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Numerical Comparison Study between Composite Material and Traditional Material for Body Armor Application

A project submitted to the University of Babylon for the award of Bachelor of Materials Engineering from polymer and petrochemical industries Department

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بسم الله الرحمن ا لرحيم

اقْرَأْ وَرَبُّكَ الْأَكْرَمُ (3) الَّذِي عَلَّمَ بِالْقَلَمِ (4)عَلَّمَ الْإِنْسَانَ مَا لَمْ يَعْلَمْ(5)

صدق الله العلي العظيم

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Dedication

To

everything in my life(My father and mother)

my brothers and My Sisters .

My esteemed supervisor (Dr.Ahmed Fadhil)

with all respect My friends.

Abstract

With the continuous development of weapons and the continuation of war in the world, it became necessary to develop protective armor as well, as composite armor was used instead of traditional steel armor, providing ,better protection and less weight.
In this study, a comparison was made between conventional and composite armor (epoxy /kavler 149 , epoxy /carbon fiber) at different speeds (780-2000)m/s using (Ansys v16.1 workbench explicit dynamic).
The numercal results indicate that the amount of deformation in steel 1006 is less then composite armor.

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Chapter One

Introduction

1.1. Introduction

Humans throughout recorded history have used various types of materials to protect themselves from injury in combat and other dangerous situations. At first, protective clothing and shields were made from animal skins. As civilizations became more advanced, wooden shields and then metal shields came into use. Eventually, metal also was used as “clothing,” what we now refer to as the suit of armor associated with the knights of the Middle Ages. However, with the advent of firearms (c.1500), most of the traditional protective devices were no longer effective. In fact, the only real protection available against firearms were manmade barriers, such as stone or masonry walls; manmade fortifications such as trenches and ditches; or natural barriers, such as rocks and trees [1].

Firearms changed the nature of armor. If it became heavy and thick to protect it from bullets, it would become very heavy and impossible to wear. Shortly thereafter, soldiers began wearing only helmets and chest plates during battle. At the end of the World War (1914-1918), soldiers wore helmets to protect their heads, and they rarely wore any other armor. Modern technology at the present time has created a shield that can resist various weapons, in addition to being light in weight, and soldiers can wear it effortlessly. Soldiers and policemen wear counter armor, which is a type of bulletproof vest, capable of fending off most light weapons and shrapnel. Some bulletproof jackets these days contain porcelain sheets or tiles that are sewn together with the fabric. The layers of heavy nylon together are like a quilt, and when the bullet is fired at this type of jacket, they flatten when it collides with the outer layers of nylon, but it does not penetrate the jacket [2].

In 1943, the Dow Company produced Doron, a material made of glass fiber bonded with an ethyl cellulose resin.,

These so-called flak vests saw service at the end of World War 11.

During the Korean War, the U.S. Army issued the M-1952 Body Armor. Although uncomfortable to wear and hot, it was the most widely issued flak jacket of the Vietnam War and became one of the conflict's ubiquitous symbols[3].

generation of ballistic vests was introduced during World War II. The “jacket,” constructed of ballistic nylon, provided protection primarily from munitions fragments and was ineffective against most pistol and rifle threats. These vests also were very cumbersome and bulky and were restricted primarily to military use. It would not be until the late 1960s that new fibers would be discovered that would make today's generation of concealable body armor possible[1].

Among different hybrid composites, ceramic-polymer composite armors are particularly interesting for their high strength and light weight with high energy absorption capability. While the function of ceramics is to retard ballistic impact penetration, a polymer panel is to absorb high energy generation from the propagation of elastic/stress waves . presented studies of composite layered systems based on monolithic armor ceramic tiles joined with polymer infiltrated ceramic foams which have been designed and evaluated for lightweight ballistic protection. Open cell silicon carbide foams of various cell sizes infiltrated with thermosetting or elastomeric polyurethane were used for this design [4].

1.2. The Aim of Research

Creating a simulation using the ANSYS program between body armor made of conventional and composite materials.

the is an object of the present invention to provide a novel form of body armor which may be more acceptable in use and which may exhibit additional advantages compared with known-types.

Chapter Two

Theoretical Part and Literature Review

2.1. Introduction

Personal protective equipment for military personnel in combat activities is extremely important for body safety, so the design of body armor should conform to military needs. There are two types of personal protective equipment for military personnel. In general terms, they are called soft body armor and hard body armor. which are distinguished based on the type of materials used. The protection level of hard body armor is higher but it is heavier and less flexible in movement compared to soft body armor [5].

2.1.1Soft Armor

Soft armor panels are typically constructed of multiple layers of ballistic-resistant materials (see Exhibit 1). The number of layers within the panel and the order in which these layers are placed influence its overall performance. Additional energy is absorbed by each successive layer of material.

A soft armor panel works much like a baseball catcher's mitt. When a handgun bullet strikes the panel, it is caught in a "web" of strong fibers. These fibers absorb and disperse the impact energy that is transmitted to the panel from the bullet. This process causes the bullet to deform or "mushroom." How well a panel absorbs and disperses the energy of the bullet is key to its ability to reduce blunt force injury to the body resulting from bullets that do not perforate an armor. As the fibers in a panel "catch" a bullet, they deform in the direction that the bullet was traveling into the body. That pushes panel material into the body of the wearer, resulting in injury to the torso. This type of non-penetrating injury can cause severe contusions (bruises) and can cause damage to the internal structures of the body (musculature, bones, ligaments, organs, vascular system) that may result in death [6].

Figure (2-1): Show BALLISTIC MATERIAL AND COVER

2.1.2 Hard Armor

Hard armor plates (see Exhibit 2) may be constructed from ceramics, compressed laminate sheets, metallic plates or composites that incorporate more than one material. Generally speaking, hard armor plates work in one of two ways: They can capture and deform the bullet, or they can break up the bullet. In both instances, the armor then absorbs and distributes the force of the impact. Although some hard armor plates are designed to be used by themselves in a carrier, in most instances they are designed to be used in conjunction (IC) with a soft armor panel as described in the next section.

Figure (2-2): Show HARD ARMOR PLATES

2.1.3 In-Conjunction (IC) Armors

Many hard armor plates are designed to be used with a specific soft armor panel to achieve a desired level of ballistic protection. They are not designed to be used alone. Such armors are called IC armors They are constructed by adding pockets to the front and rear of a soft armor's carrier (see Exhibit 3). The hard armor plates are inserted into these pockets over a portion of the underlying soft armor panel Less common, but still occasionally available, is the combination of two soft armor panels as an IC armor designed to increase the level of ballistic protection Plates that are part of an IC armor must be used only with the designated soft armor panel. If not the desired level of ballistic protection may not be achieved. Consequently, the hard armor plate

component of the IC armor is labeled to identify the corresponding model of soft armor panel with which it is to be used.

Figure (2-3): Show IC ARMOR

2.2 Styles

In the OLES selection and application guide, it divides body armor into three different styles. One is concealable body armor; one is semi-rigid body armor; the third one is rigid body armor.

Concealable body armor is the most used type of body armor, and it is worn under the normal uniform as a protective undergarment. Because of its snug, this kind of body armor should be able to offer better comfort, lightweight, and mobility than the other two styles (NIJ guide 100-01).

Semi-rigid body armor is a body armor designed for higher threat levels. Type III and IV body armors are usually categorized in this style. It is hard to conceal in that it is always composed of articulated plates, like plastic, steel, and ceramic (NIJ guide 100-01).

Rigid body armor gives wearers the lowest mobility in that it is compound with a molded ballistic material made for protect a certain part of the body. It is worn externally and only for short time periods (NIJ guide 100-01) [7].

2.3 NIJ Body Armor Classification

Personal body armors covered by this standard are classified into seven classes, or types, by level of ballistic performance. The ballistic threat posed by a bullet depends, among other things, on its composition, shape, caliber, mass, angle of incidence, and impact velocity. Because of the wide variety of bullets and cartridges available in a given caliber and because of the existence of hand loaded ammunition, armors that will defeat a standard test round may not defeat other loadings in the same caliber. For example, an armor that prevents complete penetration by a 40 S&W test round may or may not defeat a 40 S&W round with higher velocity. In general, an armor that defeats a given lead bullet may not resist complete penetration by other bullets of the same caliber of different construction or configuration. The test ammunition specified in this standard represent general, common threats to law enforcement officers [8].

2.3.1. Type I (22 LR; 380 ACP):

This armor protects against .22 caliber Long Rifle Lead Round Nose (LR LRN) bullets, with nominal masses of 2.6 g (40 gr) impacting at a minimum velocity of 320 m/s (1050 ft/s) or less, and 380 ACP Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 6.2 g (95 gr) impacting at a minimum velocity of 312 m/s (1025 ft/s) or less.

