EFFECT OF DIFFERENT IMPACTOR NOSE ON LAMINATED COMPOSITE STRUCTURE UNDER QUASI STATIC LOADING

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This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) (Hons.)

by

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DECLARATION

I hereby, declared this report Entitled ‘Effect of Different Impactor Nose on Laminated Composite Structure under Quasi Static Loading’ is the results of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the Degree of Manufacturing Engineering (Engineering Materials) (Hons.). The member of the supervisory committee is as follow:

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ABSTRAK

Kajian ini memberikan tumpuan kepada kesan daripada tiga penekan yang berbeza bentuk kepada gentian kaca bertetulang poliester berlamina komposit di bawah beban kelajuan separa pegun. Komposit berlapis yang bertindak sebagai bahan sasaran adalah rekaan dalam orientasi satu arah dengan 6 lapisan dengan menggunakan pembalutan vakum. Sebanyak 75 sampel diuji dengan penekan yang berbeza seperti tumpul, kon dan hemisfera pada kelajuan separa pegun yang berbeza iaitu 10, 20, 30, 40 dan 50 mm/min. perbandingan lanjut dibuat dengan daya maksimum yang diperlukan oleh setiap penekan itu. Kegagalan komposit berlamina yang disebabkan oleh penekan yang berbeza dipantau di bawah mikroskop electron imbasan untuk menentukan jenis kegagalan yang berlaku selepas ujian separa pegun. Dapatan kajian menunjukkan penekan kon memerlukan daya terendah untuk menebusi bahan sasaran diikuti oleh hemisfera dan tumpul. Penekan kon merupakan penekan yang paling berkesan manakala hemisfera adalah 15 % kurang dan tumpul adalah 74 % kurang daripada kon. Apabila halaju meningkat, daya yang diperlukan untuk setiap penekan bertambah. Kelajuan dapatan menunjukkan halaju 30 mm/min adalah kelajuan yang terbaik untuk ujian separa pegun bertindak. Tambahan pula, penyerapan tenaga yang disebabkan oleh tiga penekan mununjukkan bahawa penekan kon menghasilkan zon plastik yang terkecil dimana hemisfera dan tumpul menghasil sebanyak 1.8 % dan 11.6 % lebih tinggi daripada kon. Tarik keluar dan serat kerosakan gentian mewujud pada sampel selepas ujian. Ciri-ciri kegagalan berubah daripada gentian tarik keluar kepada kerosakan gentian. Kawasan permukaan hidung bersentuh dengan bahan sasaran menghasilkan kesan yang tinggi terhadap tingkah laku kegagalan bahan sassaran. Kawasan yang paling kecil mengakibatkan rintangan bahan sasaran yang tertinggi kepada penebusan.

ABSTRACT

This research focuses on the effect of three different nose design on glass fiber reinforced polyester composite laminates under different quasi-static speed loading. Laminated composite which act as target material is fabricated in orientation of unidirectional with 6 layers of plies by using vacuum bagging. A total 75 sample is tested under quasi-static test using three different impactor which is blunt, conical and hemispherical nosed impactor under loading speed of 10, 20, 30, 40 and 50 mm/min. A further comparison was made with the maximum force required of each of the impactor. The fracture behavior of laminated composite caused by different inpactor is monitored under the scanning electron microscope to determine the type of failure occur after quasi-static test. The finding shows conical nosed impactor required lowest force to penetrate the target material followed by hemispherical and blunt nosed impactor. Conical impactor shows the most effective impactor while hemispherical nosed impactor is 15 % less than conical while blunt nosed impactor is 74 % less. As the loading speed increased, the force needed for each impactor is increased. Form the finding, loading speed of 30 mm/min shows the best speed for quasi-static to carry out. Furthermore, energy absorption that caused by three impactor shows that conical nosed impactor produced smallest range of plastic zone where hemispherical nosed impactor and blunt impactor create 1.8 % and 11.6 % higher range in plastic zone. Pull out of fibers and fibers breakage is observed on the sample after testing. The failure characteristic changed from fiber pull-out to fiber breakage. The nose surface area in contact with the target material produce high effect on the failure behavior of target material, the smallest the area, the highest the resistance of target material to the penetration.

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DEDICATION

Dedicated to
my beloved father, Lai Chun Yap
my appreciated mother, Ng Yok Moi
and my adored siblings, Lai Yan Fang, Lai Yan Chan, Lai Yan Sin, Lai Teck Peng
for giving me moral support, cooperation, encouragement and also understandings.

