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MODEL OF HIGH-SPEED SHOCK INTERACTION WITH COMPATIBLE TYPE

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This research aims to the process of interaction of a bullet (fragment) with protective barriers, which are formed by a set of hollow cylinders of a compatible type. Models for determining the depth of penetration of the drummer into an obstacle in the form of a set of hollow cylinders of compatible type are proposed. The results of calculations of the value of the depth of penetration of the bullet into the protective barrier in the form of a set of compatible cylinders. Further research is related to the improvement of the armor protection designs by developing new technical solutions using the latest technologies.

Keywords: model, compatible cylinders, high-speed drummer, bullet, protective obstacle, deformation, hollow cylinder.

Formulation of the problem. In connection with the ongoing hostilities in eastern Ukraine, the issue of developing the protection of servicemen from bullets and shrapnel remains relevant. Modern research on the interaction of bullets and fragments with protective barriers is based on the search for new types of structures and protective materials. The main focus is on the development of protective structures that would increase the level of protection of servicemen, according to NATO standards, using inexpensive available materials with minimal costs for their production and intended use.

Despite some progress in the investigation of collisions of solids, the known results of theoretical and experimental research do not describe a holistic picture of the interaction of the element of damage and interference. Therefore, in the development of protective structures take into account only certain aspects of impact interaction, which are based on the absorption of kinetic energy of the element of damage [1].

The scientific and technical task remains important study of the process of interaction of bullets (fragments) with protective barriers, at the stages of penetration, breaking and their departure, which will develop new models of

protection design for servicemen, which are relevant for the Armed Forces of Ukraine.

Analysis of recent research and publications. The issues of interaction of bullets (fragments) with protective obstacles have long been dealt with and various methods and approaches to calculating the depth of penetration of obstacles have been known. Fundamental results of the study of the phenomenon of impact and determination of the conditions for breaking through obstacles by drummers (bullets, fragments) were obtained in the works of Euler, Jacob de Mar, Noble, J. Reinhart and J. Pearson, Berzin K.A. and others [1].

In modern research, methods and ways to increase the security of personnel of military bases and units, combat vehicles and fortifications are given considerable attention [1-7].

In [1] the parameters of the multilayer protective structure of combat vehicles based on nonlinear mathematical models are substantiated. In [2] the method of research of complex systems of military purpose is resulted. In [3-6] the modeling of the dynamics of the reaction of the protective structure to the action of the shock-wave load at the impact of a bullet or a fragment of a projectile is considered. In [7] materials for local and individual armoring are investigated. A study of the use of non-traditional methods of interaction of bullets (fragments) with protective barriers is given in research [8].

The main method of studying the process of impact and punching an obstacle with a bullet (fragment) is a combination of analytical and experimental researches. Analytical research methods are based on mathematical modeling of the stages of interaction of bullets (fragments) with the elements of the protective barrier, followed by appropriate mathematical calculations [1]. Experimental research methods are based on determining the level of protection of protected objects and require complex research in laboratory and landfill conditions. The combination of the results of analytical and experimental research allows us to more fully consider the level of protection of protected objects.

However, studies of the interaction of bullets (fragments) with protective obstacles have not been completed, the processes occurring when hitting bullets (fragments) on the obstacle are not fully studied, and the applied models and methods do not fully take into account the design parameters of protective obstacles.

The purpose of the article is to investigate the process of interaction of a bullets with a protective obstacle in the form of a set of compatible cylinders.

The main material. The use of single cylinders and bonded structures are only two of the possible means of increasing the strength of protective structures [8]. Another possible way to increase the strength of protective structures is a method that consists not of a nozzle of structures in the hot state with tension, but by the formation between the component structures (cylinders) of the gap into which the liquid (gas) is injected under pressure. By placing the cylinders in each other and adjusting the pressure of the liquid (gas) in the free zones between the cylinders, it can be achieved that at the

same thickness in the cylinder walls, the pressure in the inner cylinder can be greater than in a single cylinder [9].

For a single cylinder, the ultimate pressure in it can reach half the strength limit of the material. For bonded and compatible cylinders, the maximum pressure is twice as high as for a single cylinder. For compatible cylinders, the limit pressure can be increased by another 25%. If autofretted cylinders are used for compatible cylinders, the limiting pressure in the inner cylinder can be four times higher than for a single cylinder [9].

The prop that occurs in compatible cylinders and in bonded cylinders is not the same thing. The prop in the bonded cylinders, brought to a certain limit, then remains constant for the entire period of operation of the bonded cylinders. Prop in compatible cylinders can be variable.

