MECHANICAL PERFORMANCE OF KENAF FIBRE REINFORCED THERMOPLASTIC COMPOSITE

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ABSTRACT

Natural fibre is one of the potential candidates to be used with the thermoplastic as a composite. Kenaf fibre was mixed with Polypropylene (PP) in addition of maleic anhydride (MAPP). Kenaf were separated from the outer layer and bast fibre and were cut using crusher. The ash content is removed by sieving and washing the fibre. The fibre is then treated with alkaline treatment using three different concentrations of 5wt%, 10wt% and 15wt% in three different time's treatments which are 1 hour, 1.5 hour and 2 hour. 10wt% fibre and 1.5 hour of time treatment were chose as an actual value for fibre loading of the composites which were 10wt%, 20wt%, 30wt%, and 40wt%. MAPP was added with weight ratio 1:10 of fibre and finally PP was added to complete the sample. All of the samples were compounded using plastic mixer and palletized using plastic crusher. Samples were then molded by injection molding. An alternative method has been used to find a better solution for fibre treatment by using Ultrasonic for 10wt% fibre and 1.5 hour treatment. Some tests were done to analyze samples such as Fourier Transform Infrared Spectroscopy (FTIR), Melt Flow Index (MFI), water adsorption, density (Pcynometer), and tensile strength (Tensile Test). For feasibility study of alkaline treatment, the results showed that the best value is for 15wt%, 1 hour of alkaline treatmen. For feasibility study of fibre loading, the best composite selected was sample with 40wt% of fibre with tensile strength of 49.1547MPa and for comparison by using Ultrasonic for treatment; it was showed that this alternative method gave a better composite. From the data and supported theories by various authors, it can be concluded that alkaline treatment, fibre loading and treatment method have a significant effect on the composite.

ABSTRAK

Gentian asli merupakan salah satu elemen yang berpotensi untuk digabungkan dengan termoplastik. Gentian kenaf dicampurkan bersama *Polypropylene (PP)* dengan tambahan *Maleic Anhydride (MAPP)*. Kenaf pada mulanya dipisahkan dari lapisan luar dan serat dan dipotong menggunakan pemotong. Kandungan abu dipisahkan dengan mengayak dan membasuh gentian. Gentian kemudiannya dirawat dengan rawatan beralkali dengan tiga konsentrasi berat serat yang berbeza iaitu 5%, 10% dan 15% dalam tempoh rawatan yang berbeza iaitu 1 jam, 1.5 jam dan 2 jam. 10% berat serat dan 1.5 jam tempoh rawatan dipilih sebagai satu nilai untuk pemuatan serat berat komposit untuk 10%, 20%, 3% dan 40%. *MAPP* telah ditambah dengan nisbah berat 1:10 serat dan akhirnya *PP* ditambah bagi menyiapkan sampel. Kesemua sampel digabungkan menggunakan pencampur plastik dan dipotong menggunakan penghancur plastik. Sampel kemudiannya dibentuk melalui pembentuk suntikan. Satu kaedah alternatif digunakan sebagai penambahbaikan rawatan gentian dimana rawatan ultrasonik digunakan untuk 10% berat gentian serat dengan 1.5 jam rawatan. Beberapa analisis dijalankan seperti *Fourier Transform Infrared Spectroscopy (FTIR)*, *Melt Flow Index (MFI)*, penjerapan air, ketumpatan (*Pcynometer*) dan kekuatan tegangan (*Tensile Test*). Untuk rawatan beralkali, nilai yang terbaik ialah 15% berat konsentrasi serat dengan 1 jam masa rawatan manakala untuk pemuatan serat, komposisi yang terbaik adalah 40% berat gentian dengan kekuatan tegangan sebanyak 49.1547MPa. Melalui aplikasi ultrasonik, keputusan menunjukkan kaedah ini memberikan hasil yang lebih baik. Dari data dan menyokong teori oleh pelbagai penulis, kesimpulannya rawatan beralkali, komposisi serat dan kaedah rawatan adalah sesuatu yang penting kepada komposit.

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%	-	Percentage
wt%	-	Weight percentage
vol%	-	Volume percentage
°C	-	Degree celsius
T	-	Extraction temperature
V	-	Volume
μ	-	Micro
Gpa	-	Giga pascal
MPa	-	Mega pascal
KPa	-	Kilo pascal
T	-	temperature
m	-	Molecular mass

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The volume of thermoplastics used in the housing, automotive, packaging and other low-cost, high-volume applications is enormous. Recent interest in reducing the environmental impact of materials is leading to the development of newer materials or composites that can reduce the stress to the environment. In light of potential future petroleum shortages and pressures for decreasing the dependence on petroleum products, there is an increasing interest in maximizing the use of renewable materials (Roger M. Rowell *et al.*, 1999).

