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NUMERICAL ANALYSIS OF A MULTI-COMPONENT BALLISTIC PANEL

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Abstract

The paper presents a numerical study of a two layer composite panel impacted by an AP (Armour Piercing) 14.5x118mm B32 projectile. The panel consists of a number of pyramid ceramic components supported by an aluminium plate. The studied model is compared with a reference structure in which ceramic layer is in a form of a plate. The problem has been solved with the usage of modelling and simulation methods as well as a 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. A steel projectile and aluminium plate material were described by Johnson-Cook model and a 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 examined structures considering their ballistic resistance. All tests have given clear results about ballistic protection panel response under AP projectile impact. Panels consisting of sets of pyramids are slightly easier to penetrate. Despite this fact, a ceramic layer is much less susceptible to overall destruction what makes it more applicable for the armour usage. Furthermore, a little influence of the projectile impact point and consequently a part of the pyramid, which is first destroyed, is proved.

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

1. Introduction

Armour protection systems have aroused increasing attention since the development of offence weapons in modern conflicts. Modern ceramic can play an important role in improving the bulletproof ability and reducing armoured vehicle weight due to its mechanical properties such as high hardness, high compressive strength and low density. These studies have described various aspects of a ceramic fracture both in compression and tension [1], [2], [3]. The mechanisms of ballistic protection for ceramic and metal armour are also significantly different. While the metallic armour absorbs the energy of projectile by a plastic deformation mechanism, in the case of ceramics, the kinetic energy of the projectile is dissipated through fracture. Therefore, the ceramics structure, which is analysed in the paper, seems to be a very interesting issue.

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 aluminium and steel was described by Johnson-Cook model:

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

where:
$\bar{\varepsilon}_p^n$ – effective plastic strain,
$\dot{\varepsilon}^*$ – strain,

$$\dot{\varepsilon}^* = \frac{\dot{\bar{\varepsilon}}_p}{\dot{\varepsilon}_0}, \tag{2}$$

T^{*m} - homologous temperature,

$$T^{*m} = \frac{T - T_r}{T_m - T_r}, \tag{3}$$

T_m - melt temperature,

T_r - reference temperature,

A fracture occurs when damage parameter reaches unity:

$$D = \sum \frac{\Delta \bar{\varepsilon}_p^n}{\varepsilon^F} \dot{\varepsilon}^* = \frac{\dot{\bar{\varepsilon}}_p}{\dot{\varepsilon}_0} \cdot \tag{4}$$

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

$$\sigma^* = \sigma_i + D(\sigma_i * - \sigma_f *), \tag{5}$$

$\sigma_i = a(p^* + t^*)^n (1 + c \ln \dot{\varepsilon})$ - intact ceramic,

$\sigma_f = b(p^*)^m (1 + c \ln \dot{\varepsilon})$ - damaged.

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

2. Problem description

Two comparative tests have been held for the core of a 14,5x114 B32 projectile. Its initial speed was set as 854m/s and impacted a ballistic panel perpendicularly. In the reference panel, the ceramic plate was backed by an aluminium alloy (AA) as it is depicted in Fig. 1a. In the analyzed panel, the front ceramic protector consisted of set of a closely grained tetrahedrons showed in Fig. 1b. The size of the front plate in both tests was 8x50x50mm, while the back one was 5x50x50mm. The implemented models simulated HHS, AA and ceramic materials, basing on real data verified in literature [4], [5], [6].

