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MATHEMATICAL MODEL OF THE IMPACT OF 12.7 MM KINETIC ACTION AMMUNITION ON AN ARMORED OBSTACLE WITH ADDITIONAL ARMOR

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Abstract. In today's conditions, there is a need to find new and effective ways (means) to protect armored vehicles and increase their protection against modern means of destruction, as evidenced by the analysis of the damage received by armored vehicles during the repulsion of armed aggression against Ukraine.

Various methods and means of additional protection always require practical verification of their feasibility.

The purpose of this article is to present the main approaches to assessing the level of stability of an armored obstacle with additional armor and to build a mathematical model of the impact of 12.7 mm kinetic munitions on an armored obstacle with additional armor based on experimental data.

To assess the relative properties of the armor barrier to the destructive energy of the munitions, the experimental-statistical method of mathematical modeling of the process of influence of the energy of the munitions on the armor barrier of armored vehicles was used, in which the experiment is considered as the main source of information about the process, and the methods of probability theory and mathematical statistics are the main means of processing the results of the experiment.

The experimental study allowed to check the resistance of the armored barrier with additional armor to ammunition of 12.7 mm caliber, which destroys it under the action of kinetic energy.

As a result of a multifactorial experiment, experimental data were obtained. Using the experimental data, a mathematical model of the impact of 12.7 mm kinetic ammunition on an armored obstacle with additional armor was built, which takes into account the angle of the meeting of the munition with the armored obstacle, the distance from the armored obstacle to the additional armor, the thickness of the additional armor. This mathematical model can be used to find the optimal additional armor of armored vehicles, taking into account the angle of inclination, the distance of additional armor to the main armor and the thickness of additional armor.

Key words: armored vehicles, armored obstacle, experimental study, means of destruction, mathematical model, optimization.

1. Introduction. Experience in the use of armored vehicles confirms the practical dilemma, according to which the means of destruction of kinetic action and the low level of protection of armored vehicles seriously affect the content of operational decisions made regarding their use. Along with the use of explosive objects, one of the most effective ways to destroy armored vehicles is the use of kinetic ammunition. Under such conditions, there is a need to ensure a sufficient level of protection of armored vehicles from the corresponding means of destruction. Among the indicators of the effectiveness of the destruction system is the indicator of the share of kinetic action ammunition in the overall fire system. The relevance of the raised problematic issue is confirmed by the experience of using armored vehicles both in military and civilian affairs [1-4].

2. Problem Formulation. Today there are a large number of armored vehicles used for transportation of securities, precious material assets, used by the state defense forces, etc. These armored vehicles have different classes of protection according to the declared technical characteristics of the manufacturers and require verification of the declared levels of resistance to kinetic munitions.

The low protection of armored vehicles from kinetic means of destruction is evidenced by a large number of armored vehicles that have lost their performance or have been irretrievably destroyed by small arms [1-4]. These cases, unfortunately, continue to occur at the present time.

Increased protection of armored vehicles is possible only due to advanced armor manufacturing technologies. The characteristics of armor were improved by optimizing the design parameters of the relevant mechanical systems and the development of new composite materials. Successes in improving dynamic armor made it possible to create an effective system of protection against almost all modern means of destruction. The creation of new and improvement of existing systems of armored vehicles survivability technology remains relevant. This requires new approaches in mathematical modeling of the processes of strengthening and processing of materials of the armored surface of modern armored vehicles [5].

Accordingly, to ensure the protection of armored vehicles from destruction means, various methods and means of protection have been proposed recently, the appropriateness of which needs to be confirmed by experimental studies [6-7].

