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Armoured military equipment innovations

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Abstract. The war in Ukraine and global military conflicts prove that the used military equipment is mostly armoured. The Land Forces, which are primarily composed of mechanised, motorised infantry, and tank units, equipped with armoured equipment (vehicles), take a significant part in hostilities. The armoured vehicle's employment is a key part of military operations, ensures protection and troops' safety, and contributes to the task accomplishment related to overcoming enemy resistance. There is a continuing and fast global process development of designing the new and improving the existing shell types and ammunition, aimed at targeting the armed vehicle, which, in turn, results in the search of increasing directions for the existing armoured vehicle armour protection. Thus, the aim of this research is to review and evaluate the latest technical solutions in the military equipment armour protection field with a purpose to systematise them and provide recommendations on their implementation.

The main research methods are the methods of analysis and syntheses, deduction and induction, and also the expert evaluation methods.

The results of the analysis conducted by the article's author show that world's countries constantly work on improving existing models and creating new ones to increase the military vehicle protection. An overview of the latest armour protection field developments proves that one of the main advantages of creating innovative armour elements is their weight characteristics improvement. Modernised materials and constructions provide the maximum protection level with minimal weight, thus it allows to cut the armoured combat vehicles weight and to save fuel use. Created innovative armour elements have improved ergonomics, which increases their comfort in use by the personnel and allows to reduce fatigue and the stressful pressure on the personnel, and, as a result, positively impacts their fighting spirit and life safety.

Suggested innovative armour elements can be used in combat vehicles armouring which guarantees a higher protection level against bullets, shells, and mines, including enemy anti-tank measures. The leading goal of the military equipment armouring innovations is increasing its safety, which results in advantages in combat actions, personnel's lifesaving, and the equipment's term of use extension. The implementation of such technologies prevents the equipment destruction incidents in case of the projectile explosion, damage by fragments and bullets.

The article offers to get familiar with the new innovative solutions by foreign companies and homeland enterprises regarding military equipment armour protection.

The article materials can be useful for developers and manufacturers of armament systems and samples, as well as for scientists and researchers in the field of national security and the state defence sphere development.

Keywords: armour protection, armour, armoured vehicle, innovative materials for armouring, Land Forces.

Introduction

Today's challenges and the current war in Ukraine assign military equipment developers with new tasks. The prioritised direction is the creation of the armament systems that are capable of ensuring successful combat task accomplishment by the Armed Forces of Ukraine due to the qualitative superiority with a possibility to impose favourable forms and methods of military confrontation on the enemy during combat actions. The war in Ukraine and global armed conflicts prove that military equipment, which participates in these conflicts, is armoured most of the time. A significant part in hostilities is taken by the Land Forces which are based on the motorised infantry and tank brigades, armed with armoured vehicles. Armoured vehicle is used for combat operations during hostilities. Tanks and armoured personnel carriers can be used for the breakthrough of the enemy's lines, destroying enemy positions and equipment, and also for the troops' protection and movement on the battlefield. Armoured vehicles are also used for transporting cargo and troop movements, in addition, armoured personnel carriers are used for transporting the wounded and providing emergency medical assistance on the battlefield. Reliable protection against bullets, shell fragments, mines, and anti-tank weapons is essential for both the vehicle and its crew. The innovative armour elements' development is an exceptionally important task since they can significantly improve the personnel's and military equipment safety and effectiveness when performing combat missions.

Materials and Methods

The issue of the military equipment armour protection has been researched in the scientific works of a range of domestic and foreign authors, and in particular: in [3], a comprehensive research of technical solutions to increase the automotive equipment survivability in the Armed Forces of

Ukraine was carried out; the authors of [4] carried out a research of the construction features and technical characteristics (TTC) of MRAP-type armoured combat vehicles; [9] provided a justification for the perspective armoured combat vehicles types formation principles; [10] conducted an analysis of the current state and development trends of wheeled armoured combat vehicles; [12] carried out an analysis and provided recommendations for improving the recovery system functioning of the armoured armament and military equipment based on the graphical network model research. A team of authors from the Chinese school of materials science and engineering and the National Key Scientific and Technological Laboratory of China (National Key Laboratory of Science and Technology on Communications) conducted a research of multilayer armour protection products [14], which are based on metal silicon carbide cover plates purposed for withstanding the impact of a large-calibre tungsten projectile; in the work [17] the theoretical foundations of material and technical support for troops are discussed; mathematical models of the stress-strain state of armoured vehicle elements have been developed and researched by the authors [18]; in the work [6], an analysis of the additional armour protection which is applied to light armoured vehicles of the Armed Forces of Ukraine and foreign states has been conducted.

The article aims to review and assess the latest technical solutions in the military vehicles armour protection field, with the goal of systematising them and providing recommendations for their implementation.

The current development dynamics of the personnel and military equipment destructive means have been encouraging developers to create new more resistant to fire-affected materials that can ensure the personnel's survival in hostile confrontation, which has led to the emergence of numerous new technological solutions from traditional steel plates to active protection systems.

