



**UNIVERSITI PUTRA MALAYSIA**

**DESIGN, FABRICATION AND EVALUATION OF COMPOSITE  
SANDWICH PANELS FOR CRASHWORTHINESS**

**FARIS TARLOCHAN**

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**DESIGN, FABRICATION AND EVALUATION OF COMPOSITE  
SANDWICH PANELS FOR CRASHWORTHINESS**

**By**

**FARIS TARLOCHAN**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**April 2007**



## DEDICATION

I would like to dedicate this work to my parents **Mr** and **Mrs. Tarlochan**.

This work is also dedicated to my wife, **Noor Badr** and to my three lovely daughters,

**Fiza, Isha and Nadia.**

Your smiles and laughter gave me the cheerfulness and determination in completing  
this work.

May **ALLAH** Bless and Protect You All.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

**DESIGN, FABRICATION AND EVALUATION OF COMPOSITE SANDWICH PANELS FOR CRASHWORTHINESS**

By

**FARIS TARLOCHAN**

**April 2007**

**Chairman: Professor Abdel Magid S. Hamouda, PhD**

**Faculty: Engineering**

As time progressed, so did the technology of transportation and today we have a range of motorized vehicles that run on fossil fuel. The number of these vehicles is increasing year by year throughout the globe. There are two negative issues on this. First, the demand on fuel will increase and the second is that due to the increase of vehicles on road, the number of accidents and casualties has also increased the last two decades to an alarming figure. These accidents are a serious issue for the country in terms of economic losses. In 2003 alone, Malaysia had a total economic lost of RM 9.3 billion due to road accidents. One of the potential solutions to is to reduce the overall fuel consumption by reducing the overall mass of the vehicle. Reducing vehicle mass by material substitution may have implications for vehicle safety. Substitution of a lighter material of equal strength and energy absorbing capacity in the body structure can maintain the same level of kinetic energy absorption and passenger protection, while reducing overall vehicle mass. Hence the present work is



dedicated to the design and evaluation of a new crashworthy composite sandwich structure design.

The research methodology adopted in this thesis work comprises of two stages. The initial stage was an investigation to the axial crushing response of normal or conventional composite sandwich panels. The second stage was the designing stage of a potential candidate energy absorber based on inputs received from the initial stage of the thesis. All specimens were fabricated by using hand wet lay up.

It was found in the first stage that all of these conventional panels failed in a global column buckling manner. None showed any signs of progressive failure as expected in a crush energy absorber device. While maintaining the same amount of constituent materials used, several “new” sandwich panels were designed and tested quasi – statically in the second stage. From these designs, one particular design termed as “wrap” was found to be very promising as a potential candidate for crush energy absorber device. To evaluate the true crush response, a drop hammer tower facility was designed and fabricated in this study. Through this study, dynamic crush response was investigated and as suspected, indeed the “wrap” specimen displayed satisfactory crashworthiness results. Specimens made from carbon fibers displayed good specific energy absorption as high as 34.7 kJ/kg, much higher in relation to conventional metals.

In depth analysis on the macroscopic failure modes was done and its relation to the energy absorption capabilities of the specimens was studied. In general, four types of failure modes were observed. Several parameters were studied to further improve the

crashworthiness of the “wrap” design. These parameters basically included the dimension, material configuration and the cross sectional topology. Based on these findings, the study had contributed significantly in the area of crashworthiness by producing a potential candidate for a crush element that could be used in automotive industries and also extended to other vehicles such as buses, trains and ships.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**REKABENTUK, PEMBUATAN DAN PENILAIAN PANEL TERAPIT  
KOMPOSIT UNTUK “CRASHWORTHINESS”**

Oleh

**FARIS TARLOCHAN**

**April 2007**

**Pengerusi: Profesor Abdel Magid S. Hamouda, PhD**

**Fakulti: Kejuruteraan**

Dengan bertambahnya teknologi, begitu juga bertambahnya teknologi kenderaan berasaskan bahan api. Oleh yang demikian, kadar kecederaan dan kematian juga meningkat. Kemahuan untuk meningkatkan “crashworthiness” automobil tidak dapat diabaikan lagi. Ia telah dianggarkan bahawa kerugian kewangan tahunan daripada kemalangan trafik adalah berjumlah RM 9.3 bilion pada tahun 2003. Bersama dengan keprihatinan terhadap isu alam semulajadi dan tekanan sosial yang disokong oleh perundangan telah menerajui kemajuan ke arah rekabentuk yang inovatif, melibatkan bahan yang lebih ringan seperti komposit. Dekad yang lalu, minat para penyelidik telah terarah kepada struktur komposit untuk menguatkan “crashworthiness” disebabkan oleh ciri-ciri kekuatan tinggi, terutama pada nisbah nilai kekuatan dan tegasan terhadap berat bahan tersebut, dan keupayaan untuk diolah mengikut komposisi dan bentuk.

