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Puncture Resistance Properties of Natural and Synthetic Fabrics

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THE ballistic impact mechanism mainly depends on the thickness, strength, ductility, toughness, and density of the target material. Nanotechnology is an evolving technology, resulting in significant differences in product behavior. Nanomaterials are increasingly used in textiles to increase performance and provide unrivaled textile functionality. It is anticipated that materials such as dirt and waterproofing, breathability, UV protection, conductivity, and anti-static qualities, wear and wrinkle resistance, and stain resistance, and bacteria will be enhanced by nanomaterials or add new features. By incorporating nanoparticles into fibers, the mechanical qualities of textile fibers can be strengthened.

Keywords: Puncture resistance; Fabrics of Ballistic; Nanotechnology; Natural and Synthetic fabrics.

Introduction

The human body's protection against many hazards, such as sharp objects and battle projectiles, stretches back to human history. Modern military operations and technological combat tactics, weapons on streets, and ammunition require the creation of sophisticated ballistic protection armor systems which are resistant to damage, flexible, low weight, and high-power absorption. Different high-efficiency types of fibers have been produced with various structural characteristics and are responsible for specific responses and performance to ballistic effects at yarn, fabric, and its compliance laminates.

Spectra® (Allied Signal), M5 Vectran, Technora (Tee). Toyoba Specific (Hoechst Calaneses). In various phases of applications, high-performance fibers, i.e., as yarns, textiles, or associated textile reinforcement composites, need to be modified. In addition, there are several techniques to improve ballistic performance on the final ballistic goal other than the specific features of the (fiber) material. Fiber, yarn properties, material qualities, material finishes, and external elements including target situations are many internal elements. Nanotechnology is a developing technology that results in significant product behavior changes. Nanomaterials applications in textiles are steadily increasing to increase performance.

Graphene is a two-dimensional layer of allotropic carbon. The capacity to be robust, strong, and flexible at the same time offers an extraordinary use as body armor or a protection system. Penetration resistance is one of the most important parameters used to estimate the use qualities of textiles. A soft jacket should give the user comfort, lightweight and economic efficiency. It is possible to utilize multi-layer fabric but it impacts comfort. Composites for triaxial fabric (TWF) are of interest to future, rigid and flexible lightweight structures. Untreated and shear thickening fluids-treated fabrics (STF-treated fabrics) were compared to 24 para-aramid layers of stain resistance. An average value between cutting and tearing or stress is often used to measure the relative strength of a puncture. The

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objective of the project was to design a multi-layer composite fabric that has great stab resistance.

P-aramid fibers exhibit outstanding qualities, including high modulus, high strength, resistance to cuts, resistance to impacts, thermal resistance, and abrasion. Recently they have been used for rubber, protective gear, rubber and optical fibers, etc. They have been used. The global demand for aramids is predicted to rise to 130000 tons by 2015 and to 200000 tons by 2020. They can be utilized as an interlayer for body armor that resists punctures and that is not subjected to friction forces. In particular, aramid fiber recycled is as cheap as pure Kevlar fibers. The shear-thickening fluids (STF) additive enhances the puncture resistance considerably under high as well as low-speed loading circumstances by limiting filament and yarn mobility within the impact zone. A sophisticated material for stab tests made of STF and Kevlar textiles was created by Kang et al. In some unique industries such as construction, fire protection, and forestry there is a broad use of body armor to protect the workers' hands and feet from the damage. Some years ago, some stiff elements such as metal sheets, ceramic plates, or titanium foils were put into armor between the layers to resist puncture attempts. This document focuses on the structure, weaving density, and layer resistance of fabrics against almost static puncture.

Fabrics of Ballistic

Textile materials are one of the commonly used materials for personal protection and protection against various types of ballistic threats and related threats, both in soft and rigid forms. The parameters to choose the required textile fabrics are lightweight, high protective performance, and low cost as well as comfort[1]. Through the use of high-performance fibers/matrices and layers of various types of textile structures, including bi and three-dimensional (2D and 3D), it is now possible to meet these requirements (see **Figure 1**). In various technical applications, ballistic textiles made of different kinds of materials are now being used, including ballistic protection.

In addition, the development of highly tested fibers with a high module, high strength, and excellent anti-degradation characteristics plays an important role in the production of ballistic high-performance textiles for ballistic protective body armor and armored vehicles from the next generation. Due to their lightweight, impact resistance and high-energy absorption properties, structural responses of such materials are also widely used in engineering applications. Combinations of various parameters including the structure of the fabric and geometry play, however, an important role in determining ballistic performance of the fabrics and their composite in addition to fiber properties[2]. For such applications there are currently different kinds and structures of ballistic fabrics in the market. Fabrics, unidirectional (UD) structures and non-woven fabrics are typically used in ballistic protection[3].

The most common, used technically in the different applications, including bullet-proof vests and composites, are biaxial (2D) woven fabrics (single, basket, etc.), triaxial fabrics (3D) and unidirectional laminates. However, due to their crimp formation, such fabric faced low impact performance; low delamination and low flat shear properties. Even when its in-plate properties are low, 3D woven fabrics were widely used in various technical applications because of the presence of Z-fibers in the structure they confiscate problems of delamination. Multi-axis, multi-layered 3D fabrics can however solve both problems with delamination due to Z-fiber presence and increased flat properties thanks to the biased yarn layers[4]. The following section will discuss some of the textile textiles commonly used in or compound the ballistic fabrics.[5]

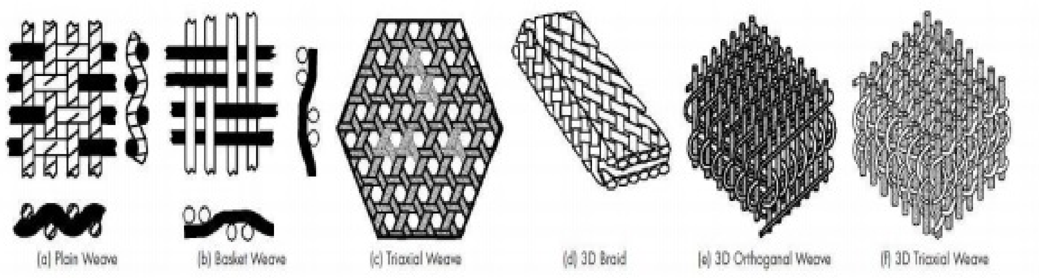

Fig.1. Different 2D and 3D fabric structures.

Materials for protection against ballistic impacts

At the end of the 1960s, high-strength module fibers, including small missiles, were invented as escorts to a new protection age by producing a system of body armor. The US Army introduced the body armor with an interceptor early on, consisting of an external tactical jacket (OTV) to stop high-speed guns and handguns by inserting hard ceramic inserts. Military and police officers use various kinds of body armor and rigid ceramic plates around the world today. These two types of material can be combined to protect different parts of the human body, depending on the level of threat. Although heavier armors are essential to protect against piercing armor, they also result in the armor system being overweight, which will influence a soldier's mobility in the field. The military and the law enforcement officers made of high-strength/module-based fabrics based on fibers[6] use today's soft body armor jackets as well. The following section will be discussed briefly on some of the fiber-protection materials currently in use in the body and other ballistic solutions.