3. Analysis of recent research and publications. A number of works are devoted to the study of the impact of destruction means on armored obstacles and increasing their level of protection, in particular, in the study [8], a methodology for determining the characteristics of armored vehicles survivability is proposed, which makes it possible to determine the indicators of durability and reproducibility, thereby determining the survivability of an individual armored vehicle or a group of vehicles of the same purpose. The analysis of the use of protective devices made from improvised materials was carried out in the study [9]. Based on this analysis, a variant of classification of such devices is proposed and attention is focused on the need to study the experience of their use. An in-depth study of this problem is reflected in the study [10], in which an experimental study was conducted to assess the relative properties of the protective screen to the damaging energy of the munitions, which allowed to test the hypothesis put forward regarding the use of several layers of materials in protective screens to protect armored vehicles from munitions that destroy the armored barrier under the action of kinetic energy. Based on the experimental data obtained, a mathematical model was built that describes the pulse of penetration of the proposed armored barrier. Paper [11] investigated the impact of high-explosive destruction means on the basic wheeled platforms. On the basis of experimental data obtained during the laboratory study, a mathematical model of the impact of high-explosive munitions on the basic wheeled platforms was built. Certain aspects of this issue are presented in the study [12], which is devoted to the analysis of trends in the development of armored vehicles, namely, ways to increase their protection against munitions. The directions of development and the main design features of armored vehicles to provide protection against weapons of destruction are considered. In the study [13], a comparison of the calculated criteria for the armor resistance of various protective materials against bullets (armor steel, armor ceramics) with the resulting steel-aluminum bimetal as a material for two-layer armor was carried out. With the help of mathematical modeling of the processes of fragmentation of armor obstacle fragments in the study [14], an approach to assessing the results of damage to armored vehicle equipment is proposed and the probability of damage (penetration) of the unit by fragments, as well as the average number of fragments that can hit the corresponding unit, is given. In the literature [15], a numerical model of the process of piercing protective ceramic elements with different designs for the protection of armored vehicles is determined. But in this work, it is not determined how the means of destruction loses energy characteristics when piercing an armored obstacle. In the study [16], analytical studies of various methods for determining the ballistic resistance of individual armor plates were carried out. The problem of limited data as a result of ballistic resistance assessment at the level of "satisfactory - unsatisfactory" is shown. In the study [17], different approaches to the study of metal, ceramic and composite armor materials are described, and dynamic armor protection systems that are necessary to increase the survivability of armored vehicles are considered. Reference [18] proposes a methodology for justifying the level of protection of armored vehicles, based on determining the number of hits to the sample during its firing from several means of destruction. This methodology determines the average number of hits to the elements of the sample to justify technical solutions to improve its protection. In the study [19], the problem statement of the experimental study of the ammunition component and the test program for small arms is considered, and in the study [20], a quantitative assessment of the relevant model parameters is carried out to assess the effectiveness of armored vehicles protection. The study of aluminum alloy plates is devoted to work [21], in which a bullet with a diameter of 12.65 mm was fired at aluminum alloy plates 2024-T351 with a thickness of 9.94 mm from a single-stage gas gun in the range of impact velocities of 133.4 m/s~363.8 m/s.

4. Setting objectives. Therefore, the purpose of this article is to present the main approaches to assessing the level of stability of an armored barrier with additional armor and to build a mathematical model of the impact of 12.7 mm kinetic means of destruction on an armored barrier with additional armor based on experimental data.

5. Presenting main material. To calculate the model, during the experimental studies on the protection of armored vehicles against kinetic means of destruction, namely a 12.7 mm bullet, empirical data on the behavior of many elements critical to the impact of destruction means on the elements of the sample (system) were obtained.

In the study of such a system on the basis of a deterministic approach, when the mechanism of all phenomena is investigated, the process theory is used, on the basis of which the system is given by a strictly deterministic model, usually in the form of differential equations. [10].

In order to calculate the model, it is necessary to accumulate statistical data on the value of the response being studied in the selected area during the experiment. This can be done most effectively with the help of an active experiment [22-24]. From the experiment it is possible to build a mathematical model in order to unambiguously determine the values of indicators (input factors, impacts) and (output indicators, response).

This model will be polynomial, which describes well enough the response function of the local plane of the factor space and is convenient for use, due to the universality and comparative simplicity of methods of its construction on the basis of statistical data [25].

Thus, the study is based on the experimental-statistical method of mathematical modeling of the process of influence of the kinetic energy of destruction means on the armored obstacle and the body of armored vehicles, in which the experiment is considered as the main source of information about the process, and the methods of probability theory and mathematical statistics - the main means of processing the results of the experiment.

It should be noted that experimental studies include a fairly large set of interdependent sequential operations that can be divided into several stages [26-27]. It should also be noted that the experimental study of the stability of the armor barrier was conducted on the ballistic track of the research and testing laboratory of weapons and special protective materials. At the same time, a ballistic pendulum was used and the conditions of the experimental study were observed, which are defined in [10].

The following factors are taken as variables in the study: γ – is the angle of impact of the munition with the armor obstacle, deg.; h – thickness of armor barrier, mm, l – distance from the additional armor barrier to the main armor of the armored vehicle, mm.

As optimization parameters, the distance of deviation of the pendulum from its axis during the penetration of the armored obstacle by the weapon is taken. The main levels and intervals of variation of factors are selected on the basis of a priori information and are given in Table 1.

