STUDIES ON THE PROPERTIES OF BAGASSE FIBER REINFORCED POLYESTER COMPOSITES

VILAY VANNALADSAYSY

UNIVERSITI SAINS MALAYSIA

2007

STUDIES ON THE PROPERTIES OF BAGASSE FIBER REINFORCED POLYESTER COMPOSITES

By

VILAY VANNALADSAYSY

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

May, 2007

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

CHAPTER 2: LITERATURE REVIEW

CHAPTER 3: EXPERIMENTALS

CHAPTER 4: RESULTS AND DISCUSSIONS

CHAPTER 5: CONCLUSIONS AND FUTURE SUGGESTIONS

ACKNOLEDGEMENT

I would like to express my gratitude to my main supervisor, Dr. Mariatti Jaafar @ Mustapha for her sincere supervision and guidance throughout the research project. I also would like to thank my co-advisors Dr. Razaina Mat Taib (USM), Associate Professor Dr. Mitsugu Todo (Kyushu University, Japan) and Associate Professor Korakanh Phasomsouk (National University of Laos, NUOL, Laos) for their help and support. It throughout the research project.

I would also like to extend my appreciation and gratitude to the person that I consider it to be my “second father” and Chairman of AUN/SEED-Net program, Professor Dr. Razali Othman. His word of advice and support meant a lot of me. Special thanks also go to the Dean of School of Materials and Mineral Resources Engineering, Assoc. Prof. Dr. Khairun Azizli and Dr. Wan Asma from Forestry Research Institute of Malaysia (FRIM).

Furthermore, the financial support received by AUN/SEED-Net scholarship, JICA program and USM are gratefully acknowledged.

Many thanks also to the technicians and friends, especially from Polymer Engineering Division and Material Engineering Division for continuous support and Assistance

Not forgetting, my parents and family for continuous moral support.

LIST OF FIGURES

LIST OF TABLES

KAJIAN KE ATAS SIFAT-SIFAT KOMPOSIT POLIESTER DIPERKUAT GENTIAN SISA TEBU

ABSTRAK

Sisa tebu merupakan hasil sampingan yang diperolehi daripada kilang gula dan kebanyakannya digunakan sebagai bahan bakar atau dihapuskan oleh proses insinerasi. Usaha telah dilakukan untuk menukarkan produk sampingan ini kepada komposit plastik yang boleh digunakan dalam pelbagai aplikasi kejuruteraan. Dalam kajian ini, sifat-sifat komposit poliester diperkuat gentian sisa tebu telah diselidik. Kesan parameter-parameter seperti teknik pengekstrakan gentian sisa tebu, rawatan gentian, kandungan isipadu gentian, penyusunan hibrid dan bilangan lapisan hibrid ke atas sifat-sifat komposit poliester diperkuat gentian tebu telah dikenalpasti. Daripada pemerhatian kaedah pengekstrakan yang berbeza, kaedah pengekstrakan secara manual telah menghasilkan gentian yang panjang dan halus. Gentian yang diperolehi daripada kaedah manual ini telah menghasilkan komposit dengan sifat-sifat mekanical yang tinggi jika dibandingkan dengan kaedah mesin. Sebagai contoh, komposit yang terhagil daripada kaedah pengestrakan manual menghasilkan kekuatan dan peleturan sebanyak 6.63% dan 59.9% lebih tiggi daripada komposit dengan menggunakan kaedan mesin. Gentian-gentian yang diperolehi secara mesin telah menghasilkan sekelompok gentian yang bersaiz besar dengan kehadiran komponen-komponen *rind* dan *pith*, ini menghasilkan sifat mekanikal dan penyerapan air yang rendah. Rawatan alkali menggunakan sodium hidrosida (NaOH) dan asid akrilik (AA) telah dijalankan bagi mengubah sifat-sifat gentian. Didapati penggunaan gentian-gentian yang dirawat oleh AA dan NaOH telah meningkatkan sifat-sifat tegangan dan pelenturan komposit masing-masing sebanyak 12.18% dan 53.54%. Komposit dengan gentian yang dirawat oleh AA dan NaOH telah menunjukkan sifat modulus penyimpanan yang tinggi iaitu masing-masing sebanyak 23% dan 34% jika dibandingkan dengan komposit yang menggunakan gentian yang tidak dirawat, ini menunjukkan perekatan antaramuka yang baik wujud di antara resin dan gentian. Sifat-sifat tegangan, pelenturan, T_g dan modulus penyimpanan dinamik (E’) pada kawasan kekaca bagi komposit poliester bergentian sisa tebu menurun dengan peningkatan kandungan gentian. Komposit hibrid (GBG dan GGB) menunjukkan sifat-sifat kekuatan tegangan yang tinggi jika dibandingkan dengan komposit bergentian sisa tebu. Penyerapan air bagi laminat yang tebal (5 dan 7 lapisan) adalah tinggi jika dibandingkan dengan laminat yang nipis. Ini adalah disebabkan oleh kecacatan yang mungkin wujud di antara lapisan dan menyebabkan peningkatan dalam penyerapan air bagi sistem komposit.

