Bulletproof Vest and Its Improvement – A Review

Naveen Kumar
Department of Mechanical Engineering
JIET, Jodhpur, India

***Abstract* – The aim of this paper to study bulletproof vest. The material Kevlar, spectra shield, twaron are used in making bulletproof vest. History of armors used in many countries. Making of Kevlar and by using it making of bulletproof vest. Study and classification of bulletproof vests - Type I, Type IIA, Type II, Type IIIA, Type III, Type IV. Quality control and tests for vest like fiber and yarn tensile strength, the tensile strength of the resultant cloth Spectra is also tested for tensile strength by the manufacturer. Bulletproof vests are tested both wet and dry. This is done because the fibers used to make a vest perform differently when wet. Tests for check quality of jacket**

A. Ballistic testing V50 and V0

B. Military testing: fragment ballistics.

We can improve performance by using grapheme. It can absorb more impact of bullet as compare to Kevlar. UHMWPE (Ultra-high-molecular-weight polyethylene).Recently a new fabric developed at the University of California which can make sweat away from our skin. Bullet proof vest must be durable so Cardura can be used .for waterproofing we can use Gore-Tex. Dyneema is a waterproof material if we use we can make light weight bulletproof vest as it doesn't require waterproofing.

***Keywords* – Kevlar, spectra, twaron, UHMWPE, Dyneema**

I. Introduction

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. Its other name is Ballistic vests.

To make bulletproof vest a strong, lighter polymer is required like Kevlar.

To make bulletproof vest first of all polymer is prepared then with the help of polymer panel cloth is made. After that cutting of panel cloth starts. And then the sewing of panel cloth starts.to provide more protection to bulletproof vest there are pouches provide in it. In which we can put plats which are made of high quality ceramic. These plates upgrade the level of bulletproof vest.

Types of bulletproof vests

Type I

Type IIA

Type II

Type IIIA

Type III

Type IV

We can improve performance of bulletproof vest and make it lighter, stronger etc. by using other polymers like grapheme, Dyneema etc.

Over the centuries, different cultures developed body armor for use during combat. Mycenaeans of the sixteenth century B.C. and Persians and Greeks around the fifth century B.C. used up to fourteen layers of linen, while Micronesian inhabitants of the Gilbert and Ellice Islands used woven coconut palm fiber until the nineteenth century. Elsewhere, armor was made from the hides of animals: the Chinese—as early as the eleventh century B.C. —wore rhinoceros skin in five to seven layers, and the Shoshone Indians of North America also developed jackets of several layers of hide that were glued or sewn together. Quilted armor was available in Central America before Cortes, in England in the seventeenth century, and in India until the nineteenth century. Mail armor comprised linked rings or wires of iron, steel, or brass and was developed as early as 400 B.C. near the Ukrainian city of Kiev.

Ballistic nylon was the standard cloth used for bulletproof vests until the 1970s. In 1965, Stephanie Kwolek, a chemist at Du Pont, invented Kevlar, trademark for poly-para-phenylene terephthalamide, a liquid polymer that can be spun into aramid fiber and woven into cloth. Originally, Kevlar was developed for use in tires, and later for such diverse products as ropes, gaskets, and various parts for planes and boats. In 1971, Lester Shubin of the National Institute of Law Enforcement and Criminal Justice advocated its use to replace bulky ballistic nylon in bulletproof vests. Kevlar has been the standard material since. In 1989, the Allied Signal Company developed a competitor for Kevlar and called it Spectra. Originally used for sail cloth, the polyethylene fiber is now used to make lighter, yet stronger, nonwoven material for use in bulletproof vests along-side the traditional Kevlar. [1]

II. RAW MATERIALS

A bulletproof vest has a panel, a vest-shaped sheet of advanced plastic polymers that is composed of many layers of either Kevlar, Spectra Shield, or, in other countries, 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.

The panel is not comfortable but it provides protection. It is inside a fabric shell which is made from polyester or cotton blend. For extra protection nylon padding may use. For make it comfortable.in some bulletproof vests pouches are provided to hold plates made of metal or ceramic bonded to fiberglass. Sides of vest are connected with elastic webbing usually, though, they are secured with straps of either cloth or elastic, with metallic buckles or Velcro closures. [1]

KEVLAR

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.