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LIST OF ABBREVIATIONS

FRP	-	Fiber-Reinforced Plastic
GRP	-	Glass Reinforced Polymer
GFRP	-	Glass Fiber Reinforced Polyester
CFRP	-	Carbon Fiber-Reinforced Composites
PMMA	-	Polymethylmethacrylate
Cr	-	Chromium
DOP	-	Depth of Penetration
BLV	-	Ballistic Limit Velocities
MEKP	-	Methyl Ethyl Ketone Peroxide
SEM	-	Scanning Electron Microscopy
SEI	-	Secondary Electron Imaging
ASTM	-	American Society for Testing and Materials
US dollars	-	United Stated Dollars
RM	-	Ringgit Malaysia
AP projectiles	-	Armor-piercing Projectiles
UD	-	Unidirectional
B1	-	Sample 1 Impact by Blunt Impactor
B2	-	Sample 2 Impact by Blunt Impactor
B3	-	Sample 3 Impact by Blunt Impactor
B4	-	Sample 4 Impact by Blunt Impactor
B5	-	Sample 5 Impact by Blunt Impactor
H1	-	Sample 1 Impact by Hemispherical Impactor
H2	-	Sample 2 Impact by Hemispherical Impactor
H3	-	Sample 3 Impact by Hemispherical Impactor
H4	-	Sample 4 Impact by Hemispherical Impactor
H5	-	Sample 5 Impact by Hemispherical Impactor

C1	-	Sample 1 Impact by Conical Impactor
C2	-	Sample 2 Impact by Conical Impactor
C3	-	Sample 3 Impact by Conical Impactor
C4	-	Sample 4 Impact by Conical Impactor
C5	-	Sample 5 Impact by Conical Impactor

LIST OF SYMBOLS

ρ	-	density
ρ_A	-	average areal density
A	-	total area
L	-	length
L_N	-	length of nose
R	-	radius
D	-	diameter
D_p	-	projectile diamater
M	-	mass
Δ	-	interfiber distance
v	-	velocity
V_o	-	ballistic limit
θ	-	delta
σ	-	tensile strength
E	-	tensile modulus
°	-	degree
%	-	percent
wt. %	-	weight percent
mm	-	millimeter
nm	-	micrometer
min	-	minute
g/m^2	-	gram per meter square
g/cm^3	-	gram per centimetre cube
kg	-	kilogram
kg/m^2	-	kilogram per meter square

kg/m^3	-	kilogram per meter cube
MPa	-	mega Pascal
GPa	-	giga Pascal
GN/m^2	-	giga newton per meter square
GN/m^3	-	giga newton per meter cube
m/s	-	meter per second
km/s	-	kilometer per second
mm/min	-	millimetre per minute
µs	-	microsecond

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Materials are one of the important element influences on our life. Barbero (2011) stated that composite, ceramic and plastics have been dominated as human kind materials where the number and volume of application on composite material has grown steadily pass few decades. One of the important factor using composite is the weight reduction provides by composite material. Composite is lightweight because both fibers and polymers used as matrices have low density, and fiber has high value of strength to weight ratio than most materials.

One of the most common composite materials is fiber reinforced composites. Fiber reinforced composites is now widely used in application due to their superiority over metal such as lightweight with high strength. In addition, fiber reinforced composite have been more prominent than other types of composite because they are stronger and stiffer in the fibrous form than in any other form. An instance, Chawla (2012) mentioned about that glass fiber reinforced resins were applied since the early twentieth century. The glass fiber reinforced resins is very light yet strong materials. Now, glass fiber and carbon fiber are common reinforcement material used to fabricate laminated composite (Onyechi *et al.*, 2014; Khan *et al.,* 2011). Glass fiber has been the most common reinforcements for polymer matrices due to its high strength, low cost, and high chemical resistance (Chawla, 2012; Kaw, 2006). Other fibers with better performance that combine high strength with high stiffness are boron, silicon carbide, carbon and alumina. The arrangement of fibers and their orientations are crucial to determine the strength and stiffness of a composite (Ye, 2003). In this case, fibers oriented in one direction give very high stiffness and strength in that direction. The main function of the matrix material is protect the fibers from environment attack, thus corrosion resistance is one of the properties to be considered. The studies of epoxy and polyester resin used as a binder is carried out by Onyechi *et al.* (2013a) and Valluzzi *et al.* (2002).

