Theoretical Study of Light-Weight Composite System for Personal Armor

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Abstract

With wars and the rise of the killings taking place in the world it was necessary for us as engineers and researchers that we step even slightest reduction in killings, and the current research is an attempt in this direction. Composite ballistic body armor materials has become a better body armor protection when contrasted with conventional steel body armor as far as its diminishment in weight and a perfection in ballistic resistance, in any case, the unpredictable reaction of composite materials combined with high expenses and restricted measure of information from ballistic testing has lead to modeling and simulation of ballistic body armor with different grade of material becomes the best option to optimize and design the composite body armor with less weight and affordable cost. The study aimed to develop domestic knowledge, model and simulate capability of composite armors compare it with other material at same weight about (0.75 kg). As a research, methodology there was modeling and simulation by ANSYS 14 Explicit Dynamic. Were used to model and simulate the bullet resistant body armor. The material used for modeling are stainless steel 304, Kevlar fibers with epoxy and composite system which consist of multi layers of different materials, and the weapon type used is assault rifle wz. 96 “BERYL”. It was used three velocities (800, 1000 and 1200 m/s) for projectile bullet. The simulation result shows that no completely penetration through the modeled composite system body armor and it has owned a high-performance compared with the other materials

Key Words: body armor, composite system, ballistic velocity, FEA, ANSYS

1- Introduction:

Individual armor is the term used to portray things that are worn or conveyed to furnish a person with security from vitality. In the military and law-implementation environment, this vitality is essentially as effect by nonpenetrating shots or blows, impact waves from blasts, and infiltrating rockets. [1]

Furthermore, personal armor is accessible to offer assurance from blazes and the acceleration speed of the body surface coming about because of the effect of the moving body against an unbending, steadfast surface—"knock" security. Numerous sorts of individual armor consolidate assurance from infiltrating and nonpenetrating sways. For instance, military caps are intended to quit infiltrating rockets, for example, slugs or sections and offer security against "knock" sways emerging from falls, rockets, for example, blocks, or deterrents at head tallness. [2]

Several research papers theoretical and experimental conducted in order to determine the possibility of the use of composite materials in the armor to resist bullets.

Philip M. *et. al* [3], studied the ballistic impact potential of M5 [fiber depends on the unbending rod polymer poly{diimidazo pyridinylene (dihydroxy) phenylene}] fiber-based armor system and assessed utilizing a "armor materials by configuration" model for personal armor, the model depends on a dimensional investigation of the mechanical properties of the filaments used to develop the armor system. They found that M5 fiber-based armor can possibly generously diminish the heaviness of body armour.

Erol ÜNALER [4] experimentally investigated E-glass/unsaturated polyester composite laminates and multilayered sandwich utilizing aluminum (Al) plates and alumina (Al_2O_3) tiles to enhance the ballistic resistance of the composite structure. The ballistic test outcomes show that the polymer composites have ballistic resistance against 7.62 mm section mimicking shots up to 1001 m/s shot speeds and the composites with no bolster layer are not adequate to stop AP shots.

K. Karthikeyan *et. al* [5] evaluated the ballistic performance of equi-mass plates made from stainless steel, carbon fiber/epoxy laminate and a hybrid plate of both materials for a spherical steel projectile. It has reached a the penetration velocity was highest for the SS plate and lowest for the CF plate

M. Grujicic *et. al* [6] study the configuration and manufacture of straightforward armor system by solely utilizing exact, experimentation and legacy approaches for the instances of single-hit and multi-hit ballistic security to the vehicle tenants. They recommended arrangement of composite structure comprise of multi-layers Polyurethane strengthened with glass fiber ceramic-glass outer layer and thought about the armor must likewise have and hold optical straightforwardness and be perfect with on-board imaging and interchanges hardware, they talked about of the essential straightforward armor models, practical layers and straightforward materials is given and an arrangement of configuration and material choice rules

G. Gopinath *et. al* [7] investigated three-dimensional distortions of delicate body armor as a clipped rectangular plate affected at typical frequency by a shot. Results have been registered by the finite element method, utilizing LSDYNA, and, two effect rates and two polymers, one stiffer than the other, have been considered. It is found that the matrix diminishes the most

