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# Design and Analysis of Bullet Resistance Jacket Projectile Penetration: Reviews

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## Abstract

The aim of this paper is to review design and analysis of bullet resistance jacket projectile penetration. The main energy absorbing mechanisms during ballistic impact are different criteria considered. Delamination, analytical model formation, Experimental, projectile and penetration will be determine impact energy absorbed and initial kinetic energy of the projectile in to target. The material of Kevlar, Twaron, spectra, non-Newtonian's fluid and natural fibers are used in making bullet proof jacket.

Finally, the total energy absorbed by damaged plate is equal to the initial kinetic energy of projectile, ballistic limit of the plate obtained.

**Keywords:** Projectile; Penetration; Impact; Bullet resistance; Perforation

## Introduction

Composite structures undergo various loading conditions during the service life. Impact loads can be classified in to three categories: low velocity impact, high velocity impact and hyper velocity impact. The reason for this classification is that energy transfer between projectile and target, energy dissipation and damage propagation mechanism undergo drastic changes as the velocity of the projectile changes. Kinetic energy of the projectile when impacted into the target is dissipated and absorbed in various ways by the target. The main energy absorbing mechanisms during ballistic impact are: kinetic energy absorbed by the moving cone formed on the back face of the target, shear plugging of the projectile into the target, energy absorbed due to tensile failure of the primary yarns, energy absorbed due to elastic deformation of the secondary yarns, energy absorbed due to matrix cracking of the secondary yarns, energy absorbed during penetration. Bulletproof vest is a vest which can protect wearer's body from the impact of bullet. This vest can't bear the total impact of bullet but it can bear most of the impact of bullet [1].

A composite material composed of two or more physically or chemically distinct constituents combined on a macroscopic scale [2].

Personal armors usually are subjected to high velocity bullet impact so while designing the personal armors energy absorbing capacity of plate is important to know. Energy absorbing capacity of composites depends on many factors like fiber properties, matrix properties, interfacial strength, thickness; fiber orientation etc. Energy of bullet is absorbed by different damage mechanisms like fiber failures by knowing the energy absorption by different damage mechanisms residual velocity of projectile can be calculated [3-6].

Bullet proof amours are made depending upon various levels of protection. Factors to be considered are weight of bullet and armor, type of bullet, velocity of bullet and comfort. When a bullet hits the armor, the energy of the bullet is dispersed on to the armor by deforming the bullet. The shape of the deformed bullet is called mushroom shaped. It consists of soft and rigid components. The rigid armor in the form of a plate is inserted into the pockets of the vest [7].

Developed analytical model to calculate the decrease in kinetic energy and residual velocity of projectile penetrating targets composed of multilayered planer woven fabric of Twaron and Kevlaon. The finite element technique has been used to determine local deformation, fiber and matrix failure as well as motion of projectile [8]. The properties of the manmade fibers and polymers from which these types of vests are made and to identify the best one based on directional deformation, total deformation, shear stresses and principal stresses, when it is subjected to a bullet impact [9].

The main use of a bullet proof material is not simply to block high-speed bullets but, also to defend the user from artillery shells, mortars, grenades, and other fragmenting devices. In terms of aerospace applications, ballistic materials protect the body of the spacecraft from external objects when it is flying at a high velocity. Bullet-proof vests and helmets or any ballistic-resistant materials are known to contain high-strength [10].

In this review, a brief work responsible the projectile penetration and impact of the bullet proof jacket with analytical model, delamination, projectile and experimental analysis with different layer of the sandwiching composite materials.

## Delamination

When the projectile enters the target, the material is displaced laterally as well as downward. Producing in-plane compression with a highly localized deformation gradient is as well as out-of-plane. This results in interlaminar cracking of mode I and mode II type. The reflection of the pressure wave created by impact generates a tensile wave, which produces incipient mode I delamination that is extended by the penetration of the projectile as shown in Figure 1.

The maximum delamination is taken to occur on the distal side , a result supported by experimental observation. So that the propagation of the crack is primarily mode I. Its shape is generally modeled as an

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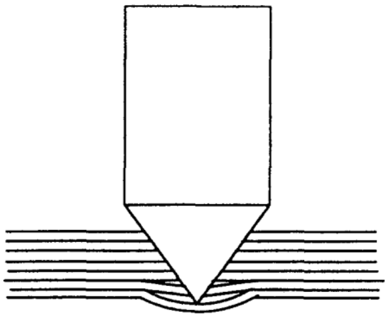

**Figure 1:** Delamination initation during penetration of a laminte by a cylinder conical projectile [11].

ellipse with semi-major axes a and b, respectively, in linear elastic fracture mechanics [11].

