INFLUENCE OF FRACTURE TOUGHNESS ON THE IMPACT PROPERTIES OF CARBON NANOTUBES/ARAMID FIBRE REINFORCED COMPOSITE

WAN MOHD HANIF BIN WAN YA'ACOB

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ABSTRACT

This research was carried out to investigate the relation of the fracture toughness of epoxy/CNT/twaron on the impact properties by dividing into two phases and use design of experiment (DoE) approach. In Phase 1, the effect of parameters such as epoxy viscosity, CNT content, stirring time, stirring speed and sonicating time on fracture toughness of epoxy/CNT composite were studied. The fracture toughness of epoxy/CNT composite was determined by using Single Edge Notch Bending (SENB) and indentation method. The Phase 2 was the continuity of the Phase 1 of the research, which the result will be used to fabricate the sample of epoxy/CNT/twaron composite. The effect of fracture toughness on the energy absorption will be studied by manipulating the CNT loading, number of layers, projectile velocity. The readings of the fracture toughness by using SENB and the indentation method were recorded from 78.764 to 287.092 $MPa.mm^{0.5}$ and 30.06 to 99.23 $MPa.mm^{0.5}$. From the analysis of variance (ANOVA), it was found that the epoxy viscosity, CNT loading, stirring speed, and sonicating time was the significant parameters, which were affecting on the fracture toughness by using SENB method. Meanwhile, epoxy viscosity, CNT loading and stirring speed were significant parameters for the indentation method. From the analysis, two statistical equations were generated. In Phase 2, the energy absorption was recorded in the range from 47.44 to 303.45 J. From the ANOVA analysis, CNT loading and numbers of layers were the significant parameters which affected the energy absorption of epoxy/CNT/twaron composite. A statistical model was derived.

ABSTRAK

Kajian ini dijalankan untuk mengkaji hubungan antara keliatan patah bagi komposit epoksi/tiub nano karbon (TNK)/twaron ke atas sifat impak. Kajian ini dibahagi kepada dua fasa dan menggunakan pendekatan kaedah reka bentuk eksperiment (RBE). Fasa 1 menumpukan kajian parameter-parameter seperti kelikatan resin epoksi, kandungan TNK, kelajuan mesin pengadun, tempoh masa proses adunan, dan tempoh masa sonikasi. Keliatan patah bahan komposit nano ditentukan melalui kaedah lenturan pada tiga titik dan kaedah lekukan. Fasa 2 merupakan kesinambungan kajian daripada Fasa 1 yang mana keputusan kajian akan digunakan untuk penyediaan panel ujian bagi kajian kesan keliatan patah terhadap penyerapan tenaga semasa impak balistik. Tiga parameter telah dimanipulasi dalam ujian ini iaitu kandungan TNK, bilangan lapisan fiber dan halaju peluru. Keputusan bagi keliatan patah bahan komposit-nano menggunakan kaedah lenturan pada tiga titik adalah dari 78.764 sehingga 287.092 $MPa.mm^{0.5}$. Manakala melalui kaedah lekukan adalah dari 30.06 sehingga 99.23 $MPa.mm^{0.5}$. Setelah melalui analisa varian (ANOVA), diketahui bahawa kelikatan epoksi, kandungan TNK, kelajuan pengadun dan tempoh masa sonikat mnyumbangkan kesan yang ketara ke atas keliatan patah bahan komposit-nano yang diperolehi melalui kaedah lenturan tiga titik. Manakala bagi kaedah lekukan, keliatan patah dipengaruhi secara ketara oleh kelikatan epoksi, kandungan TNK dan kelajuan pengadun mekanikal. Dua rumus statistik telah diterbitkan melalui analisa tersebut. Bagi penyerapan tenaga oleh epoksi/TNK/twaron semasa impak, penyerapan tenaga telah direkodkan antara 47.44 sehingga 303.45 J. Menurut analisa ANOVA, jumlah TNK dan bilangan lapisan fabrik Twaron adalah parameter yang memberi kesan yang amat ketara keatas

peyerapan tenaga oleh bahan komposit tersebut. Satu model statistik telah terbitkan melalui analisa tersebut.

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This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science (Mechanical Engineering). The members of the Supervisory Committee were as follows.