2.3.2. Type IIA (9 mm; 40 S&W):

This armor protects against 9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr) impacting at a minimum velocity of 332 m/s (1090 ft/s) or less, and 40 S&W caliber Full Metal Jacketed (FMJ) bullets, with nominal masses of 11.7 g.

(180 gr) impacting at a minimum velocity of 312 m/s (1025 ft/s) or less. It also provides protection against the threats mentioned in section 2.3.1.

2.3.3. Type II (9 mm; 357 Magnum):

This armor protects against 9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr) impacting at a minimum velocity of 358 m/s (1175 ft/s) or less, and 357 Magnum Jacketed Soft Point (JSP) bullets, with nominal masses of 10.2 g (158 gr) impacting at a minimum velocity of 427 m/s (1400 ft/s) or less. It also provides protection against the threats mentioned in sections 2.1 and 2.2.

2.3.4. Type IIIA (High Velocity 9 mm; 44 Magnum):

This armor protects against 9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr) impacting at a minimum velocity of 427 m/s (1400 ft/s) or less, and 44 Magnum Jacketed Hollow Point (JHP) bullets, with nominal masses of 15.6 g (240 gr) impacting at a minimum velocity of 427 m/s (1400 ft/s) or less. It also provides protection against most handgun threats, as well as the threats mentioned in sections 2.3.1, 2.3.2, and 2.3.3.

2.3.5. Type III (Rifles):

This armor protects against 7.62 mm Full Metal Jacketed (FMJ) bullets (U.S. Military designation M80), with nominal masses of 9.6 g (148 gr) impacting at a minimum velocity of 838 m/s (2750 ft/s) or less. It also provides protection against the threats mentioned in sections 2.3.1, 2.3.2, 2.3.3, and 2.3.4.

2.3.6. Type IV (Armor Piercing Rifle):

This armor protects against .30 caliber armor piercing (AP) bullets (U.S. Military designation M2 AP), with nominal masses of 10.8 g (166 gr) impacting at a minimum velocity of 869 m/s (2850 ft/s) or less. It also provides at least single hit protection against the threats mentioned in sections 2.3.1, 2.3.2, 2.3.3, 2.3.4, and 2.3.5.

2.3.7. Special Type:

A purchaser having a special requirement for a level of protection other than one of the above standard types and threat levels should specify the exact test round(s) and minimum reference impact velocities to be used, and indicate that this standard shall govern in all other aspects.

2.4. Body armor Construction and design

Construction Methods

Typically, concealable body armor is constructed of multiple layers of ballistic- or stab-resistant materials, assembled into the “protective panel.” The protective panel is then inserted into the “carrier,” which is constructed of conventional garment fabrics such as nylon or cotton. The protective panel may be permanently sewn into the carrier or may be removable. Although the overall finished product looks relatively simple in construction, the protective panel is very complex [9].

A typical composite armor is composed of material layers made of fiber laminates, ceramics, rubbers, metals, etc. Most frequently the design variables in a composite layers and the [10].armor design are limited to the material selection, order of the thickness of the layers .

The design of anti-bullet armor is very complex and requires many sophisticated tools. Empirical methods are the most widely used ones because they offer reliability but they are extremely expensive in terms of experimentation. Moreover, the results of the empirical methods do not give enough information about the history of the projectile, the trends when changing the configurations or the phenomenological process. The second way to tackle the problem is to use hydrocodes to simulate the physical process numerically. Either finite element or finite difference schemes need many parameters for material description which very often are difficult to quantify for a correct calculation. The numerical simulation involves finding the complete solution of some differential equations. The numerical approach provides a lot of information but again cannot give trends unless multiple configurations are calculated which consequently makes the design of armor a long and tedious process. Existing software can be used for this approach are Autodyn, Dyna3D, Lsdyna and Ansys / Lsdyna. The third approach is the analytical one. Providing the appropriate assumptions, it could be a simple and a fast way that allows obtaining phenomenological [11]information of the penetration mechanics without losing much accuracy with respect to the numerical models the principal factor that dictates the design of body armors is the type(s) of threat(s) for which protection is required that is, ballistic, fragment, blast, stab, slash, chemical, fire, etc [12].

2.5. material for body armor

Composite materials are specific materials obtained by combining more than one material at the macro level. The purpose of this process is to create superior and more effective materials. In recent years, fiber fabrics were frequently used in the production of composite materials due to their high mechanical strength and ease of production. Fiber fabrics were used in the production of personal armor material because of their good mechanical properties and their effectiveness with respect to impact[13] .Scientists have been engaging in inventing new materials for body armors in order to minimize the weight and maximized the protection and comfort. In 1965, Kevlar was developed, and was the first material that was used for a modern ballistic garment because of its lightweight and flexibility (DuPont, 2008). Today, aramid, high performance polyethylene (HPPE), and polyphehylenebenzobisoxazole (PBO) are the major types of polymer fibers used in the ballistic fabrics (Fowler, 2003). The fabrics were originated to achieve better properties such as light weight, waterproof, flexibility ,and impact absorbency [7].

2.5.1.FIBERS

is the fiber (also referred to as “filament”) scale in which fiber diameters are often measured in units of micrometers (10-6 meters) (also referred to as microns). For comparison, fiber diameters used in soft body armors are several times smaller than that of human hair. Fiber weights are classified by denier, which is the linear density defined as “the weight in grams of a9000-meter-long fiber (or yarn).” Fiber tensile strength is defined as “tenacity having units of grams-force per denier (gpd).” Tenacity generally increases with decreasing fiber diameter. The stiffness of a fiber is designated by its elastic modulus E. The elastic modulus is obtained from tensile tests of a fiber (or yarn). Table 1. is the summary of properties of the main fibers used in body armor (NIJ guide 100-01).[14]. The architecture of the protective armor with a combination of fibers and other materials properties results in the products that respond to the threats adequately and reaching the balance between comfort and safety. New fibers and architecture systems will lead to the new directions for armor of light weight and higher levels of safety[15].

Table (1) Ballistic Fiber Names, Manufacturers, and Properties.

Name	Manufacturer	Properties
Kevlar	**DuPont**	**First material used in modern body armor High strength Lightweight High chemical/ cut/ flame resistance Unaffected in water**
Spectra	**Honeywell**	**High strength Water penetration resistance High chemical/ cut resistance Lightweight**
GoldFlex	**Honeywell**	**Lightweight Thin Good protection against blunt trauma**
Twaron	**Twaron Products**	**High energy absorption Quicker impact dispersal**
Dyneema	**Netherlands**	**Very Lightweight High energy absorption**
Zylon	**Toyobo**	**High thermal properties Better tensile strength Lightweight**
Note. Zylon is currently identified as unstable material for body armor. It increases the risk of injure when used in body armor. Case studies showed that the ballistic performance of Zylon degraded in water or over time (New Scientist, 2007; NLECTC, 2005) [7].		

2.5.1.1. . Post-Kevlar

invention era One of the most important inventions of the twentieth century, apart from computers or lifesaving heart-lung machines, is a synthetic fiber from the group of aromatic polyamides. Nowadays, it is known by the name Kevlar®. The polymer out of which the fiber was made was invented in 1964 by the chemist Mrs. Stephanie Kwolek who worked in a research lab at DuPont. DuPont was looking for chemical combinations that would make stronger fibers for fabrics. In the course of lab experimentation, Kwolek heated a newly mixed combination of substances. The mixture presented unexpected features. The new era of personal body protection had begun. The initial tests performed on the fabrics made of Kevlar® proved its ability to stop a wide range of projectiles. The next stage was to elaborate a new set of bullet-resistant vests for law enforcement. In the course of these experiments, five plain weave fabrics woven from Kevlar® 29 yarns of 1000 denier (about 111 tex) were tested and turned out to be the most bullet resistant. Soon, it was discovered that this amount of layers could stop some of the projectiles, but could not prevent non-lethal injuries, which are nowadays called blunt trauma. A great number of modifications to the protective set of fabrics, as well as the design of the protection itself, were introduced. One of the most meaningful was the personal armour system for 220 Textiles for Advanced Applications ground troops (PASGT) weighing 4.5 kg (medium size). PASGT was made of Kevlar® and this abbreviation refers to both vests and helmets1 made of Kevlar®. These were utilized by all military services from the mid-1980s to around the middle of the last decade[16].

2.5.1.2.Existing high-performance fibers for ballistic protection

2.5.1.2.1. Aromatic polyamides

also known as Aramids, are chemical, man-made, synthetic polymers utilized for production of flame retardant and ballistic protection fibers. Aramids belong to the polyamide (PA) group, together with aliphatic polyamides (e.g. Polyamide 6 or 6.6 (PA 6 and 6.6)) and Polyphthalamides, also known as polyamides with semi aromatic chains, e.g. Polyamide 6T (PA 6T). A very specific aramid known as Kevlar® was commercialized by the Du Pont Company in 1972. The discovered substance was characterized as having a super-rigid molecular chain and a fiber made of it had an ultra-high modulus. Kevlar® aramid fiber is based on poly(p-phenylene terephthalamide; PPD-T), one of the Para-oriented aromatic polyamides that was obtained by S. Kwolek. PPD-T can be prepared in the frame of a classical synthesis based on a low temperature polycondensation of p-phenylene diamine (PPD) and terephthaloyl chloride (TCI) in a dialkyl amide solvent and other methods, e.g. direct polycondensation reaction.

