UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF FIBER-REINFORCED EPOXY COMPOSITE ENERGY ABSORBER FOR AUTOMOTIVE BUMPER SYSTEM

MAJID DAVOODI MAKINEJAD

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By

MAJID DAVOODI MAKINEJAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master of Science

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DEDICATION

A Special Dedication to My Kind Wife Mojgan and My Son Parsa
For their Love and Support
.

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

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May 2007

Chairman : Mohd Sapuan Salit, PhD, PEng

Faculty : Engineering

Bumper is an important safety component in a vehicle. Approximately 70% of damage claim occurred from low speed impact. In a number of European countries, pedestrians contribute 12-35% of the number of severely injured or killed victims of road traffic accidents. The bumper absorber plays an important role in energy absorption in automotive bumper system. There are two types of energy absorber in modern car. The first one is for low impact and another one for crashworthiness impact. In the case of low impact test energy absorption, it normally uses foam as an absorber which in some material cases is harmful and need more equipment for production also there are uncompleted recovery after compression. Fiber reinforced polymer composite material offers essential characteristics such as weight reduction, design and manufacturing flexibility and safety improvement. In this research the above-mentioned parameters and the inherent characteristics of fiber reinforced polymer composite material have been used in designing polymer composite parts as an energy absorber in automotive bumper system.

In developing the reinforced polymer composite absorber the work of Neopolen_P (2006) and AISI (2004) were followed as guides with some modifications. A series of reinforced composite absorber was installed between fascia and beam in place of a series of expanded polypropylene (EPP) absorber as was used by Neopolen_P (2006).

The finite element analysis and experimental work were carried out to investigate the effect of energy absorption analysis of the elliptical shape of the composite material. The simulation was performed using a commercially available finite element software package (LUSAS). It is found the ratio 150_{mm} over 75_{mm} is suitable and the fiber orientation [0],[90] are the best among [0], [10], [20], [30], [40], [45], [50], [60], [70], [80], and [90] orientations.

The experimental work had been carried out to examine the effects of composite elliptical absorber on energy absorption behavior subjected to quasi-static compressive load. The composite elliptical absorber was fabricated from E- glass and carbon fiber with the orientation of [0, 90], [0, 45,-45, 0] and $[45, 0, 90]_s$. The load and accumulative energy versus displacement were tested under compressive quasi-static loading using the universal hydraulic testing machine (Instron 8500) and the results were finally compared with FEA results.

It can be concluded that the composite absorber is useful in case of leg-form impact in car bumper and repeated compression recovery is better than expanded polypropylene (EPP) material and the equipment for manufacturing and number of

parts are lower than EPP absorber. It can be used in different cars with various spaces by small changing in production equipment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN KOMOSIT EPOKSI GENTIAN FIBER SEBAGAI PENYERAP TENAGA UNTAK SISTEM BAMPER AUTOMOTIF

Oleh

MAJID DAVOODI MAKINEJAD

Mei 2007

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Bamper adalah satu komponen keselamatan yang penting dalam sebuah kenderaan. Kira-kira 70% daripada tuntutan kerosakan berlaku semasa hentaman berkelajuan rendah. Dalam banyak negara Eropuh pejalan kaki menyumlang 12-35% kepada bilangan mangsa yang cedera parah atau lerbunuh dalam kemalangan jalan raya. Penyerap bamper mempunyai tugas utama dalam penyerapan tenaga dalam sistem bamper automotif. Terdapat dua jenis penyerap tenaga dalam kereta moden. Yang pertama adalah bagi hentaman rendah dan yang lain adalah bagi hentaman kebolehancuran. Dalam kes penyerapan tenaga ujian hentaman rendah, ia biasanya menggunakan busa sebagai penyerap di mana dalam sesetengah kes bahan adalah merbahaya dan memerlukan lebih banyak peralatan bagi pengeluaran dan juga terdapat pemulihan tidak lengkap selepas mampatan. Bahan komposit polimer bertetulang gentian menawarkan ciri-ciri yang penting seperti pengurangan berat, kefleksibelan reka bentuk dan pembuatan dan penambahbaikan keselamatan. Dalam penyelidikan ini parameter yang disebutkan di atas serta ciri-ciri yang sedia ada dalam bahan komposit polimer bertetulang gentian telah digunakan dalam mereka

bentuk komponen komposit polimer sebagai penyerap tenaga boleh balik dalam sistem bamper automotif.

