PHYSICS AND CHEMISTRY OF SOLID STATE
V. 23, No. 3 (2022) pp. 550-558

Section: Technology

DOI: 10.15330/pcss.22.3.550-558

Vasyl Stefanyk Precarpathian National University

ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
Т. 23, № 3 (2022) С. 550-558

Технічні науки

PACS: 68.65.Ac

ISSN 1729-4428

Ahmed Ehsan Jassem[1], Akram Jassim Jawad[2], Ahmed Oleiwi Samarmad[1], Ahmed Fadhil Hamzah[3]

Numerical and Experimental Study of Multi-layer Armors for Personal Protection

[1] University of Warith Al-Anbiyaa, Department of Air Conditioning and Refrigeration Techniques Engineering, Karbala, Iraq;
[2]University of Babylon, College of Engineering, Department of Biomedical Engineering, Iraq;
[3] University of Babylon, Department of Polymer Engineering and Petrochemical Industries Iraq
akrammaterials4@gmail.com

Currently, personal armor is considered the basic requirement in combat, especially in the Middle East. The current research attempts to design and manufacture a novel body armor from cheap and available materials. When compared to traditional materials' body armor, composite ballistic body armor has become a superior alternative for personal protection. In this study, alternative materials were proposed to develop an armor consisting of modified rubber and ebonite, as well as pieces of ceramic from alumina as hexagons shape, Kevlar and Carbon woven, and modern technologies shear thickening fluids. The armor was numerically evaluated using (ANSYS) commercial software using different bullet velocities ranging from (740 to 940) m/s and different numbers of carbon and Kevlar woven soaking shear thickening fluids to reach the best arrangement of layers with the best performance and compare them in the experimental data. The numerical results show the best performance for plate armor consisting of 23-layers, which were then experimentally tested using a weapon type (AK-47) rifle with bullet 7.62*39 mm. The experimental test showed no complete penetration, with a back deformation of 7.5 mm. When the shock of the double bullet into the plate at the same location showed no complete penetration with a back deformation of 11.3 mm, the body armor exhibited superior protective performance and was compatible with standard NIJ Standard-0101.03.

Keywords: Body Armor, the composite system, Ebonite, Shear Thickening Fluids, and Ansys.

Received 30.04.2022; accepted 23.08.2022.

Introduction

Personal protection is a basic requirement for police and military officers against attacks by conventional weapons. As a result of this necessity, protective gear, sometimes known as armor, has developed. As a consequence, body armor is defined as any protective covering worn on the body to defend it from physical threats [1, 2]. For this reason, different materials have been developed and used in the production of armors, such as iron, copper and steel. However, in the recent era, composite materials of lighter weight and lower cost showed better performance. In military applications, fiber-reinforced composite materials have become key technical materials utilized in lightweight armor for ballistic protection. This is because of its excellent mechanical qualities, design flexibility, manufacturing simplicity, corrosion wear and impact resistance [3]. Composite body armor is a piece of clothing or an item of equipment meant to protect the wearer from a range of threats. They can be designed to block a variety of threats, including bullets, knives, needles, or a combination of hazards. Soft body armor, which is found in normal bullet and stab proof vests, and stiff, hard armor reinforced body armor, which is used by police tactical units and combat soldiers in high-risk circumstance [3]. Several theoretical and experimental research articles were written to see if composite materials might be used in armor to repel bullets.

D.S. Preece and V.S. Berg [4] investigated the effectiveness of steel plate armor consisting of three layers (Steel-Kevlar-Steel \ Kevlar) against bullets made lead-copper. Computer hydrocode analyses and ballistic testing showed that the bullet stopped by one panel, which is 20 mm thick, was stopped by 14.275 mm of steel. R. G. Egres et al. [5] studied the performance of Kevlar and nylon fiber saturated by STF to resistance (against cut and puncture threats). Fabrics impregnated with STF exhibit better stab resistance, according to both qualitative and quantitative data. Additional experiments show that adding STF to tightly woven textiles improves their resistance to syringe needle penetration. K. Mylvaganam and L. C. Zhang [6] studied and manufactured shields made from carbon nanotubes (CNT) of a special type، the result shows that the ballistic resistance capacity of a carbon nanotube is highest when the bullet hits at center CNT. Also, larger tubes show withstands for bullet higher speed even when bullets strike at the same spot, that body armor made from six layers of 100μm carbon nanotube yarns.

M.R. Ahmad et al. [7] added glass fiber to natural rubber layers (NR) and showed the ability to absorb shock by using it in the armor industry. The addition of fibers to the fabric improved the shock absorber resistance to high speed and reduced the deformation of the rubber layers during the performance. The general resistance to rubber increases with increased fiber glasses. M. Grujicic et al. [8] studied the positioning and direction methods for fibers that are used in the manufacture of armor by using the ABAQUS / Explicit v 6.7 program for high molecular weight polyethylene fibers (HMWPE). The results obtained stopped the bullets at different initial bullet velocities. Teng et al. [9] studied simulations of shields consisting of two layers for different materials, as well as for four types of projectiles with different weights and noses, to determine the effect of material types on projectile resistance by Ansys software. The results showed that the best configuration is the upper layer from high ductility and low strength material, as well as the lower layer from low ductility and high strength material. This configuration has a 25% gain in the ballistic limit under moderate detrimental impact.

H. M. El-Fayad et al. [10] developed a model to simulate sandwich honeycomb armors by using (Ansys software) from ceramic materials (SiC) and Steel, used to resist various weapons. The results show a reduction in projectile exit velocity by about 29.4% and 39.6% for ceramic thicknesses 10 mm and 20 mm, respectively. Also, reduction the back deformation by 77.24%, only with a 3.586% increase in the total weight of the armors. C.M. Roland et al. [11] studied elastomer coating add from polyisobutylene (PIB), polyurea, polynorbornene (PNB), Nitrile rubber (NBR), 1,4-polybutadiene (PB), and both synthetic (PI) and natural (NR) 1,4-polyisoprenes) under layer steel (High Hard Steel (HHS)) to improve the ballistic limit. The result showed an increase in the penetration resistance and the ballistic limit increases further when increase layers coating number. Y. Regassa et al. [3] conducted a numerical study to simulate an armor consisting of 20 layers of Kevlar 29 and polystyrene resin with a total weight of 1.5 kg and 10 mm thickness using Abaqus 6.10. The results showed that the armor plate can withstand the impact energy of a bullet that fired at a distance of 10 m with a velocity of 720 m.

