OIL PALM EMPTY FRUIT BUNCH PULP FILLED POLYPROPYLENE COMPOSITES USING HANDSHEET MAKING CONCEPT

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by

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LIST OF ABBREVIATIONS

AQ	Anthraquinone
ASTM	American Society for Testing and Materials
CMCs	ceramic matrix composites
DMT	Dynamic mechanical thermal
DTG	Derivative thermogravimetric
EDX	Energy Dispersion of X-Ray
EFB	Empty Fruit Bunches
FT-IR	Fourier Transform Infrared Spectroscopy
FRP	Fiber-reinforced plastic
ISO	International Organization of Standardization
MMCs	metal matrix composites
OPF	Oil Palm Fronds
OPT	Oil Palm Trunks
PP	Polypropylene
PMCs	Polymer matrix composites

POME	Palm oil mill effluent
PGW	Pressure groundwood
RMP	Refiner mechanical pulp
SEM	Scanning Electron Microscopy
SGW	Stone groundwood
TAPPI	Technical Association of the Pulp and Paper Industry
TEM	Transmission Electron Microscopy
TGA	Thermogravimetric Analysis
TMP	Thermomechanical pulp
Wt.	Weight
XRD	X-Ray Diffraction

LIST OF SYMBOLS

Å	Angstrom
%	Percentage
°C	Degree Celsius
cm	Centimetre
d	Thickness
G	Giga
g	Gram
k	Kilo
Kg	Kilogram
M	Mega
M	Mass
m	meter
mg	Milligram
mm	Millimetre
>	More than

$<$	Less than
Pa	Pascal
$T_{50\%}$	Degradation at 50% weight loss
T_f	Final decomposition temperature
T_g	Glass transition temperature
T_i	Initial decomposition temperature
T_{max}	Decomposition temperature
v	Volume
V	Volt
V_f	Volume fraction
B	Beta
Wt.	Weight
W_f	Weight fraction
X	Magnification
θ	Theta
λ	Lambda
ρ	Density

P_{fb} Fiber density

P_m Matrix density

KOMPOSIT POLIPROPILENA TERISI PALPA TANDAN KOSONG KELAPA SAWIT MENGGUNAKAN KONSEP PEMBUATAN KERTAS MAKMAL

ABSTRAK

Tandan buah kosong (EFB) kelapa sawit daripada sisa pertanian dan serbuk polipropilena telah digunakan untuk membentuk bio-komposit dengan menggunakan konsep permbuatan kertas makmal. Gentian EFB telah menjalani proses pemulpaan soda dan pulpa yang terhasil turut dicirikan. Pulpa soda EFB ditambah kedalam serbuk polipropilena mengikut peratusan 0, 10, 20, 30, 40 dan 50% berdasarkan jumlah keseluruhan komposisi komposit kertas makmal tersebut. Kumpulan berfungsi EFB dikenal pasti dengan menggunakan jelmaan Fourier spektroskopi inframerah (FT-IR). Analisis pembelauan sinar-X (XRD) telah digunakan untuk menentukan indeks penghabluran bahan dan ia didapati adalah sebanyak 52.79%. Kajian terperinci mengenai sifat-sifat komposit kertas makmal termasuklah sifat-sifat fizikal, mekanik, morfologi (analisis SEM) dan haba (analisis TGA). Kesemua sifat fizikal komposit kertas makmal meningkat dengan peningkatan jumlah gentian yang ditambah. Bagi sifat mekanik, nilainya meningkat apabila penambahan pulpa EFB sebanyak 10% tetapi sekiranya melebihi peratusan ini, nilai tersebut menurun. Tambahan pula, untuk kajian pemanjangan pada takat putus, nilai didapati berkurangan sejak permulaan gentian ditambah ke dalam komposit. Kajian morfologi (SEM) menunjukkan bahawa penambahan jumlah gentian ke dalam komposit membuatkan lebih banyak pemutusan gentian, penarikan keluar gentian, pengumpalan gentian dan ruangan kosong yang menyumbang kepada kerosakan matriks. Keputusan kestabilan terma menunjukan

peningkatan penambahan gentian pulpa EFB lebih daripada 10% akan meningkatan suhu penguraian komposit kertas makmal, suhu degradasi komposit kertas makmal adalah lebih rendah berbanding dengan suhu degradasi polipropilena tulen. Dari kajian ini didapati bahawa kandungan 10% gentian pulpa EFB adalah komposisi yang optimum untuk digunakan.

