NUMERICAL SIMULATION OF BALLISTIC IMPACT ON CART BRASS

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ABSTRACT

Soft and lightweight body armour is normally made by woven fabrics. The aim is to select a metal material that enhances its performance yet complies with NIJ standard level threat IIA. Autodyn software is used for the simulation tests of ballistic impact. The projectile is blunt-nosed cylindrical and rigid body. The material selected for target is thin Cart Brass plate with thirty material parameters of Equation of State, Johnson-Cook Strength and Strain Rate Correction. In order to validate the model, ten tests are conducted on Weldox 460E steel. It is successfully achieved with 95% of confident level. Then simulation begins with ten tests on Cart Brass target to measure thickness and ballistic limit velocity, with results of 5.5 mm and 373 m/s respectively. The impact and penetration process of post-damage mechanisms are highlighted and verified with literature review. Phenomenon obtained are Tensile and Spherical Compressive Axial Strain; Through-Thickness Strain Wave; Transverse-Shear Deformation and Growth; Delamination; Local Shear Cone Formation and Membrane Tensile Failure. The final state matches the damage mechanism of body armour qualitatively so its behaviours are maintained. The real application is a layer of cart brass implanted into soft body armour to increase its performance.

ABSTRAK

Baju kebal yang lembut and ringan biasanya diperbuat dari kain tenunan fiber. Tujuan ini ialah memilih sejenis bahan logam yang menambahkan prestasinya masih ditadbirkan oleh taraf NIJ tahap ancaman IIA. Perisian Autodyn digunakan untuk ujian penyelakuan hentaman balistik. Pelancar adalah silinder bermuncung tumpul dan jasad tegar. Bahan yang dipilih bagi sasaran ialah plat Loyang Kart nipis yang mempunyai tiga puluh parameter bahan dari Equation of State, Kekuatan Johnson-Cook dan Pembetulan Kadar Terikan. Bagi tujuan pengesahan model, sepuluh ujian dijalankan atas keluli Weldox 460E. Ia berjaya mencapai tahap sela keyakinan 95%. Selepas ini, penyelakuan bermula dengan sepuluh ujian atas sasaran Loyang Kart bagi mengukur ketebalan dan halaju had balistik dengan keputusan ialah 5.5 mm dan 373 m/s masing-masing. Hentaman dan proses tusukan dari mekanisme kerosakan post akan ditekankan dan diujikan dengan kajian literatur. Fenomenan diperolehi adalah Tegangan dan Mampatan Sfera Terikan Paksi ; Lambaian Terikan Ketebalan Terus ; Pengubahbentukan Ricih Melintang dan Pertumbuhan; Delamination; Pembentukan Kon Ricih Tempatan dan Kegagalan Tegangan Membran. Keadaan muktamad sepadan dengan mekanisme kerosakan baju kebal secara kualitatif maka kelakuannya dikekalkan. Aplikasi nyata ini ialah selapisan Loyang Kart dimasukkan ke dalam baju kebal lembut bagi menambahkan prestasinya.

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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BFS	BackFace Signature
BI	Ballistic Impact
BL	Ballistic Limit
BLV	Ballistic Limit Velocity
BP	Ballistic Panel
$CaCl_2$	Calcium Chloride
CL	Composite Laminate
CP	Complete Penetration
DEM	Digital Element Method
DTT	Dynamic Tensile Test
EOS	Equation of State
FEA	Finite Element Analysis
FEC	Finite Element Codes
FEM	Finite Element Method
HMPA	Hexamethylphosphoaramide
HMPT	Hexa Methyl Phosphorous Triamide
JC	Johnson & Cook
MP	Material Parameter
MT	Melting Temperature
NIJ	National Institute of Justice Standard – 0101.06
NIJLT	National Institute of Justice Standard Level Threat
NMP	*N*-Methyl-2-pyrrolidone
P*p*PTA	*p*-phenyleneterephtalamide
PPD	*p*-phenylenediamine
PP	Partial Penetration
QST	Quasi-Static Test
RN	Round Nose
RT	Room Temperature
S&W	Smith & Wesson
SJHP	Semi Jacketed Hollow Point
TC	Terephthaloyl Chloride

UHMW	Ultra-High-Molecular-Weight
USE	Unit Single Element
USR	User-Defined Reference
a	Acceleration
a	Length Contact of Fiber Adjacent
A	Area
A	Yield Stress
B	Strain-Hardening
C	Strain Rate Constant
C_p	Specific Heat
C_{rate}	Rate Parameter
D	Diameter
D	Damage Evolution
E	Modulus Young
f	Failure Criteria Equation
F	Force
G	Shear modulus
H or h	Target Thickness
HGE	Hourglass Energy
IE	Internal Energy
k	Contact Stiffness
K	Adiabatic Heating Scale
KE	Kinetic Energy
L or l	Length
m	Mass or Temperature-Softening Exponent
M	Mass of Membrane Reactive Force
max	Maximum
n	Strain-Hardening Exponent
N	Function
n	Sample Size
p	Confident Level
P	Pressure
PRE	Penetration Resistance Energy
R	Radius
S	Strength