Y. Wang et al. [12] investigated numerically the impact deformation of multi-ply fabric panels with angled pliers by using (ABAQUS v6.3), the results showed that the orientation of pliers significantly affects the energy-absorbing capacity of the multi-ply fabric panels. In addition, the stacking sequence of oriented pliers also plays an important role in absorbing the energy. S.N. Monteiro et al. [13] designed and manufactured armor made from natural fibers (Curaua) and reinforced it with epoxy layers to resist shots and then reinforced with an Al_2O_3 ceramic plate. The results showed that conventional aramid fabric displays a similar indentation as the curaua/polyester composite but is less efficient (deeper indentation) than the curaua/epoxy composite. A. Fadhil Hamzah et al. [14] developed a model to simulate body armor (by ANSYS 14 Explicit Dynamic). The projectile bullet was made from stainless steel 304, Kevlar fibers with epoxy, and a composite system made up of multilayers of diverse materials, with three velocities (800, 1000, and 1200 m/s) employed. Their simulations revealed that the modeled composite system body armor could not be penetrated completely.

E. J. Pach et al. [15] studied and analyzed a shield plate consisting of two layers of composite materials, the first consisting of tungsten carbide, alumina balls, or steel balls in the polymer's matrix. The second plate consists of several sheets of Aramid fiber (10 layers) on the surface of styrene-butadiene rubber. The results showed that the samples containing the ceramic layer absorb 50% of the bullet energy and that the steel balls absorb 35% of the bullet energy. M. Bocian et al. [16] studied and analyzed a shield plate made of Aramid fiber with a polymer. The plate was digitally recorded using the ABAQUS program to resist a bullet 9 × 19 mm and speed 350 m/s, the results showed the ability of the plates to absorb all energy from bullets and compare with the practical results. Cho H, et al. [17] studied and simulated an armor made from bio-composites composed of natural fibers and cornstarch composites (shear-thickening fluids (STFs)) by using ABAQUS/CAE® software at velocity 407m/s and rotational speed of 27,000 rpm. Due to the hydro-clustering process, these hybrid composites, including both Hanji and cornstarch suspension layers, exhibit greater ballistic protection performance than composites containing solely Hanji. FEA modeling was used to examine the bulletproof performance of materials under impact loading, and the linear velocity of the bullet dropped as the thickness of both the Hanji and cornstarch layers increased. When the thickness of the cornstarch layers was raised, the normalized perforated area of the Hanji–cornstarch composites declined, but it steadily grew when the number of Hanji layers without cornstarch suspension layers was increased.

Narendiranath et al. [18] studied the simulation of ballistic impact on a sample of composite material made from Kevlar 29, Carbon Fiber, E-Glass Fiber, and Steel 1006. And was tested with a 9 mm parabellum bullet having a velocity of 400 m/s. by Ansys Workbench Explicit Dynamics, the results showed 100 cm2 sample of a laminate plate consisting of Kevlar carbon fiber is most effective because it had a low deformation of 4.9383 mm when the bullet hits the sample. Farah A. et al. [19] studied and simulated hybrid composite plates made from carbon fiber, date palm fiber, and Kevlar fiber. Their results showed that the material stacking sequence significantly affects the hybrid composite plates' energy dissipation mechanism and energy absorption capability. The plates consist of ten layers of carbon fiber and 30 layers of Kevlar in both shapes flat and curved, showing the best energy absorption capability and passing the actual ballistic shooting test at a velocity of 393 m/s at a distance of 15 m. Guleria T, Verma N, Zafar S, et al. [20] microwave-assisted compression molding was used to create an armor constructed from Kevlar-reinforced ultra-high molecular weight polyethylene composites. Mechanical behavior analysis revealed that the composite's ultimate tensile strength, flexural properties, impact energy absorption rate, and hardness property were increased by 92.2%, 27.1%, 91.6%, and 4.77%, respectively, when compared to ultra-high molecular weight polyethylene. The microwave heating phenomenon during microwave-assisted compression molding may have caused this Enhanced.

Tang F, et al. [21] designed and simulated body armor from polyethylene (UHMWPE) saturated with a gel shear stiffening (SSG) UHMWPE/SSG composite material. The results showed that the flexible SSG buffer plate could swiftly stiffen under ballistic impact, known as the "Jamming" effect, to resist impact deformation and absorb impact energy, with reduced impact energy transmission to the human body as the impact load increased. The back face deformation of armor was reduced (up to 50%) compared to traditional materials. Shah I, Khan R, Koloor S, et al. [22] designed and simulated body armor from aluminum alloy (Al 7075-T6) and UHMWPE (sandwich core) at the front panel, and silicon carbide (SiC) bonded together with epoxy resin as an auxetic sandwich composite at back panel, by Explicit Dynamics/Autodyne 3-Dcode program. The results showed improved indentation resistance with the auxetic armor with elastic energy dissipation at up to 400 m/s velocities, and the back facet was completely safe. Conversely, the traditional modal allowed Projectiles to pass through it at a velocity above 300 m/s; and severely damaged at 200 m/s. at back face.

The current study presents a numerical analysis (using the commecial program ANSYS 16.1) of body armor that was constructed by a set of layers (rubber, ceramics, ebonite, fibers such as Kevlar and carbon, as well as shear thickening fluids) and experimentally tested using an AK-47 rifle. When compared to armors made of standard materials, such as stainless steel and Kevlar fibers, which are subjected to projectiles at ballistic velocity.

I. Materials Used

Since the armor plate consists of several layers, there are many materials involved in the manufacture process, such as natural rubber contains. Also, nano black carbon (N-115) to modify the properties of Natural rubber, Shear Thickening Fluid (STFs) consists of Polyethylene glycol with fumed silica at a concentration of 35 wt%, ceramics layer from pure Alumina and two types of fabrics, Kevlar and Carbon.

