AN INVENT TO IMPROVE BULLETPROOF VESTS CAPABILITIES

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Abstract— Woven laminated Epoxy reinforced with Kevlar and Glass fiber vest plates are subjected to three types of projectiles with three different masses and impact velocities. An invented phenomenon is adopted by using an air gap between two composite plates. The effect of the air gap gave about 20% modification in the total absorbed energy and momentum which made a good decrease in the bullet speed after hitting the target.

Index Terms— Vest, Bulletproof, Composite material, Absorbed energy .

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1 INTRODUCTION

Bulletproof vests are specifically designed to protect the wearer's vital organs from injury caused by fire arm projectiles. All over the world, different cultures developed body armor for use during combat. Around the fifth century B.C., Persians and Greeks used up to a dozen layers of linen, while Micronesian inhabitants of the Gilbert and Ellice Islands used woven coconut palm fiber until the nineteenth century. Somewhere else, armor was made from the hides of animals: as wore rhinoceros skin in five to seven layers,Mail armor comprised linked rings or wires of iron, steel, or brass and was developed as early as 400 B.C [1].

The use of composite materials has been steadily increasing in the past several decades. The high strength, high stiffness and lightweight properties make them particularly attractive to designers in a variety of industries. The composite material consists of a matrix and one or more of the reinforcing phases such as particulate, flake and fiber.

In the continuous fiber composites, due to its large surface area, the fiber-matrix interface influences the behavior of a composite. In addition to providing a mechanism to transfer loads from matrix to fibers, the interface also plays an important role in determining the composite toughness. In spite of many advantages, the composite materials suffer from lower ductility and toughness when compared to commonly used metals [2].

Since the plastics revolution of the 1940s, bulletproof vests became available in a limited manner. The vests of the time were made of ballistic nylon and supplemented by plates of fiber-glass, steel, ceramic, titanium, Boron, and the most effective composites of ceramic and fiberglass. Ballistic nylon was the standard cloth used for bulletproof vests until the 1970s. In 1965, Kevlar is invented, a liquid polymer that can be spun into aramid fiber and woven into cloth. Primarily, Kevlar was developed for use in tires, and later for such diving products and different parts for planes and boats. In 1971, Lester Shubin of the National Institute of Law Enforcement and Criminal Justice advocated its use to replace bulky ballistic nylon in bulletproof vests. In 1989, the Allied Signal Company developed a competitor for Kevlar and called it Spectra.

Originally used for sail cloth, the polyethylene fiber is now used to make lighter, yet stronger, nonwoven material for use in bulletproof vests along-side the traditional Kevlar [3].Taguchi method to study the ballistic resistance capability of ceramic and Kevlar composite materials. Signal to Noise ratio (S/N) and ANOVA analysis are used to find the best combination among several combinations considering controllable factors including thickness ratio of ceramic to Kevlar , size of ceramic and proportion of zirconium powder (ZrO2) [4]. The energy absorbed due to impact of conical nose projectile on composite materials, which he classified energies into four types energy contact and energy delamination layers and strain energy and friction energy, The mechanical properties were calculated by standard tests and found that the calculation of modulus of elasticity is higher for composite materials with Kevlar from rest fibers with same matrix material [5]. Composite structures which a¬re subject to the impact of trauma and that lead to full or partial penetration by given velocity required and using the Projectile [6].

M. Ganesh Babu, et. al. (2006) [7] performed impact tests on different laminates between the range of 30m/sec to 60m/sec, using a cylindro-conical projectile. Energy absorption and ballistic limit are calculated experimentally. They found that increasing 1mm thickness make the ballistic limit increase about 6 m/sec. the energy absorption increased up to a certain limit and then decreased slightly for all the test panels which were consisting of 3 and 5 layers of 3 types of glass reinforcement with different combinations.

The development of science entered the composite material for the war industry. Composite material, used in the armor where used several fibers including carbon fiber, boron fiber, Fiber glass, walnut fiber and others. For light weight and flexibility and high resistance to break through. Nowadays, bulletproof vest is made from PARA-ARAMID such as polyethylene, spectra, twarone, and Kevlar fibers because of its great advantages of light weight, flexible, high durability and high tensile strength[8].

