

**COMPARATIVE STUDY ON THE PROPERTIES OF
RICE STRAW/POLYPROPYLENE AND MICACEOUS
CLAY/POLYPROPYLENE COMPOSITES**

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UNIVERSITI SAINS MALAYSIA

2009

**COMPARATIVE STUDY ON THE PROPERTIES OF RICE
STRAW/POLYPROPYLENE AND MICACEOUS CLAY/POLYPROPYLENE
COMPOSITES**

by

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**Thesis submitted in fulfillment of the
requirements for the degree of
Master of Science**

August 2009

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my supervisor, Prof. Radzali Othman, for his supervision and guidance throughout this research work. I am very thankful to Dr. Hasmaliza Mohamad (co-supervisor), Prof. Kiyoshi Okada (advisor, Tokyo Institute of Technology, Japan) and Mr. Phat Bone (advisor, Institute of Technology of Cambodia, Cambodia) for their support and encouragement.

I gratefully acknowledge AUN/SEED-Net program for the financial support to conduct and complete this research work.

Many thanks go in particular to dean, deputy dean, lecturers and technicians of School of Materials and Mineral Resources Engineering for their help and assistance. I wish to convey my special thanks to my sister, Kry Linenine, my brother Ban Leang Eng and my friends, Lily Tiong Yu Wen, Aye Aye Thant and Dilini Galpaya, for their unforgettable help and warm support throughout my research work.

Last but not least, my greatest gratitude is dedicated to my respectful parents, for their perspiration in motivating me to persist and achieve the peak of success.

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LIST OF ABBRAVIATIONS

AA	Acrylic Acid
ABS	Acrylonitrile-Butadiene-Styrene
ASTM	American Society for Testing and Materials
CA	Cellulose Acetate
CAB	Cellulose Acetate Butyrate
CMCs	Ceramic Matrix Composites
CTE	Coefficient of Thermal Expansion
DSC	Differential Scanning Calorimetry
FESEM	Field Emission Scanning Electron Microscopy
HDPE	High Density Polyethylene
HIPS	High-Impact Polystyrene
HPP	Homopolymer Polypropylene
ICP	Impact Copolymer
LDPE	Low Density Polyethylene
MA-g-PP	Maleic Anhydride Grafted Polypropylene
MC	Micaceous Clay
MMCs	Metal Matrix Composites
PA 6	Polyamide 6
PA 66	Polyamide 66
PBT	Polybutylene Terephthalate
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene Terephthalate

PHBV	Poly (hydroxybutyrate-co-hydroxyvalerate)
PMCs	Polymer Matrix Composites
PP	Polypropylene
PS	Polystyrene
PTW	Potassium Titanate Whiskers
PVC	Polyvinyl Chloride
RCP	Random Copolymer
RH%	Percentage of Relative Humidity
RHDPE	Recycled High-Density Polyethylene
RS	Rice Straw
SEM	Scanning Electron Microscopy
VHDPE	Virgin High-Density Polyethylene
WPFs	Waste-wood-Paper-Derived Fillers
XRF	X-Ray Fluorescence

**KAJIAN PERBANDINGAN SIFAT-SIFAT KOMPOSIT
JERAMI/POLIPROPILENA DAN LEMPUNG BERMIKA/POLIPROPILENA**

ABSTRAK

Suatu kajian perbandingan ke atas sifat suatu komposit polipropilena tetulang jerami (hasil buangan pertanian) dan tetulang lempung bermika (pengisi mineral) telah dilakukan. Komposit polipropilena tetulang lempung bermika telah disediakan dengan kandungan lempung bermika yang berubah dari 0 hingga 70 % berat. Sebaliknya, cuma komposit polipropilena tetulang jerami dengan kandungan 0 hingga 60 % berat jerami telah disediakan. Bahan-bahan berkenaan telah disediakan dengan mencampurkannya dalam mesin Brabender Plasticorder PLE331 (50rpm, 180°C) dan kaedah pengacuanan tekan panas (180°C, 1500psi) yang disusuli dengan penekanan sejuk. Kedua-dua jenis komposit yang diperolehi telah diuji ketumpatan, kekuatan hentam, sifat regangan (setakat 0 – 40 % berat), sifat lentur kering serta basah, jerapan air dan pengembangan tebal. Permukaan patah regang, hentam dan lentur telah dikaji menggunakan mikroskopi elektron imbasan (SEM).

Kekuatan regang dan hentam komposit RS/PP dan MC/PP menurun bila kandungan pengisi meningkat di mana kekuatan regang dan hentam komposit MC/PP adalah lebih baik daripada komposit RS/PP. Sebaliknya, kekuatan lentur kering dan basah mencecah nilai maksimum pada 20 % berat MC dalam komposit MC/PP. Kekuatan lentur kering komposit MC/PP dan RS/PP adalah lebih tinggi daripada kekuatan lentur basah. Namun, kekuatan lentur kering dan basah komposit MC/PP adalah lebih tinggi berbanding komposit RS/PP. Tambahan pula, komposit RS/PP menyerap lebih banyak air daripada komposit MC/PP. Penyerapan air RS/PP

dan MC/PP meningkat dengan peningkatan kandungan RS dan MC. Pengembangan tebal komposit RS/PP dan MC/PP meningkat bila jerapan air meningkat. Pemerhatian morfologi komposit MC/PP MC/PP menunjukkan perubahan beransur-ansur kelakuan patah regang daripada mulur ke rapuh dan saling tindakan buruk antara PP dan MC. Sebaliknya, kajian morfologi komposit RS/PP menunjukkan kehadiran rongga dan cabutan keluar jerami pada kandungan RS yang tinggi di permukaan patah regang dan hentam yang mengesahkan saling tindakan buruk antara pengisi dan matriks polimer. Namun, permukaan patah lentur pula menunjukkan lecuhan dalam komposit yang mempunyai kandungan RS rendah yang dipercayai berpunca daripada pengacuanan mampat sewaktu penyediaan sampel.