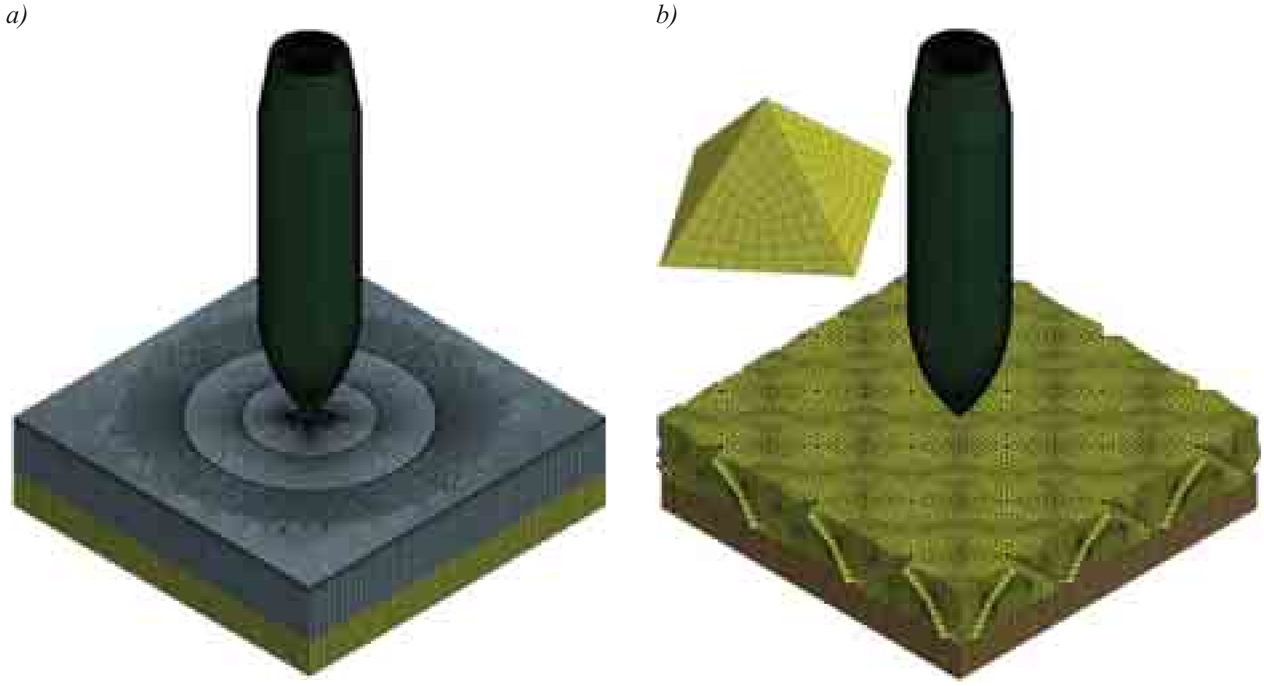

Fig. 1. Reference model structure (a) and pyramid model structure (b) including ceramic pyramid component

4. Problem solution and analysis of the results

Both FEM models were built using brick elements only. 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 an explicit time integration method. The simulation showed that the projectile has penetrated both panels, therefore, the projectile kinetic energy became a key parameter being analyzed without taking into account the debris energy. Shortly after that, the impact energy becomes stable and it can be seen clearly in Fig. 2 that a pyramid structure shows lower ballistic strength. However, the difference is not significant and is only on the level of 5%. Therefore, further analyses were done in order to measure ceramic plate's destruction. The results presented in Fig. 3 clearly show high resistance of the pyramid structure to a cracking phenomenon.

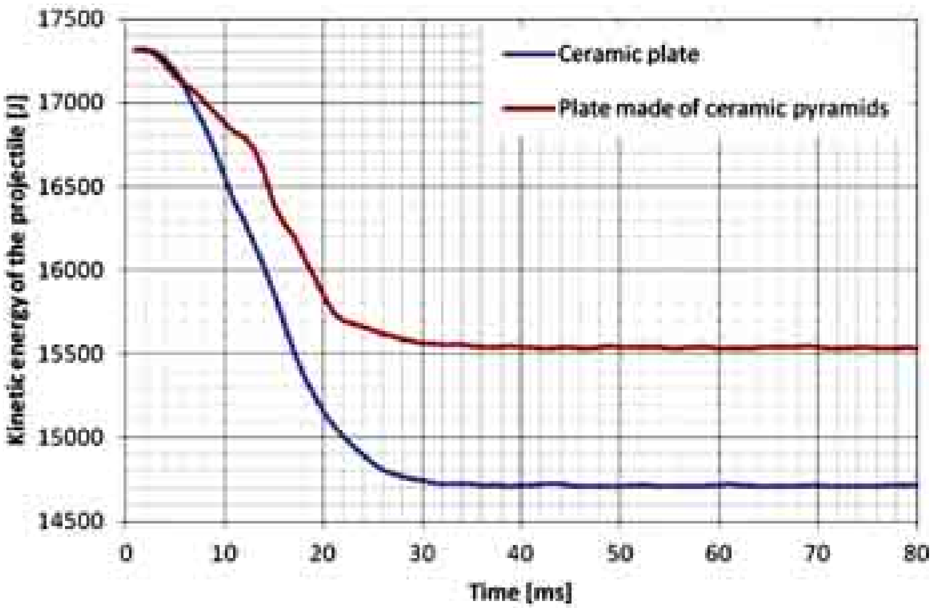

Fig. 2. Kinetic energy of the projectile for reference model and confined ceramic