Materials for fiber

The ballistic-resistance armor system helps to stop the projectile from penetrating, by transforming it into various forms of ballistic mechanisms such as defects, damage to the surface, the strain on the primary yarns, deformations of secondary yarns, delamination and breaking of the matrix, etc. Therefore, strength, modulus, and lengths at breakage, projectile deformability, and transverse fiber-shaking wave velocity are the major factors that affect the performance of the protective materials. In this section, the various fibers used in the ballistic protection world have been highlighted.

Traditionally produced fiber

High-performance fibers currently are usually utilized for various ballistic protection applications, including ballistic vests, as woven, non-woven, or fabric reinforcements within PMCs. In the past, however, in combination with metal plates in body arms systems materials like animal skin, leather, and even silk were used to provide the protection that was required until the Korean War. New ballistic vests of E-glass fiber/ethylcellulose composite were also developed during World War II to protect bomb and gene fragments.

In particular, for the development of "flak jacket" along with steel plaques from the American military, Nylon fiber was also used to supply most of the ballistic application in the early years, particularly during the Second World War. Although Nylon has absorbed energy twice as much as p-aramids, nylon was however not effective to provide adequate protection and caused many deaths and injuries to military personnel. E-glass and nylon fibers, due to their low costs, are still in use today. Because of these problems in the ballistic world, a vast amount of research has been undertaken over the last several decades to produce lightweight and flexible ballistic material to develop ballistic systems of the next generation, including corporate blindness, with improved mobility and good threat protection.

To develop ballistic materials of high-quality textiles, high-tension yarns from high modulus, high strength, and excellent anti-degradation characteristics are important[7]. The production of ballistic materials is important. For the development of impact-resistant fabrics in protected clothing not only for military and police forces but also for various applications such as vehicle blasting, protective layering for the aircraft and helicopter (i.e., containment of a turbine fragment), electrical and electronic parts, and honeycomb sandwich, high performance alongside module fibers was used. Even such high-performance fibers are now standard for most fabric-based jackets and other fiber-enhanced armors.

This subsection discusses several of the most frequent types of polymer fibers, including para-aramids and polyethylene fibers, used to develop 3D, 2D, and knitted materials for different protective purposes. shows certain basic high-Fiber of para-aramid

Para-aramid fiber is one of the most common moduli and high-resistance fibers with good melt resistance at high temperatures. Although these materials are ultraviolet (UV) sensitive, they have low water affinity. Extremely strong and heat-resistant fibers are a kind of synthetic fiber first introduced by DuPont ™ at the beginning of the 1960s. They are among the various polymer fibers most well known in protection systems applications. Polyamides also consisting of aromatic acids and amines. It is also formed. Thanks to its strong adhesion between amide groups and aromatic groups, the thermal strength, and traction compared to nylon fibers could be considerably improved[8].

Even if it is fairly expensive, fabrics of such types of fibers, which are advisable for ballistic applications, can provide high strength, high modulus, and good tenacity. Due to these special properties, the Nylon fibers in military armor have been changed more and more. The inherent flexibility and lightweight properties were introduced, which could develop a comfortable ballistic vest with an excellent protective performance by Aramid materials.

Today, these para-aramid fibers are traded under the names Kevlar® and Twaron®. Although aramid fabric offers a lightweight and greater protection, the protective solution design has to reduce the number of layers required in fabric without compromising the efficiency of the final protective armor to reduce costs. Aramid fiber is generally 43 percent lighter than fiberglass (at 1.44 g/cc in density compared to 2.55 g/cm for fiberglass), twice the strength of E-glass, ten times the strength of aluminum as high-festivity carbon on a tensile strength basis It also shows excellent dimensional stability with a slightly negative heat expansion (-2.4 x 10^{-6}°C) coefficient, which can withstand chemical substances other than certain strong acids and alkalis. The aramid fibers also demonstrated excellent stability over a wide range of long-term temperatures, with no loss of strength at -320°F (-196°C), and don›t melt, but begin to carbohydrate at approximately 800oF (427°C).

The two para-aramid materials used in the development of bullet-proof chests are Kevlar® and Twaron® ((Teijin), respectively. They are five times stronger but flexible than stainless steel. They are also heat-resistant, cut-proof, chemical-proof, and can cope with high ballistic impacts [9].

Technora (Teijin) is also a p-aramid fiber, with low creep, high melting, and good bending strength. Kevlar® production has been significantly improved due to its early development. The first Kevlar® 29 has been an innovative product that enhances the flexibility and coverage of protective panel design, as well as a lightweight product that has comfortably been used by people every day. Later, DuPont ™ developed Kevlar® 129 for body armor applications in 1988. This is significantly lighter than its predecessor and can withstand high-speed rings from weapons such as FMJ 9mm. Moreover, Kevlar® Correctional's most recent release (1995) has protected against knife and other weapons menaces and has produced threatening jacks, which can stop both the bullet and stab attacks. The Kevlar® Correctional has also been released. The properties of Para aramids can usually be synthesized as follows based on their ballistic impact behavior[10]:

- Much like E glass fiber compression strength
- Great abrasion resistance
- Good chemical strength
- High thermal degradation resistance (-42 to 180°C)
- Excellent dimensional stability with a somewhat negative thermal expansion coefficient Constant stability of high-temperature Wet fibers restored to ballistic resistance following drying
- P-aramid fibers have superior properties
- High modulus, high tensile strength, cuts, resistance to impact, thermal strength, and abrasion resistance.
- They were recently used as friction materials, protection clothing, reinforcements of rubber, and optical fibers, among other applications.

A large number of p-Aramid fabric jellies must therefore be disposed of which may occur in processing textiles, or at the end of the useful life of the fabric.

As a non-biodegradable substance p-aramid fiber has concentrated on traditional incineration approaches, as mentioned in the Buggy et al. study.[11] This way, not only more energy would be used during combustion but toxic gases like CO, NO, NO_2, etc. would also be released. Therefore, it is attractive to adopt a favorable method, like recycling. One way to regenerate pulp or yarn is to use recycled aramid fiber. Aramid fiber was chopped from Tsu kamoto and Tsunoda into cotton-like short mats or as reinforcement material for reinforced fibers and fiber-reinforced elastomers[12].

The recycling process for spun yarn with recycled and high-quality staple fibers was invented by Tsukamoto and Kosuge[13]. Flambard et al. determined that recycled, p-aramid fibers were almost as high as pure Kevlar, showing excellent cutting resistance. In addition, there was a good fire property, but an abrasion resistance, in the dual knitted material made from the recycled p-aramid filaments[14]. As regards the comprehensive properties of p-aramid fibers recycled, they can be used properly as an interlayer for puncture-resistant body arms that are not frictionally subject. In comparison with pure Kevlar fibers, particularly recycled aramid fibers are linked to low costs.

