UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF CARBON FIBER-REINFORCED POLYPROPYLENE COMPOSITE FOR CAR BUMPERS

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DEVELOPMENT OF CARBON FIBER-REINFORCED POLYPROPYLENE COMPOSITE FOR CAR BUMPERS

By

NOR HASNI BINTI ZAHARI

Thesis Submitted to
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Thanks to my beloved husband, mom, auntie, sisters and brother for their support during the long preparation of this thesis.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science in Chemical Engineering.

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May 2009

Chairman : Professor Madya Robiah Bt. Yunus, PhD

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Carbon fiber reinforced composites (CFRC) are very strong and extremely lighter than steel. Their toughness provides excellent abrasion and tear resistance. The usage of the CFRC in automotive industries is widely explored due to the new requirements related to energy conservation, safety and antipollution. In this study, discontinuous carbon fiber reinforced polypropylene composite was selected due its characteristics such as light-weight, corrosion resistance, low to moderate cost, thermal stability and ease of fabrication.

Polypropylene (PP) was chosen as the matrix because it is available in large quantities and not very sensitive to chemical stress cracking. PP also has a combination of high elongation and tensile strength. Carbon fibers are widely used in polymer–matrix composites owing to their good mechanical, thermal and electrical

properties. Cheap discontinuous carbon fiber or short fiber is the low quality carbon fiber which cannot be used in aircraft and aerospace industry which requires high quality continuous-fiber laminates as primary structures. The composite was developed to fill the mechanical property gap between the discontinuous-fiber composites and the un-reinforced polymers used in non-load-bearing applications.

The objectives of this work are to develop carbon fiber polypropylene composite under various process conditions, and to investigate the mechanical and thermal properties of carbon fiber polypropylene composite. In this study, two different types of polypropylene composites were produced by mixing and compressing the mixtures using hot press. In the first stage, the mixture was prepared by mixing polypropylene with chopped carbon fiber and carbon fiber percentage (wt%) was varied. The composites were evaluated for mechanical properties. Mixing time, mixing temperature and rotor speed were varied to determine the best conditions. Among the mechanical testing and analysis investigated were tensile test, impact test, bending test and density test. Whilst the, the Scanning Electron Microscopy (SEM) was employed to study the morphology of the composites and Dynamic mechanical analysis (DMA) and Thermal gravimetric analysis (TGA) were used to determine the thermal properties

The highest tensile strength was obtained for polypropylene with melt flow index 60 (MFI 60) composites reinforced with 10 wt% carbon fiber. The composite also showed the best tensile and flexural properties. TGA analysis of composite with 10 wt% carbon fiber content revealed excellent thermal stability compared to the plain polypropylene. The performance of the selected composite was comparable to a local commercial car bumper.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk Ijazah Master Sains dalam Kejuruteraan Kimia.

PEMBANGUNAN KOMPOSIT GENTIAN KARBON-MEMPERKUAT POLIPROPILENA UNTUK BAMPER KERETA

Oleh

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Komposit diperkuat gentian karbon (CFRC) adalah sangat kuat dan jauh lebih ringan berbanding aloi. Sifatnya yang tahan lasak menjadikan ia tahan hakisan dan mempunyai rintangan carikkan. Penggunaan CFRC di dalam industri automotif telah dipraktikkan secara meluas berdasarkan kepada kehendak terkini yang mengutamakan penjimatan tenaga, keselamatan dan antipencemaran. Dalam kajian ini, komposit gentian karbon tidak bersambung perkuat polipropilena telah dipilih berdasarkan ciri-ciri seperti ringan, tahan karat, kos yang rendah ke sederhana, kestabilan terma dan mudah dibentuk.

Polipropilena (PP) telah dipilih sebagai matrik kerana ia boleh diperolehi dalam kuantiti yang banyak dan tidak terlalu sensitif terhadap retakan tekanan kimia. PP juga mempunyai kombinasi sifat yang tinggi rintangan dan kekuatan tegangan. Gentian karbon telah digunakan secara meluas dalam komposit polimer-matrik

kerana sifat-sifat mekanikal, terma dan elektriknya. Gentian karbon tidak bersambung atau gentian pendek yang murah adalah gentian karbon yang berkualiti rendah di mana ia tidak boleh digunakan dalam industri pesawat udara dan angkasa yang memerlukan penggunaan lapisan gentian bersambung berkualiti tinggi sebagai struktur asas. Komposit ini dibangunkan untuk memenuhi jurang sifat mekanikal di antara gentian karbon tidak bersambung dan polimer yang tidak bertetulang yang digunakan untuk aplikasi galas tidak berbeban.

Objektif bagi kajian ini adalah untuk membina komposit gentian karbon polipropilena di bawah pelbagai kondisi proses, dan untuk mengkaji sifat mekanikal dan terma bagi komposit gentian karbon prolipropilena. Dalam kajian ini, dua jenis polipropilena yang berbeza dihasilkan melalui pencampuran dan himpitan bahan campuran itu dengan menggunakan penekan panas. Campuran dihasilkan dengan mencampurkan polipropilena bersama gentian karbon yang telah dipotong dan peratusan (wt%) gentian karbon ini dipelbagaikan. Komposit ini dinilai melalui sifat-sifat mekanikalnya. Masa pencampuran, kelajuan rotor, suhu dan masa pengacuan dipelbagaikan untuk mendapatkan kondisi terbaik.

