Bullet Proofing

Introduction

Bulletproofing is the process of making something capable of stopping a bullet or similar high velocity projectiles e.g. shrapnel. The term bullet resistance is often preferred because few, if any, practical materials provide complete protection against all types of bullets, or multiple hits in the same location.

Applications

- Aerospace
- Armored car
- Armored fighting vehicle
- Bank vault
- Bomb suit
- Book bags
- Bulletproof glass
- Bulletproof vest
- Liquid Armor
- Military vehicle
- Panic room
- Plastic armor
- Riot shield
- Safe

Note: What we will be discussing here is about “Body Armor” because this area is quite large to discuss all of them and their advancements.

Body Armor

Bullet proof vests

A bulletproof vest, ballistic vest or bullet-resistant vest is an item of personal armor that helps absorb the impact from firearm-fired projectiles and shrapnel from explosions, and is worn on the torso. Soft vests are made from many layers of woven or laminated fibers and can be capable of protecting the wearer from small caliber handgun and shotgun projectiles, and small fragments from explosives such as hand grenades.

History

Early modern era

In 1538, Francesco Maria della Rovere commissioned Filippo Negroli to create a bulletproof vest.

In 1561, Maximilian II, Holy Roman Emperor is recorded as testing his armor against gun-fire.

Similarly, in 1590 Sir Henry Lee expected his Greenwich armor to be "pistol proof". Its actual effectiveness was controversial at the time

During the **English Civil War Oliver Cromwell's** Iron side cavalry were equipped with **Cape line helmets** and **musket-proof cuirasses** which consisted of two layers of armor plate (in later studies involving X-ray a third layer was discovered which was placed in between the outer and inner layer). The outer layer was designed to absorb the bullet's energy and the thicker inner layer stopped further penetration. The armor would be left badly dented but still serviceable. One of the first recorded descriptions of soft armor use was found in medieval Japan, with the armor having been manufactured from silk.

Cuirass worn by a Carabiniers-à-Cheval.

Industrial era

One of the first commercially sold bulletproof armor was produced by a tailor in Dublin, Ireland in the 1840s. The Cork Examiner reported on his line of business in December 1847.

Another soft ballistic vest, Myeonje baegab, was invented in Joseon, Korea in the 1860s shortly after the French campaign against Korea. Heungseon Daewongun ordered development of bullet-proof armor because of increasing threats from Western armies. Kim Gi-Doo and Gang Yoon found that cotton could protect against bullets if 10 layers of cotton fabric were used. The vests were used in battle during the United States expedition to Korea, when the US Navy attacked Ganghwa Island in 1871. The US Navy captured one of the vests and took it to the US, where it was stored at the Smithsonian Museum until 2007. The vest has since been sent back to Korea and is currently on display to the public.

Simple ballistic armor was sometimes constructed by criminals. During the 1880s, a gang of Australian bushrangers led by Ned Kelly made basic armor from plough blades.

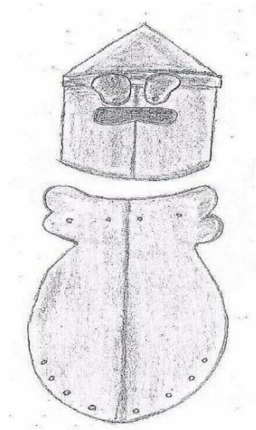
In 1881, Tombstone physician George E. Goodfellow noticed that a Faro dealer Luke Short who was shot was saved by his silk handkerchief in his breast pocket that prevented the bullet from penetrating. In 1887, he wrote an article titled Impenetrability of Silk to Bullets for the Southern California Practitioner documenting the first known instance of bulletproof fabric. He experimented with[9] silk vests resembling medieval gambesons, which used 18 to 30 layers of silk fabric to protect the wearers from penetration.

A similar vest, made by Polish inventor Jan Szczepanik in 1901, saved the life of Alfonso XIII of Spain when he was shot by an attacker. By 1900, gangsters were wearing $800 silk vests to protect themselves.

First World War

The combatants of World War I started the war without any attempt at providing the soldiers with body armor. Various private companies advertised body protection suits such as the **Birmingham Chemico** Body Shield, although these products were generally far too expensive for the average soldier.

The United States developed several types of body armor, including the chrome nickel steel Brewster Body Shield, which consisted of a breastplate and a headpiece and could withstand Lewis Gun bullets at 2,700 ft/s (820 m/s), but was clumsy and heavy at 40 lb (18 kg). A scaled waistcoat of overlapping steel scales fixed to a leather lining was also designed; this armor weighed 11 lb (5.0 kg), fit close to the body, and was considered more comfortable.