OIL PALM EMPTY FRUIT BUNCH PULP FILLED POLYPROPYLENE COMPOSITES USING HANDSHEET MAKING CONCEPT

ABSTRACT

Oil palm empty fruit bunch (EFB) from agriculture waste and polypropylene (PP) powder were used to form a bio-composite by using handsheet making concept and named as handsheet composite. The oil palm EFB underwent soda pulping process and the resultant pulp was further characterized. The EFB soda pulp was added to PP powder according to percentage of 0, 10, 20, 30, 40 and 50% in total composition of the composite. The functional group of the EFB was identified by using fourier transform infrared spectroscopy (FT-IR). The x-ray diffraction analysis (XRD) was used to determine the crystallinity index of the material which was found to be 52.79%. A detailed study on the properties of handsheet composites including physical properties, mechanical properties, morphological properties (SEM analysis) and thermal properties (TGA analysis) were conducted. All the physical properties of the handsheet composite increased as the fiber loading increased. On the mechanical properties, the value increased when the EFB pulp loading was 10% but exceeding this percentage the value started to decrease. Moreover, the value of elongation at break, found to decrease as the fiber loading were added into the composite. The SEM morphological showed that, as the addition of EFB fiber loading increased, more fiber fracture, fiber pull out, fiber agglomeration and void were in contributing the matrix breakage. The result of thermal stability showed that, the addition of oil palm EFB pulp fiber loading more than 10% would increase the decomposition temperature of the handsheet composite, but still the

degradation temperature of the handsheet composite was lower in comparison to the degradation temperature of neat polypropylene. Based on results obtained, it was found that 10% of EFB pulp fiber loading was the optimum composition to be used.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In achieving sustainable economic growth, the world moves towards environmental concern which variety of products were introduced in contributing to the green movement. It is essential and crucial in developing products with advanced properties and higher performance by the utilization of waste material which are relatively cheap, easily available (abundant) and environmentaly friendly (Khalil et al., 2012). Green resources such as the oil palm biomass become trendier among the researcher in developing a lignocellulosic product due to its properties. They are renewable, biodegradable, low cost, less equipment damage, and energy efficiency while promoting the sustainability concept (Jawaid and Khalil, 2011). Using natural materials incorporated with modern construction techniques can reduce construction waste and increases energy efficiency while promoting the concept of sustainability.

The natural materials can be harvested from the stem, leaves, or seeds of various plants (Dittenber and GangaRao, 2012). Malaysia which is the second largest country in oil palm plantation generate millions tons of oil palm waste each year. These by-products become the subject in developing various kinds of new products in many fields. Today, 4.49 million hectares of land in Malaysia is under oil palm cultivation and producing 17.73 million ton of palm oil and 2.13 tons of palm kernel oil. In Malaysia, for example, 62% of the agricultural land is covered by oil palm and one of the competitive strengths is to exploit the area where oil palm is cultivated (Basiron et al., 2004). The industry provides employment to more than half a million people and livelihood to an estimated one million people. Natural fiber-reinforced polymer composite materials have emerged in a wide spectrum of area of the polymer science. The composite materials produced from oil palm fibers and commercially available polymers have offered some specific properties that are comparable to conventional synthetic fiber composite materials (Hassan et al., 2010b).

The use of natural fiber from oil palm empty fruit bunch (EFB) becomes very trendy in this modern world and it is used for many applications at any work places. Due to environmental and financial concerns, natural fibers have become interested and fascinated nowadays to be used as an industrial material and structural material for rehabilitating of structures. Nowadays, the oil palm EFB is used as biofuel, fertilizer, and a mulching material because without proper management of this waste material can make environmental issues (Shinoj et al., 2011). The use of EFB as the main raw material along with any plastic based material in composite production is very effective in helping the reduction of environmental issues related to waste materials.

One of the important weaknesses of natural fiber including the oil palm fiber is the hydrophilic property of cellulose which impacts the weak interface bonding with hydrophobic polymer as a matrix. Natural fiber tends to absorb water in any condition especially in high humidity area which affects several mechanical properties and performance of the composite. However, these properties are greatly dependent on the compatibility of fibers and matrix phase as well as moisture absorption property which posse's critical issues to the oil palm fiber polymer composite materials. Apparently, moistue greatly affects the physical as well as mechanical properties of the composite materials. Consequently, various chemical surface modification methods of natural fiber are well documented in literature including alkaline treatment, acidity treatment, and addition of appropriate coupling agents to improve the material compatibility. Many experimental studies have been conducted to investigate the mechanical and physical properties of EFB composites recently (Mahjoub et al., 2013). For this study, the only factor to be studied on the composite compatibility is the physical interaction between EFB pulp and polypropylene (PP) powder.