extreme diversion of the armor, expands the span of the twisted range, and improves the decrease in the kinetic energy of the bullet.
M. Rojek *et. al* [8] are drawing up an option armor plate with the composite structure, which would be impervious to projectiles discharged from the weapons the Polish armed force, the composite structure included epoxy matrix strengthen with the fiberglass fit as a fiddle of mat or fabric, and steel network. The consequence of their studies is the evaluation of the nature of inspected tests. As a rule was received the conduct of the material under the shellfire, its defragmentation, cut and obliteration.
Yohannes Regassa et. al [9] investigated domestic knowledge, model and simulate capability of composite armors with less cost and weight, they used Solid work 2012 and Abaqus 6.10 software and the materials suggested for composite body armor was Kevlar-29 fiber and polyester resin for 20 layers with weight of modeled composite body armor was 1.5kg, the results shows that there is no penetration through the modeled composite body armor panel by a projectile.
We concluded that the composite ballistic body armor materials has become a better body armor protection when contrasted with conventional steel body armor as far as its diminishment in weight and a modify in ballistic resistance. The mind boggling reaction of composite materials combined with high expenses and restricted measure of information from ballistic testing has lead to modeling and simulation of ballistic body armor with different grade of material becomes the best option to optimize and design the composite body armor with less weight and affordable cost, therefore, The current research represents an attempt to numerical analysis (using the commercial software ANSYS 14) of body armor consists of composite system it includes a set of layers (splinter foil, ceramic and backing), Which is exposed to the bullets at ballistic velocity and compare it with armors manufacturing from traditional materials like stainless steel and Kevlar fibers.

2- Material and Geometric Parameters:

Inside the paper, we exhibit the consequences of the examination of light composite system, being the other option to customary ballistic armor. The modeled composite body armor in this research was consisted of multi layers as shown in **Fig (1)**

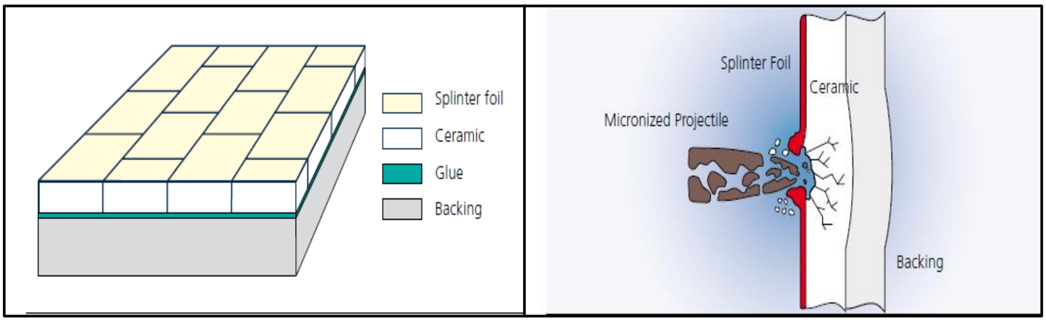


Fig. (1), layers consists of armor composite system

The model development of light-weight composite system depends on four parts:

1- Bullet foil
2- Layer of ceramic
3- Composite support, and
4- Glue

In a composite body armor , the ceramic layer is regularly put on the strike face, ideally opposite to the normal danger and consist of boron carbide (BC) which have mechanical properties listed in **table (1)**. The backing material is consist of polymer matrix composite material. The strengthen and basic upgrade of the individual polymer layers is accomplished by fiber reinforcement; the polymer used is polypropylene with glass fibers which have the mechanical properties shown in **tables (1)** and **(2)**. This chemical attach between layer of ceramic and composite support and/or between the individual polymer base composite layers is of key hugeness for the execution of the whole system, the glue utilized for this point is epoxy which have properties recorded in **table (1)**. Likewise, spall security is connected on the front side of the ceramic – glass fiber laminates are ideally used for this reason.
In this study it will be compared with the results of the proposed composite material with two types of armor materials (traditional), the first consists of a stainless steel type (304) and the second is a composite material with an epoxy as a matrix and reinforced with Kevlar fiber. The mechanical properties of above two materials are listed in **tables (1)** and **(2)**.

Table (1): Mechanical properties of components used in the study. [10, 11, 12 and 13]

Material	**Modulus of elasticity (GPa)**	**Shear modulus (GPa)**	**Poisson's ratio**	**Density (g/cm^3)**
Epoxy thermoset	3.5	1.4	0.25	1.2
Polypropylene	0.9	0.42	0.42	0.89
Boron carbide	420	125	0.18	2.48
Glass fibers	72	27	0.3	2.26
Kevlar 49	112.4	84.6	0.36	1.47
Steel stainless 304	193	76	0.26	7.9

Table (2): Mechanical properties of composite materials used in the study.