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ABSTRACT

Comparative study on the properties of an agricultural waste, rice straw (RS), reinforced polypropylene composites and mineral filler, micaceous clay (MC), reinforced polypropylene composites was investigated in this study. Micaceous clay reinforced polypropylene (MC/PP) composites were prepared with different MC contents from 0 to 70% by weight. However, for rice straw reinforced polypropylene (RS/PP) composites, only composites with rice straw contents from 0 to 60% by weight were prepared. The mixture was prepared by mixing in a Brabender Plasticorder PLE331 (50rpm, 180⁰C) and hot press molding method (180⁰C, 1500psi) followed by cold pressing. Both types of composites obtained were characterized for impact strength, tensile properties (0 wt%-40 wt%), dry and wet flexural properties, water absorption and expansion in thickness. The tensile fracture surface, impact fracture surfaces and flexural fracture surfaces were analyzed using scanning electron microscopy (SEM).

From the test results, tensile strength and impact strength of RS/PP and MC/PP composites decreased as the filler contents increased and the tensile and impact strength of MC/PP are better than the tensile and impact strength of RS/PP composite. On the other hand, dry and wet flexural strength of MC/PP composites reached maximum 20 wt% of MC content. The dry flexural strength of MC/PP composites and RS/PP composites is higher than its wet flexural strength. However,

the dry and wet flexural strengths of MC/PP composites is higher than dry and wet flexural strength of RS/PP composites. In the modulus case, the dry and wet flexural modulus and tensile modulus of RS/PP composites and MC/PP composites increased with increasing RS and MC contents. Nevertheless, the dry and wet flexural modulus and tensile modulus of MC/PP composites are higher compared to the dry and wet flexural modulus and tensile modulus of RS/PP composites. Moreover, RS/PP composites absorbed more water than MC/PP composites. The water absorption of RS/PP and MC/PP increased with increasing RS and MC contents. Expansion in thickness of RS/PP composites and MC/PP composites simultaneously increased as the water absorption increased. In addition, morphological observation of MC/PP composites indicates a gradual change of tensile fracture behavior from ductile to brittle and poor interaction between PP and MC. However, the morphological study on RS/PP composites showed the cavities and pull out of rice straw at higher RS contents for tensile and impact fracture surfaces which indicate a poor interaction between fillers and the matrix polymer. However, the flexural fracture surfaces showed blisters in the composites at lower RS contents as a result of using compression molding during the sample preparations.

CHAPTER 1

INTRODUCTION

1.1 Background

Polymer composites have been subjected to increasing interest, study, and utilization for some decades. However, the increase in environmental concern has pointed out how it is also necessary to reduce and rationalize the use of polymeric materials, not only due to their non-biodegradability, but also because their production requires large amount of oil as raw material which is notoriously not renewable. All these issues have induced mankind to look for alternatives (La Mantia & Morreale, 2006).

Lignocellulosic and clay mineral filled plastic composites have received a lot of attention. The addition of lignocellulosic or clay mineral to polymer can cause a change in properties of the natural materials and those of the polymer. For example, the development of wood-flour composites has been actively pursued (Maldas & Kokta, 1989; Lee *et al.*, 2004). With the increasing consumption of wood-based raw materials, their substitutions were inevitably needed. Recently there is a growing interest in agriculture waste as a substitute for wood-based raw materials. Among the various agricultural straws, rice straw could be very interesting materials as filler in polymer composites, due to its good thermal stability compared to other agriculture waste (Buzarovska *et al.*, 2008). On the other hand, the addition of clay mineral fillers in polymers has also become very popular research interest in the last four decades to improve the mechanical, electrical, thermal, optical, and processing

properties of polymer (Hijleh *et al.*, 2000). Many kind clay minerals such as bentonite, kaolin, talc, mica, etc. have been used as inorganic fillers for conventional polymer composites to reduce cost or to give them special properties such as modulus, hardness, thermal stability, electrical insulation, thickening, opacity, brightness etc. (Abu-Jdayil & Al-Malah, 2008). For example, bentonite was used in the formulation of unsaturated polyester-based composite materials (Abu-Jdayil *et al.*, 2002). It was found that increasing the filler content, at a constant styrene/polyester ratio, enhanced the mechanical properties of composites.