Polypropylene (PP), also known as polypropene, is a thermoplastic polymer used in a wide variety of applications. It is an addition polymer made from the monomer propylene, which is rugged and unusually resistant to many chemical solvents, bases and acids (Kumar et al., 2014). PP has a relatively slippery "low energy surface" that means that many common glues will not form adequate joints with it. PP is, in many aspects, similar to polyethylene, especially in solution behavior and electrical properties. The additionally presence of methyl group in PP improves mechanical properties and thermal resistance, while the chemical resistance decreases (Tripathi, 2002). The application of polypropylene with natural fiber such as oil palm empty fruit bunch in composite technology is widely used nowadays. Based on the previous study, the incorporation of EFB and glass fibre into PP matrix has resulted in the reduction of flexural and tensile strengths (Rozman et al., 2001). There are numerous techniques in producing composite using these materials. Previous study shows that, oil palm empty fruit bunch ground particle–polypropylene (EFB–PP) composites were produced by employing 2 types of compounding techniques, that is, an internal mixer and a single-screw extruder(Rozman and Peng, 1998). Usually the EFB fiber will go through grinding process to turn the materials into sawdust or powder form for the mixing purpose during the compounding technique takes place. A uniform blend between the fiber and the resin is important to control the composites homogeneity. The fiber dimension of the ground fiber used in this process is different to be compare with fiber in pulp form as the fiber in pulp form consists of individual separated fiber that was separated well during the pulping process. Meanwhile for the ground fiber, as the grinding process was done, most of the fiber was chopped and cut into small pieces as the fiber turns into powder form. PP-EFB composite is a remarkable unique product. Thermoplastic composites made from lignocellulosic materials such as wood and cellulose is becoming more important (Wirjosentono et al., 2004a). The surface of the composites is flat, smooth, uniform, dense, and free of knots and grain patterns, making finishing operations easier and consistent. The homogenous edge of composites allows intricate and precise machining and finishing techniques. Improved stability and strength are important assets of these composites, with stability contributing to holding precise tolerances in accurately cut parts. It is an excellent substitute for solid wood in many interior applications and suitable to be apply in many applications, since the composites has such an even texture and consistent properties.

Composites that also be called as biocomposite indicate one of the main raw materials were originally comes from bioresource material like the natural fiber. The matrix (polymer) can be either thermoplastic or thermosetting polymer in which any of these plastic materials were combined with various techniques along with bioresource material in any form in producing the biocomposite material. Plant fibers which act as the reinforced material or filler in biocomposite materials include wood and non-wood such as cotton, flax, hemp, kenaf, etc., or by-products from crops comes under natural and renewable source. Depending on the natural fiber origin (seed, bast, leaf, and fruit), bast and leaf are the most commonly used in composite applications (Williams and Wool, 2000). Natural fibers exhibit different properties. This depends on type of plant and also parts of the plants. It is believe that different type of natural fiber from plants were used in specific application because of their chemical nature and properties which help improving certain factor in their performances.

The used of any kind of fiber as reinforced materials or fillers on any applications is really depends on many factor such as cost, mechanical aspects and more. Renewable or natural resins from vegetable oils and starches are gradually replacing the commonly used fossil fuel synthetic based polymers (Fowler et al., 2006). Researchers has outlined the major factors influencing the performance of the biocomposites materials, concluding that future prospect of these materials remains need of further research and development. However, the choice of suitable natural fibers depend on many factors such as elongation at failure, thermal stability, adhesion of fibers and matrix, dynamic and long-term behavior, final price, and processing cost (Nickel and Riedel, 2003).

1.2 Problem Statement

Oil palm biomass is one of natural fiber which is abundantly available across Malaysia. In Malaysia oil palm production creating massive amount of waste material each year in which most of them were used to generate electricity for the oil palm mill by steam boiling and also be used to produce various product such as fertilizer and composting material. Research is done to study about this precious waste material to develop green product towards the sustainable economic growth and higher human development which is affordable low cost and also has advanced performance properties in applications. With sufficient knowledge from the previous studies and scientific information, the utilization of oil palm biomass waste materials has been develop ed to promote the waste material into advanced material in producing handsheet composite by using the handsheet making concept. The progress in developing green movement product has bring huge advantages towards the environment in eliminate the disposal problem of waste material and also reducing the environment pollution and health issues.