Consider a structure consisting of two cylinders – the outer (2) and inner

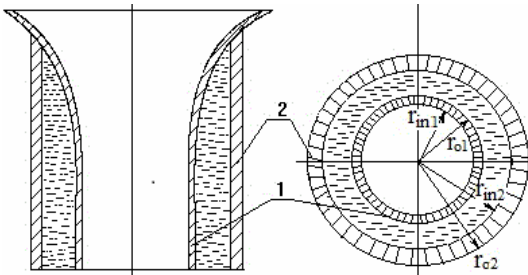


Fig. 1. Scheme of a compatible cylinder

(1), with the outer diameter of the inner cylinder, in contrast to the bonded cylinders, is smaller than the inner diameter of the outer cylinder. Fluid is injected under pressure into the gap between the outer and inner cylinders (Fig. 1).

Using the known formula for calculating normal stresses in the tangential direction [9,10]:

$$\sigma_{\theta} = \frac{p_{in} \cdot r_{in}^2 - p_{ex} \cdot r_o^2}{r_o^2 - r_{in}^2} + \frac{(p_{in} - p_{ex}) \cdot r_o^2 \cdot r_{in}^2}{r^2 \cdot (r_o^2 - r_{in}^2)}, \quad (1)$$

where p_{in} – is the internal pressure in the cylinder, Pa; p_{ex} – is external pressure on the cylinder, Pa; r_{in} – is the internal radius of the cylinder, m; r_o – is the external radius of the cylinder, m; r – is the current radius of the cylinder, m.

For compatible cylinders, the following expressions can be written [9]:

when $r = r_{in}$

$$\sigma_{\theta} = p_{in} \cdot \frac{1 + k_r^2 \cdot (1 - k_p)}{k_r^2 - 1}, \quad (2)$$

when $r = r_o$

$$\sigma_{\theta} = p_{in} \cdot \frac{2 - k_p^2 \cdot (1 + k_r^2)}{k_r^2 - 1}, \quad (3)$$

where

$$k_r = \frac{r_o}{r_{in}}, k_p = \frac{p_{ex}}{p_{in}}. \quad (4)$$

Pressure in the radial direction [9]:

on the inner surface

$$\sigma_r = p_{in} \cdot \frac{2 \cdot k_r^2 \cdot (1 - k_p)}{k_r^2 - 1}, \quad (5)$$

on the outer surface

$$\sigma_r = p_{in} \cdot \frac{2 \cdot (1 - k_p)}{k_r^2 - 1}. \quad (6)$$

Equating the values of stresses to the allowable stress for the cylinder material $[\sigma]$, to determine the expression σ_θ when $r = r_{in}$ we obtain the formula for determining the maximum allowable internal pressure [9]:

$$p_i = [\sigma] \cdot \frac{k_r^2 - 1}{2 \cdot k_r^2 \cdot (1 - k_p)}. \quad (7)$$

If the protective structure consists of two cylinders (outer and one inner), then for the outer cylinder:

$$k_{p2} = \frac{p_{ex2}}{p_{in2}} = 0, \quad (8)$$

the maximum allowable pressure will be:

$$p_{in2} = [\sigma] \cdot \frac{k_{r2}^2 - 1}{2 \cdot k_{r2}^2}. \quad (9)$$

For any intermediate cylinder (if the protective structure consists of several cylinders: external and several (i) internal), the maximum allowable internal pressure can be written as:

$$p_{ini} = [\sigma_i] \cdot \frac{k_{ri}^2 - 1}{2 \cdot k_{ri}^2 (1 - k_{pi})}. \quad (10)$$

Maximum allowable internal pressure in the inner cylinder with n cylinders [9]:

$$p_{in} = [\sigma] \cdot \frac{k_{rn}^2 - 1}{2 \cdot k_{rn}^2} + \sum_2^{n-1} [\sigma_i] \cdot \frac{k_{ri}^2 - 1}{2 \cdot k_{ri}^2} + [\sigma] \cdot \frac{k_{r1}^2 - 1}{2 \cdot k_{r1}^2}. \quad (11)$$

For a compatible design consisting of two cylinders, the value of the internal pressure in the outer cylinder is determined by the equation:

$$p_{i2} = [\sigma] \cdot \frac{k_{r2}^2 - 1}{2 \cdot k_{r2}^2}. \quad (12)$$

The value of the internal pressure in the inner cylinder is determined by the equation:

$$p_{i1} = [\sigma] \cdot \frac{k_{r1}^2 - 1}{2 \cdot k_{r1}^2} + [\sigma] \cdot \frac{k_{r2}^2 - 1}{2 \cdot k_{r2}^2}. \quad (13)$$