STUDIES ON THE PROPERTIES OF BAGASSE FIBER REINFORCED POLYESTER COMPOSITES

ABSTRACT

Bagasse is a by-product from sugar mills and is being mostly used as fuel or disposed of by incineration. An attempt has been made to convert this byproduct into useful plastic composites, which can be used for various engineering applications. In this study, the properties of bagasse fiber reinforced polyester composites were investigated. Effects of parameters such as bagasse fiber extraction techniques, fiber treatment, fiber volume content, and hybrid stacking arrangement and number of hybrid layer on the properties of glass-bagasse fiber polyester composites were evaluated. From the observation of different fiber extraction methods, manual extraction method is found to produce fine and long fibers. Fiber obtained from manual extraction method produced composite with higher mechanical properties compared to those of machine technique. For example, manual extraction composite exhibits 6.63% and 59.9% higher flexural and impact strength compared to those of latter system. Bigger size of fiber bundle presence of rind and pith components in fiber obtained from machine extraction method results in lower mechanical properties and higher water absorption of the composites. The alkali treatments using Sodium Hydroxide (NaOH) and acrylic acid (AA) treatment were carried out to modify the properties of fibers. It is noted that the use of AA treated fibers lead to 12.18% and 53.54% increased in tensile and flexural strengths of the composites, respectively, compared to untreated fiber composites. The NaOH and AA treated fiber composites exhibits higher storage modulus of 23% and 34%, respectively, compared to the untreated fiber composites. This indicates greater interfacial adhesion and bond strength exist between the resin and fibers. The tensile properties, flexural properties, T_g and dynamic storage modulus (E’) at the glassy region of bagasse fiber polyester composites increase with increasing fiber content. The moisture resistance of the composites reduced at higher fiber content. The hybrid composites (GBG and GGB) exhibits higher tensile strength compared to the bagasse fiber composites. The water absorption of thicker laminate (5 and 7 ply) is higher compared to thinner laminate (3 ply), this is due to the defect which might exist between the layers and hence increase the water absorption of the composite system.

CHAPTER 1

INTRODUCTION

1.1. Background

Over the last few years, there has been increasing interest in the use of natural fibers as reinforcement for polymer composites, such as flax fiber (Li et al., 2004), Kenaf (Nishino et al., 2003), bagasse (Cao et al., 2005) and jute (Mohanty et al., 1999). Natural fibers have the advantages of biodegradability, low cost and low density, making them competitive to glass fibers as reinforcement in composite applications (Marklund, 2005). Generally four main reasons are mentioned which make the application of natural fibers attractive (Bos and Harriette, 2004); (1) their specific properties, (2) their price, (3) their health advantage and (4) their recyclability.

An increase in the environmental awareness has led the scientist to produce biocomposites or better known as natural fiber composites. Currently large portion of composites industries are mainly made of polymer matrix composites (PMC's) with the vast majority of the matrix polymers (synthetic and non-biodegradable) (Georgopoulos et al., 2005). The use of synthetic fiber reinforced polymer process several environmental concerns particularly when land filling is the mean of disposal (Georgopoulos et al., 2005). Synthetic plastic materials are non-degradable in nature and results in continuous accumulation in the environment and may cause severe pollution. Degradation of plastic requires a long time and most of them end up over burdening on landfills (Xu et al., 2005).

Natural fibers based on lignocellulosic have a relatively low density, and relatively stiff and strong. Therefore their specific properties, i.e. the properties divided by the density are rather high, and actually comparable to those of glass fibers (Bos and Harriette, 2004). For the automotive industry, where weight reduction always is an issue, this was said to be the original reason for the development of interior parts with natural fibers as fillers (Hull, 1992). Originally, the automotive industry used wood fibers as fillers. However, wood fibers are short and have the ability to make composites stiffer, but they do not make the composites stronger. Therefore, composites reinforced with other longer natural fibers, like flax, hemp and sisal were developed. Most of the interior parts in cars are still designed for stiffness and natural fibers are well suited for this application given their high specific modulus (Bos and Harriette, 2004).

Natural fiber reinforced composites are originally aimed at the replacement of glass fiber reinforced composites (Karus et al., 2000). Depending on the exact quality of fiber needed, natural fibers are in most cases cheaper than glass fibers. Natural fibers are also expected to give less health problem for the people who producing the composites. Natural fibers do not cause skin irritations and they are not suspected of causing lung cancer (Bos and Harriette, 2004). This is especially an issue since the discussion on whether or not very small glass fibers can cause lung cancer, has still not ended.

Utilization of the agricultural crops as alternative raw materials for many industries is more than an option. Sugar cane residues are largely available in sugar producing countries such as Brazil, India, Cuba, Mexico, China (Erlich et al., 2005), and Malaysia. The residues can be divided into bagasse and cane trash (Waldheim, 2000; Zanzi, 2001). Cane trash consists of tops and leaves that in traditional sugar cane harvesting are burned off in the field before picking the cane stem (Waldheim, 2000). Bagasse is the fibrous material left over after pressing out the sugar-rich juice. In general, the combustion of sugar cane residue is used to generate heat in a steam power plant within factory.

According to Elsunni, (1993), sugar cane bagasse is established as the future fiber in tropical and subtropical regions for pulp and paper making. Previous work has demonstrated that fibers can be extracted from bagasse and formed into non-woven mats for significant and successful erosion control (Paturau, 1989; Ovidiu, 2004). These products from renewable resources have potential industrial applications based on their biodegradability for environmental purposes. The development of new products from sugar cane bi-products can be a tremendous economic benefit for the farmers and the region.

1.2 Investigation of bagasse fiber properties.

Natural fibers in composites offer some interesting properties. Fibers such as bagasse have respectively good specific properties. Natural fibers are environmental friendly and together with a certain polymer matrix they are also recyclable. Their low abrasive nature leads to reduce tool wear in production compared to glass fibers. In Table 1.1, fiber characteristics of bagasse and a number of other natural fibers as well as glass fibers are compared.