The research related the fiber reinforced composite for military application which considered the function of fiber and the influences of resins has been done by Gupta *et al.* (2007). The author showed the nose shape of a projectile is an important factor affecting the mechanism of deformation of the target plate. The different investigations have been carried out with various parameters in the study of the projectile nose shape effect on the target plate. An instance, the impact test using blunt, hemispherical and ogival shape of impactor nose done by Rittel and Dorogoy, (2014), while Rusinek *et al.* (2008) used the conical impactor on thin steel plate. However, there is a systematic review required about the influence of projectile nose design, thickness of the target plate as well as the projectile impact velocity on deformation behavior of the laminated composite plate. Besides, Rittel and Dorogoy (2014) as well as Onyechi *et al.* (2014) discussed about the penetration and perforation on target by projectiles. The most convenient in this respect are those models that allow deriving formulas determining the dependence of the ballistic limit velocity on various parameters affecting perforation (Ben-Dor *et al.*, 2002a). The increased contacting area between the projectile nose and target material may need to be considered when the penetration depth is comparable with the projectile nose length in a penetration problem or in the penetration stage of a multi-stage perforation process (Li *et al.*, 2004). Furthermore, Filiatrault (2002) discussed about quasi-static test performed to predict the behavior of structural on large scale structural elements based on strength, stiffness and ductility. Unlike dynamic test, quasi-static test may be interrupt at any time to assess the condition of the specimen. The main problem during testing is to know the specimen is overloaded or not. The quasi-static tests can replace the inertia forces generated by an earthquake on a structure with equivalent static loads. Zureick and Nettles (2002) noted that the need of a quasi-static loading test proved to be very beneficial to researchers since more data can be obtained from quasi-static test than from an impact test since the amount of impact damage formed in a laminated composite is very sensitive to stacking sequence, regardless of thickness.

Based on aforementioned above, the study on quasi-static testing is required to understand the performance of laminated composite for the different geometrical shapes of the impactor nose. It is also necessary to know the energy absorption of laminated composite under quasi-static testing with the different velocity to gain more information on the relationship between geometry of impactor nose and laminated composite structural.

1.2 Problem Statements

The structural designer seeks for the best possible design while using least amount of resources. The measure of goodness design is typically related to the strength or stiffness of resources (materials) measured in terms of weight or cost. The cost of raw materials and fabrication cost are considered in any experiment. Composite materials have properties with high strength and high stiffness which can compete with others materials. One of the advantages of composite over other materials is related to the cost. As noted by Kaw (2006), the world market for composite is only 10 x 109 US dollars as compared to more than 450 x 109 US dollars for steel. However, there is not much of scholar discussed about the using of composite materials for military proposes based on quasi-static testing.

Since there is lacking of research studied on the quasi-static test using different impactor geometry, there is be short of information and knowledge regarding quasi-static test. In this case, the ballistic testing that are commonly used and studied with the different geometry of impactor in order to develop armour (Onyechi *et al.*, 2013b). They studied specifically on the penetration phenomenon of composite armours. Even so, laminated composites are extremely susceptible to transverse impact, particularly at low velocities. The low-velocity impact can cause damage, including matrix cracks, delaminations, and fiber breakage, which is embedded within the composites (Li *et al.*, 2002).

Furthermore, Gupta *et al.* (2007) investigated using blunt, ogive along with hemispherical nosed steel projectiles to impact on aluminum target plates. Similarly, Onyechi *et al.* (2013b) studied the development of an armour protecting body of glass fiber reinforced polyester (GFRP) composite laminates of varying thicknesses which targeted with a high velocity of 355 m/s by ogival and conical nose. On this case, the impactor geometry and parameter can influence to various result of the laminated composites deformation. The different shapes of impactor nose applied to the laminated composite for identifying the mechanical deformation were on a certain thickness. The main consideration is on the energy absorption of the composite while impact by different impactor nose under low velocity.

Moreover, since the shape of impactor nose can causes the highest global deformation of the target plate, therefore the shape of impactor nose which has the lowest effective on penetration should be determined. One of the governing factors in the damage resistance is the nose shape of the impacting projectile due to the ballistic limit and failure mode of laminated composite. For that reason, to understand the shape of an impactor nose on laminated composite under quasi-static loading, this study will be carried out in the experiment using blunt, hemispherical and conical nose. This study focused on the using of composite materials so as to reduce the expense of overall experiment and produce high quality of investigation, thus parallel with current ballistic materials most made from composite structural. Specifically, through the quasi-static test that is performed with different velocities in order to determine the deformation result of laminated composite.

1.3 Objectives

The objectives of this research are:

(a) To analyze the effects of different geometry of impactor nose on laminated composite at different quasi-static speed loading.

(b) To determine failure mechanism on laminated composite after the quasi-static test.

(c) To identify the relationship between geometry of impactor nose and quasi-static speed loading.

1.4 Scope of Research

The research's scopes are as follows:

(a) Study on geometry of impactor nose besides considering the parameter of projectile in term of diameter, mass and length.

(b) Research on the effect of different nose area of projectile on the energy absorption of impact target under quasi-static loading.

(c) Discuss on influence of different speed of quasi-static loading on the deformation behavior of impact target.

(d) Determine appropriate reinforcement and matrix materials to obtain high performance of laminated composite.

(e) Design suitable number of plies and reinforcement orientations as well as thickness for laminated composite to be test under different velocity of quasi-static loading.

(f) Study on method to manufacture laminated composite to reduce production time, low cost of tooling and increase its strength.

(g) Evaluate the potential ballistic penetration response of laminated composite and conduct the comprehensive analysis based on