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Ceramic Armour for Armoured Vehicles Against Large-Calibre Bullets

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Abstract. Modelling the armour-piercing bullets B-32 calibre 12.7 mm penetration into the double-layer ceramic-composite armour has been performed for the armour blocks of two designs. The first one is a layer of ceramic square tiles supported by the glass or polyamide fabric. Modelling and subsequent ballistic tests have shown that the conical Hertz crack localized in the ceramic tile is formed. The tile is destroyed from the spread of radial cracks, and the entire armour unit becomes unable to sustain the repeated hit of the bullet. In the second case, the armour block consists of the discrete epoxy-filled cylindrical ceramic elements with spherical ends. The advantage of this "discrete" armour is localization of the damage zone and thus an ability to sustain the multiple bullet hits. The ballistic tests of the compared armour units have shown that both provide effective additional protection of light-armoured vehicles against the normal impact of the calibre 12.7 mm bullet.
Keywords: reactive sintered silicon carbide, ceramic armour element, bullet, calibre, armour block, ballistic protection.

1. INTRODUCTION

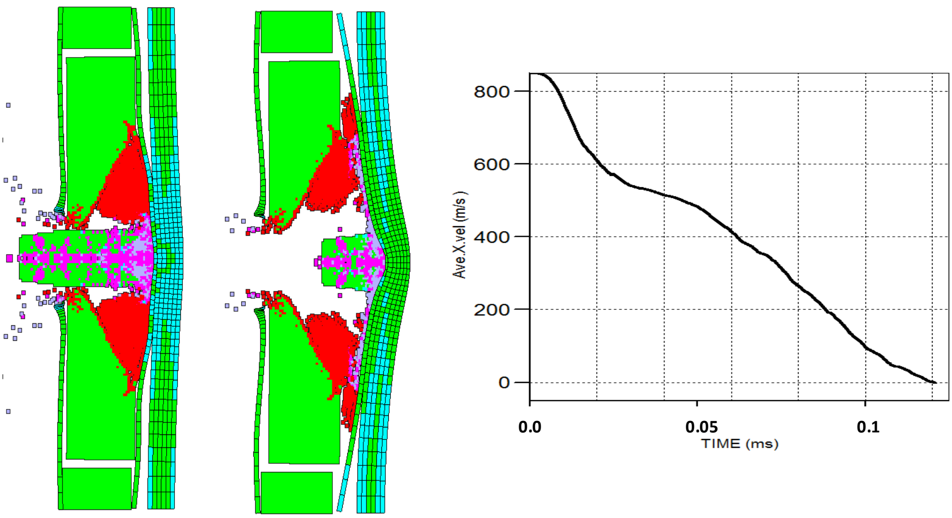
The light-armoured vehicle casing made of armoured steel provides protection of personnel against 7.62 mm calibre bullets. To protect them against the bullets with the kinetic energy from 17 to 31 kJ, an additional armour is used. This armour is located outside the casing at a certain distance from the main armour or directly on it and causes destruction or deflection of the bullet, thereby weakening its back face action. In particular, the ceramic-composite armour blocks, consisting of the ceramics and polymer composite layers with high dissipative capacity, provide an efficient protection against the armour-piercing bullets. The face ceramic layer with high hardness is aimed to deform and destruct the hard-tempered steel bullet core. The energy dissipation is due to formation of new surfaces in the fragmented/dispersed silicon carbide based ceramic armour layer and deformation and destruction of the bullet core. The role of the support, made of light alloys or polyamide fabric, is to adsorb the residual kinetic energy of the bullet and fragments of the destroyed ceramics. Energy dissipation in the polymeric composite support is due to deformation and destruction of high-strength reinforcing fibers as well as the "fiber-epoxy resin" interface debonding.

An important requirement for additional ballistic protection is its ability to withstand multiple hits of bullets. Given the low crack resistance of ceramics, the only way to localize the damage in a ceramic-composite armour unit is to use the so-called "discrete" armour, where the protective layer consists of individual ceramic elements.

In this study, ceramic elements in the form of tiles and cylinders with spherical ends are considered. The structure of double-layer armour with steel support can be considered as one of the options for additional armour in the case of the installation of ceramic elements directly on the casing of an armoured personnel carrier. Given the need for rapid replacement of the damaged elements, fixing the ceramic layer directly to the personnel carrier armour is impractical. The more promising option is an additional armour unit consisting of discrete tiles. Below, some variants of design of these armour units are considered.