The contact pressure that occurs when passing a bullet in the middle of a cylinder of smaller diameter (than the diameter of the bullet) is determined by the expression [10]:

$$p_c = \frac{\delta \cdot E}{4 \cdot r_b^3} \cdot \frac{r_b^2 \cdot (r_{co}^2 - r_b^2)}{r_{co}^2},$$

where p_c – the contact pressure between the bullet and the cylinder, Pa; r_{co} – outer radius of the cylinder, m; r_b – radius of the bullet, m; δ – tension between the bullet and the cylinder, m; E – is the modulus of elasticity of the cylinder material, Pa.

To determine the parameters of the process of interaction of the ball with a protective barrier in the form of compatible cylinders, we equate $p_i = p_c$.

Algorithm for solving the problem. Determine the depth of penetration of the bullet from the AK-74 into the protective barrier in the form of compatible cylinders. Output data: $r_{bullet}=0,00273$ m; $r_{ic1}=0,0025$ m; $r_{oc1}=0,0035$ m; $r_{ic2}=0,0036$ m; $r_{oc2}=0,0057$ m; $f = 0,9$; $E = 2,1 \cdot 10^5$ МПа; $l = 0,012$ m; $[\sigma] = 3 \cdot 10^3$ МПа (Fig. 2).

The force under which the bullet will move along the inner surface of the cylinder, determine the formula based on the equation given in [8,10]:

$$P = f_1 \cdot p_c \cdot \pi \cdot D \cdot k \cdot l, \quad (14)$$

where f_1 – effective coefficient of friction between the bullet and the inner surface of the cylinder, $f_1 = 2 \cdot m \cdot f$ [11]; m – the number of pairs of contact surfaces of the bullet with the inner surface of the cylinder; p_c – contact pressure, Pa; D – bullet caliber, m; l – length of the bullet, m; k – the proportion of the bullet that entered in the cylinder, $0 \leq k \leq 1$.

The depth of penetration of the bullet into the cylinder h is determined by the formula:

$$h = \frac{E_\Sigma}{P}, \quad (15)$$

where P – the force under which the bullet moves along the inner surface of the cylinder,

H ; E_Σ – kinetic energy of a bullet, J ($E_\Sigma = 2019 J$).

Define value $k_r = \frac{r_{ex}}{r_{in}}$ for outer 2 and inner 1 cylinders:

$$k_{r2} = \frac{r_{o2}}{r_{i2}} = \frac{0,0057}{0,0036} = 1,58; \quad k_{r1} = \frac{r_{o1}}{r_{i1}} = \frac{0,0035}{0,0025} = 1,4.$$

The value of the internal pressure in the outer cylinder is determined by the formula (12):

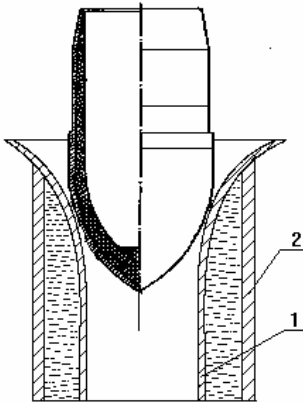


Fig. 2. The scheme of movement of a bullet along the compatible cylinder

$$p_{i2} = 3 \cdot 10^9 \cdot \frac{(1,58^2 - 1)}{2 \cdot 1,58^2} = 0,9 \cdot 10^9 \text{ Pa.}$$

The value of the internal pressure in the inner cylinder is determined by the formula (13):

$$p_{i1} = 3 \cdot 10^9 \cdot \frac{(1,4^2 - 1)}{2 \cdot 1,4^2} + 3 \cdot 10^9 \cdot \frac{(1,58^2 - 1)}{2 \cdot 1,58^2} = 1,65 \cdot 10^9 \text{ Pa.}$$

We equate the value of the internal pressure in the inner cylinder and the value of the contact pressure that occurs when the bullet passes in the middle of the inner cylinder:

$$p_{i1} = p_c,$$

and determine the magnitude of the force under which the bullet will move along the inner surface of the cylinder (14):

$$P = f_1 \cdot p_c \cdot \pi \cdot D \cdot k \cdot l = 0,9 \cdot 1,65 \cdot 10^9 \cdot 3,14 \cdot 0,00545 \cdot 0,012 = 305108 \text{ H.}$$

The depth of penetration of the bullet into the cylinder h is determined by the formula:

$$h = \frac{2019}{305108} = 0,0066 \text{ m.}$$

Thus, the obtained value of the depth of penetration of the bullet into the compatible cylinder is less than the depth of penetration of the bullet into the bonded cylinder, which is given in research [8].