Dalam membangunkan penyerap komposit polimer bertetulang kerja Neopolen_P (2006) dan AISI (2004) telah diikuti sebagai panduan dengan sedikit pengubahsuaian. Satu siri penyerap komposit bertetulang telah dipasangkan di antara fascia dan rasuk bagi menggantikan satu siri penyerap polipropilena terkembang (EPP) sebagaimana yang telah digunakan oleh Neopolen_P (2006).

Analisis unsur terhingga dan kerja eksperimen telah dijalankan bagi mengkaji kesan analisis penyerapan tenaga bahan komposit yang berbentuk elips. Penyelakuan telah dijalankan menggunakan pekej perisian unsur terhingga komersial (LUSAS). Adalah didapati bahawa nisbah 150_{mm} terhadap 75_{mm} adalah sesuai dan penghalaan gentian [0] adalah yang terbaik daripada penghalaan[0], [10], [20], [30], [40], [45], [50], [60], [70], [80], dan [90].

Kerja eksperimen telah dijalankan bagi mengkaji kesan penyerap elips komposit ke atas kelakuan penyerapan tenaga yang dikenakan beban mampatan kuasi-statik. Penyerap elips komposit telah difabrikasi daripada gentian kaca-E dan karbon dengan penghalaan [0] dan [0, 45,-45, 0] dan $[45, 0, 90]_s$ penghalaan yang terbaik adalah [0]. Beban dan tenaga tertumpuk lawan sesaran dan juga sejarah dan kegagalan telah diuji di bawah bebanan kuasi-statik mampatan menggunakan mesin pengujian hidraulik universal (Instron 8500) dan keputusan tersebut akhirnya dibandingkan dengan keputusan FEA.

Kesimpulan yang boleh dibuat ialah penyerap komposit adalah berguna dalam kes hentuman bentuk kaki dalam bamper kereta dan penyerapan tenaga spesifik serta pemulihan mampatan berulang-ulang adalah lebih baik daripada bahan polipropilena terkembang (EPP) dan peralatan bagi pembuatan dan bilangan bahagian adalah lebih rendah daripada penyerap EPP. Ia boleh digunakan dalam pelbagai jenis kereta dengan ruangan yang berbeza dengan mengubah peralatan pengeluaran.

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I certify that an Examination Committee has met on 31/May/2007 to conduct the final examination of Majid Davoodi Makinejad on his Master of Science thesis entitled "Development of Fiber Reinforced Epoxy Composite Energy Absorber for Automotive Bumper System" 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 the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory 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 concurrently submitted for any other degree at UPM or other institutions.

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MAJID DAVOODI MAKINEJAD

Date: 30 JAUARY 2007

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LIST OF ABBREVIATIONS

CCC	Carbon-Carbon Composites
CMC	Ceramic Matrix Composites
CTE	Coefficient of Thermal Expansion
EPDM	Ethylene Propylene Diene Monomer
EPP	Expanded Polypropylene
EPS	Expandable Polystyrene
FEA	Finite Element Analysis
FEM	Finite Element Method
FRC	Fiber Reinforced Composite
GE	General Electric
G_{xy}	Shear Modulus
IMC	Inter-Metallic Composites
MMC	Metal Matrix Composites
NHSTA	National Highway Safety Transport Administration
OEM	Original Equipment Manufacturer
PBT	Polybutylene Terephtalate
PC	Polycarbonate
PP	Polypropylene
PMC	Polymer Matrix Composites
PU	Polyurethane
σ_d^c	Compression Tension
σ_d^t	Tension Stress

