Engineering Symposium at Bánki
(ESB 2024)

Armor package proposal for combat vehicles

[1]Krisztián Molnár

[1] *Obuda University, Bánki Donát Faculty of Mechanical and Safety Engineering, Budapest, Hungary, molnar.krisztian@stud.uni-obuda.hu*

Abstract

[15] The primary goal of the research is to enhance the protection of combat vehicle crews against impacts of certain energy levels by implementing composite armor packages. This composite armor consists of a combination of aluminum foam, AR500 steel, and ceramic materials, which collectively reduce the energy of shockwaves, the number of shrapnel fragments. The development process is carried out in multiple stages, starting from the design of innovative protective solutions, through 3D modeling, to conducting simulations using simulation software. These simulations play a critical role in the preliminary analysis of the behavior of different materials and structural solutions under various attack scenarios.

[16] Keywords: Composite armor, Crew safety, Simulation, Innovative materials

1. Introduction

In this tank development proposal and research, I focus exclusively on the internal protection of the vehicle, as I consider this the most critical aspect, and because the development trends of modern tanks worldwide point in this direction. The research process involves identifying the areas within the fighting compartment of the vehicle type provided for the research that can be effectively reinforced with additional armor. This would enhance the tank's resistance against threats that it previously could not withstand. The next step is to select suitable materials for the development of the armor package and provide a detailed description of these materials. Following this, I will create 3D models to ensure the design exists at a conceptual level. Then, using appropriate simulation software, I will simulate the protection against specific ammunition types upon impact. Finally, I will draw the necessary conclusions from all these steps to assess the effectiveness of the proposed solutions.

During the research program, a wide range of measurement tools and IT resources were utilized. As a first step, measurements were conducted of the external and internal dimensions of the vehicle used as a test bed for the idea at the facilities of HM Currus Zrt. This step determined the direction of the development. For the measurements, a digital metal caliper and a laser distance meter were used to accurately record the dimensions of the vehicle. To analyze the materials intended for use, a YXLON Cheetah EVO CT scanner was employed for non-destructive material testing, and a METTLER TOLEDO AB204 precision scale. In the design process, two key software programs provided the necessary IT support: Autodesk AutoCAD 2024 and the student-licensed version of Ansys 2024R1. Within Ansys, specifically Ansys Workbench, was used with Speos 2024R1 and Mechanical 2024R1. AutoCAD was used to create the 3D models. Ansys Workbench allowed me to parameterize the Explicit Dynamics simulations. Ansys Mechanical calculated and graphically presented the results of the simulations. This combination ensured the precision and feasibility of both the design.

2. Materials used

This armor design is a composite one, which consequently means that it is not a homogeneous slab of armor added to the existing one, but a multilayered package where each layer has its own task. [1]

Due to the compact design of the interior of the vehicle, the internal armor could have a maximum thickness of 30 mm. Since the minimum effective thickness for internal armor layers is 10 mm, the decision was made to design it with three layers, each 10 mm thick. The layering follows the traditional principles of composite armor. The outer layer is of high hardness, capable of potentially shattering projectiles upon impact or, at the very least, posing a significant challenge to penetration. The second layer is designed to absorb energy effectively, with excellent elastic deformation properties and high yield strength. The third and final layer's role is to prevent the inner two layers from excessive deformation, primarily providing structural reinforcement.

For the outer layer, ceramic material was chosen. During research into ceramics suitable for armor, one material stood out: boron carbide. This material is excellent for the task as it is the third hardest material after boron nitride and diamond, while its relatively low density of 2500 kg/m³ allows for effective protection at a low weight. Its melting point is extremely high, at 2350 °C, and its Vickers hardness is 38 GPa. It has a high elastic limit but low ductility. In addition to providing protection against kinetic impacts, it can also take on radiation shielding duties due to its neutron absorption capabilities. Ceramics function as armor by shattering when struck, creating a shock wave that pulverizes the ceramic, increasing its volume. The resulting sharp and hard ceramic fragments act as a grinding medium, damaging the projectile as it passes through (this brittle fracture is characteristic of ceramics).