The prototypes in accordance with the specified conditions under which the study was conducted are shown in Fig. 1.

Table 1

Levels and intervals of variation of factors

Factors	Coded value	Intervals of variation	Levels of factors		
			Lower –1	Main 0	Upper +1
γ – the angle of impact of the munition with the armor obstacle, deg	x_1	10	10	20	30
h – thickness of armor barrier, mm	x_2	5	5	10	15
l – is the distance from the additional armor barrier to the main armor of the ACV, mm	x_3	50	50	100	150

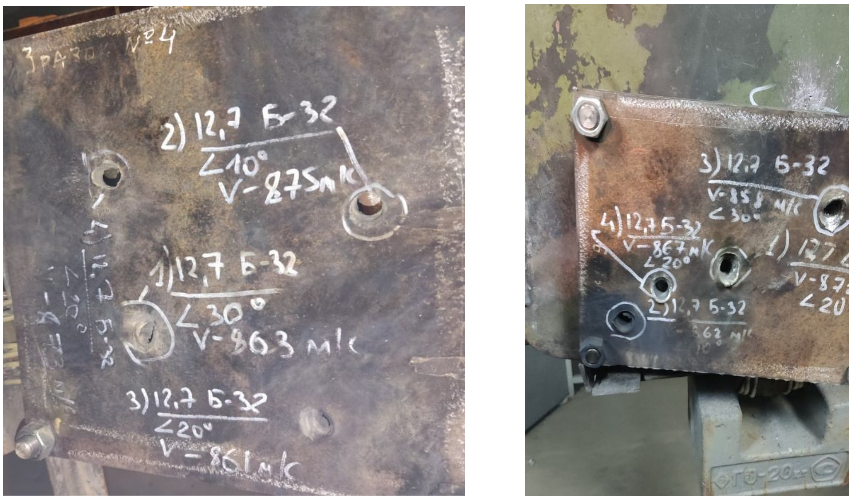

Fig. 1. Samples on which the study was conducted

To obtain a process model in the form of a second-degree polynomial, a non-compositional plan of the second order is implemented, which is presented in Table 2.

Як As follows from the table, the selected planning matrix satisfies the general properties of planning matrices, which allows to quickly calculate the objective function:

symmetry about the zero level, that is, the algebraic sum of the column elements of each factor is equal to zero;

the sum of squares of column elements of each factor is equal to the number of trials (normalization property);

the product of any two different vector-columns of factors is equal to zero;

the variances of the predicted values of the optimization parameter are the same at equal distances from the zero level (the property of rotation of the planning matrix) [30].

Table 2

Matrix of experiment planning

Experiment number	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	y_a
1	+	+	+	0	+	0	0	+	+	0	110
2	+	+	–	0	–	0	0	+	+	0	103
3	+	–	+	0	–	0	0	+	+	0	152
4	+	–	–	0	+	0	0	+	+	0	79
5	+	0	0	0	0	0	0	0	0	0	78
6	+	+	0	+	0	+	0	+	0	+	124
7	+	+	0	–	0	–	0	+	0	+	98
8	+	–	0	+	0	–	0	+	0	+	79
9	+	–	0	–	0	+	0	+	0	+	64
10	+	0	0	0	0	0	0	0	0	0	118
11	+	0	+	+	0	0	+	0	+	+	70
12	+	0	+	–	0	0	–	0	+	+	115
13	+	0	–	+	0	0	–	0	+	+	129
14	+	0	–	–	0	0	+	0	+	+	83
15	+	0	0	0	0	0	0	0	0	0	116

According to the results of the experiments set according to the considered plan, the regression equation is written in the form:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 +$$
$$+b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 . \quad (1)$$

The coefficients of equation (1) can be determined using the method of least squares, which is one of the basic methods of regression analysis for estimating unknown parameters of regression models from sample data.

The coefficients of the equation are: b_0=104; b_1=7,625; b_2=6,625; b_3=5,25; b_{12}=-16,5; b_{13}=2,75; b_{23}=-22,75; b_{11}=-0,5; b_{22}=7,5; b_{33}=-12,25.

The variance s_y^2 of the optimization parameter is found by the results of experiments in the center of the plan (Table 2 experiments 5, 10, 15). To calculate the variance, we compile auxiliary Table 3.