Ultra-High molecular-weight polyethylene (UHMWPE)

Ultra-High molecular-weight polyethylene (UHMWPE) is a new high-strength and high-modulus fiber, which is commonly used in a range of body-armor products in the material used for the ballistic panel. UHMWPE is mainly made of the high-mass molecular thermoplastic polyethylene. The Allied Signal, which is now Honeywell Advanced Fibers and Composites (Colonial Heights, Va., USA) introduced UHMWPE in the mid-1980s as well as DSM High-Performance Fibers (Heerlen, Netherlands) [15]. This fiber is a polyolefin with characteristics similar to para-aramids, composed of extremely long chains of polyethylene Compression molding and ram extrusion are the most commonly used among various manufacturing techniques for UHMWPE. Ultra-high modulus polyethylene fibers (UHMWPE) are produced for bodily armor generation utilizing a gel spinning process, involving the production of a gel material by drawing several small holes dissolved ethylene. Thanks to this technology, high molecular fiber, good toughness, good chemical resistance, and abrasion properties are achieved.

Moreover, a composite for the production of soft armor ballistic panels or rigid plates of hard armor can also be generated with twin pieces of gel sealed under polyethylene film. Such processes have also produced highly resistant and module fibers with high flexible strength and resistance to flexural fatigue, enabling them to absorb large amounts of energy. These types of high strength and modulus fibers can also be used in high stresses but are not hygroscopic and do not absorb water at low melting temperatures. The fibers in UHMWPE have a melting point of 144 to 152°C, but their tenacity and module may decrease at higher temperatures and increase at low temperatures. The strength-to-weights ratios of UHMWPE are as much as 40 percent higher than para-Aramid fibers with a similar weight basis, according to research shown by the manufacturer[16].

In terms of the lightweight ballistic blue armor with higher energy absorption capacities, the UHMWPE has a force-to-weight advantage over aramids. But also in the case of weak softening, low melting temperatures, and easy cracking high charges, UHMWPE has demonstrated certain disadvantages [17]. In contrast to para-aramid fiber, the two commonly available and widely used Ultra-High-Modulus (UHMP) Polyethylene fibers are Dyneema™ (DSM) and Spectra™ (Honeywell). Spectra fibers are ten times stronger than steel and 40 percent stronger than aramid fibers that also withstand high load strain speeds. Below is a brief description of the characteristically features of the HMPE ballistic performances.

- Good abrasion resistance and chemical resistance
- A good heat loss (50 to 100°C)
- Low penetration
- Good durability

p-phenylene-2,6benzobisoxazol efibers (PBO)

It was manufactured under the trade name Zylon around 1998 by Toyobo Co. Ltd. (Osaka, Japan), through extensive technology and research activities. It is high resistance and modular fiber with excellent thermal stability. The second chance of Body Armor Inc. (Central Lake, Mich., United States), as well as other ballistic waistcoats, was used for the first time in the production of PBO fibers. The fabrics from Zylon can also absorb nearly twice as high energy per unit of aramid or polyethylene per unit than Kevlar and Spectra when influenced on all four borders, and almost twelve times that of the skin from the aluminum fuselage. PBO systems have significantly higher ballistic impact performance than Kevlar 29 systems and are marginally better than those of Kevlar KM2. In addition, PBOs provide half the thickness of aramid jackets with equivalent protection. But, according to Toyobo test figures on the BSST Web site, PBO has been confronted with the challenge from vessel manufacturing due to the decline in aging performance irrespective of climate under relatively mild moisture conditions and sunlight heat (by which it showed a 15 percent decline in performance).

Another study has been investigated the mechanisms of PBO degradation not only with humidity but also with acid and ultraviolet radiation. Loosening of fiber morphology was observed while the humidity was exposed to an increasing number and size of defects. Moreover, the presence of aqueous acid causes both a fiber-structure loosening and oxazole-ring structure hydrolysis, whereas UV radiation has primarily affected the hydrolysis of material near the surface of the fiber with an accompanying amide formation [18]. In addition, M5 (poly[2,6- diimidazo(4,5-b 4050-e) pyridinylene 1,4-(2,5-dihydroxy)phenylene] was invented to increase its corresponding transverse bond, given both low shear module as well as the strength properties of high modular modules and high-fiber because of their weak transverse bonds[8].

Fiberglass

These filaments are amongst the most versatile industrial material produced through the fusion of silica with minerals, which quickly cools the molten weight to avoid crystallization and formed by a process called fibrilization into glass fibers[19]. The various available glass fibers with their specific properties are E-glass, S-glass, C-glass, M-glass, A-glass, and D-glass fibers, readily available on the market. Glass fibers and fabrics for a wide range of applications, including composite strengthening, filtration, insulating, or other uses, are used in ever-increasing numbers. E-Glass and S-Glass are currently commonly used in many applications amongst the different types of GF (S-Glass and S-2 Glass). E-Glass is made of 0 to 10 Wt. percent CaO, Al_2O_3, and SiO_2, and have the mechanical, electrical, and chemical stability to meet most GFP composites, and numerous industrial applications [54][55]. E-Glass is made of GFP, Al_2O_3, and SiO_2.

S-glass consists mainly of silica (SiO_2) alumina (Al_2O_3) and magnesia, a commonly used glass fiber, which was first developed primarily during the 1960s for high-temperature and high-speed applications and later in the 1970s for military ballistic protection. Normally S-2 glass fiber is about 35 to 40 percent stronger than E-glass [56] and, due to its inherent strongness and compressive component strengths, offers exceptional structural performatives and ballistic protection for hard composite armor applications. The fiber's high ultimate elongation characteristics have played an important role in the dynamic ballistic mechanism. In addition, because of structural performance, fire protection, smoke, and toxic gas, lower costs and weights for a particular ballistic performance, fibers are also highly regarded in defense markets. Glass fibers generally have low cost, are highly resistant to traction, and impact and are highly chemically resistant, while they have low modulus, low fiber abrasiveness, low fatigue and poor adherence to matrix resins[20].

Fiber of carbon

It is another important ballistic polymer fiber, made of high tensile strength acrylic fiber, high weight steepness, and very low thermal expansion. Five times stronger than steel, the carbon fiber is twice as steep but lighter. It is ideal primaries for reinforcement in a range of tapes, styles, and widths to heavier ties and unidirectional shapes for the production not just of ballistic material but also of different parts in a variety of applications. This comportment makes it ideal. Sometimes referred to as carbon fibers, the graphite fibers have a special design in which neighboring aromatic plates overlap the middle of each hexagon with one carbon atom. [21]

Fiber of ceramic

The ceramic fiber is a high-strength, high-temperature fiber that is used in required areas of high thermo-mechanical performance in aerospace and rocket industries. It is also considered to be one of the most important materials for lightweight personal armor applications and vehicle protection systems for the last decades, due to its low density, high compressive strength, and high hardness[22]. However, these fibers also show several inconveniences while using for armor, including costly, impeding processing, and a lack of the material property of adequate ballistic performance prediction[23]. In general, conventional ceramic fibers are manufactured by chemical vapor deposition to produce silicon carbide fibers, as well as spinning methods to obtain ceramic alumina fibers. Diversity studies have investigated the commercial monolithic ceramic materials available for the development of personal and vehicular protection systems for ballistic armor, such as Carbide (SiC), Boron Carbide (B4C), and Silicone Alumina (Al_2O_3), as well as Titanium Diboride (TiB_2). Density and elastics HEL limit the ceramic fibers commonly used. Al_2O_3 is the cheapest ceramic fiber of state-of-the-art ceramics with high elasticity, refractoriness, and high hardness. However, due to its highest density, Al_2O_3 brought not only a heavier final protection system but also a lower ballistic efficiency compared to others. Contrary to the harshest ceramic, with the high impact pressure, B4C weakens the ceramic due to the amorphization process. While SiC has no amorphization problem, it's more difficult than B4C. In addition to the porosity and grain size of the ceramics, the final results of the material play an important role.

