Bullet resistant armor made of polymer-metal composite

Pranay Khare (151119053)
R.Srinivasan (151119050)
Atul Soni (151119046)
Siddhant Shukla (151119055)
Atal Tiwari (151119057)

Under the guidance of
Dr. Sanjay Kumar Vajpai, Assistant Professor, Department of MME, MANIT Bhopal

Contents

Abstract

In this project, an attempt to synthesize a composite material to effectively act as a bullet-resistant armor has been made using waste raw materials. Layers of motorcycle tube rubber, reinforced with stainless steel meshes using heatproof adhesive, and one layer of motorcycle tire rubber were first manufactured. This composite has been sandwiched between two steel plates of thickness 3mm, and ballistic testing with a 9mm pistol from close range, with and without the front plate, yielded positive results. A workable design of the same has been proposed.

Acknowledgements

The team is of immense gratitude to the assistance offered by Dr.Sanjay Srivastava, HOD, and the manufacturing facilities of the Materials Testing Lab in the Materials and Metallurgical Engineering department of MANIT Bhopal. This work could not have born fruits without the crucial support extended to us by Mr.Rajesh Kumar Chandel, the Superintendent of Police, Bhopal, the speedy help of Mr. Abhay Srivastava, Assistant Commandant CRPF, Mr. Manoj Sharma, ATS Bhopal, and in particular, the officials and jawans of the CRPF Bhopal firing range, Bangrasiya. We are also very thankful to the monumental technical guidance of our supervisor Dr. Sanjay Kumar Vajpai, Assistant Professor, MANIT Bhopal. Abhishek Raj and Shubham Gajbhiye, 3rd year B.Arch, MANIT Bhopal, also made valuable contributions.

Chapters

Ballistics

Ballistics is the field of mechanics that deals with the launching, flight, behavior, and effects of projectiles, especially bullets.[1]

Bulletproof armor

The term bulletproof is a misnomer, because no protective armor used for ballistic protection is immune to bullet firing in all situations. In extremely rare cases, an armor rated to protect the bearer from the firearm could fail to do so satisfyingly. Hence it is more appropriate to use the term bullet resistant armor. Upon impact from the bullet, the primary objective of the armor is to save the life of the bearer, and to reduce the intensity of the damage occurred as a result, if any.

In general, the face of the armor on the side of the bullet is made with the intention of reducing and dispersing its impact energy, while the face on the opposite side functions as a cushion, to reduce the trauma suffered.

Upon being hit and deformed once, it is vehemently advised to replace the armor, because the function of the armor has been proven to not be so effective. However, soldiers in service could go on fighting and end up perfectly safe as well.

The challenges with this product are the major constraints it imposes, namely light weight and cost. Armors should be made as light as possible to ensure that they do not render the fighter cumbersome, perform its primary function, and at the same time be affordable enough. [2]

Classification of body armor

To reiterate, no armor is immune to bullets. Armors are hence classified according to standards set in security administrations in governments. In general, they are classified based on the ammunition used, the mass of the bullet, approximate bullet velocity, the number of hits required to survive during ballistic testing. The testing is done by experts in the field. For example, in America, the National Institute of Justice, or NIJ, is the National Institute of Justice is the research, development and evaluation agency of the United States Department of Justice. It is the governing body that verifies and carries out ballistic testing of bullet resistant armors. Broadly, however, they are classified into heavy and light armor in India.