2. ARMOUR UNIT MADE OF CERAMIC TILES

An ability of the ceramic armour to withstand repeated hits can be provided by its formation of discrete elements, in particular ceramic tiles of square or hexagonal shape. The ceramic layer is brittle and in itself does not provide reliable protection against the bullets. The protective potential of ceramics is realized only in combination with sufficiently solid support, in particular, the casing of an armoured personnel carrier. This fact should be taken into account when choosing the design of the discrete armour unit.



(a) *t*=60 μs (b) *t*=120 μs (c)

Fig. 1. Interaction of the core of B-32 bullet 12.7 mm in calibre with the ceramic element (SiC tile 100x100x15 mm) of the armour unit fixed directly on the steel casing of the armoured personnel carrier (a, b) and the bullet core speed evolution during its penetration (c)

(a) (b)

Fig. 2. General view of the armour unit (175x175 mm) consisting of ceramic (SiC) tiles before (a) and after the bullet B-32 12.7 mm in calibre hit (b)

The lack of ogive, loss of the major part of mass of a core and considerable damage of its residual is the reason why the 6.5-mm thick armoured steel withstands the impact although deforms locally due to back face action of the bullet (see Figure 1). Simple design and low cost are the main advantages of the considered armour unit but it collapses after the first bullet hit and does not provide protection against the repeated hits (Figure 2).

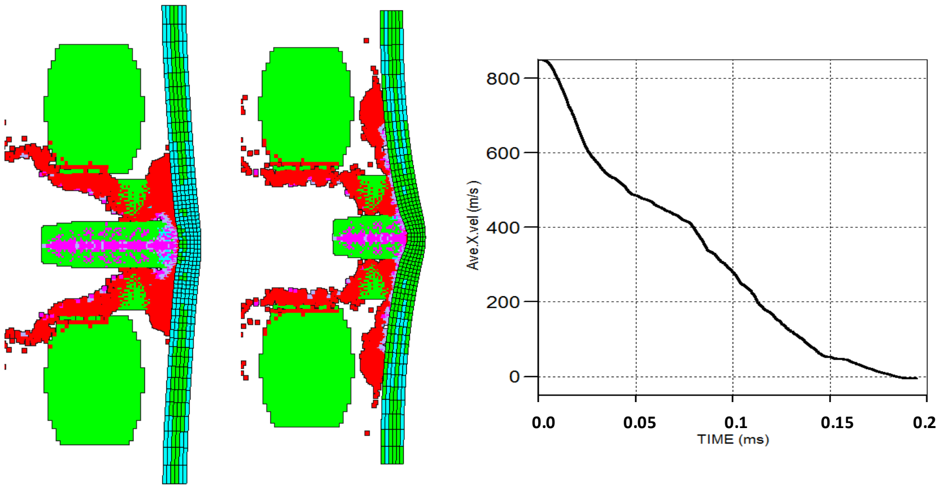
3. ARMOUR UNIT MADE OF CYLINDRICAL CERAMIC ELEMENTS

An alternate approach to creating an additional ceramic armour is based on the fact that even a small, a few degrees angle between the direction of motion and the axis of rotation of the armour-piercing bullet significantly reduces its penetrating ability and, as a rule, leads to the destruction of the core. This effect is used in discrete armour where the ceramic elements shape is chosen in such a way that makes practically impossible their normal (axial) interaction with the bullet and thus significantly increases the protection efficiency. Comparative ballistic tests indicate a high performance of this protection design in comparison with traditional metal armour. Another significant advantage of discrete armour is the high damage locality, and hence an ability to withstand multiple hits in the armour unit.

There are no publications in open literature on the rational choice of materials, shape, and size of discrete ceramic elements. There are also no studies of the mechanism of their protective action, which is probably due to complexity of the problem, whose numerical analysis requires considering the three-dimensional models of complex geometry and high computational effort.

In addition, the variety of options for interaction between the bullet and ceramic element significantly complicates the search for behaviour patterns of these products and an assessment of their ballistic properties. In this paper, an interaction of the bullet with a layer of ceramic elements of a cylindrical shape with a spherical end part is analysed.

Let us consider the central impact of an element that is most unfavourable for a given design (Figure 3). Under normal interaction, the only effect of the curvature of the element surface is that, by contrast to flat plate (see Figure 1), the elastic tensile stress waves do not lead to formation of the conical and radial cracks in the first microseconds of interaction.