For instance, ballistic performance is generally better for ceramics with low porosity and small grains than for ceramics with high porosity and greater grain sizes, respectively [24]. Overall, the ceramic-based systems have shown the potential for improving current ballistic performance standards, which include multi-hit capability, due to their low specific severity, high rigidity, toil, strength, and thermal stability.

Other special fibers, such as metal and boron, have also been used in various applications, including protection against ballistics. Due not only to their low cost but also to their environment-friendly and recycling properties, various cellulose-based natural fibers, including jute[25], hemp, flax, sisal, and coir have recently been allegedly used in composite and rigid sheet applications. [26].

Ballistic impact mechanisms

High-performance structural material with high specific rigidity and high specific resistance needs high-speed impact resistance. In this section, we examine different types of analytical and understanding approaches to ballistic mechanisms and the material responses. In various applications including armor systems, various ballistic materials from felt to metal and composite were used. New and innovative materials including fiber, composites, laminates, and ceramics have been extensively used in recent decades to meet the demands of various modern operational military and other technology-based applications. Several studies have shown that the efficiency of the ballistic performance of materials depends on different parameters against impacts as a whole.

Properties of puncture resistance

Nonwoven A with Kevlar fibers has passivated the probe tip for the 3D laminated composite and nonwoven B for reduced fabric windowing. This composing structure was expected to withstand more energy from puncture. Thermo-bonding fibers and Kevlar fibers are closely related to the perforator resistance of the proportions, as well as the volume of the composites. This part expressed the puncture in N/(g/cm^3 as the density puncture resistance (see **Figure 2**). The effect on density and dynamic puncture resistances of limited composites by the weight fraction of low-melting PET fibers. The puncture resistance is clear, regardless of the static and dynamic perforating properties, depending upon the weight of the thermo-bonding fiber. The trend revealed that both the static and dynamic resistors climb and fall, verifying the flexibility and strength of the composites was determined by static and dynamic perforations. The dynamic puncture resistance is lower than the static puncture when the composite only holds Nylon and Kevlar fiber on its superficial nonwoven compared to its respective puncture resistance. The dynamic puncture resistance seems a little higher than the static puncture resistance when it is composed of 10 wt% low-fusion Ped fibers.

Naturally, as shown in **Figure 2**, the Kevlar fibers serve to strengthen static and dynamic puncture-resistant properties. The increase in Kevlar fibers leads to an increase in the volume density of the puncture force. For static puncture properties, this trend is significant. Comparative effects on both sides of the composite components are better than that of the static-dynamic puncture property in constant low-melt PET fibers. However, at a unit volume of Kevlar fibers from 0~15 wt percent, the dynamic punching force remains nearly at 280 N.

Because of the uneven characteristic of Kevlar fibers spread over the nonwoven and needle punching effect that penetrates Kevlar fibers into PET layers, the dynamic puncture property shows an obvious increase of up to 20wt percent. The increasing addition of Kevlar fibers improves the static perforation property for the static perforation.

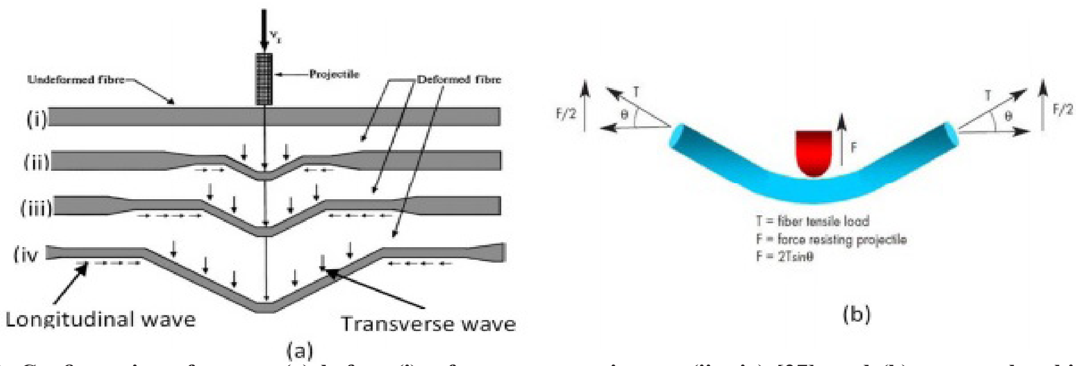

Fig. 2. Configuration of a yarn (a) before (i), after transverse impact (ii - iv) [27], and (b) energy-absorbing mechanism for a single fiber [28].

Effects of fabric finishing

Fabric finishing has also been considered one of the most important parameters for the ballistic results of materials to be considered. The main methods used for impregnating STF into a fabric include various dry ballistic finishing processes, which increase the frictional force of a single strand in the material, thus increasing the apparent yarn module. However, various internal parameters should also be studied during impregnation to determine their impact precisely on final performance. The testing was done with one panel with all neat layers of Kevlar and two-hybrid panels with Kevlar impregnated 9-mm bullets at 436 m/s. The ballistic test was carried out with one panel.

Based on the results, the back signature of the STF impregnated materials was found to be smaller behind the smooth Kevlar layers compared to the panel with all smooth fabrics, as well as hybrid Kevlar layers, placed on the rear of the panel [29]. The result is mainly the sync elongation of the face yarns both in front and rear layers during the ballistic impact, due to STF impregnated fabrics that are lined up after the clean Kevlar layers. In addition to the lamination sequence, ballistic performances were also detected as sensitive parameters, including the effect of fabric counts and shot impregnated p-aramid fabrics with shear-thickening liquid (STF). An investigation of higher fabric count body armor plates has lower ballistic limits (V50) and the BFS value due to its favor of tensile dissipation against high-speed kinetic dissipation.

