of the barrel at the extruder machine during the extrude process.**
- **Wear the appropriate self protective equipment during handling the machine.**
- **Do not touch the newly extrude pp-clay nanocomposite barehanded before it is cooled with water.**
- **Close the window all the time except during handling the plate when using the hot press.**
- **Wear glove and do not touch the press casually.**

CHAPTER 4

RESULT AND DISCUSSION

4.1 FTIR

This result is focussing on characterizing the pp/clay nanocomposite. The use of FTIR is to detect functional groups and understand the structure of the nanocomposites. The result will show the existence of nanoclay within the polymer matrix by giving the significant peak on the graph. The peak reading actually indicates that there are hydrogen bond formed between the nanoclay and pp matrix which is believed increasing the polymer strength (S. Chakraborty et al.,2007).

Previous study on polymer-clay nanocomposites based on polyamide by Bok Nam Jang and Charles A. Wilkie (2005), showed that the existence of hydrogen bond between the clay and the polymer matrix with the wavenumber peak between 1620 to 1270 cm^{-1}. The bonding between polymer matrix and the clay indicate that the clay able to interact between the polymer matrix. The result from his study showing a similar trend among all the polymer-clay nanocomposites even they have different content of clay within them. It suggested that the intensity of the hydrogen bonding of different content of clay will give a similar peak and slope even there are slight difference in the peak value. The differences were believed came from the noise and the different concentration of the functional group (Bok Nam Jang, Charles A. Wilkie,2005). Figure. showing the peak value of polyamide-clay nanocomposite.

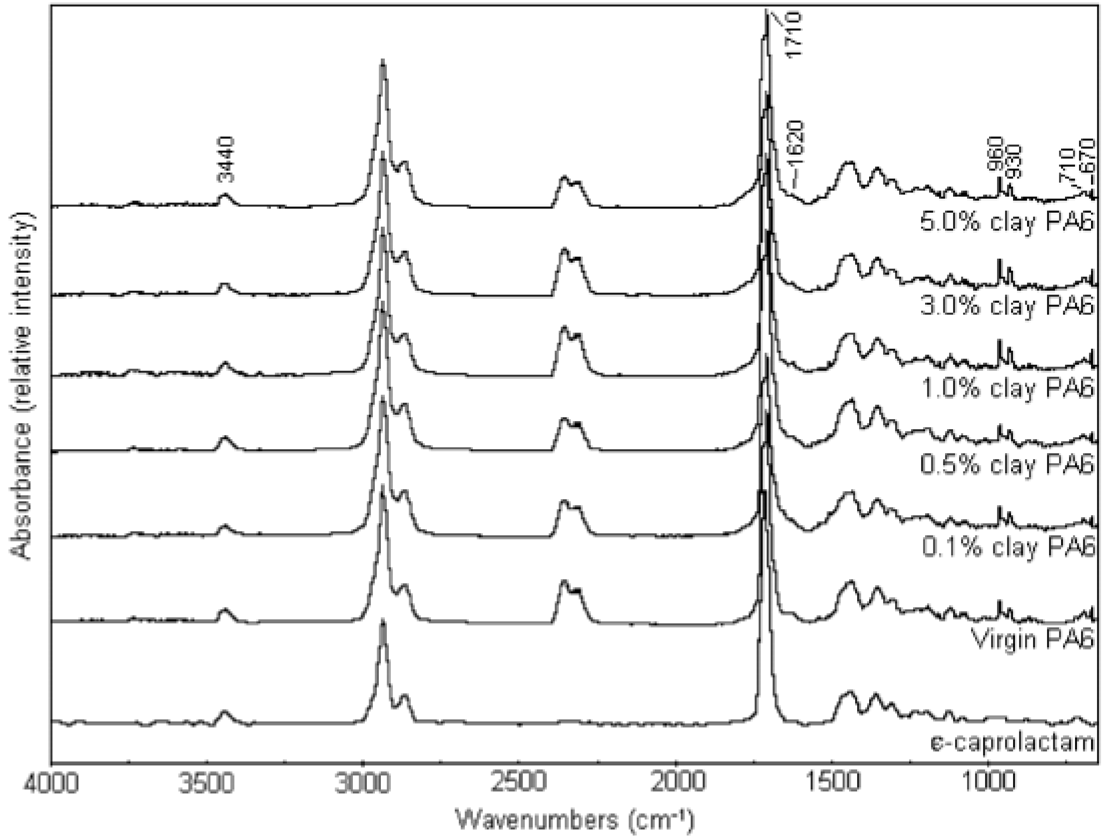

Figure 4.1 : In situ vapor phase FTIR spectra of polyamide 6 and polyamide 6–clay nanocomposites at 25% mass loss (Bok Nam Jang, Charles A. Wilkie,2005)

Another study involving the same material to this study, pp-clay nanocomposites on the water absorption investigation by Aouatef Ladhari et al..In their result, the FTIR reading showed that the existence of clay in the polymer at peak of 1150 - 1000 cm^{-1}. With different content of clay in the polymer, each of the sample gives the identical peak, showing the hydrogen bonding between the polymer matrix and the clay itself. There are other significant peak in the result and they justified the other peak correspond the compound inside the polymer. The peak at 1743 cm^{-1}probably arises in a similar manner came from a carbonyl- containing additive, possibly an antioxidant. The clear presence of the out-of-plane Si-O stretching vibration at 1073 cm^{-1} is evidence of a good degree of intercalation (Aouatef Ladhari et al., 2009). Figure. showing the peak for the hydrogen bonding of the clay, as well as other significant peak in the polymer.

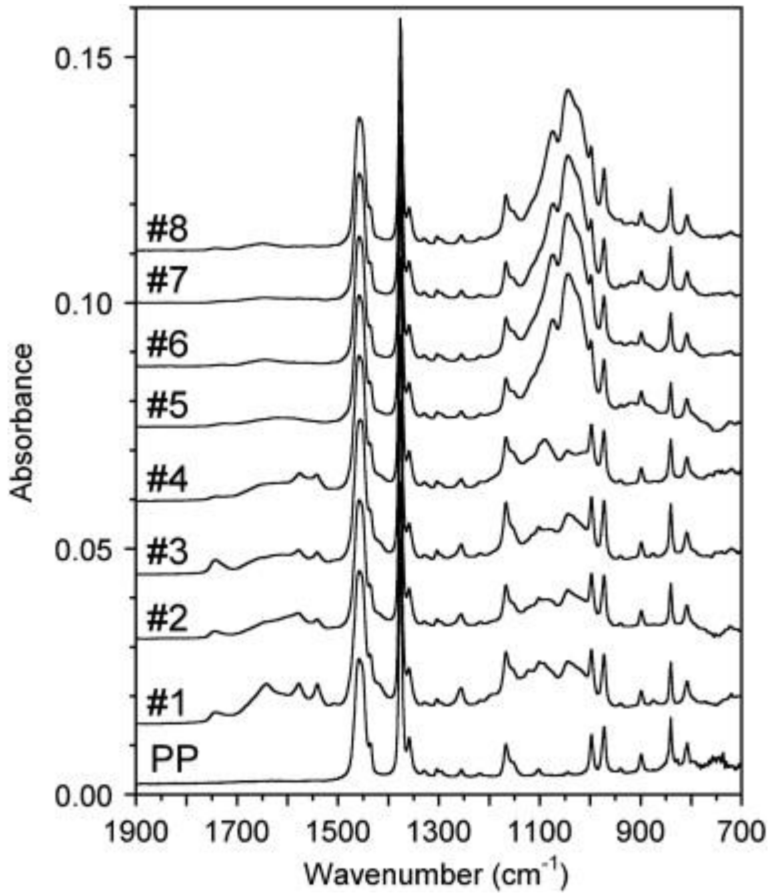

Figure 4.2: Infrared spectra measured in attenuated total reflection on the surfaces of the selected samples of nanocomposite NC-2 described in Table 4.1.

Specimen #	Nanoclay (wt %)	Water absorbed (wt %)	Immersion medium[a]	Immersion time (h)
1	3	0.1	DW	5
2	3	0.1	SW	24
3	3	0.2	DW	15
4	3	0.2	SW	144
5	10	0.3	DW	7
6	10	0.3	SW	12
7	10	0.6	DW	30
8	10	0.6	SW	55

[a] DW = distilled water; SW = sea water.

Table 4.1: Details of nanocomposite NC-2 specimens selected for IR and XRD analysis after immersion at 85 oC.

The outcome of this research gives the similar trend to the previous study. The curve like shape before the peak at 1442 – 1456 cm^{-1} showed the formation of hydrogen bond between the clay and the pp matrix. The shape before the peak did not appear in the control, which is the pure pp showed that there is no interaction between clay and the polymer matrix as there was no clay in the sample to begin with. The result showed a similarity from the study, hence proving the introduction of cloisite 30B did have interaction with the polymer matrix.

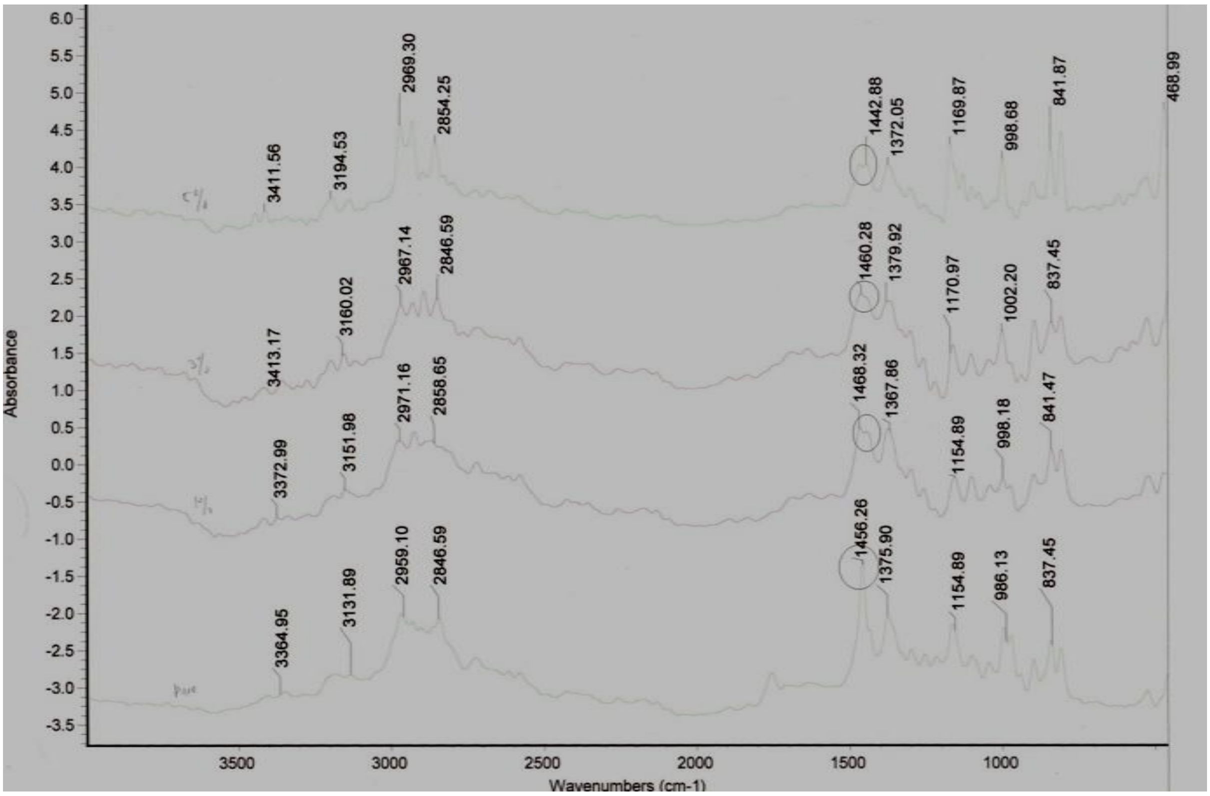

Figure 4.3: FTIR results for pure PP and PP/nanoclay composites

4.2 Tensile test

4.2.1 Tensile strength.

Tensile strength indicate the maximum stress that pp-clay nanocomposite would take before it reach failure, such as break or deform. In the nanocomposites world, the filler, which is the clay act as additives to strengthen the polymer so that more stress are needed before the polymer reach failure. The clay arranged themselves between the polymer matrix and interact with each other to form hydrogen bond with the polymer matrix (Jordan et. al, 2005). The bond created will enhance the interaction among the polymer matrix; hence avoid the polymer to break easily. The arrangement of the polymer also plays a big role where the arrangement can prevent the polymer matrix to slide from each other, which bring the improvement in polymer strength.

There are several arrangement of filler between the polymer matrix and each of them bring effects to the polymer. They are intercalated nanocomposites, flocculated nanocomposites and exfoliated nanocomposites. The intercalated nanocomposites accur when the polymer chains are inserted into layered structures such as clays, which occurs in a crystallographically regular fashion, with a few nanometers repeat distance, irrespective of the ratio of polymer to layered structure. The flocculate nanocomposites tend to happen when flocculation of intercalated and stacked layers to some extent takes place due to the hydroxylated edge–edge interactions of the clay layers. The last arrangement, exfoliate nanocomposites appear when separation of the individual layers in the polymer matrix occurs average distances that depend only on the loading of layered material such as clay. All of the arrangement of nanocomposites brings improvement with the particular polymer with different magnitude value.

The interested arrangement that have been studied in this research is the intercalated nanocomposite. PP-clay nanocomposites that have been produce should be in this arrangement as the method use which is the melt intercalation should produce a polymer with the targeted arrangement. As there are interaction that form bonding between clay and the matrix, the tensile strength could be increase.

Previous study on polypropylene-clay nanocomposites by H. Baniasadi et al. showing improvement in the mechanical properties by means the tensile strength. In their study, the method used is in-situ polymerization which bring the exfoliate nanocomposites arrangement. In figure., the tensile strength of the pp-clay nanocomposites ascending significantly corresponding to the increasing clay content. The outcome came in desirable manner as the clay disperses well in the polymer matrix. The arrangement and the dispersion of the clay form interaction with the polymer matrix, hence the bond between them become stronger. Along in their study, they also consider in producing the sample with another method which is melt intercalation method. By this method, the result showed similar trend where the increasing in clay content brings higher tensile strength (H. Baniasadi et al.,2009).

Samples	Yield strength (MPa)	Tensile modulus (MPa)	Elongation at yield (%)	Elongation at break (%)	Impact strength (MPa)
PP	34.5 ± 2.2	1500 ± 20	10 ± 0.9	350 ± 8.5	4.5 ± 0.9
In situ-PPCN[a]-1%	37 ± 2.7	1650 ± 18	9.1 ± 1	240 ± 8	4.1 ± 0.6
In situ-PPCN-3%	41 ± 2.5	1785 ± 21	7.9 ± 0.8	190 ± 8	3.5 ± 1.2
In situ-PPCN-5%	45.5 ± 3	1920 ± 23	7.2 ± 1.5	179 ± 6.8	3.3 ± 1.1
Melt-blended PPCN-3%	38.5 ± 2.2	1700 ± 19	8.5 ± 0.8	210 ± 9	3.8 ± 0.9

[a] PP/clay nanocomposite.

Table 4.4 : Mechanical properties of PP and PP/clay nanocomposites (H. Baniasadi et al.,2009).