Matrix	**Fiber**	**Fiber V%**	**E_1 (GPa)**	**E_2 (GPa)**	**G_{12} (GPa)**	**G_{23} (GPa)**	**υ_{12}**	**υ_{23}**	**Density (g/cm^3)**
Epoxy	Kevlar	60	68.84	8.21	51.32	3.47	0.316	0.182	1.362
Polypropylene	Glass	60	43.56	5.65	16.368	2.51	0.348	0.123	1.928

The mechanical properties (Young's modulus, Poisson's ratio, Shear modulus and Density) of the composite system used in this study mention above in **table (2)** are theoretically determined depending on the theoretical equation (rule of mixture) as following: [14]

$$E_1 = E_f V_f + E_m V_m \qquad \text{……………………. (1)}$$

$$E_2 = \frac{E_f E_m}{E_f + V_f (E_f - E_m)} \qquad \text{……………………. (2)}$$

$$G_{12} = \frac{G_m G_f}{G_f - V_f (G_f - V_m)} \qquad \text{……………………. (3)}$$

$$G_{23} = \frac{E_2}{2(1+\nu_{23})} \qquad \text{……………………. (4)}$$

$$\nu_{12} = V_f \nu_f + V_m \nu_m \qquad \text{……………………. (5)}$$

$$\nu_{23} = \frac{E_2}{2G_{23}} - 1 \qquad \text{……………………. (6)}$$

$$\rho_c = \rho_f V_f + \rho_m V_m \qquad \text{……………………. (7)}$$

Where:
E: modulus of elasticity
G: shear modulus
υ: Poisson's ratio
ρ: density
V: volume fraction

In order that the comparison be logical between the suggested composites material system with traditional materials of armor we have adopted the weight criterion where we were taking the sample of square plate (300 x 300) mm with variable thickness depending on the density of each material of armor used where the weight is fixed about (750 ±) g, as shown in **table (3)**.

Table (3): Materials, thickness and weight of the three plate configurations investigated.

Armor material		Thickness (mm)	Weight (g)
Steel stainless		1.06	753.66
Kevlar + Epoxy		6.15	754
Suggested composite system	Bullet foil	0.2	10.3
	Ceramic layer	1	223.2
	Glue	0.1	8.3
	Backing	3	514.5
	Total	4.3	756.3

A three dimensions (FE) model was created to simulate the firing shots process of bullets on armor in ANSYS Explicit Dynamic Workbench 14.

The model consists of two parts, are the body armor plate with dimensions as mention above as shown in **Fig. (2)** and weapon that have been adopted in this study of a type Assault rifle wz. 96 “BERYL” which shown in **Fig. (3)**

For the boundary conditions applied at proposed model is constrained plate (armor) in all degrees of freedom at back face which is in contact with the body as fixed support while the bullet was modelled as a rigid body with a various velocities (800, 1000 and 1200) m/sec as shown in **Fig. (4).**

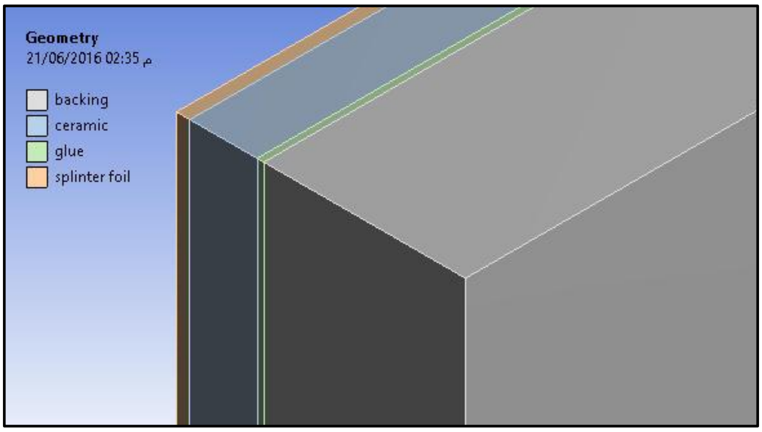


Fig. (2), FE model of composite plate armor

Calibre	5.56 mm
Cartrige	5.56x45 mm
Bullet	FMJ type SS 109
Muzzle velocity	920 m/s

Fig. (3), type of weapon and dimension of bullet used in study (8).