Furthermore, the hybridization of cleaned and STF impregnated fabrics for densely woven fabric panels has a smaller decrease in the back signature due to the larger differences in the warping-weft crimp ratio. Both the ballistic benchmarking value of the panel also affected the shot-to-edge distance from impregnated textiles. Due to the shots that were located closer to the edge and center, the BFS values were higher, respectively. As improved coefficients of surface friction are among the methods used to enhance performances of ballistic materials, one of the studies was to modify a plain-woven fabric surface for the ballistic impact application of an N_2 non-polymerizing reactive plasma gas and chemical vapor $(CH_3)_2Cl_2Si$ (see **Figure 3**). [30]

In addition, the impregnated fabrics with a colloidal fluid thickening shear (silicate parts (450 nm) distributed in ethylene glycol) could also improve the ballistic composite surface. One research study found that impregnated Kevlar fabric shows significant increases in ballistic penetration resistance compared to simple stacks of neat fabric while testing ballistic penetration measurements for fragment simulation projectile (FSP) at 244 m/s.

Moreover, in comparison to nice Kevlar materials of equal weight, the STF-impregnated textile Kevlar gives nearly the same ballistic protection but is far thinner and much more flexible due to the increased yarn pull-out force when the STF changes into its rigid condition. Silicium particles have a bearing on the ballistic performance behavior of impregnated textiles, both when impregnated with plain woven fabrics with Silica colloidal suspension and impact conditions.

To study this, researchers used the development and the application of silica colloidal suspension (SCS) in flat fabrics with average diameters of 100 nm, 300 nm, and 500 nm. These fabrics, impregnated with lower silica SCS (average diameter of 100 nm) have shown better impact performance as large particulate matter and untreated textiles both in terms of impact energy absorption and resistance to blunt traumas because more interfacial friction occurs between the films. These fabrics are subject to ballistic tests under different limit conditions. In addition, these fabrics have shown that the ballistic performance influence of impregnation with SCS has been closely linked to bordering conditions. Thus, the particle size and the limits of the SCS can be manipulated to take full advantage of the advantages of the SCS impregnated fabric for a flexible armor of the body. The laminate matrix also impacts the ballistic impact of composite laminates in textile fabrics.

One study was conducted to study the impact of matrix on the ballistic impact and damage pattern of composite laminates of the aramid fabric using a variety of aramid (Twaron) epoxy and PP composite laminates of various thicknesses [31]. Twaron PP Composites have achieved better ballistic limits than Twaron-epoxy composites with equivalent thickness, as shown by the results against 7,62 mm of armor-piercing projectiles with different SV tests.

In comparison to a global failure mode in PP-based composites, epoxy-based composites were also confronted with localized damage. A further important investigation has addressed how clothing fabrics are used to simulate soft fabric and thin cowhide for simulate skin, as intermediary objectives on ballistic penetration against a standard 12-gauges sniper shell [32].

Slightly more protective than polyester was the thickest denim and cotton fabrics. Although this study was focused only on experimental products that require a figure model to study various shot sizes, different chokes, and various fire sizes, the results show that the range and potential penetration of fire pellets were found not only in terms of speed and energy retained at short distances but also in terms of pellet pellets reaching the target with a tight paw.

A recent application for puncture resistance

On natural fabric

On cotton fabrics

Impact and explanation for punctures on the human body: clothing was used to protect the human body against actual and imagined physical, social, emotional, and spiritual threats. Protective apparel is used depending on the level of protection needed to improve functionality and is usually used for defining apparel and apparel accessories that concentrate on physical body protection. Protection apparel. [33] The bulletproof jacket is designed as protective clothing to safeguard the main organ of the body from damage caused by bullets.

A bullet, though small, causes damage because it moves at an extraordinarily high speed so its kinematic energy is immense. The fabrics in the organ are comprised and moved as temporary and permanent cavities become created when the bullet penetrates the body. Since the human body cannot quickly dissipate the energy sufficiently, the damage is caused. The human fabrics act as a semifluid when the bullet produces pressure and shock waves that affect the inner bodies and can break down them. It is not known as a blunt trauma simply because the outside of the corpse looks intact." A blunt trauma, from which more specific types such as contusions, abrasions, lacerations, and bone fractures develop, is contrasted to penetrative trauma in which an object like a projectile or a knife enters the body (see **Figure 4**). [34]

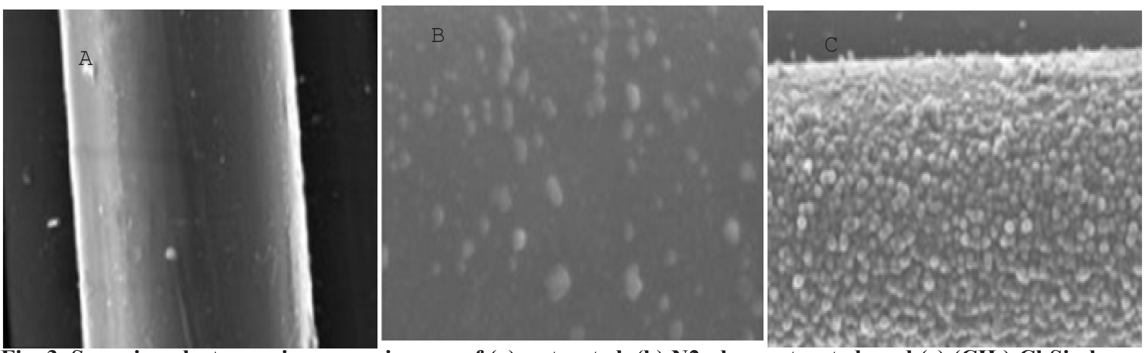

Fig. 3. Scanning electron microscopy images of (a) untreated, (b) N2 plasma-treated, and (c) $(CH_3)_2Cl_2Si$ plasma-treated fibers [30].

Fig. 4. Blunt Trauma Resulting from Excessive Impact Deformation.

The temporary cavity may cause blundered trauma to survive more elastic and more coherent fabric like muscle skeleton, lung, empty intestines, and nerves as well as blood vessels. But less elastic, less cohesive organs, like the liver, brain, and heart, cannot tolerate the functioning of protective clothing

Well, cavitation temporary blunt trauma. Because of this, the bullet has a significant impact even if the skin has no impact on the human body. Puncture and impact Resistance, which was invented to protect the body against the strong impact of ballots or fragments, is one of the primary ideas of inventing body weapons. Body armor's function is to prevent the human body from being penetrated by bullets or fragments. However, a fatal injury can result from blunt trauma, serious internal harm or contusions, and even death. It may cause fatal injury as well.

Damaging effects of shock and shock resistance: Shock occurs when, in a short period, a relatively high impact force is used, leading to an energy wave that injures or harms people and objects at the end of the shock wave. Such negative effects occur when the shock energy is transferred from the source of the impact force to the object affected. Transfer of harmful shock energy from the impact force causes injury and damage and eventually leads to reprocessing, waste, and downtimes. And shock energy is effectively absorbed to avoid damaging shock effects[35]

As the fibers work with the individual layers as well as other materials in the jacket, the bulletproof jacket's large area is involved in avoiding bullet penetration. This also helps to dispel forces not penetrating,' which is the result of an irreversible process in uniform thermodynamical systems. The dissipating process is a transformation of energy from an initial form into a final form, "internal, bulk flow kinetic, or system potentials." The ability of the final form to do mechanical work is less than the initial shaft (**Figure 5**) Bulletproof jackets can protect against the most common low- and medium-impact impacts at a variety of levels. and designed to defeat rifle fire is made of hard materials such as ceramics, metals, or semi-rigid buildings. Due to its weight and bulkiness, it is impractical for routine use and is restricted to tactical use if it is exposed to greater threats. It is used on the outside for a short period.