As it is known, the use of metal armour remains the simplest measure of guaranteeing the personnel's and combat vehicle design elements protection. The history of increasing the material protection level points at the two main ways of achieving this: increasing the thickness of the used armour plates or altering the chemical composition of the alloys and their construction. Thus, various technologies have been used for the steel strengthening, such as cementation, nitriding, boronizing, and others. Over time, the protection increase method of combining the aforementioned techniques has been added. New materials, such as ceramics and Kevlar, have become widely used, and protective products combining different types of materials have been created. A detailed assessment of existing solutions for innovative materials used in military vehicle armour protection has allowed to systematise this information according to the types and characteristics (Table 1).

Scientists from the world's leading countries remain in continuous search of the existing materials improvement ways that would meet the needs for reliable personnel and equipment protection, having an optimal price and weight characteristics. In fact, at every defence exhibition, new technological achievements in this field are demonstrated. Thus, at an exhibition in Istanbul, the Turkish company Menatek Defense Technologies, which has been engaged with the equipment armouring issue for nearly 25 years, has presented a new multi-layered armour purposed for increasing the personnel and military equipment protection level. Such a result has been achieved by implementing a new lamination technology that leads to the development of a more elastic polymer and a semi-rigid plate, which exceeds the requirements by 25% [2]. The innovative product created based on it, a fibrous armour material specifically, ensures the shock waves dispersion within a three-dimensional polymer matrix. The new polymer increases fibre stretching, which occurs through a cumulative effect, which allows to absorb all dangerous fragments efficiently. The test results have proven that the armour plates are capable of withstanding a multiply bullet impact of various calibres, at different angles and velocities.

The armour improvement works go on, the manufacturing company has moved on to working on the creation of the new armour with higher protection requirements. For example, a new fabric manufacturing technology has been developed, which resembles a honeycomb by its structure, the

set of elements that are few centimetres in size, made from a combination of materials that reduce the penetrating power of the munition before it hits the base armour like of the military vehicle. The structure of this fabric consists of a front armour made according to the "honeycomb" principles, a support panel, an empty space, and the base armour of the vehicle.

Table 1. Type and characteristics of materials used for armour protection.

Type	Characteristics
Bulletproof glass	A float glass and polyvinyl butyral (PVB) interlayer film sandwich composite – multilayer float glass laminated with PVB interlayer film
	A laminated glass and organically transparent sheet sandwich composite – multilayer glass consisting of a transparent organic plate layer and a laminated glass layer, bonded together with a polyurethane film
Bulletproof steel plate	Armoured hot-rolled steel made of the Cr2Ni2Mo alloy, which alters the armour plate hardness by regulating the carbon content
Bulletproof ceramics	Alumina ceramic panel bonded with aluminium or fiberglass. Ceramic armoured materials B4C, SiC, Si3N4
Bulletproof high-strength fiberglass	High performance glass fibre composite material S-2
Bulletproof aramid fibre	Artificial fibre made from the polymer polyparaphenylene terephthalamide/polyparazenylamide. It is known for its strength, wear and chemical resistance, and also high temperature resistance
Bulletproof polyethylene fibre	Ultra-high molecular weight polyethylene fibre composite material with excellent comprehensive properties, characterised by high strength, low elongation, and which is lighter than water

Source: Developed by the authors, considering: The Methodology for calculating integral regional indices of economic development. Order of the State Statistics Committee of Ukraine No. 114 (2003); the Methodology for calculating the economic security level of Ukraine. Order of the Ministry of Economy of Ukraine No. 60 (2007); the Methodology for integral assessment of the economic security level of Ukraine. National Institute for Strategic Studies (2013); Methodological recommendations for calculating the economic security level of Ukraine. Order No. 1277 (2003).

The developed innovative fabric has greater ballistic effectiveness compared to regular solutions, its typical modularity allows to change them easily after attack, as the energy impact of 100 kJ (typical for threats under STANAG 4569) can easily destroy the plates' integrity and render them inoperable. The new armoured plates construction, based on the element construction like that, allows to absorb the sufficient amount of attacking energy, the rest of the energy potentially can be absorbed by the armoured vehicle's body without physical destruction. According to preliminary estimates by the Menatek's manufacturing company, the proposed technology is capable to stop a 25 mm tungsten bullet.

The original innovative product was developed by the German company Havel Metal Foam. A unique technology for the industrial production of composite multi-layered armour, which was named Havel Lite®SAS, was developed by the company's specialists in collaboration with the Fraunhofer Institute for Machine Tools and Forming Technology IWU (Berlin). This is a special combination where the outer layers are made of steel and the inner fillers are made of the special aluminium foam.

Such a structure allows to absorb the energy from external explosions and provide protection for the personnel, while other composite materials can be used instead of steel with varying thickness and their combination specifics. The key armour element is special aluminium foam, which is formed at high temperatures through blowing of a small piece of material up to the required size. Additionally, the manufacturing technology allows to combine aluminium and steel without the need for additional bonding agents.