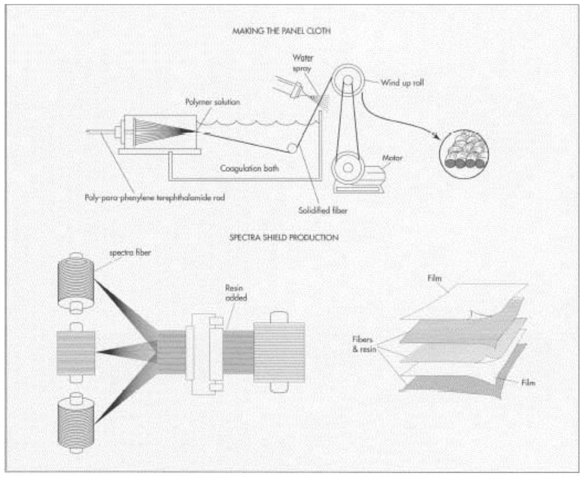
THERMAL PROPERTIES

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. [6]

III. MENUFACTURING PROCESS

a. *Making the panel cloth*

1. To make Kevlar, the polymer poly-para- phenylene terephthalamide must first be produced in the laboratory. This polymer in the shape of rods is then extruded through a spinneret (a small metal plate full of tiny holes that looks like a shower head) to form Kevlar yarn. The Kevlar fiber then passes through a cooling bath to help it harden. After being sprayed with water, the synthetic fiber is wound onto rolls. The Kevlar manufacturer then typically sends the fiber to throwsters, who twist the yarn to make it suitable for weaving. To make Kevlar cloth, the yarns are woven in the simplest pattern, plain or tabby weave, which is merely the over and under pattern of threads that interlace alternatively.
2. Unlike Kevlar, the Spectra used in bulletproof vests is usually not woven. Instead, the strong polyethylene polymer filaments are spun into fibers that are then laid parallel to each other. Resin is used to coat the fibers, sealing them together to form a sheet of Spectra cloth. Two sheets of this cloth are then placed at right angles to one another and again bonded, forming a nonwoven fabric that is next sandwiched between two sheets of polyethylene film. The vest shape can then be cut from the material.

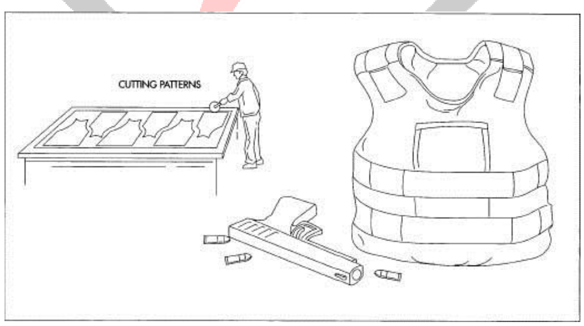


b. Cutting the panels

3. Kevlar cloth is sent in large rolls to the manufactures. The fabric is first unrolled onto a cutting table that must be long enough to allow several panels to be cut out at a time; sometimes it can be as long as 32.79 yards (30 meters). As many layers of the material as needed (as few as eight layers, or as many as 25, depending on the level of protection desired) are laid out on the cutting table.
4. A cut sheet, similar to pattern pieces used for home sewing, is then placed on the layers of cloth. For maximum use of the material, some manufacturers use computer graphics systems to determine the optimal placement of the cut sheets.
5. Using a hand-held machine that performs like a jigsaw except that instead of a cutting wire it has a 5.91-inch (15-centimeter) cutting wheel similar to that on the end of a pizza cutter, a worker cuts around the cut sheets to form panels, which are then placed in precise stacks.

c. Sewing the panels

6. While Spectra Shield generally does not require sewing, as its panels are usually just cut and stacked in layers that go into tight fitting pouches in the vest, a bulletproof vest made from Kevlar can be either quilt-stitched or box-stitched. Quilt-stitching forms small diamonds of cloth separated by stitching, whereas box stitching forms a large single box in the middle of the vest. Quilt-stitching is more labor intensive and difficult, and it provides a stiff panel that is hard to shift away from vulnerable areas. Box-stitching, on the other hand, is fast and easy and allows the free movement of the vest.
7. To sew the layers together, workers place a stencil on top of the layers and rub chalk on the exposed areas of the panel, after the cloth is made, it must be cut into the proper pattern pieces. These pieces are then sewn together with accessories (such as straps) to form the finished vest.



Making a dotted line on the cloth. A sewer then stitches the layers together, following the pattern made by the chalk. Next, a size label is sewn onto the panel.

d. Finishing the vest

8. The shells for the panels are sewn together in the same factory using standard industrial sewing machines and standard sewing practices. The panels are then slipped inside the shells, and the accessories—such as the straps—are sewn on. The finished bulletproof vest is boxed and shipped to the customer.