II. Preparation of Sample

The newly developed armor plate contains the arrangement of the layers shown in Fig. 1. It consists of

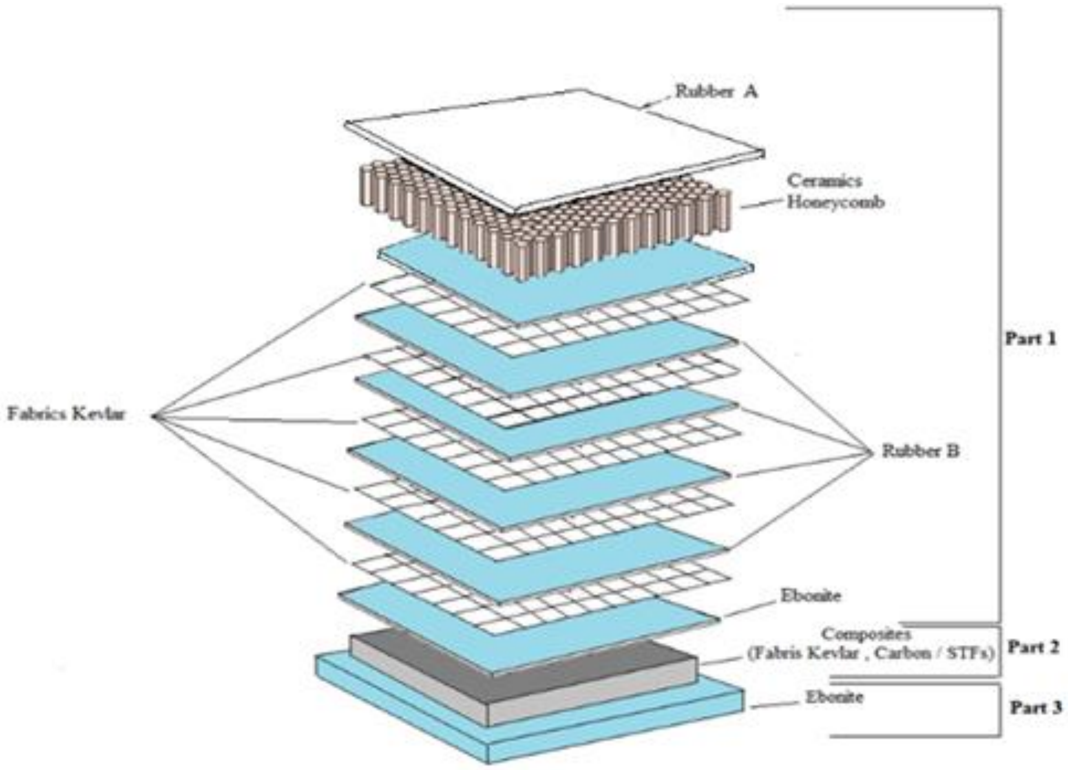

Fig. 1. The arrangement of layers and the main parts.

Table 1 The mechanical properties of layers used in plate armor.

Materials	ρ g/cm³	E_{12} GPa	E_{23} GPa	E_{13} GPa	G_{12} GPa	G_{23} GPa	G_{13} GPa	ν_{12}	ν_{22}, ν_{13}
Rubber (A)	1.1582	0.075	0.075	0.075	0.026	0.026	0.026	0.44	0.44
Ceramic	3.75	310	310	310	131.35	131.35	131.35	0.18	0.18
Rubber(B)/ Kevlar Fabric	1.47	51.92	51.92	6.664	0.2467	2.38	2.38	0.0091	0.511
Kevlar fabrics / STFs	1.43	89.01	89.01	0.967	0.583	0.543	0.543	0.0141	0.543
Carbon fabric / STFs	1.377	95	95	0.353	0.159	0.234	0.234	0.0141	0.61
Hard rubber	1.18	0.68	0.68	0.68	0.25	0.25	0.25	0.37	0.37

three main parts; the first part contains ceramics from Alumina formed in the form of hexagons with a dimension of 2 cm length of the side and thickness of 2 mm shown in Fig.2-a. The role of the ceramic layer is to distort the nose of the bullet and increase the surface area of the contact between the bullet and layer shear thickening, absorbing shock by fibers and rubber and stopping the bullet [10]. Alternating layers of fiber Kevlar and rubber (B), the fiber (Kevlar) was treated with sulfuric acid concentration (60%) (H_2SO_4) to give good adhesive with natural rubber whose owns content 24 phr sulfur and 30 phr carbon black, the first part after assembly and vulcanization becomes as in Fig.2-b [7].

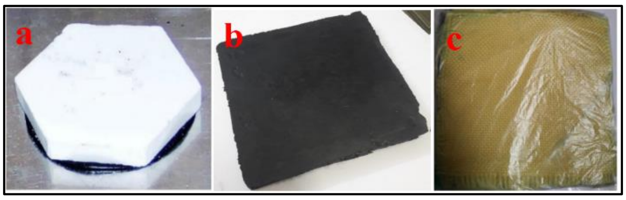

Fig. 2. (a) The sample of alumina ceramic, (b) The final first part, (c) The final second part.

The second part is the composite consisting of the Kevlar and carbon fabrics with STFs to prepare fibers saturated with STFs. STFs were diluted in ethyl alcohol to ensure better coating of fabrics. According to the rheological results, the use of STFs containing 35 w/w % silica concentrations was determined to obtain the best impact-resistant properties. Aramid and carbon fabrics were cut into (15 × 15) cm and soaking each layer by STFs solution for 12 h. Then, fabrics were dried in the oven and the fabric layers were assembled from carbon and Kevlar alternately and the number of layers was 14 layers, 7 of each type of fabric and packaging by the plastic bag shown in Fig. 2-c [5, 21]. The third part is the supporting layer consisting of hard rubber, which has a natural rubber content of 28 phr sulfur and 30 phr carbon black. Rubber A has a natural rubber content of 18 phr sulfur and 30 phr carbon black. The mechanical properties of the layer are shown in Table 1.

The mechanical parameters of the composite system employed in this work (Young's modulus, Poisson's ratio, shear modulus, and density) are experimentally and theoretically derived using the theoretical equation (rule of mixing) as follows: [23].

