ANALYSIS OF COMPOSITE MATERIALS USED IN BULLET PROOF VESTS USING FEM TECHNIQUE.

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ABSTRACT

The project aims at studying various composite materials used in bullet-proof vests and to analyse their effectiveness by using FEM technique. Hence obtained data would be utilised for designing an optimised bullet-proof vest.

When a handgun bullet strikes body armour, it is caught in a "web" of very strong fibres. These fibres absorb and disperse the impact energy that is transmitted to the vest from the bullet, causing the bullet to deform or "mushroom." Additional energy is absorbed by each successive layer of material in the vest, until such time as the bullet has been stopped.Most anti-ballistic materials, like bullet proof vests and explosion-proof blankets, are currently made of multiple layers of:

- Kevlar fibers
- Twaron fibers
- Dyneema fibers

These act by stopping bullets from penetrating by spreading the bullet's force.After comparison of different properties of the fibres, a bullet proof vest would be designed using the software. This vest will be tested for penetration and hence its effectiveness would be determined.

INTRODUCTION

A composite material is defined as a material comprising of two or more chemically and/or physically distinct constituents (phases) combined on a macroscopic scale. The constituents present in the composite material retain their individual identities and properties, but together they produce a material system, the properties of which are designed to be superior to those of the constituent materials acting independently.

A composite material consists of two phases one is called reinforcement and other is called matrix. These two phases are separated by distinct interfaces. The most useful properties of composites are high specific strength and specific stiffness, good corrosion resistance and good fatigue resistance. On account of these highly desirable characteristics, composites have rightfully emerged as important engineering materials for applications where weight of the components or structure is an important consideration. Advanced composite materials, typically consisting of reinforcing fibres (e.g. carbon fibres) in a resin matrix (e.g. epoxy), are progressively replacing metals in the transport and defence industries. Due to their high strength to weight ratios, laminated composite materials have found extensive applications in the construction of mechanical, aerospace, marine, protective gear and automotive structures.

As we have to analyse the composite material for bullet-proof material we will now give a brief introduction regarding ballistic material. The purpose of the ballistic protective materials is not to just stop the speeding bullets but to protect the individual from fragmenting devices as well, i.e. from grenades, mortars, artillery shells, and improvised explosive devices. We should note that the injury caused to the civilians is mainly due to two factors:

- High velocity bullets from rifles, machine guns which are mainly shot from a long range.
- Low velocity bullets from hand guns which are shot from close range.

ARMOR CLASSIFICATIONS FOR BALLISTIC-RESISTANT ARMOR

There are six formal armor classification types, as well as a seventh special type, as follows:

Type I (.22 LR; .380 ACP). This armor protects against .22 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 against .380 ACP full metal jacketed round nose (FMJ RN), with nominal masses of 6.2 g (95 gr), impacting at a minimum velocity of 312 m/s (1025 ft/s) or less. Type I body armor is light. This is the minimum level of protection every officer should have, and the armor should be routinely worn at all times while on duty. Type I body armor was the armor issued during the NIJ demonstration project in the mid-1970s. Most agencies today, however, because of increasing threats, opt for a higher level of protection.

Type II-A (9mm; .40 S&W). This armor protects against 9mm 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 Type I threats. Type II-A body armor is well suited for full-time use by police departments, particularly those seeking protection for their officers from lower velocity 9mm and 40 S&W ammunition.

Type II (9mm; .357 Magnum). This armor protects against 9mm full metal jacketed round nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr), impacting at a minimum velocityof 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 Type I and Type IIA threats. Type II body armor is heavier and more bulky than either Types I or II-A. It is worn full time by officers seeking protection against higher velocity .357 Magnum and 9mm ammunition.

Type III-A (High Velocity 9mm; .44 Magnum). This armor protects against 9mm full metal jacketed round nose (FJM 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 Type I, II-A, and II threats. Type III-A body armor provides the highest level of protection currently available from concealable body armor and is generally suitable for routine wear in many situations. However, departments located in hot, humid climates may need to evaluate the use of Type III-A armor carefully.

Type III (Rifles). This armor protects against 7.62mm 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 Type I through III-A threats. Type III body armor is clearly intended only for tactical situations when the threat warrants such protection, such as barricade confrontations involving sporting rifles.