Second World War

In 1940, the Medical Research Council in Britain proposed the use of a lightweight suit of armor for general use by infantry, and a heavier suit for troops in more dangerous positions, such as anti-aircraft and naval gun crews. By February 1941, trials had begun on body armor made of manganese steel plates. Two plates covered the front area and one plate on the lower back protected the kidneys and other vital organs. Five thousand sets were made and evaluated to almost unanimous approval - as well as providing adequate protection, the armor didn't severely impede the mobility of the soldier and were reasonably comfortable to wear. The armor was introduced in 1942 although the demand for it was later scaled down.

The Soviet Armed Forces used several types of body armor, including the SN-42 ("Stalnoi Nagrudnik" is Russian for "steel breastplate", and the number denotes the design year). All were tested, but only the SN-42 was put in production. It consisted of two pressed steel plates that protected the front torso and groin. The plates were 2 mm thick and weighed 3.5 kg (7.7 lb). This armor was supplied to SHISBr (assault engineers) and to Tankodesantniki (infantry that rode on tanks) of some tank brigades. The SN armor protected wearers from 9 mm bullets fired by an MP 40 at around 100 meters, which made it useful in urban battles such as the Battle of Stalingrad. However, the SN's weight made it impractical for infantry in the open.

Recent years

During the 1980s, the US military issued the PASGT Kevlar vest, rated at NIJ level II, being able to stop pistol rounds (including 9 mm FMJ) and fragmentation. West Germany issued a similar rated vest called the Splitterschutzweste.

Kevlar soft armor had its shortcomings because if "large fragments or high velocity bullets hit the vest, the energy could cause life-threatening, blunt trauma injuries"[citation needed] in selected, vital areas. Ranger Body Armor was developed for the American military in 1991. Although it was the second modern US body armor that was able to stop rifle caliber rounds and still be light enough to be worn by infantry soldiers in the field, it still had its flaws: "it was still heavier than the concurrently issued **PASGT (Personal Armor System for Ground Troops)** anti-fragmentation armor worn by regular infantry and ... did not have the same degree of ballistic protection around the neck and shoulders.

Performance standards

Due to the various types of projectile, it is often inaccurate to refer to a particular product as "bulletproof" because this implies that it will protect against any and all threats. Instead, the term bullet resistant is generally preferred.

Body armor standards are regional. Around the world ammunition varies and as a result the armor testing must reflect the threats found locally. Law enforcement statistics show that many shootings where officers are injured or killed involve the officer's own weapon. As a result, each law enforcement agency or para-military organization will have their own standard for armor performance if only to ensure that their armor protects them from their own weapons.

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 mm;.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) 7.62×51mm 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].

Backing material for ballistic testing

One of the critical requirements in soft ballistic testing is measurement of "back side signature" (i.e. energy delivered to tissue by a non-penetrating projectile) in a deformable backing material placed behind the targeted vests.

Backer type	Materials	Elastic/plastic	Test type	Specific gravity	Relative hardness vs gelatin	Application
Roma Plastilina Clay #1	Oil/Clay mixture	Plastic	Ballistic and Stab	>2	Moderately hard	Back face signature measurement. Used for most standard testing
10% gelatin	Animal protein gel	Visco-elastic	Ballistic	~1 (90% water)	Softer than baseline	Good simulant for human tissue, hard to use, expensive. Required for FBI test methods
20% gelatin	Animal protein gel	Visco-elastic	Ballistic	~1 (80% water)	Baseline	Good simulant for skeletal muscle. Provides dynamic view of event.
HOSDB-NIJ Foam	Neoprene foam, EVA foam, sheet rubber	Elastic	Stab	~1	Slightly harder than gelatin	Moderate agreement with tissue, easy to use, low in cost. Used in stab testing
Silicone gel	Long chain silicone polymer	Visco-elastic	Biomedical	~1.2	Similar to gelatin	Biomedical testing for blunt force testing, very good tissue match
Pig or Sheep animal testing	Live tissue	Various	Research	~1	Real tissue is variable	Very complex, requires ethical review for approval

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Research

- UHMWPE (**Ultra-high-molecular-weight polyethylene)**
  1. Dyneema
  2. Spectra shield
- M5- fibers
- Nano materials in ballistics
  1. Shear thickening fluids (University of Delaware)
  2. carbon nanotubes (University of Cambridge) in spider silk bullet proofing
- other materials used since 1970s
  1. Zylon HM (poly-p-phenylenebenzobisoxazole fiber)
  2. Aramid
  3. Kevlar

Now we will discuss about the materials under research because that is, about what we are concerned more in this report.