1.2 Problems statements

Emerging community concerns and a growing environmental awareness throughout the world has forced researchers to synthesize new green materials and processes that enhance the environmental quality of products. In this perspective, biodegradability, ecofriendliness, easy availability, substainability, light weight, etc. have become important considerations in the fabrications of new products. Natural fiber reinforced polymer composites materials are almost replacing materials such as ceramics, metals, glasses, etc. Moreover, in the last two decades, organic natural fillers have gained importance over the inorganic fillers due to their low densities, low cost, non abrasiveness, easy recyclability, bio-degradability and renewable nature (Singha & Thakur, 2009; Chand & Jhod, 2008). The use of natural fibers, derived from a number of renewable resources, as reinforcing fibers in both thermoplastic and thermoset matrix composites provides positive environmental benefits and offer numerous advantages over conventional materials including lightness, resistance to corrosion and ease of processing, etc. Natural fibers like flax,

hibiscus sabdariffa, pinus, jute, pineapple leaf fiber and oil palm fiber have all been proved to be good reinforcements in thermoset and thermoplastic matrices (Singha & Thakur, 2009). However, there have been limited research work on rice straws.

Nowadays, rice straw posed numerous environmental problems all over the world after the paddy fields are harvested. Hence, the problem of effectively clearing up rice straws is obviously significant. Effective solutions must be taken to overcome the problem of this waste material. Currently, only a small percentage of rice straws is used as animal feed. Most of the rice straws ended up being burnt through ‘open-burning’ by the farmers. This has resulted in several negative implications including the ‘black snow’ phenomenon that had caused major road accidents along the northern part of PLUS highway. New and innovative usage of rice straws will greatly help in overcoming the environmental issues as an effective discharge of these waste materials (Ervina, 2006).

Anyway, there are a number of research works on the properties of clay reinforced polymer composites. Many kinds of clay minerals such as mica, bentonite, kaolin, talc, etc. were used as the filler for polymer composites (Abu-Jdayil & Al-Malah, 2008). However, there is a limited study on the properties of micaceous clay reinforced polymer composites compared to other clays such as bentonite, talc, mica, kaolin, etc.

Due to the above reasons such as advantages of natural fibers and agricultural wastes, environmental problems caused by the natural fibers and agricultural wastes, limited study of micaceous clay reinforced polymer composites; the comparative

study on the properties of rice straw reinforced polypropylene composites and micaceous clay reinforced polypropylene composites was investigated.

1.3 Research objectives

The objectives of the present study are:

1. To study the effect of micaceous clay (MC) loading on the properties of micaceous clay reinforced polypropylene (MC/PP) composites
2. To study the effect of rice straw (RS) loading on the properties rice straw reinforced polypropylene (RS/PP) composites.
3. To compare the properties between mineral filler (micaceous clay) reinforced polypropylene (MC/PP) composites and natural fiber (rice straw) reinforced polypropylene (RS/PP) composites.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The expanding industrial activities create a continual demand for improved materials that satisfy increasingly stringent requirements, such as high strength, modulus, thermal and/or electrical conductivity, heat distortion temperature, lower thermal expansion coefficient, and reduced cost. These requirements, which often involve a combination of many difficult-to-attain properties, may dictate the use of composite material whose constituents will act synergistically to solve the needs of the application. As we cross the threshold into the “Composite Materials Age,” it becomes increasingly important to understand the properties, performance, cost, and potential of the available composite materials (Katz & Milewski, 1987).

An introduction of composite materials changed the world especially in engineering fields. It is because most of composite materials have been created to show improved combinations of mechanical characteristics such as stiffness, toughness, and ambient and high temperature strength that cannot be met by the conventional materials such as ceramic, metal alloys or polymers (William & Callister, 1999).

Many composites used today are at the leading edge of materials technology, with performance and costs appropriate to ultra demanding applications. But

heterogeneous materials combining the best aspects of dissimilar constituents have been used by nature for millions of years (Roylance, 2000).

Composite materials have gained popularity (despite their generally high cost) in high-performance products that need to be lightweight, yet strong enough to take harsh loading conditions such as aerospace components (tails, wings, fuselages, propellers), boat and scull hulls, bicycle frames and racing car bodies. Other uses include fishing rods and storage tanks. The new Boeing 787 Dreamliner structure including the wings and fuselage is composed of over 50 percent composites in which polymer matrix composite is included. The diversity of properties belonging to composite materials has made this field more interesting to be explored (Wikipedia, 2009a).

2.2 Composite materials

In the most general case a composite material consists of one or more discontinuous phase distributed in one continuous phase. In the case of several discontinuous phases of different natures the composite is said to be a hybrid. The discontinuous phase is usually harder and with the mechanical properties superior to those of the continuous phase. The continuous phase is called the matrix. The discontinuous phase is called the reinforcement or reinforcing materials (Figure 2.1) (Berthelot, 1999). The reinforcement phase can be in the form of particles, whiskers or short fibers, continuous fibers or sheet. Figure 2.2 and Figure 2.3 show the classification of the composite materials, which consists of three main divisions: particle-reinforced, fiber-reinforced, and structural composites; also, at least two subdivisions exist for each. The dispersed phase for particle-reinforced composites is

equiaxed (i.e., particle dimensions are approximately the same in all directions); for fiber-reinforced composites, the dispersed phase has the geometry of a fiber (i.e., a large length-to-diameter ratio). Structural composites are combinations of composites and homogeneous materials show the types of composites based on the form of reinforcement. The reinforcement in the matrix can be polymeric, metallic or ceramic (Chawla, 2003).