Apart from well-known types of Kevlar®—Kevlar®, Kevlar® 29, Kevlar® 49, Kevlar® 68, Kevlar® 100, Kevlar® 119, Kevlar® 129 and Kevlar® 149—relatively novel varieties include Kevlar® AP (15% higher tensile strength than K-29) and KM2 Plus fiber with enhanced ballistic resistance for armour applications. Another type of aramid-based paraaramid fiber is Twaron® (a brand name of Teijin Aramid). It is a heat-resistant and strong synthetic fiber which [16].

2.5.1.2.2.poly (p- phenylene-2, 6-benzobisoxazole), or PBO fibers

It is a new fibre manufactured by Toyobo Co. Ltd. (Osaka, Japan) under the trade name Zylon around 1998 with the help of immense research activities and technology. It is a high strength and modulus fibre with remarkable thermal stability. The PBO fibres has been used first to manufacture the Second Chance Body Armour Inc. (Central Lake, Mich., U.S.A.) and others ballistic vests. Zylon woven fabrics has also an ability to absorb nearly twice the energy per unit areal density than both Kevlar and Spectra when gripped on all four edges, and almost 12 times that of aluminium fuselage skin but costs several times as much as aramid or polyethylene. The ballistic impact performance of PBO systems is substantially superior to Kevlar 29 systems and marginally better than

Kevlar KM2 systems. Moreover, PBOs provide a vest with equivalent protection to aramid vests at half the thickness. However, PBO has been faced problem from vest manufacturing market due to performance decline at aging regardless of climate in a relatively mild environmental conditions of moisture and sunlight heat according to Toyobo test figures posted on the BSST Web site (by which it showed a 15 percent decline in performance). Another study on the PBO degradation mechanisms not only with moisture but also acid and radiation from the UV–vis spectrum has been investigated. Loosening of fibre morphology to increase number and size of defects were observed while exposed to moisture. Besides, presence of aqueous acid brings both loosening of fibre structure and hydrolysis of the oxazole ring structure, whereas UV radiation was primarily affected the hydrolysis of material near the fibre surface with attendant formation of amide linkages. Considering both the poor shear modulus and strength properties of high modules and high strength fibres due to their weak transverse bonds, a new types of fibre, M5 (poly {2,6-diimidazo(4,5-b 4050-e) pyridinylene1,4-(2,5-dihydroxy) phenylene}) was also invented with stronger intermolecular bonds to increase their corresponding transverse bond [17].

2.5.1.2.3-Ultra-high-molecular-weightpolyethylene (UHMWPE, UHMW)

is a subset of the thermoplastic polyethylene. Also known as high-modulus polyethylene (HMPE) or high performance polyethylene (HPPE), it has extremely long chains. UHMWPE is a type of polyolefin. It is made up of extremely long chains of polyethylene, which all align in the same direction. It derives its strength largely from the length of each individual molecule (chain). UHMWPE is synthesized from monomers of ethylene, which are bonded together to form the base polyethylene product. This type of fiber is produced from the polymer via the process of gel spinning. It is about 40% stronger than most aramid fibers. Due to these fibers' properties, they are predominantly utilized in ballistic protection. During the gel-spinning process, the fiber-forming polymer is dissolved in a solvent and spun through a spinneret. The polymer itself is in a gel-like state, which means it is only partially liquid. After spinning, the filaments have a highly oriented structure and the liquid crystals are aligned along the axis of the fiber. Currently, there are two major types of these fibers that are commercially available. They are produced by Honeywell and DSM under the names Spectra® and Dyneema®, respectively. Different series of these fibers have been established as their properties were modified during the production process, e.g. Spectra® 900, 1000 and 2000; Dyneema® SK25, SK60, SK65, SK71, SK75 and SK75. Both Spectra® and Dyneema® are utilized in ballistic protection products as they are characterized as having high-energy absorption and can dissipate the hit wave more easily compared with other existing ballistic [16].

2.5.2.Ceramic material

The application of ceramics for armor continues to be primarily used in lightweight armor systems for protection against small arms and machine gun threats. The design of these systems is typically based upon the mechanical properties of the ceramic to fracture the penetrator and the ability of a rear compliant layer to catch the projectile debris and the damaged ceramic material For defeat of these low-velocity, short projectiles, the fracture mechanism occurs very early in the process with the majority of the interaction time dedicated to energy conversion of the kinetic energy of the debris into deformation and delamination of compliant backing. For medium caliber and heavy armor applications, where the dominant threat is modern, high velocity, heavy metal eroding projectiles, the defeat mechanisms are much more complicated and of longer time duration. For the past three decades, a wide variety of research programs, both domestic and foreign, have focused on developing improved ceramic armor systems for the defeat of these threats….[16] . Ceramic armor is continually evolving to meet ever-increasing threat levels, particularly for body armor for which light weight is a necessity. The initial vehicle and aircraft armor solutions were based on metals (5083 Al, RHA (rolled homogeneous armor-grade steel) or HH (high-hard steel)). However, as the threats in the battlefield changed and, particularly, harder direct fire and fragment threats appeared, metals and PMCs were inadequate because of their low hardness (and or high weight). Hence it became necessary to use other materials such as ceramics These cracks grow in size until they lead to catastrophic failure[18].

An early hint of the potential for using a hard brittle material in armour occurred when Major Neville Monroe-Hopkins found that a thin layer of enamel improved the ballistic performance of a thin steel plate (Dunstan and Volstad 1984). This work was carried out in 1918. Indeed, many early designs employed a hard cera"nic face backed by a relatively ductile mate-rial, thereby employing the disruptor (or 'disturber')/absorber recipe that is still used in modern armour systems today. Arguably, of course, Monroe-Hopkins's invention was not ceramic-faced armour because enamel is not polycrystalline ceramic; it is made by fusing powdered glass to a substrate at temperatures of between 750°C and 850°C. Nevertheless, one of the prin- ciples of ceramic-armour design was developed, namely, placing a hard brit- tle structure onto a relatively ductile backing layer to provide a disturber/ absorber combination[19].

2.5.2.1. Alumina Materials

Alumina with an Al2 O3 content of 96 to 99 mass percentages is still the most important ceramic material in vehicular ballistic protection. It is characterized by good processability and economic volume production and possesses very high mechanical properties.(ALOTEC 96 SB, ALOTEC 98 SB, ALOTEC 99 SB).

2.5.2.2.Silicon Carbide Materials

Aside from alumina materials which are widely in use today, silicon carbide will be used where significant weight reduction or increased mechanical properties are required(SICADUR® FC (SSiC),).

Since the ceramic component is the major player in system weight, the selection of a different material quality is often the only solution. If, for instance, Al2 O3 is replaced by SiC, a reduction of system weight is possible. However, this is associated with a corresponding and significant increase in cost [20].

2.5.2.3.BoronCarbide

Boron carbide's hardness ranks behind only diamond, cubic boron nitride and boron oxide (see Figure 2). Difficult to sinter to full density, boron carbide is usually produced with the addition of sintering aids such as fine carbon or silicon carbide. Boron carbide is typically characterized by:

- Extreme hardness
- Low thermal conductivity
- High elastic modulus
- High compressive strength
- Good nuclear properties
- Low density

where Body armour, requiring a critical balance of hardness, compressive strength, high elastic modulus and low specific density[21].

2.5.3.Fabrics

Fabrics It is normal, and conventional, practice for body armour designers to use multiple layers of dry fabric, like a woven aramid fabric. However, some researchers have investigated the effects of adding an elastomeric matrix to the fabrics. Gopinath , for example, showed that such additions can reduce the maximum deflection of the armour but increased the deformed area. However, the mass efficiency of the soft armours, with and without a matrix, was not calculated. Earlier work in this area has regularly shown that there is little to be gained, ballistic ally, in using a matrix material for soft armour applications [9] .It is necessary to understand the mechanism of yarn pull-out and the role of yarn pull-out friction in the fabric to enhance ballistic performance. Yarn pull-out is defined as one end of the yarn pulled out of the fabric structure by the motion of the bullet penetrates. The force required to pull the yarn from the fabric structure is the sum of the frictional forces between the yarns sets at all the intersecting points [22].

2.5.3.1. fabrics Materials

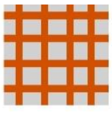
Several materials are used in form of woven fabrics, knitted fabrics and triaxial fabrics. In this work several samples were made of the following fabrics with the specifications given in Table (1).