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 Type I through III threats. Type IV body armor provides the highest level of protection currently available. Because this armor is intended to resist "armor piercing" bullets, it often uses ceramic materials. Such materials are brittle in nature and may provide only single-shot protection, since the ceramic tends to break up when struck. As with Type III armor, Type IV armor is clearly intended only for tactical situations when the threat warrants such protection.

Special type. A purchaser who has a special requirement for a level of protection other than one of the above standard threat levels should specify the exact test rounds and minimum impact velocities to be used and indicate that this standard shall govern in all other respects.

Manufacturing of Ballistic Body Armor

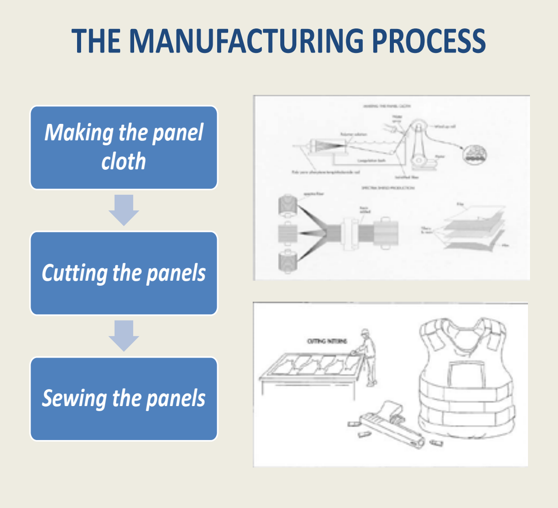
Ballistic resistant body armor is developed for a variety of scenarios and levels of protection. Factors that are considered when developing body armor include weight (i.e. areal density), type of bullet, bullet velocities, and comfort. The idea behind stopping a bullet is to reduce its energy. When the bullet hits the ballistic resistant system, it absorbs and disperses the energy of the bullet by deforming it into a mushroom shape. Typically, military ballistic armor consists of soft and rigid components. The soft armor forms the flexible, protective vest. It contains several layers of ballistic fabric material(s). The rigid armor is used for enhanced protection in specific areas, normally this is over the chest region to protect vital organs. The rigid armor is in the form of a plate that is inserted into a pocket of the vest. The entire body armor system has a carrier, usually made of nylon that has the sole purpose of supporting the ballistic material and securing the armor to the body for correct positioning and comfort

Fig 1. Typical structure of a ballistic vest and plate which is inserted in a front panel.

The ballistic fabric materials can be arranged to provide effective protection. Each body armor developer has its own method when developing protective systems. The fibers are usually plain woven together, although there are other methods of weaving that are used. Some armors use one single material stacked in multiple layers, others use several types of materials. Each layer of material can be comprised of varying directional fibers. Additional layers of material increase the ballistic resistance and blunt trauma protection, but the weight is also increased. Several stitching methods are employed to hold the layers together. For example, a bias stitch can be applied around the perimeter of the materials. There are several other forms of stitching which include rows of parallel or overlapped vertical, horizontal and diagonal lines. Stitching of ballistic materials has been shown to slightly improve ballistic integrity and enhance protection against blunt trauma.

MANUFACTURING PROCESS:

Some bulletproof vests are custom-made to meet the customer's protection needs or size. Most, however, meet standard protection regulations, have standard clothing industry sizes (such as 38 long, 32 short), and are sold in quantity.



QUALITY CONTROL

Bulletproof vests undergo many of the same tests a regular piece of clothing does. The fiber manufacturer tests the fiber and yarn tensile strength, and the fabric weavers test the tensile strength of the resultant cloth. Nonwoven Spectra is also tested for tensile strength by the manufacturer. Body armor manufacturers test the panel material (whether Kevlar or Dyneema) for strength, and production quality control requires that trained observers inspect the vests after the panels are sewn and the vests completed. Bulletproof vests, unlike regular clothing, must undergo stringent protection testing as required.

Not all bulletproof vests are alike. Some protect against lead bullet at low velocity, and some protect against full metal jacketed bullets at high velocity.

TESTING:

Bulletproof vests are tested both wet and dry. This is done because the fibers used to make a vest perform differently when wet. Testing (wet or dry) a vest entails wrapping it around a modelling clay dummy. A firearm of the correct type with a bullet of the correct type is then shot at a velocity suitable for the classification of the vest. Each shot should be three inches (7.6 centimetres) away from the edge of the vest and almost two inches from (five centimetres) away from previous shots.