The choice of individual components for composite, the processing required to produce the composite, and the mechanical behaviour of the composite are the important factors for the ultimate performance of the composite. However, an addition and a very important factor that enters into the evaluation of the performance of a composite is the presence of an interface region between the matrix and the reinforcement, which can occupy a rather large area (Chawla, 2003).

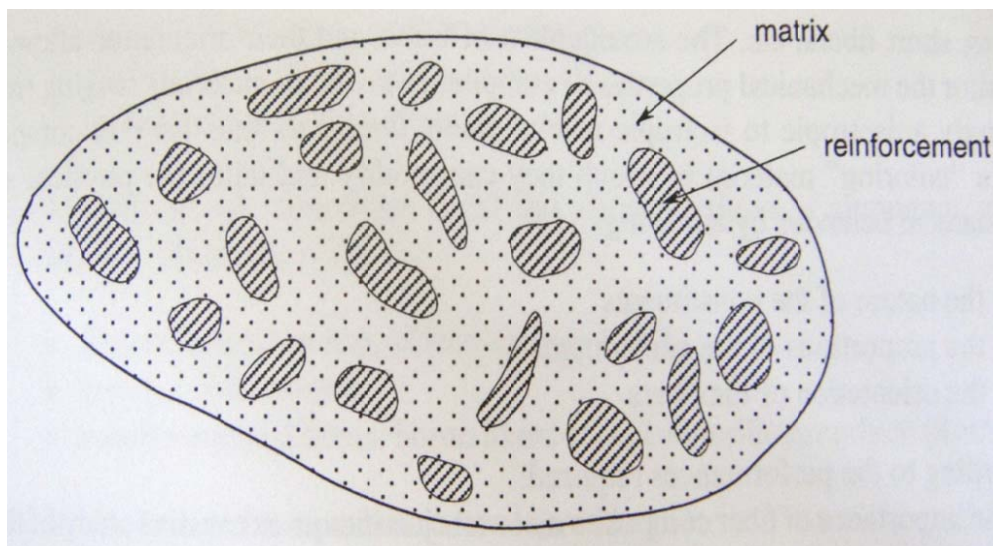


Figure 2.1 Composite materials (Berthelot, 1999)

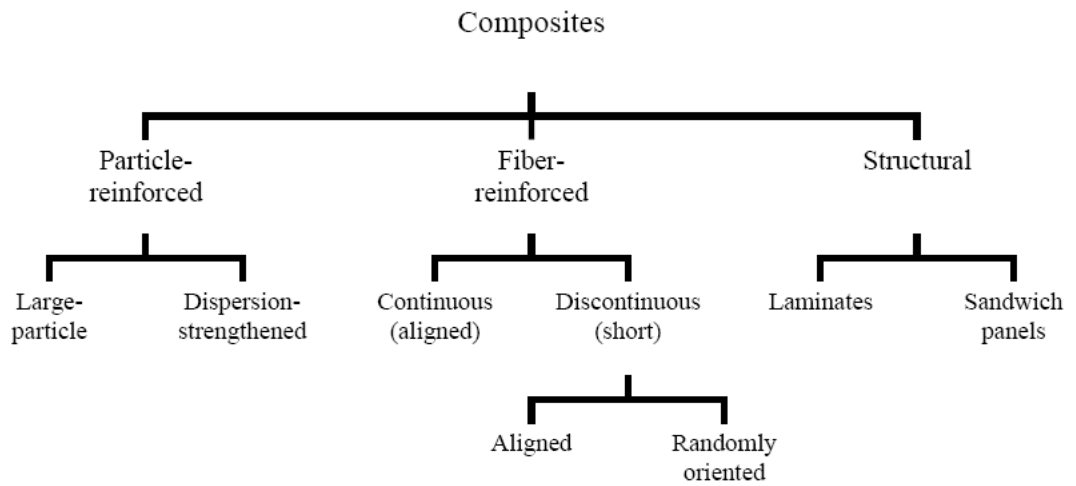


Figure 2.2 Type of reinforced composites (Mitchell, 2003)

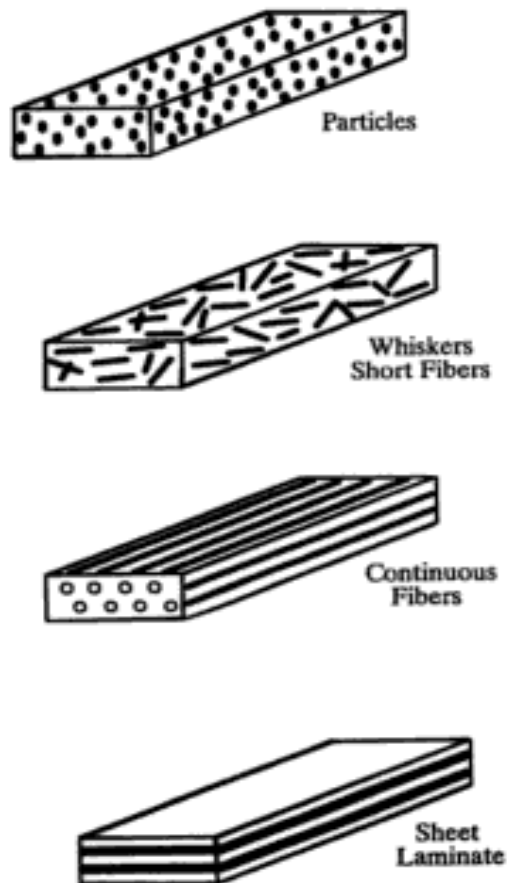


Figure 2.3 Types of composites based on the form of reinforcement (Chawla, 2003)

2.3 Classification of composite materials based on matrix

According to the nature of the matrix, composite materials are classified as metal matrix composites, ceramic matrix composites and polymer matrix composites (Berthelot, 1999).