The penetration of composite lamintes by sharp projectile usually alocalized selamination region, since the sublaminate cannot deform very much before it is perforated. The maximum delamination and the maximum deflection of the sublaminate relative to the plate can be determined from these relations. From the static penetration of a single layer laminate and the fractura toughness test [12].

## Projectile

The concept of total energy absorbed by damage plate is equal to reduction in kinetic energy of bullet, residual velocity of the projectile has been determined. When the total energy absorbed by damaged plate is equal to the initial kinetic energy of projectile, ballistic limit of the plate obtained. For the development of the model following assumptions have been made:

1. Energy absorbed in projectile deformation is negligible compared to total energy absorbed.
2. Energy lost due to friction between projectile and composite is negligible.
3. Failure mechanism of composite is uniform across the thickness.
4. Fibers in each layer act independently. Fiber failure in one lamina doesn't affect failure in other lamina.
5. Material properties remain constant during impact.
6. Strain rate will remain constant during preformation.

Total kinetic energy of projectile is (Figure 2):

$$KE_{po} = \frac{1}{2} m_p V_o^2 \tag{1}$$

Where $m_p$ is the mass of projectile (m=9.7 g is the projectile mass) and $V_o$ is initial velocity of projectile. Some of the projectile energy is absorbed by the laminates by deforming into various failure modes and reduce the velocity of projectile to $V_r$. Thus from energy balance law:

$$\frac{1}{2} m_p V_o^2 = E_o + \frac{1}{2} m_p V_r^2 \tag{2}$$

Where $E_o$ is the total energy absorbed by different deformation mechanisms of the laminate [13].

The penetration of the projectiles to the kinetic energy, momentum and kinetic energy density in an attempt to determine whether the impact will have lethal consequences antlernative approach for the evaluation of the penetration is the analysis of impact of fluidic or granular materials by spheres [14].

## Penetration and Perforation Process

When a high velocity projectile strikes onto a target transversely, longitudinal compressive and shear stress waves along the thickness direction and longitudinal tensile and shear stress waves along the in-plane direction are generated [15].

The penetration phenomenon was divided into three successive and non-interactive stages (a) Indentation, (b) peroration, and (c) exit of the projectile. The predictions of this model have been compared with data from corresponding experiments for a variety of impact conditions [8].

## Formulation of Analytical Model

Primary yarns, which receive direct impact from the projectile, provide primary the resistance to the projectile causing its deceleration. The impact is transmitted to the secondary yarns in ballistic panel due to the cross-over points between the warp and weft yarns involved in the fabric, as shown in Figure 3 [16].

The components of the analytical model include one projectile and a number of layers of layers of primary yarns as shown in Figure 4. It is assumed that there is a small air gap between every two adjacent layers of fabrics, and the size of the gap was set to be around 1/10 of the thickness of a single layer of fabric. This assumption is made based on the fact that intermittent air gaps exist between the layers in

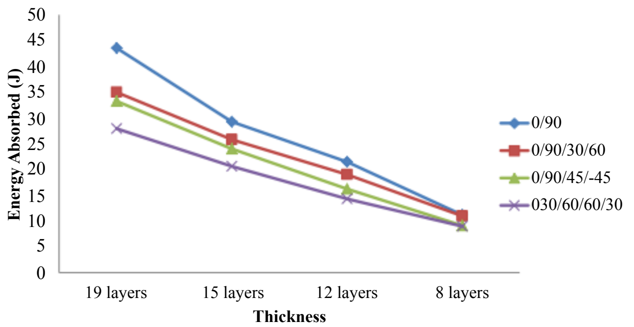


**Figure 2:** Experiment all determined variation of average energy absorbed by plates having different thicknesses and lay-ups [13].