Natural fibre reinforced unsaturated polyester have generated much interest in recent years as a potential environmentally friendly and cost-effective option for making low cost engineering materials. New environmental regulations have forced the industries to search for new materials that can substitute for the traditional non-renewable reinforcing materials such as carbon fibres and glass fibres. Thus the environmentally friendly natural fibres combined with unsaturated polyester resin are widely introduced to the industries as they possess many advantages compared to other thermosetting resins including room temperature cure capability, good mechanical properties and transparency. Natural plant fibre reinforced polymeric composite also have some disadvantages such as the incompatibility between the hydrophilic fibres and hydrophobic thermoplastic and thermoset matrices requiring appropriate treatments to enhance the adhesion between fibre and the matrix (Gassan *et al.*, 2000, Dhakal *et al.*, 2007).

One of the celebrated constituents of natural fibre reinforced plastic composites in Malaysia is kenaf fibre. The research in kenaf plastic composite is growing tremendously along with the plastic industry's high demand for it for producing petroleum-based materials. Kenaf long fibre plastic composite could be used for a wide variety of applications if the properties were found to be comparable to existing synthesis composites. Since kenaf is always available in long fibre form, the mechanical properties found could be of use in many industrial applications such as insulators seals. In addition, kenaf fibre offers the advantages of being biodegradable, of low density, non-abrasive during processing and environmentally safe (Nishino T., 2003).

The attractive features of kenaf fibres are the low cost, lightweight, renewability, biodegradability and high specific mechanical properties. Kenaf has a bast fibre which contains 75% cellulose and 15% lignin and offers the advantages of being biodegradable and environmentally safe (Kamai R., 1996).

Among natural fibre composites, kenaf fibre reinforced composites have found potential applications for mobile phone shells consisting 15–20% kenaf fibres (Iji, 2008). Another example in the automobile industry is the Toyota RAUM, which is equipped with a spare tire cover made of kenaf fibre composites (Maya Jacob John *et al.*, 2007).

1.2 Problem Statement

As industry attempts to lessen the dependence on petroleum based fuels and products there is an increasing need to investigate more environmentally friendly, sustainable materials to replace the existing glass fibre and carbon fibre reinforced materials. Therefore, attention has recently shifted to the fabrication and properties of natural fibre reinforced materials (Mohanty AK *et al.*, 2003).

The worldwide automotive production rate is increasing and is estimated to reach 76 million cars annually by 2020 (WBCSD, 2004). Limited petroleum resources will increase petroleum-based products’ prices in the near future. It is estimated that a 25% reduction in car weight would be equivalent to saving 250 million barrels of crude oil (Lan R. Mair, 2000); therefore it is possible that manufacturers will consider expanding the use of natural fibre in their new products. Moreover, the recycling concerns being driven by EU regulations (ELV) are forcing manufacturers to consider the environmental impacts of their production and possibly shift from petroleum-based to agro-based materials (Rasshofer W. *et al*., 2001; Davoodi MM. *et al.*, 2008).

Natural fibre-reinforced (NFR) composites are likely to be environmentally superior to glass fibre reinforced (GFR) composites in most applications because natural fibre production results in lower environmental impacts compared to glass fibre. The production of natural fibre-reinforced transport pallets uses 45% less energy, and results in lower emission of toxic gases (CO2, methane, SO2, and CO) than production of GFR transport pallets (Van de Velde K, *et al*., 2001).

However, natural fibres are hydrophilic in nature as they are lignocellulosic, which contain strongly polarized hydroxyl groups and require chemical modification to increase the compatibility and adhesion between fibres and matrix (John & Anandjiwala, 2008); which is associated with a low compatibility of hydrophobic polymers like polypropylene, as well as with a loss of mechanical properties after moisture uptake (Tajvidi M. *et al.*, 2003; Bledzki KA *et al.*, 1998; Khan AM *et al.*, 1997).

Due to the poor compatibility, surface of fibres must be treated with coupling or compatibilizing agents to improve the interface between the fibre and the matrix. However, the use of both matrix resin (maleated polyolefins) and fibre surface treatment (coupling agents) have received considerable attention due to their effectiveness in modifying the interface by forming a link between the components (Felix MJ *et al.*, 1991; Zafeiropoulos EN *et al.*, 2002).