Antara ujian dan analisa secara mekanikal diperoleh melalui ujian kekuatan tegangan, kekuatan hentaman, kekuatan lenturan dan ujian ketumpatan. Analisis dinamik mekanik (DMA) dan analisis gravitian terma (TGA) dijalankan untuk mengenalpasti sifat-sifat terma. Scanning Electron Microscopy (SEM) digunakan untuk mengkaji kesan morfologi.

Kekuatan tegangan yang tertinggi bagi komposit gentian karbon perkuat polipropilena diperoleh adalah pada 10 wt% gentian karbon perkuat polipropilena dengan MFI 60. Komposit tersebut menunjukkan keputusan sifat-sifat kekuatan tegangan dan lenturan yang lebih baik. Analisis TGA bagi 10 wt% gentian karbon memberi menunjukkan kestabilan terma yang lebih baik berbanding polipropilena asli. Prestasi komposit terpilih telah dibandingkan dengan sebuah bamper komersial tempatan.

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I certify that the Examination Committee meet on 21st May 2009 to conduct the final examination of Nor Hasni Binti Zahari on her Master of Science in Chemical Engineering thesis entitled **"Development of Carbon Fiber Reinforced Polypropylene Composite for Car Bumper Application"** in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded a relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or co currently submitted for any other degrees at UPM or other institutions.

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NOR HASNI BINTI ZAHARI

Date:

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LIST OF SYMBOLS AND ABBREVIATIONS

ASTM	American Society for Testing Materials
BIW	Body-In-White
CF	Carbon Fiber
CFPP	Carbon Fiber Reinforced Polypropylene
CFPU	Carbon Fiber Reinforced Polyurethane
CR	Controlled Rheology
CTE	Coefficients of Thermal Expansion
DMA	Dynamic Mechanical Analysis
E’	Storage Modulus or Elastic Modulus
E”	Loss Modulus or Viscous Modulus
FRP	Fiber Reinforced Plastic
GFRP	Glass Fiber Reinforced Plastic
GMT	Glass Mat Thermoplastic
IC	Isocyanates
Lc	Critical Fiber Length
LFT	Long Fiber Thermoplastic
MFI	Melt Flow Index
Mn	Number Average Molecular Weight
Mn/Mw	Molecular Weight Distribution or Dispersity Index
MOCA	4,4'-methylene-bis(2-chloroaniline)
mph	Miles Per Hour
MFR	Melt Flow Rate

Mw	Weight Average Molecular Weight
NVH	Noise, Vibration, and Harshness
OEM	Original Engineering Manufacturing
PAN	Polyacrylonitrile
PP	Polypropylene
PU	Polyurethane
r	Fiber Radius
RH	Rockwell Hardness
RIM	Reaction Injection Molding
SEM	Scanning Electron Microscope
SFRP	Short Fiber Reinforced Polypropylene
SFRT	Short Fiber Reinforced Thermoplastic
SMC	Sheet Moulding Compound
t	Interfacial Shear Strength
Tan δ	Tangen delta
Tg	Glass Transition
TGA	Thermal Gravimetric Analysis
Tm	Melting Point (^{o}C)
UPM	Universiti Putra Malaysia
wt	Weight
σmax	Tensile Stress Acting on the Fiber
µm	Micro Meter

CHAPTER ONE

INTRODUCTION

1.1 Background

Glass fibers are the most common reinforcing fibers for polymeric (plastic) matrix composites. The advantages of this fiber are low cost, high tensile strength, high chemical resistance and excellent insulating properties. Thus it has always been chosen as a filler in a composite production. However, this type of fibers has a low tensile modulus, relatively high specific gravity (among commercial fibers), sensitive to abrasion and low fatigue resistance (Mallick, 1993).

In the early 1960s, carbon fiber was invented at the Royal Aircraft Establishment, Farnborough, Hampshire (England) (Wikipedia, 2006). Carbon fibers are fibrous material with carbon content of more than 90%. They are transformed from organic matter by 1000-1500^{o}C heat treatment, which is the substance with imperfect graphite crystalline structure arranged along the fiber axis (Donnet et al. 1998). They are characterized by very high stiffness and low density. Some carbon fibers have a stiffness that are ten times higher and densities that are one half that of glass fibers. According to Adam (1997), the application of carbon fiber is due to the high energy absorption ability. Thus the material can contribute to an improved crash management and therefore to an improved passive safety of a passenger car.

Carbon fiber composite can be designed as a component of energy absorbers to absorb a portion of the kinetic energy from a vehicle collision. Energy absorbers are very effective in a low speed impact, where the bumper springs back to its original position. Energy absorber types include foam, honeycomb and mechanical devices. All foam and honeycomb absorbers are made from polypropylene, polyurethane or low-density polyethylene. Mechanical absorbers are metallic and resemble shock absorbers. However, mechanical absorbers have several times the weight of foam or honeycomb absorber and receive very limited usage. In some bumper systems, the reinforcing beam itself is designed to absorb energy and separate energy absorbers are not required.