Six shots are fired, two at a 30-degree angle of incidence, and four at a O-degree angle of incidence. One shot should fall on a seam. This method of shooting forms a wide triangle of bullet holes. The vest is then turned upside down and shot the same way, this time making a narrow triangle of bullet holes.

TESTING PROCESS

MATERIALS USED

There are several types of ballistic fabrics that are used today:

STRUCTURE & PROPERTIES

When Kevlar is spun, the resulting fiber has a tensile strength of about 3 620 MPa, and a relative density of 1.44. The polymer owes its high strength to the many inter-chain bonds. These inter-molecular hydrogen bonds form between the carbonyl groups and *NH* centers. Additional strength is derived from aromatic stacking interactions between adjacent strands. These interactions have a greater influence on Kevlar than the van der Waals interactions and chain length that typically influence the properties of other synthetic polymers and fibers such as Dyneema. The presence of salts and certain other impurities, especially calcium, could interfere with the strand interactions and caution is used to avoid inclusion in its production. Kevlar's structure consists of relatively rigid molecules which tend to form mostly planar sheet-like structures rather like silk protein.

THERMAL PROPERTIES

Kevlar maintains its strength and resilience down to cryogenic temperatures (-196°C); indeed, it is slightly stronger at low temperatures. At higher temperatures the tensile strength is immediately reduced by about 10-20%, and after some hours the strength progressively reduces further. For example at 160°C about 10% reduction in strength occurs after 500 hours. At 260°C 50% strength reduction occurs after 70 hours.

FIBRE PROPERTIES

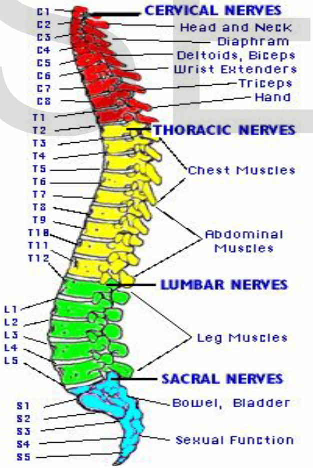
Kevlar 49	3.6	1.44	3.5	2.4	< 0.1	427
Twaron	3.2	1.44	6.5	3.6	< 0.1	500
Dyneema	2.4	0.97	< 0.1	2.7-3.5	N/A	147

RISKS OF INJURY

There are several components of the body where protection should be provided. The spinal column, heart and kidneys are the two major elements that need protection. They perform functions essential for a person to live a normal life. Other areas where protection should be provided are the ribs and scapulae. They are important structures where considerable discomfort could be caused by injuries.

SPINE

The spinal column can be considered the most structurally important element in the body. This complex structure plays a crucial role in our activities of daily living. The main functions of the spine are to communicate between the brain and the body, to provide structural support and flexibility. Various anatomical and physiological elements work together in order to supply these functions. The three major components of the spine are the neural elements, the spinal column, and the supporting structures. Each of these components contain elements that interact together to provide the functions of the spine.



Lateral view of the spine indicating the five sections and the bodily components that these sections interact with (Spinal Cord Injury Information network, 1999) Comfort and Fit

When selecting armor for full-time routine use by an officer, comfort is a major factor. Armor that is set aside or relegated to the trunk of a cruiser is of no benefit.
Two fundamental factors were considered fit—from the standpoint of mobility and the weight distribution of the armor—and heat discomfort.

Following points shold be kept in mind while designing armor:

1. The neck opening should not be too high and should be properly shaped.

The shoulder, neck, and armholes should be feathered to minimize bulk and maximize comfort at these areas, but still not reduce protection.

The shoulder straps should be wide enough for comfort and to distribute the weight of the armor, but not so wide as to restrict movement

Seam construction of the armor should allow maximum flexibility and yet maintain protective coverage. The armor should permit size adjustment while retaining protective integrity for the sides of the torso.
The carrier for the armor material should have a tail that can be tucked into the pants to prevent the armor from riding up.

1. The armor should be as light as possible, while still providing protection against the threat that is most prevalent in the geographical area of use.
2. The length of the front of the armor should not be too long; otherwise, it will be pushed up into the throat when the officer sits or bends.

