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STRUCTURE AND BALLISTIC PROPERTIES OF ARMOURED PANELS ON THE BASE OF CERAMICS

STRUKTURA I WŁAŚCIWOŚCI BALISTYCZNE CERAMICZNYCH OSŁON PANCERNYCH

Ballistic properties of armoured panels on the base of ceramics were investigated experimentally. The panels comprised the components which were made from alumina in the shape of cylinder and arranged in a specific way. The panels were subjected to fire using different types of small arms. Some correlations between ballistic properties and structural characteristics of armour were revealed and some features of bullet-armour interaction were discussed.

Keywords: Armoured panel, Ceramics, Structure, Ballistic properties

W pracy przedstawiono doświadczalne wyniki badań właściwości balistycznych ceramicznych osłon pancernych. Osłony obejmowały cylindryczne elementy, które wykonane były z ceramiki korundowej i odpowiednio ułożone. Osłony poddawano testom ostrzału z broni małokalibrowej. Ustalono korelacje pomiędzy właściwościami balistycznymi wybranych typów broni a opancerzeniem.

1. Introduction

The use of armoured panels on the base of ceramics is well established [1-3]. These panels make it possible to achieve better ballistic performance from projectiles due to the fact that sintered ceramics, such as alumina, boron carbide and silicon carbide, have virtually zero porosity, as well as the hardness and compression resistance properties needed to break up the projectile. As a rule, ceramic armour assures a protection level ranging from ordinary small calibres up to medium armour piercing calibres or higher and has a weight of 2-3 times less than its steel equivalent.

However the ceramics-based armour has lower multi-hit resistance in comparison with metal-based one that is explained by higher brittleness of ceramics. Usually ceramics is very fragile to shocks, with the result that ceramic components become broken right after the first projectile impact. To increase the multi-hit resistance of the armour as well as to limit the destructive effects of the impact, it is promising to create the armoured panels comprising comparatively small ceramic components that are adhered to each other and affixed to a flexible backing. Typically, the latter is made from fabric layers e.g. made of aramid fibers that form a penetration resistant backing which deforms to absorb the residual kinetic energy of the projectile broken by the ceramic frontal layer.

The aim of given paper is to investigate experimentally the ballistic properties of armoured panels comprising the components of alumina which are widely used as grinding media in size-reduction mills of various types, typically in tumbling mills, and are thus commercially available at a reasonable cost [3, 4].

2. Structure of armoured panels

Armoured panels used in the experiments consisted of three layers: front (external) and back (internal) layers of ceramic components and flexible backing layer (Fig. 1). Typically, panels had a square shape with the side about 100 mm and there thickness was no more than 25 mm.

Ceramic components were made from alumina in the shape of cylinder (Fig. 2, a, Tab. 1) and bound by an epoxy resin matrix. Flexible backing comprised the layers of aramid textile of Twaron-type (Fig. 2, b, Tab. 2) which were compressed and impregnated with epoxy resin. For different panels the quantity of aramid textile layers in the backing was equal to 5 or 15 (correspondingly, the backing was about 1,5 or 5 mm in thickness).

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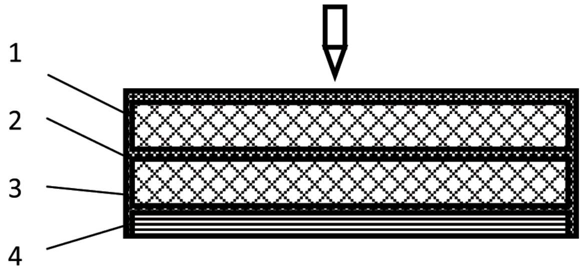


Fig. 1. Armoured panel structure 1, 2 – front and back layers of ceramic components, 3 – matrix, 4 – backing

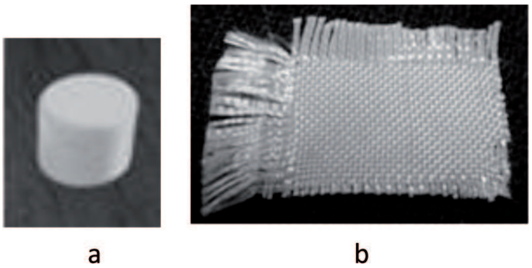


Fig. 2. Ceramic component (a) and aramid textile (b)

TABLE 1

Characteristics of ceramic components

Material type	Height, mm	Diameter, mm
Alumina	13.3	12.3
Density, g/cm^3	Hardness HRA	
3.75	84	

TABLE 2

Characteristics of aramid fibers

Material type	Density, g/cm^3	Tensile strength, MPa	Modulus of elasticity, GPa
Twaron	1.45	3100	100-150

There were some peculiarities in the arrangement of ceramic components (Fig. 3). First, the longitudinal axes of cylinders were parallel to each other as well as to the panel plane. Du to it the closest packing of the components were achieved. As a result, the gaps between the components decreased. Besides, the thickness of the panels decreased, too. Second, the components belonging to different layers were displaced in relation to each other so the components placed in one layer cover the gaps between the components placed in another. Du to it the penetration of bullet through the gaps was limited. Thus, such arrangement of ceramic components provided the higher strength-to-weight ratio of armour. Ceramic components were separated from each other by means of single-layer aramid textile in order to reduce the destructive effect of bullet (Fig. 4). Besides, ceramic components were covered with single-layer aramid textile.