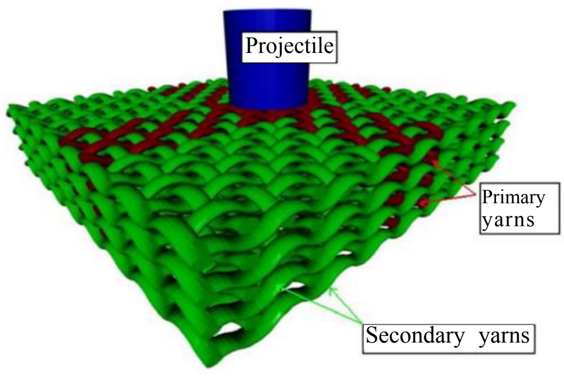


**Figure 3:** Illustration of ballistic impact on multi-layered fabric panel by a cylindrical projectile [16].

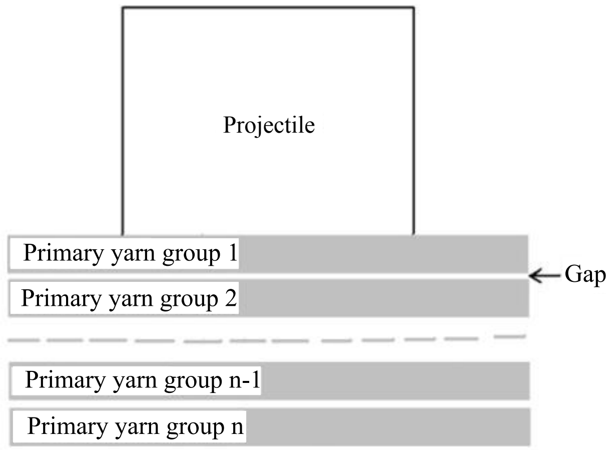


**Figure 4:** schematic representation of the model [16].

practical multi-layer fabric panels and it is not possible to eliminate them completely from the assembly.

Assumed air gaps when they considered fabrics assemblies. In order to separate the spatial and temporal variables during the impact process, the distance travelled by the projectile, from the moment the projectile started to contact the first layer of fabric in the multiple layered fabric panel to the moment when the projectile's velocity became zero or to the moment when the last layer of fabric in the multiple layered fabric panel failed, is divided in to a number of constant distance intervals. The value of this distance interval is determined according to the value of air gap [16].

The main aim of the analytical model is to predict the exit velocity of the projectile when the panel has been penetrated. The projectile penetration ends when either the velocity of the projectile becomes zero or the last layer of fabric in the multiple layered panels fails. Assuming conservation of momentum and linear deceleration of the projectile in each distance interval, according to newton's second law of motion, the reduction of the projectile velocity in the case of consideration is the sum of the components of tensile forces of all the active primary yarns in the impacting direction.

The velocity of the cone is the same as the velocity of the projectile. Initially, the cone has velocity equal to that of the projectile and has zero mass [1].

Generally continuum mechanics principles, such as newton's third law of motion, have been adapted in the analysis. Under the assumption that (i) the elastic stress-strain relation is linear, (ii) there is no effect of Poisson's ratio, and (iii) no creep and stress relaxation take place in the material, the reaction of a textile filament subjected to transverse impact has been described using the following equations:

$$u_y = \sqrt{\frac{E}{\rho}} \tag{3}$$

$$W = u_{y\varepsilon_{ins}} \tag{4}$$

$$u_{lab} = u_y(\sqrt{\varepsilon_{ins}(1+\varepsilon_{ins})} - \varepsilon_{ins}) \tag{5}$$

$$U = u_y\sqrt{\frac{\varepsilon_{ins}}{1+\varepsilon_{ins}}} \tag{6}$$

$$V = u_y\sqrt{2\varepsilon_{ins}\sqrt{\varepsilon_{ins}(1+\varepsilon_{ins})} - \varepsilon_{ins}^2} \tag{7}$$

$$\cos\theta = \frac{1}{1+\varepsilon_{ins}}\frac{V}{U} \tag{8}$$

The symbols involved in these equations are listed below:

E: Fiber young's modulus.

$U_y$: Longitudinal stress wave velocity in yarn.

$E_{ins}$: instant strain in yarn caused by longitudinal wave.

U: Transverse stress wave velocity.

$\rho$: Volume density of yarn.

W: Velocity of inflow of fiber materials.

$U_{lab}$: Transverse stress wave velocity in yarn [17].

V: Impact velocity of the projectile.

## Experimental Setup

The experiments were performed with the setup of having the projectile shot through a firearm chronograph, which was placed two meters away from the firearm, after which it would penetrate the Kevlar samples, followed by the ballistic gel placed behind it. The Kevlar samples consisted of 3 layers, layered in the order of 90/ ±45/90. They were bound together with epoxy resin and hardener [18].