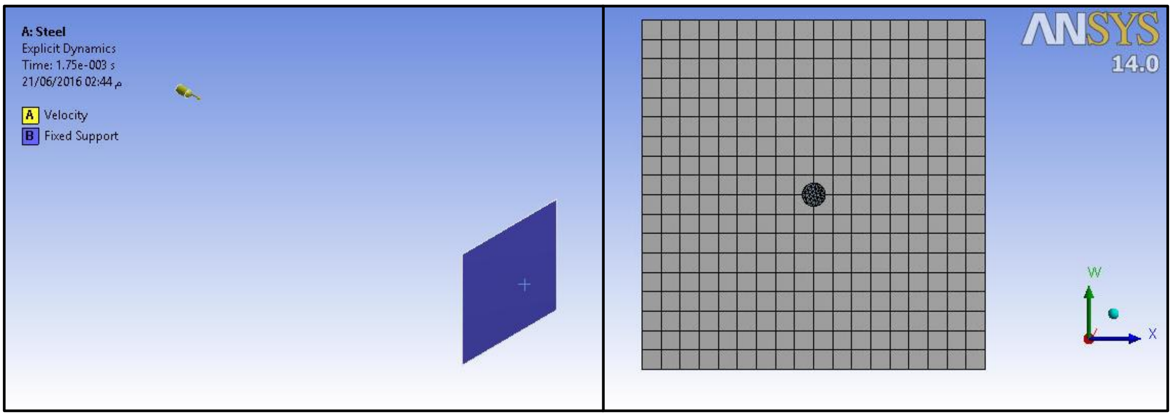


Fig. (4), FE model and boundary condition

3- Results and Discussion:

In this area, the results of the examination of the execution of the body armor composites structure furthermore the ballistic performance of alternate structures of armors and compare with suggested system are presented.

3-1- Deformation

Figures (5, 6 and 7) shows the amount of deformation happening in the armor consists of composite system, Kevlar and s. steel respectively with time for various velocities, which used in the study (800, 1000 and 1200) m/s

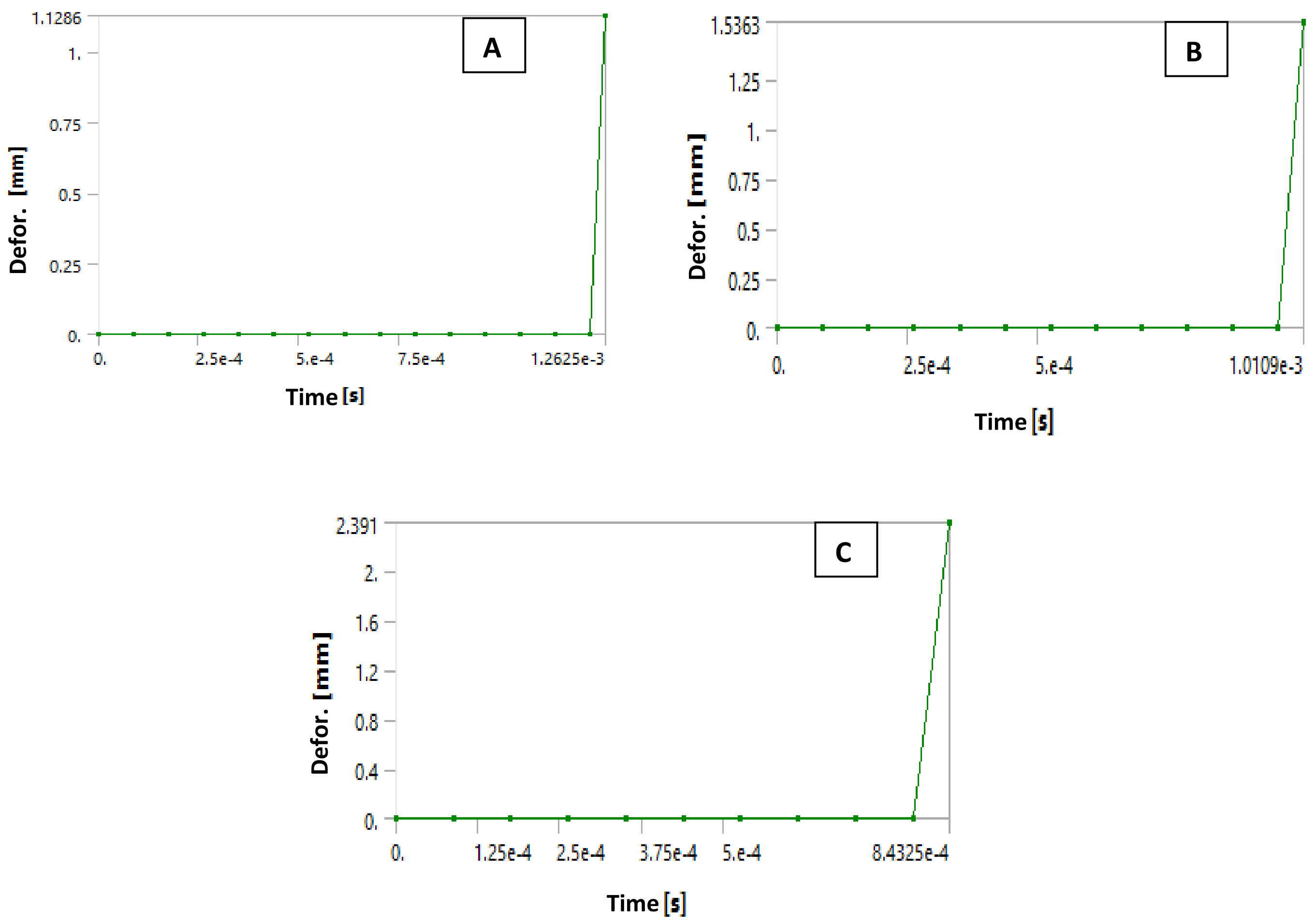


Fig. (5), variation deformation with time at a) 800 m/s, b)1000 m/s and c) 1200 m/s for composite system armor