From Table 1.1 it can be concluded that bagasse fiber has a slightly higher stiffness and comparable strength compared to coir, moderate specific modulus and elongation at break and the price of bagasse is corporately every low. If compared to glass fiber, bagasse has low density, low specific modulus (E), higher elongation at failure and low cost.

Table 1.1 A comparison of the main fiber characteristics between bagasse and a number of other natural fibers as well as glass fibers (Brothers et al., 2003).

	Fibers									
Properties	Bagasse	Coir	Flax	Hemp	Jute	Ramie	Sisal	Abaca	Cotton	Glass
Density (g/cm^3)	0.586	1.25	1.4	1.48	1.46	1.5	1.33	1.5	1.51	2.55
Tensile Strength* (MPa)	200-300	220	800-1500	550-900	400-800	500	600-700	980	400	2400
Young's modulus (GPa)	5-9	6	60-80	70	10-30	44	38	-	12	73
Specific modulus	8-16	5	26-46	47	7-21	29	29		8	29
Elongation at failure (%)	4-7	15-25	1.2-1.6	1.6	1.8	2	2-3		3-10	3
Relative price compared to bagasse	100%	100%	200%-600%	240%-700%	140%	600%-1000%	240%-280%	600%-1000%	600%-900%	520%-600%

* Tensile strength strongly depends on type of fiber, being a bundle or a single

1.3 Research objectives

The objectives of the present study are:

1- To study the effect of two fiber extraction methods (manual and machine method) on the properties of bagasse fiber reinforced polymer composites.

2- To investigate the effect of fiber treatments using sodium hydroxide (NaOH) and acrylic acid (AA) on the properties of polyester composites.

3- To study the effect of fiber loading on the properties of bagasse fiber reinforced polyester composites.

4- To determine the effect of stacking arrangement and number of laminate layers on the properties of hybrid composites (bagasse fiber and glass reinforced polyester composites).

CHAPTER 2

LITERATURE REVIEW

2.1 Composite Materials

Modern technology places challenging demands on the performance capabilities of materials for new applications. An introduction of composite materials changed the world especially in the 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 ceramics, metal alloys or polymers (Callister, 2000). Other factor too should be considered in material selection. For examples, the development in transportation industries are utilizing increasing amounts efficiencies, the rising of the energy cost is now making it a primary factor in design (Ashby and Jones, 1980).

The major classification of composites consists of metal matrix composites, ceramic matrix composites and polymer matrix composites (Kalpakjian and Schmid, 2001). Nowadays, the applications of composite materials have been increase for applications such as in automobiles, space shuttles, boats, aircraft, electronics, piping, offshore structures and etc (Kalpakajian and Schmid, 2001). The most suitable example are Boeing 727, 757, 767 and 777 commercials aircrafts, some of the components are made of reinforced plastics (Kalpakajian and Schmid, 2001). About 9% composites by total weight has been manufactured for Boeing 777. The floor beams and panels and most of the vertical and horizontal tail are made of composite materials and the proportion is triple than the previous Boeing transport aircraft (Mustaffa, 2006). By virtue of the resulting weight savings, reinforced plastics have reduced fuel consumption by about 2% (Kalpakajian and

Schmid, 2001). The diversity of properties belongs to composite materials has made this field more interesting to be explored (Mohd Shad et at. 2005).

In addition to polymers, composite material matrices can be metallic or ceramic (Elisabete et al., 2004). Polymeric matrices can be divided into thermoplastic and thermoset categories (Mishra et al., 2000). In general, polymeric matrices are comparatively lighter and more inexpensive than metallic or ceramic ones, but ends use temperature, generally, 100-200°C, is more limited. Polymeric matrices are also susceptible to weathering and residual tension created by the difference in thermal expansion coefficients between the fibers and the matrix (for fibrous composites) (Herakovich et al., 1998). Despite these limitations, there still are an intensive range of applications for polymeric matrix composites in which these limitations are not critical, as for instance in interior car parts and other lower temperature applications (Elisabete et al., 2004).

2.1.1 Composites: Definition

Generally speaking, a composite is considered to be any multiphase materials that exhibit a significant proportion of the properties of both constituent phases, matrix phase and dispersed phase, such that a better combination of properties is realized (Callister, 2000; William and Callister, 2006). According to Matthews and Rawlings (2000), composites have two (or more) chemically distinct phases on a microscopic scale, separated by a distinct interface, and it is important to be able to specify these constituents. The constituent that is continuous and is often but not always, present in this greater quantity in the composite is termed as the matrix (Matthews and Rawlings, 2000). There is no specified definition for composites, but approach that can be used to define composites materials which the properties of composite that had been produced are better and might be unique in other condition compared to its constituent (Ismail, 2004). In designing composite materials, scientist and engineers have ingeniously combined various metals, ceramics and polymers to produce a new generation of extraordinary materials (William and Callister, 2006). Most composites have been created to improve combinations of mechanical characteristics such as stiffness, toughness, and ambient and high temperature strength.

In bulk form, the constituent materials work together but remain in their original forms. The final properties of composite materials are better than constituent material properties (Millick et al., 1993). The main concept of a composite is that it contains matrix materials. Typically, composite material is formed by reinforcing fiber in a matrix resin. The reinforcement can be fibers, particulates, or whiskers, and the matrix materials can be metals, plastics, or ceramics (Millick et al., 1993).