NIJ Standard -0108.01 Ballistic Resistant Protective Material						
Armor Type	Test Ammunition	Nominal Bullet Mass	Suggested Barrel Length	Required Bullet Velocity	Required Hits Per Armor Specimen	Permitted Penetration
I	22 LRHV Lead	2.6g 40gr	15 to 16.5cm 6 to 6.5in	320 ± 12m/s 1050 ± 40ft/s	5	0
	38 Special RN Lead	10.2g 158gr	15 to 16.5cm 6 to 6.5in	259 ± 15m/s 850 ± 50ft/s	5	0
II - A	357 Magnum JSP	10.2g 158gr	10 to 12cm 4 to 4.75in	381± 15m/s 1250± 50ft/s	5	0
	9mm FMJ	8.0g 124gr	10 to 12cm 4 to 4.75in	332± 12m/s 1090± 40ft/s	5	0
II	357 Magnum JSP	10.2g 158gr	15 to 16.5cm 6 to 6.5in	425± 15m/s 1395± 50ft/s	5	0
	9mm FMJ	8.0g 124gr	10 to 12cm 4 to 4.75in	358± 12m/s 1175± 40ft/s	5	0
III - A	44 Magnum Lead SWC Gas Checked	15.55g 240gr	14 to 16cm 5.5 to 6.25in	426± 15m/s 1400± 50ft/s	5	0
	9mm FMJ	8.0g 124gr	24 to 26cm 9.5 to 10.25in	426± 15m/s 1400± 50ft/s	5	0
III	7.62mm 308 Winchester FMJ	9.7g 150gr	56cm 22in	838± 15m/s	1	0
IV	30-06AP	10.8g 166gr	56cm 22in	868± 15m/s 2850± 50ft/s	1	0

Above is an illustrative example of how governments classify body armors. [3]

General effect of ballistics on ceramics

A bullet is essentially a piece of metal, so placing a piece of something very hard in front of a bullet, although would cause cracking, would also cause fracture during the impact, which will in a way, stop the bullet. Ceramics, being extremely hard materials, fit the bill in this application. To keep the ceramic armor in place it is in general inserted into layers of Kevlar fibre. Upon impact, the bullet will shatter the ceramic, turning it into powder, but by doing so it absorbs the shock of the bullet. After the ceramic has failed, it actually wears the bullet away as it continues to penetrate because it's now a very hard powder.

However, moulding ceramics into suitable body shapes has been a challenge. Efforts are being made to make an armor, which is potentially lighter for the same stopping power as the ones in use, but also can be made easily into curved shapes, for parts such as shoulders and headgear. To form a ceramic, extremely high pressure is required, and their machining is not done easily through conventional routes economically. Their stiffness and weight, if used extensively, are deleterious to movement. Tackling these aspects is work under progress. [4]

Above is a photograph of Level IV AR500 ceramic body plate armor. [5]

General effect of ballistics on polymers

Polyethylene fibers have replaced Kevlar in many modern hard armor applications, due to greatly improved ballistic resistance and a significant reduction in weight. This is a result of the dense molecular chains formed when processing UHMWPE fibers, and the fact that dense impregnated resins are no longer required. Polyethylene armor systems are manufactured by bonding unidirectional UHMWPE (Ultra High Molecular Weight Polyethylene) fibers over an HDPE (High Density Polyethylene) sheet. The sheets are then cut to a shape and placed in a mold where it is then compressed under high heat and pressure resulting in a cohesive, lightweight hard armor plate. When struck by a projectile the plate delaminates at the point of impact, distributing the force over a wide area while trapping the round within the plate itself, thereby eliminating spall entirely.

Polyethylene can be used independent of other materials to form Level III plates capable of defeating .223/7.62 rounds, however it cannot stop armor piercing ammunition without the addition of ceramic breaker plates. In either case, the cost of the armor plate is around $350, which is extremely high. With the addition of ceramic plates, the light weight advantage also reduces significantly. We also have to keep in mind that armor piercing ammunition could be smaller in size than the ballistic rated for this armor. [6]

Above is a photograph of the Level III UHMWPE armor. [7]

General effect of ballistics on metals

There is general agreement on some of the key features of good metal protection materials: high-strength, good ductility, some strain hardening, and some increase in strength with an increasing rate of deformation ("rate-sensitivity"). Other characteristics that are desirable include good form-ability so that the material can be formed into structures of the appropriate shapes, good long-term performance in the operating environment (e.g., corrosion and fatigue resistance), and weldability for ease of joining.