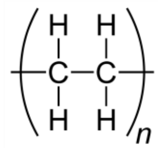
UHMWPE (**Ultra-high-molecular-weight polyethylene)**

Ultra-high-molecular-weight polyethylene (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, with a molecular mass usually between 2 and 6 million u. The longer chain serves to transfer load more effectively to the polymer backbone by strengthening intermolecular interactions. This results in a very tough material, with the highest impact strength of any thermoplastic presently made.

Structure

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). Van der Waals bonds between the molecules are relatively weak for each atom of overlap between the molecules, but because the molecules are very long, large overlaps can exist, adding up to the ability to carry larger shear forces from molecule to molecule. Each chain is bonded to the others with so many Van der Waals bonds that the whole of the inter-molecule strength is high. In this way, large tensile loads are not limited as much by the comparative weakness of each Van der Waals bond.

When formed to fibers, the polymer chains can attain a parallel orientation greater than 95% and a level of crystallinity from 39% to 75%. In contrast, Kevlar derives its strength from strong bonding between relatively short molecules.



Properties

UHMWPE is odorless, tasteless, and nontoxic.

It is highly resistant to corrosive chemicals except oxidizing acids; has extremely low moisture absorption and a very low coefficient of friction; is self-lubricating; and is highly resistant to abrasion, in some forms being 15 times more resistant to abrasion than carbon steel.

Its coefficient of friction is significantly lower than that of nylon and acetal, and is comparable to that of poly tetra fluoro ethylene (PTFE, Teflon), but UHMWPE has better abrasion resistance than PTFE.

Its melting point is around 130 to 136 °C (266 to 277 °F), and, according to DSM, it is not advisable to use UHMWPE fibers at temperatures exceeding 80 to 100 °C (176 to 212 °F) for long periods of time. It becomes brittle at temperatures below −150 °C (−240 °F).

It is very resistant to water, moisture, most chemicals, UV radiation, and micro-organisms.

Under tensile load, UHMWPE will deform continually as long as the stress is present—an effect called creep.

Applications

Dyneema and Spectra are lightweight high-strength oriented-strand gel spun through a spinneret. They have yield strengths as high as 2.4 GPa (350,000 psi) and specific gravity as low as 0.97 (for Dyneema SK75). High-strength steels have comparable yield strengths, and low-carbon steels have yield strengths much lower (around 0.5 GPa). Since steel has a specific gravity of roughly 7.8, this gives strength-to-weight ratios for these materials in a range from 8 to 15 times higher than steel. Strength-to-weight ratios for Dyneema are about 40% higher than for aramid. Dyneema was invented by Albert Penning's in 1963 but made commercially available by DSM in 1990.

UHMWPE fibers are used in armor, in particular, personal armor and on occasion as vehicle armor, cut-resistant gloves, bow strings, climbing equipment, fishing line, spear lines for spear guns, high-performance sails, suspension lines on sport parachutes and paragliders, rigging in yachting, kites, and kites lines for kites sports. Spectra is also used as a high-end wakeboard line.

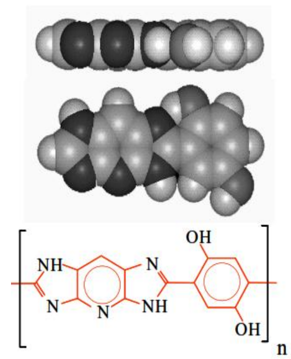
For personal armor, the fibers are, in general, aligned and bonded into sheets, which are then layered at various angles to give the resulting composite material strength in all directions. Recently developed additions to the US Military's Interceptor body armor, designed to offer arm and leg protection, are said to utilize a form of Spectra or Dyneema fabric. Dyneema provides puncture resistance to protective clothing in the sport of fencing.

Spun UHMWPE fibers excel as fishing line, as they have less stretch, are more abrasion-resistant, and are thinner than traditional monofilament line.

M5- fibers

M5 fiber (polyhydroquinone-diimidazopyridine) is a high-strength synthetic fiber first developed by Dr. Doetze Sikkema and his team at the Dutch chemical firm Akzo Nobel. Currently, it is being produced by the United States Magellan Systems International LLC.

Preparation



M5 fiber is prepared by a condensation polymerization between tetraaminopyridine and dihydroxyterephthalic acid using diphosphorus pentoxide as a dehydrating agent. The polymer mixture is then heated and extruded to form brightly blue polymer fibers. The fibers are then washed extensively with water and base in order to remove the phosphoric acid generated by the hydration of diphosphorus pentoxide from the polymer.