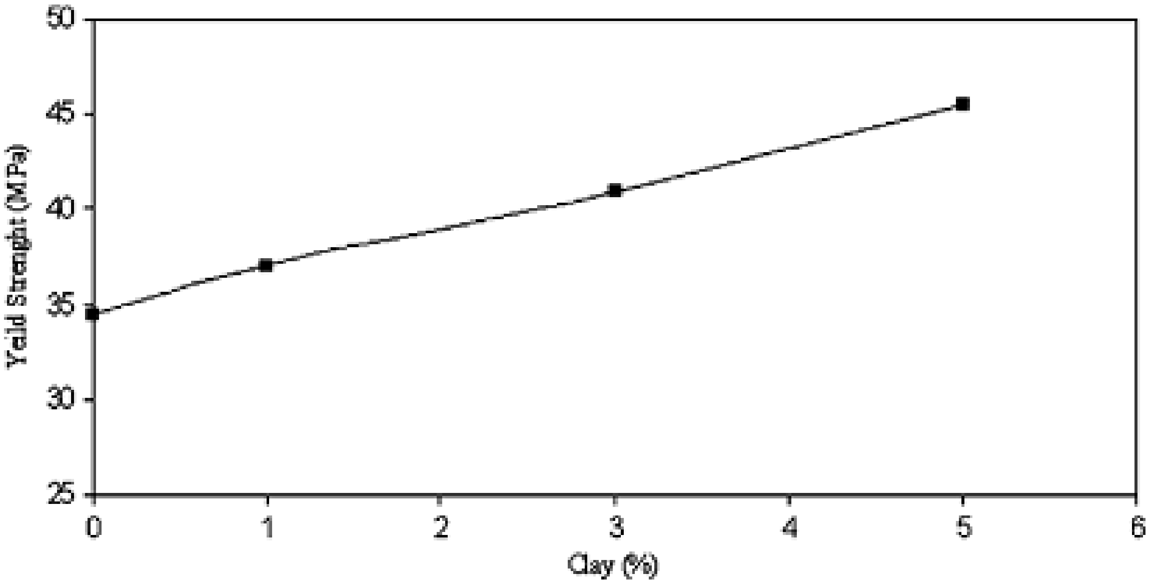

Figure 4.5 : Yield strength as a function of clay loading (H. Baniasadi et al.,2009).

Another research involving pp-clay nanocomposites prepared by grafting-melt intercalation had been run by Xiao Hui Liu and Qiuju Wu. The expected arrangement for their nanocomposite would be intercalate nanocomposite. Similar to the study before, their result showed the same trend of improvement in tensile strength. There is new information of the improvement of their sample regarding the tensile strength when the clay content approaching beyond 5wt%. From 1-5 wt% of clay content, the tensile strength increase dramatically with a significant value. When the clay content approaching beyond 5wt%, the tensile strength still increase, but the differences compare to 5wt% is not that much. This phenomenon showed that the clay content in polypropylene is approaching its optimum composition. A further increment in clay content would bring to constant value of tensile strength. Other method might solve the problem such as in-situ polymerization (Xiao Hui Liu, Qiuju Wu, 2001).

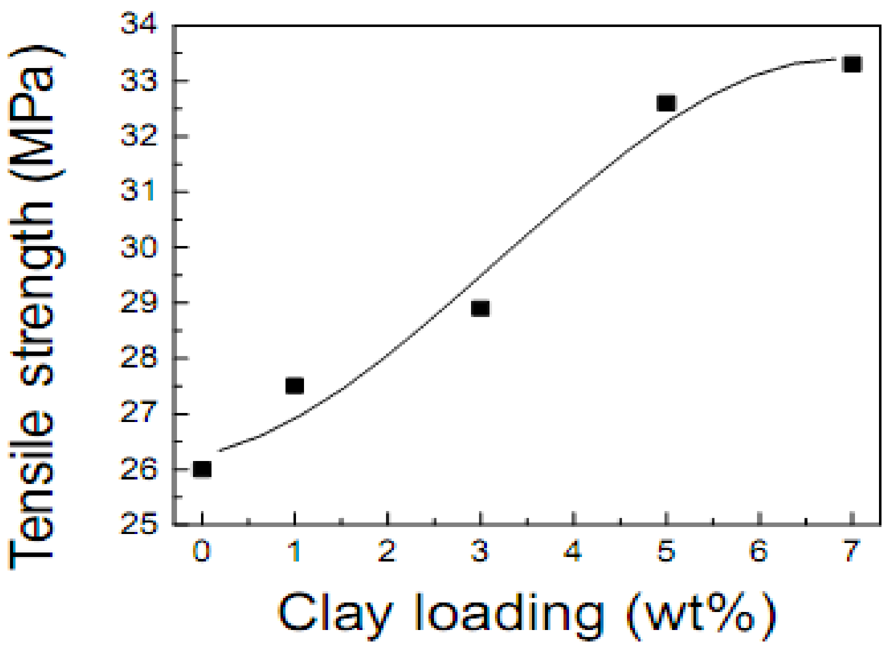

Figure 4.6: Effect on clay content over tensile loading of PPCN (Xiao Hui Liu, Qiuju Wu, 2001).

In this study, the result showed a very identical outcome of tensile strength where as the clay content increasing, the tensile strength also increase. This trend showed that the intercalate nanocomposite manage to achieve. The intercalation of polymer matrix between the clay layers had formed interaction, hence increasing the bond between the components. The hydrogen bond formed also play role in strengthen the polymer. However, at the maximum clay content in this study, which is the 5wt%, the tensile strength dropped. This phenomenon is believed came from the agglomeration of the clay. Agglomeration tends to form when small particles floc together as there are too many of them, hence they tend to form a strong van der walls bonding. The floc form unable to disperse well inside the polymer matrix, hence form crack to the polymer. Therefore, the tensile strength obtained decreased.

Sample	Tensile strength (N/cm^2)
Pure	667.587
1wt%	741.0785
3wt%	1503.1415
5wt%	963.5165

Table 4.3: Result for tensile strength corresponding to the clay content.

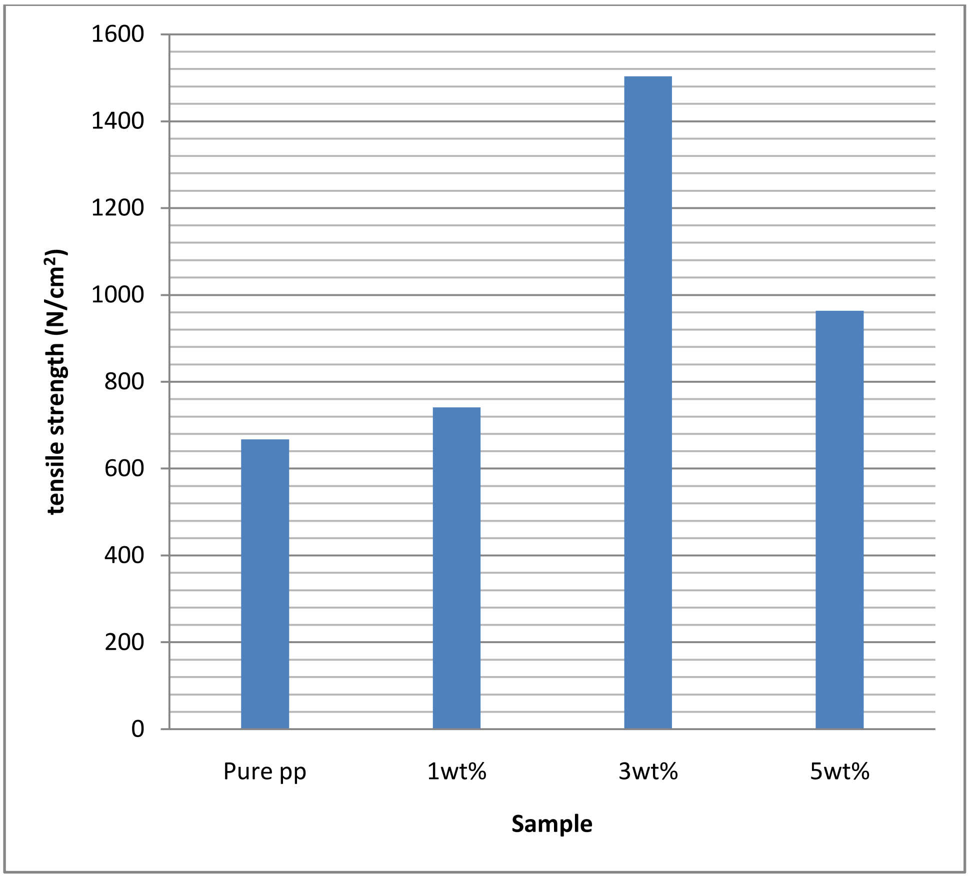

Figure 4.7: Bar chart showing tensile strength.

4.2.2 Tensile modulus

Tensile modulus showed the ratio of stress over the strain of the particular sample. Whenever the polymer has an increasing in tensile strength, its strain value will be decrease. This is because higher strength would lower its elongation value. Thus, the strain value will be decrease. Normally, polymer with high tensile strength will have high tensile modulus value. In general, the higher tensile modulus of the particular polymer will indicate that the polymer is better in strength and sturdier.

As the tensile modulus depending on the polymer strength, the arrangement of the clay and the polymer matrix also play a big role in the achieving a better result. Corresponding to this study, the arrangement of the composite would be the intercalate nanocomposite. The value of the tensile modulus should be increasing along with the polymer strength.

A.S. Luyt and his colleagues had performed a study on Morphology, mechanical and thermal properties of composites of polypropylene and nanostructured wollastonite filler. In their study, the result showed that increasing the filler content will eventually increased the tensile modulus of the polymer nanocomposite. In their study, the result comes with the flocculate nanocomposite arrangement. Despite of the arrangement, the improvement in tensile modulus is significant to be in consideration (A.S. Luyt et al., 2009)

Filler content (vol.%)	$E \pm \sigma$ (GPa)	$\sigma_b \pm \sigma$ (MPa)	$\varepsilon_b \pm \sigma$ (%)
0	0.65 ± 0.2	19.8 ± 0.2	23 ± 4
1.5	0.66 ± 0.1	20.4 ± 0.3	7 ± 2
3	0.72 ± 0.1	19.6 ± 0.3	6 ± 2
6	0.74 ± 0.1	18.6 ± 0.4	5 ± 1

E – Elastic modulus, σ_b – tensile strength, ε_b – elongation at break, σ – standard deviation.

Table 4.4:Mechanical properties of the pure PP and the PP–wollastonite nano-composite samples (A.S. Luyt et al., 2009).

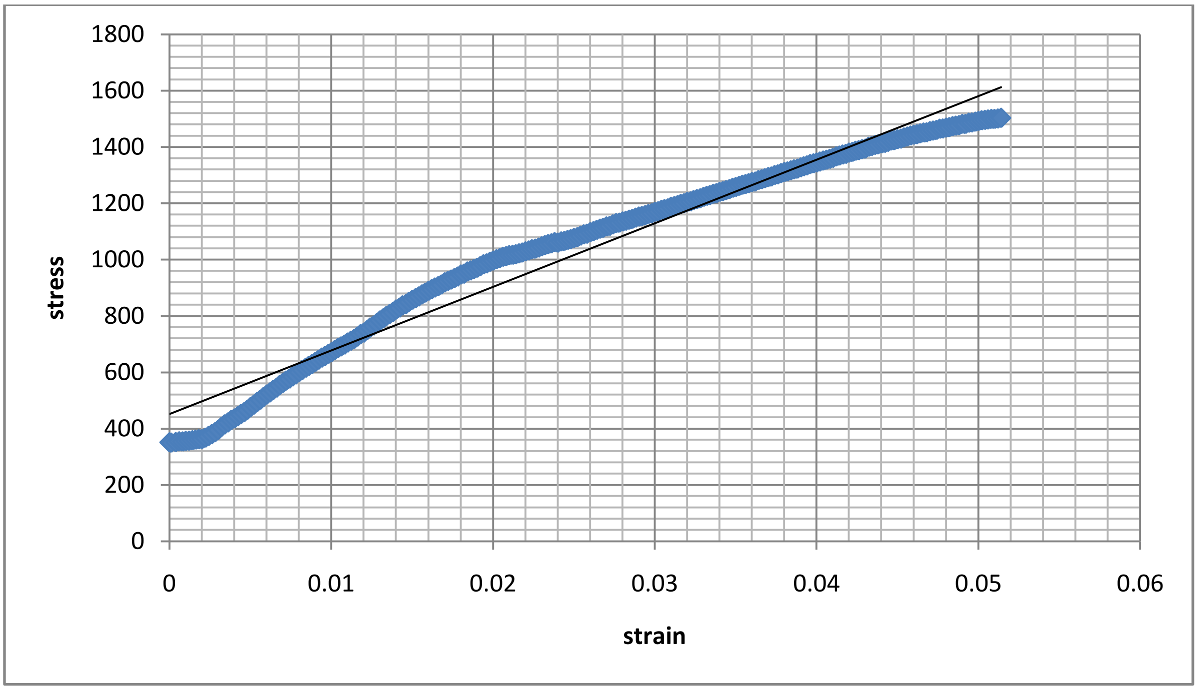

Figure 4.8: Stress versus strain graph for pure PP

From the figure 4.8, the tensile modulus for pure PP had been calculated from the slope of the graph. The tensile modulus for pure PP is 21666.667. Since tensile modulus is the ratio of stress over strain, the figure did not have any unit.