IV. PERFORMANCE STANDARDS

Armor Level	Protection
Type I (.22 LR;.380 ACP)	This armor would protect against 2.6 g (40 gr) .22 Long Rifle Lead Round Nose (LR LRN) bullets at a velocity of 329 m/s (1080 ft/s ± 30 ft/s) and 6.2 g (95 gr) .380 ACP Full Metal Jacketed Round Nose (FMJ RN) bullets at a velocity of 322 m/s (1055 ft/s ± 30 ft/s). It is no longer part of the standard.
Type IIA (9×19mm;.40 S&W;.45 ACP)	New armor protects against 8 g (124 gr) 9×19mm Parabellum Full Metal Jacketed Round Nose (FMJ RN) bullets at a velocity of 373 m/s ± 9.1 m/s (1225 ft/s ± 30 ft/s); 11.7 g (180 gr) .40 S&W Full Metal Jacketed (FMJ) bullets at a velocity of 352 m/s ± 9.1 m/s (1155 ft/s ± 30 ft/s) and 14.9 g (230 gr) .45 ACP Full Metal Jacketed (FMJ) bullets at a velocity of 275 m/s ± 9.1 m/s (900 ft/s ± 30 ft/s). Conditioned armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 355 m/s ± 9.1 m/s (1165 ft/s ± 30 ft/s); 11.7 g (180 gr) .40 S&W FMJ bullets at a velocity of 325 m/s ± 9.1 m/s (1065 ft/s ± 30 ft/s) and 14.9 g (230 gr) .45 ACP Full Metal Jacketed (FMJ) bullets at a velocity of 259 m/s ± 9.1 m/s (850 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in [Type I].
Type II (9 mm;.357 Magnum)	New armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 398 m/s ± 9.1 m/s (1305 ft/s ± 30 ft/s) and 10.2 g (158 gr) .357 Magnum Jacketed Soft Point bullets at a velocity of 436 m/s ± 9.1 m/s (1430 ft/s ± 30 ft/s). Conditioned armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 379 m/s ±9.1 m/s (1245 ft/s ± 30 ft/s) and 10.2 g (158 gr) .357 Magnum Jacketed Soft Point bullets at a velocity of 408 m/s ±9.1 m/s (1340 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in [Types I and IIA].
Type IIIA (.357 SIG;.44 Magnum)	New armor protects against 8.1 g (125 gr) .357 SIG FMJ Flat Nose (FN) bullets at a velocity of 448 m/s ± 9.1 m/s (1470 ft/s ± 30 ft/s) and 15.6 g (240 gr) .44 Magnum Semi Jacketed Hollow Point (SJHP) bullets at a velocity of 436 m/s (1430 ft/s ± 30 ft/s). Conditioned armor protects against 8.1 g (125 gr) .357 SIG FMJ Flat Nose (FN) bullets at a velocity of 430 m/s ± 9.1 m/s (1410 ft/s ± 30 ft/s) and 15.6 g (240 gr) .44 Magnum Semi Jacketed Hollow Point(SJHP) bullets at a velocity of 408 m/s ± 9.1 m/s (1340 ft/s ± 30 ft/s). It also provides protection against most handgun threats, as well as the threats mentioned in [Types I, IIA, and II].
Type III (Rifles)	Conditioned armor protects against 9.6 g (148 gr)7.65×51mm NATO M80 ball bullets at a velocity of 847 m/s ± 9.1 m/s (2780 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in [Types I, IIA, II, and IIIA].
Type IV (Armor Piercing Rifle)	Conditioned armor protects against 10.8 g (166 gr) .30-06 Springfield M2 armor-piercing (AP) bullets at a velocity of 878 m/s ± 9.1 m/s (2880 ft/s ± 30 ft/s). It also provides at least single hit protection against the threats mentioned in [Types I, IIA, II, IIIA, and III].

[2]

For higher protection we can use plates which can upgrade performance plates are easily fit in pouches provide in bulletproof vest.

The Bullet Safe Ballistic Plate upgrades vest to class IV protection. Each ballistic plate is made from a ceramic of alumina and high strength polyethylene.

V. QUALITY CONTROL AND TESTS

Bulletproof vests are tested when they completed. Fiber manufacture 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. Vest manufacturers test the panel material (whether Kevlar or Spectra) for strength, and production quality control requires that trained observers inspect the vests after the panels are sewn and the vests completed.