In order to remove the water from the fiber structure and enable the intermolecular hydrogen bonds to be created and thus greatly increase the strength of the polymer, the fiber is heated and exposed to controlled stress. This aligns the atomic structure of the fiber in a better configuration for tensile and compressive strength.

Properties

M5 is stronger than Aramid (Kevlar, Twaron) and UHMWPE (Dyneema, Spectra).

M5 is more fire resistant than meta-Aramid. It is the most fire resistant organic fiber yet developed. It is less brittle than carbon fiber and will yield when stretched.

Table 1: Average M5 Mechanical Properties of 10 cm Gage Length Fibers (as of 2000)

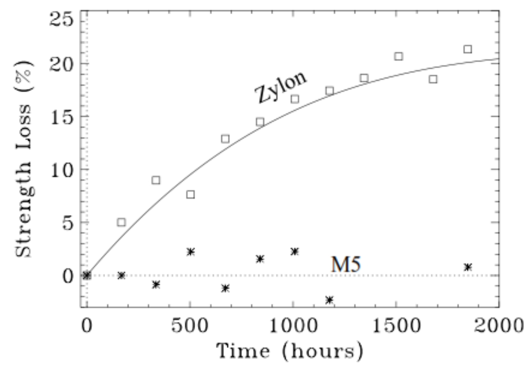
Tensile Modulus (GPa)	271
Tensile Strength (MPa)	3960
Elongation at Break (%)	1.4
Density (g/cm^3)	1.7

Table 2: M5 Goal Mechanical Properties

Property	
Tensile Modulus (GPa)	450
Tensile Strength (GPa)	9.5
Elongation at Break (%)	2.0 - 2.5
Density (g/cm^3)	1.7

Table 3: Fiber Mechanical Properties

Fiber	Strength (σ) (GPa)	Failure Strain (ε) (%)	Modulus (E) (GPa)	$(U)^{\frac{1}{3}}$ (m/s)
PBO	5.20	3.10	169	813
Spectra 1000	2.57	3.50	120	801
600 den. Kevlar KM2	3.40	3.55	82.6	682
850 den. Kevlar KM2	3.34	3.80	73.7	681
840 den. Kevlar 129	3.24	3.25	99.1	672
1500 den. Kevlar 29	2.90	3.38	74.4	625
200 den. Kevlar 29	2.97	2.95	91.1	624
1000 den. Kevlar 29	2.87	3.25	78.8	621
1140 den. Kevlar 49	3.04	1.20	120	612
carbon fiber	3.80	1.76	227	593
E-Glass	3500	4.7	74	559
nylon	0.91	N/A	9.57	482
M5 Conservative	8500	2.5	300	940
M5 Goal	9500	2.5	450	1043
M5 (2001 Sample)	3960	1.4	271	583



Reference

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Nano Materials in ballistic

Shear thickening fluid (Liquid Body Armor)

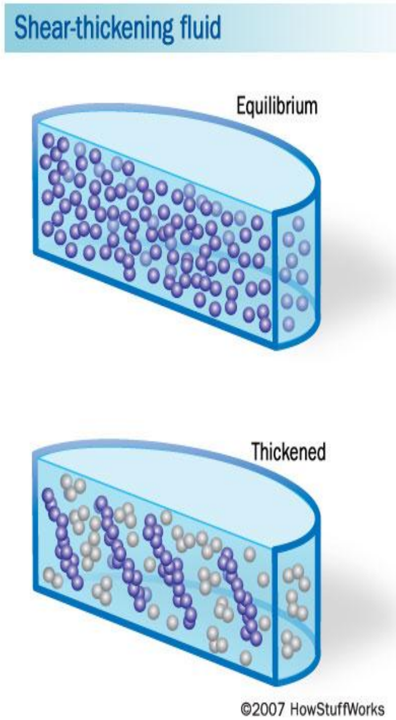
The term "liquid body armor" can be a little misleading. For some people, it brings to mind the idea of moving fluid sandwiched between two layers of solid material. However, both types of liquid armor in development work without a visible liquid layer. Instead, they use Kevlar that has been soaked in one of two fluids.

The first is a shear-thickening fluid (STF), which behaves like a solid when it encounters mechanical stress or shear. In other words, it moves like a liquid until an object strikes or agitates it forcefully. Then, it hardens in a few milliseconds. This is the opposite of a shear-thinning fluid, like paint, which becomes thinner when it is agitated or shaken.