3. The armor should be wide enough to allow the front panel to overlap the back panel. The armholes of the armor should not be too small.
4. The concealed undergarments for officers should conform to the anatomy. The seam construction for such garments that include seams is critical. It is very important that the joined pieces overlap each other a minimum of 1 inch. Particular attention should be paid to the length of the garment, which is a frequent problem. The adjustment straps for the undergarment may be fastened to the back to improve the overall appearance of the uniform.

PROBLEM FORMULATION

INTRODUCTION

The composite laminates are formed by stacking layers of different materials and/or layers of saline material but different fiber orientation. Therefore, the composites are capable of resisting loads in several directions. The stiffness of such composite laminates are obtained from the properties of the constituent elements. Different theories are available for determination stiffness and the strength criterion for laminates using stress and deformation hypothesis. Since
the composite laminate, by construction have their planar dimensions one or two orders of magnitude larger than their thickness. These laminates are generally requiring axial and bending strength therefore these composite laminates are regarded as plate element.
The various theories available for the study and analysis of composite laminates are:

1. Equivalent single layer theories(2-D)
   (a)- Classical laminate theory
   (b)- Shear deformation theory

2. Three dimensional elasticity theory(3-D)
   (a)- Traditional 3-D elasticity formulation
   (b)-Layer wise theory

CALCULATION

- Name of the fiber = Kevlar 29
- Name of the bullet = NATO ball fired from 7.62 SLR
- Weight of the bullet = .0096 kg
- Distance of firing = 10m
- Relative velocity = 838m/sec
- Deflection of fiber before the bullet stops = .0125m
- Using

v2 –u2 =2as
a = - (838)2/(2*.0125)
= - 28089760 m/sec2

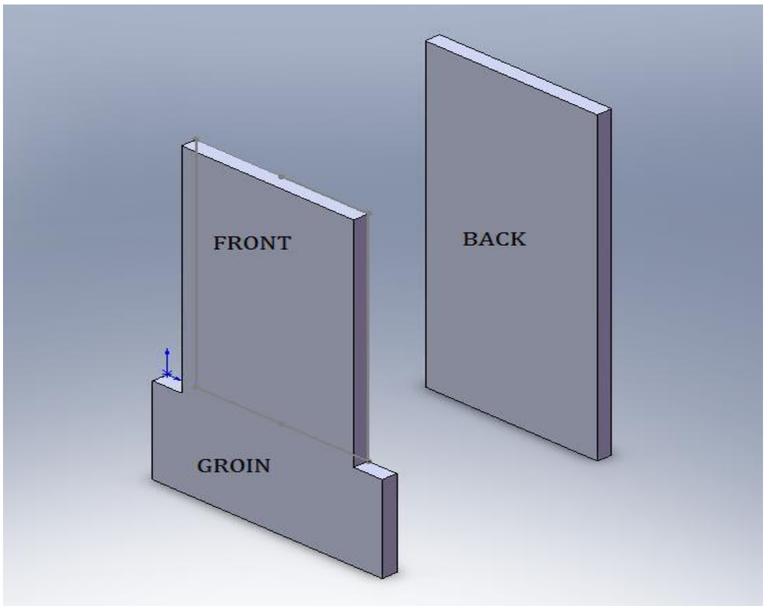
where, negative sign shows that bullet is stopped.

- Taking two cases,
  - CASE 1 : when the bullet strikes at 0^{o} angle of incidence
  - CASE 2 : when the bullet strikes at 30^{o} angle of incidence

