NUMERICAL ANALYSIS OF AN INFLUENCE OF CERAMIC PLATE SURROUNDING BY METAL COMPONENTS IN A BALLISTIC PANEL

Sebastian Stanisławek, Andrzej Morka, Tadeusz Niezgoda

Military University of Technology
Gen. S. Kaliski 2 St., 00-908 Warsaw, Poland
tel.: +48 22 6837610, fax: +48 22 683 9355
e-mail: sstanislawek@wat.edu.pl

Abstract

The paper presents a numerical study of the three layer composite panels impacted by an AP (Armor Piercing) 7.62x51mm projectile. The standard panel is built with aluminum and Al2O3 ceramic plate. The studied model, however, consists of the same aluminum plate but the ceramic one is surrounded by a steel packet.
The problem has been solved with the usage of the modelling and simulation methods as well as finite elements method implemented in LS-DYNA software. Space discretization for each option was built with three dimension elements guaranteeing satisfying accuracy of the calculations. For material behaviour simulation, specific models including the influence of the strain rate and temperature changes were considered. Steel projectile and aluminum plate material were described by Johnson-Cook model and ceramic target by Johnson-Holmquist model. In the studied panels, the area surrounding back edges was supported by a rigid wall.

The obtained results show interesting properties of the new structures considering their ballistic resistance. The ballistic protection of a three layer panel under the WC projectile impact is indentified. Panels containing the ceramic plate surrounded at each side by a steel packet plate are stronger. However, this difference reaches only the level of 2.4% regardless erosion parameters. Definitely technological complication and an area density mass increase cannot balance a small improvement of ballistic protection. However, this kind of panel is not suggested as a useful solution. Further investigations are suggested in order to analyze an influence of initial ceramic compression. The results of those numerical simulations can be used for designing of modern armour protection systems against hard kinetic projectiles.

Keywords: *computational mechanics, ballistic protection, composite armour, ceramics*

1. Introduction

Both the designers and users of armour face interesting difficulty how to reconcile the competing requirements posed by weight and thickness of the crust. Advanced ceramic is one of the most important components of modern ballistic panels nowadays [1]. As any other component of the armour systems, advanced ceramics assist to defeat projectiles through the ballistic impact energy dissipation. However, the mechanisms of protection against projectiles for ceramic are significantly different than the one observed in metals. While ballistic alloys absorb the energy by a plastic deformation mechanism, in ceramics the kinetic energy of the projectile is dissipated through the process of fracture [2]. While the fracture starts, it is progressing by itself with especially high intensives for the material extension. In this paper, the focus is on the aspect of limiting this phenomenon by surrounding the ceramic plate with steel materials.

2. Constitutive model of metal and alumina materials

Each numerical model requires constitutive relations to be defined. It completes the fundamental laws of nature and characterizes specific properties of the studied material. The yield stress for both aluminum and steel was described by:

$$\sigma_y = \left(A + B\bar{\varepsilon}_p^n\right)\left(1 + C\ln\dot{\varepsilon}^*\right)\left(1 - T^{*m}\right) \ , \tag{1}$$

$\bar{\varepsilon}_p^n$ - effective plastic strain ,

where: $\dot{\varepsilon}^*$ is strain ,

$$\dot{\varepsilon}^* = \frac{\dot{\bar{\varepsilon}}_p}{\dot{\varepsilon}_0}. \quad (2)$$

Homologous Temperature:

$$T^{*m} = \frac{T - T_r}{T_m - T_r}, \quad (3)$$

where:
T_m - melt temperature,
T_r - reference temperature

Fracture occurs when damage parameter reaches unity:

$$D = \sum \frac{\Delta \bar{\varepsilon}_p^n}{\varepsilon^F} \dot{\varepsilon}^* = \frac{\dot{\bar{\varepsilon}}_p}{\dot{\varepsilon}_0}. \quad (4)$$

Ceramic brittle behaviour is described with Johnson-Cook model, where the equivalent stress is described by:

$$\sigma^* = \sigma_i + D(\sigma_i * - \sigma_f *), \quad (5)$$

$\sigma_i = a(p^* + t^*)^n (1 + c \ln \dot{\varepsilon})$ - intact ceramic , (6)
$\sigma_f = b(p^*)^m (1 + c \ln \dot{\varepsilon})$ - damaged behaviour. (7)

Damage is described in a similar way as in equation (4).