Table 3

Auxiliary table for calculating variance s_y^2

Experiment number in the center of the plan	y	$\bar{y}$	$y-\bar{y}$	$(y-\bar{y})^2$
5	78	104	-26	676,00
10	118		14	196
15	116		12	144

$$S_E = (y_5 - \bar{y}_{5,10,15})^2 + (y_{10} - \bar{y}_{5,10,15})^2 + (y_{15} - \bar{y}_{5,10,15})^2 = 1016,$$

$$s^2\{y_z\} = \frac{S_E}{3-1} = 508.$$

The variance of the coefficients of the regression equation will be:

$$s^2\{b_0\} = \frac{1}{3}s_y^2 = 55{,}9551,$$

$$s^2\{b_i\} = \frac{1}{8}s_y^2 = 34{,}26536,$$

$$s^2\{b_{il}\} = \frac{1}{4}s_y^2 = 48{,}45854,$$

$$s^2\{b_{ii}\} = \frac{13}{48}s_y^2 = 50{,}43725.$$

According to the regression equation, we recalculate all coefficients using the least squares method. To do this, we make a system of normal equations:

$$15b_0 + 0b_1 + 0b_2 + 0b_3 + 0b_{12} + 0b_{13} + 0b_{23} + 8b_{11} + 8b_{22} + 8b_{33} = 1518,$$
$$0b_0 + 8b_1 + 0b_2 + 0b_3 + 0b_{12} + 0b_{13} + 0b_{23} + 0b_{11} + 0b_{22} + 0b_{33} = 61,$$
$$0b_0 + 0b_1 + 8b_2 + 0b_3 + 0b_{12} + 0b_{13} + 0b_{23} + 0b_{11} + 0b_{22} + 0b_{33} = 53,$$
$$0b_0 + 0b_1 + 0b_2 + 8b_3 + 0b_{12} + 0b_{13} + 0b_{23} + 0b_{11} + 0b_{22} + 0b_{33} = 42,$$
$$0b_0 + 0b_1 + 0b_2 + 0b_3 + 4b_{12} + 0b_{13} + 0b_{23} + 0b_{11} + 0b_{22} + 0b_{33} = -66,$$
$$0b_0 + 0b_1 + 0b_2 + 0b_3 + 0b_{12} + 4b_{13} + 0b_{23} + 0b_{11} + 0b_{22} + 0b_{33} = 11,$$
$$0b_0 + 0b_1 + 0b_2 + 0b_3 + 0b_{12} + 0b_{13} + 4b_{23} + 0b_{11} + 0b_{22} + 0b_{33} = -91,$$
$$8b_0 + 0b_1 + 0b_2 + 0b_3 + 0b_{12} + 0b_{13} + 0b_{23} + 8b_{11} + 4b_{22} + 4b_{33} = 809,$$
$$8b_0 + 0b_1 + 0b_2 + 0b_3 + 0b_{12} + 0b_{13} + 0b_{23} + 4b_{11} + 8b_{22} + 4b_{33} = 841,$$
$$8b_0 + 0b_1 + 0b_2 + 0b_3 + 0b_{12} + 0b_{13} + 0b_{23} + 4b_{11} + 4b_{22} + 8b_{33} = 762.$$

After calculating this system of equations, we obtain the following coefficients: $b_0 = 108{,}6154$; $b_1 = 7{,}625$; $b_2 = 6{,}625$; $b_3 = 5{,}25$; $b_{12} = -16{,}5$; $b_{13} = 2{,}75$; $b_{23} = -22{,}75$; $b_{11} = -1{,}07692$; $b_{22} = 7{,}5$; $b_{33} = -12{,}8269$.

The regression equation obtained as a result of planning is written in the form:

$$y = 108{,}6154 + 7{,}625x_1 + 6{,}625x_2 + 5{,}25x_3 - 16{,}5x_1x_2 +$$
$$+2{,}75x_1x_3 - 22{,}75x_2x_3 - 1{,}0769x_1^2 + 7{,}5x_2^2 - 12{,}826x_3^2. \qquad (2)$$

The adequacy of the obtained model is checked by Fisher's criterion F.