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-

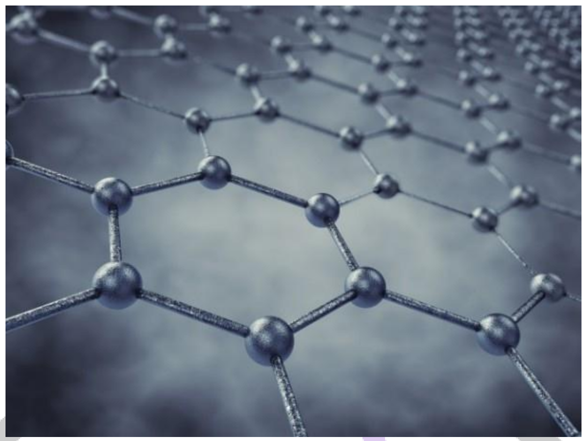
degree angle of incidence, and four at a O-degree angle of incidence. One shot should fall on a seam. This method of shooting forms a wide triangle of bullet holes. The vest is then turned upside down and shot the same way, this time making a narrow triangle of bullet holes.[6]

Tests for check quality of jacket

a. *Ballistic testing V50 and V0*
b. *Military testing: fragment ballistics*

VI. How To Improove Bulletproof Vest

We can use graphene in bulletproof vest. It can absorb more impact of bullet as compare to Kevlar.



Graphene is a very thin and nearly transparent sheet of pure carbon. It is lightweight, but 100 times stronger than steel. Scientists have been studying the material and its application such as using for the development of air-powered electric generators, screen displays of smartphones and other electronic devices, improvement of electric cars range and power, and more.

It is long-known that graphene is one of the stronger materials on the planet, but scientists still don't know the extent of its strength. The latest study, led by Jae-Hwang Lee from the University of Massachusetts at Amherst, tested its strength through miniature ballistic tests using lasers to fire micro bullets to penetrate the thin layers of graphene. The researchers observed the kinetic energy within the sheets to trace changes.

The recent analysis showed that grapheme is 8 to 10 times stronger than steel. It is two times stronger than Kevlar.

But grapheme has a disadvantage the impact holes left on the graphene sheets were wider than steel and other materials that could result in cracks.

This could be resolved though by combining graphene with another material.[3]

We can also use UHMWPE (Ultra-high-molecular-weight polyethylene)

UHMWPE can be formed in several different ways, including ram extrusion and compression molding. However when it is used for body armor it is created using a process called gel-spinning. This involves drawing dissolved ethylene through a series of small holes, which creates a gel material. Two pieces of this gel are then sealed within polyethylene film, and this creates a composite that can then be made into both flexible, lightweight ballistic panels, and more rigid, hard armor plates.

Strength to weight ratio for UHMWPE can be up to 40% higher than para-aramid fibers (e.g. Kevlar) that is why it is becoming popular in body armor market. [4]

Bulletproof vests are uncomfortable and they can't make sweat away from our body so we can use materials which can make sweat away from our body. Recently a new fabric developed at the University of California. The new fabric is threaded with tiny channels that pull the sweat from one side to the other where it forms into droplets that drain away. The fabric not only remains completely dry but breathable as well, which should make the technology attractive to clothing manufacturers. [5]

Bullet proof vest must be durable so Cordura can be used Cordura is made of high tenacity fiber technologies, and is used to make highly durable products. Cordura is a heavy duty fabric which is designed to withstand the rigors of day to day wear.

Bulletproof vest must be water proof for waterproofing we can use Gore-Tex.

A new material developed by Dutch scientists has made its way into soft body armor. Dyneema SB61 is a fiber made from an extremely high grade of the common plastic polyethylene. This new material is stronger pound for pound than everything else on the market.

Dyneema the newest grade of the super-tough material that is vastly better at stopping bullets.

Dyneema is a waterproof material if we use we can make light weight bulletproof vest as it doesn't require waterproofing. [7]

VII. CONCLUSIONS

1. This paper tells us different properties of materials like Kevlar, spectra shield etc.
2. We learn how we can increase performance of bulletproof vest. By using grapheme, UHMWPE, Dyneema etc.
3. The final conclusion of this paper that Dyneema SB61 is best material for making bulletproof vest as it is waterproof and light weight.
4. We can use the fabric (developed in California University) in bulletproof vest to make sweat away from body. So a soldier can wear it 24 hours.

VIII. REFERENCES

[1] http://www.madehow.com/Volume-1/Bulletproof-Vest.html
[2] https://en.wikipedia.org/wiki/Bulletproof_vest
[3] http://www.hngn.com/articles/51160/20141130/graphene-is-stronger-than-current-bulletproof-vest-material-tests-show.htm
[4] http://www.safeguardarmor.com/articles/body-armor-materials/
[5] http://www.gizmag.com/microfluidic-fabric-sweat/27589/
[6]http://www.ijser.org/researchpaper%5CANALYSIS-OF-COMPOSITE-MATERIALS-USED-IN-BULLET-PROOF-VESTS-USING-FEM-TECHNIQUE.pdf
[7] http://www.wired.com/2007/05/new_material_fo/