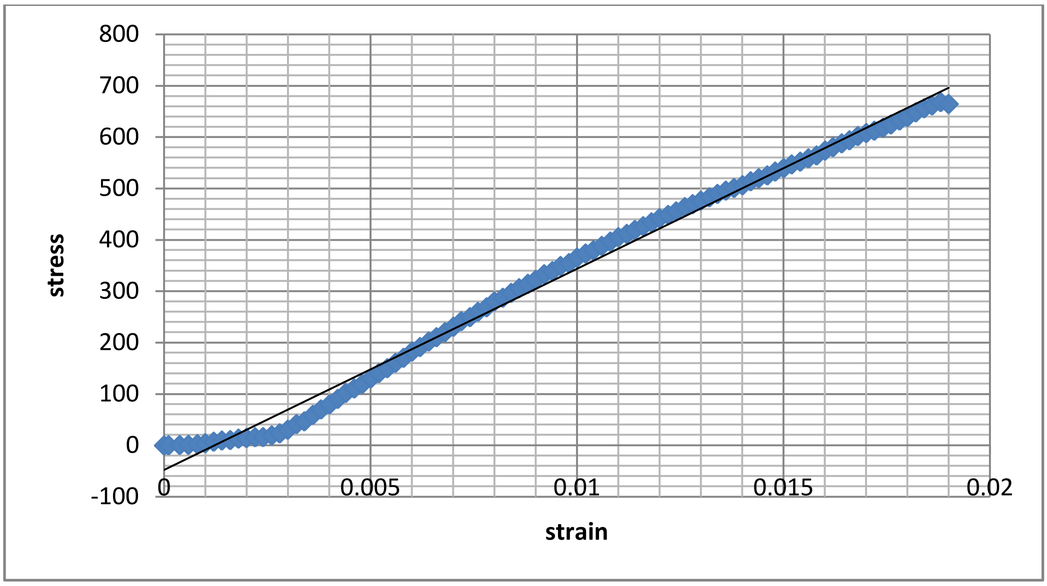

Figure 4.9: Stress versus strain graph for PP/nanoclay composite 1wt%

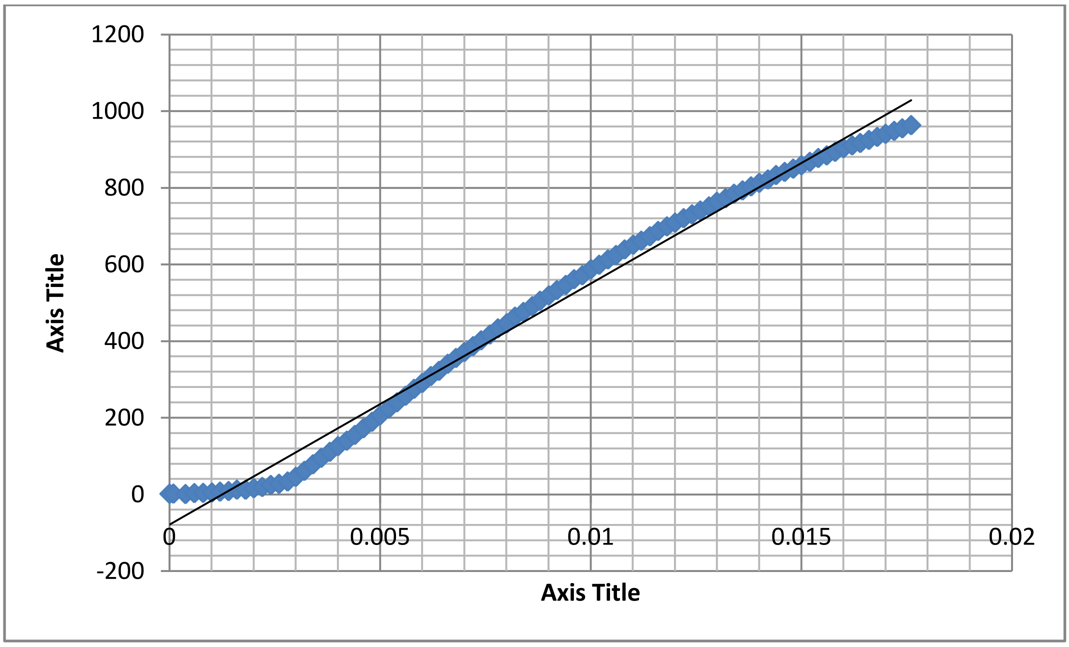

Figure 4.10: Stress versus strain graph for PP/nanoclay composite 3wt%

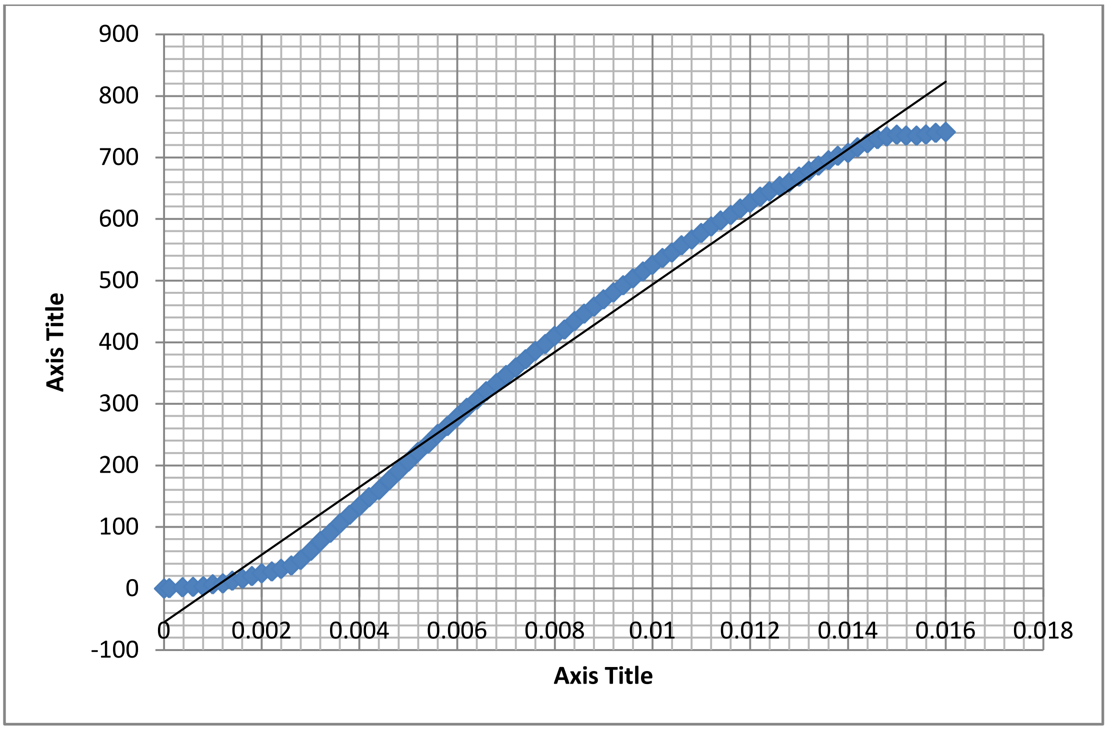

Figure 4.11: Stress versus strain graph for PP/nanoclay composite 5wt%

Figure 4.9, 4.10 and 4.11 showing the stress versus strain yield by each sample. The tensile modulus for each sample had been calculated using the slope of the graph.

	Tensile modulus	percentage of improvement
pure	21666.667	0
1wt%	60000	176.9230727
3wt%	66666.667	207.6923045
5wt%	54444.444	151.2820454

Table 4.5: result for tensile modulus for pure PP and PP/nanoclay composites and the improvement percentage

From the table 4.5, the value of tensile modulus increase significantly compared to the pure PP. The highest value would be the nanocomposite with nanofiller 3wt%. As for the 5wt%, the value seems to decline to a certain number. In this result, the tensile modulus increase due to the increment in clay content. The result showed similar trend with the previous study. However, at 5wt% clay content, the tensile modulus drops below expectation. It is suggested that the value drop comes from the arrangement of the nanocomposite itself. The clay is believed to agglomerate with each other and form floc inside the polymer matrix. This situation happened as 5wt% content of clay is too much for the polypropylene. The clay tends to form van der walls interaction among themselves and floc. The floc formation will form crack in the polymer and lessen the strength of the particular sample. As the result, the tensile modulus will be decreased.

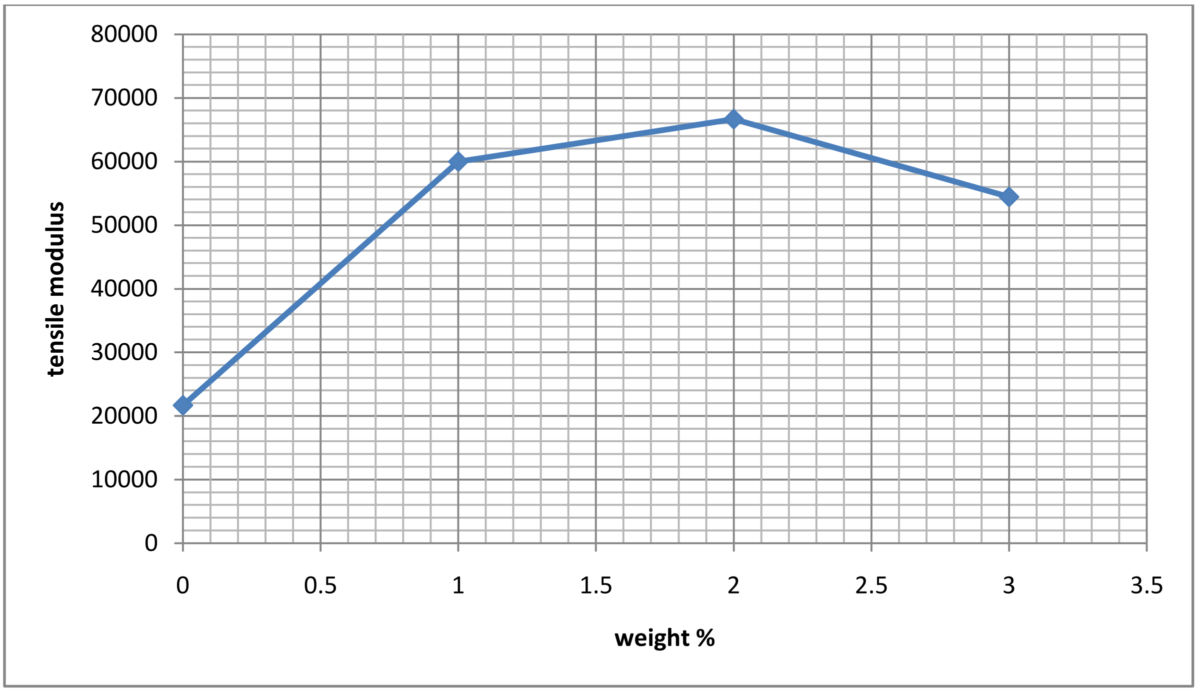

Figure 4.12: Graph of tensile modulus versus nanoclay content

4.4 Hardness test

Hardness result will show the hardness of the particular polymer. Usually, hardness value brings a great deal in producing polymer that will be used for coating. The hardness of a polymer can be measured using several equipments such as Rockwell-Brinell hardness tester or the Vicker tester. The main operation of this test is where we put load using a small indenter and measure the indentation that have been applied to the polymer (E.J. Pavlina and C.J. Van Tyne,2009) .

In this test, the selected testing method is the Rockwell hardness test using the Rockwell-Brinell hardness tester. The scale for the test was set to HRT-15. In this scale, the minor load applied would be 3kgf while the major load is 15kgf. The ball indenter is in 1/16 inch and the time indentation is set to 4 second. The indentation of the polymer will be measured and calculated in HRT-15 scale.

Previous study on the hardness of Al2O3/polymer for coating by Y.wang et al. had found that the nanofiller content in the polymer manage to increase the particular nanocomposite hardness. In his study, the selected tester is was the vicker tester. The result showed that there are increments in hardness as the nanofiller content increase. The increasing of the hardness value was because the well dispersion of the nanoparticle throughout the entire polymer matrix. The result also show that there only small standard deviation among the sample in the same composition. This situation can be explained as the nanoparticle is well distributed over the polymer surface (Y.wang et al., 2006).

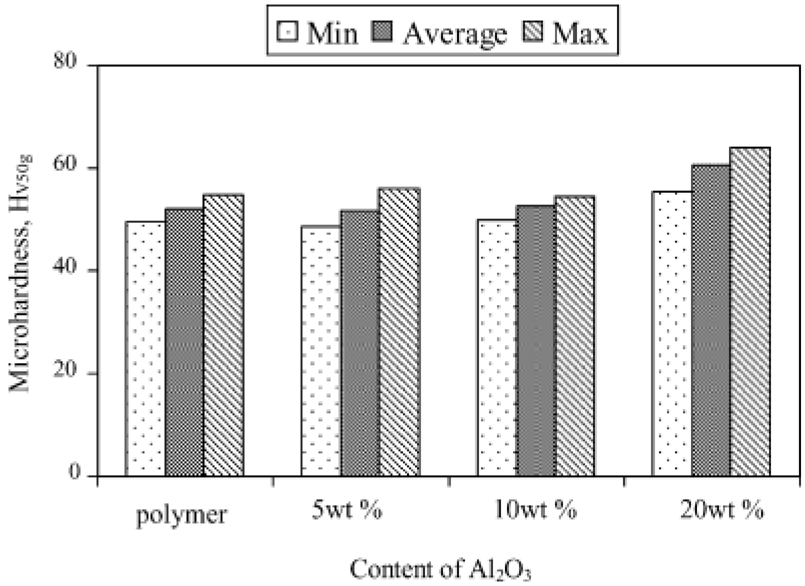

Figure 4.13: Micro-hardness results of different polymer coatings with and/or without Al2O3 nanoparticles (Y.wang et al., 2006).

PP PURE	**61.57333333**
PP 30B 1%	72.92333333
PP 30B 3%	81.83
PP 30B 5%	74.88333333

Table 4.6: Result for Hardness test

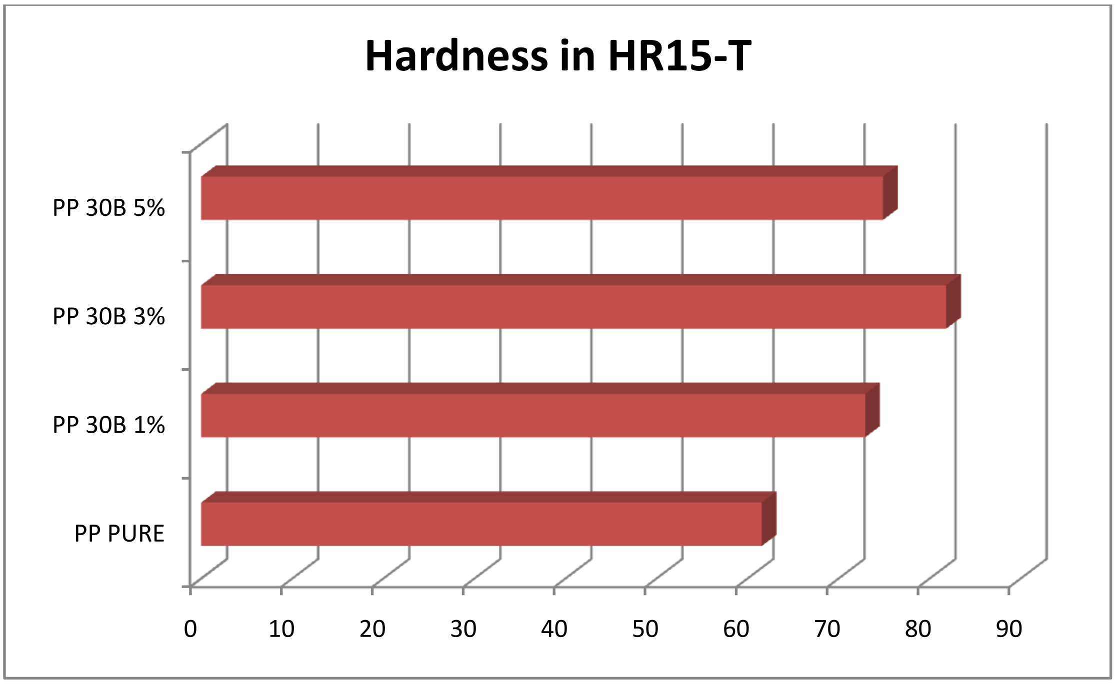

Figure 4.14: Bar chart for hardness test result.

From figure 4.14 and Table 4.6, the hardness increase with the addition of nanoclay. The maximum improvement in hardness falls to the PP/nanoclay 3 wt%. The PP/nanoclay 5wt% shows a lower value of hardness compare to the other nanocomposite. The outcomes from this study show a promising trend as it similar from the previous study. The hardness value of the pp-clay nanocomposite increase due to the increment in clay content. However, for pp-clay nanocomposite 5wt%, the hardness drops between the 1wt% and 3wt% reading. This situation can be explained by the agglomeration phenomenon occurring in the particular sample. The clay agglomerate and floc together, preventing the clay to well distributed among the polymer matrix, hence weakened the bonding. The sample surfaces lack of clay therefore the hardness decrease.

CHAPTER 5

CONCLUSION & RECOMENDATION

5.1 Conclusion

The introduction of nanoclay in the popropylene manages to increase its mechanical properties. By using the melt intercalation method, the expected nanocomposite arrangement is the intercalate naocomposite.

The FTIR result showed that hydrogen bonding between nanoclay and the polymer matrix manage to be formed. The bonding is shown by the peak appear at 1442 – 1456 cm^{-1}. The hydrogen bond formed makes the bonding between polymer matrixes stronger. The arrangement of nanocomposite allows the clay to interact with the polymer matrix, hence improve the mechanical properties.

The mechanical properties of polypropylene improved significantly with the introduction of nanoclay. The mechanical improvement is directly proportional to the clay content. The tensile modulus and tensile strength manage to improve up to 207% and 125% for each of them. The hardness test come with the improvement up to 32.9%. However, there is unexpected result with the 5wt% clay content where it decreases in value. The potential cause is believed to be the agglomeration phenomenon of the clay itself.

5.1 Recommendation

To overcome the agglomeration problem, in situ polymerization method can be introduce to enhance the dispersion of clay in the polymer. In situ polymerization method builds the polymer nanocomposite from its very monomer structure. Since it starts with the liquid form, the clay can be well distributed in the polymer. Another suggestion to reduce the possibilities of agglomeration is by using surfactant. The surfactant work as a catalyst to prevent the filler to agglomerate and help the filler to disperse finely in the polymer matrix (Hamed Azizi, 2003).