You can see what shear-thickening fluid looks like by examining a solution of nearly equal parts of cornstarch and water. If you stir it slowly, the substance moves like a liquid. But if you hit it, its surface abruptly solidifies. You can also shape it into a ball, but when you stop applying pressure, the ball falls apart.

Here's how the process works. The fluid is a colloid, made of tiny particles suspended in a liquid. The particles repel each other slightly, so they float easily throughout the liquid without clumping together or settling to the bottom. But the energy of a sudden impact overwhelms the repulsive forces between the particles -- they stick together, forming masses called hydro clusters. When the energy from the impact dissipates, the particles begin to repel one another again. The hydro clusters fall apart, and the apparently solid substance reverts to a liquid.

The fluid used in body armor is made of silica particles suspended in polyethylene glycol. Silica is a component of sand and quartz, and polyethylene glycol is a polymer commonly used in laxatives and lubricants. The silica particles are only a few nanometers in diameter, so many reports describe this fluid as a form of nanotechnology.



To make liquid body armor using shear-thickening fluid, researchers first dilute the fluid in ethanol. They saturate the Kevlar with the diluted fluid and place it in an oven to evaporate the ethanol. The STF then permeates the Kevlar, and the Kevlar strands hold the particle-filled fluid in place. When an object strikes or stabs the Kevlar, the fluid immediately hardens, making the Kevlar stronger. The hardening process happens in mere milliseconds, and the armor becomes flexible again afterward.

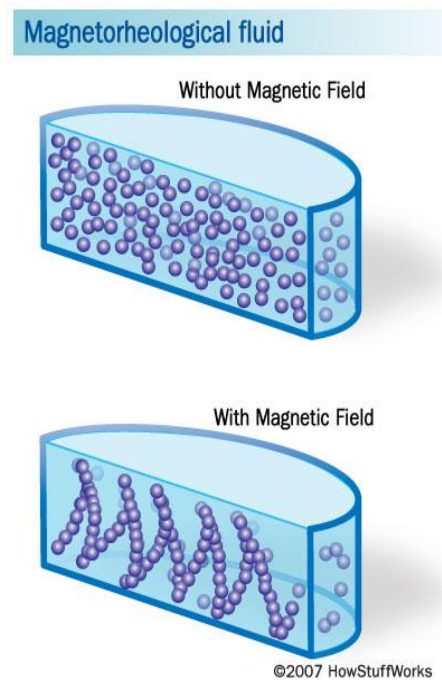
In laboratory tests, STF-treated Kevlar is as flexible as plain, or neat, Kevlar. The difference is that it's stronger, so armor using STF requires fewer layers of material. Four layers of STF-treated Kevlar can dissipate the same amount of energy as 14 layers of neat Kevlar. In addition, STF-treated fibers don't stretch as far on impact as ordinary fibers, meaning that bullets don't penetrate as deeply into the armor or a person's tissue underneath. The researchers theorize that this is because it takes more energy for the bullet to stretch the STF-treated fibers.

Research on STF-based liquid body armor is ongoing at the U.S. Army Research Laboratory and the University of Delaware. Researchers at MIT, on the other hand, are examining a different fluid for use in body armor

THE SLOW BLADE PENETRATES THE SHIELD

STF-based body armor has parallels in the world of science fiction. In the universe of Frank Herbert's "Dune," a device called a Holtzman generator can produce a protective shield. Only objects moving at slow speeds may penetrate this shield. Similarly, slowly-moving objects will sink through shear-thickening fluid without causing it to harden. In low-speed, or quasistatic, knife tests, a knife can penetrate both neat Kevlar and STF-treated Kevlar. However, the STF-treated Kevlar sustains slightly less damage, possibly because the fluid causes the fibers to stick together.

Magneto rheological Fluid



The other fluid that can reinforce Kevlar armor is magnetorheological (MR) fluid. MR fluids are oils that are filled with iron particles. Often, surfactants surround the particles to protect them and help keep them suspended within the fluid. Typically, the iron particles comprise between 20 and 40 percent of the fluid's volume.

The particles are tiny, measuring between 3 and 10 microns. However, they have a powerful effect on the fluid's consistency. When exposed to a magnetic field, the particles line up, thickening the fluid dramatically. The term "magnetorheological" comes from this effect. Rheology is a branch of mechanics that focuses on the relationship between force and the way a material changes shape. The force of magnetism can change both the shape and the viscosity of MR fluids.