In this case, processing a polymeric composite does not necessarily involve high temperature, so the problem associated with reinforcement degradation during manufactures are less significant for this composites than those with other matrices (Elisabete et al., 2004). The equipment necessary to obtain composites with these matrices is normally simple. For these reasons, polymeric matrix composites developed quickly and were accepted for structural applications. Polymeric composites have found, for instance, large application in construction in general. They are also particularly interesting for the ships. Resistance to corrosion in a marine environment is another advantage of these materials (Kusak et al., 1998).

2.2 Constituent phase of composites

2.2.1 Matrix phase

The selection of the matrix materials is of great importance for the tailored design properties of composites (Baer and Moet, 1991). Matrix is a continuous phase that surrounded the dispersed phase (Matthews and Rawlings, 2000). It functions as an adhesive for fillers (Ismail, 2004). The matrix phase serves several functions, for examples in fiber reinforced composites (Callister, 2000). Matrix has successful functions which are:

- To support the fibers in place and transfer the stresses to them, while they carry most of the load. So, the matrix phase will undergo a small portion of stress loading because the external applied stress will be distributed to the fibers.
- To give protection to fibers against physical damage and from the environment. For examples, damage can be created through mechanical abrasion or effect from heat and moist due to chemical reaction.
- To reduce or prevent a catastrophic failure due to crack propagation in the composite. This is possible because matrix material is usually tough and ductile.

The matrix phase of composites may be a metal, polymer or ceramic (Matthews and Rawlings, 2000). For fibers to carry maximum load, the matrix must have a lower modulus and greater elongation than the reinforcement (Matthews and Rawlings, 2000). Matrix selection is based on chemical, thermal, electrical, flammability, environmental, cost, performance, and manufacturing requirements. The matrix determines the service operating temperature of a composite as well as processing parameters for part manufacturing (Kalpakjian and Schmid, 2001).

2.2.1.1 Thermoset Matrices

Thermoset materials once cured cannot be remelted or reformed. During curing, they form three-dimensional molecular chains, called cross-linking, as shown in Figure 2.1. Due to these cross-linkings, the molecules are not flexible and cannot be remelted and reshaped (Sanjay and Mazumdar, 2002). The higher the number of cross-linkings, the more rigid and thermally stable the material will be. In rubbers and other elastomers, the densities of cross-links are much lower and therefore they are flexible (Mazumdar et al., 1996). Thermosets may soften to some extent at elevated temperatures. This characteristic is sometimes used to create a bend or curve in tubular structures, such as filament-wound tubes. Thermosets are brittle in nature and are generally used with some forms of filler and reinforcement. Thermoset resins provide easy processability and better fiber impregnation because the liquid resin is used at room temperature for various processes such as filament winding, pultrusion, and resin transfer molding (RTM) (Sanjay and Mazumdar, 2002). Thermosets offer greater thermal and dimensional stability, better rigidity, and higher electrical, chemical, and solvent resistance. The most common resin materials used in thermoset composites are epoxy, polyester, vinylester, phenolics, cyanate esters, bismaleimides, and polyimides. Some of basic properties of the selected thermoset resins are shown in Table 2.1

Thermoset polymeric matrix composites can substitute efficiently for steel and concrete in civil construction structures, showing greater resistance to oxidation for the former and better freeze-thaw for the latter (Elisabete et al., 2004). This behavior could lead to structural component with improved weathering capability. However, one of the greatest obstacles to the use of organic materials in construction is related to their high combustibility. In this case, phenolic resins (novalac, resols) can be good choice, because they are widely used commercially owing to their excellent flame retardation and low cost.

Because of their low smoke generation, phenolic resins have been used in aircraft interior such as in the DC-10 (Tyberg et al., 1999). In addition, phenolic resins have a large number of applications in the electric-electronic, and aerospace industries (Achary et al, 1998; Tyberg et al., 1999).

Figure 2.1 Cross-linking of thermoset molecules during curing (Sanjay and Mazumdar, 2002).

Table 2.1 Typical unfilled thermosetting resin properties (Sanjay and Mazumdar, 2002).

Resin materials	Density (g/cm^3)	Tensile strength (MPa)	Tensile modulus (GPa)
Epoxy	1.2-1.4	50-110	2.5-5.0
Phenolic	1.2-1.4	35-60	2.7-4.1
Polyester	1.1-1.4	17-95	1.6-4.1

Researchers and engineers engaged in the polymer industry believed that, in the not too distant future, the field of polymeric materials will be dominated by composites; non-reinforced polymers will be considered unfinished products, as with rubber nowadays (Elisabete et al., 2004). Reinforcement such as fibers, are added to polymer matrices to improve their physical and mechanical properties, and processability, in association with an effort to reduce costs. The greatest challenge is to combine the fibers and matrix to produce the most efficient material for a specific application (Herakovich, 1998).

2.2.1.2 Advantages of thermoset composites

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

- Processing of thermoset composites is easy because the initial resin system is in the liquid state.
- Fibers are easy to wet with thermosets, thus voids and porosities are less.
- Heat and pressure requirements are less in the processing of thermoset composites than thermoplastic composites, thus providing energy savings.
- A simple low-cost tooling system can be used to process thermoset composites (Sanjay and Mazumdar, 2002).

2.2.1.3 Disadvantages of thermoset composites

Thermoset composite materials also have some disadvantages which are:

- Thermoset composite processing requires a lengthy cure time and thus results in lower production rates than thermoplastics.
- Once cured and solidified, thermoset composite parts cannot be reformed to obtain other shapes.
- Thermoset composites are difficult to recycle.