The number of sample could be increased to have more reading. By that, the result can be analyze statically to have a precise result.

The gap between the clay content differences can be narrow down to have a better view on the optimum clay content for the maximum improvement. With this method, the data obtain could be analyze easily and precisely.

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APPENDICES

Table A.1: Tensile Test Result for Pure PP

Load N	Stress	Extension mm	Elong	lo	strain	Stress
70.2029	351.0147	-7.4072	0.0000	25.00	0.0000	351.0147
69.8943	349.4713	-7.4047	0.0025	25.00	0.0001	349.4713
70.3229	351.6144	-7.3976	0.0096	25.00	0.0004	351.6144
70.8169	354.0844	-7.3924	0.0148	25.00	0.0006	354.0844
70.7466	353.7329	-7.3871	0.0201	25.00	0.0008	353.7329
71.1321	355.6606	-7.3823	0.0249	25.00	0.0010	355.6606
71.2797	356.3983	-7.3771	0.0301	25.00	0.0012	356.3983
71.5958	357.9788	-7.3720	0.0352	25.00	0.0014	357.9788
72.0061	360.0305	-7.3672	0.0400	25.00	0.0016	360.0305
72.3075	361.5374	-7.3622	0.0450	25.00	0.0018	361.5374
72.4427	362.2137	-7.3572	0.0500	25.00	0.0020	362.2137
73.3716	366.8578	-7.3521	0.0551	25.00	0.0022	366.8578
74.5466	372.7332	-7.3473	0.0599	25.00	0.0024	372.7332
75.8762	379.3809	-7.3422	0.0650	25.00	0.0026	379.3809
77.3040	386.5199	-7.3370	0.0702	25.00	0.0028	386.5199
78.9223	394.6114	-7.3322	0.0750	25.00	0.0030	394.6114
81.1630	405.8149	-7.3271	0.0801	25.00	0.0032	405.8149
82.8641	414.3207	-7.3222	0.0850	25.00	0.0034	414.3207
84.2276	421.1381	-7.3171	0.0901	25.00	0.0036	421.1381
85.9594	429.7970	-7.3121	0.0951	25.00	0.0038	429.7970
87.0691	435.3455	-7.3071	0.1001	25.00	0.0040	435.3455
88.6482	443.2408	-7.3020	0.1052	25.00	0.0042	443.2408
90.1127	450.5637	-7.2973	0.1099	25.00	0.0044	450.5637
91.5408	457.7041	-7.2920	0.1152	25.00	0.0046	457.7041
93.2116	466.0579	-7.2872	0.1200	25.00	0.0048	466.0579
95.1321	475.6607	-7.2822	0.1250	25.00	0.0050	475.6607
96.8934	484.4669	-7.2770	0.1302	25.00	0.0052	484.4669
98.6610	493.3052	-7.2723	0.1349	25.00	0.0054	493.3052
100.3660	501.8300	-7.2671	0.1401	25.00	0.0056	501.8300
102.2510	511.2550	-7.2623	0.1449	25.00	0.0058	511.2550
104.0698	520.3490	-7.2571	0.1501	25.00	0.0060	520.3490
105.5610	527.8050	-7.2522	0.1550	25.00	0.0062	527.8050
107.3042	536.5210	-7.2473	0.1599	25.00	0.0064	536.5210
108.9039	544.5195	-7.2420	0.1652	25.00	0.0066	544.5195
110.7117	553.5585	-7.2373	0.1699	25.00	0.0068	553.5585

112.3740	561.8700	-7.2320	0.1752	25.00	0.0070	561.8700
113.9503	569.7515	-7.2273	0.1799	25.00	0.0072	569.7515
115.3359	576.6795	-7.2221	0.1851	25.00	0.0074	576.6795
116.9826	584.9130	-7.2171	0.1901	25.00	0.0076	584.9130
118.3528	591.7640	-7.2123	0.1949	25.00	0.0078	591.7640
120.1252	600.6260	-7.2070	0.2002	25.00	0.0080	600.6260
121.5079	607.5395	-7.2023	0.2049	25.00	0.0082	607.5395
123.0683	615.3415	-7.1969	0.2103	25.00	0.0084	615.3415
124.3948	621.9740	-7.1922	0.2150	25.00	0.0086	621.9740
125.7550	628.7750	-7.1871	0.2201	25.00	0.0088	628.7750
127.2518	636.2590	-7.1820	0.2252	25.00	0.0090	636.2590
128.7549	643.7745	-7.1772	0.2300	25.00	0.0092	643.7745
130.2728	651.3640	-7.1721	0.2351	25.00	0.0094	651.3640
131.4264	657.1320	-7.1672	0.2400	25.00	0.0096	657.1320
132.8902	664.4510	-7.1619	0.2453	25.00	0.0098	664.4510
134.0808	670.4040	-7.1571	0.2501	25.00	0.0100	670.4040
135.5951	677.9755	-7.1521	0.2551	25.00	0.0102	677.9755
137.1408	685.7040	-7.1470	0.2602	25.00	0.0104	685.7040
138.2402	691.2010	-7.1422	0.2650	25.00	0.0106	691.2010
139.4643	697.3215	-7.1371	0.2701	25.00	0.0108	697.3215
140.9620	704.8100	-7.1323	0.2749	25.00	0.0110	704.8100
142.2792	711.3960	-7.1271	0.2801	25.00	0.0112	711.3960
143.5330	717.6650	-7.1221	0.2851	25.00	0.0114	717.6650
145.1671	725.8355	-7.1171	0.2901	25.00	0.0116	725.8355
146.9116	734.5580	-7.1121	0.2951	25.00	0.0118	734.5580
148.0015	740.0075	-7.1071	0.3001	25.00	0.0120	740.0075
149.8025	749.0125	-7.1020	0.3052	25.00	0.0122	749.0125
151.6358	758.1790	-7.0973	0.3099	25.00	0.0124	758.1790
153.0272	765.1360	-7.0922	0.3150	25.00	0.0126	765.1360
154.7534	773.7670	-7.0870	0.3202	25.00	0.0128	773.7670
156.6631	783.3155	-7.0821	0.3251	25.00	0.0130	783.3155
158.1450	790.7250	-7.0771	0.3301	25.00	0.0132	790.7250
159.8830	799.4150	-7.0722	0.3350	25.00	0.0134	799.4150
161.2820	806.4100	-7.0671	0.3401	25.00	0.0136	806.4100
162.6462	813.2310	-7.0621	0.3451	25.00	0.0138	813.2310
164.4559	822.2795	-7.0571	0.3501	25.00	0.0140	822.2795
165.7539	828.7695	-7.0520	0.3552	25.00	0.0142	828.7695
167.4002	837.0010	-7.0473	0.3599	25.00	0.0144	837.0010
168.2477	841.2385	-7.0421	0.3651	25.00	0.0146	841.2385
169.9220	849.6100	-7.0373	0.3699	25.00	0.0148	849.6100
171.3009	856.5045	-7.0323	0.3749	25.00	0.0150	856.5045
172.4989	862.4945	-7.0270	0.3802	25.00	0.0152	862.4945
173.7118	868.5590	-7.0222	0.3850	25.00	0.0154	868.5590
175.1886	875.9430	-7.0171	0.3901	25.00	0.0156	875.9430

176.3778	881.8890	-7.0122	0.3950	25.00	0.0158	881.8890
177.7014	888.5070	-7.0071	0.4001	25.00	0.0160	888.5070
178.8638	894.3190	-7.0022	0.4050	25.00	0.0162	894.3190
180.0528	900.2640	-6.9973	0.4099	25.00	0.0164	900.2640
181.0753	905.3765	-6.9920	0.4152	25.00	0.0166	905.3765
182.1646	910.8230	-6.9873	0.4199	25.00	0.0168	910.8230
183.7512	918.7560	-6.9820	0.4252	25.00	0.0170	918.7560
184.7496	923.7480	-6.9773	0.4299	25.00	0.0172	923.7480
185.6943	928.4715	-6.9721	0.4351	25.00	0.0174	928.4715
186.7585	933.7925	-6.9671	0.4401	25.00	0.0176	933.7925
187.8153	939.0765	-6.9622	0.4450	25.00	0.0178	939.0765
189.3205	946.6025	-6.9570	0.4502	25.00	0.0180	946.6025
189.8758	949.3790	-6.9523	0.4549	25.00	0.0182	949.3790
191.4519	957.2595	-6.9471	0.4601	25.00	0.0184	957.2595
192.1542	960.7710	-6.9423	0.4649	25.00	0.0186	960.7710
193.1721	965.8605	-6.9371	0.4701	25.00	0.0188	965.8605
194.0735	970.3675	-6.9319	0.4753	25.00	0.0190	970.3675
195.2018	976.0090	-6.9271	0.4801	25.00	0.0192	976.0090
196.5774	982.8870	-6.9221	0.4851	25.00	0.0194	982.8870
197.1855	985.9275	-6.9172	0.4900	25.00	0.0196	985.9275
198.3501	991.7505	-6.9120	0.4952	25.00	0.0198	991.7505
199.1831	995.9155	-6.9072	0.5000	25.00	0.0200	995.9155
200.1272	1000.6360	-6.9021	0.5051	25.00	0.0202	1000.6360
200.9251	1004.6255	-6.8971	0.5101	25.00	0.0204	1004.6255
201.8834	1009.4170	-6.8922	0.5150	25.00	0.0206	1009.4170
202.3775	1011.8875	-6.8871	0.5201	25.00	0.0208	1011.8875
203.1033	1015.5165	-6.8823	0.5249	25.00	0.0210	1015.5165
203.3138	1016.5690	-6.8771	0.5301	25.00	0.0212	1016.5690
203.7265	1018.6325	-6.8721	0.5351	25.00	0.0214	1018.6325
204.3689	1021.8445	-6.8671	0.5401	25.00	0.0216	1021.8445
204.9148	1024.5740	-6.8623	0.5449	25.00	0.0218	1024.5740
205.7604	1028.8020	-6.8572	0.5500	25.00	0.0220	1028.8020
206.3905	1031.9525	-6.8521	0.5551	25.00	0.0222	1031.9525
207.2759	1036.3795	-6.8473	0.5599	25.00	0.0224	1036.3795
207.6732	1038.3660	-6.8421	0.5651	25.00	0.0226	1038.3660
208.3944	1041.9720	-6.8370	0.5702	25.00	0.0228	1041.9720
209.3565	1046.7825	-6.8321	0.5751	25.00	0.0230	1046.7825
210.2192	1051.0960	-6.8271	0.5801	25.00	0.0232	1051.0960
210.8968	1054.4840	-6.8223	0.5849	25.00	0.0234	1054.4840
211.4421	1057.2105	-6.8172	0.5900	25.00	0.0236	1057.2105
212.3575	1061.7875	-6.8121	0.5951	25.00	0.0238	1061.7875
211.9771	1059.8855	-6.8071	0.6001	25.00	0.0240	1059.8855
212.8357	1064.1785	-6.8020	0.6052	25.00	0.0242	1064.1785
213.1413	1065.7065	-6.7972	0.6100	25.00	0.0244	1065.7065

213.8593	1069.2965	-6.7921	0.6151	25.00	0.0246	1069.2965
214.4169	1072.0845	-6.7872	0.6200	25.00	0.0248	1072.0845
215.2548	1076.2740	-6.7823	0.6249	25.00	0.0250	1076.2740
215.8822	1079.4110	-6.7770	0.6302	25.00	0.0252	1079.4110
216.8576	1084.2880	-6.7723	0.6349	25.00	0.0254	1084.2880
217.8501	1089.2505	-6.7671	0.6401	25.00	0.0256	1089.2505
218.2833	1091.4165	-6.7623	0.6449	25.00	0.0258	1091.4165
219.3578	1096.7890	-6.7571	0.6501	25.00	0.0260	1096.7890
220.1005	1100.5025	-6.7521	0.6551	25.00	0.0262	1100.5025
220.9915	1104.9575	-6.7472	0.6600	25.00	0.0264	1104.9575
221.8639	1109.3195	-6.7420	0.6652	25.00	0.0266	1109.3195
222.4567	1112.2835	-6.7373	0.6699	25.00	0.0268	1112.2835
223.4640	1117.3200	-6.7321	0.6751	25.00	0.0270	1117.3200
223.7832	1118.9160	-6.7273	0.6799	25.00	0.0272	1118.9160
224.9230	1124.6150	-6.7221	0.6851	25.00	0.0274	1124.6150
225.8752	1129.3760	-6.7171	0.6901	25.00	0.0276	1129.3760
226.1074	1130.5370	-6.7122	0.6950	25.00	0.0278	1130.5370
226.9860	1134.9300	-6.7070	0.7002	25.00	0.0280	1134.9300
227.4573	1137.2865	-6.7023	0.7049	25.00	0.0282	1137.2865
228.2210	1141.1050	-6.6970	0.7102	25.00	0.0284	1141.1050
228.7855	1143.9275	-6.6922	0.7150	25.00	0.0286	1143.9275
229.6613	1148.3065	-6.6871	0.7201	25.00	0.0288	1148.3065
230.4693	1152.3465	-6.6820	0.7252	25.00	0.0290	1152.3465
230.8665	1154.3325	-6.6773	0.7299	25.00	0.0292	1154.3325
231.5168	1157.5840	-6.6721	0.7351	25.00	0.0294	1157.5840
232.2899	1161.4495	-6.6672	0.7400	25.00	0.0296	1161.4495
232.8172	1164.0860	-6.6619	0.7453	25.00	0.0298	1164.0860
233.8496	1169.2480	-6.6571	0.7501	25.00	0.0300	1169.2480
234.2630	1171.3150	-6.6521	0.7551	25.00	0.0302	1171.3150
235.2487	1176.2435	-6.6471	0.7601	25.00	0.0304	1176.2435
235.7965	1178.9825	-6.6423	0.7649	25.00	0.0306	1178.9825
236.2782	1181.3910	-6.6371	0.7701	25.00	0.0308	1181.3910
237.3999	1186.9995	-6.6323	0.7749	25.00	0.0310	1186.9995
237.9451	1189.7255	-6.6271	0.7801	25.00	0.0312	1189.7255
238.6064	1193.0320	-6.6220	0.7852	25.00	0.0314	1193.0320
239.4802	1197.4010	-6.6171	0.7901	25.00	0.0316	1197.4010
239.9370	1199.6850	-6.6121	0.7951	25.00	0.0318	1199.6850
240.9518	1204.7590	-6.6072	0.8000	25.00	0.0320	1204.7590
241.2364	1206.1820	-6.6020	0.8052	25.00	0.0322	1206.1820
242.1933	1210.9665	-6.5974	0.8098	25.00	0.0324	1210.9665
242.8855	1214.4275	-6.5922	0.8150	25.00	0.0326	1214.4275
243.4521	1217.2605	-6.5871	0.8201	25.00	0.0328	1217.2605
244.4261	1222.1305	-6.5821	0.8251	25.00	0.0330	1222.1305
245.1600	1225.8000	-6.5771	0.8301	25.00	0.0332	1225.8000