Incorporating the oil palm EFB pulp with polypropylene powder in developing handsheet composite material helps reducing the agriculture waste at the same time reducing the usage of plastic material which is one of the materials that is hard to be dispose naturally. The handsheet making technique is simple and efficient which require simple tools and handling as well as low cost production and safe to be used. High demand of using plastic material from fossil fuel as the main source in plastic industry production is devastating to the environment as it takes thousands years to degrade the material. In this study, the biocomposites helps reducing the earth pollution by combining both bioresource material which is the natural fiber considered as waste product such as EFB pulp and also plastic material like polypropylene powder that lead to beneficial uses of agricultural waste in the same time reducing the usage of plastic material by combining with bioresource material. The utilization of oil palm EFB pulp into handsheet could at least reduce the environmental issues especially in this country which tons of biomass were created each year.

1.3 Objective of Study

The objectives of this present research are:

- To develop the natural fiber plastic composite with oil palm empty fruit bunch pulp as the reinforcement material and polypropylene powder as the matrix using handsheet making concept.
- To investigate the effect of empty fruit bunch pulp and polypropylene powder ratio on physical, mechanical, thermal and morphological properties of handsheet composites.

CHAPTER 2

LITERATURE REVIEW

2.1 Composites

Composites are comprised of individual materials which refer to as constituent materials. There are two principle classifications of constituent materials which is matrix and reinforcement (Hull and Clyne, 1996). The matrix material encompasses and backings the reinforcement materials by keeping up their relative positions (Šimkovic, 2008). The combinations give their uncommon mechanical and physical properties to upgrade the grid properties for example combining both natural fibers such as EFB with polypropylene in conventional way may increase the composite properties in certain applications. The composite created materials with properties which obtained from the individual constituent materials, while the wide assortment of grid and reinforcing materials permits the planner of the item or structure to pick an ideal combinations of materials. The individual segments stay partitioned and particular inside the completed structure. The new material might be favored for some reasons: basic cases incorporate materials which are stronger, lighter, or less costly when contrasted with conventional materials. In this new era, specialists have likewise started to effectively incorporate detecting, incitation, calculation and correspondence into composites (McEvoy and Correll, 2015).

Composite materials mostly utilized for extensions and structures, for example, pontoon bodies, swimming pool boards, race auto bodies, shower stalls, bathtubs, impersonation tank and refined marble sinks and ledges. The most progressive cases perform routinely on shuttle and flying machine in requesting situations (Rawal, 2001).

An assortment of moulding methods can be utilized by end-products requirements. The chief elements affecting the composites are the natures of the picked matrix and reinforcement materials (Tavares et al., 2007). Another vital element is the gross amount of material to be created. Vast amounts can be utilized to legitimize high capital consumptions for quick and computerized fabricating innovation. Small quantities amounts are suited with lower capital uses however higher work and tooling costs at a correspondingly slower rate. The relative tooling costs tend to increment geometrically with part measure, so that exclusive the least expensive and most simplest tooling alternatives are proper for the biggest segments. There is additionally a limitation because of accessible press size and compression limit, which imposes an upper limit on the size of mass-produced parts. Size may likewise be restricted by the inside measurements of autoclaves or stoves required for curing the moldings (Sain et al., 2005).

2.1.1 Classification of Composites

Composite materials are in general solids which obtained from the blend of two or more simple materials that build up a continuous and a dispersed phase. Composite materials represents to a combination of distinct materials which shows better qualities in correlation than each constitutive material considered independently. Despite the fact that the individual materials keep up their individual behavior on a macroscopic level in the composite, their association creates diverse attributes for the combination as a whole. The example for continuous and dispersed phase are polymers, metals, ceramic, glass fiber, carbon particles, silica powder, clay minerals, and so forth individually (Ruiz-Hitzky and Van Meerbeek, 2006). The properties of the composites are basically not quite the same as the original components. Presently the composites are being combined with nanomaterials where nanoscale fillers are utilized and the materials give multifunctional properties. Indeed, even a little expansion of nanoparticles can possibly radically change the properties of the origin polymer that it is utilized as a dispersed phase (Singh et al., 2014).