Kevlar is used in protective bullet proof vests in order to contain a series based on the strong bonding between atoms of carbon rings where the strength of these rings is five times the strength of steel. Kevlar is one of the greatest inventions of people working on the distracting Strength of trauma to the shot and absorbs the high kinetic energy smoothly to limit danger that reach the body and save the life of the soldier. But there are disadvantages, it's expensive and is influenced by ultraviolet rays and humidity which invited us to use other materials to increase the efficiency and reduce the price and make it resistant to sunlight and humidity.

This research includes the study of composite materials used in bulletproof armor to find an innovative way in the layers compaction to get the best penetration resistance by obtaining the maximum absorbed energy. Fiberglass was chosen as reinforced material for Kevlar and the matrix material is epoxy with titanium dioxide powder. This powder resists sunlight and humidity, while epoxy increases the hardness and gives armor satin face able to repel the shot and stop it and prevent it from breakthrough.

2 EXPERIMENTAL WORK

Three combinations of composite materials (A_1, B_1, and C_1) are used to form the shield plates as described in table 1.

TABLE 1: THE LAYER COMBINATIONS AND MATERIAL'S VOLUME FRACTIONS USED IN THIS WORK

Type	Layers arrangement in single plate	Plate thickness (mm)	Volume fraction %			
			Kevlar	Glass	Epoxy	Titanium powder
A_1	4 layers Kevlar, 4 layers fiber glass 2k-4g-2k	7.4	0.39	0.191	0.415	0.0115
B_1	2 layers Kevlar, 4 layers fiber glass 1k-4g-1k	4.5	0.321	0.312	0.355	0.0098
C_1	2 layers Kevlar, 6 layers fiber glass 1k-6g-1k	6.5	0.222	0.324	0.443	0.0123

The properties of these materials are listed in table 2.

TABLE 2: THE MATERIAL'S PROPERTIES

Properties	Material			
	Kevlar29 29K	Fiber glass E-glass	Epoxy Resin	Titanium powder
Density (g/cm³)	1.44	2.54	1.25	4.51
Modulus of elasticity (Gpa)	62.05	72.4	3.5	115
Shear modulus (Gpa)	3	35.42	1.27	44
Poisson's ratio	0.44	0.20	0.38	0.33

This rig consists of the following:

1- Shotguns: three types are used as described in table 3.
2- Shotgun holder.
3- Chronograph (velocity measurement device).
4- Steel bracket to hold the target plates

Simply, the test depends on reading the bullet speed before and after hitting the target (initial and final velocities) to calculate the total absorbed energy using the Kinetic energy as shown in equation 1 as follows:

$$KE_{abs} = \frac{1}{2} m (v_1^2 - v_2^2) \ldots\ldots\ldots\ldots\ldots 1$$

Where
KEabs   is the absorbed kinetic energy (joule)
m   is the mass of the projectile (bullet) (in grams)
v_1 is the bullet's initial velocity before hitting the target plate. (meter/second)
v_2 is the final bullet's velocity.

Also the initial and final momentums are calculated from equation 2.