245.7296	1228.6480	-6.5722	0.8350	25.00	0.0334	1228.6480
246.6151	1233.0755	-6.5671	0.8401	25.00	0.0336	1233.0755
247.0757	1235.3785	-6.5621	0.8451	25.00	0.0338	1235.3785
248.0365	1240.1825	-6.5571	0.8501	25.00	0.0340	1240.1825
248.5394	1242.6970	-6.5521	0.8551	25.00	0.0342	1242.6970
249.2307	1246.1535	-6.5473	0.8599	25.00	0.0344	1246.1535
249.9464	1249.7320	-6.5421	0.8651	25.00	0.0346	1249.7320
250.8812	1254.4060	-6.5372	0.8700	25.00	0.0348	1254.4060
251.4874	1257.4370	-6.5322	0.8750	25.00	0.0350	1257.4370
252.2565	1261.2825	-6.5270	0.8802	25.00	0.0352	1261.2825
253.0109	1265.0545	-6.5222	0.8850	25.00	0.0354	1265.0545
253.5417	1267.7085	-6.5171	0.8901	25.00	0.0356	1267.7085
254.1904	1270.9520	-6.5122	0.8950	25.00	0.0358	1270.9520
254.9703	1274.8515	-6.5071	0.9001	25.00	0.0360	1274.8515
255.3523	1276.7615	-6.5021	0.9051	25.00	0.0362	1276.7615
256.4126	1282.0630	-6.4972	0.9100	25.00	0.0364	1282.0630
256.9997	1284.9985	-6.4920	0.9152	25.00	0.0366	1284.9985
257.7262	1288.6310	-6.4872	0.9200	25.00	0.0368	1288.6310
258.5200	1292.6000	-6.4820	0.9252	25.00	0.0370	1292.6000
258.9277	1294.6385	-6.4773	0.9299	25.00	0.0372	1294.6385
259.9817	1299.9085	-6.4721	0.9351	25.00	0.0374	1299.9085
260.4611	1302.3055	-6.4671	0.9401	25.00	0.0376	1302.3055
261.3573	1306.7865	-6.4622	0.9450	25.00	0.0378	1306.7865
262.1134	1310.5670	-6.4571	0.9501	25.00	0.0380	1310.5670
262.5363	1312.6815	-6.4523	0.9549	25.00	0.0382	1312.6815
263.3260	1316.6300	-6.4470	0.9602	25.00	0.0384	1316.6300
264.0142	1320.0710	-6.4422	0.9650	25.00	0.0386	1320.0710
264.4942	1322.4710	-6.4371	0.9701	25.00	0.0388	1322.4710
265.4086	1327.0430	-6.4319	0.9753	25.00	0.0390	1327.0430
266.1863	1330.9315	-6.4271	0.9801	25.00	0.0392	1330.9315
266.8319	1334.1595	-6.4221	0.9851	25.00	0.0394	1334.1595
267.7755	1338.8775	-6.4173	0.9899	25.00	0.0396	1338.8775
268.2903	1341.4515	-6.4120	0.9952	25.00	0.0398	1341.4515
268.8704	1344.3520	-6.4072	1.0000	25.00	0.0400	1344.3520
269.5586	1347.7930	-6.4022	1.0050	25.00	0.0402	1347.7930
270.2558	1351.2790	-6.3971	1.0101	25.00	0.0404	1351.2790
270.7846	1353.9230	-6.3922	1.0150	25.00	0.0406	1353.9230
271.4653	1357.3265	-6.3871	1.0201	25.00	0.0408	1357.3265
272.1106	1360.5530	-6.3823	1.0249	25.00	0.0410	1360.5530
273.1893	1365.9465	-6.3771	1.0301	25.00	0.0412	1365.9465
273.7837	1368.9185	-6.3721	1.0351	25.00	0.0414	1368.9185
274.5246	1372.6230	-6.3672	1.0400	25.00	0.0416	1372.6230
274.9647	1374.8235	-6.3622	1.0450	25.00	0.0418	1374.8235
275.9044	1379.5220	-6.3572	1.0500	25.00	0.0420	1379.5220

276.3984	1381.9920	-6.3521	1.0551	25.00	0.0422	1381.9920
277.1770	1385.8850	-6.3473	1.0599	25.00	0.0424	1385.8850
277.6382	1388.1910	-6.3421	1.0651	25.00	0.0426	1388.1910
278.3555	1391.7775	-6.3370	1.0702	25.00	0.0428	1391.7775
278.7287	1393.6435	-6.3321	1.0751	25.00	0.0430	1393.6435
280.0300	1400.1500	-6.3271	1.0801	25.00	0.0432	1400.1500
280.5449	1402.7245	-6.3222	1.0850	25.00	0.0434	1402.7245
281.3363	1406.6815	-6.3171	1.0901	25.00	0.0436	1406.6815
281.7789	1408.8945	-6.3121	1.0951	25.00	0.0438	1408.8945
282.4712	1412.3560	-6.3071	1.1001	25.00	0.0440	1412.3560
282.7457	1413.7285	-6.3020	1.1052	25.00	0.0442	1413.7285
283.4713	1417.3565	-6.2972	1.1100	25.00	0.0444	1417.3565
284.4829	1422.4145	-6.2921	1.1151	25.00	0.0446	1422.4145
284.7408	1423.7040	-6.2872	1.1200	25.00	0.0448	1423.7040
285.4339	1427.1695	-6.2823	1.1249	25.00	0.0450	1427.1695
285.8372	1429.1860	-6.2770	1.1302	25.00	0.0452	1429.1860
286.6841	1433.4205	-6.2722	1.1350	25.00	0.0454	1433.4205
287.3231	1436.6155	-6.2671	1.1401	25.00	0.0456	1436.6155
287.9906	1439.9530	-6.2622	1.1450	25.00	0.0458	1439.9530
288.6075	1443.0375	-6.2571	1.1501	25.00	0.0460	1443.0375
288.9783	1444.8915	-6.2521	1.1551	25.00	0.0462	1444.8915
289.5983	1447.9915	-6.2472	1.1600	25.00	0.0464	1447.9915
290.1708	1450.8540	-6.2420	1.1652	25.00	0.0466	1450.8540
290.2959	1451.4795	-6.2373	1.1699	25.00	0.0468	1451.4795
291.1409	1455.7045	-6.2321	1.1751	25.00	0.0470	1455.7045
291.5676	1457.8380	-6.2273	1.1799	25.00	0.0472	1457.8380
291.9684	1459.8420	-6.2221	1.1851	25.00	0.0474	1459.8420
292.8754	1464.3770	-6.2171	1.1901	25.00	0.0476	1464.3770
293.0432	1465.2160	-6.2122	1.1950	25.00	0.0478	1465.2160
293.6635	1468.3175	-6.2070	1.2002	25.00	0.0480	1468.3175
293.9960	1469.9800	-6.2023	1.2049	25.00	0.0482	1469.9800
294.7258	1473.6290	-6.1970	1.2102	25.00	0.0484	1473.6290
295.0415	1475.2075	-6.1923	1.2149	25.00	0.0486	1475.2075
295.4228	1477.1140	-6.1871	1.2201	25.00	0.0488	1477.1140
296.3096	1481.5480	-6.1820	1.2252	25.00	0.0490	1481.5480
296.2607	1481.3035	-6.1773	1.2299	25.00	0.0492	1481.3035
297.1630	1485.8150	-6.1721	1.2351	25.00	0.0494	1485.8150
297.3399	1486.6995	-6.1673	1.2399	25.00	0.0496	1486.6995
297.8884	1489.4420	-6.1619	1.2453	25.00	0.0498	1489.4420
298.3705	1491.8525	-6.1571	1.2501	25.00	0.0500	1491.8525
298.8823	1494.4115	-6.1522	1.2550	25.00	0.0502	1494.4115
299.1500	1495.7500	-6.1471	1.2601	25.00	0.0504	1495.7500
299.4501	1497.2505	-6.1423	1.2649	25.00	0.0506	1497.2505
299.8240	1499.1200	-6.1371	1.2701	25.00	0.0508	1499.1200

299.8395	1499.1975	-6.1323	1.2749	25.00	0.0510	1499.1975
300.1362	1500.6810	-6.1270	1.2802	25.00	0.0512	1500.6810
300.6283	1503.1415	-6.1221	1.2851	25.00	0.0514	1503.1415
300.5774	1502.8870	-6.1171	1.2901	25.00	0.0516	1502.8870
300.2932	1501.4660	-6.1121	1.2951	25.00	0.0518	1501.4660
300.1462	1500.7310	-6.1072	1.3000	25.00	0.0520	1500.7310
299.5826	1497.9130	-6.1021	1.3051	25.00	0.0522	1497.9130
297.7342	1488.6710	-6.0973	1.3099	25.00	0.0524	1488.6710
290.3482	1451.7410	-6.0922	1.3150	25.00	0.0526	1451.7410
96.8584	484.2922	-6.0896	1.3176	25.00	0.0527	484.2922

Table A.2: Tensile result for PP-clay nanocomposite 1wt%

Load N	Stress	Extension mm	Elong	lo	strain	Stress
-0.1003	-0.5013	0.0000	0.0000	25.00	0.0000	-0.5013
-0.0245	-0.1227	0.0027	0.0027	25.00	0.0001	-0.1227
0.0784	0.3918	0.0094	0.0094	25.00	0.0004	0.3918
0.1350	0.6748	0.0147	0.0147	25.00	0.0006	0.6748
0.3872	1.9361	0.0201	0.0201	25.00	0.0008	1.9361
0.7561	3.7806	0.0249	0.0249	25.00	0.0010	3.7806
1.3588	6.7938	0.0300	0.0300	25.00	0.0012	6.7938
1.8170	9.0852	0.0349	0.0349	25.00	0.0014	9.0852
1.9944	9.9718	0.0400	0.0400	25.00	0.0016	9.9718
2.5575	12.7876	0.0450	0.0450	25.00	0.0018	12.7876
2.7682	13.8409	0.0498	0.0498	25.00	0.0020	13.8409
3.0947	15.4733	0.0551	0.0551	25.00	0.0022	15.4733
3.1461	15.7305	0.0599	0.0599	25.00	0.0024	15.7305
3.8074	19.0372	0.0651	0.0651	25.00	0.0026	19.0372
4.5939	22.9695	0.0699	0.0699	25.00	0.0028	22.9695
6.0119	30.0595	0.0748	0.0748	25.00	0.0030	30.0595
8.2186	41.0929	0.0801	0.0801	25.00	0.0032	41.0929
9.2749	46.3744	0.0849	0.0849	25.00	0.0034	46.3744
11.7973	58.9863	0.0901	0.0901	25.00	0.0036	58.9863
13.9193	69.5964	0.0949	0.0949	25.00	0.0038	69.5964
15.8631	79.3157	0.1001	0.1001	25.00	0.0040	79.3157
17.9969	89.9847	0.1051	0.1051	25.00	0.0042	89.9847
20.3235	101.6176	0.1099	0.1099	25.00	0.0044	101.6176
22.0554	110.2768	0.1151	0.1151	25.00	0.0046	110.2768
23.8118	119.0588	0.1199	0.1199	25.00	0.0048	119.0588
26.0386	130.1932	0.1251	0.1251	25.00	0.0050	130.1932
28.0646	140.3231	0.1299	0.1299	25.00	0.0052	140.3231

29.9479	149.7396	0.1351	0.1351	25.00	0.0054	149.7396
32.0583	160.2916	0.1400	0.1400	25.00	0.0056	160.2916
33.9923	169.9615	0.1449	0.1449	25.00	0.0058	169.9615
36.4779	182.3896	0.1501	0.1501	25.00	0.0060	182.3896
38.1664	190.8322	0.1549	0.1549	25.00	0.0062	190.8322
40.3555	201.7776	0.1602	0.1602	25.00	0.0064	201.7776
42.0106	210.0530	0.1649	0.1649	25.00	0.0066	210.0530
43.9819	219.9095	0.1700	0.1700	25.00	0.0068	219.9095
46.0838	230.4191	0.1751	0.1751	25.00	0.0070	230.4191
48.2459	241.2296	0.1799	0.1799	25.00	0.0072	241.2296
49.8165	249.0826	0.1851	0.1851	25.00	0.0074	249.0826
51.8749	259.3747	0.1899	0.1899	25.00	0.0076	259.3747
53.6411	268.2056	0.1952	0.1952	25.00	0.0078	268.2056
55.9163	279.5817	0.1999	0.1999	25.00	0.0080	279.5817
57.3653	286.8263	0.2050	0.2050	25.00	0.0082	286.8263
59.2576	296.2880	0.2101	0.2101	25.00	0.0084	296.2880
61.0908	305.4541	0.2149	0.2149	25.00	0.0086	305.4541
62.7935	313.9673	0.2202	0.2202	25.00	0.0088	313.9673
64.3134	321.5670	0.2249	0.2249	25.00	0.0090	321.5670
66.5297	332.6485	0.2301	0.2301	25.00	0.0092	332.6485
67.7122	338.5609	0.2350	0.2350	25.00	0.0094	338.5609
69.7413	348.7063	0.2399	0.2399	25.00	0.0096	348.7063
70.8626	354.3130	0.2451	0.2451	25.00	0.0098	354.3130
72.9899	364.9495	0.2499	0.2499	25.00	0.0100	364.9495
74.6020	373.0100	0.2551	0.2551	25.00	0.0102	373.0100
75.8561	379.2806	0.2599	0.2599	25.00	0.0104	379.2806
77.5513	387.7566	0.2649	0.2649	25.00	0.0106	387.7566
79.2324	396.1622	0.2701	0.2701	25.00	0.0108	396.1622
80.9521	404.7605	0.2749	0.2749	25.00	0.0110	404.7605
82.2353	411.1766	0.2801	0.2801	25.00	0.0112	411.1766
83.7741	418.8707	0.2849	0.2849	25.00	0.0114	418.8707
85.2223	426.1116	0.2900	0.2900	25.00	0.0116	426.1116
86.7104	433.5522	0.2950	0.2950	25.00	0.0118	433.5522
88.3417	441.7083	0.2999	0.2999	25.00	0.0120	441.7083
89.6078	448.0389	0.3051	0.3051	25.00	0.0122	448.0389
90.9757	454.8783	0.3099	0.3099	25.00	0.0124	454.8783
92.6525	463.2624	0.3152	0.3152	25.00	0.0126	463.2624
93.7980	468.9900	0.3199	0.3199	25.00	0.0128	468.9900
95.1737	475.8684	0.3249	0.3249	25.00	0.0130	475.8684
96.4618	482.3092	0.3301	0.3301	25.00	0.0132	482.3092
97.7816	488.9078	0.3349	0.3349	25.00	0.0134	488.9078
99.0651	495.3256	0.3400	0.3400	25.00	0.0136	495.3256
100.0948	500.4740	0.3450	0.3450	25.00	0.0138	500.4740
101.1560	505.7800	0.3501	0.3501	25.00	0.0140	505.7800