For unidirectional fibers (UD), the equations rule

$$E_{12} = E_m V_m + E_f V_f \,, \tag{1}$$

$$\rho c = \rho \, V_f + \rho \, V_m \,, \tag{2}$$

$$\nu_{12} = \nu \, V_f + \nu \, V_m \tag{3}$$

$$G_{12} = \frac{Gm\,Gf}{Gf - Vf(Gf - Vm)} \tag{4}$$

$$\frac{1}{E23} = \frac{Vf}{Ef} + \frac{Vm}{Em} \tag{5}$$

The modulus of woven (E_{12} = E_{23} and E_{13}) is equal [24]:

$$\left(\frac{1}{E12}\right)^{WF} = \left(\frac{2\left(E12\left(E12+\left(1-\upsilon12^2\right)E23\right)-\upsilon12^2\,E23^2\right)}{E12\left(E12(E12+2E23)+\left(1+2\upsilon12^2\right)E23^2\right)}\right)^{UD} \tag{6}$$

$$\left(\frac{1}{E13}\right)^{WF} = \left(\frac{E12^2\left(1-\upsilon23^2\right)+E12E23(1+2\upsilon12+2\upsilon12\upsilon23)-\upsilon12^2E23^2}{E12E23(E12+(1+2\upsilon12)E23)}\right)^{UD} \tag{7}$$

The passion ratio of woven (wf) (ν_{12} and ν_{23} = ν_{13}) is equal [24]:

$$\left(\frac{\upsilon12}{E12}\right)^{Wf} = \left(\frac{4\left(\upsilon12E23\left(E12-\upsilon12^2E23\right)\right)}{E12\left(E12(E12+2E23)+E23^2\left(1+2\upsilon12^2\right)\right)}\right)^{UD} \tag{8}$$

$$\left(\frac{\upsilon13}{E12}\right)^{WF} = \left(\frac{E12(\upsilon12+\upsilon23+\upsilon12\upsilon23)+\upsilon12^2E23^2}{E12(E12+E23(1+2\upsilon12))}\right)^{UD} \tag{9}$$

The modulus of rigidity of woven (G_{12} and G_{23} =G_{13}) is equal [24]:

$$\left(\frac{1}{G12}\right)^{WF} = \left(\frac{1}{G12}\right)^{UD} \tag{10}$$

$$\left(\frac{1}{G12}\right)^{WF} = \left(\frac{1}{2G12} + \frac{1+\gamma23}{E2}\right)^{UD} \tag{11}$$

where *E* – modulus of elasticity, *G* – shear modulus, *υ* – Poisson's ratio, *ρ* – density, *V* – Volume fraction, γ – *Shear* strain.

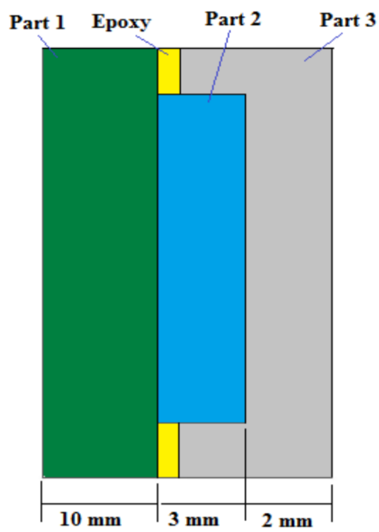

Fig. 3. The arrangement of the main parts of the armor plate.

After the preparation of the main parts, they are gathered together assembly with them and gluing by an epoxy, as shown in Fig. 3. We get the final armor plate.

III. Modelling Processing

The modeling process was carried out using ANSYS Explicit Dynamic and includes two parts: a 3-D model for bullet and plate armor to the ballistic test simulation with true dimensions and boundary conditions. A 3-D model of the AK-47 bullet 7.62 × 39 mm was created and the dimensions of the bullet are shown in Fig. 4 [25]. A 3-D model of the plate armor was modeled, and it is a square plate (150 × 150) mm that consists of 23 layers. The dimensions of the layers are shown in Fig. 5. The thickness of the Rubber\Kevlar layer is 0.6 mm, Kevlar fabric\STFs is 0.5 mm, and Carbon fabric \STFs is 0.5 mm. The distance between the plate and the bullet is 15 m.

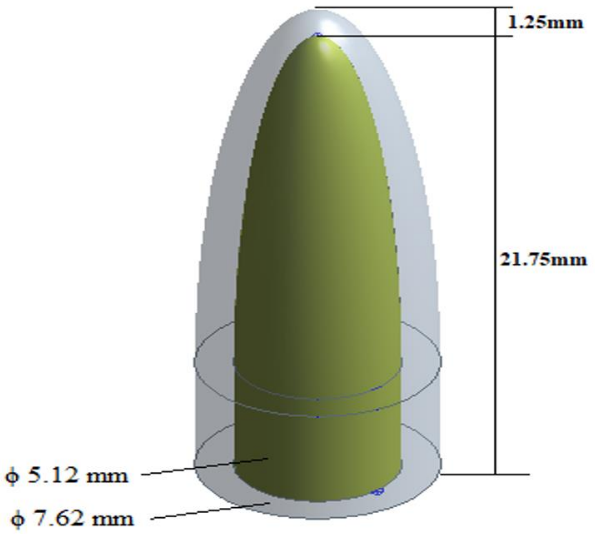

Fig. 4. Dimensions of bullet.

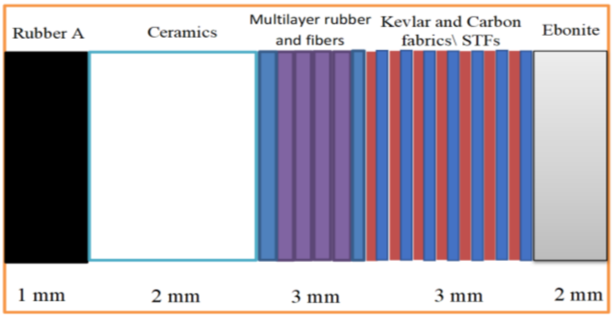

Fig. 5. Arrangement of Layers with Thickness.

The boundary conditions applied to this model are in all degrees of freedom restricted plate (armor) and the side is fixed support, but the bullet was represented as a stiff entity moving at different speeds. (840 and 940) m/sec. Air resistance was not considered in the current study.