a) *b)*

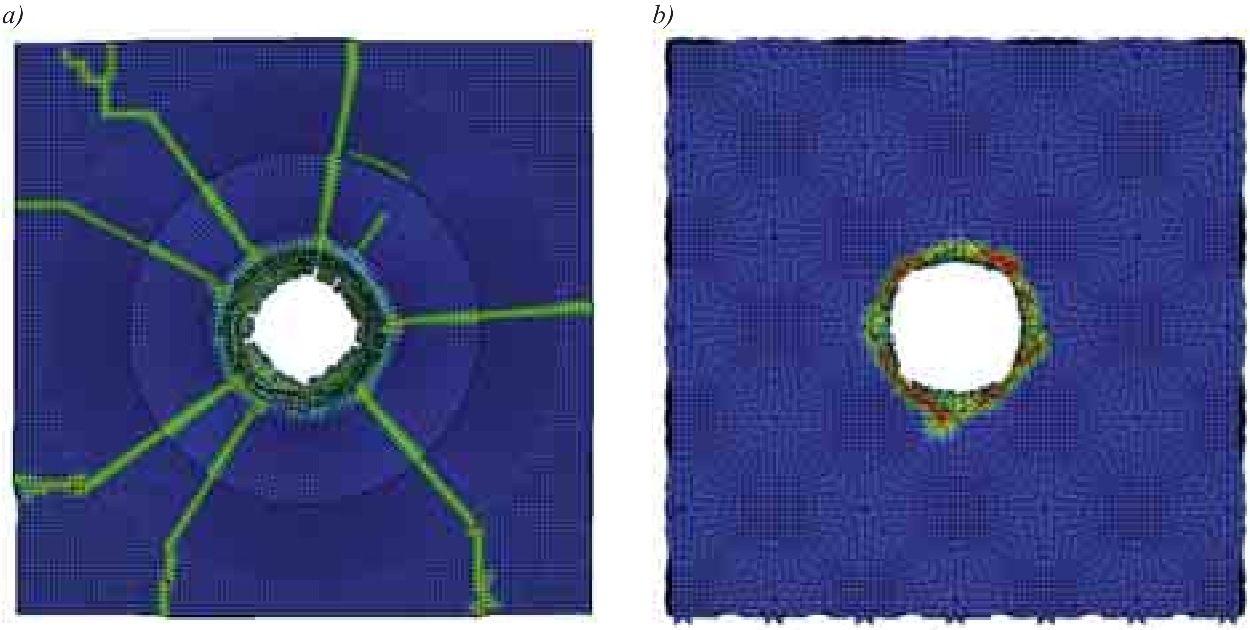

Fig. 3. Ballistic panel's destruction 20μs after the impact: ceramic plate (a), plate mad of ceramic pyramids (b)

5. Conclusions

The obtained results show interesting properties of the examined structures considering their ballistic resistance. All tests have given clear results about ballistic protection panel response under AP projectile impact. Panels consisting of sets of pyramids are slightly easier to penetrate. Despite this fact, a ceramic layer is much less susceptible to overall destruction, what makes it more applicable for the armour usage. Furthermore, a little influence of the projectile impact point and consequently a part of the pyramid, which is first destroyed, is proved.

References

[1] Tracy, C., Slavin, M., Viechnicki, D., *Ceramic failure during ballistic impact,* Advances in Ceramics: Fractography of Glasses and Ceramics, 22 (1988), pp. 295–306, 1988.

[2] Mayseless, M., Goldsmith, W., Virostek, S. P., Finnegan, S. A., *Impact on ceramic targets,* Journal of Applied Mechanics, 54 (1987), pp. 373–378, 1987.

[3] Woodward, R. L., Gooch, W. A., O'Donnell, R. G., Baxter, B. J., Pattie, S. D., *A study of fragmentation in the ballistic impact of ceramics,* International Journal of Impact Engineering, 15 (5) (1994), pp. 605–618, 1994.

[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.