102.7110	513.5550	0.3551	0.3551	25.00	0.0142	513.5550
103.9137	519.5685	0.3599	0.3599	25.00	0.0144	519.5685
104.9884	524.9420	0.3651	0.3651	25.00	0.0146	524.9420
106.4710	532.3550	0.3699	0.3699	25.00	0.0148	532.3550
107.8239	539.1195	0.3751	0.3751	25.00	0.0150	539.1195
109.2645	546.3225	0.3799	0.3799	25.00	0.0152	546.3225
110.3421	551.7105	0.3851	0.3851	25.00	0.0154	551.7105
111.6215	558.1075	0.3900	0.3900	25.00	0.0156	558.1075
112.7484	563.7420	0.3949	0.3949	25.00	0.0158	563.7420
114.6388	573.1940	0.4001	0.4001	25.00	0.0160	573.1940
115.9837	579.9185	0.4049	0.4049	25.00	0.0162	579.9185
117.4656	587.3280	0.4102	0.4102	25.00	0.0164	587.3280
118.6529	593.2645	0.4149	0.4149	25.00	0.0166	593.2645
120.3043	601.5215	0.4199	0.4199	25.00	0.0168	601.5215
121.4855	607.4275	0.4251	0.4251	25.00	0.0170	607.4275
122.3773	611.8865	0.4299	0.4299	25.00	0.0172	611.8865
123.4996	617.4980	0.4351	0.4351	25.00	0.0174	617.4980
124.7955	623.9775	0.4399	0.4399	25.00	0.0176	623.9775
126.3482	631.7410	0.4452	0.4452	25.00	0.0178	631.7410
127.7089	638.5445	0.4499	0.4499	25.00	0.0180	638.5445
129.5067	647.5335	0.4550	0.4550	25.00	0.0182	647.5335
131.0970	655.4850	0.4601	0.4601	25.00	0.0184	655.4850
132.2300	661.1500	0.4649	0.4649	25.00	0.0186	661.1500
133.5174	667.5870	0.4701	0.4701	25.00	0.0188	667.5870
132.7930	663.9650	0.4749	0.4749	25.00	0.0190	663.9650
132.3693	661.8465	0.4801	0.4801	25.00	0.0192	661.8465
132.3480	661.7400	0.4850	0.4850	25.00	0.0194	661.7400
126.7915	633.9575	0.4899	0.4899	25.00	0.0196	633.9575
124.0651	620.3255	0.4951	0.4951	25.00	0.0198	620.3255
123.0096	615.0480	0.4999	0.4999	25.00	0.0200	615.0480
121.9361	609.6805	0.5051	0.5051	25.00	0.0202	609.6805
105.3265	526.6325	0.5099	0.5099	25.00	0.0204	526.6325
96.9134	484.5671	0.5149	0.5149	25.00	0.0206	484.5671
89.3404	446.7019	0.5201	0.5201	25.00	0.0208	446.7019
-1.1727	-5.8634	0.5250	0.5250	25.00	0.0210	-5.8634
1.5283	7.6416	0.5301	0.5301	25.00	0.0212	7.6416
1.2280	6.1401	0.5350	0.5350	25.00	0.0214	6.1401
1.7176	8.5882	0.5400	0.5400	25.00	0.0216	8.5882
1.2758	6.3788	0.5450	0.5450	25.00	0.0218	6.3788
1.4839	7.4195	0.5499	0.5499	25.00	0.0220	7.4195
1.5770	7.8850	0.5550	0.5550	25.00	0.0222	7.8850
1.6001	8.0007	0.5599	0.5599	25.00	0.0224	8.0007
1.4975	7.4875	0.5651	0.5651	25.00	0.0226	7.4875
1.2568	6.2840	0.5700	0.5700	25.00	0.0228	6.2840

1.4033	7.0167	0.5749	0.5749	25.00	0.0230	7.0167
1.6306	8.1531	0.5802	0.5802	25.00	0.0232	8.1531
1.6710	8.3549	0.5849	0.5849	25.00	0.0234	8.3549
1.5789	7.8944	0.5900	0.5900	25.00	0.0236	7.8944
1.4736	7.3682	0.5949	0.5949	25.00	0.0238	7.3682
1.3528	6.7641	0.6000	0.6000	25.00	0.0240	6.7641
1.5330	7.6652	0.6050	0.6050	25.00	0.0242	7.6652
1.3949	6.9743	0.6099	0.6099	25.00	0.0244	6.9743
1.4590	7.2952	0.6151	0.6151	25.00	0.0246	7.2952
1.5342	7.6711	0.6199	0.6199	25.00	0.0248	7.6711
1.2190	6.0952	0.6251	0.6251	25.00	0.0250	6.0952
1.6773	8.3864	0.6299	0.6299	25.00	0.0252	8.3864
1.3509	6.7547	0.6351	0.6351	25.00	0.0254	6.7547
1.4139	7.0697	0.6400	0.6400	25.00	0.0256	7.0697
1.5757	7.8787	0.6449	0.6449	25.00	0.0258	7.8787
1.4750	7.3751	0.6501	0.6501	25.00	0.0260	7.3751
1.5427	7.7134	0.6549	0.6549	25.00	0.0262	7.7134
1.5370	7.6850	0.6602	0.6602	25.00	0.0264	7.6850
1.4484	7.2422	0.6649	0.6649	25.00	0.0266	7.2422
1.7257	8.6285	0.6700	0.6700	25.00	0.0268	8.6285
1.4214	7.1071	0.6751	0.6751	25.00	0.0270	7.1071
1.5926	7.9631	0.6799	0.6799	25.00	0.0272	7.9631
1.4096	7.0482	0.6851	0.6851	25.00	0.0274	7.0482
1.4335	7.1674	0.6899	0.6899	25.00	0.0276	7.1674
1.6326	8.1628	0.6952	0.6952	25.00	0.0278	8.1628
1.1126	5.5629	0.6999	0.6999	25.00	0.0280	5.5629
1.5411	7.7055	0.7051	0.7051	25.00	0.0282	7.7055
1.5770	7.8849	0.7101	0.7101	25.00	0.0284	7.8849
1.2667	6.3333	0.7149	0.7149	25.00	0.0286	6.3333
1.3307	6.6536	0.7201	0.7201	25.00	0.0288	6.6536
1.2773	6.3863	0.7249	0.7249	25.00	0.0290	6.3863
1.7164	8.5821	0.7301	0.7301	25.00	0.0292	8.5821
1.3364	6.6820	0.7349	0.7349	25.00	0.0294	6.6820
1.3886	6.9431	0.7399	0.7399	25.00	0.0296	6.9431
1.3900	6.9498	0.7450	0.7450	25.00	0.0298	6.9498
1.5145	7.5726	0.7500	0.7500	25.00	0.0300	7.5726
1.8736	9.3680	0.7552	0.7552	25.00	0.0302	9.3680
1.5475	7.7374	0.7599	0.7599	25.00	0.0304	7.7374
1.4745	7.3725	0.7649	0.7649	25.00	0.0306	7.3725
1.7470	8.7350	0.7701	0.7701	25.00	0.0308	8.7350
1.3480	6.7398	0.7749	0.7749	25.00	0.0310	6.7398
1.3776	6.8878	0.7800	0.7800	25.00	0.0312	6.8878
1.3673	6.8363	0.7850	0.7850	25.00	0.0314	6.8363
1.8762	9.3808	0.7900	0.7900	25.00	0.0316	9.3808

1.2117	6.0586	0.7950	0.7950	25.00	0.0318	6.0586
1.4072	7.0360	0.7999	0.7999	25.00	0.0320	7.0360
1.7451	8.7255	0.8051	0.8051	25.00	0.0322	8.7255
1.6517	8.2584	0.8099	0.8099	25.00	0.0324	8.2584
1.4272	7.1361	0.8151	0.8151	25.00	0.0326	7.1361
1.6374	8.1872	0.8200	0.8200	25.00	0.0328	8.1872
1.2885	6.4425	0.8249	0.8249	25.00	0.0330	6.4425
1.8433	9.2163	0.8301	0.8301	25.00	0.0332	9.2163
1.0556	5.2781	0.8349	0.8349	25.00	0.0334	5.2781
1.6497	8.2485	0.8400	0.8400	25.00	0.0336	8.2485
1.4621	7.3105	0.8450	0.8450	25.00	0.0338	7.3105
1.7395	8.6975	0.8501	0.8501	25.00	0.0340	8.6975
1.7898	8.9491	0.8550	0.8550	25.00	0.0342	8.9491
1.4755	7.3775	0.8599	0.8599	25.00	0.0344	7.3775
1.5176	7.5878	0.8651	0.8651	25.00	0.0346	7.5878
1.5226	7.6129	0.8699	0.8699	25.00	0.0348	7.6129
1.5399	7.6997	0.8751	0.8751	25.00	0.0350	7.6997
1.7466	8.7332	0.8799	0.8799	25.00	0.0352	8.7332
1.6261	8.1307	0.8851	0.8851	25.00	0.0354	8.1307
1.5245	7.6225	0.8901	0.8901	25.00	0.0356	7.6225
1.4700	7.3499	0.8949	0.8949	25.00	0.0358	7.3499
1.5987	7.9933	0.9001	0.9001	25.00	0.0360	7.9933
1.6409	8.2046	0.9048	0.9048	25.00	0.0362	8.2046
1.4470	7.2350	0.9102	0.9102	25.00	0.0364	7.2350
1.3586	6.7932	0.9149	0.9149	25.00	0.0366	6.7932
1.8041	9.0204	0.9200	0.9200	25.00	0.0368	9.0204
1.5296	7.6479	0.9251	0.9251	25.00	0.0370	7.6479
2.0350	10.1749	0.9299	0.9299	25.00	0.0372	10.1749
1.4440	7.2201	0.9351	0.9351	25.00	0.0374	7.2201
1.3814	6.9072	0.9399	0.9399	25.00	0.0376	6.9072
1.7054	8.5269	0.9451	0.9451	25.00	0.0378	8.5269
1.2534	6.2668	0.9499	0.9499	25.00	0.0380	6.2668
1.7609	8.8044	0.9551	0.9551	25.00	0.0382	8.8044
1.8146	9.0730	0.9601	0.9601	25.00	0.0384	9.0730
1.5228	7.6141	0.9649	0.9649	25.00	0.0386	7.6141
1.5747	7.8734	0.9701	0.9701	25.00	0.0388	7.8734
1.3376	6.6879	0.9749	0.9749	25.00	0.0390	6.6879
1.8724	9.3622	0.9801	0.9801	25.00	0.0392	9.3622
1.7337	8.6683	0.9850	0.9850	25.00	0.0394	8.6683
1.4300	7.1500	0.9899	0.9899	25.00	0.0396	7.1500
1.6162	8.0810	0.9950	0.9950	25.00	0.0398	8.0810
1.3462	6.7310	0.9999	0.9999	25.00	0.0400	6.7310
2.0213	10.1063	1.0051	1.0051	25.00	0.0402	10.1063
1.5422	7.7109	1.0099	1.0099	25.00	0.0404	7.7109

1.6485	8.2425	1.0149	1.0149	25.00	0.0406	8.2425
1.7417	8.7084	1.0201	1.0201	25.00	0.0408	8.7084
1.8586	9.2932	1.0250	1.0250	25.00	0.0410	9.2932
1.5449	7.7243	1.0301	1.0301	25.00	0.0412	7.7243
1.5874	7.9371	1.0350	1.0350	25.00	0.0414	7.9371
1.5469	7.7344	1.0399	1.0399	25.00	0.0416	7.7344
1.4024	7.0121	1.0450	1.0450	25.00	0.0418	7.0121
1.3573	6.7865	1.0499	1.0499	25.00	0.0420	6.7865
1.7319	8.6595	1.0551	1.0551	25.00	0.0422	8.6595
1.4424	7.2121	1.0599	1.0599	25.00	0.0424	7.2121
1.3273	6.6366	1.0651	1.0651	25.00	0.0426	6.6366
1.6197	8.0984	1.0700	1.0700	25.00	0.0428	8.0984
1.5138	7.5689	1.0749	1.0749	25.00	0.0430	7.5689
1.7792	8.8961	1.0801	1.0801	25.00	0.0432	8.8961
1.4770	7.3849	1.0849	1.0849	25.00	0.0434	7.3849
1.3354	6.6772	1.0900	1.0900	25.00	0.0436	6.6772
1.5442	7.7210	1.0949	1.0949	25.00	0.0438	7.7210
1.4610	7.3048	1.1001	1.1001	25.00	0.0440	7.3048
1.5781	7.8905	1.1051	1.1051	25.00	0.0442	7.8905
1.5619	7.8095	1.1099	1.1099	25.00	0.0444	7.8095
1.6767	8.3836	1.1151	1.1151	25.00	0.0446	8.3836
1.4696	7.3479	1.1199	1.1199	25.00	0.0448	7.3479
1.4137	7.0684	1.1251	1.1251	25.00	0.0450	7.0684
1.6007	8.0037	1.1299	1.1299	25.00	0.0452	8.0037
1.5060	7.5299	1.1351	1.1351	25.00	0.0454	7.5299
1.5806	7.9028	1.1400	1.1400	25.00	0.0456	7.9028
1.6003	8.0016	1.1449	1.1449	25.00	0.0458	8.0016
1.4880	7.4401	1.1501	1.1501	25.00	0.0460	7.4401
1.5206	7.6031	1.1549	1.1549	25.00	0.0462	7.6031
1.4404	7.2019	1.1602	1.1602	25.00	0.0464	7.2019
1.4460	7.2302	1.1649	1.1649	25.00	0.0466	7.2302
1.2630	6.3152	1.1699	1.1699	25.00	0.0468	6.3152
1.6918	8.4588	1.1751	1.1751	25.00	0.0470	8.4588
1.9060	9.5302	1.1799	1.1799	25.00	0.0472	9.5302
1.6928	8.4639	1.1851	1.1851	25.00	0.0474	8.4639
1.5442	7.7208	1.1899	1.1899	25.00	0.0476	7.7208
1.6724	8.3618	1.1953	1.1953	25.00	0.0478	8.3618
1.3886	6.9432	1.1999	1.1999	25.00	0.0480	6.9432
1.8248	9.1241	1.2051	1.2051	25.00	0.0482	9.1241
1.6332	8.1661	1.2101	1.2101	25.00	0.0484	8.1661
1.3996	6.9978	1.2149	1.2149	25.00	0.0486	6.9978
1.5091	7.5454	1.2201	1.2201	25.00	0.0488	7.5454
1.4139	7.0693	1.2249	1.2249	25.00	0.0490	7.0693
1.7651	8.8254	1.2301	1.2301	25.00	0.0492	8.8254

1.7111	8.5553	1.2350	1.2350	25.00	0.0494	8.5553
1.4236	7.1180	1.2399	1.2399	25.00	0.0496	7.1180
1.5561	7.7805	1.2451	1.2451	25.00	0.0498	7.7805
1.4461	7.2306	1.2499	1.2499	25.00	0.0500	7.2306
1.3696	6.8479	1.2551	1.2551	25.00	0.0502	6.8479
1.6733	8.3666	1.2599	1.2599	25.00	0.0504	8.3666
1.5047	7.5237	1.2649	1.2649	25.00	0.0506	7.5237
1.6495	8.2475	1.2701	1.2701	25.00	0.0508	8.2475
1.2952	6.4759	1.2749	1.2749	25.00	0.0510	6.4759
1.7330	8.6650	1.2801	1.2801	25.00	0.0512	8.6650
1.2828	6.4140	1.2850	1.2850	25.00	0.0514	6.4140
1.5050	7.5249	1.2901	1.2901	25.00	0.0516	7.5249
1.7469	8.7346	1.2950	1.2950	25.00	0.0518	8.7346
1.4521	7.2606	1.2999	1.2999	25.00	0.0520	7.2606
1.6874	8.4370	1.3050	1.3050	25.00	0.0522	8.4370
1.4246	7.1228	1.3099	1.3099	25.00	0.0524	7.1228
1.1730	5.8650	1.3151	1.3151	25.00	0.0526	5.8650
1.4666	7.3329	1.3199	1.3199	25.00	0.0528	7.3329
1.4295	7.1477	1.3249	1.3249	25.00	0.0530	7.1477
1.3919	6.9595	1.3302	1.3302	25.00	0.0532	6.9595
2.1386	10.6928	1.3350	1.3350	25.00	0.0534	10.6928
1.0071	5.0353	1.3400	1.3400	25.00	0.0536	5.0353
1.5445	7.7225	1.3450	1.3450	25.00	0.0538	7.7225
1.5918	7.9592	1.3500	1.3500	25.00	0.0540	7.9592
1.7148	8.5741	1.3550	1.3550	25.00	0.0542	8.5741
1.6204	8.1018	1.3599	1.3599	25.00	0.0544	8.1018
1.3559	6.7795	1.3651	1.3651	25.00	0.0546	6.7795
1.8162	9.0810	1.3699	1.3699	25.00	0.0548	9.0810
1.6489	8.2444	1.3751	1.3751	25.00	0.0550	8.2444
1.8613	9.3066	1.3799	1.3799	25.00	0.0552	9.3066
1.4563	7.2815	1.3851	1.3851	25.00	0.0554	7.2815
1.6857	8.4285	1.3900	1.3900	25.00	0.0556	8.4285
1.4518	7.2589	1.3949	1.3949	25.00	0.0558	7.2589
1.7873	8.9365	1.4001	1.4001	25.00	0.0560	8.9365
1.3795	6.8977	1.4049	1.4049	25.00	0.0562	6.8977
2.2380	11.1899	1.4101	1.4101	25.00	0.0564	11.1899
1.2998	6.4989	1.4149	1.4149	25.00	0.0566	6.4989
1.5123	7.5613	1.4201	1.4201	25.00	0.0568	7.5613
1.5735	7.8674	1.4251	1.4251	25.00	0.0570	7.8674
0.8382	4.1909	1.4299	1.4299	25.00	0.0572	4.1909
1.6102	8.0509	1.4351	1.4351	25.00	0.0574	8.0509
1.2308	6.1541	1.4399	1.4399	25.00	0.0576	6.1541
1.4599	7.2996	1.4452	1.4452	25.00	0.0578	7.2996
1.5401	7.7003	1.4499	1.4499	25.00	0.0580	7.7003