2.3.1 Metal matrix composites (MMCs)

Metal matrix composites (MMCs), like all composites, consist of at least two chemically and physically distinct phases, suitably distributed to provide properties not obtainable with either of the individual phases. Generally, there are two phases, e.g., a fibrous or particulate phase, distributed in a metallic matrix. For example, continuous Al₂O₃ fiber reinforced Al matrix composites used in power transmission lines (Chawla, 2006).

As the reinforcement in MMCs serves to reduce the coefficient of thermal expansion (CTE) and increase the strength and modulus in the composites, most of these materials have been developed for the aerospace industries and some are being used in other application such as automobile engines (Chung, 2003).

Compared to monolithic metal, MMCs have (Composite-by-design, 2009):

- Higher strength-to-density ratios
- Higher stiffness-to-density ratios
- Better fatigue resistance
- Better elevated temperature properties

- Higher strength
- Lower creep rate
- Lower coefficients of thermal expansion
- Better wear resistance

However, MMC has the following disadvantages compared to metal itself and the corresponding PMC (Chung, 2003; Composites-by-design, 2009):

- Higher cost of some material systems
- Relatively immature technology
- Complex fabrication methods for fiber-reinforced systems (except for casting)
- Limited service experience

2.3.2 Ceramic matrix composite

Ceramic matrix composites (CMCs) combine reinforcing ceramic phases with a ceramic matrix to create materials with new and superior properties (Ceramic Industry, 2009). Ceramic matrix composites (CMCs) have been developed to overcome the intrinsic brittleness and lack of reliability of monolithic ceramics, with a view to introduce ceramics in structural parts used in severe environments, such as rocket and jet engines, gas turbines for power plants, heat shields for space vehicles, fusion reactor first wall, aircraft brakes, heat treatment furnaces, etc. It is generally admitted that the use of CMCs in advanced engines will allow an increase of the temperature at which the engine can be operated and eventually the elimination of the cooling fluids, both resulting in an increase of yield. Further, the use of light CMCs in place of heavy super alloys is expected to yield significant weight saving.

Although CMCs are promising thermostructural materials, their applications are still limited by the lack of suitable reinforcements, processing difficulties, sound material data bases, lifetime and cost (Naslain, 2009).

2.3.3 Polymer matrix composites (PMCs)

The word *polymer* is derived from classical Greek *poly* meaning “many” and *meres* meaning “parts”. Thus a polymer is large molecule (macromolecule) build up by the repetition of small chemical units as shown in Figure 2.4 (Ebewele, 2000).

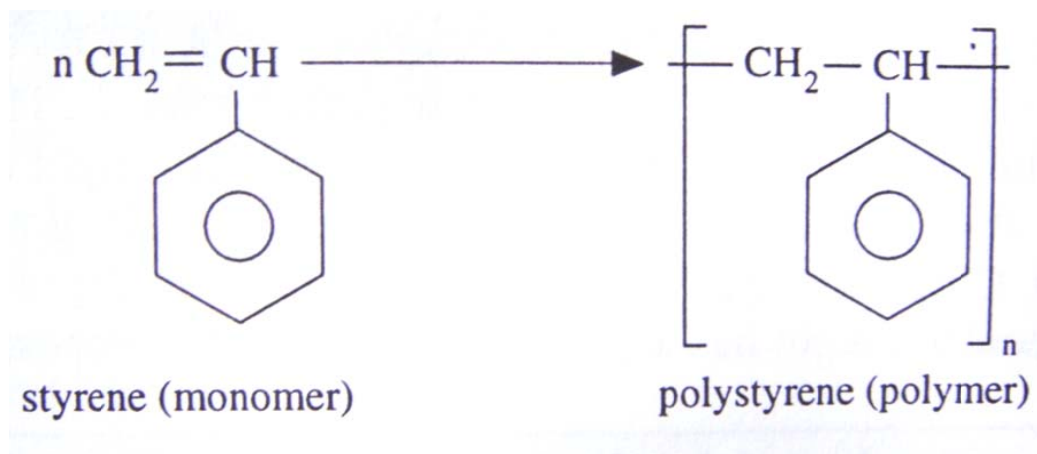


Figure 2.4 Formation of the polymer polystyrene (Ebewele, 2000)

Modification of organic polymer through the incorporation of additive yields, with few exceptions, multiphase system containing the additive embedded in the continuous polymeric matrix. The resulting mixtures are characterized by unique microstructures or macrostructures that are responsible for their properties. The primary reasons for using additives are (Xanthos, 2005):

- Property modification or enhancement

- Overall cost reduction
- Improving and controlling of processing characteristics

Important types of modified polymer systems include polymer composite, polymer-polymer blends and polymeric foam (Xanthos, 2005).