To determine the variance s_{ad}^2 of adequacy, we calculate the sum of s_R squares of deviations of the calculated values of the response y_a function from the experimental ones $\hat{y}_a$ at all points of the plan (Table 4). The calculated value is y_a determined according to expression (2).

$$s_R = \sum(\hat{y}_a - y_a)^2 = 5856{,}24.$$

We find the dispersion of adequacy:

$$s_{a\partial}^2 = \frac{s_R - s_E}{N - k' - (n_0 - 1)} = 1613{,}41272 ,$$

where k' – is the number of statistically significant coefficients of the model; N – is the total number of experiments; n_0 – is the total number of experiments in the center of the plan; S_R – is the sum of squares of deviations of the calculated y_a values of the response function from the experimental ones at all points of the plan; S_E – sum of squares of deviations of the calculated $\widehat{y}_{zj}$ values of the response function from the experimental ones $\widehat{y}_a$ in the center of the plan.

Table 4

Auxiliary table for calculating the sum of squares of deviations of calculated values s_R

Experiment number	$\widehat{y}_a$	y_a	$\widehat{y}_a - y_a$	$(\widehat{y}_a - y_a)^2$
1	110	108,1731	1,826923	3,337647929
2	103	127,9231	-24,9231	621,1597633
3	152	125,9231	26,07692	680,0059172
4	79	79,67308	-0,67308	0,453032544
5	78	104	-26	676
6	124	105,7212	18,27885	334,1162167
7	98	89,72115	8,278846	68,53929364
8	79	84,97115	-5,97115	35,65467825
9	64	79,97115	-15,9712	255,0777552
10	118	104	14	196
11	70	110,2981	-40,2981	1623,935004
12	115	100,2981	14,70192	216,1465422
13	129	97,54808	31,45192	989,2234652
14	83	86,54808	-3,54808	12,58884985
15	116	104	12	144

We find the calculated value of the Fisher criterion F :

$$F_p = \frac{s_{a\partial}^2}{s^2\{y_z\}} = 3{,}1760093 < F_T = 19{,}3,$$

where $s_{a\partial}^2$ – variance of adequacy; s_{y}^2 – variance of the optimization parameter.

Thus, the mathematical model in which s_{y}^2 is taken as – $s^2\{y_z\} = 1613{,}41272$, the value of Fisher's criterion F_p= 3,1760093. The tabular value of Fisher's criterion F_T at 5% level of significance, in particular the degrees of freedom for the numerator 9 and for the denominator 2 is 19.39.

Therefore, the obtained mathematical model (2) is adequate at 5% level of significance, since $F_p < F_T$.

Thus, using the mathematical model (2) it is possible to construct contour response curves, y_a, which are shown in Figs. 2, 3, 4.

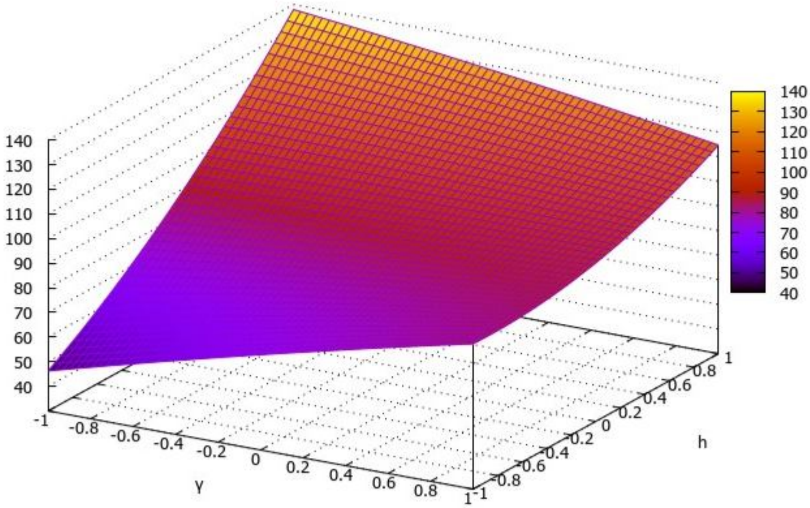

Fig. 2. Characteristics of the impact of the kinetic energy of destruction means on the penetration of the main armor with additional armor depending on the angle of inclination and thickness of additional armor at a fixed distance of additional armor to the main armor at the level of -1