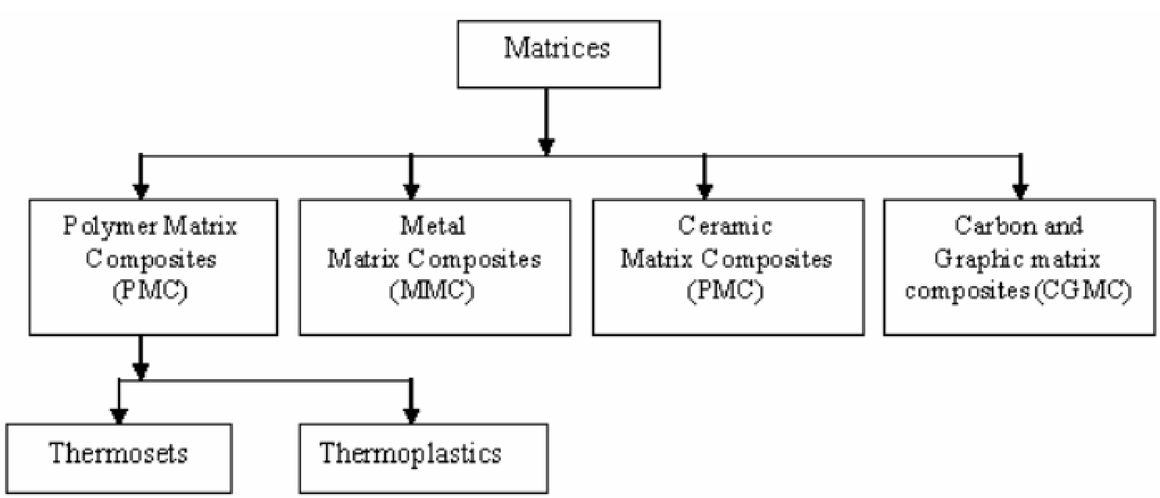
The mechanical properties of metals can be changed substantially by controlling the microstructure by chemical and thermomechanical means. Typical strengthening mechanisms include solid solution hardening, precipitation and dispersoid hardening, and grain boundary strengthening. In addition, many metals and metal alloys can be strengthened substantially by increasing the internal dislocation density through processes such as work hardening. This is one of the advantages of metallic materials: that the processing routes associated with metalworking can often be optimized to increase the strength and the ductility. An example of such a useful work-hardening route is rolling, which is typically used to produce plate geometries. Rolled metal can be much stronger than the metal before rolling, and indeed the largest tonnages of metallic armor materials are rolled alloys (such as RHA). Materials with submicron structural features are known to have higher yield strengths. Indeed, controlling not only grain size but also feature size—for example, in metals and bicontinuous composites like ceramic/polymer or metal/ceramic—can improve mechanical behavior. [8]

Although there is an added advantage of well understood mechanisms and processing techniques, and hence naturally the cost, the main challenge in a metal based armor is the density of the material and its weight.

Composite materials

Fibers or particles embedded in matrix of another material are the best example of modern-day composite materials, which are mostly structural.

Reinforcing materials generally withstand maximum load and serve the desirable properties. Further, though composite types are often distinguishable from one another, no clear determination can be really made. To facilitate definition, the accent is often shifted to the levels at which differentiation take place viz., microscopic or macroscopic. In matrix-based structural composites, the matrix serves two paramount purposes viz., binding the reinforcement phases in place and deforming to distribute the stresses among the constituent reinforcement materials under an applied force.



In the image above, classification based on matrix is illustrated.

Composite materials are commonly classified at following two distinct levels:

- The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

- The second level of classification refers to the reinforcement form – fibre reinforced composites, laminar composites and particulate composites. Fibre Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibres.
- Fibre Reinforced Composites are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if its properties vary with fibre length. On the other hand, when the length of the fibre is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fibre reinforced. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres from bending and buckling.
- Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.
- Particulate Composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

Polymer Matrix Composites (PMC)

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications. Two main kinds of polymers are thermosets and thermoplastics. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermosets find wide ranging applications in the chopped fiber composites form particularly when a premixed or moulding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins. Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of conventional compress techniques to mould the compounds. [9]

Current top designs in market

The Strike Face Level III Ballistic Plate is one of the best plates on the market for protection against rifle fire. Providing level IV protection for the BulletSafe vest, the highest rating for body armor, the Strike Face ballistic plate gives ample coverage against armor-piercing rounds (AR-15 and AK-47). Weighing in at only 5.65 pounds and made of ceramic material containing alumina and high-strength polyethylene, it is significantly lighter and comparably priced to a steel plate.