Conclusions

1. The process of interaction of a bullet with a protective obstacle in the form of a set of hollow cylinders of compatible type is investigated.
2. A model for determining the depth of penetration of a high-velocity bullet into a hollow cylinder of a compatible type is proposed.
3. Calculations performed of the depth of penetration of the bullet from a Kalashnikov rifle (AK-74) into steel hollow cylinders of compatible type.
4. Further improvement of armor protection structures can be achieved by developing new technical solutions using the latest technologies.

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МОДЕЛЬ ВЗАЄМОДІЇ ВИСОКОШВИДКІСНОГО УДАРНИКА З ЗАХИСНОЮ ПЕРЕШКОДОЮ СУМІСНОГО ТИПУ

В даній роботі розглянуто процес взаємодії кулі (осколку) з захисними перешкодами, які утворені набором порожнистих циліндрів сумісного типу. Запропоновані моделі визначення глибини проникнення ударника в перешкоду у вигляді набору порожнистих циліндрів сумісного типу. Наведені результати розрахунків величини глибини проникнення кулі в захисну перешкоду у вигляді набору сумісних циліндрів. Подальші дослідження пов'язані з вдосконаленням конструкцій бронезахисту шляхом розробки нових технічних рішень з використанням новітніх технологій.

Ключові слова: модель, високошвидкісний ударник, куля, захисна перешкода, деформація, порожнистий циліндр.

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MODEL OF HIGH-SPEED SHOCK INTERACTION WITH COMPATIBLE TYPE

In connection with military operations, the issue of developing protection for military personnel against bullets and splinters remains an issue. Modern studies of the interaction of bullets and fragments with protective obstacles are based on the search for new types of structures and materials of protection. The focus is on the development of NATO-compliant protective structures to increase the level of protection for military personnel using low-cost, affordable materials with minimal production and intended use.

Despite some advances in the study of solid-body impact, the known results of theoretical and experimental studies do not describe the overall picture of the interaction of the element of damage and interference. When designing protective structures, only certain aspects of the shock interaction are considered, based on the absorption of the kinetic energy of the element of damage. Therefore, it remains important for the scientific and technical task - to continue the study of the process of interaction of bullets (fragments) with protective obstacles, at the stages of penetration, penetration and their departure, which will allow to develop new models of protection structure of military personnel that are relevant for military use.

The main method of studying the process of striking and punching an obstacle with a bullet (fragment) is a combination of analytical and experimental studies. Analytical methods of research are based on mathematical modeling of stages of interaction of bullets (fragments) with elements of a protective obstacle with the subsequent carrying out of corresponding mathematical calculations. Experimental research methods are based on determining the level of security and require complex research in laboratory and polygonal conditions. The combination of analytical and experimental research results makes it possible to consider the level of security more fully.

In this work the process of interaction of a ball (fragment) with the protective obstacles formed by a set of hollow cylinders of compatible type is considered. Models for determining the depth of penetration of the impactor into the obstacle in the form of a set of hollow cylinders of compatible type are proposed. The results of calculations of the depth of penetration of the ball from Kalashnikov (AK-74) in steel hollow cylinders of compatible type are presented. Further research is concerned with improving the design of armor by developing new technical solutions using the latest technologies.

Keywords: model, high-speed impactor, ball, protective obstacle, deformation, hollow cylinder.

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В даній роботі розглянуто процес взаємодії кулі (осколку) з захисними перешкодами, які утворені набором порожнистих циліндрів сумісного типу. Запропоновані моделі визначення глибини проникнення ударника в перешкоду у вигляді набору порожнистих циліндрів сумісного типу. Наведені результати розрахунків величини глибини проникнення кулі в захисну перешкоду у вигляді набору сумісних циліндрів. Подальші дослідження пов'язані з вдосконаленням конструкцій бронезахисту шляхом розробки нових технічних рішень з використанням новітніх технологій.

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Fig. 2. Ref. 11.

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В данной работе рассмотрен процесс взаимодействия пули (осколка) с защитными препятствиями, которые образованы набором пустотелых цилиндров совместного типа. Предложены модели определения глубины проникновения ударника в препятствие в виде набора пустотелых цилиндров совместного типа. Приведены результаты расчетов величины глубины проникновения пули в защитную преграду в виде набора совместимых цилиндров. Дальнейшие исследования связаны с совершенствованием конструкций бронезащиты путем разработки новых технических решений с использованием новейших технологий.

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