UNIVERSITI PUTRA MALAYSIA

FINITE ELEMENT MODELING OF BALLISTIC PENETRATION INTO FABRIC ARMOR

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FINITE ELEMENT MODELING OF BALLISTIC PENETRATION INTO FABRIC ARMOR

By

HOSSEIN TALEBI

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

December 2006

To

My Beloved Mother,
Mehdi, Mohsen and Mina

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

FINITE ELEMENT MODELING OF BALLISTIC PENETRATION INTO FABRIC ARMOR

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Chairman: Professor Abdel Magid Salem Hamouda, PhD

Institute: Advanced Technology

The goal of this work is to analyze the ballistic performance of plain woven fabric used in soft armor systems using a detailed finite element analysis at yarn level. As more complex materials systems are introduced in engineering practice, the design engineer faces the dilemma of utilizing homogenization techniques or detailed numerical models. The latter offers a number of advantages, such as the ability to introduce separate constitutive laws and failure criteria for each phase, at the expense of computation cost. This is particularly important in ballistic performance of the soft armor where the projectile-fabric interaction and failure modes are complicated and can not be realized in other approaches.

An automatic geometry generation algorithm for textile is developed that can generate complex fabric geometries spanning several unit cells. This program (named DYNTEX) based on the mentioned algorithm is designed using MATLAB code. A commercial finite element code named LS-DYNA is used as the solver and DYNTEX program is then extended to do the pre-processing for LS-DYNA.

Four types of projectile shapes were chosen which consist of spherical, blunt, conical, hemi-spherical and a conically cylindrical military sized bullet. An orthotropic material with von-Mises stress at failure of 2.7GPa was chosen for material behavior of yarns. Since projectiles did not have considerable deformation, they assumed as rigid bodies. Furthermore a general surface to surface contact was selected for the contact between the yarns and projectile-fabric. Initial conditions and results of experimentations were extracted from literature to validate the simulation results for different projectile shapes.

To verify the mesh built by DYNTEX program a relatively low velocity impact simulation performed in oblique angle. Then convergence analysis is then carried out by changing the mesh density of fabric target and it was shown primary mesh density was fine enough to start the remaining simulations.

Finite element models of fabric impact were made with initial conditions extracted from literature and simulations were performed. The results of simulations showed close agreement with experimental tests. Moreover several parameters which affect the energy absorption of fabric were studied. These parameters were friction, boundary conditions, projectile nose diameter and projectile nose angle. The mentioned parameters were studied with respect to several projectile nose shapes and boundary conditions.

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

PEMODELAN ELEMEN TERBATAS MENGENAI PENEMBUSAN BALISTIK MELALUI PERISAI FABRIK

Oleh

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Matlamat tugasan ini adalah untuk menganalisis kebolehan balistik sehelai fabrik bertenun biasa yang digunakan sebagai sistem perisai lembut menggunakan elemen terbatas yang dianalisis secara terperinci pada peringkat benang. Sebagai sistem yang lebih kompleks, latihan kejuruteraan diperkenalkan dan jurutera reka bentuk terpaksa berdepan dengan dilema dalam menggunakan teknik-teknik dan model-model terperinci yang pelbagai. Ini kemudiannya mewujudkan beberapa kelebihan seperti kebolehan untuk memperkenalkan undang-undang terkandung yang berasingan dan kegagalan kriteria bagi setiap fasa pengiraan kos perbelanjaan.

Ini adalah penting dalam perlaksanaan balistik perisai lembut ini di mana tindak balas fabrik dan kegagalaan cara melaksanakannya adalah sukar dan tidak dapat dikesan melalui pendekatan yang lain.Algoritma sejenis generasi geometri yang automatik untuk tekstil telah dibangunkan kandan ia dapat menjana kekompleksan geometri fabrik tersebut kepada beberapa jarak sel unit. Program ini yang dinamakan DYNTEX berdasarkan algoritma yang disebutkan tadi, direka bentuk menggunakan

kod MATLAB. Sejenis kod elemen terbatas komersil yang dinamakan LS-DYNA telah digunakan sebagai penyelesai dan program DYNTEX kemudiannya dipanjangkan bagi melaksanakan pra-pemprosesan untuk LS-DYNA.

Terdapat 4 jenis bentuk senjata atau bahan yang dipilih dimana ia terdiri daripada bentuk bulat, tumpul, kon, hemisfera dan sejenis kon yang berbentuk silinder bersaiz peluru. Sejenis bahan ortotrafik dengan ketegangan yang rendah telah dipilih sebagai bahan yang bersifat seperti benang. Memandangkan senjata atau bahan yang dipilih tidak mengambil kira cecacatan, mereka menganggap ia sebagai badan yang tegar.

Tambahan lagi, sejenis hubungan am din antara satu permukaan dengan permukaan lain telah dipilih sebagai hubungan di antara benang dan fabrik senjata. Keadaan-keadaan dan keputusan awal daripada eksperimen telah diperolehi daripada lisan bagi mengesahkan keputusan simulasi bagi bentuk senjata atau bahan yang berlainan.

Untuk mengesahkan jaringan yang terhasil oleh program DYNTEX sejenis simulasi hubungan berkelajuan rendah telah dilaksanakan di dalam sudut serong. Kemudian, analisa pemusatan telah dilakukan dengan menukarkan ketebalan target fabrik dan ia menunjukkan jaringan ketebalan permulaan adalah cukup untuk melaksanakan simulasi bagi yang seterusnya.