3. Problem description

Two comparative tests have been held for WC core, which impacts a ballistic panel perpendicularly at 854m/s speed. In the reference panel, the ceramic plate was surrounded by an aluminum alloy (AA) and a steel plate at the front and back side and connected by eight bolts, as it is depicted in Fig. 1.a. The size of the front and back AA plates are 4x100x100mm while the investigated ceramic has dimension 6x53x53mm. A tested panel has a very similar design but the ceramic plate is surrounded by a steel packet plate, as it can be seen in Fig.1.b.The implemented models simulated WC, AA and ceramic materials, basing on real data verified in literature [4], [5], [6].

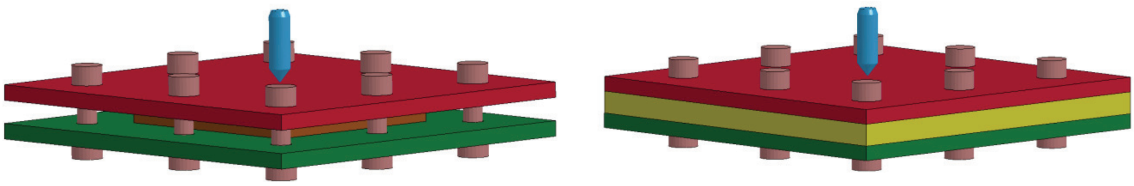

Fig1. Model structure: a) reference model structure, b) model with middle plate surrounding a ceramic tile

4. Problem solution and analysis of the results

All FEM models were built using brick and tetra elements. The initial velocity was defined for the projectile with the same value for both examples and a backing plate was supported in the neighbourhood of its edges. LS-Dyna software [3] was used to solve each variant with explicit time integration method. The simulation showed that the projectile has penetrated both panels, therefore kinetic energy became a key parameter being analyzed without taking into account the debris energy. In Fig. 2, this parameter can be seen as a function of time. After the initial 25µs energy becomes stable and is slightly higher for ballistic panel in which the ceramic plate is located inside a steel cover. The tiny difference brings a question of credibility of this calculations and simplification of the model. Especially, the damage equations deciding about the erosion of failed finite elements seem to influence and disturb the result. Therefore, there was done a simulation test enabling elements to deform much more before they were automatically removed. Fig.2 shows clearly that erosion has influenced energy of the projectile. However, this impact is not substantial and, more importantly, the difference in kinetic energy between compared panels remains on the same level.