The hardening process takes around twenty thousandths of a second. The effect can vary dramatically depending on the composition of the fluid and the size, shape and strength of the magnetic field. For example, MIT researchers started with spherical iron particles, which can slip past one another, even in the presence of the magnetic field. This limits how hard the armor can become, so researchers are studying other particle shapes that may be more effective.

As with STF, you can see what MR fluids look like using ordinary items. Iron filings mixed with oil create a good representation. When no magnetic field is present, the fluid moves easily. But the influence of a magnet can cause the fluid to become thicker or to take a shape other than that of its container. Sometimes, the difference is very visually dramatic, with the fluid forming distinctive peaks, troughs and other shapes. Artists have even used magnets and MR fluids or similar Ferro fluids to create works of art.

With the right combination of density, particle shape and field strength, MR fluid can change from a liquid to a very thick solid. As with shear-thickening fluid, this change could dramatically increase the strength of a piece of armor. The trick is activating the fluid's change of state. Since magnets large enough to affect an entire suit would be heavy and impractical to carry around, researchers propose creating tiny circuits running throughout the armor.

Without current flowing through the wires, the armor would remain soft and flexible. But at the flip of the switch, electrons would begin to move through the circuits, creating a magnetic field in the process. This field would cause the armor to stiffen and harden instantly. Flipping the switch back to the off position would stop the current, and the armor would become flexible again.

In addition to making stronger, lighter, more flexible armor, fabrics treated with shear-thickening and magnetorheological fluids could have other uses as well. For example, such materials could create bomb blankets that are easy to fold and carry and can still protect bystanders from explosion and shrapnel. Treated jump boots could harden on impact or when activated, protecting paratroopers' boots. Prison guards' uniforms could make extensive use of liquid armor technology, especially since the weapons guards are most likely to encounter are blunt objects and homemade blades.

However, the technologies do have a few pros and cons. Here's a rundown:

Shear-thickening Fluid	Magnetorheological Fluid
Hardens instantly and reversibly, allowing thinner, lighter, more flexible armor	Hardens instantly and reversibly, allowing thinner, lighter, more flexible armor
Silica particles generally stay in suspension	Iron particles may clump together, settle or precipitate out of the fluid, eventually making the fluid ineffective
Armor hardens almost instantly on impact	Armor hardens only after a person activates the magnetic field
Requires no electricity	Requires current traveling through wires to create a magnetic field; loss of power or short circuits could deactivate the system, causing the armor to fail

Neither type of armor is quite ready for battlefield use. STF-treated Kevlar armor have been available by the end of 2007. MR fluid may require another five to 10 years of development before it can consistently stop bullets

References

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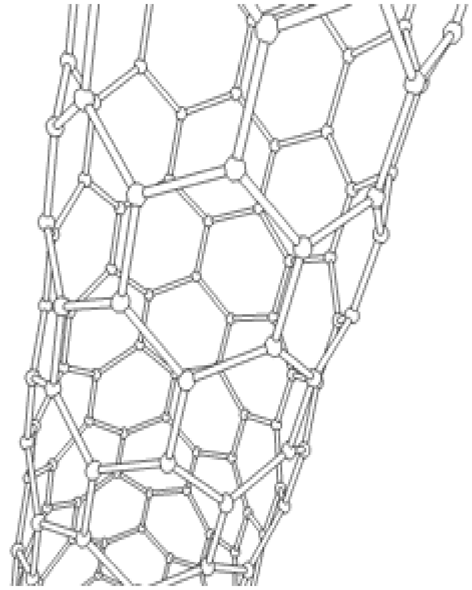
2. http://science.howstuffworks.com/liquid-body-armor1.htm (page 3)

Carbon nanotubes



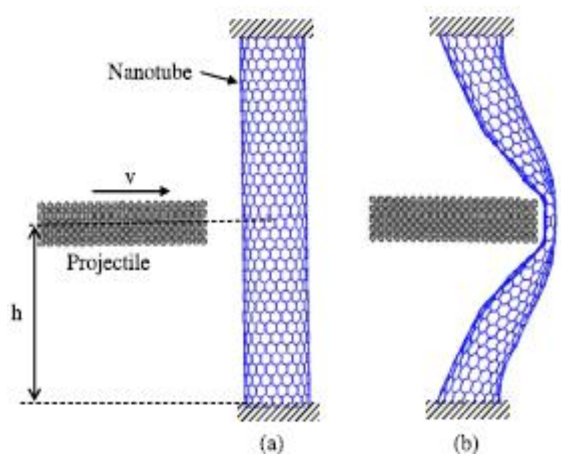
Carbon nanotubes are cylindrical, beehive-shaped structures that are chemically related to graphite. The beehive structure of the nanotube is formed with hexagonal rings of carbon, and contains a “cap” at the end of each cylinder (Adams.) The length- diameter ratio of a nanotube has known to be incredibly large, with the length being millions of times larger than the diameter.