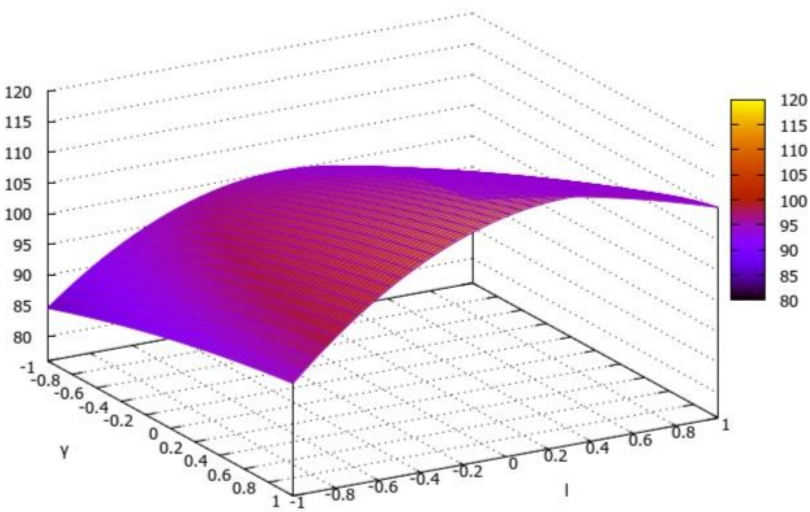

Fig. 3 Characteristics of the impact of kinetic energy of destruction means on the penetration of the main armor with additional armor depending on the angle of inclination and distance of additional armor to the main armor at a fixed thickness of additional armor at the level of 0

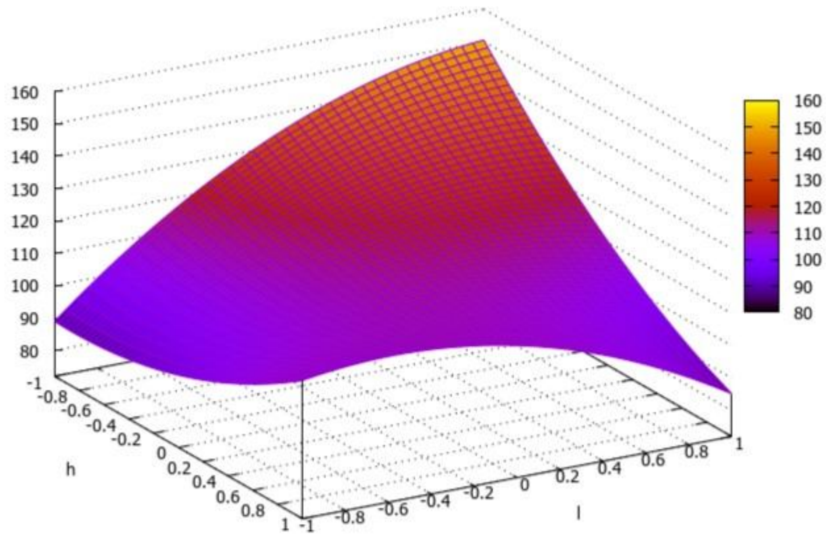

Fig. 4. Characteristics of the impact of the kinetic energy of destruction means on the penetration of the main armor with additional armor depending on the thickness of the additional armor and the distance of the additional armor to the main armor at a fixed angle of inclination at the level of 1.

Conclusions. Thus, the obtained mathematical model based on statistical data on the impact of 12.7 mm munitions on the armor barrier with additional armor makes it possible to determine the optimal thickness of additional armor and the distance of additional armor to the main armor, depending on the angle of inclination of the armored vehicle hull elements. It should also be noted that the use of an additional armor barrier to increase the survivability of armored vehicles is a more rational way to protect them, as an increase in the thickness of the main armor will increase the weight of the armored vehicle, which in turn will lead to loss of buoyancy and reduce other technical characteristics of armored vehicles.

In the future, it is necessary to conduct an experimental study of the effect of the kinetic energy of a 14.5 mm bullet on an armored obstacle with additional armor to obtain statistical data on the basis of which to build a mathematical model to assess the level of protection.

REFERENCES

1. Analysis of hostilities in the area of Ilovaisk after the invasion of Russian troops on August 24-29, 2014. URL: http://www.mil.gov.ua/news/2015/10/19/analiz-illovausk--14354/.
2. Analysis of hostilities in eastern Ukraine during the winter campaign of 2014-2015. URL: http://www.mil.gov.ua/news/2015/12 /23/analiz-bojovih-dij-na-shodi-ukraini-v-hodi-zimovoi-kampanii-2014–2015-rokiv--16785/.
3. Analysis of the General Staff of the Armed Forces of Ukraine on the fighting at the Debaltseve bridgehead from January 27 to February 18, 2015. URL: http://www.mil.gov.ua/analitichni-materiali/analiz-generalnogo-shtabu-zsu-shhodo-bojovih-dij-na-debalczevskomu-placzdarmi-z-27-sichnya-do-18-lyutogo-2015-roku.html.