The foam-based armour's key advantages are a 25-30% reduction in the armour plate weight, increased mechanical strength and a higher degree of protection against blast effects. As it should be highlighted, the protection against grenade, mine and shell fragments is increased. However, in combination with high-strength steel or ceramic-aramid fibres, aluminium foam can be used for ballistic protection. The potential application sphere for aluminium foam is strengthening the command posts, barracks, bunkers, and hangars, military container, as well as providing mine protection for military equipment and armoured vehicles.

The manufacturing company conducted a series of armour plate strength tests using a detonation of an HG85 grenade (155 g of explosive substance). As a result, the plate deformed to a depth of 23 mm, with all fragments contained by the internal filler, no ruptures were found on the plate’s reverse side. Similar results were obtained during tests with the DM51 hand grenade (59 g of explosive substance), where the entire panel deformed to a depth of 15 mm, and again, there were no damages on the reverse side. According to the company, the aluminium foam complies with fire safety standards (DIN EN 45545-2) and fire resistance standards (E30 – DIN EN 13501-2, DIN EN 1363-1). The claimed aluminium foam is 100% recyclable and vibration dampening. It can also be further processed by sawing, milling, and welding.

In Sweden, within the vehicle armour protection system, a soft (Swedish) armour has been developed (Saab Barracuda Soft Armor System). The soft armour configuration is a sheet steel container containing spherical-shaped ceramic pellets, any hard material can be used as for the pellets. As a result of the shockwave dispersing throughout the container, the pellets’ array is capable to absorb the energy from the striking element, such a construction can be made up of several interconnected containers and can take any shape. However, heavy weight and dimensions can be marked as the disadvantages of this system.

In modern combat conditions, one of the effective armoured vehicles' destruction means is armour-piercing bullets with 7.62 to 14.5 mm calibres. Ensuring protection for armoured vehicles against armour-piercing bullets requires a significant increase in armour thickness, with a weight reduction purpose, various design solutions are used, one of which is the perforated and spaced armour application.

Domestic developers and engineers are working on solving this problem. Scientists from the National Science Centre of "Kharkiv Institute of Physics and Technology" and the National Academy of the National Guard of Ukraine, together with designers from the State Enterprise "Kharkiv Morozov Machine Building Design Bureau" (SE "KhKBM"), have developed perforated armour protection elements samples, which are installed on the armoured vehicles’ body. In terms of additional protection, bimetallic perforated sheets are used, which are installed at a specified distance from the vehicle's body.

In 2018, a new ceramic-polymer composite armour was introduced, which was invented by the Ukrainian company State Enterprise "Specialized Foreign Trade Firm PROGRESS" and which is already being supplied for the Armed Forces of Ukraine’s needs and is being exported abroad. The armour protection system, based on ceramic armour panels, is modular, therefore, when needed, both full and partial combat vehicle armour protection application is possible, without making changes to its design.

The armour panels have a macro-layered layout and consist of a discrete ceramic layer, placed within a high-strength polymer matrix, and a textile-polymer retention layer. Additionally, the armour

panels are equipped with ultra-high molecular weight polyethylene lining, such an armour type is easy to replace in the field, meaning the armoured vehicle's crew can replace damaged armour panels in short terms with new ones by themselves. The armour panels developers are sure that this suggested innovative product can provide reliable protection for light armoured vehicles against high-energy dynamic loads.

The IBD Deisenroth Engineering company has developed transparent ceramic armour that can be compared in characteristics with opaque samples. The weight of this advanced ceramic armour is 70% lighter compared to bulletproof glass and has the ability to withstand multiple bullet penetrations to a single target. This development is a by-product of the IBD NANOTech armoured ceramics series creation. During the development process, the company created technologies that allow to bond large-area mosaics made from small armour elements (the Mosaic Transparent Armour technology), as well as laminating the bonding with strengthening linings made from the company's proprietary Natural NANO-Fibre nanofibers, this approach provides an opportunity to produce strong transparent armour panels that are significantly lighter than traditional ones, especially the tempered glass ones.

The Ceradyne Inc Company has developed a new type of armour protection called "liquid armour". This product allows to protect any body's part and can take the body's shape without losing its protective properties. The increased protection effect is achieved thanks to special Kevlar pack filled with a solution of ultra-hard nanoparticles suspended in a non-evaporating liquid. When high-energy mechanical pressure is applied to the Kevlar shell, the nanoparticles cluster together, altering the liquid solution structure, which then transforms into a solid composite. This phase transition occurs in less than a millisecond, which allows to protect the soldier not only from knife stabbing but also from bullets or shrapnel. During the regular exploitation (in the low-energy range), the armour behaves like a regular liquid, which allows it to fill the Kevlar shell of a protective "shirt" or "vest." The protection based on such a liquid was developed by different companies and at different times. The British branch of BAE Systems presented a working prototype: packages filled with a special gel called Shear Thickening Liquid, or bulletproof cream, which offered protection comparable to a 30-layer Kevlar body armour.