1.7347	8.6736	1.4550	1.4550	25.00	0.0582	8.6736
1.7016	8.5082	1.4601	1.4601	25.00	0.0584	8.5082
1.6170	8.0852	1.4649	1.4649	25.00	0.0586	8.0852
1.5333	7.6666	1.4701	1.4701	25.00	0.0588	7.6666
1.3138	6.5688	1.4749	1.4749	25.00	0.0590	6.5688
1.9146	9.5729	1.4801	1.4801	25.00	0.0592	9.5729
1.5125	7.5625	1.4850	1.4850	25.00	0.0594	7.5625
1.2795	6.3973	1.4899	1.4899	25.00	0.0596	6.3973
1.5100	7.5498	1.4950	1.4950	25.00	0.0598	7.5498
1.5128	7.5642	1.4999	1.4999	25.00	0.0600	7.5642
1.7070	8.5351	1.5051	1.5051	25.00	0.0602	8.5351
1.4226	7.1130	1.5099	1.5099	25.00	0.0604	7.1130
1.9842	9.9208	1.5149	1.5149	25.00	0.0606	9.9208
1.6731	8.3653	1.5201	1.5201	25.00	0.0608	8.3653
1.6617	8.3087	1.5249	1.5249	25.00	0.0610	8.3087
1.8805	9.4027	1.5300	1.5300	25.00	0.0612	9.4027
1.7125	8.5625	1.5350	1.5350	25.00	0.0614	8.5625
1.5802	7.9008	1.5400	1.5400	25.00	0.0616	7.9008
1.5344	7.6721	1.5449	1.5449	25.00	0.0618	7.6721
1.5545	7.7723	1.5499	1.5499	25.00	0.0620	7.7723
1.7347	8.6736	1.5551	1.5551	25.00	0.0622	8.6736
1.8188	9.0940	1.5599	1.5599	25.00	0.0624	9.0940
1.2766	6.3828	1.5652	1.5652	25.00	0.0626	6.3828
1.6343	8.1717	1.5699	1.5699	25.00	0.0628	8.1717
1.2207	6.1036	1.5749	1.5749	25.00	0.0630	6.1036
1.5565	7.7823	1.5801	1.5801	25.00	0.0632	7.7823
1.5386	7.6932	1.5849	1.5849	25.00	0.0634	7.6932
1.6553	8.2767	1.5900	1.5900	25.00	0.0636	8.2767
1.5166	7.5831	1.5949	1.5949	25.00	0.0638	7.5831
1.3606	6.8031	1.6001	1.6001	25.00	0.0640	6.8031
1.6176	8.0882	1.6051	1.6051	25.00	0.0642	8.0882
1.7876	8.9381	1.6099	1.6099	25.00	0.0644	8.9381
1.5643	7.8213	1.6151	1.6151	25.00	0.0646	7.8213
1.5724	7.8621	1.6199	1.6199	25.00	0.0648	7.8621
1.9020	9.5099	1.6238	1.6238	25.00	0.0650	9.5099

Table A.3: Tensile result for PP-clay nanocomposite 3wt%

Load N	Stress	Extension mm	Elong	lo	strain	Stress
0.2739	1.3695	-4.4213	0.0000	25.00	0.0000	1.3695
0.3050	1.5250	-4.4190	0.0023	25.00	0.0001	1.5250
0.0889	0.4443	-4.4118	0.0094	25.00	0.0004	0.4443
0.5925	2.9625	-4.4066	0.0147	25.00	0.0006	2.9625
0.7076	3.5380	-4.4013	0.0199	25.00	0.0008	3.5380
0.8916	4.4582	-4.3961	0.0251	25.00	0.0010	4.4582
1.3602	6.8011	-4.3913	0.0299	25.00	0.0012	6.8011
1.6583	8.2915	-4.3863	0.0350	25.00	0.0014	8.2915
2.4006	12.0030	-4.3813	0.0399	25.00	0.0016	12.0030
2.3529	11.7645	-4.3761	0.0451	25.00	0.0018	11.7645
3.1456	15.7281	-4.3713	0.0500	25.00	0.0020	15.7281
3.7714	18.8568	-4.3663	0.0550	25.00	0.0022	18.8568
4.8224	24.1118	-4.3612	0.0601	25.00	0.0024	24.1118
5.4564	27.2822	-4.3563	0.0649	25.00	0.0026	27.2822
6.6527	33.2637	-4.3512	0.0701	25.00	0.0028	33.2637
9.0580	45.2900	-4.3464	0.0749	25.00	0.0030	45.2900
12.1881	60.9405	-4.3413	0.0800	25.00	0.0032	60.9405
15.6207	78.1033	-4.3362	0.0851	25.00	0.0034	78.1033
18.9988	94.9938	-4.3313	0.0900	25.00	0.0036	94.9938
22.1036	110.5179	-4.3262	0.0951	25.00	0.0038	110.5179
25.1226	125.6131	-4.3213	0.0999	25.00	0.0040	125.6131
27.9242	139.6209	-4.3161	0.1051	25.00	0.0042	139.6209
30.9288	154.6440	-4.3113	0.1099	25.00	0.0044	154.6440
34.4072	172.0359	-4.3063	0.1150	25.00	0.0046	172.0359
37.8014	189.0071	-4.3011	0.1201	25.00	0.0048	189.0071
41.2039	206.0193	-4.2963	0.1249	25.00	0.0050	206.0193
44.6968	223.4840	-4.2912	0.1301	25.00	0.0052	223.4840
47.9695	239.8476	-4.2863	0.1349	25.00	0.0054	239.8476
51.3957	256.9783	-4.2812	0.1401	25.00	0.0056	256.9783
54.9984	274.9918	-4.2762	0.1451	25.00	0.0058	274.9918
58.1118	290.5588	-4.2713	0.1500	25.00	0.0060	290.5588
61.6930	308.4651	-4.2662	0.1551	25.00	0.0062	308.4651
64.3881	321.9403	-4.2614	0.1599	25.00	0.0064	321.9403
68.0808	340.4038	-4.2562	0.1651	25.00	0.0066	340.4038
71.1282	355.6410	-4.2513	0.1699	25.00	0.0068	355.6410
74.2464	371.2318	-4.2463	0.1750	25.00	0.0070	371.2318
77.2973	386.4864	-4.2411	0.1801	25.00	0.0072	386.4864
80.3340	401.6701	-4.2364	0.1849	25.00	0.0074	401.6701
83.3672	416.8362	-4.2311	0.1901	25.00	0.0076	416.8362
86.5963	432.9817	-4.2264	0.1949	25.00	0.0078	432.9817

89.2159	446.0796	-4.2211	0.2001	25.00	0.0080	446.0796
92.6897	463.4486	-4.2163	0.2050	25.00	0.0082	463.4486
95.1467	475.7336	-4.2113	0.2100	25.00	0.0084	475.7336
98.1689	490.8447	-4.2060	0.2152	25.00	0.0086	490.8447
101.0396	505.1980	-4.2014	0.2199	25.00	0.0088	505.1980
103.8210	519.1050	-4.1961	0.2251	25.00	0.0090	519.1050
106.5554	532.7770	-4.1914	0.2299	25.00	0.0092	532.7770
109.2569	546.2845	-4.1861	0.2351	25.00	0.0094	546.2845
112.2488	561.2440	-4.1812	0.2401	25.00	0.0096	561.2440
114.2870	571.4350	-4.1763	0.2449	25.00	0.0098	571.4350
117.5249	587.6245	-4.1711	0.2501	25.00	0.0100	587.6245
119.8115	599.0575	-4.1663	0.2549	25.00	0.0102	599.0575
122.5802	612.9010	-4.1611	0.2602	25.00	0.0104	612.9010
124.8661	624.3305	-4.1563	0.2649	25.00	0.0106	624.3305
127.7874	638.9370	-4.1512	0.2701	25.00	0.0108	638.9370
130.2689	651.3445	-4.1461	0.2752	25.00	0.0110	651.3445
132.3702	661.8510	-4.1413	0.2799	25.00	0.0112	661.8510
134.7059	673.5295	-4.1362	0.2851	25.00	0.0114	673.5295
137.4439	687.2195	-4.1313	0.2899	25.00	0.0116	687.2195
139.8373	699.1865	-4.1261	0.2952	25.00	0.0118	699.1865
141.7770	708.8850	-4.1213	0.3000	25.00	0.0120	708.8850
144.1168	720.5840	-4.1161	0.3051	25.00	0.0122	720.5840
146.1138	730.5690	-4.1112	0.3101	25.00	0.0124	730.5690
148.0952	740.4760	-4.1063	0.3150	25.00	0.0126	740.4760
150.2702	751.3510	-4.1011	0.3201	25.00	0.0128	751.3510
152.6801	763.4005	-4.0964	0.3248	25.00	0.0130	763.4005
154.5492	772.7460	-4.0913	0.3300	25.00	0.0132	772.7460
156.8729	784.3645	-4.0863	0.3350	25.00	0.0134	784.3645
158.6155	793.0775	-4.0812	0.3401	25.00	0.0136	793.0775
160.7290	803.6450	-4.0761	0.3451	25.00	0.0138	803.6450
162.5933	812.9665	-4.0713	0.3500	25.00	0.0140	812.9665
164.3180	821.5900	-4.0661	0.3551	25.00	0.0142	821.5900
166.6310	833.1550	-4.0613	0.3599	25.00	0.0144	833.1550
168.2671	841.3355	-4.0562	0.3651	25.00	0.0146	841.3355
169.9729	849.8645	-4.0511	0.3701	25.00	0.0148	849.8645
171.7691	858.8455	-4.0463	0.3750	25.00	0.0150	858.8455
173.5333	867.6665	-4.0413	0.3800	25.00	0.0152	867.6665
175.5281	877.6405	-4.0363	0.3850	25.00	0.0154	877.6405
176.8830	884.4150	-4.0313	0.3900	25.00	0.0156	884.4150
178.7489	893.7445	-4.0263	0.3950	25.00	0.0158	893.7445
180.6816	903.4080	-4.0213	0.4000	25.00	0.0160	903.4080
182.1484	910.7420	-4.0161	0.4051	25.00	0.0162	910.7420
183.3758	916.8790	-4.0113	0.4099	25.00	0.0164	916.8790
184.9800	924.9000	-4.0062	0.4151	25.00	0.0166	924.9000

186.5575	932.7875	-4.0013	0.4200	25.00	0.0168	932.7875
188.1597	940.7985	-3.9963	0.4249	25.00	0.0170	940.7985
189.7078	948.5390	-3.9912	0.4301	25.00	0.0172	948.5390
191.0377	955.1885	-3.9864	0.4349	25.00	0.0174	955.1885
192.7033	963.5165	-3.9811	0.4401	25.00	0.0176	963.5165
95.3543	476.7713	-3.9776	0.4436	25.00	0.0177	476.7713

Table A.4: Tensile result for PP-clay nanocomposite 5wt%

Load N	Stress	Extension mm	Elong	lo	strain	Stress
-0.0380	-0.1900	-8.7971	0.0000	25.0	0.0000	-0.1900
0.0623	0.3114	-8.7945	0.0026	25.0	0.0001	0.3114
0.3550	1.7748	-8.7877	0.0094	25.0	0.0004	1.7748
0.4923	2.4615	-8.7823	0.0148	25.0	0.0006	2.4615
0.6823	3.4117	-8.7771	0.0201	25.0	0.0008	3.4117
1.3259	6.6296	-8.7723	0.0249	25.0	0.0010	6.6296
1.6095	8.0474	-8.7671	0.0301	25.0	0.0012	8.0474
2.4912	12.4559	-8.7623	0.0349	25.0	0.0014	12.4559
3.1027	15.5136	-8.7570	0.0401	25.0	0.0016	15.5136
3.9904	19.9522	-8.7522	0.0449	25.0	0.0018	19.9522
4.9171	24.5855	-8.7472	0.0499	25.0	0.0020	24.5855
5.4913	27.4565	-8.7420	0.0551	25.0	0.0022	27.4565
6.3392	31.6961	-8.7373	0.0599	25.0	0.0024	31.6961
7.4316	37.1578	-8.7320	0.0651	25.0	0.0026	37.1578
9.2431	46.2155	-8.7273	0.0699	25.0	0.0028	46.2155
12.1708	60.8538	-8.7221	0.0751	25.0	0.0030	60.8538
15.3393	76.6964	-8.7171	0.0800	25.0	0.0032	76.6964
18.0129	90.0645	-8.7121	0.0850	25.0	0.0034	90.0645
21.1460	105.7300	-8.7071	0.0901	25.0	0.0036	105.7300
23.8447	119.2236	-8.7023	0.0949	25.0	0.0038	119.2236
26.8029	134.0144	-8.6970	0.1001	25.0	0.0040	134.0144
29.5998	147.9991	-8.6923	0.1049	25.0	0.0042	147.9991
31.9836	159.9179	-8.6871	0.1101	25.0	0.0044	159.9179
35.1343	175.6714	-8.6819	0.1152	25.0	0.0046	175.6714
38.0948	190.4738	-8.6771	0.1200	25.0	0.0048	190.4738
41.1387	205.6933	-8.6721	0.1250	25.0	0.0050	205.6933
44.2573	221.2866	-8.6672	0.1299	25.0	0.0052	221.2866
47.0106	235.0528	-8.6620	0.1351	25.0	0.0054	235.0528
50.1194	250.5969	-8.6571	0.1400	25.0	0.0056	250.5969
52.6850	263.4249	-8.6521	0.1450	25.0	0.0058	263.4249
55.6679	278.3396	-8.6471	0.1501	25.0	0.0060	278.3396
58.5997	292.9984	-8.6422	0.1549	25.0	0.0062	292.9984