SLE	Frictional Sliding Energy
t	Time
t	Student's *t*- Distribution
T	Temparature
TE	Total Energy
u	Displacement
U	Energy
V	Velocity
V_{50}	Ballistic Limit Velocity
W	Work
X_1 or X_2	Test Sample
α	Coefficient of Active Layer
$\bar{\alpha}$	Gruneisen Expansion Coefficient
β	Damage Parameter or Lambert Equation Parameter
δ	Delta Distance
Δ	Increment
ε	Plastic strain
$\dot{\varepsilon}$	Plastic Strain Rate
Σ	Dimensionless Rate Dependent Strength
Ξ	Rate Equation for Elastic Modulus
σ	Stress
$\acute{\sigma}$	In-Plane Compression Stress
σ^2	Variance
ρ	Density
ϕ	Diameter
s	Standard Deviation
τ	Shear Stress
Γ	Areal Density Ratio
μ	Friction Coefficient
μ	Population Mean
ν	Poisson's ratio
ϖ	Modulus Reduction Parameter
χ	Taylor-Quinney Coefficient
$\overline{x_1}$ or $\overline{x_2}$	Sample Mean
Z	Test Statistic

CHAPTER 1

INTRODUCTION

1.0 Overview

In traditional warfare, the highest percentage of casualties is caused by fragments from shell fragments, mines, grenades, mortars and other munitions. For many years, the soft body armour (BA) (Sacks, 1992) (Colvin, 2002) (Yavin, 2002) performed well against fragments, relatively lightweight and afford a wide-range of mobility as compared to hard armour (Justice, 2008). As a result, it is particularly applicable for military use in anti-fragmentation and small-arms protection garments.

Generally, ancient BA is solid metal armour made of steel, aluminium, titanium or alloys. Solid metal armour usually possesses excellent stopping power and multi-hit characteristics. Titanium is the best but expensive when compared with steel and aluminium on low weight efficiency. Metal armour also causes additional dangers on its backside whereby fragments are widely dispersed. Composite laminate (CL) armour has high weight efficiency to deflect fragment. However, CL armour based on ceramic strike face with composite backing layer which typically included carbon, glass and aramid polymer composites are expensive.

Lightweight BA was not popular until the late 1960s when new fiber was discovered that made today's modern generation of concealable or flexible BA possible. Flexible BA is constructed of pliable, textile-based materials such that the complete system is capable of being flexed. Such systems are typically in the form of vests or jackets that provide greater coverage area than rigid plate armour. Generally, these armours provide protection against handgun threats.

Traditionally, the design and research of BA is empirical which is ineffective and costly. Simulation attempts were carried out to simplify a broad collection of experiment methods and applications to mimic the behaviour of real system. Simulation modeling methods assist in understanding the latest process improvements and systems instead of laboratory or the unforgiving real world. The philosophy of simulation is based on lucid and authoritative exposition of the fundamentals of the mathematical modeling of systems with an insightful discussion of practical applications and stimulating cross-referencing. A simulation model can open the door to what was thought to be impossible.

Simulation is the art of using physical or conceptual models, or computer hardware and software to attempt to create the illusion of reality. The result of the simulations is always an approximation and simplification of the reality so it is some kind of an illusion. An appropriate numerical simulation tool should be created to encounter uncertainty failure mechanism for demonstration of BI into BA. A preliminary study by differential inclusion approach had been conducted to make the approximation of physical reality with idealized mathematical constructs. With the much richer interpretation of numerical simulation results, the limitation is ability to measure the physical phenomenon accurately and leads to better analysis.The science of simulation and modeling strives to showcase the highest possible level of reality in order to determine the conditions necessary for optimal performance of BA.

1.1 Problem Statement

Most of the studies of BI of projectile on thin target plate had been simulated using Ls-Dyna or Ls-Dyna 3D but there were certain limitations found. Several simulation studies using Autodyn showed some advantages with regards to parametric studies and composite structures facilitate on. So, some of the limitations may be improved by using Autodyn. However, the new simulation model using Autodyn shall be validated before running simulation test. A model with numerous published data of projectile impact velocity (PIV) complying with NIJLT IIA within 364m/s and 382m/s should be selected.