For the middle layer, which serves as the pressure and impact-absorbing layer, an interesting material was deemed suitable: aluminum foam. Aluminum foam is produced by injecting neutral gas into molten metal as it cools, creating solidified bubbles within the material. The density of foamed aluminum is lower than that of solid aluminum, making it an effective choice for this application. The dimensions of the test block I measured were 25.6 mm × 26.5 mm × 6.8 mm, and its mass was 1.9979 g. Based on these measurements, I calculated its density to be 433.09 kg/m³, which is 16.04% of the density of solid aluminum (2700 kg/m³). Its compressive strength is higher than that of solid aluminum, nearly four times greater. I created a CT scan of the test sample, which, thanks to the processing software, resulted in a three-dimensional model. Using this model, it was possible to observe the wall thickness of the cells in the sample's cross-section. The typical values ranged between 0.5 and 1 mm, although in some places the thickness reached between 3 and 3.5 mm. Since there is no distinct axis along which the walls are thinner compared to others, it can be stated that for a body with equal side lengths, despite the randomness of bubble formation, the material's strength does not depend on the direction of the force vector.

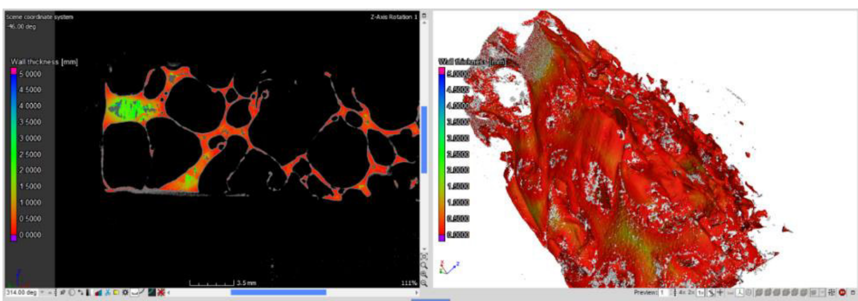

Figure 1. The CT scan of the aluminium foam

For the layer in direct contact with the crew compartment of the vehicle, a metal was intended to be used that is both lightweight and flexible. My first choice was titanium; however, an important consideration is that titanium is very expensive to produce, and manufacturing it in 10 mm thick sheets over a large area is disproportionately costly compared to the level of protection it provides. Therefore, I consider AR500-grade steel plate to be a satisfactory alternative. According to the American MIL-A 46177 standard, its Brinell hardness ranges between 477 and 534 HBW10/3000-W. The carbon content of AR500 steel is between 0.27% and 0.3%, with its main alloying elements being manganese, chromium, molybdenum, and nickel, present at 0.95%, 0.75%, 0.65%, and 0.35%, respectively.[3] Due to its greater hardness and comparable weight, AR500 is a better choice than RHA (rolled homogeneous armor).