IV. Results and Discussion

In this section, the results obtained from the numerical simulation have been discussed and compared with the field application. Fig.6 and 7 show the deformation of plate armor at a velocity bullet of 740 m/s. They show the ability of the plate to withstand the all value of velocities used. Fig. 6 shows the amount of deformation happening in the armor that consists of the composite system (Rubber-Ceramic- Ebonite-5 multi-layer from rubber and Kevlar-Ebonite), with the total number of layers of (8). It is noted that the amount of deformity and deformation area is larger but no penetration through the armor plate was observed and that the amount of deformation at the backside of the plate was approximately 17.1 mm, as shown in Fig.5 (Side view). This amount of deformation could cause internal injuries to the human body. However, the initial results of the test were similar to the ability of the material to withstand the high shocks of extruded objects. When adding 5-layers of STFs\Kevlar, with a total number of layers (13), we noticed a slight decrease in the amount of deformation in the armor plate, where the backside deformation of the plate decreased to 16.2 mm, as shown in Fig.7. This is because STFs absorb energy from bullets [5] whic this caed thell "Jamming" effect [21]. Furthermore, when adding additional 5-layers from STFs\Kevlar, with a total number of layers of (17), a further decrease in the amount of deformation in the armor plate has been observed. The back deformation of the plate decreased to 15.47 mm, as shown in Fig. 8. This was also due to the STF effect [17].

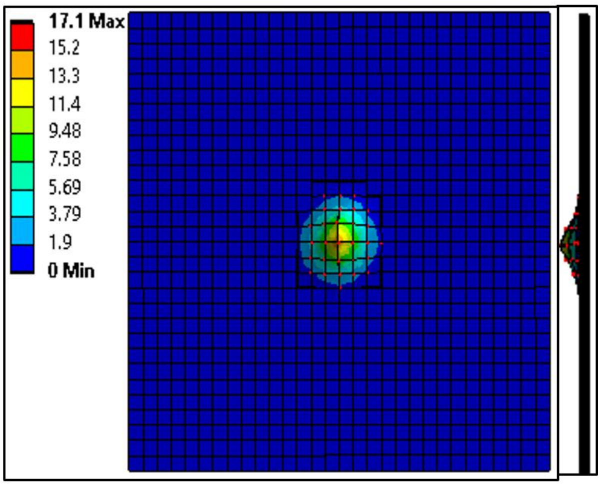

Fig. 6. The Deformation of Armor Plate has (Rubber-Ceramic-Ebonite-5 Multilayer Rubber Kevlar-Ebonite), Side and Front views of Armor Plate.

Increasing the number of layers of STFs to 14 layers (composed of 7 layers from STFs\Kevlar and 7 from STFs\Carbon), with a total number of layers of (23), the amount of deformation was significantly reduced to 7.12 mm, as shown in Fig.9. This improvement and a significant decrease in the back deformation is due to an increase in the STFs effect, due to an increase in the number of layers saturated with it [17]. This is a very encouraging results to be applied in practice since it does not cause danger to the internal exhortation of the human body. Due to NIJ Standard-0101.03, the backface is less than 44 mm. Accordingly, it is considered the best results obtained by the back deformation of the plate [26].

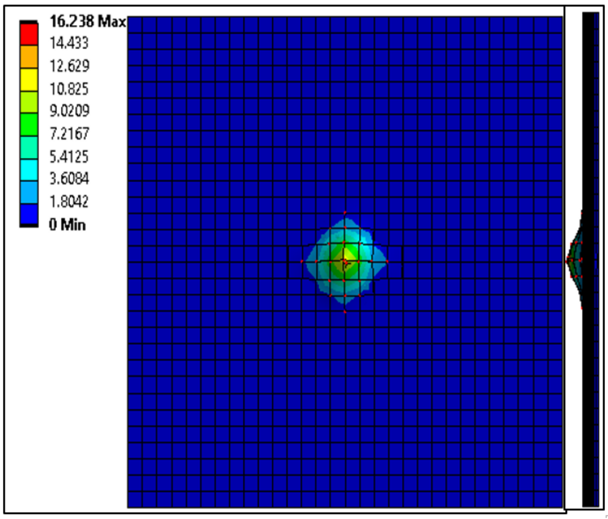

Fig. 7. The Deformation of Armor Plate Have (Rubber-Ceramic-Ebonite-5 Multilayer Rubber Kevlar-5 Stfs\Kevlar Layers-Ebonite), Side and Front Views of Armor Plate.

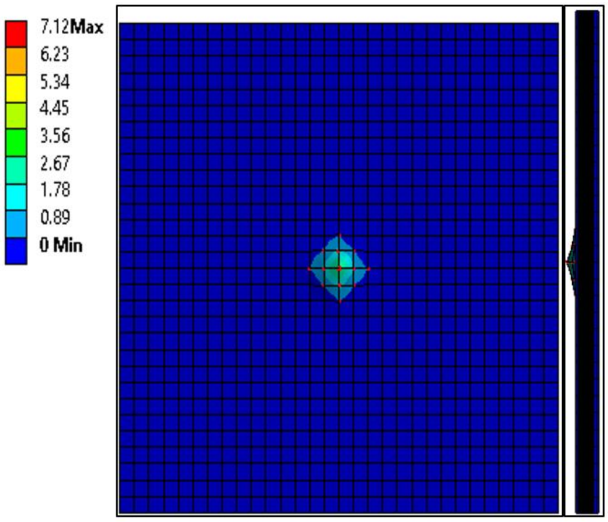

Fig. 8. The Deformation of Armor Plate have (Rubber-Ceramic-Ebonite-5 Multilayer Rubber Kevlar-10 Stfs\Kevlar Layers-Ebonite), Side and Front Views of Armor Plate.