The classification of composites depends on the matrix and reinforcement phase of the materials. The characterization referring to matrix phase can be classified into three distinct composites type which is the polymer matrix composites (PMCs), metal matrix composites (MMCs), and ceramic matrix composites (CMCs) respectively (Hull and Clyne, 1996). The matrix can be named either degradable or non-degradable matrices. While, particulate, fibrous, and laminate are classified into the reinforcement phase order of composites. These reinforced composites are recognized based on size, shape, orientation and interlocking components of their constituent. Fibrous composites can be further subdivided into two different types which is the natural fiber or artificial fiber, natural fiber are relatively low cost, renewable, and biodegradable. Their production systems are associated with low equipment wear and are energy efficient. In addition, the incorporation of lignocellulosic fiber into PMCs may significantly improve some mechanical properties (Monteiro et al., 2009). Wood is common three-dimensional polymeric composite and comprises fundamentally of cellulose, hemicellulose and lignin. Furthermore, wood itself is a unique composite. The natural world offers different case of composites in bone and teeth, which are basically made out of hard inorganic crystal in a matrix of tough organic collagen (Bledzki et al., 1998). Scheme of the classification of the composites is shows in Figure 2.1.

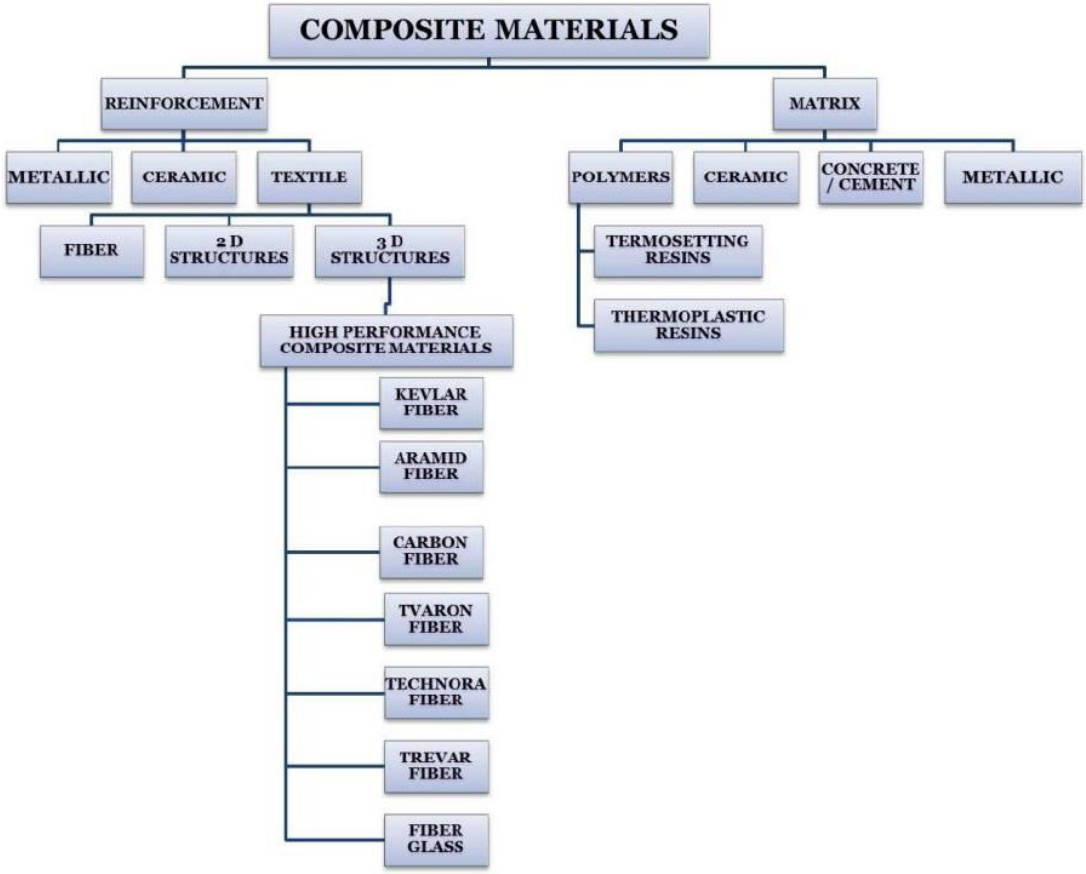

Figure 2.1: The classification composite materials (Ciobanu, 2011)

The structure of the composite materials is made out of two components: the matrix, as the continuous phase and the reinforcement, known as the discontinuous phase, conveyed uniformly on the whole volume of the network (CERBU, 2006). Basically, constituents of the composites hold their individual, physical and chemical properties which together they create a mix of characteristics which individual constituents would be incapable of producing alone.