It is ideal for hunting, a police officer at work or a civilian living in dangerous areas, the Strike Face Level III Ballistic Plate provides an additional layer of protection. It costs $169 per plate. [10]

Above is an illustration of the same. [11]

Scorpius has partnered with a premier leader in the body armor industry to fabricate Polyethylene Hard Armor Rifle Plates are manufactured using high-performance, high density polyethylene, resulting in a lightweight, durable hard armor rifle plate ideal for maritime, rugged transport, and extended duty operations.

These plates are designed to achieve NIJ Level III protection and are Stand Alone plates. Stand Alone plates are designed and tested to defeat ballistic threats using the plate only.

No ballistic vest is required, as all the ballistic energy and fragments are stopped in the plate. These plates are usually reserved for tactical operations or anti-terrorist work where the ammunition threat is unknown, or if the wearing of a vest is considered too cumbersome. [12]

Above is an illustration of the same. [13]

Product design and experimentation

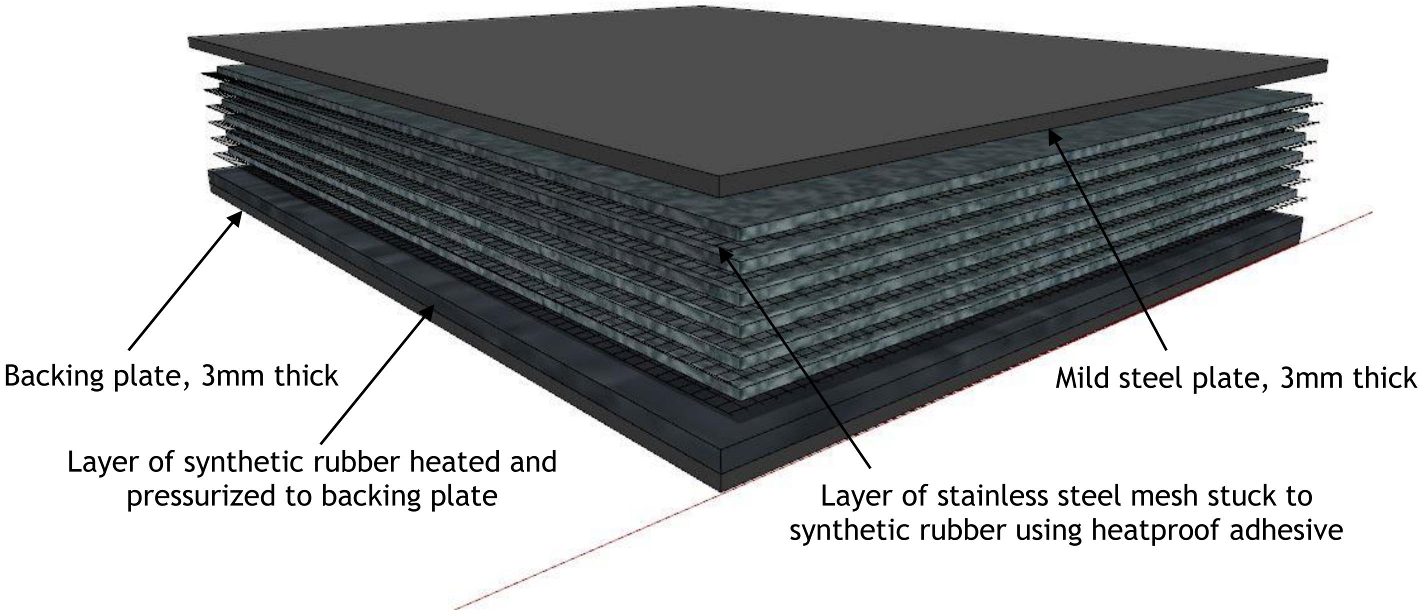
The bullet resistant armor made in the current work comprises of:

- A mild steel plate of thickness approximately 3mm on the front
- Six layers of synthetic rubber reinforced with stainless steel mesh, held together by heatproof adhesive resin
- A piece of synthetic rubber tire heated (400-430°C) and pressurized to the back plate
- A steel plate of thickness approximately 3mm on the back (in that order)