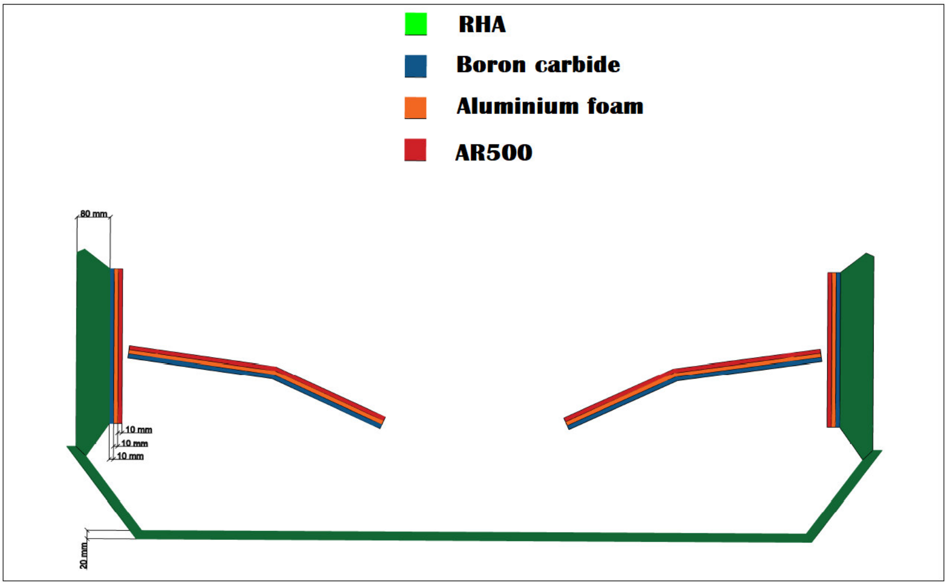

Figure 2. The cross-section of the proposed armor scheme on the existing one

The design for the installation of the supplemental or shrapnel armor involves utilizing the existing threading on the hull and mounting it in 250×250 mm 'tiles' onto the internal armor [2]. A 1 mm gap would be left between the tiles to allow the metals within to expand laterally, thereby increasing the stress distribution across the plate, which can elastically absorb impacts more effectively. Another reason for using small tiles is that replacing the shattered ceramic from a direct hit is much easier with this size compared to having to remove the entire turret along with the internal equipment. These three-layer tiles would be secured with screws equipped with self-locking washers, making them difficult to loosen.

The weight of the supplemental armor is 149.37 kg per side. This calculation is based on the densities of the three materials multiplied by the volumes of their respective layers, resulting in a requirement of 6.02 kg of aluminum foam, 35.01 kg of boron carbide, and 108.34 kg of AR500 steel. The layered armor for the revolving ammunition storage would also be replaced with this same configuration, with a total weight of 215.73 kg. This consists of 8.69 kg of aluminum foam, 50.58 kg of boron carbide, and 156.46 kg of AR500 steel. The armor would be mounted on the axis of the revolving ammunition storage, preserving the trapdoor through which the charge and projectile are transferred.

3. Simulations

I tested my armor concept using simulations. In these simulations, I analyzed how the armor behaves under the impact of armor-piercing projectiles in its current configuration compared to the proposed configuration under identical conditions with the same type of round. The simulations were conducted using the Ansys 2024R1 student license. The parameters in the Workbench program were set, and the calculations and visualizations were performed in the Mechanical module. The simulation environment used was Explicit Dynamics, which is a linear dynamic system. A total of five simulations were conducted, during which all deformations, velocity changes, and stress effects were calculated and analyzed. Specifically, the total deformation, elastic and plastic deformation, and the resulting stress distribution were examined.

In the first simulation, it was examined how the current 80 mm thick rolled homogeneous steel armor behaves when impacted from a distance of 500 meters. The projectile used in this case was the 30 mm APDS (Armor Piercing Discarding Sabot) 3UBR8 tungsten carbide round. For the three-dimensional model of the projectile, only the tungsten carbide core was created, as the ballistic cap does not significantly influence the impact dynamics. After running the simulation, the point on the armor was identified where the projectile first causes a rupture in material continuity. Additionally, the results revealed that this projectile, with its 300 g mass and impact velocity of 1050 m/s, can only perforate the armor, achieving partial penetration, which results in a shrapnel effect on the inner side of the armor.