It would be ideal if the chemicals used for the modification of natural fibres preserve the biodegradable nature of natural fibres. In this study, Sodium Hydroxide (NaOH) is used for fibre treatment while Maleic Anhydride Polypropylene (MAPP) is used as a coupling agent to see its effect on interfacial adhesion in kenaf fibre reinforced polypropylene composites.

1.3 Objectives of the study

The objective of this research is to make an improvement for mechanical performance of kenaf fibre reinforced thermoplastic.

1.4 Scope of Study

In order to achieve the objective, the scope of research was to make a feasibility study on fibre treatment for hemicelluloses and lignin removal. Different fibre loading is used to get the best composition for the composite. Furthermore, affect of using an alternative method, Ultrasonic, was investigated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes the physical, chemical and mechanical properties of kenaf fiber, and some methods to produce composites. Matrix, its types and role of matrix in composites were also discussed. Major factors controlling the performance of composites were briefly described. Special emphasis was given on the methods of modification of fiber-matrix interface as it plays an important role on mechanical properties of composites.

2.2 Natural Fiber

Natural fiber is class of hair-like materials that are continuous filaments or are in discrete elongated pieces, similar to pieces of thread. They can be spun into filaments, thread, or rope. They can be used as a component of composite materials. The use of natural fibers as reinforcements in polymer composites to replace synthetic fibers like glass is presently receiving increasing attention because of the advantages, including cost effectiveness, low density, high specific strength, as well as their availability as renewable resources.

Since the 1990s, natural fiber composites are emerging as realistic alternatives to glass-reinforced composites in many applications. Natural fiber composites such as hemp fiber-epoxy, flax fiber-polypropylene (PP), and china reed fiber-PP are particularly attractive in automotive applications because of lower cost and lower density. Glass fibers used for composites have density of 2.6 g/cm^3 and cost between $1.30 and $2.00/kg. In comparison, flax fibers have a density of 1.5 g/cm^3 and cost between $0.22 and $1.10/kg (Foulk JD *et al.*, 2000).

Several different natural fiber–polypropylene composites is determined the ability to replace glass fiber–reinforced materials. Polypropylene with a very high melt flow index was used to aid in fiber matrix adhesion and to ensure proper wetting of the fibers. Samples were made with 40% fiber content of kenaf, coir, sisal, hemp, and jute. After the samples were fabricated, tensile and impact tests were run to compare the properties of these composites to those made with glass fiber. The tensile strengths all compared well with glass, except for the coir, but the only sample with the same flexural strength was hemp. It was shown with kenaf fibers that increasing fiber weight fraction increased ultimate strength, tensile modulus, and impact strength. However, the composites tested showed low impact strengths compared to glass mat composites. This study demonstrated that natural fiber composites have a potential to replace glass in many applications that do not require very high load bearing capabilities (P. Wambua *et al.*, 2003).

Table 2.1: Comparison between natural and glass fibers
(P. Wambua *et al.*, 2003)

	Natural fibers	**Glass fibers**
Density	Low	Twice that of natural fiber
Cost	Low	Low, but higher thnoan natural fiber
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
Distribution	Wide	Wide
CO2 neutral	Yes	No
Abrasion to machines	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Not biodegradable

Natural fiber composites are also claimed to offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradability of components. Since, such superior environmental performance is an important driver of increased future use of natural fiber composites, a thorough comprehensive analysis of the relative environmental impacts of natural fiber composites and conventional composites, covering the entire life cycle, is warranted (S.V. Joshi *et al.*, 2003).

2.2.1 Types of Natural Fiber

These natural fibers can be split up into two categories, bast and leaf fibers. The bast fiber composites include kenaf, hemp and flax while sisal maybe considered a leaf fiber (M. Zampaloni *et al.*, 2007).

Bast:

The bast fibers exhibit a superior flexural strength and modulus of elasticity (M. Zampaloni *et al.*, 2007).

Leaf:

The leaf fibers show superior impact properties (M. Zampaloni *et al.*, 2007).

2.2.2 Properties of Natural Fiber

Table 2.2: Properties of Natural Fiber

(**P**.Wambua *et al*., 2003; Mohanty A.K *et al.*, 2000; Parikh DV *et al.*, 2009)

Properties	Hemp	Jute	Ramie	Coir	Sisal	Flax	Cotton	Kenaf
Density g/cm3	1.48	1.46	1.5	1.25	1.33	1.4	1.51	1.4
Tensile Strength, MPa	550-900	400-800	500	220	600-700	800-1500	400	283-800
E-Modulus, GPa	70	10-30	44	6	38	60-80	12	21-60
Specific (E/d)	47	7-21	29	5	29	26-46	8	-
Elongation at failure, %	1.6	1.8	2	15-25	2-3	1.2-1.6	3-10	1.6
Moisture absorption, %	8	12	12-17	10	11	7	8-25	-

Natural fiber properties are highly variable and depend on conditions of growth. It is therefore very difficult to get the same mechanical properties after repeat testing.