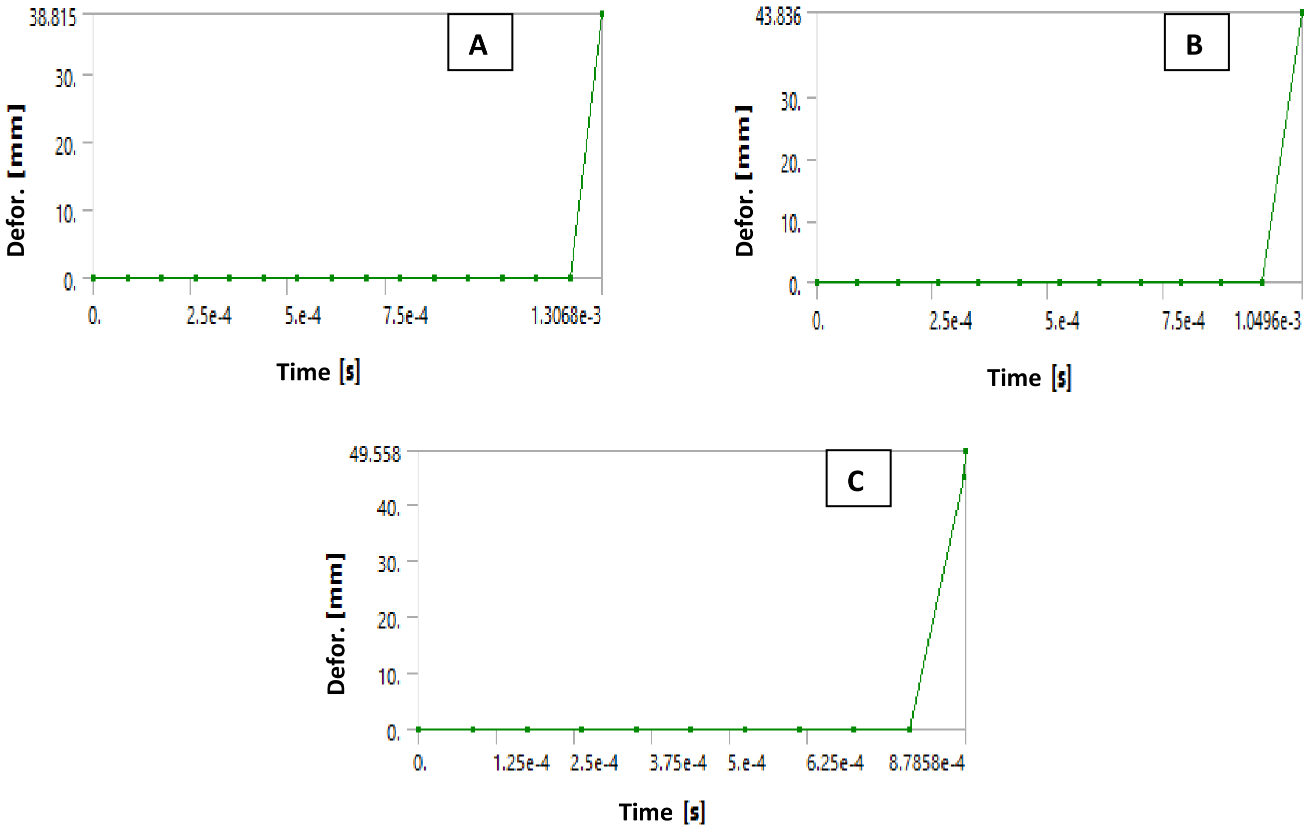
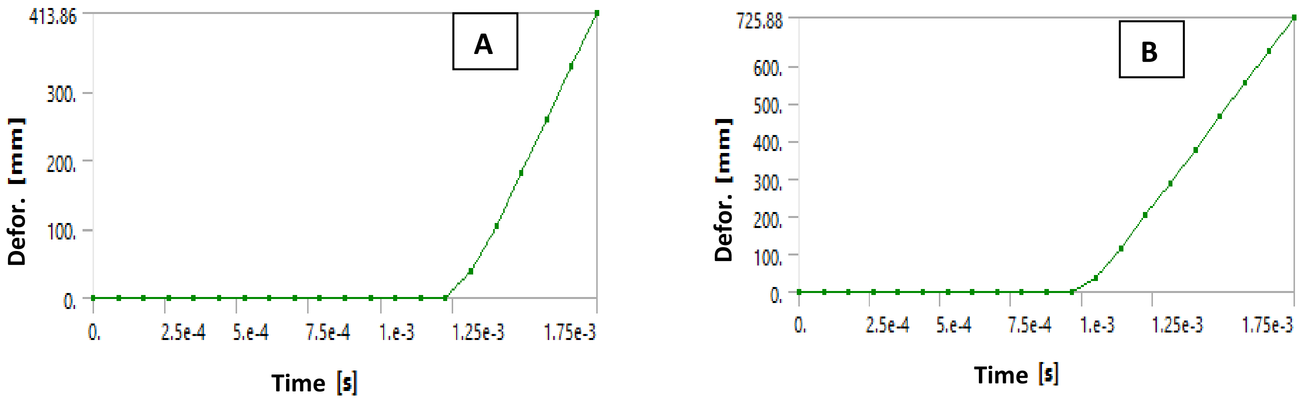


