UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF COMBAT ARMOR FROM RAMIE-ARAMID-POLYESTER COMPOSITE

ZAINAB SHAKER RADIF

DEVELOPMENT OF COMBAT ARMOR FROM RAMIE-ARAMID-POLYESTER COMPOSITE

By

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

JUNE 2009

DEDICATION

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Chairman : Dr. Aidy Ali

Faculty : Engineering

In this study the laminates composite material is developed from ramie-aramid-polyester resin. The aim of this study is to developed solid body armor by using ramie-aramid reinforced polyester composite structure design. The design of body armor meet the specific requirements of ballistic resistance. The matrix of the developed composite is unsaturated Polyester resin reinforced with aramid-natural ramie fiber. This ramie-aramid composite is subjected to high impact loading. The target is shot by using gas gun machine supported by camera hardware to capture the projectile speed. To achieve the goal of the research, experiments were conducted with a focus on estimation the ballistic limit, maximum energy absorption, composite failure mode, life time rupture, target geometry and environmental effect. The results of these experiments indicated that the maximum ballistic limit validated at impact speed is in the range of 250 m/s to 656.8 m/s for the second protection level. The targets are improved in the area of impact respond with increase in the relative humidity in the range of 50% ± 20%.

Whereby, reduction of resistance results in the increase of temperature. The range of temperatures was between 20 ^{O}C to 70 ^{O}C. A limited delamination was generated under multiple shots. Targets geometry plays a main role in increasing impact response. Hence, the results were presented high resistant impact for pairs from panels with total thickness of 15 mm ± 3mm. This body armor is one of most economical armor products in that; common materials were used in its production especially to the reduction of the using Kevlar amount that led to decrease in its cost. On the other hand this armor met the ballistic threats under 623 m/s of 15 mm ± 3 mm target thickness and 837.5 m/s of 25 mm ± 2 mm. Thus, the armor is equivalent to third level of protective ballistic limits in National Institute of Justice (NIJ) standards.

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

PEMBANGUNAN PERISAI BADAN DARI SERAT RAMIE-ARAMID-POLIESTER

Oleh

ZAINAB SHAKER

JUN 2009

Pengerusi : Dr. Aidy Ali

Fakulti : Kejuruteraan

Di dalam kajian ini, bahan lapisan komposit dibangunkan dari serat ramie-aramid yang diperkukuhkan dengan resin poliester. Kajian ini bertujuan untuk membangunkan perisai badan dengan menggunakan struktur rekabentuk komposit yang diperkukuhkan dengan ramie-aramid. Rekabentuk perisai badan tersebut dapat memenuhi keperluan tahanan balistik yang spesifik. Matrik yang terhasil dari komposit yang dibangunkan adalah resin poliester yang diperkukuhkan dengan serat ramie-aramid semulajadi. Komposit ramie- aramid ini didedahkan kepada kelajuan yang berimpak tinggi. Sasaran diuji dengan tembakan dari senjata gas dan kelajuan projektil dirakamkan dengan menggunakan peralatan kamera. Bagi mencapai matlamat kajian, beberapa eksperimen telah dijalankan untuk menganggar had kalis peluru, serapan tenaga yang maksimum, mod kegagalan komposit, keruntuhan jangka hayat, geometri sasaran dan kesan terhadap persekitaran.

Keputusan eksperimen ini menunjukkan had maksimum kalis peluru adalah pada kelajuan impak diantara 250 m/s hingga 656.8 m/s bagi tahap perlindungan ke dua. Sasaran diperbaiki dalam lingkungan maklumbalas impak dengan peningkatan kelembapan relatif di antara 50% ± 20% ; di mana pengurangan ketahanan menyebabkan peningkatan suhu di antara 20 ^{o}C hingga 70 ^{o}C. Pelekangan yang terhad diperolehi dari pelbagai tembakan. Geometri sasaran memainkan peranan penting dalam meningkatkan maklumbalas impak. Oleh itu keputusan menunjukkan impak ketahanan tinggi bagi pasangan lapisan yang mana jumlah ketebalannya adalah di antara 15 mm ± 3 mm. Perisai ini merupakan produk perisai yang paling ekonomi kerana bahan-bahan biasa yang digunakan untuk menghasilkannya terutama bagi pengurangan penggunaan amaun Kevlar yang menyebabkan kos berkurangan. Selain itu, kalis peluru ini memenuhi hentaman balistik di bawah 623 m/s dari 15 mm ± 3 mm ketebalan sasaran dan 837.5 m/s dari 25mm ± 2mm. Oleh itu, perisai tersebut adalah sama dengan tahap ketiga had perlindungan balistik mengikut piawaian Institut Kehakiman Kebangsaan (NIJ).

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APROVAL

I certify that an Examination Committee has met on 29th September 2009 to conduct the final examination of Zainab Shaker Radif on her Master of Science thesis "The Development of Combat Armor from Ramie-Aramid-Polyester Composite" 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.

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment 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 citation 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.

ZAINAB SHAKER RADIF

Date:

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LIST OF ABBREVIATIONS / GLOSSARY OF TERMS

KRP	Kevlar29 –Ramie Fiber Reinforced Polyester
UP	Unsaturated Polyester
FEA	Finite Element Based Analyses
MMC	Metal Matrix Composite
CMC	Ceramic Matrix Composite
PMC	Polymer Matrix Composite
V_f	Fiber Volume Friction
V_m	Matrix Volume Friction
V_{li}	Composite Volume Friction
G_{li}	Composite Shear Modulus
v_{it}	Composite Poisson Coefficient
v_f	Fiber Poisson Ratio
v_m	Matrix Poisson Ratio
e_{werp}	Elastic Modulus of Warp Direction
e	Total Layer Thickness
n_1	Number of Warp Yarns Per Meter
n_2	Number of Fill Yarns Per Meter
e_{fill}	Elastic Modulus of Fill Direction
E_x	Elastic Modulus of x Direction
E_t	Elastic Modulus of Transverse Direction
E_l	Elastic Modulus along The Direction of Fiber

G_{xy}	Shear Modulus in Two Directions
G_{it}	Shear Modulus
V_{xy}	Volume Friction in Two Direction
C	Velocity of Longitudinal Strain Wave
E	Dynamic Modulus of Elasticity
ρ	Yarn Density
V_b	Ballistic Limit Velocity
N_{PLY1}	Number of Nylon Plies
N_{PLY2}	Number of Humpt Plies
MEKP	Mety1 Ethy1 Ketone Peroide
NIJ	National Institute of Justice
OSP	One Separated Panel
TSP	Two Separated Panels
FTP	Flexible –Tough Panels
P_a	Cylinder Gas Pressure
D	Diameter of The Projectile
E_{abs}	Energy Absorption
m	Mass of The Projectile
V_{imp}	Strike Velocity
b	Target Thickness
FMJ	Full Metal Jacket
ACP	Automatic Colt Pistol
AP	Armor Piercing

JHP	Jacketed Hollow Point
JSP	Jacketed Soft Point
LR	Long Rifle
LRN	Lead Round Nose
RN	Round Nose
S&W	Smith & Wesson
S_1	Longitudinal Wave
S_2	Transverse Wave

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