$$M_{initial} = m \, v_1$$
$$M_{final} = m \, v_2$$

$\ldots\ldots\ldots\ldots\ldots 2$

Where M refers to the momentum

The test rig is prepared and assembled as shown in figure 1

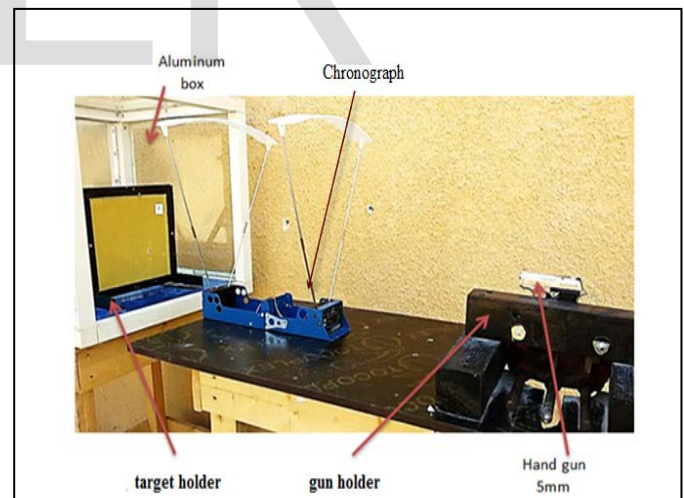Fig 1. The test rig

TABLE 3: THE USED SHOTGUNS

Weapon type	size of bullet (mm)	mass of bullet (gm)	speed of bullet (m/sec)
Hand gun	5	3.6	200
Hand gun	9	8	360
Kalashnikov	7.62	9.7	760

In the first step, one plate of each combination is used as a target exposed to three types of bullets shot from the three types of shotguns within a distance of 5 meters for the first two guns and 25 meters for the Kalashnikov.

In the next step, the targets were made of two closed fitting plates. For the third step, the same targets of the last step are used but, after separating the two plates of each target making an air gap between them and repeating the shooting procedure. The air gap thickness equals to one plate thickness.

The absorbed energy for each case is calculated and presented in curves related to the initial momentum of the projectile.

Another curve is presented relating the initial and final momentum. Our goal is only to discover the effect of the presence of the air gap between the two plates on energy absorption.

4 NUMERICAL CHECKS

A numerical sample for type A1 is prepared using ANSYS program with LS-DYNA, using two attached plates (named AA), these plates are exposed to the second and third types of bullets i.e. (8gm with 360 m/s speed) and (9.7 gm with 760 m/s speed). A second sample of A1 is prepared with a gap between the two plates (named AGA) and exposed to the predefined bullets. The velocity profile for each case are presented in order to be discussed for the effect of the air gap.

5 RESULTS AND DISCUSSION

Figures 2,3 and 4 show the relationship between the initial momentum and final bullet speed for single plate, double attached plates and double plates with gap respectively for the three types A_1, B_1 and C_1.

Figures 5, 6 and 7 show the relationship between the initial momentum and absorbed energy for the mentioned cases.
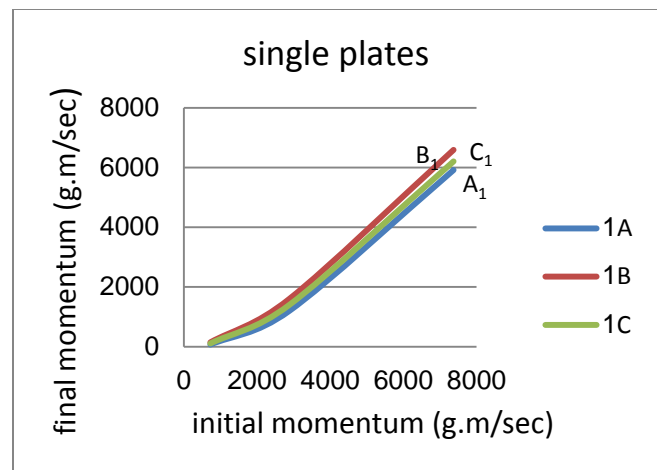

Fig.2.Relationship between initial momentum and final Bullet velocity single plate
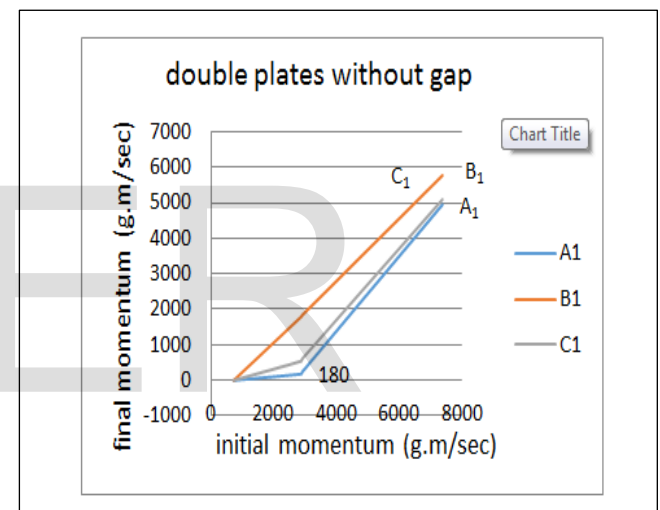