Model elemen terbatas bagi kesan fabrik telah dilakukan menggunakan keadaan permulaan yang diperolehi daripada lisan dan simulasi yang telah dilakukan. Keputusan daripada simulasi menunjukkan keputusan yang diperolehi hampir sama dengan ujian eksperimen. Malahan beberapa parameter yang memberi kesan kepada penyerapan tenaga oleh fabrik telah dikaji. Parameter ini adalah perselisihan, sempadan keadaan, diameter muncung senjata dan diameter muncung sudut.

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I certify that an Examination Committee has met on 15 December 2006 to conduct the final examination of Hossein Talebi on his Master of Science thesis entitled "Finite Element Modeling of Ballistic Penetration into Fabric Armor" 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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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.

HOSSEIN TALEBI

Date:

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LIST OF ABBREVIATIONS

EA	Energy absorption
FE	Finite Element
A	Yarn cross sectional area
d_f	Filament diameter
n	Yarn filament count
p_d	Yarn packing density
a	Yarn spacing
H_a	Cell height
V_f	Overall fiber volume fraction
w_a	Arial weight of dry fabric
t	Yarn thickness
L_a	Yarn shape parameter
θ_c	Crimp angle
ρ	Density
v_i	Velocity
σ_{ij}	Stress tensor
p	Pressure
f_i	External body force
Δt	Time step
X_a	Cartesian coordinate system
t	time
V_i	Initial velocity

V_r Residual velocity

C_0, C_1 Viscosity coefficients

v_e Element volume

c Sound speed

E Young’s modulus

G Shear modulus

υ Poisson’s ration

f Coefficient of friction

ΔE_{pk} Projectile kinetic energy

ΔE_{ys} Yarn strain energy

ΔE_f Friction Energy

CHAPTER 1

INTRODUCTION

Human being has always quested for new materials to improve functional performance. Performance may be specified by various criteria including less weight, more strength and lower cost. One area of that question was protection against several threats in combat and other dangerous situations. The first protective clothing and shields were made from animal skins. Consequently as civilizations became more advanced, wooden shields and then metal shields came into use. Eventually, metal was also used as body armor, what we now refer to as the suit of armor associated with the knights of the Middle Ages. However, with the invention of firearms around 1500, metal body armor became ineffective. Then only real protection available against firearms was stone walls or natural barriers such as rocks, trees, and ditches.

For hundreds of years, metal constructions have been used for body armor as well as for the protection of objects such as vehicles (hard protection). It was only a few decades ago, at the end of WW II, that the softer constructions, so called "ballistic nylon vests" appeared; and finally in series of researches for better material, Aramid fibers were developed.

Historically the first type of Aramid fibers was KEVLAR made by Du Pont in 1960's. KEVLAR itself is a long chain like molecule known as a polymer, which consists of repeating units called monomers. KEVLAR fiber is an array of molecules oriented parallel to each other like a package of uncooked spaghetti. The crystallinity of KEVLAR polymer strands, contributes significantly to KEVLAR unique strength and flexibility (Clements, 1998).

Because of its high strength and at the same time light weight and flexibility it first used in building high speed tires. Shortly after that KEVLAR became the technology of the choice for bullet resistant vests. Soft body armors made from KEVLAR which offered light weight, mobility and concealment for police forces.

After innovation of KEVLAR several types of Aramid fibers were made like KEVLAR 29, KEVLAR 49, TWARON, SPECTRA and DYNEEMA. The basic ideas of building such fibers are almost the same; however their mechanical properties vary.

1.1 Composite Materials, Textiles and Bullet Proof Vests

Composites can be defined as a combination of materials, in a system, composed of mixture of two or more macro constituents that differ in form or material composition and are essentially insoluble in each other.

In the beginning, composite materials were introduced because of their high specific strength and stiffness compared to conventional engineering materials. As their unique advantages are being widely appreciated, many different types of composites, having different types of matrix and reinforcements combination, have been developed. The fact is that even during this stage of the technology explosion, the unique advantages of a composite material, i.e. the ability to tailor their properties to the structural or material system of which they are intended, has not been fully explored (Jones, 1998).

Aramid fibers are now being used widely in design and manufacturing of composite materials. These composites are then used to build bullet proof vests. The U.S. Patent and Trademark Office lists records dating back to 1919 for various designs of bullet proof vests and body armor type garments. One of the first documented instances where such a garment was demonstrated for use by law enforcement officers was detailed in the April 2, 1931 edition of the Washington, D.C., Evening Star, where a bullet proof vest was demonstrated to members of the Metropolitan Police Department (US Patents, 2006).

In *hard body armors* which are mostly a hard plate made of several layers of different materials, the Aramid fibers are mixed with epoxy resin. The composite material is then placed on the back of a ceramic plate to absorb the energy and stop the bullet. This type of bullet proof vest can stop a bullet traveling at 800m/s.

However in *soft armors* no such protection is needed because the kinetic energy of the projectile is much lower in situations were soft armors are used. The types of threats which soft body armors are exposed are bullets shot by hand guns and pistols traveling utmost 400m/s. Therefore in soft armors the main factors are light weight, mobility and concealment. As a result high strength fibers *can not* mixed with epoxy to form a hard plate.