The most well-known propelled composites are polymer matrix composites. These composites comprise of a polymer thermoplastic or thermosetting strengthened by fiber (natural and synthetic). Despite the engaging quality of natural fiber reinforced polymer matrix composites, they experience the effects of lower modulus, lower strength, and generally poor moisture content compare with manufactured artificial fiber reinforced composites such as glass fiber fortified plastics (Thwe and Liao, 2002). These materials can be designed into an assortment of shapes and sizes. They give extraordinary quality and stiffness along with resistance to erosion. Fiber-reinforced polymers provide advantages over other conventional materials when specific properties are compared. These composites are serving applications in many fields from a small device to spacecrafts (Saheb and Jog, 1999). The explanation behind these being most common is their minimal cost, high quality and simple assembling processing.

2.1.2 Biocomposites

Composites are termed as biocomposite materials when one of its stages either matrix (polymer) or reinforcement/filler (fibers) originates from natural source. Plant strands including wood and non-wood, for example, cotton, flax, hemp, kenaf, and so forth or by-items work as reinforcement or fillers in biocomposite materials. Depending upon the regular fiber origin (seed, bast, leaf, and natural product), bast and leaf are the most normally utilized as a part of composite applications (Williams and Wool, 2000). The mechanical quality of these natural fiber is practically identical to that of manufactured strands, for example, E-glass fiber for each weight basis (Netravali and Chabba, 2003). Renewable or natural resins from vegetable oils and starches are slowly supplanting the generally utilized fossil fuel engineered based polymers (Fowler et al., 2006). They additionally have sketched out the main considerations influence the performance of the biocomposites materials, reasoning that future prospect of these materials remains need of further innovative work. In any case, the decision of appropriate of natural fiber stays on numerous factors, for example, elongation at failure, thermal stability, adhesion of fibers and matrix, dynamic and behavior, final cost, and handling cost (Nickel and Riedel, 2003).

Natural fiber-fortified polymer composite materials have risen in a wide range of zone of the polymer science. The composite created from these sorts of materials are low density, low cost, comparable specific properties, and most importantly they are environmental friendly. The composite materials created from natural fiber and commercially accessible polymers have offered some particular properties that can be practically identical to conventional synthetic fiber composite materials such as glass fiber. In any case, these properties are incredibly reliant on the compatibility of the natural fiber and matrix phase with moisture absorption as one of the basic issues that turns into the disadvantages of the natural fiber polymer composite materials (Hassan et al., 2010b). Also, the modification method which is by physical and chemical interaction gives specific properties into the composite. The wide assortment of biocomposites processing technique include moisture content, fiber type and substance, coupling operators and their impact on composites properties also influencing the composite processing procedures (Faruk et al., 2012). Obviously, the processing technique and the elements incredibly influences the physical, mechanical and others properties of the composite materials.

2.2 Polymer Composites

The polymer composites consist of polymer matrix or known as resin and reinforcement that provide strength and stiffness as the raw materials. The composites are created structurally for the mechanical loads are supported by the reinforcement, for example the fiber. The type and properties of composites depend on the type of raw material being used. The reasons behind the high usage of desirable polymer composite material are low cost and simple in fabrication processes (Malhotra et al., 2012).

With the great strength of reinforced raw material, the polymer composites capable to obtain high specific strength, high specific stiffness, high fracture resistance, good resistance towards impact, abrasion, fatigue and corrosion. The properties of polymer composites are affected by interfacial adhesion of matrix and reinforced materials, physical properties of reinforcement phase, and the properties of matrix constituents (Bednarcyk, 2003).

2.2.1 Resin material

Resin is a polymeric material made up of large molecule (Gedde, 1999, Balasubramanian, 2016). Polymer is a combined Greek word of 'poly' and 'mer'. The Greek word of 'poly' and 'mer' simply means many and part respectively (Gedde, 1999). According to Balasubramanian (2016), the polymer is referred as a macromolecule that contain huge amount of the constitutional repeating unit. These constitutional repeating unit is covalently bond order to form a polymers (Gedde, 1999). Polypropylene is an example of a polymer that made up of a monomer of propylene. The chemical structure of PP polymer is demonstrated in Figure 2.2.