Results and Discussions

The register of innovative developments in the armour protection field is presented in Table 2.

The team of authors from the Chinese School of Materials Science and Engineering and the National Key Scientific and Technological Laboratory of China [14] conducted research on multi-layered armour protection products, which are designed on the basis of metal silicon carbide cover plates to withstand impacts from tungsten-core projectiles (Fig. 1).

The presented armour protection scheme consists of four protective layers, namely: a rear steel plate, a cover plate, a silicon carbide armour plate, and an iron restrictor plate.

The armour protection structure includes a multi-layer construction made from various materials, including steel plates (carbon, high-alloy, mild), aluminium alloys, copper alloys, titanium alloys, composite materials such as W, SiC, RHH, Kevlar, UHMPE, carbonate, nylon, and others. The results of the experiment are presented in Table 3.

The experiments were conducted with different target variants, in particular: non-coated and coated targets with different plates made from aluminium alloy, soft steel and copper alloy. Comparative results showed that the ballistic characteristics were different with the coating change in front of the ceramic plate, using aluminium alloys plates, the residual depth did not exceed 1.4 mm. The results of practical multi-layered products tests are presented in Figure 2.

The tests were conducted using different materials, and their results were: a) without an additional plate (coating) – destruction diameter of 30 mm, b) with an aluminium alloy plate – destruction diameter of 17 mm, c) with a mild steel plate – destruction diameter of 25 mm, d) with a copper alloy plate – destruction diameter of 23 mm.

Table 2. Innovative developments in the armour protection field.

Innovative product	Developer	Main characteristics
Multilayer armour based on lamination	Menatek Defense Technologies, Türkiye	Created fibrous armour material that ensures the shock wave dissipation in a three-dimensional polymer matrix
Composite multilayer armour	Havel Metal Foam, Germany	The key element of the armour is a special aluminium foam, which is formed at high temperature by blowing a small piece to the required size
Soft (Swedish) armour	Saab Barracuda Soft Armour System, Sweden	The soft armour configuration is a sheet steel container, with spherical shaped ceramic pellets in it
Perforated armour protection elements	The National scientific centre "Kharkiv Institute of Physics and Technology", Ukraine	As additional protection, bimetallic perforated sheets are used, which are installed on the armour at a specified distance from the main armour body
Ceram-polymer composite armour	State Enterprise "Specialized Foreign Trade Firm PROGRESS", Ukraine	The armour panels have a macro-layer layout and consist of a discrete ceramic layer, which is placed in a high-strength polymer matrix, and a textile-polymer retention layer
Transparent ceramic armour	IBD Deisenroth Engineering, Germany	The weight of the latest ceramic armour is 70% less compared to bulletproof glass and has the ability to withstand multiple bullet penetrations to a single target
Liquid armour	Ceradyne Inc, USA	A created special Kevlar pack filled with a solution of ultra-hard nanoparticles in a non-evaporating liquid. In case of the high-energy mechanical pressure, applied to the Kevlar shell, the nanoparticles cluster together, changing the liquid solution structure, which transforms into a solid composite in less than 1 millisecond

Source: authors' original development.

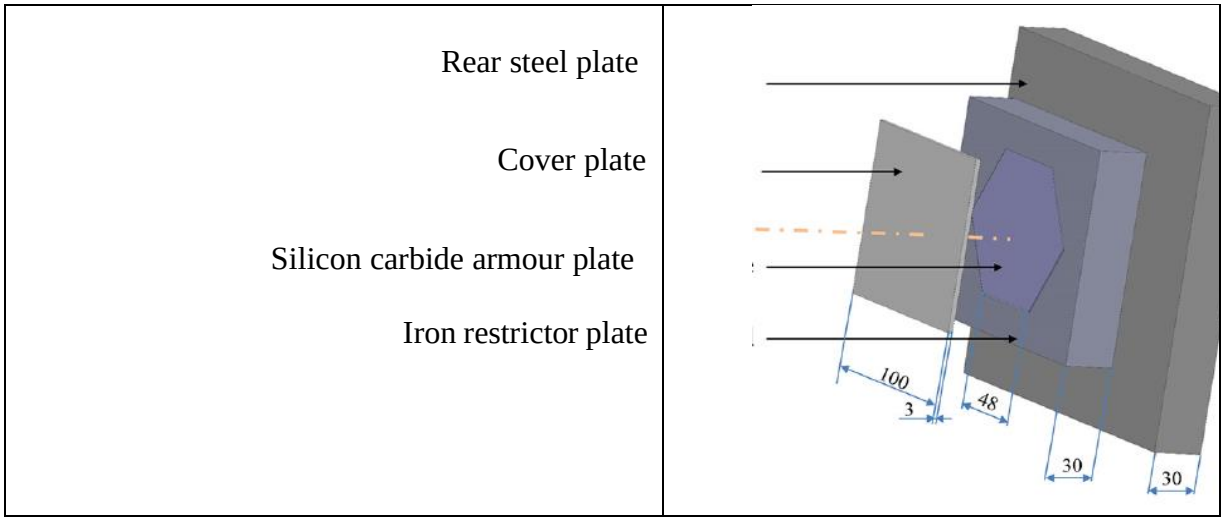


Figure 1. Structural diagram of armour protection for military equipment and personnel

Source: processed by the authors based on [14].