Area of the panels

PANEL	AREA(sq. meters)
Front	0.15
Back	0.24
Groin	0.08

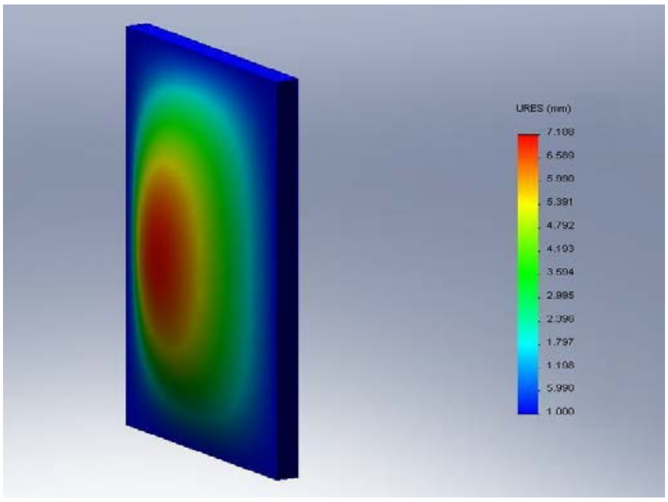
CAD DESIGN FOR BULET PROOF VEST



FRONT PANEL

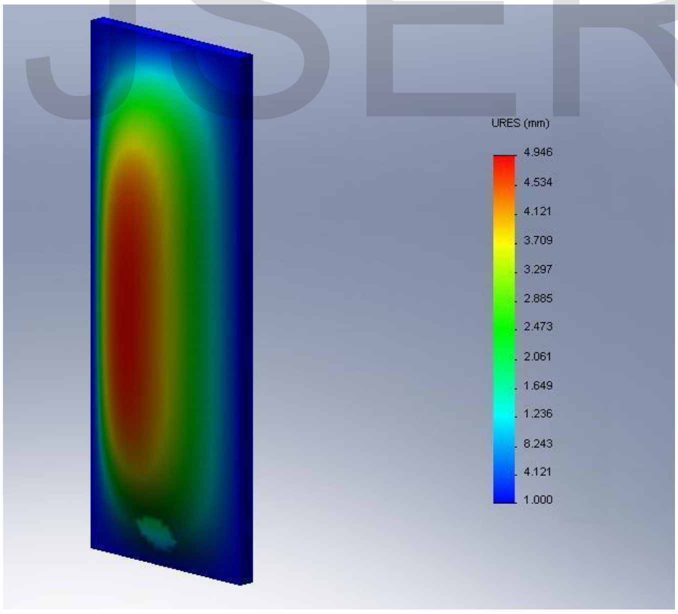
- Dimension of the panel = 500 mm X 300 mm
- No of ply = 10 Nos.
- Thickness of panel = 25 mm

- Stress on the front panel = f / A
  = 269661.696/.15
  = 1797744.64 Pa
  = 1.8 MPa



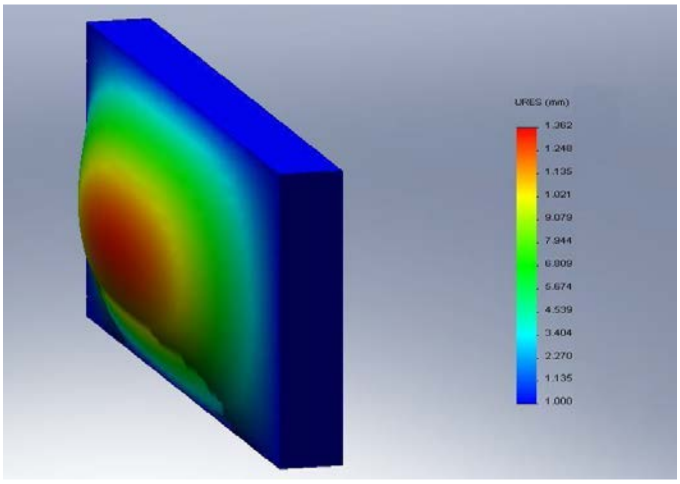
BACK PANEL

- Dimension of the panel = 800 mm X 300 mm
- No of ply = 14 Nos.
- Thickness of panel = 35 mm
- Stress on the back panel = f / A
  = 269661.696/.24
  = 1123590.4 Pa
  = 1.1 MPa



GROIN PANEL

- Dimension of the panel = 400 mm X 200 mm
- No of ply = 10 Nos.
- Thickness of panel = 25 mm
- Stress on the groin panel = f / A
  = 269661.696/0.08
  = 337077.12 Pa
  = 3.40 MPa



CONCLUSION

The major goals of this project were to 1) identify the risks and levels of injury associated with high velocity impacts to the back 2) evaluate ballistic materials in relation to the levels of safety.

From above calculations and analysis we conclude that dyneema fibers are the best among three fibers that we have analysed, as it had the minimum deflection under given force of the striking bullet.

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