### Ballistic testing

Body (bullet proof) armor ballistic testing is conducted to evaluate to evaluate the resistance of penetration of body armor test samples. The evaluation of this bullet proof armor happed at a constant velocity of the bullets. The armor plate inserts were subjected to ballistic testing in accordance to the standards of the national institute of justice (NIJ). ballistic clay was used as a backing layer in most of the tests to measure performance parameters of the plate post-impact [19].

## Material Selection

Composite material is a material that consists of strong carry-load materials which are embedded in a somewhat weaker material. The stronger material is commonly referred to as reinforcement and the weaker material is commonly referred to as the matrix. The reinforcement provides the strength and rigidity that is needed and which helps to support the structural load [20].

### Raw materials

The Commonly used synthetic fibers include Kevlar, spectra, Twaron, ballistic nylon and nylon. Mostly used material for bullet proof vest is Kevlar, but Kevlar is not used in pure form because it has some drawbacks.it use of spectra for a vest is also increasing now a days.

The draw backs of pure Kevlar fiber are degraded by UV rays, low stability under wet conditions because Kevlar has low strength under wet condition. Therefore, Kevlar is blended with natural fiber which is mostly wool.

**Properties of Kevlar**

- Strength to weight ratio is more.
- With stands temperatures up to 450°C and as low temperature as-196°C.
- Self-extinguishable.

- Resistant to almost all types of chemicals.
- Negative co-efficient of thermal expansion.
- Abrasion resistance.

The advantage of blended fabrics of wool and Kevlar are:

- Better tear strength even under wet conditions,
- Better energy absorbing capacity and reduced number of layers in a vest.
- Better breathability and feels good on skin.
- Restricts the displacement of Kevlar yarns under the impact of bullet
- Increases the friction at yarn intersections and penetrating bullet comes across, a stronger resisting force.

A bulletproof vest has a panel, a vest-shaped sheet of advanced plastic polymers that is composed of many layers of Kevlar, Spectra Shield, Twaron (similar to Kevlar) or Bynema (similar to Spectra). The layers of woven Kevlar are sewn together using Kevlar thread, while the nonwoven Spectra Shield is coated and bonded with resins such as Kraton and then sealed between two sheets of polyethylene film [21,22].

Kevlar sandwiched with Oobleck, Oobleck and PEG and $SiO_2$ mixture are the two Non-Newtonian fluids that were taken for experimentation. Oobleck is a mixture of corn flour and water [23].

**A) Nylon 66**

Nylon 66 is frequently used when high mechanical strength, rigidity, good stability under heat and/or chemical resistance is required. It is used in fibers for textiles and carpets and molded parts. Tsai etal of University of Tennessee produce Nano fibers from different polymers like polycarbonate, poly (ethylene oxide), polyurethanes, polystyrene, polycaprolactone. Nylon 6, nylon 66 and the fabrics made out of these Nano fibers were studied for their barrier properties against microorganisms and chemicals [20].

**B) Ultra-high modulus polyethylene (UHMPE)**

In all bullet proof protective wear; there is a particular core material which contributes to the stopping of the bullet in a significant manner. Currently materials made from ultra-high molecular weight polyethylene (UHMWPE) and Armid fibers are used widely for this purpose. *Dyneema* and *Spectra* are lightweight high strength oriented strand gel spun through a spinneret.

## Conclusion

In this work different important concept related to projectile penetration of bullet resistance jacket with composite material revised. Impact load can be classified as, low velocity, highly velocity and hyper velocity. The main energy absorbing mechanism of the ballistic impact considered different criteria's. Energy absorbing capacity of composite depends on factors like fiber properties, matrix properties, interfacial strength, and thickness, type of bullet and velocity of bullet.

The maximum delamination was taken to occur on the distal side, a result supported by experimental observation. A small air gap between every two adjacent layers of fabrics, and the size of the gap was set to be around 1/10 of the thickness of a single layer of fabric. Composite material is a material that consists of strong carry-load materials which are embedded in a somewhat weaker material. Kevlar is blended with natural fiber which is mostly wool. The penetration phenomenon was divided into three successive and non-interactive stages (a) Indentation, (b) peroration, and(c) exit of the projectile.

Generally continuum mechanics principles, such as newton's third law of motion, have been adapted in the analysis.

The future work can be done by sandwiching non-Newtonian fluids in fluid form between layers of Kevlar. Only constrains is that thickening of the solution. Once this problem is solved, this can even replace metals plate in the armours completely.

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