Table 3. The experiment results on firing projectiles at a ceramic target with different covering options.

Materials	Tungsten projectile velocity, m/s	Residual DOP, mm	Average value, mm	Residual mass, g
Non-coated	1234	8	9,3	-
Aluminium alloy	1266	8	1,4	42,6
Mild steel	1261	2	4,8	40,9
Copper alloy	1247	8,32	3,5	38,0

Source: created by the authors, considering the data from [14], [15].

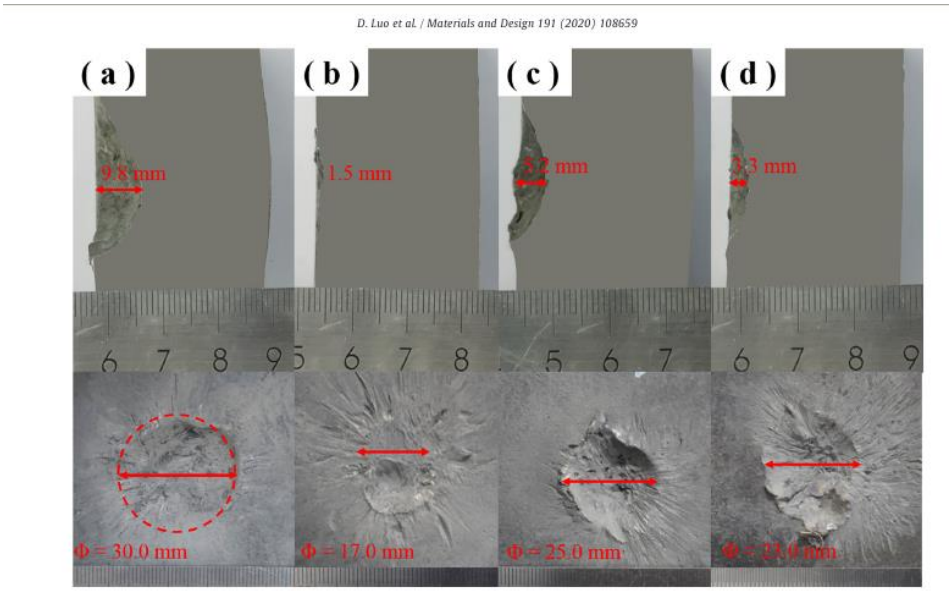


Figure 2. Armour plate test results using additional plates made of different materials

The literature sources analysis regarding the armoured vehicle protection products and systems design allowed to group the main materials that had been used during constructing armoured vehicle protection products according to their properties and characteristics (Table 4).

Table 4. Mechanical properties and technical characteristics for the armour protection products' construction.

Material type	Longitudinal stress modulus E - kgf/cm²	Shear modulus G - kgf/cm²	Poisson ratio μ	Density ρ - g/cm²	Ultimate strength σ / GPa	Brinell hardness HB - kgf/mm²	Specific weight ρ / cm²
1. Carbon steel	$(2,0\text{-}2,1)*10^6$	$8,1*10^5$	0,24-0,28	-	-	-	
2.Alloy steel	$2,1*10^6$	$8,1*10^5$	0,25-0,30				
3.Aluminum alloy	$(0,7\text{-}0,77)*10^6$	$2,7*10^4$	0,32	2,7	235	72	
4.Mild steel	$0,77*10^6$			7,83	420 ГПа	136	
5 Copper alloy	1,15				384 ГПа	120	
6.Titanium VT1-VT5			0,3	4,52-4,40			
7. Nylon	$(1,4\text{-}2,0)*10^4$						
Material W	383	160	0,2	17.8 кг*м^3			
SiC	441	183.8	0,18	316 кг*м^3			
RHH	203	77	0,32	783 кг*м^3			
Carbon SYT495-3	169,49		0,28				1,8
Kevlar 49	90,4		0,36			0,47	1,44
UHMPE SK75, DSM	87,72		0,2	8,56			0,97

Source: authors' original development.

The analysis of the armoured vehicle protection systems development continues all the time, highly depending on the development level of the different armoured vehicle destruction types on the

battlefield, as long as each side strives to destroy the other. During the research, it was found that developers and users of armoured vehicles, except for the primary protection elements, use additional protection components. The additional protection elements include:

Improved Armour: The first tanks were protected from firearms primarily using steel armour. However, over time, this armour was improved to become more resistant to new types of projectiles. The advancements included armour plates with enhanced penetration characteristics, which are better able to withstand the destructive impact of a shot.