Physical and chemical treatments may be wedded to enhance the adhesion between reinforcement and matrix (Gassan et al., 2000).

2.2.1.4 Thermoplastic Resins

Thermoplastic materials are, in general, ductile and tougher than thermoset materials and are used for a wide variety of nonstructural applications (Gassan et al., 2000). Thermoplastics can be remelted by heating and then solidified by cooling, which render them capable of repeated reshaping and reforming. Thermoplastic molecules do not cross-link and therefore they are flexible and reformable. Thermoplastics can be either amorphous or semicrystalline, as shown in Figure 2.2. In amorphous thermoplastics, molecules are randomly arranged; whereas in the crystalline region of semi-crystalline plastics, molecules are arranged in an orderly fashion (Sanjay and Mazumdar, 2002). It is not possible to have 100% crystallinity in plastics because of the complex nature of the molecules.

The lower stiffness and strength values of thermoplastics require the use of fillers and reinforcements for structural applications. Thermoplastics generally exhibit poor creep resistance, especially at elevated temperatures, as compared to thermosets. They are more susceptible to solvents than thermosets. Thermoplastic resins can be welded together, making repair and joining of parts more simple than for thermosets. Repair of thermoset composites is a complicated process, requiring adhesives and careful surface preparation. Thermoplastic composites typically require higher forming temperatures and pressures than comparable thermoset systems. Thermoplastic composites do not enjoy as high level of integration as currently obtained with thermosetting systems (Sanjay and Mazumdar, 2002). The higher viscosity of thermoplastic resins makes some manufacturing processes, such as hand lay-up and tape winding operations, more difficult. As a consequence of this, the fabrications of thermoplastic composite parts have drawn a lot of attention from researchers to overcome these problems. Some of the properties of themoplastics are given in Table 2.2.

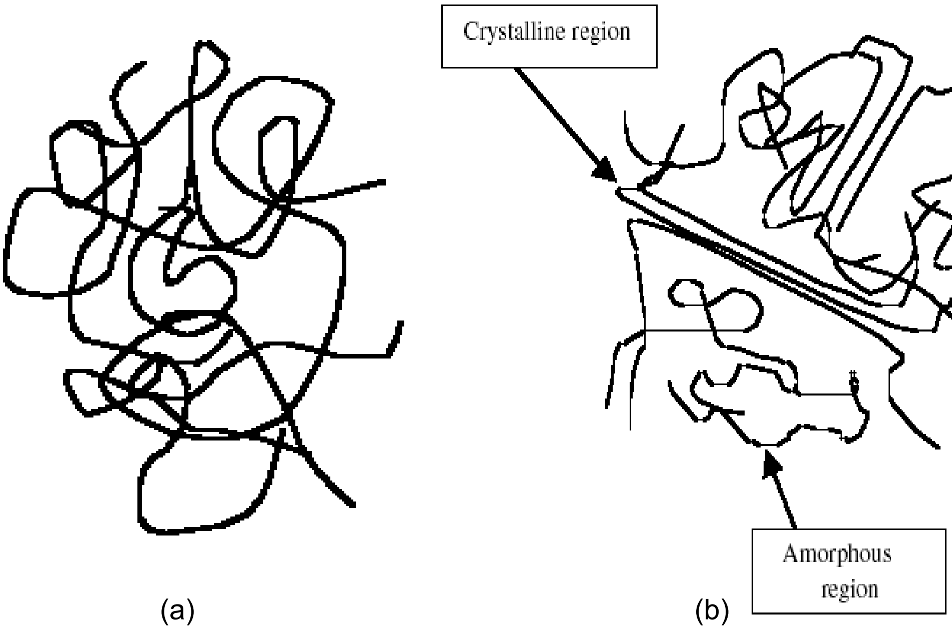


Figure 2.2 Molecular arrangements in (a) amorphous and (b) semi-crystalline polymers (Sanjay and Mazumdar, 2002).

Table 2.2 Typical unfilled thermoplastic resin properties (Sanjay and Mazumdar, 2002).

Resin materials	Density (g/cm^3)	Tensile strength (MPa)	Tensile modulus (GPa)
Nylon	1.1	55-90	1.3-3.5
Polyetheretherkertone (PEEK)	1.3-1.35	100	3.5-4.4
Polyphenylene Sulfide (PPS)	1.3-1.34	80	3.4
Polyester	1.3-1.4	55-60	2.1-2.8
Polycarbonate	1.2	55-70	2.1-3.5
Acetal	1.4	70	3.5
Polyethylene	0.9-1.0	20-35	0.7-1.4
Teflon	2.1-2.3	10-35	_

2.2.1.5 Advantages of thermoplastic composites

The advantages of thermoplastic composites include:

- The process cycle time is usually very short because there is no chemical reaction during processing, and therefore can be used for high-volume production methods. For example, process cycle time for injection molding is less than 1 min and therefore very suitable for automotive-type markets where production rate requirements are usually high.
- Thermoplastic composites can be reshaped and reformed with the application of heat and pressure.
- Thermoplastic composites are easy to recycle.

2.2.1.6 Disadvantages of thermoplastic composites

- Thermoplastic composites require heavy and strong tooling for processing. Moreover, the cost of tooling is very high in thermoplastic composites manufacturing processes. For example, the tooling cost in the injection molding process is typically more than $50,000, whereas the mandrel for a filament winding process costs less than $500.
- Thermoplastic composites are not easy to process and sometimes require sophisticated equipment to apply heat and pressure.