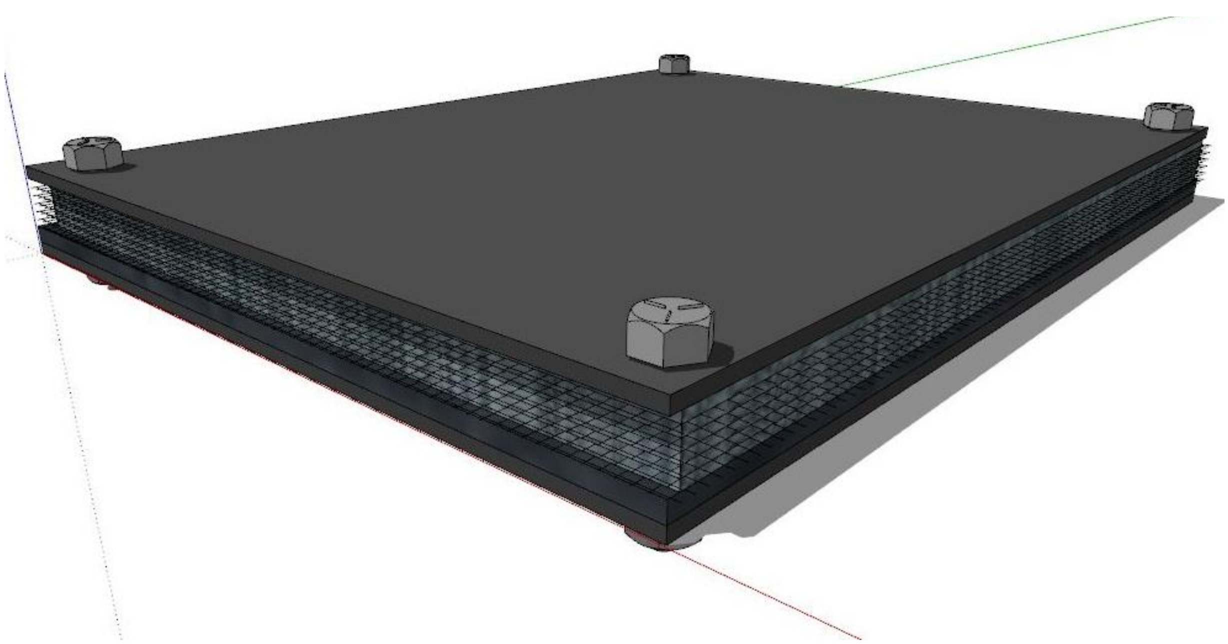
The whole assembly was tightened with fasteners and heated in a microprocessor controlled furnace from 300-400°C, to enable shaping and sticking of the rubber layers to the base metal and adjacent layers. Then the assembly was pressed under a 40 ton load under a hydraulic press almost immediately to provide good compaction.

3D render of design

EXPLODED VIEW



COMPACTED VIEW



Salient features of design

- When compared to heavy metallic armors, **2.7 Kg is a very comfortable weight** to carry.
- The mild steel plates used are **waste scrap** material, of less utility otherwise.
- Rubber tire and tubes used are **waste tires**, unfit for automobile applications anymore.
- **Energy** spent on heating and pressing the assembly is **very less**, and the machinery could be further reduced if a hot press is directly available.
- **Environmentally friendly** processing has been done, since harmful gases, toxins, or harmful discard materials are not generated, and energy is also very minimal.
- The most vital aspect of this novel design is the price. The USP of the current design is an incredible **500 INR!**

Experimentation

The armor was put under ballistic testing under a 9mm pistol.

Four shots were fired in total, each from a distance of about 10 yards.

The first shot was shot on the **whole assembly**. (Weight approx 4.9 Kg total)

Subsequent shots were fired in the **absence of** the front plate. (Weight approx 2.7 Kg total)

Results

No signs of complete penetration of the 9mm pistol bullets were found on the back plate during any of the shots.

Conclusion

The polymer-metal composite proposed in this work has hence been proven to sufficiently withstand the impact of a 9mm bullet fired from a distance of 10 yards, and excluding extremely less probabilities of severe damage, will save the bearer’s life with good efficacy.