Protective clothes which make material: protective clothes can be made of a variety of materials depending on the level of protection needed by the carrier, e.g. the protection needed for a person at risk of shooting could be guaranteed through the use of heavy weapons that are brilliant in defense against penetrating jabs and low to medium fire force, but which have a huge impact. The armor would scatter the energy across the whole surface, but the impact would otherwise not be reduced and the wearer injured. In the textiles industry, applications have been widely spread due to the progress of nanotechnology in producing Fibers and yarns, including enhancing fabric finishes. Recent progress in manufacturing finishing and processing has made significant progress in nanotechnology.

The use of titanium dioxide (TiO_2) nanoparticles for ultraviolet protection has been made by the combination of nanoparticles with organic and inorganic compounds. The surfaces of fabrics that are treating with abrasion resistant, water repellent, ultraviolet (UV) finish can be appreciably altered. The use of engineered cross-relationship agents in the final process increases the resistance to wrinkles in cotton textiles. In the textile industry for flame and fire retardants, the newly developed technique of microencapsulation is used. For antimicrobial effects and odor control, microcapsules using silver nanoparticles (AgNPs) were developed. The following New techniques for protective clothing production have therefore recently been introduced and developed using nano and nanomaterials. [36]

The capability to absorb energy during deformation before fracture, which represents its toughness factor (CNT), is the most important factor in the production of protective material, A range of important applications, such as aerospace, aircraft, construction, and bulletproof jackets can be found in highly tough materials. Traditional composite materials like glass fiber and carbon fiber-reinforced composites are often strong, but not hard. Therefore, it is highly required to explore new tough materials. (10, in particular for improved tensile strength, CNT has its unique mechanical characteristics. Calcillinated, beehive-shaped structures chemically associated with graphite are carbon nanotubes (CNT). At the end of each cylinder, the structure of the beehive of the nanotubes consists of hexagonal carbon rings and contains a cap (Figure 4). [37] The ratio of length and diameter of a Nanotube (CNT) with the bullet-proof vests of length is known to be extremely large. They consist of a single sheet of the rolling graph.

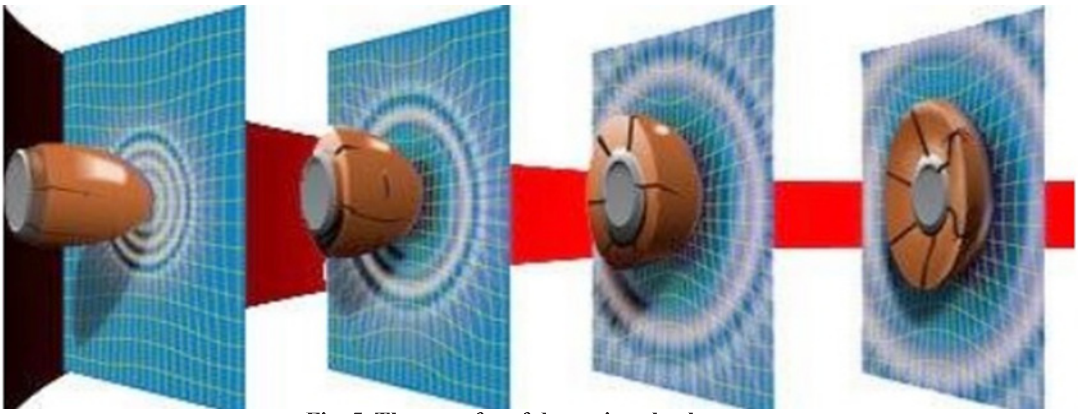

Fig. 5. The transfer of damaging shock energy.

A study of the capacity of various carbon nanotubes to resist balls. It showed that larger radius nanotubes could withstand more than millions of times the diameter. Although the nanotubes are extremely light and tiny, they are hundreds of times stronger than steel. It is a chemical link involving the share of atoms in electron pairs due to the molecular covalent bonds. These pairs of electrons are called joint pairs or bonding pairs and the stable balance of attractive and repulsive forces among the carbon-atomic atoms that are formed in a single tube. Nanotubes consist entirely of sp2 connections that are stronger than the sp3 connections found in the diamond. Due to the weak Van der Waal Forces, individual nanotubes naturally lined up into "ropes" to determine the attraction of intermolecular forces between molecules which are formed between nanotubes, rather than individual sheets. Nanotubes fuse when placed under high pressure. Some sp2 bonds are in this case trading in sp3 bonds, producing strong cables in unlimited length.

Improve the ballistic effectiveness of the CNT body armor: Millions of carbon nanotubes consist of nanofibers made of carbon, which are woven in a highly light material.

Without constant deformation or degradation, they absorb energy extremely well. That is why carbon nanotubes are perfect for a bull-proof vest. The high elasticity module of carbon nanotubes has developed a new material that really can rebuild the force of a bullet . For purposes of the manufacture of bulletproof chips, single-wall nanotubes (SWNTs) are preferred over multi-wall nanotubes. It consists of a single graph sheet rolling. A study on the ballistic capacity of various nanotubes of carbon. It showed that larger-radius nanotubes can withstand high bullet speeds and larger-length nanotubes can absorb more energy. They also found the absorption and recovery of energy to be higher when the bullet hits the center of the nanotubes. To improve the ballistic performance of body armor, there are many approaches to using the CNT.

Use of graphene in high-tech body weapons

The replacement of Kevlar into bullet-proof jackets is one of the most favorable applications for graphene. Outdated bulletproofing aramid fibers have many design and execution flaws. The jackets are of little help when the bullet has been stopped and disperse the force applied to the wearer. This is a big problem because of the large effects that can easily break the internal organs in massive amounts of force on the organ, even without penetration. It is also possible that high-speed objects will penetrate fully in the jacket, as most are intended to stop small to medium force impacts, such as pistol rounds which have significantly less kinetic energy and are thus more easily absorbed by the jackets. Kevlar is a revolutionary technology, but it still does not fully protect the user as severe blunt trauma wounds are common. It provides an enormous increase against its previous users. It is vital to stop the bullet itself, but to ensure complete protection, the strength it applies should also be stopped. Nanoparticles were used in cotton fabrics with hematites (Iron III oxide).