Fig.3. Relationship between initial momentum and final Bullet Velocity doubles plate
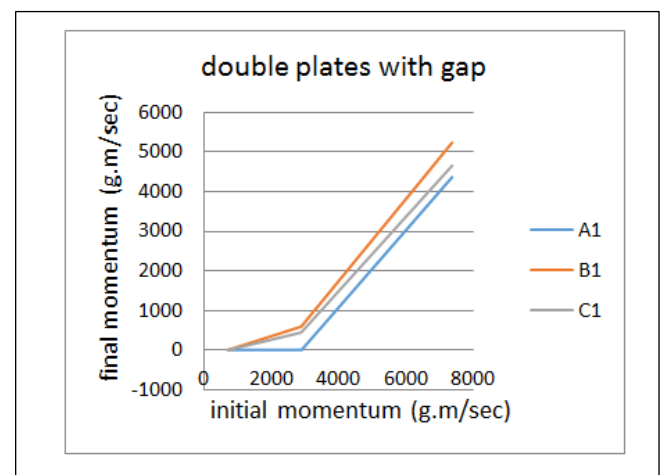

Fig.4. Relationship between initial momentum and final Bullet Velocity doubles plate with gab
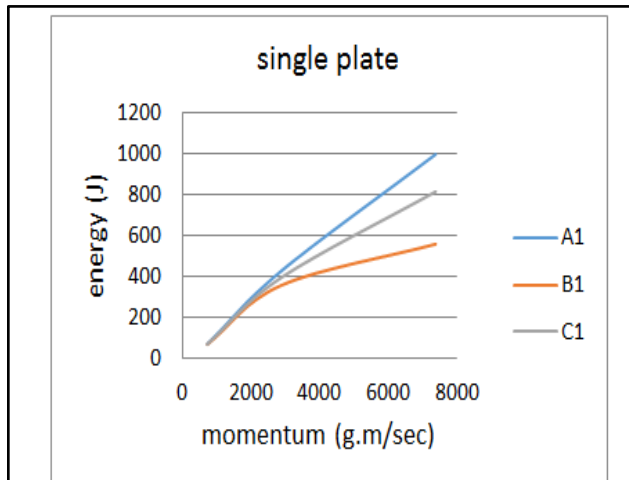
Fig .5.Relationship between the initial momentum and the absorbed energy, single plate.
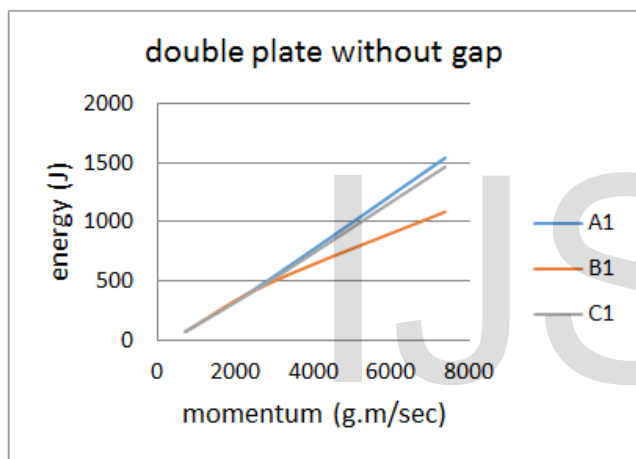