Reactive Armour Panels: this technology is used to protect against cumulative projectiles, which explode upon impact, destroying the projectile's cumulative jet and reducing its effectiveness.

Composite Multilayer Armour Panels: modern armour often consists of multiple layers of different materials, such as ceramics, steel, and composite materials. This allows for more effective protection against various types of bullets and projectiles, while also increasing the overall armour's strength.

Active Protection: Modern tanks use active protection systems, which include sensors and reactive systems. These systems detect the approach of anti-tank projectiles and reduce their destructive effect on tank armour by a blast wave.

Infrared Protection Systems: represent a set of electro-optical active protection systems designed to defend against high-precision weapons, which warns the tank crew about the targeting and use of laser sights – rangefinders, enemy anti-tank projectiles and anti-tank guided missiles (ATGMs). This system is designed for the enemy's laser targeting systems work disruption by automatically activating an obscuration and alerting crew members (light and sound indication).

The passive protection development for armoured vehicles is an ongoing process that evolves in line with military technology and emerging threats. Military developers are constantly seeking new ways to improve armour to ensure the maximum protection level for tanks and other armoured vehicles.

Conclusion

The research of the current innovative developments in the armour protection field allows us to conclude that world's countries are continuously working on the existing technologies improvement and on the new models creation to improve the personnel and military equipment protection. A review of the latest developments in armour protection field has been completed, which proves that one of the main advantages of creating innovative armour elements is the increase of their protective (impermeable) characteristics, while also reducing weight through the use of innovative materials and the exploration of new designs. Modernised materials and designs provide the maximum level of protection with minimal weight, which allows to reduce the armoured military vehicles' weight, ultimately leading to fuel savings. Moreover, innovative armour elements have advanced ergonomics, which increases the comfort of their use by the personnel and reduces the personnel's fatigue and stressful pressure, which, in turn, positively affects their fighting spirit and life safety. Thus, innovations in the armour elements creation have significant importance in improving the protection of personnel and military equipment's safety and effectiveness.

The proposed types of innovative armour elements can be used for the military equipment armouring, ensuring a higher level of protection against enemy bullets and projectiles. The primary goal of innovations in military vehicle armour is to enhance safety of such equipment, which leads to advantages in combat actions, the preserving the personnel's lives and extending the vehicles operational lifespan. The implementation of these technologies prevents the potential damage to equipment in case of explosions, destruction by projectiles, shrapnel, and bullets.

Recommendations

The implementation of innovations in the military equipment armouring will contribute to the

irretrievable personnel and equipment combat losses reduction and will contribute to the effectiveness of the combat capabilities of the Armed Forces of Ukraine.

References

1. Andrei (n.d.). Materialy ta tekhnolohii bronezakhystu nadiahaiut bronetransportery dlia viiskovoi tekhniky. [Armor protection materials and technologies worn by military equipment armoured personnel carriers]. *Defense Express*. http://btvt.info/4ourarticles/armor_future/edz.htm.
2. NATO Standardization Agency. (2014). Armament and military equipment protection and support. The procedures of the armoured vehicles protection level assessment. Kinetic and conventional artillery munitions attack threat. *STANAG 4546*, 138.
3. Kovba, R.M., Rii, V.B. (2020). Obgruntuvannia tekhnichnykh rishen shchodo pidvyshchennia zhyvuchosti avtomobilnoi tekhniky zbroinykh syl Ukrainy [Justification of technical solutions for increasing the survivability of the military vehicle equipment of the Armed Forces of Ukraine]. *Systemy upravlinnia, navihatsii ta zviazku. Zbirnyk naukovykh prats*. National University «Yuri Kondratyuk Poltava Polytechnic». https://doi.org/10.26906/SUNZ.2020.1.054.
4. Hrubel, M.H., Kraynyk, L.V., Khomenko, V.P. (2018). Doslidzhennia konstruktyvnykh osoblyvostei ta TTKh boiovykh bronovanykh mashyn typu MRAP [The study of the design features and technical specifications (TTS) of MRAP-type armored fighting vehicles]. *Ukrainian Military Pages*. https://www.ukrmilitary.com/2018/05/mrap.html.
5. Bronia mitsna: evoliutsiia vyrobnytstva bronovoi stali [Hard Armour: The evolution of the armoured steel production]. (2021). Metinvest. https://metinvestholding.com/ua/media/news/bronya-krepka-evolyuciya-proizvodstva-bronevoj-stali.
6. Podryhalo M. A. (2022). Analiz dodatkovoho bronezakhystu lehkobronovanoi tekhniky Zbroinykh Syl Ukrainy ta inozemnykh derzhav [The additional armour analysis of analysis of the light armoured vehicles of the Armed Forces of Ukraine and foreign countries]. *Journal of Mechanical Engineering and Transport, 14*(2). https://doi.org/10.31649/2413-4503-2021-14-2-89-96.
7. Rosiia postachaie na Donbas novitniu zbroiu, shcho probyvaie bud-yaki bronezhylety [Russia supplies Donbas with new weapons that penetrates any bulletproof vests] (n.d.). Ukrinform.
8. Defence IQ (2016, January 25-28). *Global armoured vehicles market report 2016* [Conference report]. International Armoured Vehicles. http://cdn.base.parameter1.com/files/base/acbm/ooh/document/2015/11/Global_Armoured_Vehicles_Market_Report_2016.pdf.
9. Kuprinenko, O. M. (2012). Obgruntuvannia pryntsypiv formuvannia perspektyvnykh typiv boiovykh bronovanykh mashyn [Formation principles justification of the perspective armoured combat vehicles types]. *Systemy Ozbroiennia i Viiskova Tekhnika, 4*(32).
10. Bisyk, S. P., Boiko, H. O. (2014). Deiaki dani suchasnoho stanu y tendentsii rozvytku kolisnykh boiovykh bronovanykh mashyn [Some data about the armoured combat vehicles current state and development trends]. *Ozbroiennia ta Viiskova Tekhnika: Quarterly scientific and technical journal, 3*(3). The Central Research Institute of the Armament and Military Equipment of the Armed Forces of Ukraine.
11. Zeleniah, O. (2020). Obgruntuvannia napriamkiv pidvyshchennia tekhnichnykh kharakterystyk boiovykh bronovanykh mashyn [Justification of the increase directions of armoured combat vehicles characteristics]. *Systemy upravlinnia, navihatsii ta zviazku. Zbirnyk naukovykh prats*. National University «Yuri Kondratyuk Poltava Polytechnic».