2.2.2 Dispersed phase

Dispersed phase is used to be an additional material in the matrix phase (Mohd Shah, 2005). This inert material is usually available in various shapes such as fiber, particulate, flake, filler or laminate and has been added to improve mechanical and physical properties of composites especially strength, toughness and stiffness properties (Callister, 2000). Composite materials may be classified according to various criteria (Brandt, 1995). The most important from the physical viewpoint relate to the type of discontinuities created in the material structure. The structural elements are distributed at random or regularly, using many different techniques, which are different elements may fulfils various conditions: blocking and controlling crack propagation, improving strength, increasing porosity, improving thermal isolation, modifying the transfer of fluids and gases across the material, and so on (Brandt, 1995). Figure 2.3 shows four main groups of composite materials with different types of discontinuities which are:

1) Dispersion strengthening, e.g. metals with fine dispersed particles of hard material which restrain the motion of dislocations.
2) Grain strengthening, e.g. Portland cement-based matrices with sand and aggregate grains randomly distributed.
3) Fiber reinforced, e.g. cement paste with asbestos fibers or polymer matrices with glass fibers.
4) Laminated composites, e.g. timber plywood or laminated plastics.

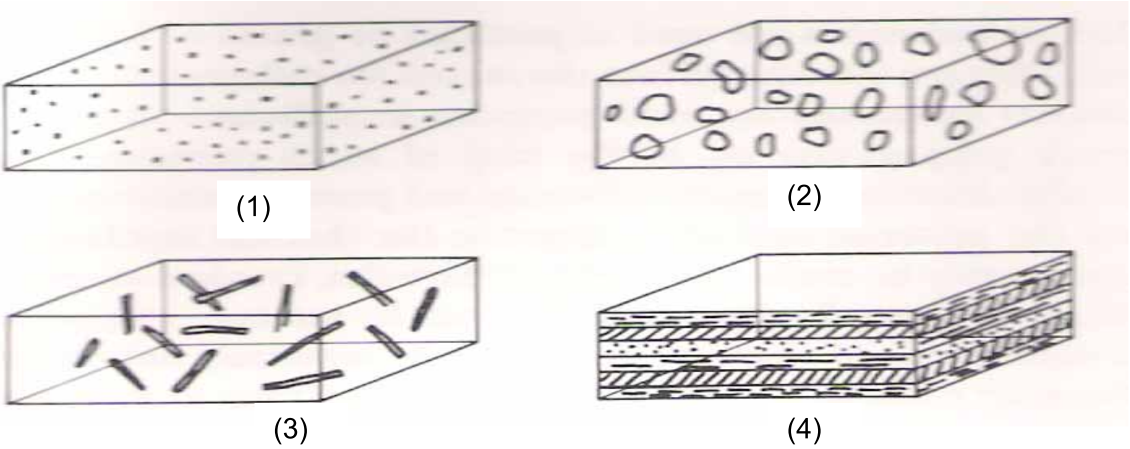


Figure 2.3 Schematic representation of four types groups of composites (1) refers to dispersion strengthening, (2) grain strengthening, (3) fiber reinforced, (4) laminated composites (Brandt, 1995)

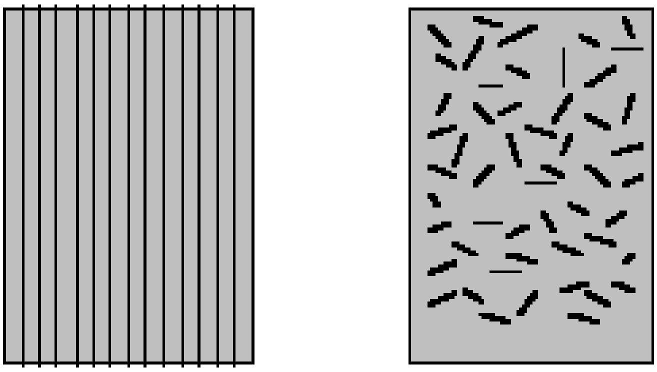
2.2.3 Classification of dispersed phase

2.2.3.1 Fibers reinforcement

Fibers for composite materials can come in many forms, from continuous fibers to discontinuous (Figure 2.4), organic fibers to inorganic fibers (Reigner and Sanders, 1979). The most important composites are those in which the dispersed phase is in the form of fiber. Design goals of fiber-reinforcement composites often include high strength and/or stiffness on a weight basis. These characteristics are expressed in term of specific strength and specific modulus parameters, which correspond, respectively, to the ratios of tensile strength to specific gravity and modulus of elasticity to specific gravity (Sanjay and Mazumdar, 2002).

The properties of fiber-reinforced composites are strongly dependent on the way the fibers are laid in the composites. Only one form can be used in a composite. The important thing to remember about composites is that the fiber carries the load and the composite strength is the greatest along the axis of the fiber (Mallick, 1993). Long continuous fibers in the direction of the load result in a composite with properties far exceeding the matrix resin itself. The same material chopped into short lengths yields lower properties than continuous fibers. Depending on the type of application (structural or nonstructural) and manufacturing method, the fiber form is selected. Figure 2.4 shows the two types of fiber composites, continuous and short fiber composites (Sanjay and Mazumdar, 2002). For structural applications, continuous fibers or long fibers are recommended; whereas for nonstructural applications, short fibers are recommended. Injection and compression molding utilize short fibers, whereas filament winding, pultrusion, and roll wrapping use continuous fibers (Mallick, 1993; Sanjay and Mazumdar, 2002).