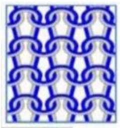
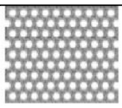
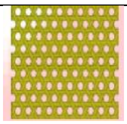
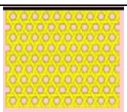
• Woven fabric of cotton from warp yarns 11.8 tex and weft yarns 19.5 tex , ends/cm 20, and picks/cm 20.

• Woven fabric of Kevlar from warp and weft yarns 200 tex, ends/cm 15, and picks/cm 15.

• Single jersey knitted fabrics made of textured polyester multi- filament of count 20 tex with 16% Lycra.

• Triaxial woven fabrics from different types of fibers. Triaxial pattern is basic with a count of 9 yarns/inch (3.6 yarns/cm) in all three axes.

Fabri c no	Fabric Type	Materi al	Weave Yarns per cm	Yarn count tex	Fabric weight 2 (gm/m2)
1	Plain weave 	100% Cotton	20ends/c m, and 20picks/c m	Warp =11.8 Weft =19.5 85	85
2	Plain weave 	kevlar	15ends/c m, and 15picks/c m	200	385

3	 Single Jersey knitted 16% LYCRA	Polyester textured continuous filament yarn	15 wales/cm 16.2 courses/cm	20	200
4	 Triaxial Basic Weave	Polyester	Open Basic 3.6 X3.6 X 3.6	144	166
5	 Triaxial Basic Weave	Para aramid ® 29	Open Basic 3.6 X3.6 X 3.6	6 167	196.7
6	 Triaxial Basic Weave	vectran	Open Basic 3.6 X3.6 X 3.6	140	199
7	fibers 	Continuous filament Carbon fibers - 50B)	(type M46JB)(1 2000-50B)		

Para-aramid Kevlar 29, the yarn counts 167 tex, tenacity 203 cN/tex, and breaking elongation 3.6%. - Polyester, the yarn counts 144 tex, tenacity 80 cN/tex, and breaking elongation14.5%. - Vectran filament, the yarn counts 140 tex, tenacity 233 cN/tex, and breaking elongation 3.8%[22].

2.5.4. strike-face materials

Even with the advent of ultra-lightweight laminates based upon UHMWPE, with their remarkable ability to arrest some of the mild steel-cored ammunition, ceramics remain the most important and influencial group of armour materials because they are very effective against hard-cored, armour-piercing ammunition. This is because for glasses and ceramics, the hardness of the strike-face material by and large governs its ballistic performance. High hardness steels (HHS), like AR500, and most recently Ultra High Hardness steels (UHHS), like Armox Advance from SSAB, have been a popular stand-alone HAP for decades, and still represent the lowest cost option. Advances in metallurgical practices have enabled thinner and thinner products to be produced. However, on a weight-for-weight basis, they do not compete very favourably with the ceramic grades For body armour applications, three main grades have established themselves in the market place: high-purity aluminas, silicon carbides and boron carbides, increasing in ballistic merit rating, and price, in that ascending order. Nowadays, little attention is being given to the well-established families of alumina's whilst the glass-ceramics continue to play only a small part in body armour systems. This latter family has recently been thoroughly reviewed by Benetez and co-workers from Brazil and Germany since they offer great potential for transparent armours. The family of silicon carbides are also well established and the hot-pressed, SiCeN variant still represents the ceramic of choice, in tile form, for many vehicular systems. However, for body armour applications, Reaction Sintered Silicon Carbide (RSSC) grades have become more popular because of their ability to be near-net shaped and, over the past 15 years or so, both US and Australian-made HAPs, incorporating this material, have been fielded. In support of such acquisitions, these inherently more defective grades have been extensively researched, new quality control procedures adopted, and improved NDI techniques developed, . A wide variety of siliconized silicon carbide grades, like Silit® SKDH, are now available through suppliers like St. Gobain, . For most ballistic applications, boron carbide remains the ultimate armour material of choice e it is one of the hardest ceramic [23].

2.5.5. Backing Material

The backing material plays a critical role in quantifying penetration resistance characteristics of the armor material since, when a bullet is defeated by soft body armor, the energy dissipation deforms the armor and the backing material. Traditionally, BFS testing used ballistic gelatin as a backing material, but the use of gelatin was very expensive cause of the need for high-speed video to characterize the back-face depth over time. it was determined that a backing material that responded similarly to gelatin was needed. Ideally, the LEAA wanted a new backing material that had a similar deformation depth and rate as gelatin, was reusable, and had a limited material recovery so that high-speed video was not required To find a backing material that fit the needs of the NILECJ, depth and rate of deformation tests were performed These tests were performed using a 200-g, 80-mm hemispherical impact or at 55 m/s with no vest material over the backing material [24].

2.6.Mechanism of Protection

The principles on which the ballistic protective materials work can be broadly divided into two categories that are (1) absorption of impact energy and (2) redistribution of impact energy (Karahan, 2008). A protective material should absorb the energy of a projectile before it completely penetrates the material. Energy absorption is achieved by stretching, compressing or destroying the material. In other words, the principle on which body armour operates is based on the rapid conversion and dispersion of the kinetic energy from a striking bullet into strain energy within the ballistic body armour (Cooper and Gotts, 2005). The protection provided by body armour is achieved by three different methods namely [25].

i) The armour decelerates and stops the ballistic projectile by dissipating its kinetic energy along the plane of the material impacted;

ii) The armour completely bounces the projectile, which is very rare; and

iii) A possible combination of the above (i) and (ii).

Some projectiles can be defeated using flexible textile materials and some require a rigid structure. When any projectile of a mass m, travelling at a velocity v,

impacts a target, it possesses kinetic energy ($KE = 1/2\ mv^2$). The energy acts over a very small impact area and enables the projectile to perforate materials. The term often used to describe the ability of a projectile to defeat its target is its kinetic energy density, that is, the projectile energy per unit area at the impact site. However, without consideration of projectile material, this term often is used in a misleading way. In the most general terms, an armor system defeats the projectile by absorbing this kinetic energy and spreading it over a larger area before the projectile has a chance to punch through [26].

2.7. Composite Material

A composite material is made by combining two or more materials .often ones that have very different properties. The two materials work together to give the composite unique properties.

2.7.1.Fiber-Reinforced Composites

The Rule of Mixtures in Fiber-Reinforced Composites

$$\square c = Ff\ \square f + Fm \square m$$

Strength of Composites - The tensile strength of a fiber-reinforced composite (TSc) depends on the bonding between the fibers and the matrix[27]

The equation depending theoretical (rule of mixture) as following[28].

$$E_1 = E_f V_f + E_m V_m \qquad \ldots\ldots\ldots\ldots...(1)$$

$$E_2 = \frac{E_f E_m}{E_f + V_f(E_F - E_m)} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

$$G_2 = \frac{G_f G_m}{G_m + V_f(G_F - V_M)} \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

$$G_{23} = \frac{E_2}{2(1 + V_{23})} \qquad \ldots\ldots\ldots\ldots\ldots(4)$$

$$v_{12} = V_f v_f + V_m v_m \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

$$v_{23} = V_F v_f + v_m V_m \left[\frac{1 + v_m - v_{12}\left(\frac{E_m}{E_1}\right)}{1 - {v_m}^2 + v_m v_{12}\frac{E_m}{E_1}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(6)[36]$$

$$P_C = P_f V_f + P_m V_m \qquad \ldots\ldots\ldots\ldots...(7)$$

2.8. Previous Studies

Some studies of the development of body armor designed from composite materials .

M.A.G. Silvaa- 2005 The paper reports experimental and numerical simulation of ballistic impact problems on thin composite laminated plates reinforced with Kevlar 29. Ballistic impact was imparted with simulated fragments designed in accordance with STANAG-2920 on plates of different thickness. Numerical modelling was developed and used to obtain an estimate for the limit perforation velocity ðV50Þ and simulate failure modes and damage. Computations were carried out using a commercial code based on finite differences and values obtained are compared with the experimental data to evaluate the performance of the simulation. Good correlation between computational simulation and experimental results was achieved, both in terms of deformation and damage of the laminates. Future work is advanced to include the interposition of an outer ceramic layer as well as examining the influence of dry-wet and temperature cycles on the mechanical strength of the plates and their emporal evolution under accelerated ageing.

M.M. Shokrieh in 2007-Abstract In this research an armor material with constant thickness has been studied. The armor consists of two layers: one is a boron carbide ceramic and the other is Kevlar 49 fiber composite material. By using Ansys/Lsdyna software, the ballistic limit velocity of this armor has been obtained and the Heterington equation (optimum thickness of layers) has been verified for constant thickness of the armor. In this research, mechanical properties of Kevlar 49 under different strain rates are utilized and showed that consideration of the strain rate is very important for the simulation of penetration process. Results from the model have confirmed the validity of the Chocron–Galvez analytical model. Moreover, the projectile velocity prediction, especially at high velocity, shows a good agreement with numerical simulations. Finally, normal and oblique impacts of projectile to armor have been simulated and compared. The results show that the ballistic limit velocity of armor increases under oblique impact conditions [11].