12. Kopashynskyi, S. (2020). Obgruntuvannia rekomendatsii shchodo vdoskonalennia funktsionuvannia systemy vidnovlennia bronetankovoho ozbroiennia y viiskovoi tekhniky na osnovi doslidzhennia hrafichnoi merezhevoi modeli. [Justification of the recommendations on the renewal system functional advancement of the armoured and tank armament and military equipment based on the graphical network model research]. *Systemy upravlinnia, navihatsii ta zviazku. Zbirnyk naukovykh prats*. National University «Yuri Kondratyuk Poltava Polytechnic».
13. Anuryyev, V.I. (1980). Spravochnik konstruktora mashinostroityelya [Mechanic Engineer's Handbook]. *Mashinostroeniya*, 728.
14. Luo, D., Wang, Y., Wang, F., Cheng, H., Zhang, B., & Zhu, Y. (2023). The influence of metal cover plates on ballistic performance of silicon carbide subjected to large-scale tungsten projectile. *Materials and Design, 191*. https://www.sciencedirect.com/science/article/pii/S0264127520301933?via%3Dihub.
15. Li, Zh., Xue, Y., Sun, B., & Gu, B. (2023). Ballistic penetration damages of hybrid plain-woven laminates with carbon, Kevlar and UHMWPE fibers in different stacking sequences. *Defence Technology, 26*. https://www.sciencedirect.com/science/article/pii/S2214914722001507?via%3Dihub.
16. Cabinet of Ministers of Ukraine Resolution of Jul 26, 2018, #591 "Pro vnesennia zmin do Poriadku vidnovlennia, remontu, modernizatsii, zbilshennia ustanovlenoho resursu ta prodovzhennia stroku sluzhby (zberihannia) ozbroiennia, viiskovoi i spetsialnoi tekhniky [On Amendments to the Procedure for the Restoration, Repair, Modernization, Increase of the Established Resource, and Extension of the Service Life (Storage) of Armament, Military and Special Equipment]." https://ips.ligazakon.net/document/view/KP180591.
17. Shuienkin, V.O., Zakusylo, P.S., & Khazanovych, O.I. (2010) Teoretychni osnovy materialno-tekhnichnoho zabezpechennia viisk (syl) [The theorethical foundations of the troops'(Forces') material and technical support]. *Learning handbook*. The Central Research Institute of the Armed Forces of Ukraine.
18. Tkachuk, M.A., Khlan, O.V., Hrabovskyi, A.V., Zavorotnii, A.V., Vetelnyk, O.V., Holovin, A.M., & Cherkashyn, A.O. (2018). Matematychni modeli napruzheno-deformovanoho stanu elementiv boiovykh mashyn ta tekhnolohichnykh system dlia yikh vyhotovlennia. [Mathematical models of the stressed-deformed state of elements of combat vehicles and technological systems for their production]. The bulletin of the National Technical University "Kharkiv Polytechnic Institute." http://library.kpi.harkov.ua.
19. Poliakov, A. P., Khazanovych, O. I., Chepak, O. H. (2004). Metodyka planuvannia tekhnichnoho obsluhovuvannia bronetankovoho ozbroiennia i tekhniky [Methodology for Planning the Maintenance of Armored and Tank Armament and Equipment]. Trudy akademii [Works of the academy]: Kyiv.
20. Abtew MA, Boussu F, Bruniaux P, Loghin, K., Cristian, I., Chen, Y., & Wang, L. (2021). Ballistic impact performance and surface failure mechanisms of two-dimensional and three-dimensional woven p-aramid multi-layer fabrics for lightweight women ballistic vest applications. *Journal of Industrial Textiles, 50*(9):1351-1383. doi:10.1177/1528083719862883.
21. Safri, S., Sultan, M., Jawaid, M., & Jayakrishna, K. (2018). Impact behaviour of hybrid composites for structural applications: A review. *Composites Part B: Engineering, 133*. https://doi.org/10.1016/j.compositesb.2017.09.008.
22. Zukas, J., & Scheffler, D. (2001). Impact effects in multilayered plates. *International Journal of Solids and Structures, 38*(19). https://doi.org/10.1016/S0020-7683(00)00260-2.
23. Palta, E., Gutowski, M., & Fang, H. (2018). A numerical study of steel and hybrid armor plates under ballistic impacts. *International Journal of Solids and Structures, 136-137*. https://doi.org/10.1016/j.ijsolstr.2017.12.021.