61.2572	306.2858	-8.6371	0.1601	25.0	0.0064	306.2858
64.0101	320.0507	-8.6323	0.1649	25.0	0.0066	320.0507
66.5738	332.8691	-8.6271	0.1701	25.0	0.0068	332.8691
69.2569	346.2846	-8.6221	0.1751	25.0	0.0070	346.2846
71.7009	358.5047	-8.6171	0.1800	25.0	0.0072	358.5047
74.3625	371.8123	-8.6121	0.1850	25.0	0.0074	371.8123
77.0765	385.3824	-8.6071	0.1900	25.0	0.0076	385.3824
79.3238	396.6190	-8.6020	0.1951	25.0	0.0078	396.6190
81.9435	409.7173	-8.5973	0.1999	25.0	0.0080	409.7173
84.0245	420.1225	-8.5922	0.2049	25.0	0.0082	420.1225
86.7723	433.8615	-8.5870	0.2101	25.0	0.0084	433.8615
89.1798	445.8988	-8.5821	0.2150	25.0	0.0086	445.8988
91.4750	457.3752	-8.5771	0.2201	25.0	0.0088	457.3752
93.8293	469.1464	-8.5722	0.2249	25.0	0.0090	469.1464
96.0755	480.3773	-8.5671	0.2300	25.0	0.0092	480.3773
98.4025	492.0123	-8.5621	0.2350	25.0	0.0094	492.0123
100.6745	503.3725	-8.5571	0.2400	25.0	0.0096	503.3725
102.8896	514.4480	-8.5520	0.2451	25.0	0.0098	514.4480
105.0422	525.2110	-8.5472	0.2499	25.0	0.0100	525.2110
107.2536	536.2680	-8.5420	0.2551	25.0	0.0102	536.2680
109.0486	545.2430	-8.5372	0.2599	25.0	0.0104	545.2430
111.3817	556.9085	-8.5323	0.2649	25.0	0.0106	556.9085
113.2635	566.3175	-8.5270	0.2701	25.0	0.0108	566.3175
115.3725	576.8625	-8.5222	0.2749	25.0	0.0110	576.8625
117.5054	587.5270	-8.5171	0.2801	25.0	0.0112	587.5270
119.4363	597.1815	-8.5123	0.2849	25.0	0.0114	597.1815
121.2324	606.1620	-8.5071	0.2901	25.0	0.0116	606.1620
123.3076	616.5380	-8.5022	0.2949	25.0	0.0118	616.5380
125.2095	626.0475	-8.4972	0.2999	25.0	0.0120	626.0475
127.1693	635.8465	-8.4920	0.3051	25.0	0.0122	635.8465
128.9310	644.6550	-8.4873	0.3099	25.0	0.0124	644.6550
130.6293	653.1465	-8.4820	0.3151	25.0	0.0126	653.1465
131.7815	658.9075	-8.4773	0.3199	25.0	0.0128	658.9075
133.6794	668.3970	-8.4721	0.3251	25.0	0.0130	668.3970
135.5440	677.7200	-8.4671	0.3301	25.0	0.0132	677.7200
137.2456	686.2280	-8.4622	0.3349	25.0	0.0134	686.2280
138.9986	694.9930	-8.4570	0.3401	25.0	0.0136	694.9930
140.4495	702.2475	-8.4523	0.3449	25.0	0.0138	702.2475
141.4107	707.0535	-8.4470	0.3501	25.0	0.0140	707.0535
143.2168	716.0840	-8.4422	0.3549	25.0	0.0142	716.0840
144.5506	722.7530	-8.4371	0.3601	25.0	0.0144	722.7530
145.8575	729.2875	-8.4319	0.3652	25.0	0.0146	729.2875
146.7186	733.5930	-8.4272	0.3699	25.0	0.0148	733.5930
147.3001	736.5005	-8.4221	0.3751	25.0	0.0150	736.5005

147.0085	735.0425	-8.4173	0.3799	25.0	0.0152	735.0425
147.0001	735.0005	-8.4119	0.3852	25.0	0.0154	735.0005
147.3588	736.7940	-8.4071	0.3900	25.0	0.0156	736.7940
147.9070	739.5350	-8.4021	0.3950	25.0	0.0158	739.5350
148.2157	741.0785	-8.3970	0.4001	25.0	0.0160	741.0785
139.1720	695.8600	-8.3922	0.4049	25.0	0.0162	695.8600
137.7120	688.5600	-8.3870	0.4101	25.0	0.0164	688.5600
137.1473	685.7365	-8.3823	0.4149	25.0	0.0166	685.7365
-4.4301	-22.1504	-8.3770	0.4201	25.0	0.0168	-22.1504
0.8128	4.0639	-8.3721	0.4251	25.0	0.0170	4.0639
0.9044	4.5218	-8.3671	0.4300	25.0	0.0172	4.5218
0.8619	4.3096	-8.3622	0.4349	25.0	0.0174	4.3096
0.4171	2.0857	-8.3571	0.4400	25.0	0.0176	2.0857
0.7506	3.7528	-8.3520	0.4451	25.0	0.0178	3.7528
1.0097	5.0487	-8.3473	0.4498	25.0	0.0180	5.0487
0.7472	3.7358	-8.3421	0.4550	25.0	0.0182	3.7358
0.9415	4.7074	-8.3370	0.4601	25.0	0.0184	4.7074
0.9776	4.8880	-8.3321	0.4650	25.0	0.0186	4.8880
0.5685	2.8425	-8.3271	0.4700	25.0	0.0188	2.8425
0.8379	4.1894	-8.3222	0.4749	25.0	0.0190	4.1894
0.7107	3.5535	-8.3171	0.4800	25.0	0.0192	3.5535
0.8338	4.1691	-8.3121	0.4850	25.0	0.0194	4.1691
0.8697	4.3487	-8.3071	0.4901	25.0	0.0196	4.3487
0.7098	3.5491	-8.3020	0.4951	25.0	0.0198	3.5491
0.7811	3.9057	-8.2972	0.4999	25.0	0.0200	3.9057
0.7347	3.6737	-8.2920	0.5051	25.0	0.0202	3.6737
0.9473	4.7364	-8.2872	0.5099	25.0	0.0204	4.7364
0.7612	3.8058	-8.2822	0.5149	25.0	0.0206	3.8058
1.0044	5.0219	-8.2770	0.5201	25.0	0.0208	5.0219
0.8824	4.4121	-8.2722	0.5249	25.0	0.0210	4.4121
1.0102	5.0512	-8.2671	0.5300	25.0	0.0212	5.0512
0.8081	4.0405	-8.2622	0.5349	25.0	0.0214	4.0405
1.0223	5.1116	-8.2571	0.5401	25.0	0.0216	5.1116
0.8054	4.0271	-8.2521	0.5450	25.0	0.0218	4.0271
0.6845	3.4226	-8.2472	0.5499	25.0	0.0220	3.4226
0.8796	4.3981	-8.2419	0.5552	25.0	0.0222	4.3981
0.7511	3.7553	-8.2372	0.5599	25.0	0.0224	3.7553
1.0127	5.0635	-8.2320	0.5651	25.0	0.0226	5.0635
0.9380	4.6900	-8.2273	0.5699	25.0	0.0228	4.6900
0.7994	3.9971	-8.2221	0.5750	25.0	0.0230	3.9971
0.9882	4.9409	-8.2171	0.5801	25.0	0.0232	4.9409
0.7689	3.8446	-8.2121	0.5850	25.0	0.0234	3.8446
1.0149	5.0746	-8.2071	0.5901	25.0	0.0236	5.0746
0.7522	3.7608	-8.2023	0.5949	25.0	0.0238	3.7608

0.4912	2.4558	-8.1971	0.6001	25.0	0.0240	2.4558
1.1423	5.7117	-8.1922	0.6049	25.0	0.0242	5.7117
0.7784	3.8922	-8.1870	0.6101	25.0	0.0244	3.8922
0.6303	3.1514	-8.1819	0.6152	25.0	0.0246	3.1514
1.0541	5.2704	-8.1772	0.6199	25.0	0.0248	5.2704
0.8157	4.0783	-8.1721	0.6251	25.0	0.0250	4.0783
0.9073	4.5363	-8.1672	0.6299	25.0	0.0252	4.5363
0.7183	3.5915	-8.1619	0.6352	25.0	0.0254	3.5915
0.8579	4.2896	-8.1572	0.6399	25.0	0.0256	4.2896
1.0840	5.4201	-8.1522	0.6449	25.0	0.0258	5.4201
0.8627	4.3137	-8.1471	0.6501	25.0	0.0260	4.3137
0.8686	4.3430	-8.1423	0.6549	25.0	0.0262	4.3430
0.9250	4.6250	-8.1370	0.6601	25.0	0.0264	4.6250
0.8747	4.3736	-8.1322	0.6649	25.0	0.0266	4.3736
0.9504	4.7522	-8.1271	0.6701	25.0	0.0268	4.7522
0.9055	4.5276	-8.1220	0.6751	25.0	0.0270	4.5276
0.8120	4.0598	-8.1171	0.6800	25.0	0.0272	4.0598
0.7213	3.6065	-8.1122	0.6849	25.0	0.0274	3.6065
1.0592	5.2960	-8.1072	0.6899	25.0	0.0276	5.2960
0.9912	4.9561	-8.1020	0.6951	25.0	0.0278	4.9561
0.7353	3.6767	-8.0973	0.6999	25.0	0.0280	3.6767
0.8748	4.3740	-8.0921	0.7051	25.0	0.0282	4.3740
1.0563	5.2816	-8.0869	0.7102	25.0	0.0284	5.2816
0.5394	2.6970	-8.0821	0.7151	25.0	0.0286	2.6970
0.6398	3.1990	-8.0771	0.7201	25.0	0.0288	3.1990
0.7353	3.6763	-8.0722	0.7249	25.0	0.0290	3.6763
0.8944	4.4722	-8.0671	0.7300	25.0	0.0292	4.4722
0.6492	3.2460	-8.0621	0.7350	25.0	0.0294	3.2460
0.9034	4.5169	-8.0571	0.7401	25.0	0.0296	4.5169
0.6594	3.2971	-8.0520	0.7451	25.0	0.0298	3.2971
0.8832	4.4162	-8.0472	0.7499	25.0	0.0300	4.4162
1.2355	6.1775	-8.0420	0.7551	25.0	0.0302	6.1775
0.8045	4.0226	-8.0372	0.7599	25.0	0.0304	4.0226
0.7581	3.7903	-8.0322	0.7649	25.0	0.0306	3.7903
0.8469	4.2347	-8.0270	0.7701	25.0	0.0308	4.2347
0.4881	2.4404	-8.0222	0.7749	25.0	0.0310	2.4404
0.6815	3.4077	-8.0171	0.7801	25.0	0.0312	3.4077
0.6742	3.3710	-8.0123	0.7849	25.0	0.0314	3.3710
0.8856	4.4280	-8.0070	0.7901	25.0	0.0316	4.4280
0.7927	3.9633	-8.0021	0.7950	25.0	0.0318	3.9633
1.0185	5.0927	-7.9971	0.8000	25.0	0.0320	5.0927
1.0318	5.1592	-7.9920	0.8051	25.0	0.0322	5.1592
0.5600	2.7998	-7.9873	0.8099	25.0	0.0324	2.7998
0.7773	3.8866	-7.9820	0.8151	25.0	0.0326	3.8866

0.8407	4.2035	-7.9773	0.8199	25.0	0.0328	4.2035
0.9246	4.6232	-7.9721	0.8251	25.0	0.0330	4.6232
0.8379	4.1894	-7.9671	0.8300	25.0	0.0332	4.1894
0.7354	3.6768	-7.9622	0.8349	25.0	0.0334	3.6768
1.0987	5.4935	-7.9570	0.8401	25.0	0.0336	5.4935
0.8159	4.0795	-7.9523	0.8449	25.0	0.0338	4.0795
0.8731	4.3656	-7.9470	0.8501	25.0	0.0340	4.3656
1.0953	5.4767	-7.9423	0.8549	25.0	0.0342	5.4767
0.8253	4.1266	-7.9371	0.8601	25.0	0.0344	4.1266
0.7761	3.8803	-7.9320	0.8651	25.0	0.0346	3.8803
0.5330	2.6650	-7.9272	0.8699	25.0	0.0348	2.6650
0.5841	2.9205	-7.9221	0.8751	25.0	0.0350	2.9205
1.0480	5.2402	-7.9172	0.8799	25.0	0.0352	5.2402
0.6852	3.4262	-7.9119	0.8852	25.0	0.0354	3.4262
1.0465	5.2327	-7.9071	0.8900	25.0	0.0356	5.2327
0.4829	2.4145	-7.9021	0.8951	25.0	0.0358	2.4145
0.6067	3.0335	-7.8971	0.9001	25.0	0.0360	3.0335
0.9784	4.8919	-7.8923	0.9049	25.0	0.0362	4.8919
0.6185	3.0923	-7.8871	0.9100	25.0	0.0364	3.0923
0.7747	3.8733	-7.8823	0.9149	25.0	0.0366	3.8733
0.9374	4.6870	-7.8771	0.9201	25.0	0.0368	4.6870
0.8417	4.2084	-7.8720	0.9251	25.0	0.0370	4.2084
1.1539	5.7693	-7.8671	0.9301	25.0	0.0372	5.7693
0.9489	4.7447	-7.8622	0.9349	25.0	0.0374	4.7447
0.8901	4.4506	-7.8571	0.9400	25.0	0.0376	4.4506
0.8886	4.4432	-7.8520	0.9451	25.0	0.0378	4.4432
0.5795	2.8974	-7.8473	0.9498	25.0	0.0380	2.8974
1.2641	6.3205	-7.8421	0.9550	25.0	0.0382	6.3205
0.7975	3.9875	-7.8370	0.9601	25.0	0.0384	3.9875
0.8448	4.2242	-7.8321	0.9650	25.0	0.0386	4.2242
0.7285	3.6427	-7.8271	0.9701	25.0	0.0388	3.6427
0.9737	4.8684	-7.8221	0.9750	25.0	0.0390	4.8684
0.8269	4.1346	-7.8171	0.9801	25.0	0.0392	4.1346
1.0539	5.2696	-7.8121	0.9851	25.0	0.0394	5.2696
0.8646	4.3229	-7.8071	0.9901	25.0	0.0396	4.3229
0.6913	3.4566	-7.8020	0.9951	25.0	0.0398	3.4566
0.8913	4.4567	-7.7972	0.9999	25.0	0.0400	4.4567
1.1612	5.8059	-7.7921	1.0051	25.0	0.0402	5.8059
0.4430	2.2150	-7.7872	1.0099	25.0	0.0404	2.2150
0.7430	3.7151	-7.7823	1.0149	25.0	0.0406	3.7151
1.0054	5.0272	-7.7770	1.0201	25.0	0.0408	5.0272
0.9030	4.5152	-7.7721	1.0250	25.0	0.0410	4.5152
0.7492	3.7459	-7.7671	1.0301	25.0	0.0412	3.7459
0.6705	3.3526	-7.7622	1.0349	25.0	0.0414	3.3526

0.7382	3.6911	-7.7571	1.0400	25.0	0.0416	3.6911
0.9799	4.8993	-7.7522	1.0449	25.0	0.0418	4.8993
0.7833	3.9163	-7.7472	1.0499	25.0	0.0420	3.9163
0.6022	3.0109	-7.7419	1.0552	25.0	0.0422	3.0109
0.7387	3.6937	-7.7372	1.0599	25.0	0.0424	3.6937
0.7882	3.9412	-7.7320	1.0651	25.0	0.0426	3.9412
0.9031	4.5153	-7.7272	1.0699	25.0	0.0428	4.5153
0.7144	3.5722	-7.7221	1.0750	25.0	0.0430	3.5722
0.8469	4.2346	-7.7171	1.0801	25.0	0.0432	4.2346
0.7431	3.7155	-7.7122	1.0849	25.0	0.0434	3.7155
1.0419	5.2093	-7.7070	1.0901	25.0	0.0436	5.2093
0.6518	3.2590	-7.7023	1.0949	25.0	0.0438	3.2590
0.8698	4.3488	-7.6970	1.1001	25.0	0.0440	4.3488
1.1628	5.8142	-7.6922	1.1049	25.0	0.0442	5.8142
0.6569	3.2843	-7.6871	1.1101	25.0	0.0444	3.2843

Table A.5: Result for Hardness Test in HR15-T

Sample	1	2	3	avg
PP 30B 1%	83.46	81.93	80.1	72.92333
PP 30B 3%	78.58	60.11	80.08	81.83
PP 30B 5%	59.36	82.51	82.78	74.88333

Figure A.1: FTIR result