P. CHABERA in 2015 - two armour configurations with different ceramics have been fabricated. The composite armoursystems consisted of the front layer made of Al2O3 or SiC ceramic and high strength steel as the backing material. The ballistic performance of the proposed protective structures were tested with the use of 7.62 mm Armour Piercing (AP) projectile. A comparison of impact resistance of two defence systems with different ceramic has been carried out. Application of silicon carbide ceramic improved ballistic performance, as evidenced by smaller deformations of the second layer. In addition, one of armour systems was complemented with an intermediate ceramic-elastomer layer. A ceramic-elastomer component was obtained using pressure infiltration of gradient porous ceramic by elastomer. Upon ballistic impact, the ceramic body dissipated kinetic energy of the projectile. The residual energy was absorbed by the intermediate composite layer. It was found, that application of composite plates as a support of a ceramic body provided a decrease of the bullet penetration depth[29] .

A. Fadhil Hamzah 2016 Modeling and simulation of protective armor by using the ANSYS 14 Explicit Dynamic.. 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[27].

Yohannes Regassa 2016 he was modeling and simulation by use Solid work 2012 and Abaqus 6.10software to model and simulate the composite bullet resistant body armor respectively. The material used for modeling of composite body armor was Kevlar-29 fiber and polyester resin. The simulation result for 20layers (10mm thick) of woven Kevlar-29 fiber with polyester resin as a matrix shows that there is no penetration through the modeled composite body armor panel by a projectile of 7.62x39mm bullet impact load at 10 and 50meters and the weight of modeled composite body armor was 0.9kg. There is also bullet resistant body armor that modeled as integral armor from16layers and 5mmthick 20 sheet metal steel and it weighs about 1.5Kg. These results were validated against published data and good correlation was observed. By considering the current thickness and weight of modeled and simulated bullet resistant composite body armor[30].

Abhishek Kushwaha 2018 Models of the armor shield and projectile are created using UNIGRAPHICS-NX10 and simulated using

ANSYS 18.1 software which is based on the finite element method (FEM). The investigation is carried out on the effect of the impact of bullet on the armor. In our project we take Graphene & Kevlar 149 fiber. Finally, comparisons between these materials are carried out at stresses and deformations level. Then we have found out, Graphene is best material than other materials. The obtained result could be utilized to design an optimized antiballistic vest[31].

Chapter Three

Modeling and Numerical Simulation

3.1. introduction

The ANSYS program is highly capable of representing a studied the problem no matter how complex. It is considered to be one of the most powerful numerical modeling programs using the finite element.

When Using ANSYS, several simulations were conducted using finite element analysis, including a direct center impact, along with various other impacts to investigate possible weak points in the armor. In doing so, it is determined that only one of these impact locations is indeed a potential weak point. The finite element analysis continues to show that a rifle projectile impacting at an oblique angle reduces the energy transferred to the wearer by about 25% (compared to a direct impact). A design of experiments approach was used to determine the influence of various input parameters, such as projectile impact velocity and impact location. It is shown that the projectile impact velocity contributes 36% to the ability of the wearer to absorb energy, whereas impact velocity contributes only 13% to the energy absorbed by the top armor component. Furthermore, the analysis shows that the impact location is a highly influential factor (with a 69% contribution) in the energy absorption by the top armor component [32].

- **Advantages of Numerical Simulation?**

- Lower Development Costs
  - Ansys can provide accurate answers faster, so you can do more in less time while using fewer resources than ever before
- Reduced Time to Market
  - Ansys ’ software drastically shortens development time and prototype iterations so you can be first to market with tomorrow’s products, today
- Optimized Product Performance
  - The Ansys simulation software allows users optimize product reliability, performance and safety
- Outperform the Competition
  - In today’s competitive market, fully understanding your design allows you to perfect it and edge out the competition via performance improvements or cost reductions

Finite Element Analysis (FEA) or the Finite Element Method (FEM) has developed from its infancy in the late 1940s into the mature computational science that it has become today. It is becoming an integral part of the prototyping of new designs. By allowing engineers to model a design and test it in a computer environment, savings are realized in both time and money [33].

3.2. Modeling Processing:

The armor has been modeled with ANSYS Workbench (v16.). first, the geometry of both the projectile and the armor has been modeled with ANSYS Explicit Dynamic software, and then a separate simulation of the projectile against system was performed, The main objective of using the simulation is to know the correct order and direction of the layers and to know the amount of deformation of the composite material during the ballistic test and the amount of energy absorption and compare them with the practical part to obtain reliable results in order to be applied the composite materials to the actual production of armor.

3.2.1. Assumption

In order to simulate the ballistics test, there are some assumptions:

1. Modeling of the armor plate as layers in ANSYS programs with orthogonal properties.

2. Bullet model which consist of two materials brass alloy and lead alloy with a total weight of 8.9 g and a dimension of 7.62 x 39 mm.

3. The d istance between the bullet and the plate is (10000-20000) mm according to the standard NIJ.

4. The plate is fixed at the edges only to make the rear surface deformation free.

5. Take into account gravity of earth and neglect air resistance

Table-3.1. Mechanical properties of components used in Simulation [31],[34],[35].

Material Field Variable	Kevlar 149 Fiber	epoxy resin	Carbon fiber	Steel 1006
Density(g/cm^3)	1.47	1.2	1.81	7.896
Young's modulus (Gpa)	2.3	3.78	288	206
Poisson Ratio	0.36	0.35	0.31	0.24
Shear modulus (Gpa)	0.845	1.4	41.16	80
Tensile Strength (Mpa)	3450	54.6	3220	330

Table (3.2) The Properties of Bullet Materials [33].

Material	Density ($kg \cdot m^{-3}$)	Young's modulus GPa	Shear modulus (GPa)	Poisson Ratio
jacket brass	8450	115	4.6	0.31
core lead	11340	16	8.6	0.45

We take three sample with dimension (40*40 cm) and thickness 2 mm for steel 1006.

Table-3.3 Materials, thickness and weight of the three plate configurations investigated

Armor material	Thickness (cm)	Weight (g)
Steel1006	0.2	253
Kevlar + Epoxy	1.15	252
CRFB+ Epoxy	1.005	252

3.2.2. Engineering Data

There are several methods that have been followed to obtain the properties of the layers materials, which include (density (ρ), modulus of elasticity (E_{12}, E_{23}, E_{13}), modulus of rigidity (G_{12}, G_{23}, G_{13}) and Poisson ratio (ν_{12}, ν_{23}, ν_{13})), which are used in the simulations. The properties of the Kevlar 149 Fiber, epoxy resin, carbon fiber, steel1006 layers were calculated as mentioned in up and are shown in the table (3.1).

We will rely on the equations for the base of the matrix to obtain the properties for each of the classes for the materials used, which include (density (ρ), modulus of elasticity (E_{12}, E_{23}), modulus of rigidity (G_{12}, G_{23}) and Poisson ratio (ν_{12}, ν_{23}), which are used in the simulations.

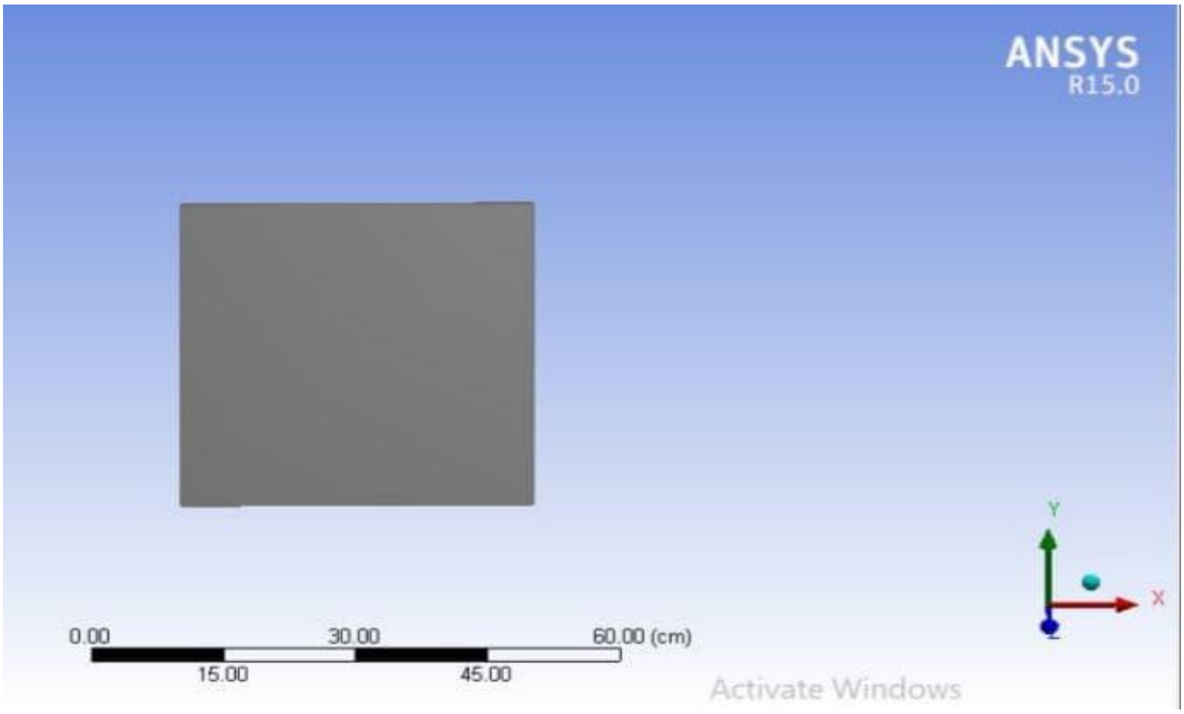
Table (3.4) Mechanical properties of composite materials used in the study