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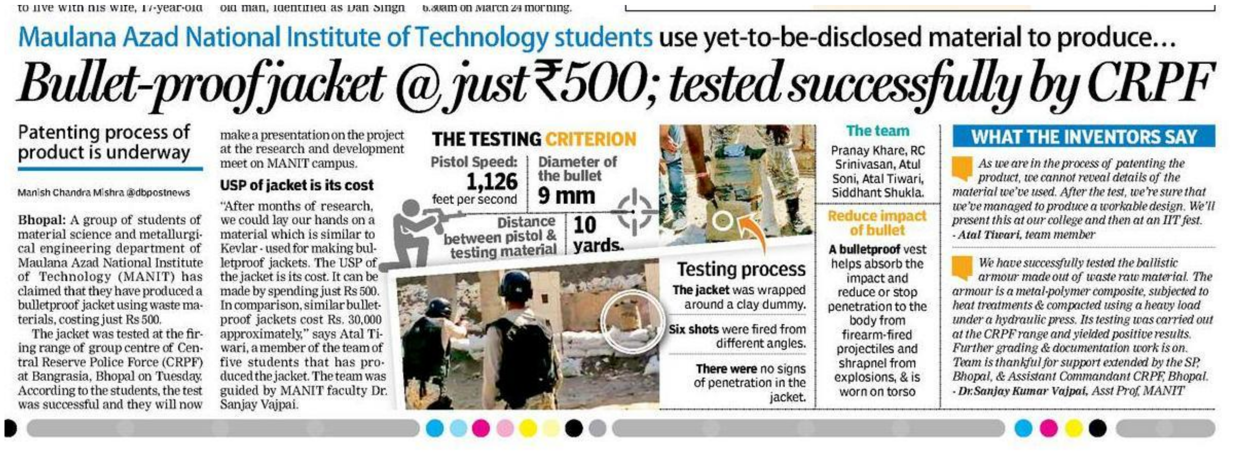
Appreciation in media



to live with his wife, 17-year-old old man, identified as Dan Singh 6.30am on March 24 morning.

Maulana Azad National Institute of Technology students use yet-to-be-disclosed material to produce…

Bullet-proof jacket @ just ₹500; tested successfully by CRPF

Patenting process of product is underway

Manish Chandra Mishra @dbpostnews

Bhopal: A group of students of material science and metallurgical engineering department of Maulana Azad National Institute of Technology (MANIT) has claimed that they have produced a bulletproof jacket using waste materials, costing just Rs 500.

The jacket was tested at the firing range of group centre of Central Reserve Police Force (CRPF) at Bangrasia, Bhopal on Tuesday. According to the students, the test was successful and they will now make a presentation on the project at the research and development meet on MANIT campus.

USP of jacket is its cost

"After months of research, we could lay our hands on a material which is similar to Kevlar - used for making bulletproof jackets. The USP of the jacket is its cost. It can be made by spending just Rs 500. In comparison, similar bulletproof jackets cost Rs. 30,000 approximately," says Atal Tiwari, a member of the team of five students that has produced the jacket. The team was guided by MANIT faculty Dr. Sanjay Vajpai.

THE TESTING CRITERION

Pistol Speed: 1,126 feet per second

Diameter of the bullet 9 mm

Distance between pistol & testing material 10 yards.

Testing process

The jacket was wrapped around a clay dummy.

Six shots were fired from different angles.

There were no signs of penetration in the jacket.

The team

Pranay Khare, RC Srinivasan, Atul Soni, Atal Tiwari, Siddhant Shukla.

Reduce impact of bullet

A bulletproof vest helps absorb the impact and reduce or stop penetration to the body from firearm-fired projectiles and shrapnel from explosions, & is worn on torso

WHAT THE INVENTORS SAY

As we are in the process of patenting the product, we cannot reveal details of the material we've used. After the test, we're sure that we've managed to produce a workable design. We'll present this at our college and then at an IIT fest.
*- **Atal Tiwari**, team member*

We have successfully tested the ballistic armour made out of waste raw material. The armour is a metal-polymer composite, subjected to heat treatments & compacted using a heavy load under a hydraulic press. Its testing was carried out at the CRPF range and yielded positive results. Further grading & documentation work is on. Team is thankful for support extended by the SP, Bhopal, & Assistant Commandant CRPF, Bhopal.
*- **Dr. Sanjay Kumar Vajpai**, Asst Prof, MANIT*

DB Post, dated 28-03-2018