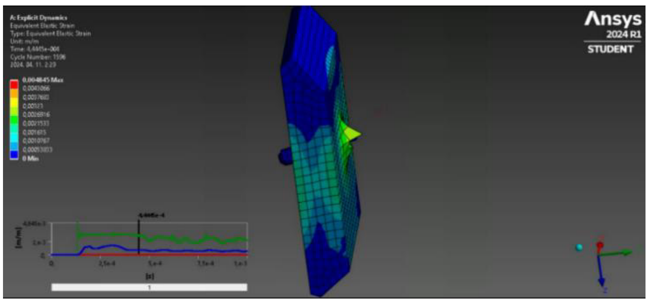

Figure 3. 3UBR8 impact at the moment of armor failure

In the second simulation, the effect of the 3UBR8 projectile was analyzed with the same parameters as in the previous test, but this time including the additional armor layers. These layers were applied not only to the side armor but also to the top of the carousel of the automatic loading system. The results showed that the projectile penetrated the existing 80 mm outer plate, but the additional internal armor stopped it. While the boron carbide layer was also overcome, the process caused most of the projectile to shear off. As a result, the remaining part of the projectile ricocheted back in the opposite direction due to the high elasticity of the foamed aluminum and the innermost AR500 layer. On the side of the crew compartment, the impact resulted in a significant but non-critical dent.

All materials involved exceeded their yield strength, leading to a permanent bulge in the affected area. An important result, which was not previously expected, was that the small gap between the ammunition rack and the side armor caused the armor of the rack to act as a brace. This bracing effect reduced the extent of the dent and absorbed part of the impact energy. The armor on the ammunition rack underwent only elastic deformation, returning to its original shape after the event. Unlike the first simulation, where fragments entered the crew compartment, the fragments in this scenario were ejected outward, meaning no damage occurred inside the tank. This demonstrates the effectiveness of the proposed additional armor in mitigating internal damage.

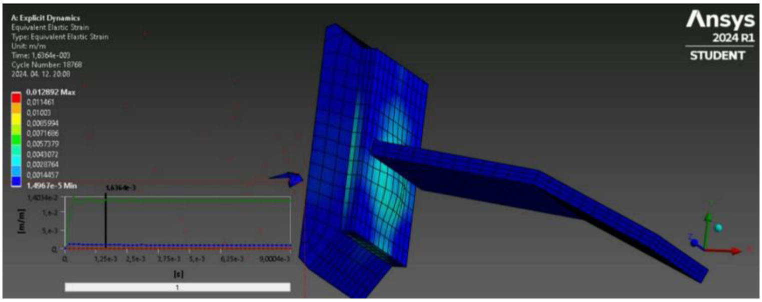

Figure 4. The impact of the 3UBR8, with red dots representing fragments outside the armor, alongside the deformed projectile

In the third simulation, the impact of an APFSDS (Armour-Piercing Fin-Stabilized Discarding Sabot) projectile on the baseline armor was examined. The projectile type used was the 3VBM-17 ’Mango’, which, while not the most modern, is one of the most widespread in its caliber. The projectile body is made of hardened steel, while the nose cap is tungsten. For the simulation, only these components were considered. The muzzle velocity was 1700 m/s, and the shot was simulated from a distance of 2 km, well within the effective range of the projectile. The projectile’s mass was 4850 g, and the angle of impact was 90°, which is optimal for the projectile and poses the greatest challenge for the armor.

Upon running the simulation, the expected outcome occurred: the projectile easily penetrated the armor. During penetration, the projectile deformed and generated a large amount of high-velocity shrapnel that dispersed into the crew compartment. In addition, the main body of the projectile itself also entered the compartment, causing significant internal damage. This confirmed the limitations of the current armor configuration against such a threat.

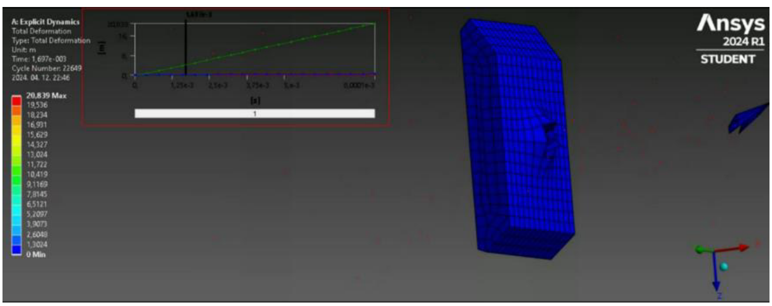

Figure 5. The penetration of the 3VBM-17, showing the plastically deformed armor plate and projectile, with red dots representing the fragments