For this research, kenaf fiber is used instead of other natural fiber. This is because kenaf requires less than 6months for attaining a size suitable for practical application. Due to the fast growth and good fiber quality, since the 1960s, there has been increasing interest in kenaf, primarily for its potential use as a commercial fiber crop for the manufacture of newsprint and other pulp and paper products, leading to collaborations between R&D, economist, and market research (H.P.S. Abdul Khalil *et al.*, 2010).

2.2.3 Kenaf Fiber

Kenaf (Hibiscus cannabinus L.) is a traditional, third world crop after wood and bamboo that is poised to be introduced as a new annually renewable source of industrial purpose in the so-called developed economies. Kenaf is a warm-season annual fiber crop growing in temperate and tropical areas. It is related to cotton, okra, and hibiscus due to systematics. It is a fibrous plant, consisting of an inner core fiber (75–60%), which produces low quality pulp, and an outer bast fiber (25–40%), which produces high quality pulp, in the stem. The plant grows to a height of 2.7–3.6mand is harvested for its stalks, from which the fiber is extracted (H.P.S. Abdul Khalil *et al.*, 2010).

Mankind has skillfully made use of kenaf from ancient times, traditionally as a rope, canvas and sacking. There are numerous advantages of using natural lignocellulosic fibers as reinforcements of the matrix. Especially, kenaf is well known as a cellulosic source with economical and ecological advantages. Kenaf exhibits low density, non-abrasiveness during processing, high specific mechanical properties, and biodegradability.

Recently, kenaf is used as a raw material to be alternative to wood in pulp and paper industries for avoiding destruction of forests (Pande H *et al.*, 1998), and also used as non-woven mats in the automotive industries (Magurno A. *et al.*, 1999).

Kenaf is an herbaceous annual plant that is grown commercially in the United States in a variety of weather conditions, and it has been previously used for rope and canvas. Kenaf has been deemed extremely environmentally friendly for two main reasons; (a) kenaf accumulates carbon dioxide at a significantly high rate and (b) kenaf absorbs nitrogen and phosphorous from the soil (Michell A., 1986).

2.2.4 Characteristic and Properties of Kenaf Fiber

Kenaf has a bast fiber which contains 75% cellulose and 15% lignin and offers the advantages of being biodegradable and environmentally safe (Kamani R., 1996). Malaysian kenaf is composed of two distinct fibers, bast and core, with a makeup of about 35% and 65%, respectively. Each fiber has its own usage; thus, separation of the fibers produces higher monetary returns over whole-stalk kenaf. Major factors involved in separation of kenaf into its two fractions include: size and amount of each portion; type and number of separation machinery; processing rate through separation machinery; moisture content of whole-stalk kenaf; humidity of ambient air (H.P.S. Abdul Khalil *et al.*, 2010).

Table 2.3: Characteristic and properties of kenaf stems, Malaysia (H.P.S Abdul Khalil *et al*., 2010)

Characteristics/properties	**Bast**	**Core**	**Stem**
Dimension (cm)			
Height (range)			145-250
Diameter		1.52 (0.095)	1.74 (0.212)
Perimeter		5.73 (0.131)	6.60 (0.101)
Proportion (%)			
Cross-section area	21.96 (2.03)	78.04 (2.51)	
Weight proportion	32.2	68.5	
Density (g/cm^3)	-	0.21 (0.038)	0.29 (0.044)
Acidity (pH)	7.13	5.21	5.87

2.3 Matrix

The first and the most important problem is the fiber-matrix adhesion. The role of the matrix in a fiber reinforced composite is to transfer the load to the stiff fibers through shear stresses at the interface. This process requires a good bond between the polymeric matrix and the fibers. Poor adhesion at the interface means that the full capabilities of the composite cannot be exploited and leaves it vulnerable to environmental attacks that may weaken it, thus reducing its life span. Insufficient adhesion between hydrophobic polymers and hydrophilic fibers result in poor mechanical properties of the natural fiber reinforced polymer composites (P. Wambua *et al.*, 2003).

2.3.1 Thermoplastic

While, natural fibers traditionally have been used to fill and reinforce thermosets, natural fiber reinforced thermoplastics, especially polypropylene composites, have attracted greater attention due to their added advantage of recyclability (Mohanty AK *et al.*, 2002).