24. Karthikeyan, K., Russel, B., Fleck, N., Wadley, H., & Deshpande, V. (2013). The effect of shear strength on the ballistic response of laminated composite plates. *European Journal of Mechanics - A/Solids, 42*. https://www.sciencedirect.com/science/article/abs/pii/S0997753813000454.
25. Chu, T., Minh, C., & Imad, A. (2016). A numerical investigation of the influence of yarn mechanical and physical properties on the ballistic impact behavior of a Kevlar KM2® woven fabric. *Composites Part B Engineering, 95*. DOI:10.1016/j.compositesb.2016.03.018.
26. Bandaru, A., Vetiyatil, L., & Ahmad, S. (2015). The effect of hybridization on the ballistic impact behavior of hybrid composite armors. *Composites Part B: Engineering, 76*. https://doi.org/10.1016/j.compositesb.2015.03.012.
27. Mousavi, M., & Khoramishad, H. (2020). Investigation of energy absorption in hybridized fiber-reinforced polymer composites under high-velocity impact loading. *International Journal of Impact Engineering, 146*. https://doi.org/10.1016/j.ijimpeng.2020.103692.

Інновації щодо бронезахисту військової техніки

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Анотація. Війна в Україні та світові військові конфлікти доводять, що та військова техніка яка бере участь у цих конфліктах є в переважній більшості броньованою. Вагому участь у проведені військових дій беруть Сухопутні війська, основу яких складають механізовані, мотопіхотні та танкові підрозділи, на озброєні яких знаходиться броньована техніка. Застосування броньованої техніки є основною частиною військових операцій, забезпечує захист та безпеку військових, а також сприяє у вирішенні завдань щодо подолання ворожого опору. В світі продовжується швидкий розвиток процесу створення нових та вдосконалення існуючих типів снарядів, боєприпасів для ураження броньованої техніки, це в свою чергу призводить до пошуку напрямів зміцнення існуючого бронезахисту броньованої техніки. Тому, метою даного дослідження є огляд та оцінка новітніх технічних рішень в галузі бронезахисту військової техніки з метою їх систематизації та надання рекомендацій щодо їх імплементації.

Основними методами досліджень є методи аналізу й синтезу, дедукції та індукції, а також методи експертного оцінювання.

Результати проведеного авторами статті аналізу засвідчують, що країни світу постійно працюють над вдосконаленням вже існуючих та над створенням нових зразків щодо підвищення захисту військової техніки. Огляд новітніх розробок в галузі бронезахисту доводить, що одним із основних переваг створення інноваційних бронеелементів є поліпшення їх вагових характеристик. Модернізовані матеріали та конструкції забезпечують максимальний рівень захисту при мінімальній вазі і це дозволяє знизити вагу броньованої бойової військової техніки та заощадити використання палива. Створені інноваційні бронеелементи мають покращену ергономіку, що підвищує зручність їх використання особовим складом та дозволяє зменшити втому й стресові навантаження на особовий склад і як наслідок позитивно впливає на їх бойовий дух та безпеку життя.

Запропоновані види інноваційних бронеелементів, можуть бути використанні в бронюванні військової техніки, що гарантує більш високий рівень захисту проти куль та снарядів та мін, включаючи протитанкові засоби противника. Провідною метою інновацій в бронюванні військової техніки є зростання безпеки такої техніки, що призводить до переваг у веденні бою, збереженні життя особового складу та продовження терміну використання техніки. Впровадження таких технологій унеможливлює випадки руйнування техніки в разі підриву снарядів, ураження осколками та кулями.

У статті пропонується ознайомитися з новими інноваційними рішеннями іноземних компаній та вітчизняних підприємств щодо бронезахисту військової техніки.

Матеріали статті можуть бути корисними для розробників і виробників систем та зразків озброєння, а також науковцям і дослідникам в галузі національної безпеки та розвитку оборонної сфери держави.

Ключові слова: бронезахист, броня, броньована техніка, інноваційні матеріали для бронювання, Сухопутні війська.