Even though nanotubes are extremely light and tiny, they have been known to be hundred times as strong as steel. This unique strength is due to the covalent bonds that form within the carbon atoms in a single tube. Nanotubes are entirely composed of sp2 bonds, which are even stronger than the sp3 bonds found in diamond. Individual nanotubes naturally align themselves into “ropes” due to the weak Van der Waal Forces that form between tubes. Van der Waal forces also allow for the rolling up of nanotubes, rather than individual sheets.

Nanotubes can merge together if put under high pressure. In this case, some sp2 bonds will trade for sp3 bonds, and produce strong wires in unlimited length (Wylie).

To explain the carbon nanotubes are such an ideal material for bullet proof vests, scientists Kausala Mylvaganam and L. C. Zhang practiced two related experiments in 2006 and 2007.

Energy absorption capacity of carbon nanotubes under ballistic impact: the impact of a bullet of nanotubes on different radii in two extreme cases, a nanotube with one end fixed and a nanotube with bot ends fixed.



The result was (1) on one end fixed nanotube, the energy absorption efficiency decreases when the relative heights of the bullet strikes increased, (2) on both ends fixed, like the picture above, the energy absorption efficiency reaches the minimum when the bullet strikes around a height of 0.5.From this experiment, the scientists learned that both ends fixed nanotubes are more efficient than the one with one end fixed nanotubes.Ballistic resistance capacity of carbon nanotubes: ballistic impact and bouncing back process on carbon nanotubes.

The result was (1) nanotubes with large radii endure higher bullet speeds, (2) the ballistic resistance is the highest when the bullet hits the center of the carbon nanotube, (3) the ballistic resistance of nanotubes will remain the same even when bullets strike at the same spot as long as there is a small interval between bullet strikes.

These two experiments proved how carbon nanotubes will be highly efficient in the future military service due to its flexibility and high energy absorbability.

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Soft body armors

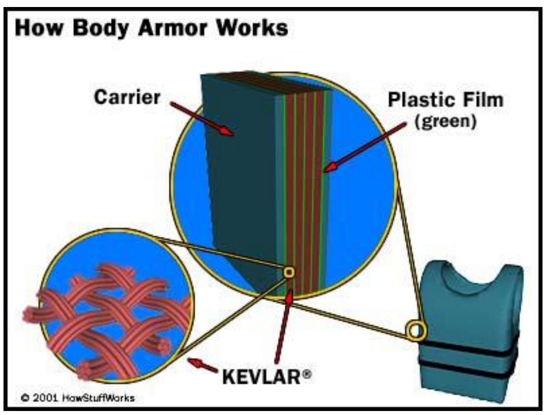
Soft body armor is a fairly mystifying concept: How can a soft piece of clothing stop bullets? The principle at work is actually quite simple. At its heart, a piece of bullet-proof material is just a very strong net.

To see how this works, think of a soccer goal. The back of the goal consists of a net formed by many long lengths of tether, interlaced with each other and fastened to the goal frame. When you kick the soccer ball into the goal, the ball has a certain amount of energy, in the form of forward inertia. When the ball hits the net, it pushes back on the tether lines at that particular point. Each tether extends from one side of the frame to the other, dispersing the energy from the point of impact over a wide area.

The energy is further dispersed because the tethers are interlaced. When the ball pushes on a horizontal length of tether, that tether pulls on every interlaced vertical tether. These tethers in turn pull on all the connected horizontal tethers. In this way, the whole net works to absorb the ball's inertial energy, no matter where the ball hits.

If you were to put a piece of bulletproof material under a powerful microscope, you would see a similar structure. Long strands of fiber are interlaced to form a dense net. A bullet is traveling much faster than a soccer ball, of course, so the net needs to be made from stronger material. The most famous material used in body armor is DuPont's KEVLAR fiber. KEVLAR is lightweight, like a traditional clothing fiber, but it is five times stronger than a piece of steel of the same weight. When interwoven into a dense net, this material can absorb a great amount of energy.

In addition to stopping the bullet from reaching your body, a piece of body armor also has to protect against blunt trauma caused by the force of the bullet. In the next section, we'll see how soft body armor deals with this energy so that the wearer doesn't suffer severe injuries.