In general, parameters affecting the properties of polymer composites include (Xanthos, 2005):

- The properties of the additives (inherent properties, size, shape)
- Composition
- The interaction of components at the phase boundaries, which is also associated with the existence of a thick interface, known also as the interphase, this is often considered as a separate phase, controlling adhesion between the components
- The method of fabrication.

Polymeric composites are increasingly gaining importance as substitute materials for metals in applications within the aerospace, automotive, marine, sporting goods and electronic industries. Their light weight and superior mechanical properties make them especially suited for transportation applications (Seavey, 1999).

2.3.3.1 Polymer matrices

The matrices in composite materials have the role of transferring the mechanical loading to the fillers (reinforcing materials) and to protect them from the outside environment. The matrices must therefore be quite flexible and offer good

compatibility with the fillers. In addition they must have a low density to keep in the composite's high specific mechanical characteristics (Berthelot, 1999). Polymers are used as the matrix phase for the composites namely polymer matrix composites. The polymer matrices are divided into two types, thermosetting resins and thermoplastic resins (Lubin & Peters, 1998). These two types of matrix have the property of being able to be molded or manufactured in order to yield either a finished product or a semi-finished product whose form can be modified (Berthelot, 1999).

A. Thermosetting resins

Thermosetting resins have a network structure formed exclusively by covalent bonds. Thermosets have a high density of cross-links and are consequently infusible, insoluble, thermally stable, and dimensionally stable under load. The major commercial thermosets include epoxies, polyesters, and polymers based on formaldehyde. The formaldehyde-based resins, which are the most widely used thermosets, consist essentially of two classes of thermoset. These are the condensation products of formaldehyde with phenol (or resorcinol) (phenoplasts or phenolic resins) or with urea or melamine (aminoplastics or amino resins) (Ebewele, 2000). Some basic properties of the selected thermosetting resins are shown in Table 2.1.

Thermosetting resins can be processed only once. In fact polymerization by applying heat in the presence of catalyst, these resins lead to a geometric structure that can be destroyed only by a considerable application of thermal energy (Berthelot, 1999). It may soften to some extent at elevated temperature. This characteristic is sometimes used to create a bend or curve in tubular structure, such as filament

wound tubes. Thermosetting resins are brittle in nature and are generally used with some forms of the filler or reinforcement.

Thermoset polymeric matrix composites can substitute efficiently for steel and concrete in civil constructions, showing greater resistance to oxidation for the former and better freeze thaw for the latter. This behavior could lead to structural component with improved weathering capability (Tyberg *et al.*, 1999).

Table 2.1 General characteristic of thermosetting resin (Berthelot, 1999)

Properties	Resin materials		
	Polyester	Phenolic	Epoxide
Density (kg/cm ³)	1,200	1,200	1,100-1,500
Tensile strength (MPa)	50-80	40	60-80
Tensile elongation (%)	2-5	2.5	2-5
Flexural strength (MPa)	90-130	90	100-150
Heat deflection temperature (°C)	60-100	120	290

B. Advantages of thermoset composites

These resin materials could be one-part or two-part system and are generally in the liquid state at room temperature. These resin systems are then cured at elevated temperature or sometime at room temperature to get final shape. Manufacturing methods for processing thermoset composites provide the following advantages (Reigner and Sander, 1979):

- Processing of thermoset composites is easy because the initial resin system is in the liquid state.
- Fillers are easy to wet with thermoset, thus voids and porosities are less.
- Heat and pressure requirements are less in the processing of thermoset composites than thermoplastic composites, thus provide energy savings.
- A simple low-cost tooling system can be used to process thermoset composites.

C. Disadvantages of thermoset composites

Thermoset composite materials also have some disadvantages which are (Reigner and Sander, 1979):

- Thermoset composite processing requires a lengthy cure time and thus results in low production rates than thermoplastics.
- Once cured and solidified, thermoset composite parts cannot be reformed to obtain other shapes.
- Recycling of thermoset is an issue.
- Physical and chemical treatment may be wedded to enhance the adhesion between reinforcement and matrix.

D. Thermoplastic resins

Almost 85% of polymer products produced worldwide are thermoplastic. Over 70% of the total production of thermoplastics is accounted for by the large volume, low cost commodity resin: polyethylene (PE) of different densities,

isostatic polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). Next in performance and cost are acrylics, acrylonitrile-butadiene-styrene (ABS) terpolymers, and high-impact polystyrene (HIPS) (Xanthos, 2005). Table 2.2 lists the densities, tensile strengths, impact strengths, and maximum-use temperatures for some selected engineering thermoplastics.

Thermoplastic materials are, in general, ductile and tougher than thermoset materials and are used for wide variety of nonstructural applications. Thermoplastics can be remelted by heating and solidified by cooling, which render them capable of repeated reshaping and reforming. Thermoplastic can be either amorphous or semi-crystalline as shown in Figure 2.5 and Figure 2.6. In amorphous thermoplastics, molecules are randomly arranged, whereas in the crystalline region of semi-crystalline plastics, molecules are arranged in an orderly fashion (Mazumdar, 2002).