Fig. (6), variation deformation with time at a) 800 m/s, b)1000 m/s and c) 1200 m/s for Kevlar armor



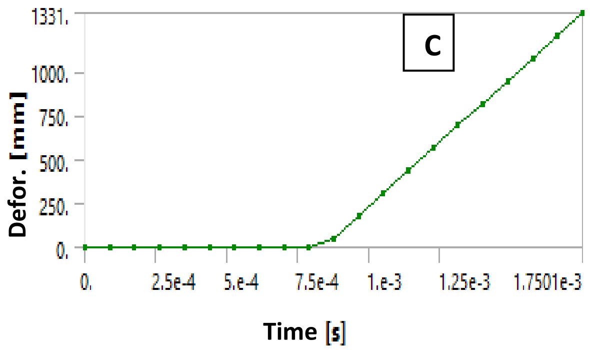


Fig. (7), variation deformation with time at a) 800 m/s, b)1000 m/s and c) 1200 m/s for s. steel armor

From the above figures, we find the arrival time of the bullet and colliding the armor varies depending on the velocity of ejaculation with less time to increase velocity and to encourage types of armor as well as find a time that latency varies from armor to another and at the same velocity, and this is due to the variation in the thickness of the armor where we find that less time in consisting of armor of s. steel, which is thinner, followed by armor made of composite system and finally Kevlar armor. On the other hand, we find that the amount of deformation varies depending on the velocity of bullet so that the deformation increases with velocity and this is due to increasing the amount of energy shot which is proportional to the velocity and the expected, but what concerns us here is the difference in the amount of deformation winning with a different type of material armor and at the same velocity, which dates back to resistance armor, where we find that the amount of deformation in the armor made of composite system does not exceed (2.39) mm at 1200 m/s the velocity of a bullet that did not penetrate the armor because the thickness of the armor (4.3) mm while we find that the amount of deformation in a much higher in other armors.

3-2- Depth of Penetration:

Figures (8, 9 and 10) shows the depth of penetration in the armor plate consists of s. steel, Kevlar and composite system respectively for various velocities, which used in the study.

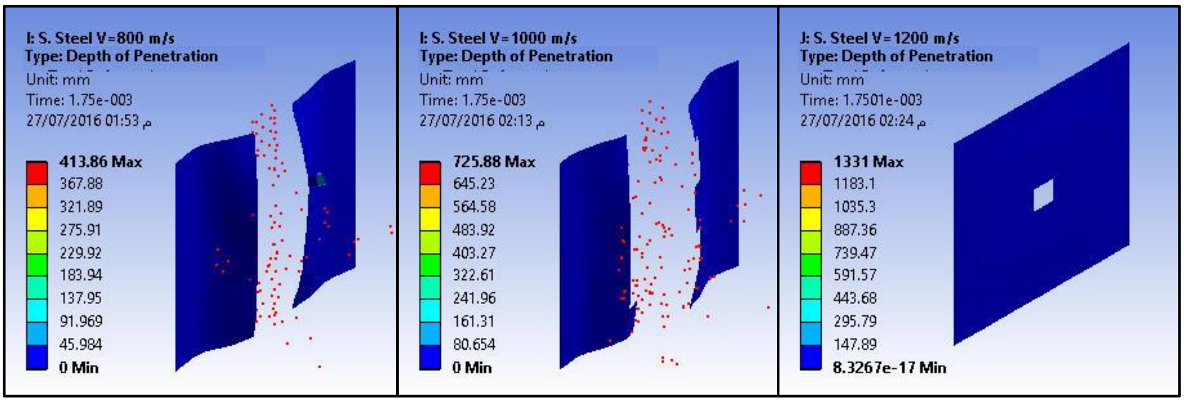


Fig. (8), depth of penetration at 800 m/s, 1000 m/s and 1200 m/s for s. steel armor