Matrix	**fiber**	**Vf %**	**E_{12} (GPa)**	**E_{23} (GPa)**	**G_{12} (GPa)**	**G_{23} (GPa)**	**υ_{12}**	**υ23**	**density**
epoxy resin	Kevlar 149	60%	2.892	6.157	2.046	2.287	0.35	0.34	1.356
epoxy resin	carbon fiber	60%	174.312	2.37	2.227	0.846	0.326	0.39	1.566

3.2.3. Geometry

Create a 3-D model for the plate and the dimension of the plate shown in Figure (3.1). To create 3-D model the pleat , first create X, Y plane- Sketch 1 and drown pleat with demotion (40*40) cm then extrude the plate with thinness of steel 2 mm , Epoxy resin/Kevlar 149 11.5 mm, Epoxy resin/carbon fiber 10.05 mm .

Create a 3-D model for the bullet 7.62 × 39 mm and the dimension of the bull shown in Figure (3.2). To create 3-D model the bullet, first create Y,Z Sketch 2 then drew the bullet with dimension (56,38.7 ,11.35) mm finally, Revolve the Sketch 1 in operation Add material.



Figure(3.1)the plate

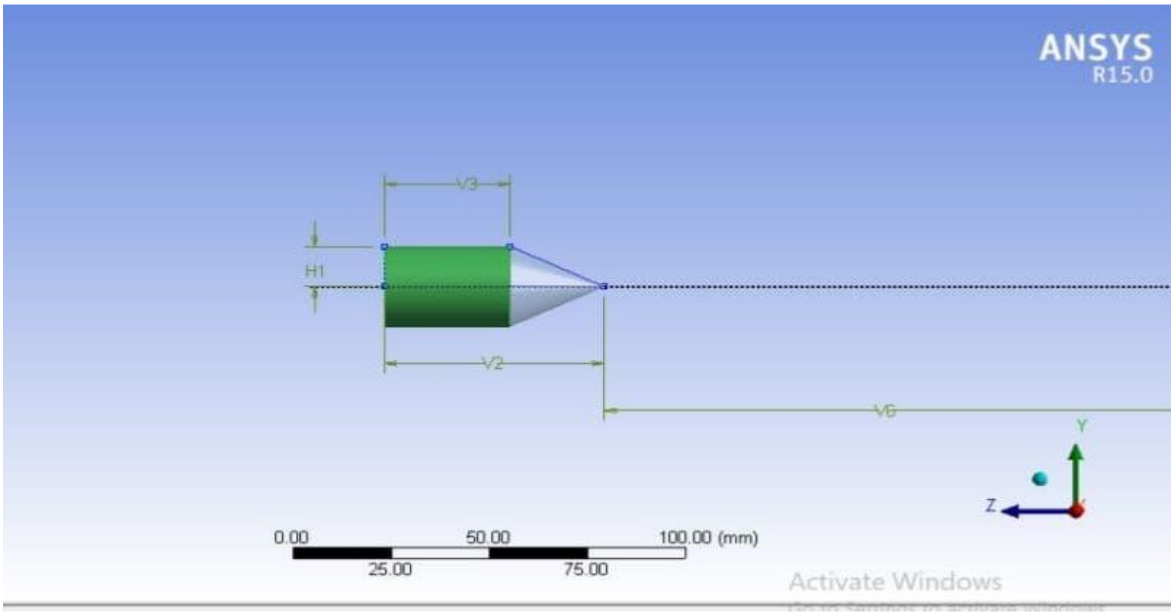
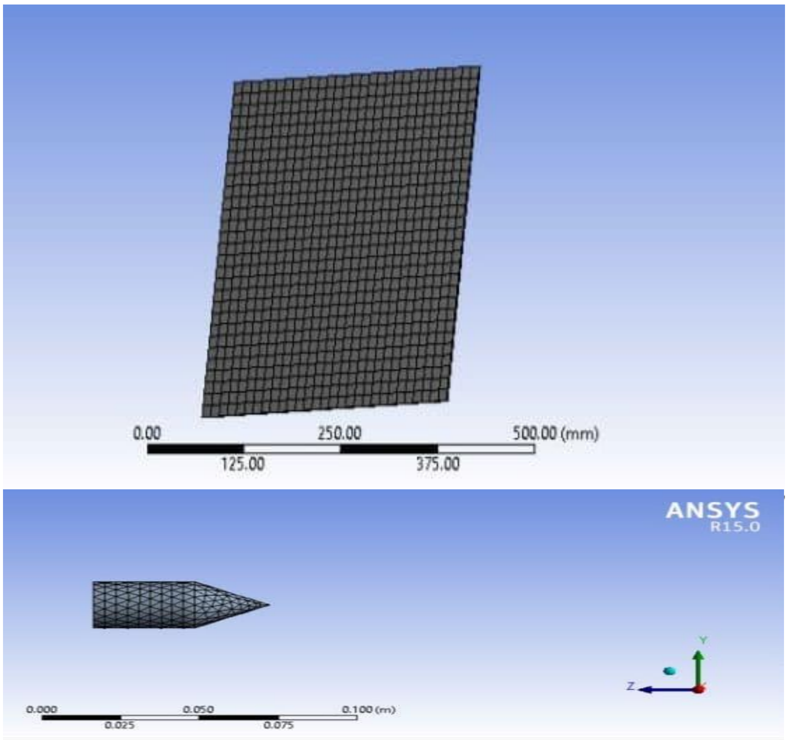


Figure (3.2)the bull

3.2.4. Meshing

is the process in which the continuous geometric space of an object is broken down into thousands or more of shapes to properly define the physical shape of the object. The more detailed a mesh is, the more accurate the 3D CAD model will be, allowing for high fidelity simulations

we do meshing for pleat and bullet which show in figure (3.3)



show in figure (3.3)meshing for pleat and bullet.

3.2.5. Setup

After we do step up we selected the support (fixed support) of plate and velocity of bullet but before that selected type of material of plate and bullet (epoxy /kevlar149, lead core, brass jacket), (epoxy /carbon fiber, lead core, brass jacket), (steel 1006, lead core, brass jacket).

3.2.6. Solution

The solution will be using a program ANSYS by connecting the setup of Explicit dynamic in ANSYS program in order to speed the solution and give more precision, in solution will show the deformation with different velocity and for different type of plates as qualitative, kinetic and internal energy as curve Quantitative in plate armor will be discussed in the chapter four.

Chapter four

Results&

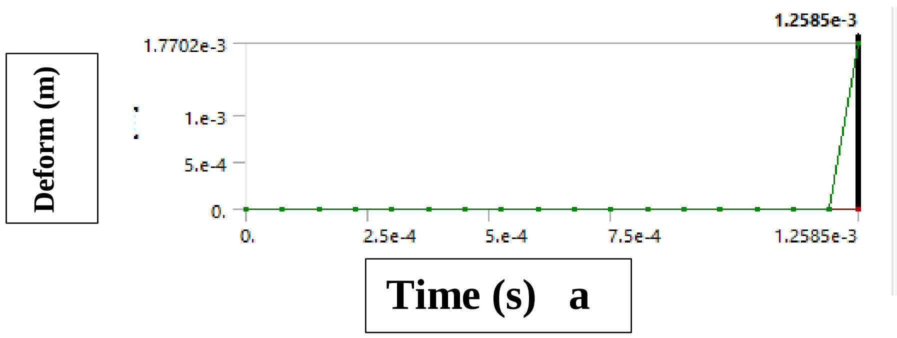
Discussions

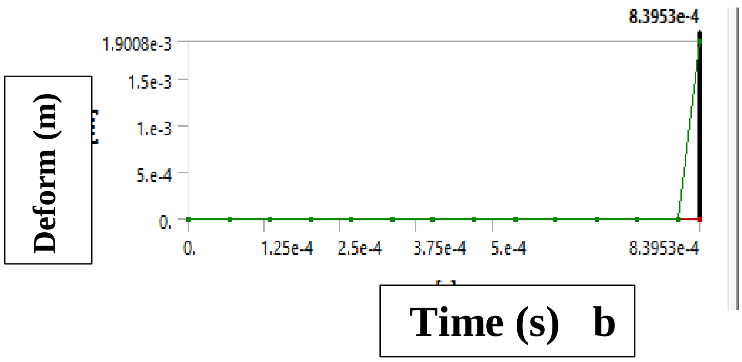
4.1.Results and Discussion

The results were based on the ballistic performance of composite armor compared to steel armor by using simulations.