In the fourth simulation, the same initial conditions were used as in the third simulation, with the key difference being that the target was equipped with my proposed composite armor plates instead of the existing baseline armor. In this case, the projectile successfully penetrated the side armor and its additional layers. However, the impact caused significant deformation and reduced the projectile's velocity from 1450 m/s to 500 m/s. This deceleration rendered the projectile unable to penetrate the ammunition storage compartment's armor. Instead, due to the configuration of the layers, the projectile was deflected downward, toward the chassis of the vehicle.

The rotating ammunition compartment's armor once again acted as reinforcement. However, due to the more forceful impact, plastic deformation occurred in the area where the armor of the compartment came into contact with the deformed side armor and the slowed projectile. Despite this, the additional armor successfully protected the turret crew not only from lethal shrapnel but also from the projectile itself. This result highlights the effectiveness of the reinforced composite armor in safeguarding critical crew areas, even against high-energy threats.

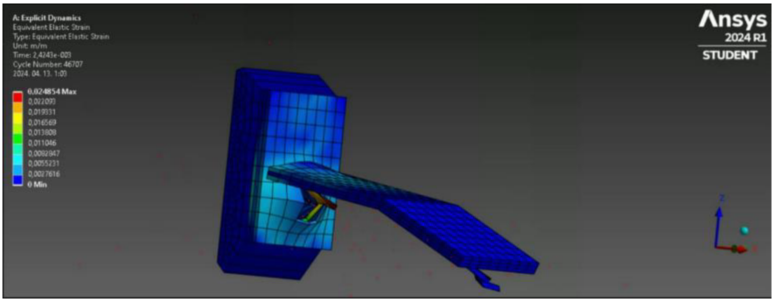

Figure 6. The 3VBM-17 continues its path toward the chassis, with fragments marked by red dots remaining below the crew compartment

4. Conclusion

Simulations have demonstrated that the three-layer additional shrapnel armor, with the specified layer order and thicknesses, effectively enhances protection. In the first control simulation using a smaller autocannon projectile on existing armor, perforation occurred. However, with the additional armor, the second simulation showed successful crew protection. The third simulation, testing the existing armor against a 125 mm shell, resulted in penetration, while the fourth, with the additional armor, deflected the projectile via ammunition storage plates, safeguarding the crew.

The simulations confirmed the shrapnel protection capabilities of the armor. It prevented perforation in one case and deflected a projectile in another, validating the materials used and the concept of angled armor plates. Future experiments should include high-explosive fragmentation and shaped charges, utilizing more advanced simulation tools. If further tests corroborate these findings, live-fire trials could lead to a universal shrapnel-resistant armor applicable beyond T-72 tanks, marking significant progress in crew protection

5. References

[1] W.N.M. Jamil, A. M. Azlan, Z. Sajuri, S. Abdullah, M.Z. Omar, F. Abdullah, és W. F. H. W. Zamri, "Mechanical properties and microstructures of steel panels for laminated composites in armoured vehicles," International Journal of Automotive and Mechanical Engineering, vol. 13, no. 3, pp. 3741-3753, December 2016, DOI: 10.15282/ijame.13.3.2016.16.0306.

[2] MN HTI, "T-72 harckocsi századparancsnoki változata sorozatgyártási dokumentációja HTJ.TU.1980," levéltári forrás, HM Currus Zrt levéltár, 1981.02.01

[3] "MIL-A-12560H(MR), Military Specification: Armor Plate, Steel, Wrought, Homogeneous (For Use in Combat-Vehicles and for Ammunition Testing)," Department of Defense, USA, 2009.