Numerical Simulation of Ballistic Impact on Ceramic Armor

Tarin Vanichayangkuranont¹, Nuwong Chollacoop² and Kuntinee Maneeratana¹

¹Department of Mechanical Engineering, Chulalongkorn University, Bangkok 10330
Phone 0-2218-6639, Fax. 0-2252-2889, E-Mail: tarinv@yahoo.com and kuntinee.m@chula.ac.th

²National Metal and Materials Technology Center (MTEC), Pathumthani 12120
Phone 0-2564-6500 ext 4700, Fax. 0-2564-6403, E-Mail: nuwongc@mtec.or.th

Abstract
A preliminary investigation of ballistic impact on ceramic armor was carried out by recourse to numerical simulation using finite element method. Following our earlier study [1] on the effect of stress wave propagation from dynamic loads, the current computational model was developed with built-in brittle failure criteria, aiming to correlate with experimental ballistic testing. It was found that the rate that the ceramic armor absorbed the bullet kinetic energy raised as the armor thickness increased.

Keywords: Ballistic impact, finite element method, ceramic armor

1. Introduction
The National Metal and Materials Technology Center (MTEC) had initiated a collaborative research project to develop the light-weight hard armor for the Royal Thai Military Armory [2]. The project aims to build import-comparable armor prototypes made from various materials available and/or assembled domestically in order to reduce the quantity of armor imported annually.

As hard armors typically comprise of layers of ceramic, metal and polymer, there are many design parameters involved in the construction of prototypes. Even if all materials are selected, geometrical factors such as size, thickness and arrangement are critical to the performance. The design by trials and errors would require a lot of firing tests on prototypes, which are both time-consuming and expensive (Fig. 1). The numerical simulation provides an alternative approach for analyzing ballistic impact, helps guiding the design process and reducing the number of the firing tests required to achieve the optimal configuration.

Fig. 1 Standard firing tests [1].

The present study aims to develop computational model that can qualitatively describe ballistic impact of fast moving bullet onto ceramic armor during the firing tests [2]. The effects of ceramic thickness are discussed in terms of deformation area and energy absorption.

2. Computational Model
All finite element calculations are performed using ABAQUS/Explicit [3] due to the nature of high speed, non-linear transient responses in the solutions. An axisymmetric model is used for simulations of a round-
shape bullet penetrating a layer of ceramic material, as shown in Fig. 2.

The modeled bullet emulates the caliber 0.22 long rifle cartridge with the 40 grains lead round nose (LRN) bullet. However, the diameter of the modeled bullet body is slightly reduced to match those of head and heel. The bullet geometry comprises a half-hemisphere with radius $w_h$ and the cylindrical body of arbitrary length $h_b$. Both parameters are set to $w_h = 2.794$ mm and $h_b = 7.21$ mm in this study such that the model corresponds to commercial bullets in terms of diameter and mass.

The ceramic layer has the thicknesses $h_c$ of 3 and 6 mm, corresponding to the tested ceramic tile. In order to eliminate edge effects, the ceramic layer has a much larger radius $w_c$ of 60 mm was used for both cases.

Due to the anticipated severe deformation at contact, the fine mesh ($0.1 \times 0.1$ mm$^2$) is used at the ceramic region directly beneath the bullet tip while coarser mesh ($0.1 \times 0.5$ mm$^2$) is used further away to reduce computational expense, as shown in Fig. 2.

The fully restrained boundary condition is applied to the right edge of the ceramic layer while the left side of the model follows axisymmetric boundary condition. The bullet is given a downward initial speed of 437 m/s, the actual average bullet speed obtained from the firing test.

![Fig. 2 The bullet/ceramic configuration and meshes](image)

The ceramic armor is modeled as an alumina layer with Young’s modulus of 303 GPa, Poisson’s ratio of 0.21 and density of 3,720 kg/m$^3$. Brittle failure criterion is invoked to simulate failure in the layer. Crack initiates when cracking stress reaches flexural strength, assumed here as 300 MPa [4]. Then, the material strength deteriorates linearly to zero at the critical cracking strain of 1% [3]. When this local cracking strain at a material point is reached, the material point fails and all the stress components are set to zero. For the shear behavior, the shear modulus is reduced to 1% of the undamaged value when the critical cracking strain [3] is reached.

### 3. Results and Discussions

The bullet is allowed to penetrate the ceramic layer completely. Fig. 3a shows Mises stress contour plot for the 3-mm-thick layer at initial, half-way and full penetration whereas Fig. 3b shows the results for the 6-mm-thick armor. The blue-to-red stress levels range from 0 to 300 MPa (flexural strength) in an equal incremental order. The red color denotes that areas in which the Mises stress exceeds the flexural strength. In addition, these contours clearly show ripples of interfering stress waves traveling away from the impact [1].

The larger region experiencing high Mises stress in the thicker sample in Fig. 3 agrees with the larger damaged areas in the actual firing tests of thicker ceramic tiles [2]. Furthermore, this observation is confirmed in the energy breakdown plots in Fig. 4, showing the total energy ($E_{sys}$), kinetic energy ($E_{bul}$) and internal energy ($E_{cer}$) of the system ($E_{sys}$), bullet ($E_{bul}$) and ceramic armor ($E_{cer}$). The initially large kinetic energy ($E_{bul}$) from the bullet is largely transmitted through the kinetic energy of the ceramic layer (i.e. flying fractured pieces) and some via internal energy ($E_{sys}$) of the remaining ceramic layer. A
reduction in the total energy ($TE_{sys}$) of the whole system due to mass erosion (element removal after critical cracking strain) is also observed as pointed out in [5].

4. Conclusion

In this study, a preliminary investigation of ballistic impact was conducted via finite element method. The developed computational model was consistent with the experimental results from the firing test. Further refinement of the current model is warranted for quantitative predictability.

Acknowledgments

This research is supported by MTEC, contract no. MT-B-48-CER-07-188-I with special thanks for Dr. K. Sujirote, Dr. D. Atong, Dr. K. Prapakorn, Dr. A. Manonukul, Assc. Prof. Dr. T. Amornsakchai, Asst. Prof. Dr. S. Rimdusit and Maj. Gen. Dr. W. Phlawadana.

Fig. 3. The Mises contour plots of (a) 3mm and (b) 6mm thick layers at initial, half-way and through penetrations.

(a) 3-mm-thick armor (b) 6-mm-thick armor

Fig. 4 Breakdown of energy in components.

References