Table 2.2 Some properties of selected engineering thermoplastics (Smith, 2004)

Materials	Density (g/cm ³)	Tensile strength (MPa)	Impact strength, Izod (J/m)	Max-use temperature (°C)
Polypropylene	0.9	35	27.5	135
Nylon 6.6	1.13-1.15	62.1-82.8	106.76	82-150
Polyacetal, homo.	1.42	69	74.73	90
Polycarbonate	1.2	62.1	640.56- 854.08	120
Polyester PET	1.37	71.76	42.7	80
Polyester PBT	1.31	55.2-56.58	64.05-69.4	120
Polyphenylene oxide	1.06-1.10	53.82-66.24	267	80-105
Polysulfone	1.24	70.38	64.05	150
Polyphenylene sulfide	1.34	69	16	260



Figure 2.5 Molecular arrangements in amorphous polymers (Mazumdar, 2002)

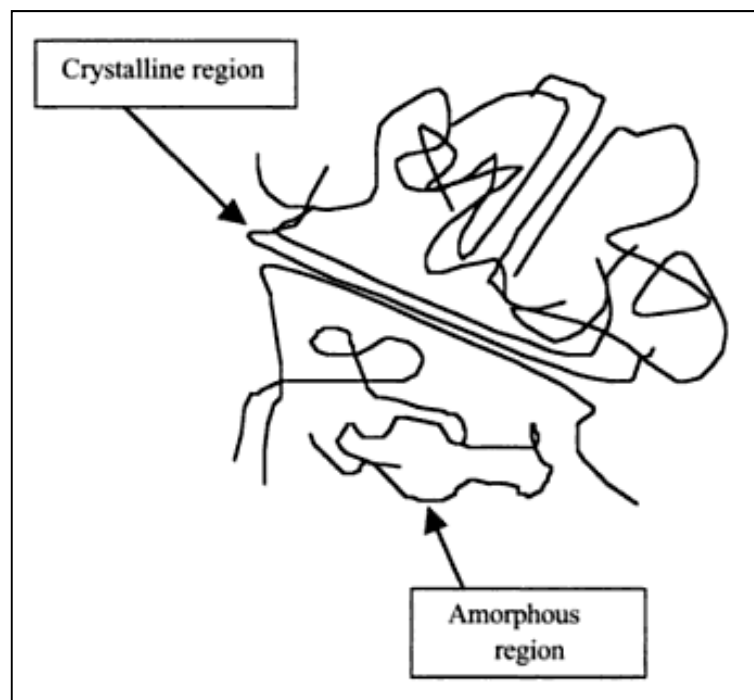


Figure 2.6 Molecular arrangements in semi-crystalline polymers
(Mazumdar, 2002)

E. Advantages of thermoplastic composites

The advantages of thermoplastic composites include (Lubin & Peters, 1998):

- The processing for thermoplastic composites can be faster than for thermoset composites since curing reaction is required. Thermoplastic composites only require heating, shaping and cooling.
- The properties are attractive, in particular, high delamination resistance and damage tolerance, low moisture absorption and the excellent chemical resistance of semi-crystalline polymers.
- In light of environmental concern, thermoplastic composites offer advantage. They have very low toxicity since they do not contain reactive chemicals (therefore storage life is infinite). It is possible to remelt and dissolve such thermoplastics, their composites are also easy recycled or combined with other recycled materials in the market for molding compound.

F. Disadvantages of thermoplastic composites

The disadvantages of thermoplastic composites include:

- Thermoplastic composites require heavy and strong tools for processing. Moreover, the cost of the tools is high. For example the injection molding equipment costs more than \$50,000, whereas the mandrel equipment for filament winding process costs less than \$500.

G. Polypropylene

Polypropylene (PP) is a thermoplastic matrix material that received attention for the production of polymer composites (Fung *et al.*, 2003). PP was first product produced by G. Natta, following the work of K. Ziegler, by the polymerization of propylene monomer in 1954 (Figure 2.7). The macromolecule of PP contains 10,000 to 20,000 monomer units. The steric arrangement of the methyl groups attached to every second carbon atom in the chain may vary (Figure 2.8). if all the methyl groups are on the same side of the winding spiral chain molecule, the product is referred to as isotactic PP. A PP structure where pendant methylene groups are attached to the polymer backbone chain in an alternating manner is known as syndiotactic PP. The structure where pendant groups are located in a random manner on the polymer backbone is atactic form (Billmeyer, 1971).

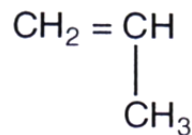
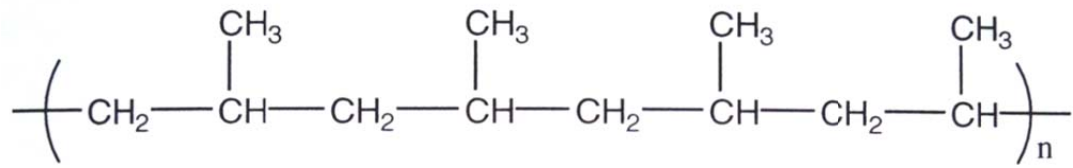
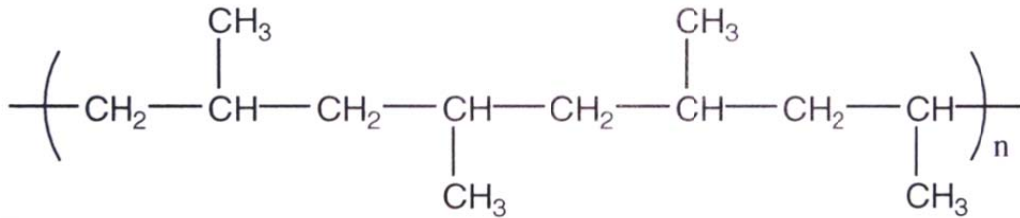