Risby Bin Mohd Sohaimi, Phd
Associate Professor
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Supervisor)

Mazlee Bin Mohd Noor, Phd
School of Material Engineering
Universiti Malaysia Perlis
(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Author's full name	:	Wan Mohd Hanif Bin Wan Ya'acob
Date of birth	:	03 January 1988
Title	:	Influence of Fracture Toughness on the Impact Properties of Carbon Nanotube/Aramide Fibre Reinforced Composite
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880103-29-5269 IC/PASSPORT NO.	NAME OF SUPERVISOR
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LIST OF ABREVIATIONS

3D	Three dimensions
a	Crack length
Adeq	Adequate
Adj	Adjusted
ANOVA	Analysis of variance
ASTM	American Standard of Testing Method
B	Specimen thickness
c	Diagonal length
CNT	Carbon nanotube
Cps	centipoises
CT	Compact tension
CVD	Chemical vapour deposition
DMA	Dynamic mechanical analysis
DoE	Design of experiment
F	Applied force
f(x)	Shape factor.
FMJ RN	Full metal jacket round nose
H_2SO_4	Sulfuric acid
HNO_3	Nitric acid
H_v	Vickers hardness
LBL	Layer by layer
Li-Ion	Lithium ion
MWCNT	Multiwall carbon nanotube

NH_3	Ammonia
NIJ	National Institute of Justice
NiO	Nickel oxide
P	Maximum applied load
PP	Polypropylene
Pred	Predicted
Rpm	Rotation per minute
RSM	Response surface method
SEM	Scanning electron microscopic
SENB	Single edge notch bending
W	Specimen width

CHAPTER 1

INTRODUCTION

1.1 Background

Composite is widely used in many applications because of the suitability to use in many conditions and requirements. Combination of variety type of materials in a composite system can serve the specific properties and purpose of high-end application.

As an example, synthetic or natural fibre reinforces polymer. This type of composite system will improve the structure to become high strength and stiffness, resist to corrosion and environment, reduce weight, improve fatigue life and wear resistance, improve the properties of thermal and electrical and reduce the cost and life cycle of production (Zahid, 1997).

As mentioned before, the main nature of composite is to produce materials to fulfil the requirement of a specific product, which is cannot be achieved by single component or system material. The numbers of research and development of composite material needs to increase, because they will cover the diversity of application in many industries. As an example, automotive industries need to produce low weight and high mechanical performance car structure. The low weight car structure is significant affects the fuel consumption. The market price for fuel is increasing from time to time and effect to the consumers. By reducing the weight of car structure, the fuel consumption can be reduced too. So, automotive industries try to improve their product by increasing the usage of composite’s part in their car and producing for customers fuel saving cars. Other than automotive application, composite materials use also in defence, aircraft, construction, sport and recreation, electric and electronic, oil and gas and medical application.

Defence application demands the material which has advanced performance and properties such as low weight, good mechanical properties, better fatigue life, durability and flexibility at lower cost. Composite materials are the perfect choice to choose as replacement material for conventional defence materials, especially metals.

In defence application, the protection system is very important. It consists the personal protection (body armour) and protection of mobility unit (vehicle). Actually the protection system, especially for body armour has been use long time ago. In ancient war, the armies protect their body by using metal, animal skin or shell and wood.

First World War body armour test conducted by United States Army's Ordinance Department (US Army, 1918). The body armour was made from chrome-nickel-steel. Figure 1.1 shows the effect of bullet on the armour. It shows the effect of pistol, (A), rifle, (B), and machine gun, (C). From the observation, the body armours can resist bullet from pistol and rifle from penetrating them. Meanwhile, they cannot withstand the penetration from the machine gun. However, this type of body armour is heavy and unsuitable in battlefield. The army need to a low weight body armour to make sure their movement in battlefield more effective. During World War II, the next-generation bullet proof-jacket (soft body armour) was invented from ballistic nylon (also known as flak jacket). It gives the protection against pistol and rifle bullets.