Kaedah penyelidikan yang digunakan dalam tesis ini merangkumi dua peringkat. Peringkat pertama merupakan penyelidikan terhadap respon mampatan terhadap spesimen yang diperbuat daripada komposit senang atau konvensional. Peringkat

kedua adalah peringkat dimana rekabentuk menyerap kuasa kinetik semasa kemalangan dicipta.

Atas kepentingan ini, beberapa buah panel terapit polimer komposit telah dibina dan diuji. Didapati, spesimen – spesimen ini gagal dalam lengkokan tiang global. Dengan menggunakan bahan yang sama dalam kuantiti yang sama, beberapa rekabentuk baru dibuat dan diuji. Didapati rekabentuk baru ini mempunyai tahap “crashworthiness” yang agak baik dan memuaskan. Untuk menguji kecekapan rekabentuk baru ini, sebuah mesin dinamik pelepas berat telah direkabentuk dan dibuat. Dalam ujian dinamik ini, rekabentuk spesimen yang baru memang memenuhi ciri ciri sesebuah alat untuk digunakan dalam “crashworthiness”. Specimen yang terbagus telah menunjuk menyerapan tenaga kinetaic sebanyak 34.7 kJ/kg.

Analisa secara mendalam tentang kegagalan struktur secara makroskopik telah dijalankan untuk mengenal pasti beberapa mod kegagalan bahan. Secara am terdapat empat mod kegagalan bahan. Beberapa parameter dijalankan untuk mempertingkatkan lagi hasil rekabentuk elemen menyerap tenaga kinetic. Berpandukan kepada penemuan dalam kajian ini, di dapati rekabentuk yang dicipta mempunyai bakat digunakan sebagai elemen penyerap tenaga kinetik bukan sahaja di dalam industri automobile, tetapi dalam industri perkapalan, bas dan keretapi.



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I certify that an Examination Committee has met on 25 April 2007 to conduct the final examination of Faris Tarlochan on his Doctor of Philosophy thesis entitled “Design, Fabrication and Evaluation of Composite Sandwich Panels for Crashworthiness” 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:

**Megat Mohamad Hamdan Megat Ahmad, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Mohd Sapuan Salit, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Shamsuddin Sulaiman, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**S.A. Meguid, PhD**

Professor  
School of Mechanical and Aerospace Engineering  
Nanyang Technological University  
Singapore  
(External Examiner)

---

**HASANAH MOHD GHAZALI, PhD**

Professor/ Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 21 JUNE 2007



This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

**Abdel Magid Hamouda, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Barkawi Bin Sahari, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Elsadig Mahdi Ahmed, PhD**

Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**AINI IDERIS, PhD**

Professor/ Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 17 JULY 2007



## **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.

---

**FARIS TARLOCHAN**

Date: 4 JUNE 2007

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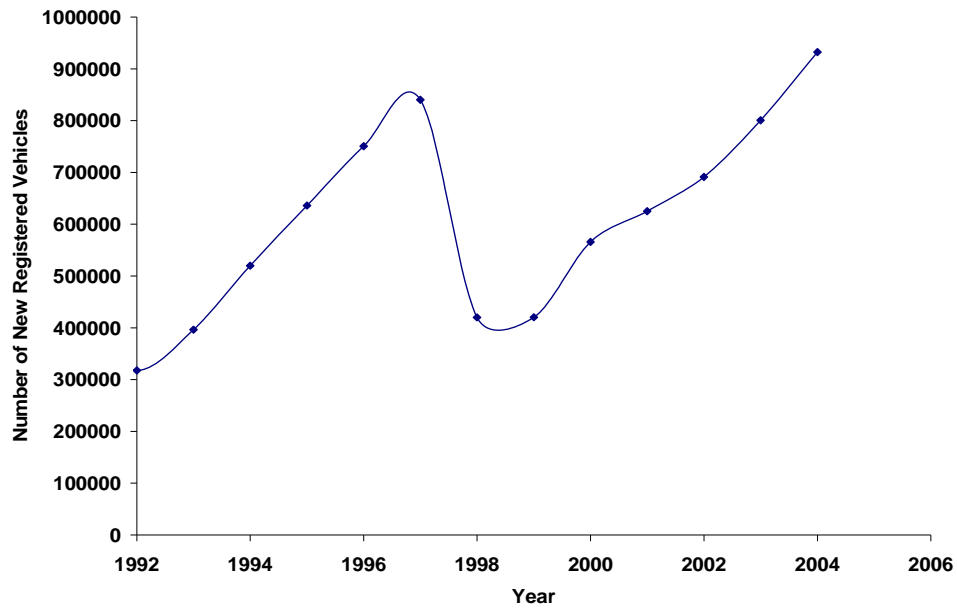
# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Since men's very existence, mobility has been an essential part of daily life. Collecting food and visiting fellow men were the main motives for traveling. Originally, mobility could only be achieved by going on foot. This started to change when new means of transportation started to evolve due to innovations. Deploying animals, such as horse, for transport of men and luggage was the step that started this process. As time progressed, so did the technology of transportation and today we have a range of motorized vehicles that run on fossil fuel. The number of these vehicles is increasing year by year throughout the globe. An example of this is given in Figure 1.1 which depicts the number of new land vehicles registered in Malaysia from 1992 – 2004. It is appropriate to mention here that in Figure 1.1, there was a decline in the number of new vehicles registered in 1998 -1999 due to the Asian economy crisis. Nonetheless, in general, from this figure it can be concluded that the total number of land vehicles is increasing from year to year. It is something that a nation should be concerned of. There are several severe implications to this:

- ✓ Increase in fuel demand
- ✓ Increase in fatalities and injuries due to collisions of vehicles.



**Figure 1.1: Number of new registered vehicles in Malaysia from 1992 – 2004 [1]**

### **1.1.1 Increase In Fuel Demand**

#### *Fuel Price and Availability*

As the demand of fuel increases so will its price. This can be seen in Malaysia where the fuel price has been increasing since 2001. A direct impact due to this is the increase of cost of living which is evident today in Malaysia. Besides the price, fuel is not a renewable energy in the sense that the more it is used in a period of time, the faster the oil reservoirs will run dry. This may lead to an oil crisis across the globe if renewable energies or alternate energy sources are not found.

#### *Greenhouse Gases*

Besides the increase of fuel price, greenhouse gases have also increased due to the increase in fuel usage. The main greenhouse gas emission associated with transport is CO<sub>2</sub> emission that is a direct result of the combustion of vehicle fuels (petrol,

diesel, aviation kerosene etc). There are also emissions of nitrous oxide (N<sub>2</sub>O) and methane from combustion of the fuel, which are minor compared to emissions of CO<sub>2</sub>. An ever-growing concern among government, industry and environmental organizations is global climate change due to greenhouse effect. A buildup of carbon dioxide (CO<sub>2</sub>) in the atmosphere over the last century has been identified as a possible contributor to climate change. In Malaysia, the transportation industry contributes about 28 % of CO<sub>2</sub> emission [2] and the total amount of CO<sub>2</sub> gas emission has increased by 121 % from 1990 – 2003, in Malaysia [3]. This increase is alarming and some means of action has to be taken to reduce greenhouse gas emission. This is a shared phenomenon across the globe.

#### *Potential Solutions*

Taking into account the hike in fuel price and the increase of CO<sub>2</sub> emission, the best solution is by reducing the overall nation's fuel consumption for the transportation industry. The author believes that in principle there are three main ways in which the total fuel consumption for transport can be reduced:

- ✓ Vehicle Design:                      reducing the fuel use per km driven by incorporating technology into the vehicle design.
- ✓ Vehicle Usage Planning:            optimization of the vehicle use, reducing total vehicle kilometer per passenger. Example, car pooling system.
- ✓ Vehicle Demand:                      Reducing the overall demand for travel.



From amongst the three possible ways described above, the first option is within the reach of engineers and scientists. The remaining two are possibilities, but will face some potential barriers with the legislatures and public in general, for these require proper regulations, infrastructures, public awareness and voluntary agreements.

In terms of vehicle design, engineers and researchers have several factors to consider in their design decision to further improve the fuel economics of a vehicle. Some of the factors that may influence the fuel economy are as follows:

- ✓ Engine efficiency improvements
- ✓ Major engine changes
- ✓ Mass reduction
- ✓ Friction and drag reduction
- ✓ Alternative fuels

The most direct method of reducing fuel consumption and gas emissions is to reduce the mass of the vehicle. This is because 75 % fuel consumption depends on factors related to mass [4]. In current conventional vehicles, mass is the parameter that best correlates fuel economy. Large, heavy vehicles require big engines to perform well; they consequently consume more fuel. For a given vehicle size, reducing vehicle mass will permit reductions in engine and transmission mass, tire and wheel mass, braking system mass, fuel storage mass, steering system mass, engine radiator mass, and so on, compounding the gains in direct mass reduction of the vehicle frame. The principal means for reducing mass is the substitution of lighter materials of equal strength and stiffness, such as aluminum alloys or composites for steel and