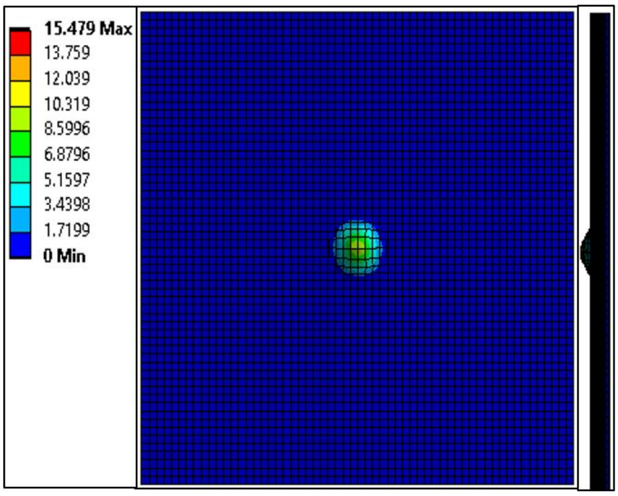

Fig. 9. The Deformation of Armor Plate Have (Rubber-Ceramic-Ebonite-5 Multilayer Rubber Kevlar-14 STFs\Kevlar and Carbon Layers-Ebonite), Side and Front Views of Armor Plate.

From the above results, it is concluded that the best results obtained were for the plate containing 14 layers of STFs with a total number of layers (23) at velocity 740 m/s and 15 m distance between armor and bullet. Increasing the speed to (840 and 940) m\s was considered to study the tolerance of the plate and its ability deformation at the same distance. The amount of deformation of the plate is shown in Fig. 10.

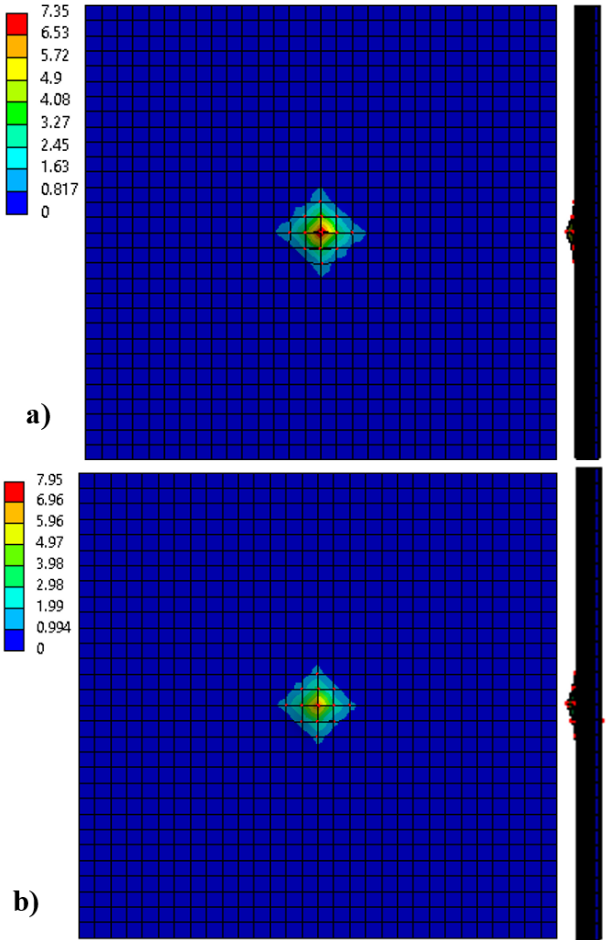

Fig. 10. Front and Side of views of armor plate and Chart Deformation of Plate have (Rubber-Ceramic-Ebonite-5 Multilayer Rubber Kevlar-14 STFs\Kevlar And Carbon Layers-Ebonite) at a) 840 m/s, b) 940 m/s.

In all cases, the ability of the plate to resist penetration was obtained. In contrast, the amount of deformity of the back increased slightly from 7.35 to 7.95 mm. However, this amount is within the limits allowed for the material and does not affect the internal preaching of the human body, since it is within the amount of safety allowed.

V.Ballistic Test

A field study (experimental test) was conducted on the plate containing 14 layers of STFs at a distance of 15 m and velocity of 838 m/s (note: the speed mentioned measured by the M-1 shooting Chrony device during the test and the bullet consist of core from lead alloy and shell copper alloy).[26] The results showed the ability of the plate to resist the penetration, with an amount of back

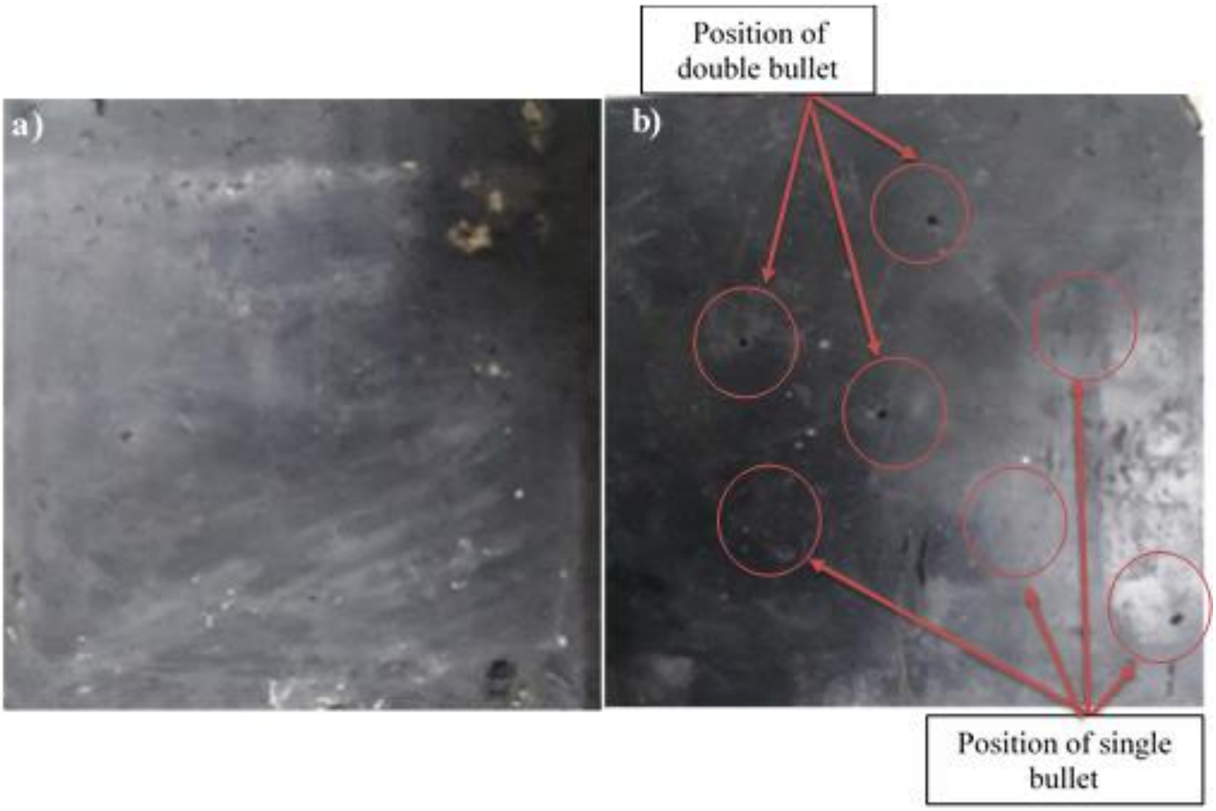

Fig. 11. The plate after test a) backside of the plate, b) front side of the plate.