1.2 Problem Statement

A bumper is a shield made of steel, aluminum, rubber or plastic that is mounted on the front and rear of a passenger car. Traditionally, metal alloys were used in manufacturing automobile exteriors. Nowadays, the car bumper generally consists of a plastic cover and, underneath, reinforcement is made of steel, aluminum, fiberglass composite or plastic and includes mechanisms that compress to absorb crash energy. Usually, bumper system consists of built-in fascia, beam and energy absorbers.

There are several factors that an engineer must consider when selecting a bumper system. The most important factor is the ability of the bumper system to absorb enough energy to meet the Original Engineering Manufacturing (OEM) internal bumper standard. Another important factor is the bumper's ability to absorb energy and stay intact at high-speed impacts (AISI, 2003). Five miles per hour (5 mph) is a benchmark that engineers must comply when designing the bumper system. It is an impact speed at which bumpers could prevent damage in barrier test (Cheon, et al. 1995). The 5 mph crash test can be used to assess bumper performance, including front-into-flat-barrier test, rear-into-flat-barrier test, front-into-angle-barrier test and rear-into-pole test. The least demanding impacts are front and rear-into-flat-barrier because the energy of the crash is spread across the whole width of the vehicle.

Automotive bumper system plays a very important role not only in absorbing impact energy (original purpose of safety) but also in a styling stand point. In recent years, a great deal of attention within the automotive industry has been focused upon lightweight and safety issues. The bumper system equipped with thermoplastic and energy absorbing element is a new trend in the market. While experimental test is rather costly and time consuming, finite element analysis helps engineers to study design concept at an early design stage when prototypes are not available (Lee and Jang, 1993).

Automobile design engineers face many constrictions when designing with metal, such as corrosion and dents. Low-cost, single-unit production of large automobile sections, such as a front grille, is nearly impossible when using metal. Plastic offers auto engineers a variety of practical, costs-effective alternatives, as well as tremendous advantages over traditional automobile production materials. By using plastics, manufacturers have the possibility of adopting modular assembly practices, lowering production costs, improving energy management, achieving better dent resistance, and using advanced styling techniques for sleeker, aerodynamic exteriors. However, plastic outer cover does not promise good protection if it performs alone (Mallick, 1993).

With current technology, many manufacturers are using composite instead of plastic alone to fabricate the automotive parts including the bumper. Fuel efficiency and emission gas regulations are the main causes for reducing the weight of passenger cars by using composite structures (Hosseinzadeh et al. 2005). In the last few years, more intense effort have been spent on the application of fiber reinforced plastics. While glass fiber reinforced plastics (GFRP) are used in several vehicle components, the carbon fibers as reinforcing material are of relative low significance for the lightweight construction in motor vehicles (Adam, 1997).

Short fiber reinforced composites have enormous potential for automotive application (Adam, 1997). To achieve these advantages, many researchers focus on the discontinuous carbon fiber reinforced polypropylene composite where the material is expected to have a better property and has a potential to reduce the weight of a car and fuel consumption. The use of a short-carbon-fiber or discontinuous carbon fiber reinforced polypropylene (SCF/PP) composite has been investigated by Rezaei et.al (2007) for car bonnet application. They found that the SCF/PP composite is a good option for replacing steel in car bonnet and can achieve the standards of car bonnet with remarkable lower weight and higher mechanical properties. However, this study focuses on the use of discontinuous carbon fiber reinforced polypropylene composite for the application of car bumper which requires different specifications.

1.3 Objectives and Scope of Research Work

The objectives of this research are:

(a) To develop carbon fiber polypropylene composites under various process conditions.

(b) To investigate the mechanical and thermal properties of carbon fiber polypropylene composites.

Based on the first objective, the scope of work stated with preliminary investigation on the existing bumper system of a passenger car in order to understand the material properties. This was undertaken so that improvement on the material designs can be made. A local commercial car bumper was used as a reference to develop an alternative material that is comparable with the existing material for the application of bumper. This is an important step to ensure that the composite is viable and practical to be used as a bumper fascia. The work continued with the manufacture of carbon fiber reinforced polypropylene composite where the procedure were began with fiber preparation followed by melt compounding process. Hot press was used to mold the composite into a sheet so that the sample for analysis can be made. As to accomplish the second objective, the research work was continued with sample analysis where the samples were evaluated to investigate the mechanical and thermal properties. The analyses consist of tensile, flexural, impact and hardness test, thermal gravimetric and dynamic mechanical analysis. These results were finally compared with local commercial car bumper properties.

1.4 Thesis Layout

This thesis contains five chapters. Chapter One covers the introduction that includes the background of carbon fiber and its application followed by the problem statement and the objectives of the research. In Chapter Two, a survey is presented on carbon fiber composite, matrix and the concept of bumper system. Subsequently, Chapter Three describes the research materials and methodology used in the study. The results and discussion are covered in Chapter Four where the analysis on experimental results is included. The thesis ends with the Conclusion in Chapter Five. Here the results are compared with the objectives and some recommendations for future works are also presented.

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