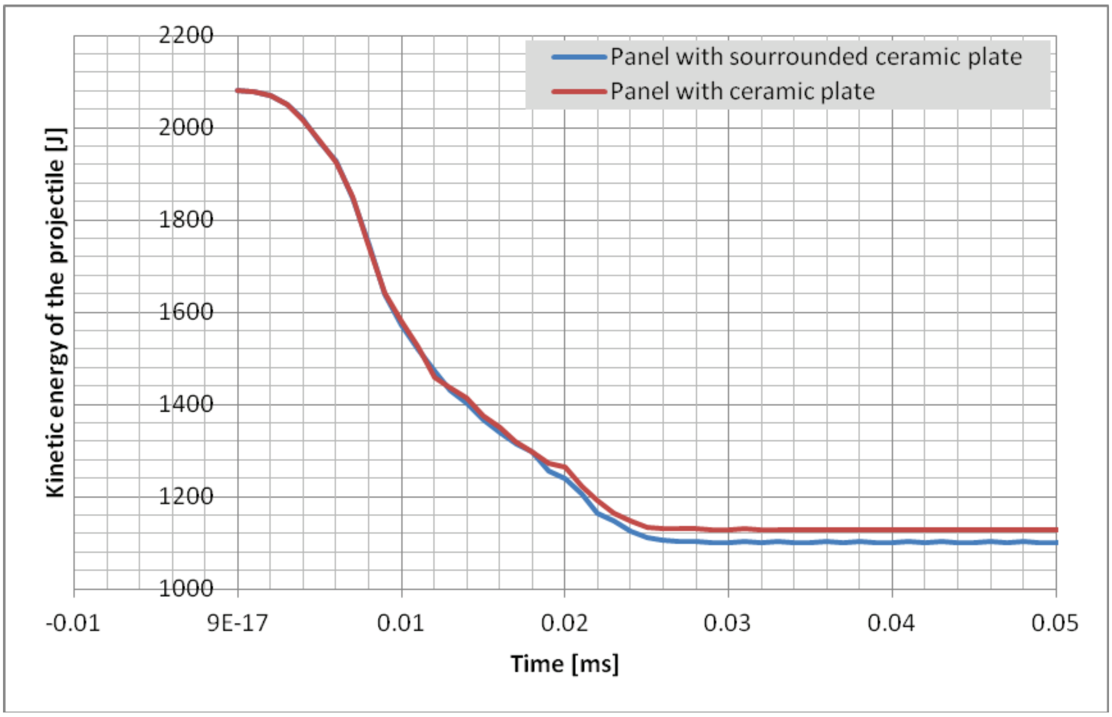

Fig.2. Kinetic energy of the projectile for reference model and confined ceramic

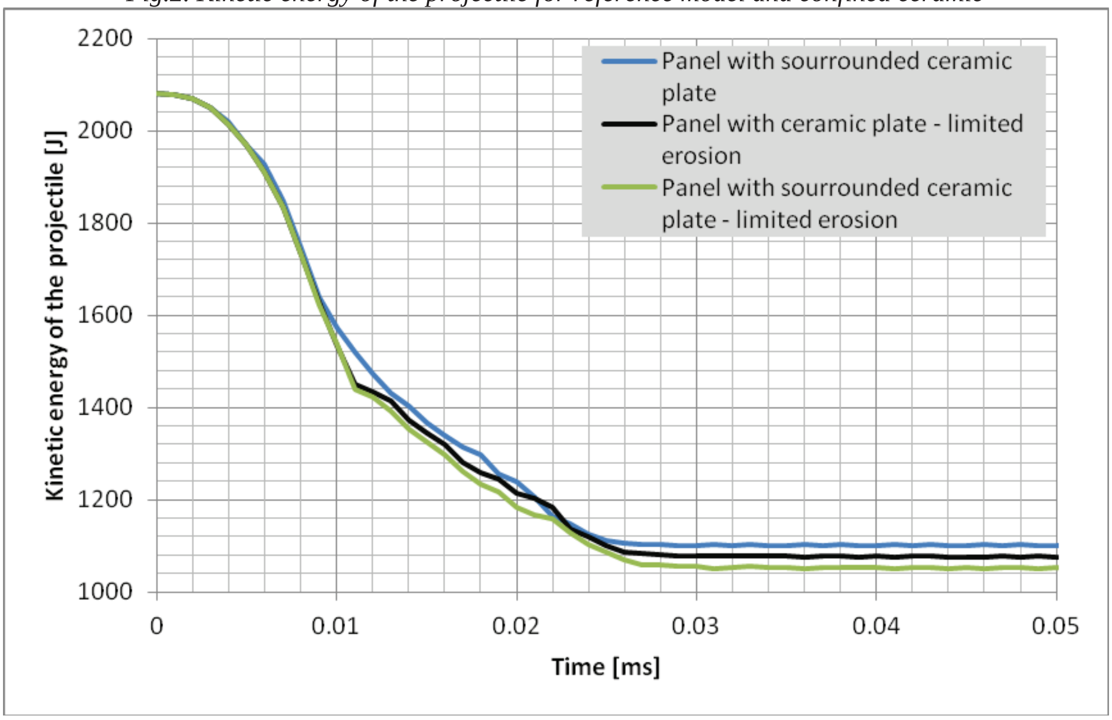

Fig.2. Kinetic energy of the projectile for reference model and confined ceramic including the changes in simulation erosion parameters

Despite the fact that projectile almost does not react to the steel plate, which confines ceramic tile, the brittleness of plate is smaller. This effect can be seen in Fig.3, where damage parameter is presented for both options 50µs after the impact. The fracture is less observable for the ceramic which is surrounded by steel. Its perpendicularity is caused by meshing but it has no influence on the result.