A fibrous reinforcement is characterized by its length being much greater than its cross-sectional dimension. The ratio of fiber length to the cross-sectional dimension is called the aspect ratio; the orientation of the continuous fibers maybe random or preferred (Mallick, 1993).



Continuous fiber composites (a)

Short fiber composites (b)

Figure 2.4 Fibers reinforced composites (a) Continuous fiber and (b) short fiber composites (Sanjay and Mazumdar, 2002).

2.2.3.2 Particle reinforcement

The range of materials available in particulate form is far more extensive than as fibers because the production is so much simple as most materials maybe ground into a powder from the bulk (Matthews and Rawlings, 2000). Particle reinforcements have dimensions that are approximately equal in all directions. The shape of the reinforcing particles maybe spherical, cubic, platelet or any regular or irregular geometry; the arrangement of the particulate reinforcement maybe random or with a preferred orientation, and characteristic is also use as a part of the classification scheme. In the majority of particulate reinforced composites the orientation of particles is considered, for practical purposes, to be random.

2.2.3.3 Whisker reinforcement

Whiskers are very thin single crystals that have extremely large length to diameter ratios (William et al., 2006). As a consequence of their small size, they have a high degree of crystalline perfection and are virtually flaw free, which accounts for their exceptionally high strengths; they are among the strongest known materials (Jack and Chou, 1975). In spite of these high strengths, whiskers are not utilized extensively as reinforcement medium because they are extremely expensive. Moreover, it is difficult and often impractical to in corporate whisker into a matrix (William et al., 2006).

According to the theories of short fiber composites, the composites reinforced with thinner, stronger fibers can be anticipated to achieve much higher mechanical properties (Zhuang, 2007). Generally, whiskers possess high strength and stiffness due to their nearly perfect crystal structure. Therefore, whiskers are reckoned as more effective reinforcements than traditional fiber, such as carbon fiber and glass fiber. However, the expensive cost of some whiskers, such as SiC whiskers, becomes an obstacle for their applications in polymer composites (Zhuang et al., 2007). Fortunately, a cheaper whisker, potassium titanate whisker (PTW), was developed with a price ranging from one-tenth to one-twentieth of the cost for the SiC whisker (Sugarnuma et al., 1989). Some studies on PTW reinforced polymer composites have been carried out (Tjong et al., 1998a; Tjong et al., 1999b; Yu et al., 2000; Qu et al., 2004; Tjong et al., 2005c; Hao et al., 2005). Generally, the Young's moduli of the PTW reinforced composites increase with increasing whiskers content where the impact strengths of composites have opposite variation (Zhuang et al., 2007). The tensile strengths of the composites, however, exhibit a complicated variation.

2.3 Interface

The interface is a layer between two different phases of a composite material. The structure and composition of an interface depend on the nature of both neighbouring phases and also on the conditions of mixing, hydration and ageing of the material (Brandt, 1995).

Several important test results and conclusions concerning the interfaces, their structure, properties and influence have been published by Mindess and Shah (1988). The interface is formed partly by two neighbouring phases or predominantly by one of them, but in this region strong modifications with respect to both phases are observed. Its structure is often composed of several layers, with the inclusion of gains and pores. The structure of the interface may be very complex when exposed to the external actions and loads. Interfacial regions usually occupy only a small part of the material volume, but their properties influence considerably its behaviour and quality (Brandt, 1995).

In the discussion of reinforcements, it has been mentioned that sometimes a surface treatment is carried out to achieve the required bonding to the matrix (Matthews and Rawlings, 2000). The reason why the reinforcement-matrix bonding is important, because of their significance, the main points is the load acting on the matrix has to be transferred to the reinforcement via the interface. Thus reinforcement must be strongly bonded to the matrix, if their high strength and stiffness are to be imparted to the composites. The fracture behavior is also dependent of the strength of the reinforcement (Matthews and Rawlings, 2000). A weak fracture surface results in low stiffness and strength but high resistance to fracture, whereas a strong interface product high stiffness and strength but often low resistance to fracture, i.e., brittle behavior (Matthews and Rawlings, 2000). The interface is important whether the reinforcement is in the form of continuous fibers, short fibers or whiskers or particles, although the exact role of the interface may differ with the type of reinforcement (Matthews and Rawlings, 2000). As the strength of the interface between the matrix and reinforcement plays a major role in the determining the mechanical performance of a composite, the different chemical bonding treatments to enhance the interfacial adhesion will be discussed in this project.

It is pointed out that the major function of interfaces in composites is to transmit the load from the matrix to the reinforcing fibers. The behavior of the interface determines not only strength but also the mode of failure and the work of fracture of a composite (Jack and Chou, 1975). In order to optimize the performance of composite materials, it is necessary to gain some fundamental understanding of the nature of interfaces.

2.4 Fiber reinforced polymer composites

2.4.1 Synthetic fiber reinforced polymer composites

There are naturally occurring fibers which are used to produce composites (Bracke et al., 1984). Many different fibers are manufactured for the reinforcement in composites and some typical properties are given in Table 2.3 (Matthews and Rawlings, 2000). The values for stiffness and strength in the table should be viewed with some caution. The manufacture of the fibers involves a number of processing steps and variability of properties from one fiber to another is large even when made by the same processes, the resulting microstructure and properties can differ even more markedly.

Table 2.3 Properties of synthetic fibers (Matthews and Rawlings, 2000).