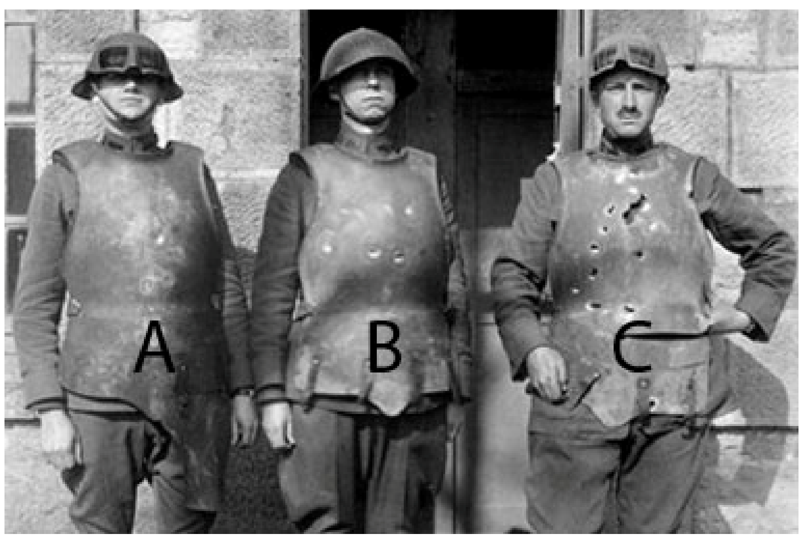

Figure 1.1: First World War Body Armour Test (US Army, 1918).

In the 1965, the first type of aramid, poly paraphenylene terephthalamide (para-aramid) was introduced by DuPont. It was known as Kevlar as the DuPont Company trademark name. Another similar material is Twaron (developed by Teijin Aramid).

Aramid is a type of polymer, which consists of carbon, hydrogen, nitrogen and oxygen molecules. Actually, this fabric was used to replace steel belting in vehicle tires. Because of flexibility, high strength and low density properties, it was used to produce bullet-proof jackets.

Aramid is also used to produce armour grade composite. This is because aramid has high modulus and strength characteristic and high capability of energy absorption likes. Armour grade composite generally uses to give maximum protection from ballistic impact and blast. It uses as personal protection (ballistic helmet) and component part for helicopter, light weight armour vehicle, aircraft and etc.

Nowadays, the trend shows numbers of research try to apply nanomaterial into the composite by using variety of types of nanomaterial such as nanoclays, nanometal oxide particles, carbon nanotubes, carbon nanofibres and nanocarbon particles and etc. (Qian and Hinestroza, 2004). Table 1.1 illustrate the using of nanomaterial in defence applications.

Table 1.1: Application of nanomaterials in defence.

Type of Nanomaterial	Application	Reference	Year
Nanoclay	Improve ballistic protection for body armour	Ma *et al.* Ma *et al.* Antonio *et al.*	2010 2010b 2011
Carbon black nanoparticle	Radar absorption material	Jung-Hoon *et al.* Saville *et al.* Habeish *et al.* Folgueras *et al.*	2004 2005 2008 2009
Nanometal Oxide	Self-cleaning fabric for military application	Thilagavathi *et al.* Samal *et al.* Rajendran	2008 2010 2010
Carbon nanotube	Renewable energy and energy sources	Dillon & Hebben Hui-Ming *et al.* Becker & Lampe	2001 2001 2010

The most popular nanomaterial which has been used is carbon nanotube (CNT). The implementation of nanomaterial in composite is a branch of nanotechnology. Nanotechnology may produce the high-end performance products likes armour grade composite. The main factor of the selection CNT as reinforcement material in armour grade composite is CNT is one of the strongest and stiffest materials.

CNT has contributed many benefits in defence technology development. For this application, researchers have studied the potential of CNT and come out with the idea of CNT capability such as the biosensor (Bhattacharya *et al.*, 2001), energy source for military device (Hai-Wei *et al,* 2009) and smart uniform (Thilagavathi *et al.,* 2008).

Recently, many studies were conducted to discover the potential of CNT. In terms of mechanical properties, it may increase the properties of ballistic impact resistant, fracture toughness and reduce the internal stress. This is because CNT has significant properties such as high elastic modulus, exceptional tensile strength; fracture toughness and can reinforce many matrixes like metal, ceramic and polymer to increase stiffness, strength and toughness (Chen *et al.*, 2009). CNT has high strength to weight ratio, high resistant to chemical, which is difficult to oxidize, high surface area and high thermal conductivity (Wei *et al.*, 2010).

1.2 Problem Statements

Owing to their high strength- and stiffness-to-weight ratios, polymer-matrix composites are increasingly being used as structural materials in the personnel protective system (body armour, vehicles and etc.). With respect to their overall performance under ballistic impact conditions, advanced fibre-reinforced polymer-matrix composites are generally classified into two main categories: (a) High-strength/ high-stiffness composites (typically based on carbon-fibre reinforcements), which are highly effective in deforming and/or fracturing the incoming projectile while having a very limited ability for absorbing the projectile's kinetic energy; and (b) High-ductility/high-toughness advanced composites (typically based on glass or aramid reinforcements) whose properties are optimized with respect to absorb the maximum fraction of the kinetic energy carried by the projectile. The resistance in terms of