deformation of 7.5 mm. when the shock of the double bullet in the plate at same location the amount of back deformation is 11.3 mm, as shown in Fig.11.

These results are within NIJ Standard-0101.03, published in 1978, which was the first version of the standard to incorporate a 44 mm (1.73 inches) Back Face Signature (BFS) limit as the minimum performance threshold for blunt force injury [26], and this agreed with the theoretical results obtained by the Ansys program.

Conclusions

In this research, a novel multilayer armer was numerically developed and experimentally tested. It was concluded that the armor that consists of 23 layers (Rubber – Ceramic – Ebonite – 5 multilayer Rubber Kevlar – 14 STFs Kevlar and Carbon layers – Ebonite) have the best performance to absorb the shock at high speed. The model shown that at a bullet velocity of 840m/s, the back deformation is about 7.35 mm, and in ballistic experimental tests at a velocity of 838 m/s (same distance and type of bullet), the back deformation was about 7.5 mm. The experimental date confirms well with the numerical results. In addition, through the ballistic test, it was shown that when two successive bullets were fired at the same location, no penetration was observed and the back deformation was about 11.3 m/s. This is within the allowable range of standard NIJ Standard-0101.03 [26]. This confirms the effectiveness of the newly proposed shield. The armor has a total weight of 700 g with a dimension of (300 x 300 mm).

Ahmed Ehsan Jassem – Asst. teacher at the University of Warith Al-Anbiyaa in the Air Conditioning and Refrigeration Techniques Engineering field, He got his B.Sc. degree in materials engineering in 2014, and received his M.Sc. in materials engineering also in 2018 from the University of Babylon.

Akram Jassim Jawad – Assistant lecturer at the University of Babylon in biomaterials engineering filed, He got his B.Sc. degree in polymer and composites materials engineering in 2014 from University of Babylon, and achived his M.Sc. in biomedical engineering with biomaterials and tissue engineering in 2021 from Queen Mary University of London, and currently he do his Ph.D. at University of Surrey, the UK.

Ahmed O.Samarmad. **–** Asst. teacher at the University of Warith Al-Anbiyaa in Air Conditioning and Refrigeration Techniques Engineering field

Ahmed Fadhil Hamzah – Professor at the University of Babylon in materials engineering filed, He got his B.Sc. degree in materials engineering in 2004, and received his M.Sc. in materials engineering also in 2007 from University of Babylon, and his Ph.D. in materials engineering (composite materials) in 2013 at University of Technology.

[1] P.V. Cavallaro, Soft Body Armor : An Overview of Materials, Manufacturing, Testing, and Ballistic Impact Dynamics Naval Undersea Warfare Center Division, vol. 12, no. August. Washington, 2011.