Fibers	Density (Mg/m^3)	Young's modulus (GPa)	Tensile strength (MPa)	Failure strain (%)
E-glass	2.54	70	2200	3.1
Aramid (Kevlar 49)	1.45	130	2900	2.5
SiC (Nicalon)	2.60	250	2200	0.9
Alumina (FP)	3.90	380	1400	0.4
Boron	2.65	420	3500	0.8
Polyethelene (S1000)	0.97	172	2964	1.7
Carbon (HM)	1.86	380	2700	0.7

2.4.2. Natural fiber reinforced composites

Composites of polymers reinforced with natural fibers have received ever increasing attention, both from the academic world and from various industries. These fibers are composed of composite materials. There is a wide variety of different natural fibers which can be applied as reinforcers or fillers. Recently, many studies on natural fiber composites have been made. Natural fibers such as kenaf (Nishino et al., 2003), bagasse (Sousa et al., 2004), jute (Gassan et al., 1999; Ray et al., 2001; Gowda, 2002), ramie, oil palm (Wollerdorfer et al., 1998) and hemp (Keller, 2003) have been investigated as reinforcements for fiber reinforced plastics. Those studies were performed to improve the mechanical properties such as tensile strength, impact strength, flexural modulus and etc.

2.5 Natural fiber reinforced polymers

Interest in natural fiber reinforced polymer composites is growth in due to the fibers which are renewable, low cost, completely or partially recyclable and biodegradable (Frederick, 2004).

2.5.1 Limitation of natural fibers reinforced composites

Quality production efficiency depends on environmental conditions. Natural fibrous raw materials are not homogeneous; homogeneity depends on the cultivar and on growing, harvesting and primary processing conditions. Fiber presentation is time and labor intensive. Large areas are required for cultivation, if substantial amounts of raw materials are required. The change in the properties and dimensions of polymer composites reinforced with natural fibers depend on the inherent physical properties of the fibers (Frederick, 2004). The lower density of the natural vegetable fibers can be disadvantageous in processing due to the need for pressure application (the fiber tends to emerge on the surface).

2.5.2 Properties of natural fibers

Properties of natural fibers result from their structure and chemical composition. Plant fibers are characterized by cellular structure, each cell containing crystalline cellulose region (microfibrils), which are interconnected via lignin and hemicellulose fragments. A cell has one external wall and three thick side walls as shown in Figure 2.5 (Ye and Sundstrom, 1997). The more parallel the microfibrils are to the fiber axis, the higher is the fiber strength. Most natural fibers have a porous structure, which can affect their saturation with resins (Frederick, 2004).

The mechanical properties of vegetable fibers, especially flax, hemp, jute and sisal, are very good and may successfully compete with glass fiber in specific strength and modulus (Table 2.4). Vegetable fibers such as cotton and coir show higher elongation to break than glass or carbon fibers, which may enhance composites performance.

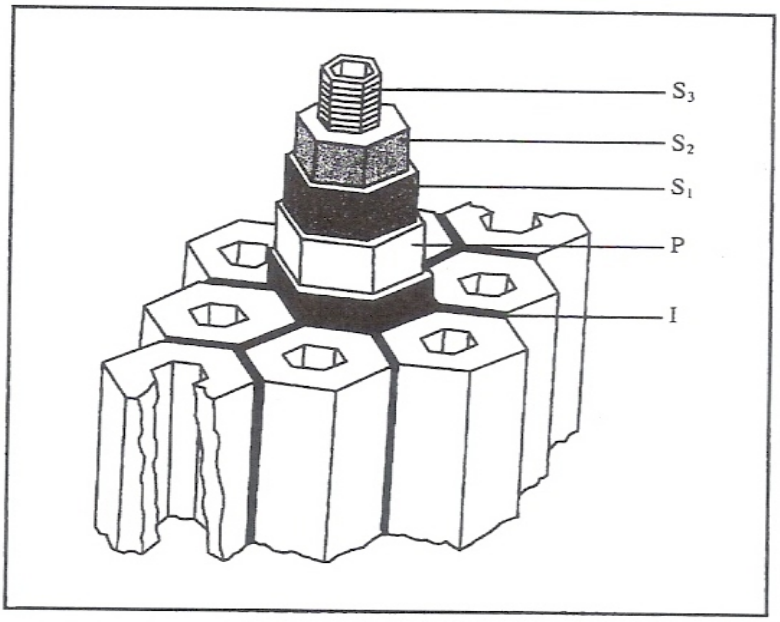


Figure 2.5 Schematic picture of plant fiber cellular structure. P-external wall; I-Intercellular adheshive (e.g. lignin); S1-external side wall; S2-middle side wall; S3-internal side wall (Frederick, 2004)

Table 2.4 Mechanical properties of natural fiber compared to glass fiber (Brouwer et al., 2000; Frederick, 2004).

Fiber	Density (g/cm^3)	Tensile strength (MN/m^2)	Young's modulus (GPa)	Specific modulus	Elongation at break (%)	Moisture absorption (%)
E-glass	2.55	2400	73	29	3	-
Flax	1.4	800-1500	60-80	26-46	1.2-1.6	7
Hemp	1.48	550-900	70	47	1.6	8
Jute	1.46	400-800	10-30	7-21	1.8	12
Ramie	1.5	500	44	29	2	12-17
Coir	1.25	220	6	5	15-25	10
Sisal	1.33	600-700	38	29	2-3	11
Abaca	1.5	980	-	-	-	-
Cotton	1.51	400	12	8	3-10	8-25