The treatment improved the mechanical characteristics of processed samples By adding nanoparticles into fibers the mechanical properties of textile fibers can be increased, such as increased puncture strength, the strength of traction, tearing strength, regeneration of the wrinkling, and rigidity of textiles. Researchers around the world have said this may lead to high-performance fiber production with increased strength, a rebounding of wrinkles, and increasing wear and tear resistance of a fabric. The application in household nanohematite synthesized nano (Iron III Oxide) particulates for textiles to TiO_2, Ag, Cu, and Zn Nanoparticles in textile fabrics. By the scanning of the electron microscope, normal and treatment cotton textile, the treated material is morphologically observed. Effect of iron nanoparticles on different fabric properties examined in standard

On silk fabrics

Many different materials in the field of protective clothing are used to provide resistance to cuttings, tearing, and punching where high steadiness and shear strength are important. Multi-layer pads, highly formed fabrics, and triaxial materials are used as supports to improve the punch resistance of protective fabric. The results show that when we use a silk-filled pad supported on a highly resistant Internet the specific puncture load is highest. Triaxial fabric (TWF) multi-layered silk manufactured over para-aramid is superior to the plain weave fabric of para-aramid.

The other triaxial fabric has been prepared from polyester yarns. Other composite silk fab fabric samples have been prepared using the supported grid either of high-tipped woven polyester made of cord or triaxial fabrics. Puncture strength tests have been carried out on a specially designed set-up for the penetration strength test, as demonstrated in **Figure 6**. The test aims primarily to identify the maximum loads required to drill fabrics.

When the fiber in contact with the eye of the knife is cut through the material, the stress is high, it tends to stretch and the yarns move in a weft and a warp direction that allows the edge of the chrome to pass through. The fabric is formed with strength and the edge of the cuff begins to cut the yarn. The cutting resistance depends on the material, thread cross-section, strength, and support points for the base fabric[38]. By the friction between the yarn and the sliding blade, the puncture resistance is also increased. The total energy needed to penetrate depends heavily on the energy lost when the yarns are cut around the blade rim and the friction between the blade surface and the surrounding fabric is overwhelming.

The cutting behavior of the pure silk fabric shows different types of shapes than the Para-aramid fabric as shown in **Figure 7**, which shows that the tip of the blade will cut one yarn while pushing the others away; the shear modulus, therefore, plays a major role in preventing the blade from penetrating through the fabric.

Fig. 6. Penetration resistance test set-up (a), fabric sample clamp (b), and knife blade (c) [38].

Fig.7.Cut behavior in silk fabric and para-aramid samples.

Improving fabric resistance for punching Using a polyester net of high resistance

The simple weaving of high tenacity polyester from cord threads to support silk fabric layers is used to enhance the puncher load.

Multi-layered silk para-aramid fabric design Lightweight, low material cost, isotropy, and shear resistance are the main points for triaxial fabric. Militiky[39] points out that the strength of the burst biaxial structures and the force of cutting are not correlated. Generally, Triaxial fabrics (TWFs) are more evenly strained than biaxial structures in the event of a burst deformation, as loads are more evenly distributed throughout the fabric plane[40]. Tearing is always opposite with triaxial fabric with two sets of yarn, instead of one; therefore, overall tear resistance results are improved. The shear resistance of woven fabrics is more than 5 times greater. The tearing resistance of triaxial fabric exhibits four times the same weight resistance as conventional fabric.

Triaxial textiles demonstrated far superior characteristics of stress distribution in ball-burst tests compared to conventional textiles because of their isotropic feature. However, the triaxial fabric will transmit the strain more effectively than conventional fabric. The sample deforms under axial stress from a uniaxial to a biaxial strain as samples are loaded employing triaxial fabric as a supporting net for silk fabric. Further threads of the triaxial fabric resist the deformation. Therefore, the blade must pass through the protecting fabric with extra energy, in our case around 20%. When the pale penetration is utilized as a single layer, **Figure 8** shows the pale via the triaxial fabric whereas **Figure 9** displays shapes of pale penetration when the triaxial fabric is placed between silk fabric layers. **Figure 8** and **Figure 9** show that before the blade can be passed the triaxial fabric is distorted in every direction to enhance the energy necessary for the structure, certain filaments are wrapped in the blade and lift through the upper layers of the silk fabric. This is especially true for polyester and para-aramid triaxial rice, but the blade can cut the fabric before it passes through in the case of woven fabrics. In **Figure 10** a distinct cut appears. [41]

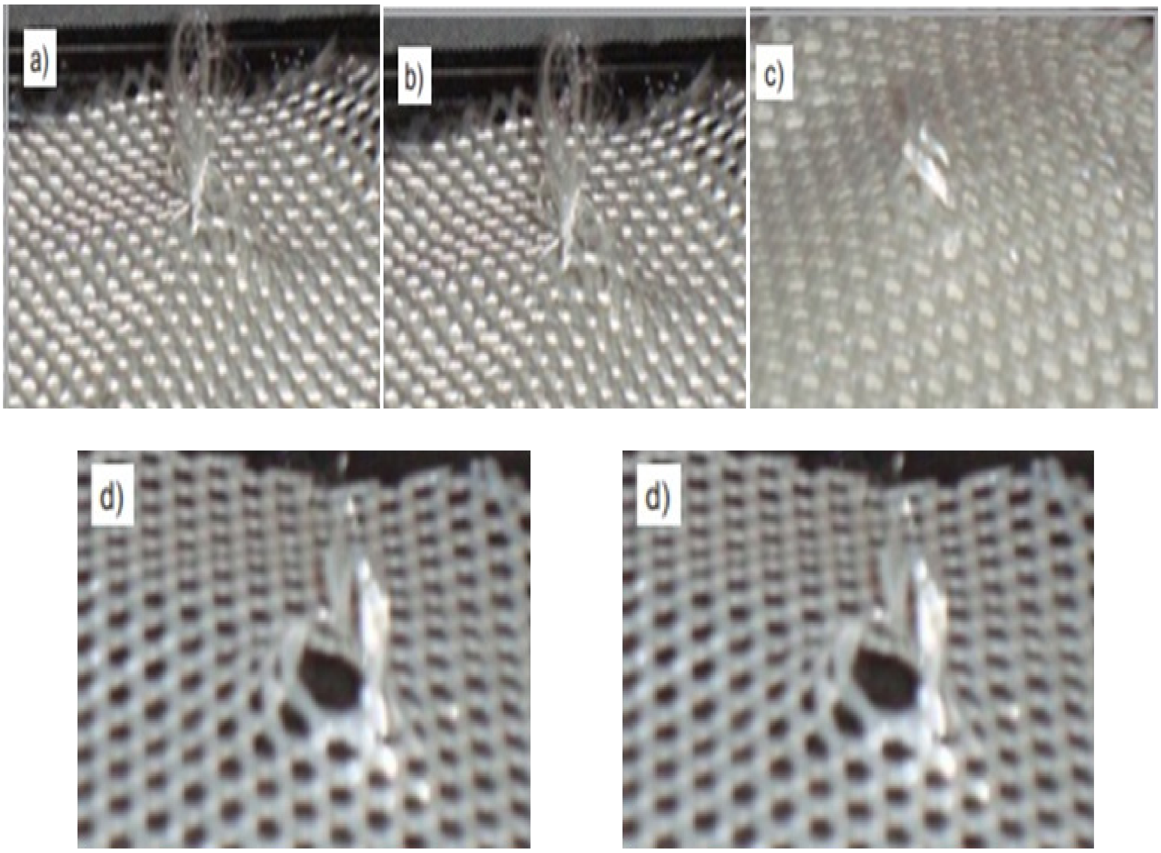

Fig. 8. Cut behavior in the case of polyester triaxial fabric between multi-layer silk fabric a, b & c and single polyester triaxial fabric e & f