References

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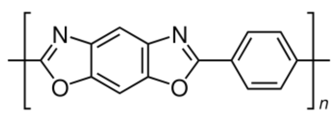
Materials for body armor since 1970s

Zylon

Zylon (IUPAC name: poly (p-phenylene-2, 6-benzobisoxazole)) is a trademarked name for a range of thermoset liquid crystalline polyoxazole. This synthetic polymer material was invented and developed by SRI International in the 1980s, and is currently manufactured by the Toyobo Corporation.

Zylon has 5.8 GPa of tensile strength, which is 1.6 times higher than that of Kevlar. Like Kevlar, Zylon is used in a number of applications that require very high strength with excellent thermal stability.

Molecular structure



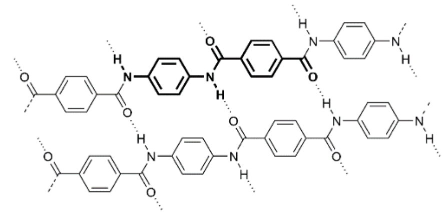
Use in body armor

Zylon gained wide use in U.S. police officers body armor protection in 1998 with its introduction by Second Chance Body Armor, Inc. But protective vests constructed with Zylon became controversial in late 2003 when Oceanside, CA Police Officer Tony Zeppetella's and Forest Hills, PA Police Officer Ed Limbacher's vests failed, leaving Zeppetella mortally wounded and Limbacher seriously injured. Some studies subsequently reported that the Zylon vests may degrade rapidly, leaving wearers with significantly less protection than expected. Second Chance eventually recalled all of its zylon-containing vests, which led to its subsequent bankruptcy. In early 2005, Armor Holdings, Inc. first recalled its existing Zylon-based products, and decreased the rated lifespan warranty of new vests from 60 months to 30 months. In August 2005, AHI decided to discontinue manufacturing all of its Zylon-containing vests. This was largely based on the actions of the U.S. government's National Institute of Justice, which decertified Zylon for use in its approved models of ballistic vests for law enforcement.

Aramid

Aramid fibers are a class of heat-resistant and strong synthetic fibers. They are used in aerospace and military applications, for ballistic rated body armor fabric and ballistic composites, in bicycle tires, and as an asbestos substitute. The name is a portmanteau of "aromatic polyamide". They are fibers in which the chain molecules are highly oriented along the fiber axis, so the strength of the chemical bond can be exploited.

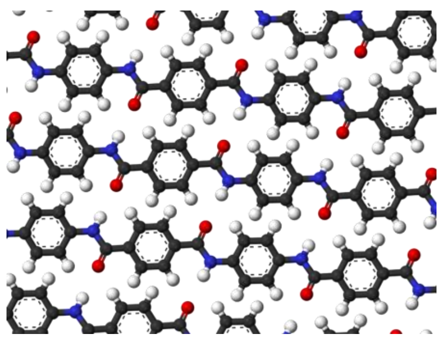
Molecular structure



Kevlar

Kevlar is the registered trademark for a para-aramid synthetic fiber, related to other aramids such as Nomex and Technora. Developed by Stephanie Kwolek at DuPont in 1965, this high-strength material was first commercially used in the early 1970s as a replacement for steel in racing tires. Typically it is spun into ropes or fabric sheets that can be used as such or as an ingredient in composite material components.

Currently, Kevlar has many applications, ranging from bicycle tires and racing sails to body armor because of its high tensile strength-to-weight ratio; by this measure it is 5 times stronger than steel on an equal weight basis. It is also used to make modern drumheads that withstand high impact. When used as a woven material, it is suitable for mooring lines and other underwater applications.



Summary regarding bullet proofing materials

Kevlar is by far the most common fiber used to make body armor, but other materials are being developed.

The most readily available alternative fiber is called Vectran, which is approximately twice as strong as Kevlar. Vectran is 5 to 10 times stronger than steel.

Another rapidly emerging fiber is spider silk. Yes, spider silk. Goats have been genetically engineered to produce the chemical constituents of spider silk, and the resulting material is called Biosteel. A strand of Biosteel can be up to 20 times stronger than an equivalent strand of steel.Chicken feathers are also a possibility. University of Nebraska-Lincoln researchers are spinning them into cloth that is lightweight and very sturdy. Because the feathers have a fine honeycomb texture, they could be resistant to bullets.

Another candidate is carbon nanotubes, which promise to be even stronger than spider silk. Carbon nanotube thread is still rare, and fabric is even rarer. CNet reports the current price of nanotubes at $500/gram. In time, prices should fall and make carbon nanotubes a viable fiber for body armor.

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