Thermoplastic composites are composites that use a thermoplastic polymer as a matrix. A thermoplastic polymer is a long chain polymer that can be either amorphous in structure or semi-crystalline. These polymers are long chain, medium to high molecular weight materials.

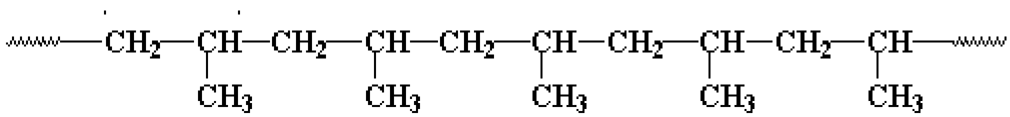
Advantages of thermoplastic matrices:

- Unlimited shelf life
- Short processing time
- Resistance to chemical attack
- Recyclability
- Superior impact

Disadvantages of thermoplastic matrices:

- Easy to melt
- High viscosity

Polypropylene (PP)



Polypropylene

Figure 2.1: Molecular structure of Polypropylene (PP)

Polypropylene's (PP) intrinsic properties of high stiffness, good tensile strength and inertness toward acids, alkalis and solvents has secured its position in a wide range of consumer and industrial products. Polypropylene are also flexible and can have very high elongation before breaking. The other advantages are:

- Homopolymer
- Good process ability
- Good stiffness
- Good impact resistance
- Copolymer
- High flow index
- Chemically coupled

Although polypropylene gives a lot of advantages, there are several difficulties for this thermoplastic such as:

- Degraded by UV
- Flammable, but retarded grades available
- Low temperature

The advantages of using polypropylene (PP) as matrix are their low cost and relatively low processing temperature which is essential because of low thermal stability of natural fibers. Amongst eco-compatible polymer composites, special attention has been given to PP composites, due to their added advantage of recyclability.

2.4 Kenaf Fiber Reinforced Polypropylene

The research done in this study has proven the ability to successfully fabricate kenaf–polypropylene natural fiber composites. The optimal fabrication method for the compression molding process has proven to be the layered sifting of a microfine polypropylene powder and chopped kenaf fibers. Also shown through this work was that kenaf–PP composites have a higher Modulus/Cost and a higher specific modulus than sisal, coir, hemp, flax and E-glass (M. Zampaloni *et al.*, 2007)

2.5 Factors Controlling Performance of Fiber Reinforced Composites

2.5.1 Fiber Thermal Stability

High temperatures must also be avoided due to the possibility of fiber degradation (M. Zampaloni *et al.*, 2007). The main limitation to the use of lignocellulosic fibers is the lower processing temperature permissible due to the possibility of fiber degradation and/or the possibility of volatile emissions that could affect composite properties. The processing temperatures are thus limited to about 200°C, although it is possible to use higher temperatures for short periods. This processing factor limits the type of thermoplastics that can be used with lignocellulosic-fibers; to commodity thermoplastics such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) and polystyrene (PS) (Roger M. Rowell *et al*., 1999).

Shinji Ochi *et al.*, 2008, proved that kenaf fibers revealed tensile strength of kenaf fibers decreased when kept at 180°C for 60 min, therefore the fabrication method for composite in this research is ensured to be below the temperature. For compounding, mixing temperature is 190°C (outer temperature) because the rotating blade inside plastic mixer will be lower than that while for moulding the temperature is 180°C.

2.5.2 Fiber Hydrophilic Nature

In fiber reinforced polymer (FRP), not only polymer matrix that absorb moisture but also the fiber especially the natural fiber. This particularly due to the hydrophilic nature of the natural fiber that is more sensitive towards water absorption than synthetic fiber which causing instability in the properties of the composites (Espert A., 2003).

The inherently polar and hydrophilic nature of lignocellulosic fibers and the nonpolar characteristics of most thermoplastics result in compounding difficulties leading to nonuniform dispersion of fibers within the matrix, which impairs the properties of the resultant composite. This is a major disadvantage of natural fiber-reinforced composites (Maya Jacob John *et al*., 2007).

Alkaline treatment was applied in order to solve the problem of fiber–matrix adhesion when manufacturing biocomposites. Natural fibers are mainly composed of cellulose, whose elementary unit, anhydro d-glucose, contains three hydroxyl (–OH) groups. These hydroxyl groups form intramolecular and intermolecular bonds, causing all vegetable fibers to be hydrophilic. The alkaline solution regenerated the lost cellulose and dissolved unwanted microscopic pits or cracks on the fibers resulting in better fiber matrix adhesion (Feng D *et al.*, 2001; Mutje P *et al.*, 2006; Keener TJ *et al.*, 2004).