4.1.1.Deformation

the amount of deformation happening in the armor components of composite system, (Kevlar and epoxy),(epoxy and carbon fiber). steel respectively with time for various velocities, which used in the study (800, 990 and 1200) m/s, show in figure (1,2,3).





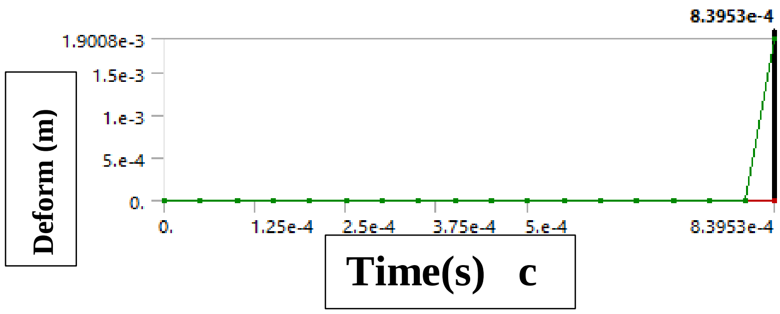


Fig. (2), variation deformation with time at a) 800 m/s, b)990 m/s and c) 1200 m/s for steel

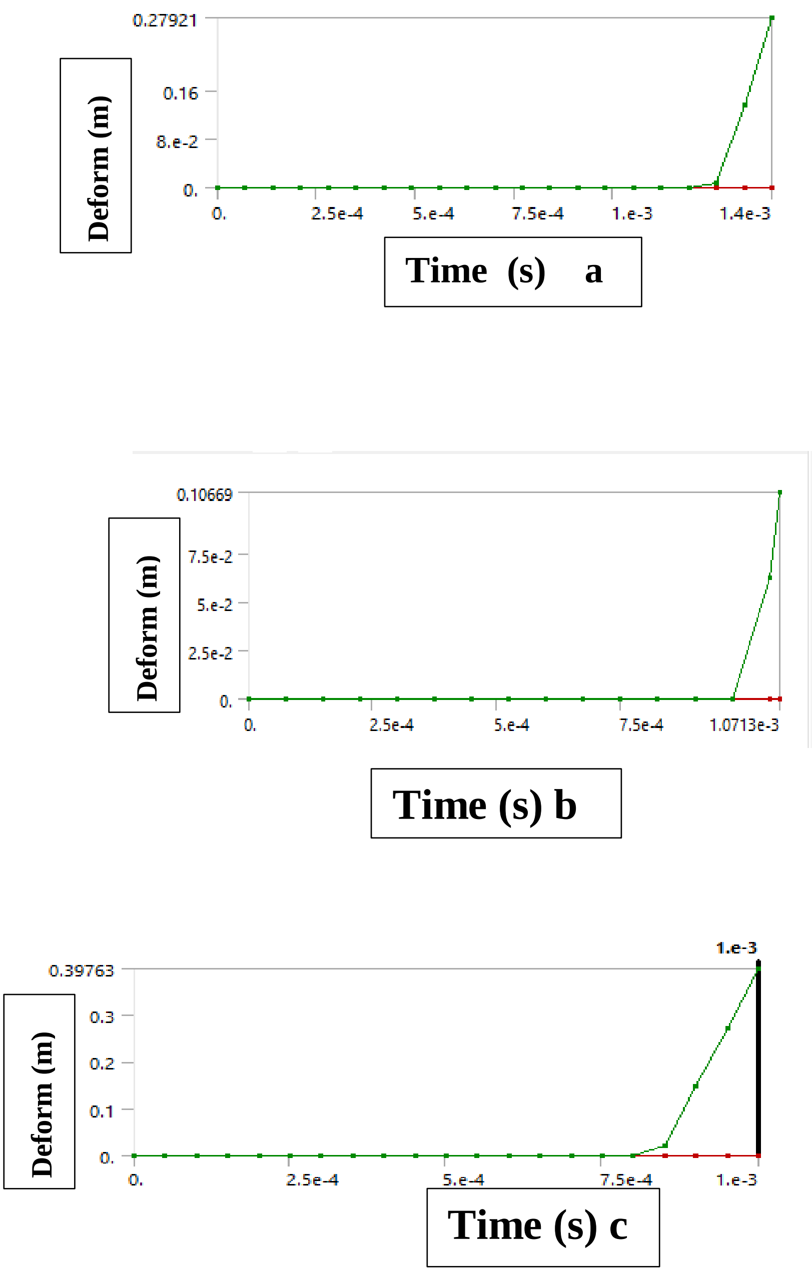
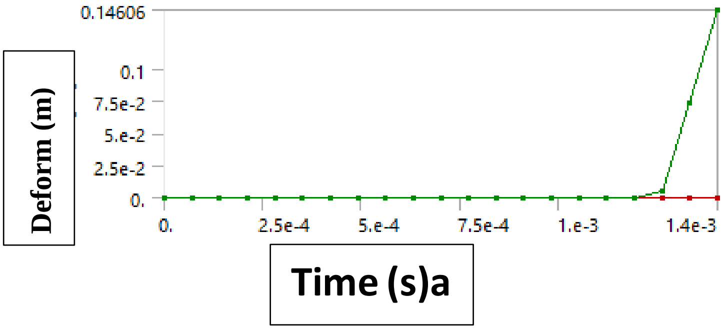
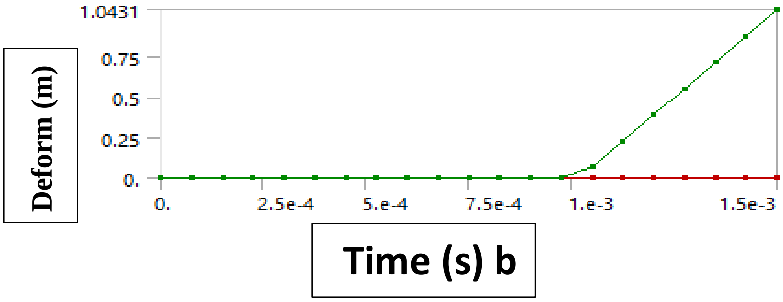


Fig. (1), variation deformation with time at a) 800 m/s, b)990 m/s and c) 1200 m/s for composite system armor epoxy/Kevlar





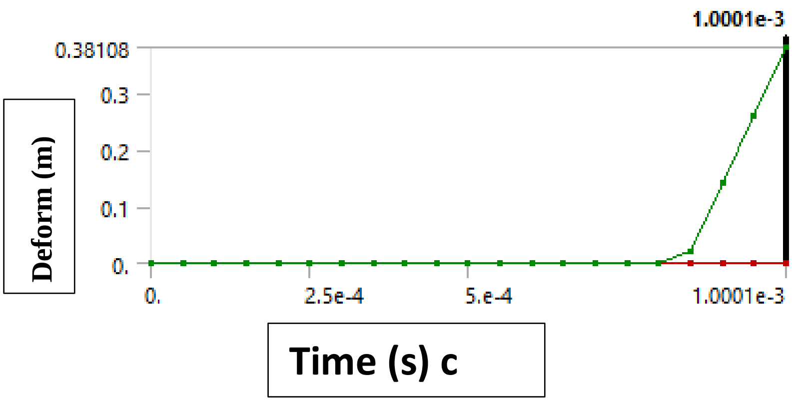


Fig. (3), variation deformation with time at a) 800 m/s, b)990 m/s and c) 1200 m/s for composite system armor epoxy/carbon .

We note a difference in the values of deformation for each of the three types above, where the amount of deformation varies from one shield to another depending on the type of material as well as the amount of directed velocity, where the higher the velocity, the greater the amount of deformation that occurs. where the less deformation was 0.0019 m when 1200 m/s of steel , when Compare with other types velocity of a bullet which have higher deformation in table (4.1) .

Deformation of Armor (m)			Velocity m/s
Steel1006	epoxy/ kavler	epoxy/carbon	
0.0017702	0.2792	0.14606	800
0.0019008	0.1066	1.0431	990
0.0019008	0.397	0.3810	1200

Table 4.1 the deformation of armor with differences of velocity.