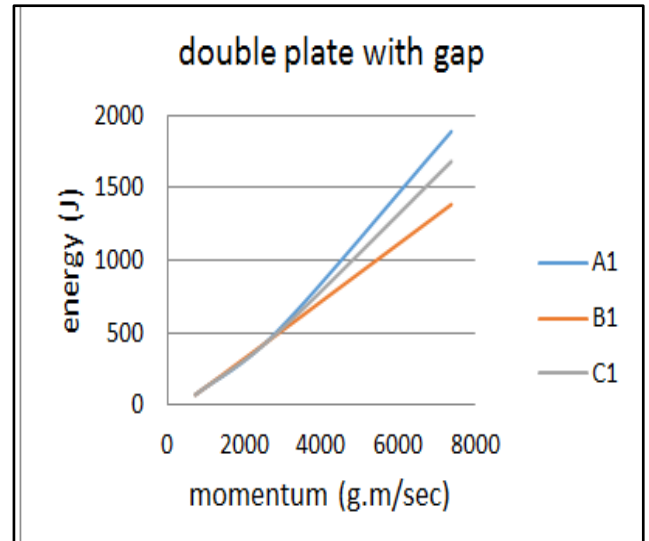Fig. 6. Relationship between the initial momentum and the absorbed energy, double plate without gap

Fig.7.Relationship between the initial momentum and the absorbed energy, double plate with gap

Regarding to figures (2 – 7) the effect of the number of plies and the type of reinforcement fibers are noticed. The effect of Kevlar fiber presence is noticed comparing the results of tensile test for (A1 and C1) plates. The cause belongs to the higher contact stiffens for the high modulus materials such as Kevlar compared with fiberglass. This property gives the reason for using Kevlar layer as a stiffened layer for the fiberglass. The most important result is that comes from figures (4 & 7), it leads to invent in the field of vest shields. This result is due to the presence of the air gap between two plates of the composite materials where the absorbed energy increased when the air gap is used for about 20% or more.

The above results may be confirmed from the numerical results of LS-DYNA by producing the velocity profile

Figure (8) demonstrates the velocity profile for a bullet having 600 m/sec initial velocity hitting the target of A1 double plate with a gap in between [AGA]. The bullet is a 9 mm spherical head and 8 g mass. The bullet reaches zero speed after 0.2x10-4 second for the target with gap while the time required for the case of no gap was 0.6x10-4 as shown in figure (9), and this means that there is an advantage to gain 300% in time.

Figures (10) and (11) give the velocity profile for a 7.6 mm bullet hitting the same target but, in this case the bullet speed is 760m/sec and 9.7g mass having sphere-conical head. Although the bullet did not stop and passed through the targets but, the speed reduction is noticed obviously. The speed reduction in the presence of gap [AGA] was about 11% as shown in figure (10), and the reduction in the case of no gap [AA] was 6.5% i.e. the advantage of gap is 50% as shown in figure (11).

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• *Co-Author name is currently pursuing masters degree program in electric power engineering in University, Country, PH-01123456789. E-mail: author_name@mail.com*
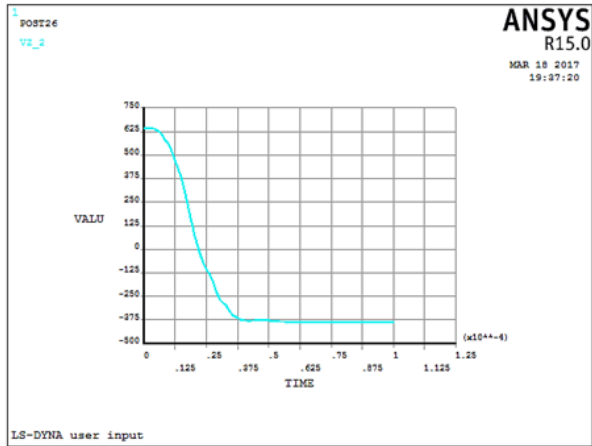 (*This information is optional; change it according to your need.*)

Fig .8. The velocity profile for a bullet with initial velocity 600 m/sec for 1x10-4 sec period from hitting a target of (A1) double plate type with gap between the plates [AGA].