4. Analysis of the ATO and the consequences of the Russian invasion of Ukraine in August-September 2014. URL: https://www.slideshare.net/tsnua/2014-51587585
5. *Voitovych M., Lishchynska H., Senyk A.* Ways to improve the mechanical characteristics of materials of armored surfaces of combat vehicles. Application of the Land Forces of the Armed Forces of Ukraine in the conflicts of our time: collection of abstracts of the scientific and practical conference of the Ivan Sahaidachnyi Army. -.Lviv, 2019. – C. 21. – ISBN 978-966-2699-86-9.
6. *Gorbacheva Y.S.* Study of the protection of modern armored combat vehicles from kinetic means of destruction. Problematic issues of repair of the latest models of weapons and military equipment: materials of scientific and practical seminar (Kyiv, November 18, 2021). Kyiv, 2021. C. 17-18.
7. *Dachkovskyi V.O., Ovcharenko I.V.* Analysis of the development of armored combat vehicles. Modern information technologies in the field of security and defense. 2016. № 2(26) C. 127 - 132. URL: http://nbuv.gov.ua/UJRN/sitsbo_2016_2_24.
8. *Dachkovskyi V.O.* Method of determination of survival characteristics of weapons and military equipment. Social development & Security. 2020. №10(1), C. 18 – 24. DOI: https://doi.org/10.33445/sds.2020.10.1.3
9. *Brel M.P.* Analysis of Application of Non-Standard Protective Devices for Armoured Fighting Vehicles. Collection of scientific articles of the Military Academy of the Republic of Belarus. 2018. № 34. C. 127-134.
10. *Dachkovskyi V., Datsenko I., Kotsiuruba V., Yalnytskyi O., Holda O., Nedilko O., Syrotenko A.* Experimental investigation of impact of injury measures on the protection screens of combat armoured vehicles. Strength of Materials and Theory of Structures. 2020, No. 104, p. 117-135.
11. *Kurtseitov T.L., Dachkovsky V.O., Kizyak Y.O., Ugrynovych O.I.* Experimental study of the resistance of basic wheeled platforms to the impact of explosive objects. Natural, Mathematical and Technical science NaMaTech. 2018, Held in Budapest on 16th of December 2018. DOI:https://doi.org/10.31174/SEND-NT2018-186VI22-15.
12. *Lysyi M., Mysyk A., Dachkovskyi V., Gorbachova Y.* Directions of development of weapons and military equipment to increase the level of security: Collection of scientific works of the National Academy of the State Border Guard Service of Ukraine Series: Military and Technical Sciences. 2019. № 3 (87). C. 411-428. DOI: https://doi.org/10.32453/3.V81i3.483.
13. *Zagoryansky V.G.* Substantiation of applicability of bimetal steel-aluminum on the calculated criteria of anti-bullet armor resistance. Bulletin of NTUU "KPI".Series: mechanical engineering. Kremenchuk.№ 3 (75). 2015. C. 37-41.
14. *Horbachova Y, Dachkovskyi V.* Modeling of the behind armor action of fragments of armor obstacle on elements of combat armored vehicles. Political Science and Security Studies Journal. 2021. № 2(1). P. 26-32. DOI: https://doi.org/10.5281/zenodo.4646156.
15. *Maystrenko A.L., Kushch V.I., Kulych V.H., Neshpor O.V, Bisyk S.P.* Increasing the protection of combat armored vehicles against the defeat of 12.7-mm B-32 bullets. Weapons and military equipment. 2017, No 1(13), p. 18-23. (in Ukraine). DOI:https://doi.org/10.34169/2414-0651.2017.1(13).18-23
16. *Perchun G.I., Samofalova A.O., Kononenko G.A.* Methods for determination of ballistic performance of armor plates. Fundamental and applied problems of ferrous metallurgy: Collection of scientific papers Dnipropetrovsk,. 2015. Vol. 30. c. 337-342. URL: http://dspace.nbuv.gov.ua/handle/123456789/143971
17. *Madhu V. and Balakrishna Bhat T.* Armour Protection and Affordable Protection for Futuristic Combat Vehicles. Defence Science Journal, Vol. 61, No. 4, July 2011, p. 394-402
18. *Golub V.A.* Methodology of substantiation of the level of protection of combat wheeled vehicles. Weapons systems and military equipment. Kyiv, 2013. № 3 (35). C.9-12.
19. *Antipko O.B., Biryukov I.Y., Syschuk S.I., Shcheptsov A.V.* Setting the task of experimental research of composite ammunition and test program for small arms. System of armament and military equipment. 2016. № 1 (45). C.10-13.
20. *Chunxu Li, Zhanjun Niu, Baozhan Qin, Zhenggen Yu, Xuesong Tang, Xiaobing Lu*. Combat Performance Evaluation and the Analysis Combat Requirements of Amphibious Armored Vehicles. Proceedings of the 5th International Conference on Information Engineering for Mechanics and Materials. 2015. pp. 455-458. https://doi.org/10.2991/icimm-15.2015.86.