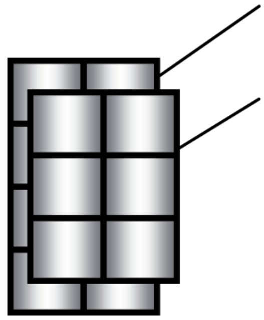


Fig. 3. Scheme of arrangement of ceramic components: 1, 2 – front and back layers

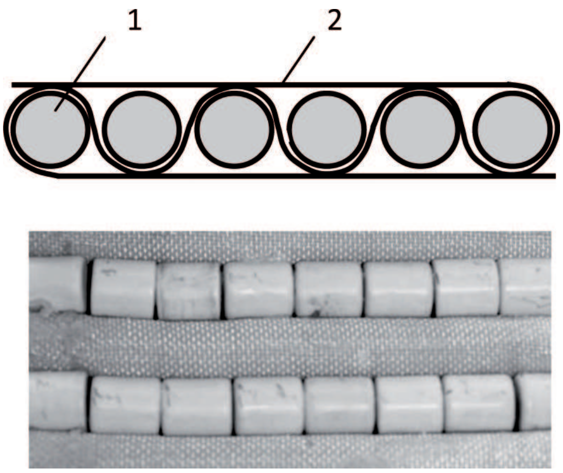


Fig. 4. Scheme of separation of ceramic components (1) by means of a flexible interlayer (2)

3. Ballistic properties of armoured panels

Armoured panels were subjected to fire (single firing, distance 25 m) using two types of small arms: Kalashnikov assault rifle (AK) and Dragunov sniper rifle (SVD) (Tab. 3).

In the case of AK all the panels stood the tests: AK-bullet was arrested at the ceramic layers or at the backing (Fig. 5).

In the case of SVD, as a rule, the panels were pierced when the quantity of aramid textile layers in backing was equal to 5. Sometimes SVD-bullet was arrested at the backing however the backing was subjected to extremely high deformation that resulted in significant damaging action. Unlike these situations, the panels stood the test when the quantity of aramid textile layers in backing was equal to 15.

TABLE 3

Characteristics of AK-74 and SVD

Arms type	Characteristics of cartridge	
AK-74	Cartridge index 7H6 Caliber 5.45 mm	
SVD	Cartridge index 57-H-323c Caliber 7.62 mm	
Characteristics of shocked element		
Core type	Mass, g	Muzzle velocity, m/s
Thermo-strengthened steel	3.4	870-890
Steel	9.6	820-835

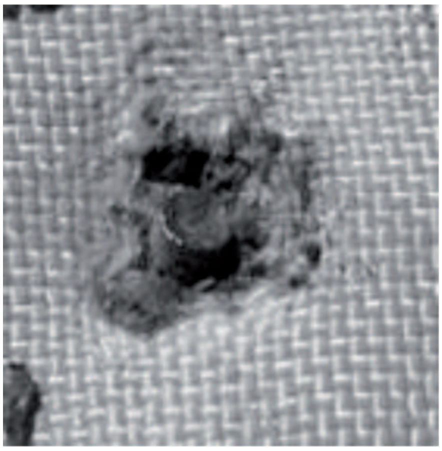
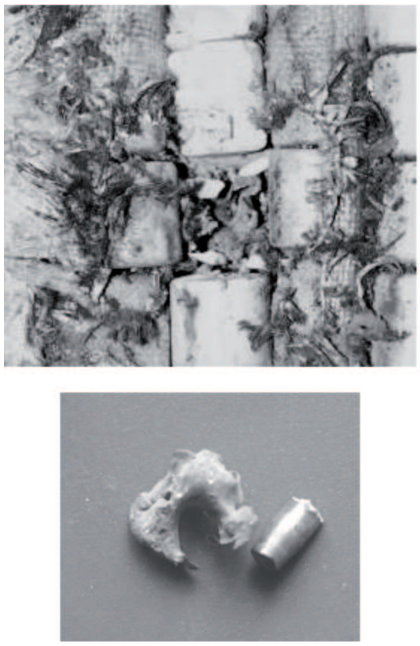


Fig. 5. Front surface of backing with arrested bullet core

The indicated differences in test results are explained by the features of bullet-armour interaction taking place for different kinds of arms. SVD-bullet exerts a higher impact on the panel because of higher kinetic energy in comparison with AK-bullet. At the same time the action of SVD-bullet covers a greater area of the panel because of greater size and deformation of SVD-bullet in comparison with AK-bullet. Thus SVD-bullet causes significant bending stresses of backing. To withstand these stresses it is necessary to strengthen the bending.