3-2- Depth of Penetration:

Figures (8, 9 and 10) shows the depth of penetration in the armor plate consists of steel1006, composite system(epoxy/carbon epoxy/kavler) respectively for various velocities, which used in the study.

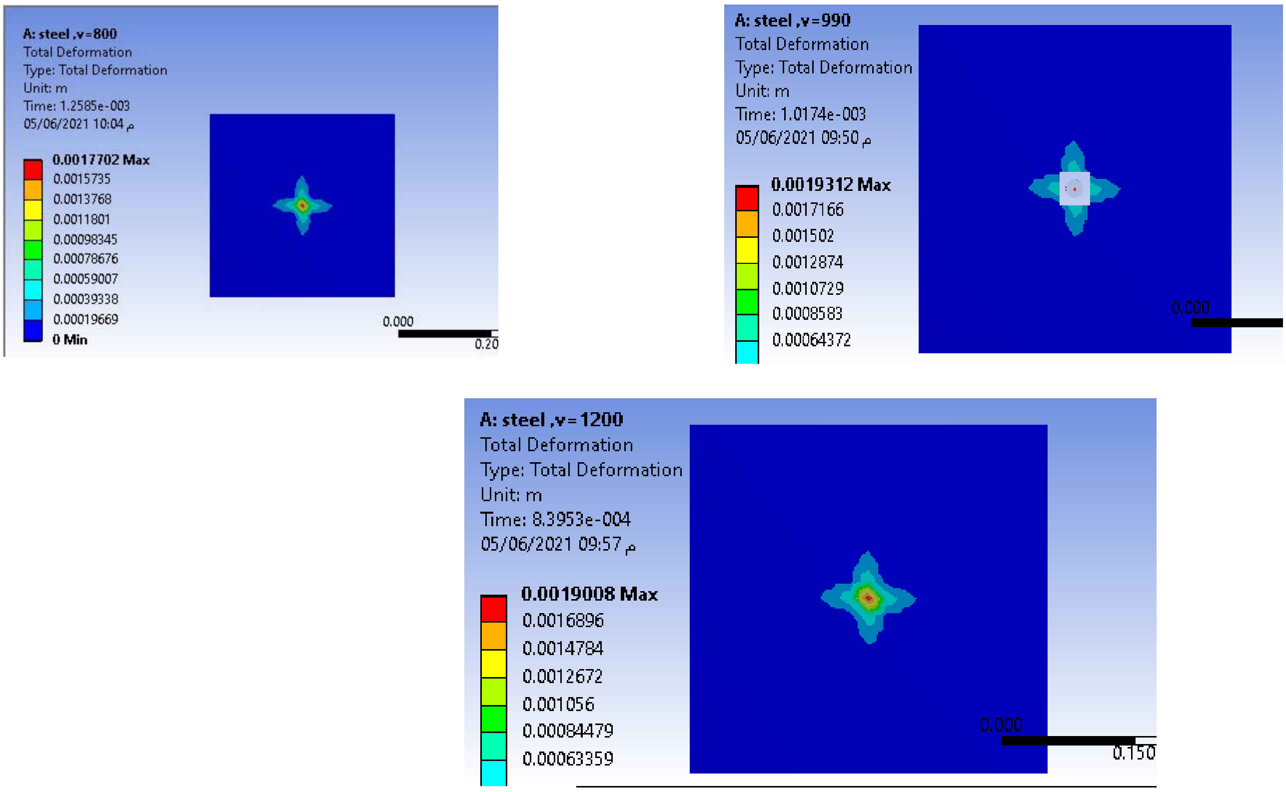


Fig. (8), depth of penetration at 800 m/s, 990m/s and 1200 m/s for steel1006 armor.

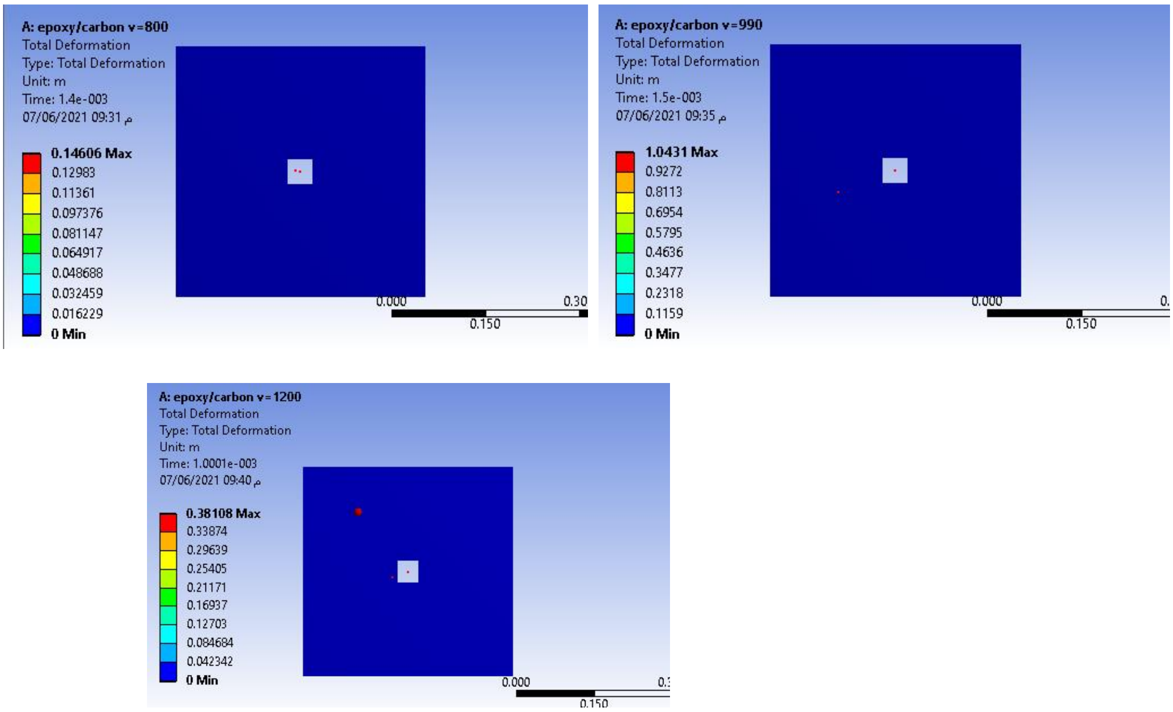


Fig. (9), depth of penetration at 800 m/s, 990m/s and 1200 m/s for for composite system armor epoxy/carbon

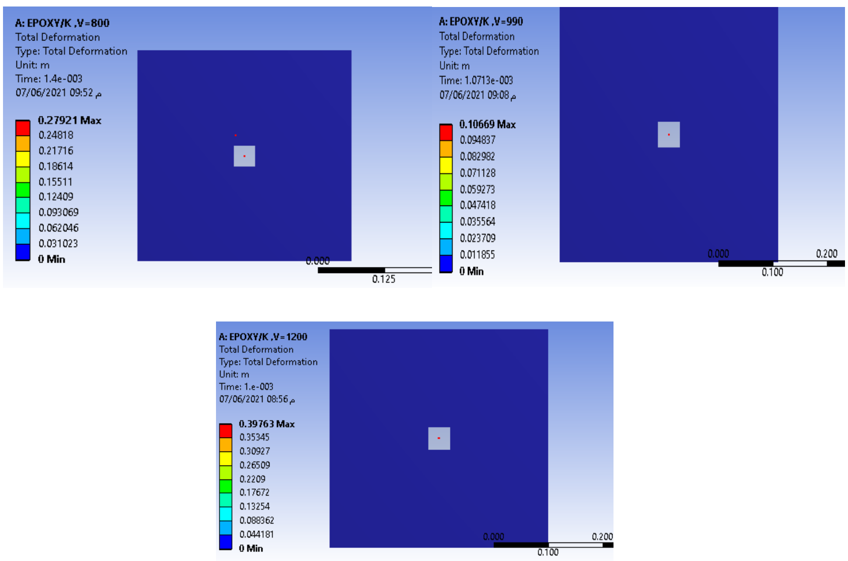


Fig. (9), depth of penetration at 800 m/s, 990m/s and 1200 m/s for for composite system armor epoxy/kavler

We note the difference in the depth of deformation from one type to another due to the different type of material and thickness taken Where the depth of deformation of steel is less than other types Then other material epoxy /carbon fiber. The depth of penetration also varies according to the applied speed, as the depth increases with the increase in the applied speed, the depth of deformation was 0.0019m for steel at 1200m/s, while the depth of deformation was 0.38m for epoxy/carbon fiber at same velocity so that in this study the steel armor the best .

4.2. Conclusions:

In this study, the modeling and simulation of body armor that modeled from different materials all with the same weight was investigated . steel 1006 , composite system (epoxy/carbon epoxy/kavler) , We applied the system at different speeds and we found that the least deformed material was steel armor.

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