21. *Xiao Xinke, Hao Pan, Yuanli Bai, Lou Yanshan, Chen Lina*. Application of the modified Mohr–Coulomb fracture criterion in predicting the ballistic resistance of 2024-T351 aluminum alloy plates impacted by blunt projectiles. International Journal of Impact Engineering. Vol. 123, 2019, p. 26-37. https://doi.org/10.1016/j.ijimpeng.2018.09.015
22. *Barabashchuk V.I., Kredencer B.P., Miroshnichenko V.I.* Planning experiments in engineering. K.: Technique, 1984. 200 c.
23. *Lavrenchik V.N.* Setting up a physical experiment and statistical processing of its results. Moscow: Energoatomizdat, 1986. 272 c.
24. *Spirin N.A., Lavrov V.V.* Methods of planning and processing the results of engineering experiment. Ekaterinburg: GOU VPO UGTU-UPI, 2004. - 257 c. - ISBN 5-321-00319-X.
25. *Spiridonov, A.A.* Experiment planning in the study of technological processes. Moscow: Mashinostroenie, 1981. 184 c.
26. *Mukhachev V.A.* Planning and Processing of Experimental Results: Textbook. Tomsk: Tomsk State University of Control Systems and Radio Electronics. 2007. 116 c.
27. *Johnson N., Lyon F.* Statistics and experimental planning in engineering and science: Experimental planning methods. (English translation, eds. Letsky E.K., Markova E.V.). Moscow: Mir, 1981. 520 c.

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МАТЕМАТИЧНА МОДЕЛЬ ВПЛИВУ БОЄПРИПАСІВ КІНЕТИЧНОЇ ДІЇ 12,7 ММ НА БРОНЬОВУ ПЕРЕШКОДУ З ДОДАТКОВИМ БРОНЮВАННЯМ

В умовах сьогодення випливає необхідність пошуку нових та ефективних способів (засобів) захисту броньованих автомобілів та підвищення їх захищеності від сучасних засобів ураження, про що свідчить аналіз отриманих пошкоджень броньованими автомобілями під час відбиття збройної агресії проти України.

Різноманітні способи та засоби додаткового захисту завжди потребують практичної перевірки на доцільність їх застосування.

Метою даної статті є викладення основних підходів до оцінювання рівня стійкості броньової перешкоди з додатковим бронюванням та побудова на основі експериментальних даних математичної моделі впливу кінетичних засобів ураження 12,7 мм на броньову перешкоду з додатковим бронюванням.

Для оцінювання відносних властивостей броньової перешкоди до уражаючої енергії засобів ураження використано експериментально-статистичний метод математичного моделювання процесу впливу енергії засобів ураження на броньову перешкоду броньованих автомобілів, при якому експеримент розглядається як основне джерело інформації про процес, а методи теорії ймовірності та математичної статистики – основним засобом обробки результатів експерименту.

Проведене експериментальне дослідження дозволило перевірити стійкість броньової перешкоди з додатковим бронюванням до боєприпасів калібру 12,7 мм, які руйнують її під дією кінетичної енергії.

В результаті багатофакторного експерименту було отримано експериментальні дані. Використовуючи експериментальні дані було побудовано математична модель впливу боєприпасів кінетичної дії калібру 12,7 мм на броньову перешкоду з додатковим бронюванням, яка враховує кут зустрічі засобу ураження із броньовою перешкодою, відстань від броньової перешкоди до додаткового бронювання, товщину додаткового бронювання. Дана математична модель може бути використана для знаходження оптимального додаткового бронювання броньованих автомобілів із врахування кута нахилу, відстані додаткового бронювання до основної броні та товщини додаткового бронювання.

Ключові слова: броньовані автомобілі, броньова перешкода, експериментальне дослідження, засоби ураження, математична модель, оптимізація.

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Fig. 4. Ref. 27

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