It is possible to mark out three main stages of bullet-armour interaction in accordance with three-layer structure of armoured panels.

At the first stage the bullet interacts with front layer of ceramic components. At this stage, the bullet kinetic energy is comparatively high while the impact area is comparatively small. Therefore the bullet influences significantly the ceramic components which are subjected to fragile destruction (Fig. 6, a). A lot of cracks are formed during the impact. As a result, the ceramic components are disintegrated to particles ranging from a fine powder to relatively large chunks. At the same time the bullet during the contact with ceramic components is deformed as well as destroyed (Fig. 6, b). At this stage, the probability for bullet to penetrate through the layer of ceramic components is rather high.



a

b

Fig. 6. Typical destruction of ceramic components (a) and bullet (b) (fragments of bullet core and shell)

At the second stage the bullet interacts with back layer of ceramic components. At this stage, the bullet kinetic energy is smaller while the impact area is larger than at the first one. The kinetic energy is decreased because of energy expenditure related with bullet-front layer interaction. In its turn the impact area is increased because of bullet deformation. Besides, back layer is subjected to the action of both bullet or pieces of bullet and pieces of front layer. Due to it the impact area is increased additionally. All these factors result in the destruction of ceramic components that is less intensive in comparison with the destruction taking place in the case with front layer. As a result, at this stage, the probability for bullet to penetrate through the layer of ceramic components is rather small.

At the third stage the deformed and destroyed bullet together with the debris of ceramic components of both front and back layers bring pressure to bear on backing. The backing resistance level depends on its structural parameters. Aramid textile can withstand significant bending stresses without fracture that is explained by high tensile strength of their fibres.

Taking into account cylindricity and specific arrangement of ceramic components it is possible to mark out three main types of incoming bullet-ceramic component contacts: center, flank and valley (Fig. 7).

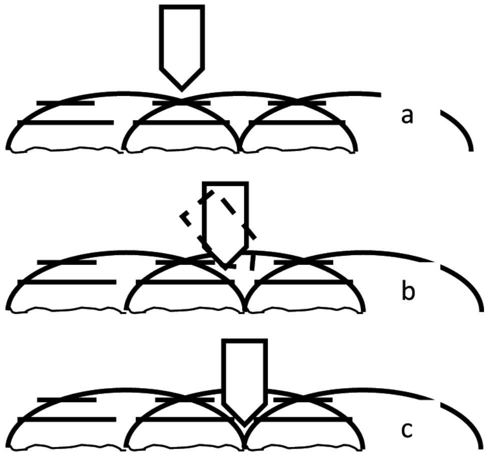


Fig. 7. Different types of incoming bullet-ceramic component contacts: center (a), flank (b) and valley (c)

In the case of center contact, the impact allows the full volume of the component to participate in stopping the bullet, which cannot penetrate without pulverizing the whole component.

In the case of flank contact, the impact causes bullet yaw, thus making bullet arrest easier, as a larger frontal area is contacted, and not only the sharp nose of the bullet. The bullet is deflected sideways and needs to form for itself a large aperture to penetrate, thus allowing the armor to absorb the bullet energy.

In the case of valley contact, the bullet is jammed, usually between the flanks of two components which participate in bullet arrest. The high side forces applied to the components is resisted by the components adjacent thereto as held by the solid matrix, and penetration is prevented.

4. Conclusion

Armoured panels on the base of ceramic components considered above possess higher strength-to-weight ratio and multi-hit resistance. In its turn, the components used in the panels are characterised by commercial availability at a reasonable cost. So these panels are rather promising for both military and law-enforcement applications. First of all they can be applied as body armors and helmets to protect the personal of defense and police forces against small arms. Besides, they can be effectively used as protection against projectile threats in various vehicles such as military airplanes, helicopters, ships, tanks as well as military or police cars.

There are a number of bullet-armour interaction features caused by armour structure as well as projectile parameters which are specific for different kinds of arms. All these factors can exert significant influence on ballistic performance of armour. Therefore it is important to take into account them in the designing the advanced bullet-proof light-weight armoured panels on the base of ceramics.

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