[2] M. J. Decker, C. J. Halbach, C. H. Nam, N. J. Wagner, and E. D. Wetzel, Stab resistance of shear thickening fluid (STF)-treated fabrics, Composites Science and Technology, 67(3–4), 565, (2007); https://doi.org/10.1016/j.compscitech.2006.08.007
[3] Y. Regassa, G. Likeleh, and R. Uppala, Modeling and Simulation of Bullet Resistant Composite Body Armor , International Journal of Research Studies in Science, Engineering and Technology, 1(3), 39 (2014);
[4] D.S. Preece and V.S. Berg, Bullet Impact on Steel and Kevlar®/Steel Armor: Computer Modeling and Experimental Data, ASME Pressure Vessels and Piping Conference (2004).
[5] R.G. Egres Jr., C.J. Halbach, M.J. Decker, E.D. Wetzel, and N.J. Wagner, Ballistic and rheological properties of stfs reinforced by short discontinuous fibers, SAMPE 2005:New Horizons for Materials and Processing Technologies, (2005).
[6] K. Mylvaganam and L.C. Zhang, Ballistic resistance capacity of carbon nanotubes, Nanotechnology, 18(47), 475701 (2007); https://doi.org/10.1088/0957-4484/18/47/475701 .
[7] M.R. Ahmad, W.Y.W. Ahmad, J. Salleh, and A. Samsuri, Effect of fabric stitching on ballistic impact resistance of natural rubber coated fabric systems, Materials and Design, 29(7), 1353 (2008); https://doi.org/10.1016/j.matdes.2007.06.007 .
[8] M. Grujicic and G. Arakere, A ballistic material model for cross-plied unidirectional ultra-high molecular-weight polyethylene fiber-reinforced armor-grade composites, Materials Science and Engineering, 498(1–2), 231 (2008); https://doi.org/10.1016/j.msea.2008.07.056 .
[9] X. Teng, T. Wierzbicki, and M. Huang, Ballistic resistance of double-layered armor plates, International Journal of Impact Engineering, 35(8), 870 (2008); https://doi.org/10.1016/j.ijimpeng.2008.01.008 .
[10] H.M. El-Fayad, M.M. Abdel-Wahab, A.A. El-Ashaa, and H.M. Farag, Protection of Honeycomb Sandwich Armours Against the Ballistic Attacks, Aerospace Sciences & Aviation Technology, Asat- 13, 1 (2009).
[11] C.M. Roland, D. Fragiadakis, and R.M. Gamache, Composite Structures, 92(5), 1059 (2010); https://doi.org/10.1016/j.compstruct.2009.09.057 .
[12] Y. Wang, X. Chen, R. Young, I. Kinloch, and G. Wells, Elastomer–steel laminate armor, Composites Part B: Engineering, 68, 259 (2015); https://doi.org/10.1016/j.compositesb.2014.08.049 .
[13] S.N. Monteiro, L.H.L. Louro, and W. Trindade, Natural curaua fiber-reinforced composites in multilayered ballistic armor, Metallurgical and Materials Transactions A, 46(10), 4567 (2015); https://doi.org/10.1007/s11661-015-3032-z .
[14] A. Fadhil Hamzah, E. Zuheir Fadhel, and M. Baqir Hunain, Experimental and Numerical Investigation of Fatigue Behavior of Chopped GFRP Composite Rod under Rotating Bending Load, International Journal of Engineering and Technology, 6(9), 327 (2016).
[15] J. Pach, D. Pyka, K. Jamroziak, and P. Mayer, The experimental and numerical analysis of the ballistic resistance of polymer composites, Composites Part B: Engineering, 113, 24 (2017); https://doi.org/10.1016/j.compositesb.2017.01.006 .
[16] M. Bocian, J. Pach, and K. Jamroziak, Experimental and numerical analysis of aramid fiber laminates with DCPD resin matrix subjected to impact tests, MATEC Web of Conferences, 112, 04013, (2017); https://doi.org/10.1051/matecconf/201711204013 .
[17] H. Cho, J. Lee, S. Hong, and S. Kim, Bulletproof performance of composite plate fabricated using shear thickening fluid and natural fiber paper, Applied Sciences, 10(1), 88 (2019); https://doi.org/10.3390/app10010088 .
[18] B.T. Narendiranath, A.P. Singh, N.S. Reddy, and D. Murpani, Simulation of Ballistic Impact on Different Composite Samples of Bullet Proof Vest, IOP Conference Series: Materials Science and Engineering, 1123(1), 012030 (2021); https://doi.org/10.1088/1757-899X/1123/1/012030 .
[19] F. Alkhatib, E. Mahdi, and A. Dean, Design and evaluation of hybrid composite plates for ballistic protection: experimental and numerical investigations, Polymers (Basel), 13(9), 1450 (2021); https://doi.org/10.3390/polym13091450
[20] T. Guleria, N. Verma, S. Zafar, and V. Jain, Fabrication of Kevlar®-reinforced ultra-high molecular weight polyethylene composite through microwave-assisted compression molding for body armor applications, Journal of Reinforced Plastics and Composites, 40(7–8), 307 (2021); https://doi.org/10.1177/0731684420959449 .
[21] Tang, F., Dong, C., Yang, Z., Kang, Y., Huang, X., Li, M., Chen, Y., Cao, W., Huang, C., Guo, Y. and Wei, Y., Protective performance and dynamic behavior of composite body armor with shear stiffening gel as buffer material under ballistic impact, Composites Science and Technology, 218, 109190 (2022); https://doi.org/10.1016/J.COMPSCITECH.2021.109190 .
[22] Shah, I.A., Khan, R., Koloor, S.S.R., Petrů, M., Badshah, S., Ahmad, S. and Amjad, M., Finite Element Analysis of the Ballistic Impact on Auxetic Sandwich Composite Human Body Armor, Materials, 15(6), 2064 (2022); https://doi.org/10.3390/ma15062064 .
[23] W.D. Callister, Fundamentals of Materials Science and Engineering: An Interactive, (Fith. John Wiley & Sons,Inc, 2001).
[24] M.F. Aly, I.G.M. Goda, and G.A. Hassan, Experimental Investigation of the Dynamic Characteristics of Laminated Composite Beams, International Journal of Mechanical & Mechatronics Engineering, 10(3), 59 (2010); https://doi.org/10.1.1.207.5914 .

[25] D.W.H. Michael B. Mukasey, Jeffrey L. Sedgwick, The characteristics of systems and their changes of state disperse, Ballistic Resistance of Body Armor :NIJ Standard-0101.06, (7th ed., no. August. Washington, 2008). https://doi.org/10.1017/CBO9781107415324.004

[26] National Institute of Justice, Ballistic Resistance of Police Body Armor. NIJ Standard 0101.03, 2008.

А.Е. Джассем[1], А.Д. Джавад[2], А.О. Самармад[1], А.Ф. Хамза[3]

Чисельні та експериментальні дослідження багатошарової броні для персонального захисту

[1]Університет Варіт Аль-Анбія, кафедра техніки кондиціонування повітря та інженерії холодильної техніки, Кербела, Ірак,
[2]Університет Вавилону, інженерний коледж, факультет біомедичної інженерії, Ірак
[3]Університет Вавилону, кафедра полімерної інженерії та нафтохімічної промисловості, Ірак
akrammaterials4@gmail.com

На даний час індивідуальна броня розглядається як основна вимога в бою, особливо на Близькому Сході. Поточні дослідження спрямовані на розроблення та виготовлення нових бронежилетів із дешевих і доступних матеріалів. У порівнянні із бронежилетами з традиційних матеріалів, композитні балістичні бронежилети стали чудовою альтернативою для індивідуального захисту. У даному дослідженні запропоновано альтернативні матеріали для розробки броні, що складається з модифікованої гуми та ебоніту, а також керамічних частин на основі оксиду алюмінію шестикутної структури, кевлару та вуглецю та сучасні технології згущувальних рідин. Чисельна оцінка броні здійснювалася за допомогою комерційного програмного забезпечення (ANSYS) із використанням різних швидкостей куль у діапазоні від 740 до 940 м/с та різної кількості вуглецевих і кевларових тканин та згущувальних рідин для досягнення найкращого розташування шарів із максимальною продуктивністю. Виконано порівняння із експериментальними даними. Чисельні результати показали найкращі показники для пластинчастої броні, що складається із 23 шарів, які потім були експериментально перевірені на бойовій гвинтівці типу АК-47 з кулею 7,62*39 мм. Експериментальне випробування показало відсутність повного проникнення із зворотною деформацією 7,5 мм. Удар подвійної кулі в пластину в тому самому місці не показав повного проникнення з задньою деформацією 11,3 мм, бронежилет продемонстрував чудові захисні характеристики та був сумісний зі стандартом NIJ Standard-0101.03.

Ключові слова: захист, композити, ебоніт, рідина для загущення, Ansys.