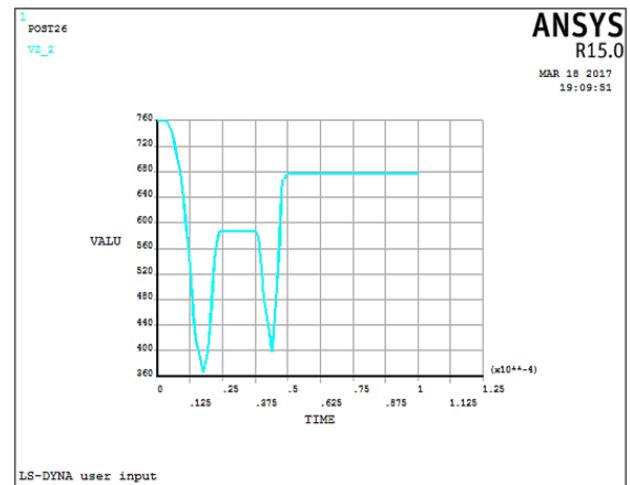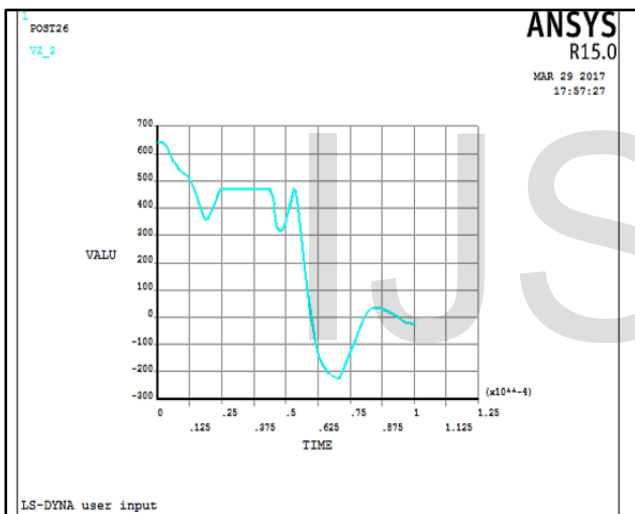Fig.9.The velocity profile for a bullet with initial velocity 600 m/sec for 1x10-4 sec period from hitting a target of (A1) double plate type without a gap between the plates [AA].

Fig.10.The velocity profile for a bullet with initial velocity 760 m/sec for 1x10-4 sec period from hitting a target of (A1) double plate type with gap between the plates [AGA].
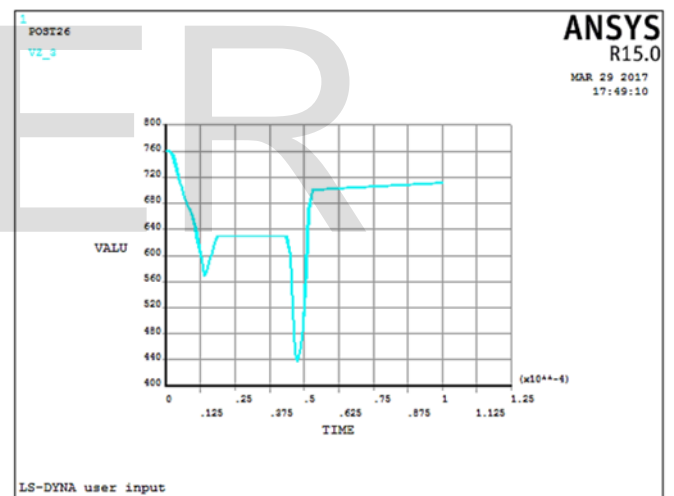

Fig.11.The velocity profile for a bullet with initial velocity 760 m/sec for 1x10-4 sec period from hitting a target of (A1) double plate type without a gap between the plates [AA]

6 CONCLUSIONS

From the above results and discussion we can conclude that there is a noticeable effect for the presence of an air gap between two plates on the absorbed energy. This advantage is real whatever the shape of the bullet is or the number of the plate layers or the materials used, the difference is only in the percentage of gain in energy absorption.

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