Previous studies showed that several materials had been used as material for the target plate. However not many simulation studies had been carried out on thin target plates which was similar with the phenomenon, behaviours and damage mechanisms of flexible body armour. This study is to identify a material which has failure behaviour similar to flexible BA and thus resemble with NIJLT IIA flexible BA. Then the thickness and BLV of the material are predicted by simulation test.

Finally, the study presents the comparison of penetration phenomenon and damage mechanisms of target plate with flexible BA. From literature review, the main challenge is the observations of post damage and delamination failure showing similar effects with the behaviour of flexible BA.

1.2 Objectives of Study

The objectives of this study are:

1. To validate the BI simulation test model with NIJLT IIA.
2. To predict the thickness and BLV of thin Cart Brass target plate.
3. To analyse the phenomenon and PD mechanisms of flexible BA.

1.3 Scope of Study

The scopes of study are;

1. The actual bullet consists of projectile, cartridge case, propellant and rim but the simulation tests are only conducted with projectile.
2. The interest of this study is the target only. In order to simplify this study, the projectile is assumed to be rigid body and blunt nose head.

3. The PIV is limited within 364m/s and 382m/s which comply with NIJLT IIA (Justice, 2008). This study only measures the phenomenon and mechanisms of BLV but not the others.
4. The element erosion process with large energy losses at the early stage of penetration is omitted.
5. Autodyn only explicitly solves the problem with part calculations for structured and unstructured solvers.

1.4 Significances of Study

The penetration and perforation of CL panels by projectiles involve highly complex processes which have been investigated experimentally for more than two centuries and analytically largely during the last few decades. This study will provide an extrapolate knowledge about MM of BI fibre. The new numerical simulation approach Autodyn is more effective, powerful, economical and safe than empirical approach in demonstrating an explicit dynamics analysis of BI test. At the end, it is a necessity to create a numerical simulation tool using Finite Element Analysis (FEA) techniques to investigate the BI simulation test. Then a large number of mechanical properties and parameters of fibre MM like BA are required for this tool.

1.5 Thesis Layout

This research is aimed to analysis the behaviour and PD mechanisms of thin cart brass target plate. Then the ultimate objective is to create a validated model of BI simulation test with NIJLT IIA. This thesis consists of six chapters.

Chapter One introduces the overview. Then the problem statement, objectives, significances and scope are derived from this study.

Chapter Two reviews the literature related to research work. It consists of compliance test of flexible BA, DFEN, geometry and MPs of projectile and target, BI, damage failure parameter, PD mechanisms, validation and conclusion.

Chapter Three derives the overview of methodology used for BI simulation test of projectile into thin Cart Brass target plate. It includes initiating simulation test of 2D modelling; preset data of MM, local and global conditions; generating parts and components, geometries of projectile and target then meshing and filling; convert to 3D model; set solutions and output controls and validation test.

Chapter Four presents the results and discussion. Firstly, a partial validation test is conducted by measuring basic assumptions. Secondly, a pre-test is conducted by measuring BLV of a numerous published material model then verified by statistical test of 95% confident level hypothesis. Thirdly, the thickness of thin Cart Brass target plate and BLV within NIJLT IIA are measured. Lastly, the details and behaviours of thin Cart Brass target are compared with flexible BA.

Chapter Five is the conclusions from this study. Some recommendations have been established for further study.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the literature review was carried out in relation with the present study. It was also found that it was necessary to introduce the background of this study such as compliance test and standard classification of flexible body armour (BA). Further to that, the literature on the fundamental aspect of this study was also carried out consisting of digital fiber element network (DFEN) connections, the ballistic impact (BI) laws, the conservations, the theories, the constitutive relations, fracture criterions and damage mechanisms. Last but not least, the construction of this study also includes geometry, material model (MM), Finite Element Method (FEM), the validation model and verification. Finally, there are summary of literature reviews and comments on previous studies.

2.1 Compliance Test of Flexible BA

2.1.1 National Institute of Justice Standard – 0101.06

National Institute of Justice Standards (NIJ) "*Ballistic Resistance of* BA," is a minimum performance standard developed in collaboration with the Office of Law Enforcement Standards of the National Institute of Standards and Technology, USA. This standard is a technical document that specifies the minimum performance requirements that equipment must meet to satisfy the requirements of criminal justice agencies and the methods that shall be used to test this performance. This standard is used by the NIJ Voluntary Compliance Testing Program to determine which BA models meet the minimum performance requirements for inclusion on the NIJ Compliant Products List (Justice, 2008).

2.1.2 Military Standard– 662F (MIL)

The purpose of MIL (MIL-STD, 1997), is to provide general guidelines for procedures, equipment, physical conditions, and terminology for