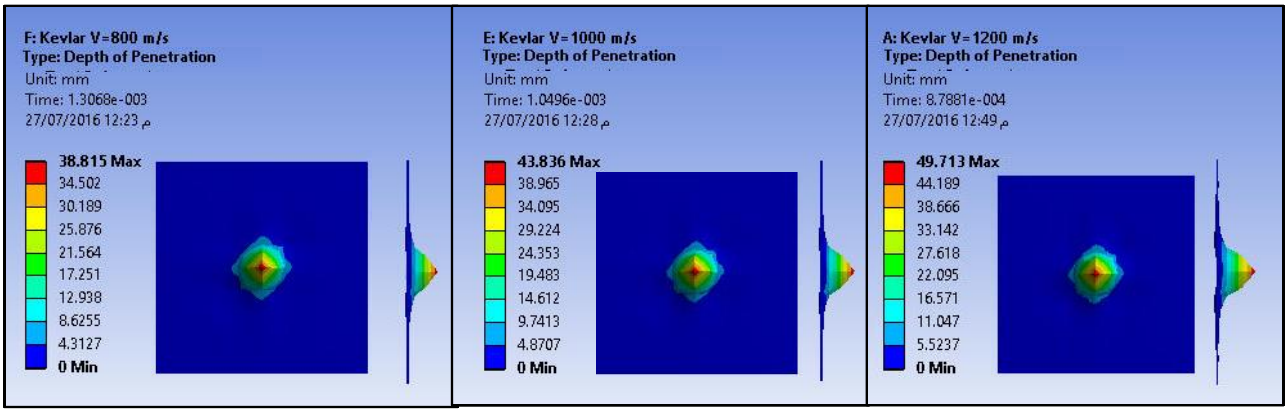


Fig. (9), depth of penetration at 800 m/s, 1000 m/s and 1200 m/s for Kevlar armor

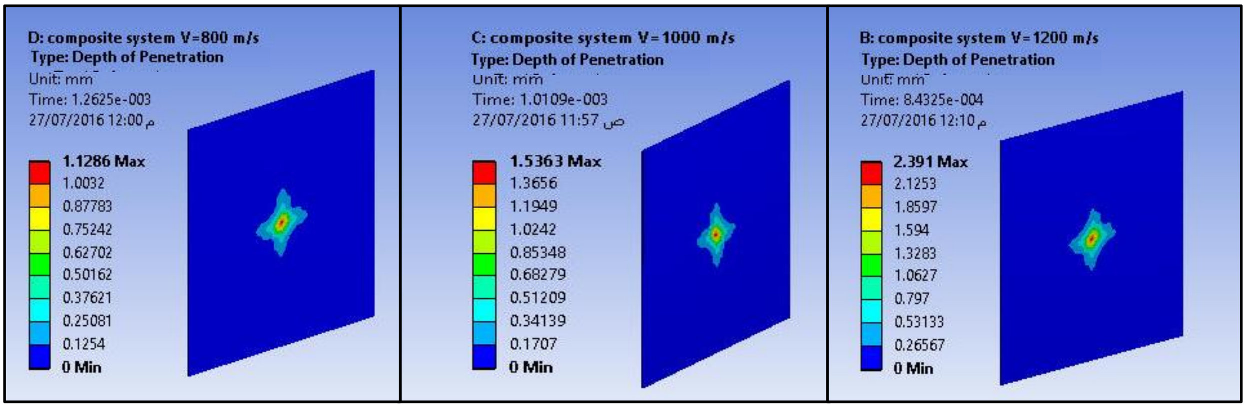


Fig. (10), depth of penetration at 800 m/s, 1000 m/s and 1200 m/s for composite system armor

From above figures, we find that the steel armor has collapsed completely when the collision bullet and it was due to the weakness of its resistance and for all the velocities used in the study, namely that bullet penetrate the armor is fully due to lack of thickness of the armor, on the other hand, we find that the armor composed of Kevlar fibers with epoxy did not collapse which mean that bullet has not been pass through by armor, but the depth of penetration was greater than the thickness of the armor dramatically due to plastic deformation in material of armor, which causing injuries to the person who wears armor and we know how well a armor absorbs and scatters the vitality of the projectile is vital to its capacity to decrease injury harm to the body coming about because of slugs that don't puncture an armor. As the fibers in an armor, they twist in the course that the projectile was going into the body. That pushes armor material into the body of the wearer, injury about harm to the middle. This kind of nonpenetrating harm can bring about serious injuries (wounds) and can make harm the inward structures of the body (musculature, bones, ligaments, organs, vascular framework) that may bring about death.