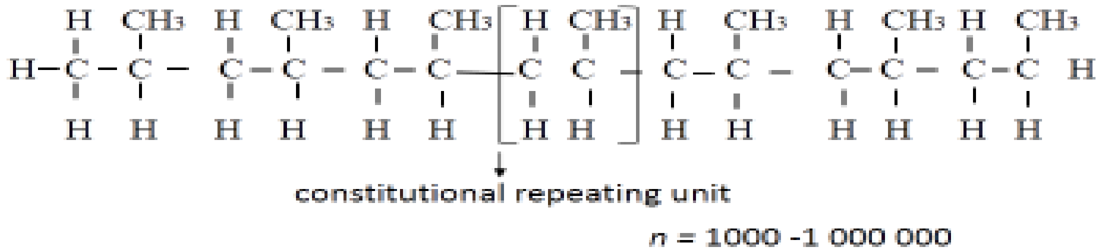

Figure 2.2: The chemical structure of polypropylene (Gedde, 1999).

Resin is recognized as an essential material that usually found in a continuous phase and possess as a binder works to attach the fiber during composite making (Wang et al., 2011). The load is balanced and transferred as the presence of resin resulted in transmission of force to the fiber. Fiber and resin are main component required for making of composite. Both of these components work simultaneously and dependently to each other. Supporting from the resin consequently makes the fiber is hardly to buckle and able to withstand under compression stress. The withstand ability of composite towards heat, corrosion and solvent as well as its moisture absorbability and mechanical characteristics such as tensile, compressive and shear are mainly influenced by the quality of used resin during preparation of composite (Wang et al., 2011).

Basically, the material of resin can be categorized into thermoplastic and thermoset (Brigante, 2014, Gedde, 1999). Thermoset polymer is a cross-linked polymer which makes it irreversibly to return its original form after it has been polymerized by heating it with specific temperature (Brigante, 2014). In contrast, the thermoplastic polymer is recognized as a linear or branch type of resin that able to melt when it is continuously heated and finally it is converted into a liquid state (Brigante, 2014, Gedde, 1999). The thermoplastic polymer is solidified as this polymer is cooled down (Brigante, 2014). This reversible property of the thermoplastic polymer consequently cause the thermoplastic polymer is able to be reshaped into various forms (Brigante, 2014).

Selection of resin in composite making is basically based on its operating cost and process together with characteristics of it usage performance (Wang et al., 2011). Wang et al. (2011) stated that the curing temperature, pressure, life of work and binder viscosity is operating parameter that affected the resin selection. Meanwhile, the operating cost of resin determines its potential marketability. The resin is said uneconomical efficient if the operating cost and process is too expensive and complicated. The usage performance of resin is depending on the functioning of the designed composite. The chosen resin must meet with the requirement need for preparation of composite. For example, the designed composite must contain resins that resistance towards chemical corrosion, abrasion and weather if the designed composite is used for structural application. Chosen inappropriate resin may affect the properties and application of the composite.

2.2.1(a) Thermoset

A thermoset is a type of polymer possesses low molecular weight that able to form into hard structures upon heating (Whelan, 1994). It is believed that, heating process has caused the thermoset polymer undergo the crosslinking process (Nicolais et al., 1993). The cross-linked thermoplastic polymer is said has a permanent and irreversible shape once the molecule of the thermoset polymer is cured (Whelan, 1994). Moreover, the cross-linked thermoset resin is not recyclable as well as unable to be melted again. According to Pascault et al. (2002), thermoset resin can be considered as amorphous thermoplastic polymer since it possesses a disordered network structure. The crosslink that bonded the molecule of thermoplastic resin has caused the network structure of thermoplastic polymer become restricted and disordered. Thermoset polymer can be molded by utilizing the method of spin casting, extrusion and compression molding (Thomas and Yang, 2009). Urea-formaldehyde, melamine-formaldehyde, epoxy and polyimide are typical examples of thermoset polymer (Pascault et al., 2002). The application of these thermoset polymers with is demonstrated in Table 2.1.