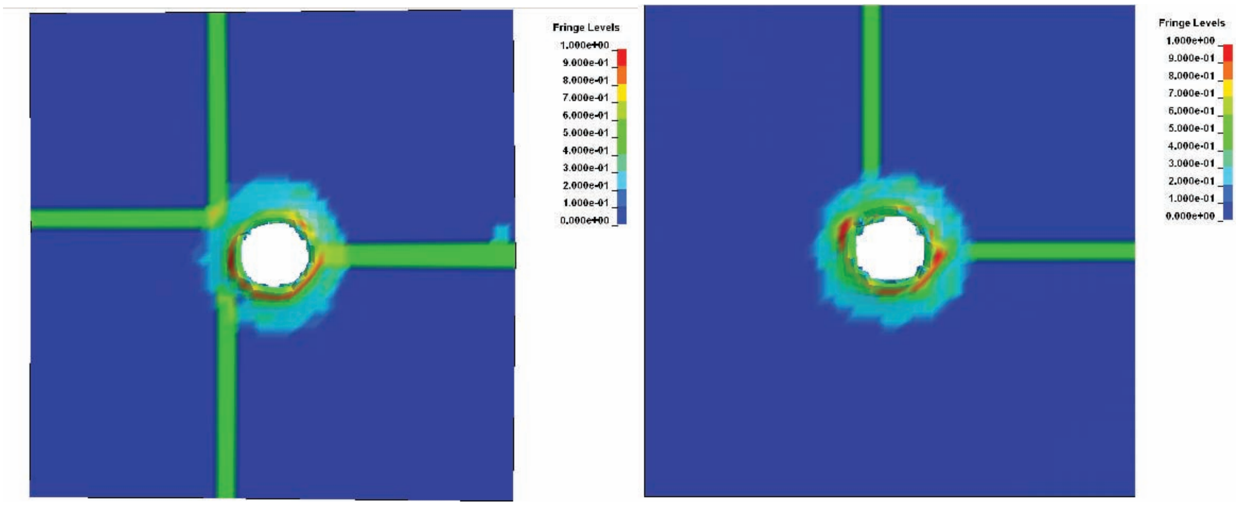

Fig.2. Structure of the plate 50µs after the impact for: a) not confined ceramic, b) ceramic surrounded by steel packet

5. Conclusions

The obtained results show interesting properties of the new structures considering their ballistic resistance. The ballistic protection of a three layer panel under the WC projectile impact is indentified. Panels containing the ceramic plate surrounded at each side by a steel packet plate are stronger. However, this difference reaches only the level of 2.4% regardless erosion parameters. Definitely technological complication and an area density mass increase cannot balance a small improvement of ballistic protection. However, this kind of panel is not suggested as a useful solution. Further investigations are suggested in order to analyze an influence of initial ceramic compression. The results of those numerical simulations can be used for designing of modern armour protection systems against hard kinetic projectiles.

Bibliography

[1] Medvedovski, E. *Ballistic performance of armour ceramics: Influence of design and structure*, Umicore Indium Products, 50 Sims Ave., Providence, RI 02909, USA.

[2] Gogots, G. A., *Fracture toughness of ceramics and ceramic composite*, Institute for Problems of Strength, 2 Timiryazevskaya Street, Kiev 01014, Ukraine.

[3] *Ls-Dyna Keyword User's Manual*, May 2010 Version 971/Rev 5.

[4] Nilsson, M., *Constitutive model for Armox 500T and Armox 600T at low and medium strain rates*, Swedish Defence Research Agency, TR FOI-R-1068-SE, 2003.

[5] Johnson, G. R., Cook, W. H., *A Constitutive Model and Data for Metals Subjected to Large Strains, High Strain Rates and High Temperatures*, Proceedings of the 7th International Symposium on Ballistics, The Hague, The Netherlands, April 1983.

[6] Panov, V., *Modelling of behaviour of metals at high strain rates*, Cranfield University, PhD Thesis, 2005.