RIM	Reaction Injection Molding
RRIM	Reinforced Reaction Injection Molding
SEA	Specific Energy Absorption
SMC	Sheet Metal Compound
TSF	Thick Sheet Forming
UNECE	United Nations Economic Commission for Europe

CHAPTER 1

INTRODUCTION

1.1 Background

As of 2002 there were 590 million passenger cars worldwide (roughly one car for every eleven people), of which 140 million in the USA (approximately one car for every two people).As automobiles increased in number and became larger and faster, between 1945 and 1995, 2 million people died and about 200 million were injured in automobile accidents—many more than were wounded and injured in all the wars in the nation's history combined (Answers.com, 2006).In year 2005 328,264 road accident, 47.012 road casualties, and 6200 road death was reported in Malaysia which 3,523 (7.49%) is pedestrian accident and 7372 (15.68%) car accident (Nizam,2005) and the cost of the road accidents in 2003 was about 9,374,000,000 RM (ADB-ASEAN,2003).

According to the Association of British Insurers report (ABI) in year 2002 about 70% of 10 billion Pounds of total annual cost of vehicle insurance is related to damage repair from low speed impact crashes, and about 80% of damage claims have no associated injury claim. It is clear that low speed crash constitutes a large portion of the total cost to society for repairing crash vehicle. Consequently, reducing vehicle damage in low speed crashes could have a massive global benefit. Alignment of structures could also have a key part in ensuring better compatibility of vehicles in higher speed crashes. Better bumper design could have a positive benefit

since bumper units are often the first components to connect in frontal car to car crashes (Avery and Weeks, 2006).

From 1965 to 1995, more than fifty safety standards were imposed on vehicle manufacturers, regulating the construction of windshields, safety belts, head restraints, brakes, tires, lighting, door strength, roof strength, and bumper strength (Answers.com, 2006). The North American and Canadian bumper performance standards have been issued and it is more severe than European ones. The former stipulates impact speed of 5 mph (8km/h) whereas the European pendulum impacts are performed at 2.5 mph (4 km/h). There are no damages allowed to other parts of the vehicle. Also the key to developing a bumper system capable to fulfill the upcoming performance requirements as well as the design criteria lies in a differential stiffness profile over a restricted total deformation. At the beginning of the compression, the stress should be kept low to comply with pedestrian leg criteria, after that the stiffness increase with increasing stroke to cover the energy absorption necessary for 2.5 mph impact (Murata and Shioya, 2004).

Each bumper system consists of three main components namely bumper beam, fascia and energy absorber (Sapuan et al., 2005).The energy absorber is a key part in bumper system which has to dissipate the impact energy in collision. New bumper system consists of two types of energy absorbers, low stiffener absorber which is called the reversible absorber in this research and located between fascia and reinforcement beam and the irreversible energy absorber which is consist of the beam and the crushable energy absorber that it located at the back of the beam and attached to the main face bar. Therefore the suitable geometry, light weight

materials, and study of mechanical properties in the limited packaging space in design of the bumper absorber have to be precisely considered.

There are numerous works in crashworthiness energy absorption in different applications such as airplane, ship and car industry, but there is linked the low impact collision work developed to low impact test and reversible energy absorbing system. In case of lower impact and pedestrian criteria the most common method proposed for cushioning the lower limb in an impact uses an energy absorber (plastic foam, egg-crate, spring steel, steel foam composites, crush-cans and plastic beam (Schuster, 2006). The common material is expanded polypropylene foam which demonstrates some essential properties for bumper absorber but it suffers from some percentage of incomplete recovery after absorption. Different foam stiffness in a unique part for obtaining different energy absorption to comply with the pedestrian criteria causes some manufacturing problems (Murata and Shioya, 2004).Certain of materials such as polyurethane exhales some toxic gas during production that is harmful for worker.

1.2 Problem statements

Production of foam energy absorber not only needs some special equipment and tools but also the production line must be control pressure, temperature, and mixing rate. As well as some kind of material such as polyurethane foam exhales toxic gas during production which is very harmful for workers. PU foam product need to release the air trap after production and EPP foam need to store for post shrinkage at least 8 hours.