Table 2.1: The typical examples of thermoset polymer with its application

Thermoset polymer	Application
Urea-formaldehyde	Serve as a binder in wood composite preparation
Melamine-formaldehyde	As a coating material to coat the furniture
Epoxy	As a packaging laminates
Polyimide	Important adhesive in industry of semiconductor

*(Pascault et al., 2002)

2.2.1(b) Thermoplastic

Whelan (1994) has defined thermoplastic as a unique polymer that could be softened when heat is directly supplied into it and immediately change into solid and hard form upon cooling it. Basically, thermoplastic can be divided into amorphous and crystalline. The difference between crystalline and amorphous thermoplastic polymer is summarized in Table 2.2. A thermoplastic that is composed of single monomer is called as a homopolymer, while thermoplastic that made up of dual monomers is referred as a copolymer (Whelan, 1994). The polymer chain of thermoplastic can be characterized as a linear or branched. Heating of thermoplastic has weakened the bond that jointed all molecules in the polymer due to increment in its molecular motion. Thermoplastic can be heated and cooled repeatedly. The outstanding performance of thermoplastic is unaffected if this polymer is frequently subjected into heating and cooling process (Brigante, 2014). The softened thermoplastic can be forged. Extrusion and molding are examples of typical method used to forge the thermoplastic polymer.

Table 2.2**:** The difference between crystalline and amorphous thermoplastic polymer

Crystalline thermoplastic polymer	Amorphous thermoplastic polymer	References
Orderly structure	Disordered structure	(Brigante, 2014)
Opaque	Transparent	(Brigante, 2014)
Excellent wear property	Poor wear property	(MacDermott and Shenoy, 1997)
Highly resistant to almost type of organic solvent	Sensitive to organic solvent	(MacDermott and Shenoy, 1997)
Example: polypropylene, nylon and polyethylene	Example: polystyrene, acrylonitrile butadiene styrene and polysulfone	(MacDermott and Shenoy, 1997), (Poli, 2001)

2.2.1(b)(i) Polypropylene (PP)

Polypropylene (PP) is a kind of resin under category of thermoplastic. PP resin is formed when propylene monomer is polymerized via addition polymerization process. The chemical reaction for the production of PP polymer is presented in Figure 2.3.

Figure2.3: Polymerisation of propylene to form polymer of polypropylene (Doran and Cather, 2013).

Historically, the idea to use gas of propylene to synthesis PP resin was initially introduced by Natta in the year of 1954 (Doran and Cather, 2013). According to Doran and Cather (2013), Natta has successfully prepared the PP resin by polymerization of propylene in the presence of titanium oxide (TiO_2) that works as a catalyst. Polypropylene resin was commercialized in 1957. In the year 1975, researcher was able to synthesize highly crystalline polypropylene. Up to now, polypropylene is recognized as a versatile material that useful in various applications especially in industrial application.

The wide application of PP resin is owing to its excellent mechanical, optical and physical properties. PP is a transparent and low density type of thermoplastic polymer that highly resistant towards the flame and easy to process it (T. H. Shubhra et al., 2011, Biron, 2007). Moreover, PP is not expensive, abundantly available and the temperature of its heat distortion can be considered low (T. H. Shubhra et al., 2011). Finally, PP polymer possesses the outstanding mechanical characterizes at room temperature (Biron, 2007). Description on several mechanical characteristics of PP resin is tabulated in Table 2.3.

Table 2.3: Several mechanical characteristics of cast polypropylene

Mechanical property	**Value**
Tensile strength	22 MPa
Young's modulus	545 MPa
Elastic break	322%
Bending strength	27 MPa
Bending modulus	2050 MPa

***(Shubhra et al., 2010, T. H. Shubhra et al., 2011)

2.2.1(b)(ii) Polypropylene Composites

PP is recognized as an important material for preparation of composite. It can be filled, reinforced and blended with fiber during composite fabrication. Recently, utilization of natural fiber with a polymer such as PP in order to create biocomposite has received great attention from researchers due awareness of people towards the environment by incorporation of natural fiber as a natural element. Tremendous studies about the incorporation of natural fiber with PP have been made as it is a green alternative of conventional composite.

Rana et al. (1999) attempted to prepare biocomposite by utilizing PP polymer and natural fiber of jute. The preparation of this biocomposite is involving speedy thermokinetic mixer. The biocomposite was prepared with different weight percent of PP resin. Their study found out that, jute-PP bicomposite that contain 50 wt. % of PP resin have superior characteristics of dynamic mechanical thermal (DMT). Similar to