(a) $t = 80$ μs (b) $t = 160$ μs (c)

Fig. 3. Interaction of the bullet B-32 12.7 mm in calibre with the ceramic armour elements of cylindrical shape with spherical ends (central impact) (a, b); the bullet core velocity variation (c).

Small size of the ceramic element stipulates its virtually complete destruction (see Figure 3), but up to this point (≈80 μs) it has already played its role. The ogive part of a bullet is completely destroyed, and the rest is significantly damaged and its speed is reduced to 400 m/s, i.e., more than 75% of the original kinetic energy has been lost. As a consequence, the casing armour is not punched. Instead, the adjacent ceramic elements are damaged due to the "billiard" effect (Figure 4). The localization of the destruction zone of ceramic elements ensures survivability of the armour unit as a whole. As calculations show, for an appropriate choice of design parameters, the armour unit is a sufficient protection against a normal and lateral impact of a 12.7 mm calibre B-32 bullet at a speed of 840 m/s.

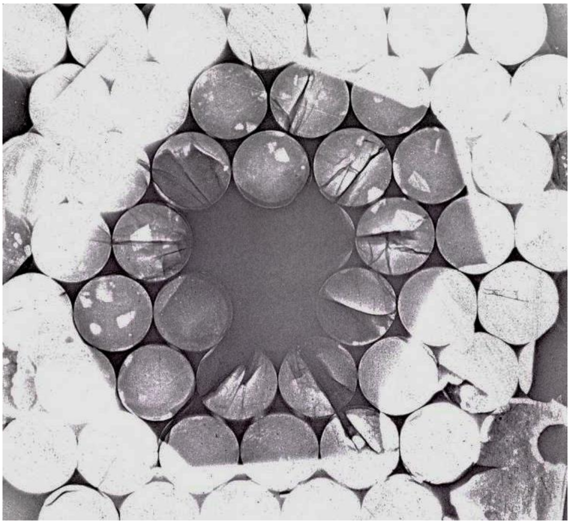


Fig. 4. Localization of the destruction zone in the armoured unit
due to B-32 calibre 12.7 mm bullet hit (X-ray photography)

The abovementioned mechanisms of interaction of a bullet core with discrete ceramic elements are realized in the armour unit of 300x270 mm size design with a hexagonal arrangement of cylindrical elements with spherical ends (Figure 5a) filled with epoxy resin and packed in a fiberglass cloth (Figure 5b). An armour unit as an additional protection is bolted on the 6.5-mm thickness steel casing of the armoured vehicle.

(a) (b)

Fig. 5. General view of the armour unit 300x270 mm with discrete ceramic elements Ø33x27 mm at the assembly stage (a) and the finished armour unit filled with epoxy resin

The advantages of this armour unit design in comparison with the thickening the steel casing or using the mosaic type ceramic armour units are simplicity, manufacturability, and survivability, which consists in withstanding multiple hits in the armour unit without piercing the steel body of a light-armoured vehicle. The results of the series of ballistic tests carried out by the 12.7-mm calibre B-32 bullets (Figure 6) confirm that the design of the armoured unit corresponds to its purpose.

(a) (b)

Fig. 6. General view of the armour unit 270x230 mm with discrete ceramic elements Ø33x27 mm as an additional armour of the vehicle casing (Miilux 500 steel - 6.5 mm) after ballistic tests with B-32 12.7 mm bullets (a) and the bullet imprints on the casing of the armoured vehicle (0.3-2.4 mm) (b)

4. CONCLUSIONS

Modelling the armour-piercing bullets B-32 calibre 12.7 mm penetration into the double-layer ceramic-composite armour has been performed for the armour blocks of two designs. The first structure is a layer of ceramic square tiles supported by the glass or polyamide fabric. Modelling and subsequent ballistic tests have shown that the conical Hertz crack localized in the ceramic tile is formed. The tile is destroyed from the spread of radial cracks, and the entire armour unit becomes unable to sustain the repeated hit of the bullet. In the second case, the armour block consists of the discrete epoxy-filled cylindrical ceramic elements with spherical ends. An advantage of the "discrete" armour is the damage zone localization and thus an ability to sustain the multiple bullet hits.

The ballistic tests of the compared armour blocks have shown that they both provide effective additional protection of light-armoured vehicles against the normal impact of the calibre 12.7 mm bullet. The particular choice of that or another design also has to take into account the survivability, surface density, cost, repairability and manufacturability of the armour blocks.

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