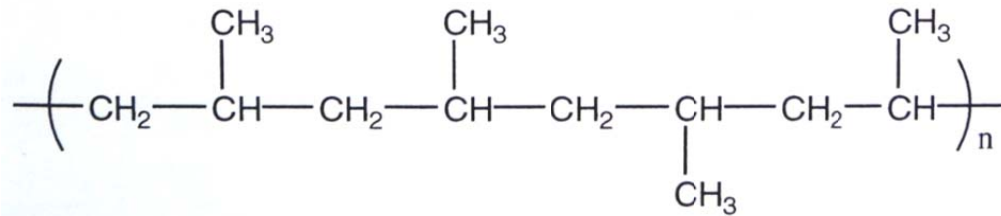
Figure 2.7 Propylene Monomer (Billmeyer, 1971)



isotactic polypropylene



syndiotactic polypropylene



atactic polypropylene

Figure 2.8 PP polymer molecule in isotactic, syndiotactic and atactic forms

(Billmeyer, 1971)

Major competitive materials for PP and their crude advantages/disadvantages over PP are given in Table 2.3. This table is for broad comparison only (Billmeyer, 1971).

Table 2.3 Comparative advantages/disadvantages of other thermoplastics over PP

(Billmeyer, 1971)

Polymer	Advantages	Disadvantages
Low Density Polyethylene (LDPE)	Higher impact resistance Lower brittle temperature	Lower strength and stiffness Lower surface hardness
High Density Polyethylene (HDPE)	Lower cost Higher impact resistance Lower brittle temperature	Lower heat distortion temperature
High-Impact Polystyrene (HIPS)	Lower shrinkage and warpage Better gloss Better rigidity	Lower chemical resistance Higher cost Environmental stress cracking
Polyvinyl Chloride (PVC)	Better clarity Better processing window Better weather resistance	Worse environmental acceptance Lower solvent stress crack
Polyethylene Terephthalate (PET)	Higher clarity Better oxygen barrier Better impact properties	Worse water barrier properties Unsuitable for hot fill and sterilization High price
Acrylonitrile-Butadiene-Styrene (ABS)	Better stiffness Better gloss Better processibility	Higher cost and weight Lower solvent resistance Lower heat resistance
Polyamide 6, 66 (PA 6, 66)	Higher toughness Better feel Better hydrocarbon resistance	Higher water absorption Higher cost and density
Polycarbonate (PC)	Better transparency Higher toughness and modulus Higher continue use temperature	Higher cost and density Notch sensitive Lower fatigue resistance

Table 2.3 Continues

Cellulose Acetate (CA)	Better transparency Better impact strength at lower temp. Higher modulus	Lower solvent resistance Greater moisture absorption Higher cost
Cellulose Acetate Butyrate (CAB)	Better transparency Better gloss	

2.3.3.2 Fillers/Reinforcements

In general, filler are defined as materials that are added to the formulation to lower the compound cost. For effective utilization of fillers, a complete understanding of individual characteristics is essential. Each class of the fillers appears to exhibit specific characteristics which make them especially suited for the given application (Lutz & Grossman, 2000). Fillers, being much stiffer and stronger than the polymer, usually increase its modulus and strength. Thus, mechanical property modification may be considered as their primary function, although their presence may significantly affect thermal expansion, transparency, thermal stability, etc (Xanthos, 2005).

Selecting of fillers is not just an art but a science and various factors would have to be considered in the choice such as (Shenoy, 1999)

- Cost and availability
- Wettability or compatibility with the polymer

- Effect on polymer flow characteristics
- Physical properties

2.3.3.3 Classification of filler/reinforcement

A. Fibers reinforcement

Fiber reinforced materials have been around for thousands of years. The earliest fibrous reinforcements were straw or horsehair for toughening mud in order to make bricks. Modern composites are reinforced with fibers such as glass, carbon or Kevlar. There are also particulate reinforcements using materials such as silica flour, glass beads and sand and there are now even lamellar reinforcements possible (De & White, 1996).

Fibers for composite materials can come in many forms, from continuous fibers to discontinuous fibers (Figure 2.9), organic fibers to inorganic fibers while the properties of fiber-reinforced composites are strongly dependent on the way the fibers are laid in the composites. The important thing in fiber-reinforced composites is that the fibers carry the load and the composite strength is greatest along the axis of the fiber. Long continuous fibers in the direction of the load result in a composite with the properties far exceeding the matrix resin itself. The same material chopped in the short length yields lower properties than continuous fibers. Depending on the types of application (structural or nonstructural) and manufacturing method, the fiber form is selected. For structural applications, continuous fibers or long fibers are recommended; whereas for nonstructural applications, short fibers are recommended.