As for the composite system armor we note that the depth of penetration of a few does not exceed (2.39) mm at highest velocity and less than the thickness of armor therefore cannot cause injuries to the body and this is due to every part inside the composite system has a particular function. The ceramic layer diminishes the velocity of the shot and micronizes the projectile. The resulting low mass and the fundamentally decreased pace of these remaining parts, is totally absorbed by the elastic/plastic distortion in the composite substrate, and when the bullet impact the surface of the ceramic, its kinetic energy is incredibly lessened without pass in the ceramic in that stage the bullet encounters an exceptionally pliable misshapening. After approx. 1.5 to 2 μs, the bullet really enters the ceramic body, and in the process the kinetic energy of the shot is diminished further by erosion.

4- Conclusions:

In this study, the modeling and simulation of body armor that modeled from different materials all with the same weight was investigated. The three types of armor were stainless steel 304, Kevlar-epoxy composite and composite system with multi layers of different materials at different velocities. We concluded from research that the steel armor has collapsed completely and no resistance to absolute and did not have at this thickness, while Kevlar fibers with epoxy armor resisted the bullet pass through somewhat but the depth of penetration is greater than the thickness of the armor which causing injuries that may result in death.

On the other hand the composite system armor resisted the pass through and the depth of penetration is safe.

5- References:

1- Lanthier J-M. “The effects of soft textile body armour on the wound ballistics of high velocity military bullets”. MSC Thesis, Cranfield University College of Defence Technology, Shrivenham,Wiltshire, UK; 2003.

2- Michael B. Mukasey, Jeffrey L. Sedgwick and David W. Hagy, “ Ballistic Resistance of Body Armor”, U.S. Department of Justice, Office of Justice Programs, National Institute of Justice, 2005.

3- Philip M. Cunniff, Margaret A. Auerbach, Eugene Vetter and Doetze J Sikkema, “HIGH PERFORMANCE “M5” FIBER FOR BALLISTICS / STRUCTURAL COMPOSITES”, Magellan Systems International, SB Arnhem, the Netherlands, 2002.

4- Erol ÜNALER, “ DEVELOPMENT AND CHARACTERIZATION OF LIGHT-WEIGHT ARMOR MATERIALS”, MSC Thesis, İzmir Institute of Technology, Turkey, İzmir, 2005.

5- K. Karthikeyan, B.P. Russell*, V.S. Deshpande and N.A. Fleck, “Multi-hit armour characterisation of metal-composite bi-layers”, Department of Engineering, Cambridge University, U.K, 2012.

6- M. Grujicic, W.C. Bell, B. Pandurangan, “Design and material selection guidelines and strategies for transparent armor systems”, Material and Design (34), Elsevier Ltd, 2012.

7- G. Gopinath a, J.Q. Zheng b, R.C. Batra, “Effect of matrix on ballistic performance of soft body armor”, Composite Structure (94), Elsevier Ltd, 2012.

8- M. Rojek , M. Szymiczek and J. Stabik, “Composite materials with the polymeric matrix applied to ballistic shields”, Archives of Materials Science and Engineering”, volume (63), issue (1), 2013.

9- Yohannes Regassa, Gessesew Likeleh and Ratnam Uppala, “Modeling and Simulation of Bullet Resistant Composite Body Armor”, International Journal of Research Studies in Science, Engineering and Technology, Volume (1), Issue (3), 2014.

10- Advanced Armor Technology: Application Potential for Engine Fragment Barriers for Commercial Aircraft, U.S. Department of Commerce, National Technical Information Service, 1997.

11- Flat Products Stainless Steel Grade Sheet, North American Stainless, 2016

12- Kenneth Horn, Kimberlie Biever, Kenneth Burkman and Paul DeLuca, “Lightening Body Armor", Technical Report, Library of Congress Cataloging-in-Publication Data, American United State, 2012.

13- Paul V. Cavallaro, “Soft Body Armor: An Overview of Materials, Manufacturing, Testing, and Ballistic Impact Dynamics”, NUWC-NPT Technical Report 12,057, Naval Undersea Warfare Center Division Newport, Rhode Island, 2011.

14- George S. Springer, “Mechanics of Composite Structures”, Cambridge University Press, 2003.