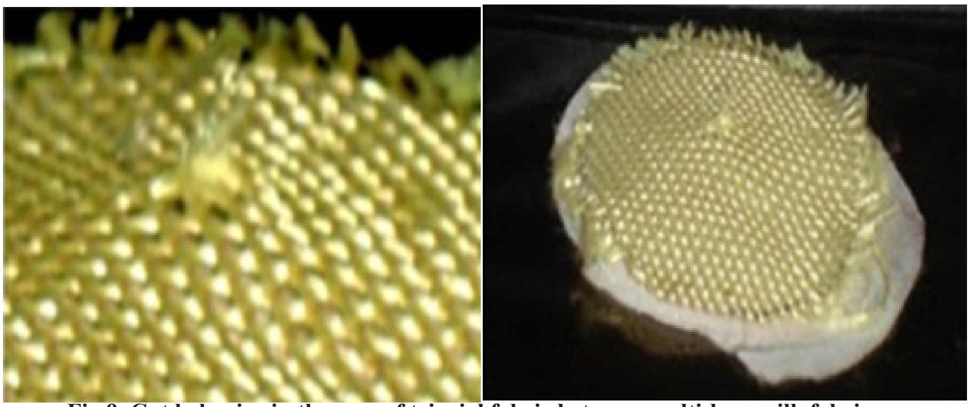

Fig.9. Cut behavior in the case of triaxial fabric between multi-layer silk fabrics.

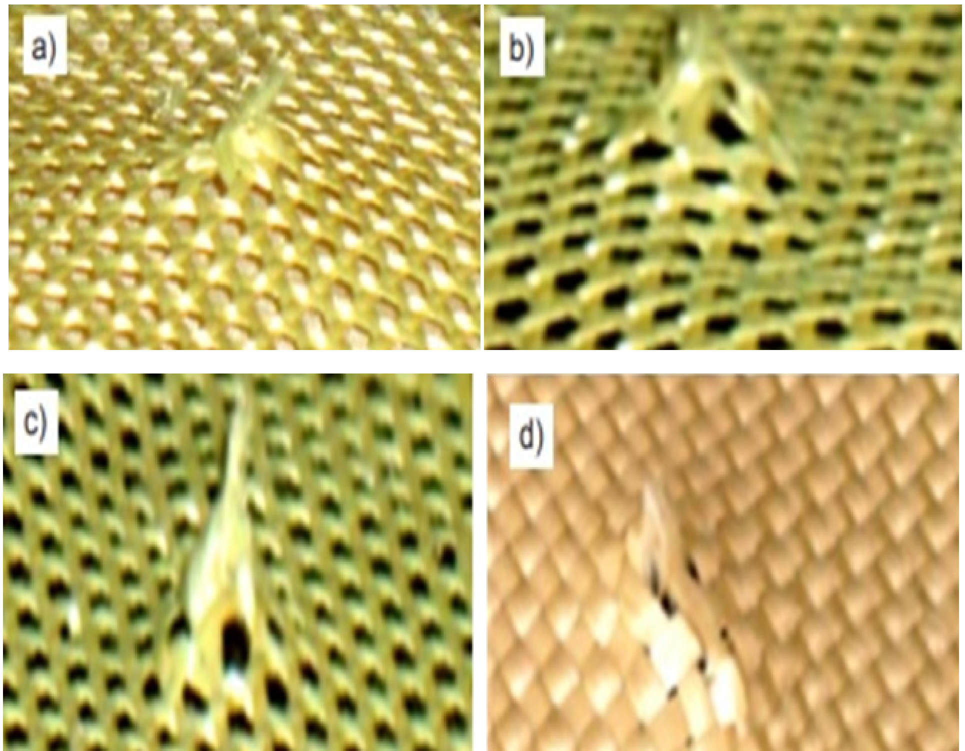

Fig. 10. Cut behavior in the case of; a) triaxial fabric between multi-layer silk fabric, b, c) single para-aramid triaxial fabric, d) para-aramid woven fabric.

On synthetic fabrics

Kevlar fibers

Developing organic and inorganic composites that are low-cost to improve their resistance to punching and thermally insulating qualities. Kevlar fiber and glass textiles have been utilized along with polyester/slurry polyester nonwovens recycling high modulus. The result reveals that the resistance to static perforation improves in proportion with Kevlar fibers, but first, the resistance to dynamic perforations remains the same and later increases for Kevlar fibers. With increasingly low polyester fibers on the surface, the trend for both static and dynamic puncture resistance is upward and lower. Furthermore, the nonwovens of polyester/low-melting polyester help increase the strength of puncture. In addition, all-composite materials' heat conductivity.

Preparation of 3D layered composites

A 3D laminated composite was constructed of a double layer of nonwoven PET (a), PET/LM nonwovens (B), and one layer of a glass fabric according to the needle punching and therapeutic bonding methods. The composite consists of a double layer of PET nonwovens (B). On both sides, the composite was squeezed and then pushed to heat.

Both nonwovens have been manufactured via opening, blending, carding, and lapping processes at our laboratory. Kevlar, PA6, and PET fiber blending ratios in non-woven products.

Testing of Puncture Resistance

The resistor to static and dynamic punching was determined to represent various punching behavior. The static punching property has been established in compliance with ASTM F1342-05 using the universal Instron 5566 testing machine (Instron, USA). A drop-tower with Data Acquisitions (PCD 300A) was used following NIJ Standard 0115.00 2000 to assess the dynamic punch resistance. From a height on the specimen, the dynamic sample was placed free of load, which was clamped in the middle of the quadrant plate (see **Figure 11**).

The thermal-isolating property has a thermal conductivity(w/m•K), which is compatible with ASTM C177 with the DXR-I-SPB Guardedhot-plate devices (Xiangtan Huafeng Equipment Manufacture Co. Ltd, China). Each test lasted 6 hours and three specimens were concurrently put in the testing machine in which cold water flowed by the center calorimeter at a velocity of passes.[42]

Polyester fabric

Zhejiang Guxiandao Industrial Fiber Co., Ltd, China bought high-strength polyester yarns that were utilized for the experiment. They had a fineness of 280dtex/48f. The thread strength of the yarn was tested using the Instron 5565 (Instron, USA) Universal Tester and the thread strength and elongation at yarn break.

The textiles used in the test were produced for sample weaving on the rapier loom. As warp and woven threads, high-strength polyester yarn was employed. The three main varieties of textile textiles are plain, twill and satin. The warp and weft strands in the plain weave are aligned to a pattern of interlacing. Every strip yarn passes through the weft yarn by passing one, then the next strip yarn, and so on. The numerator shows a warp yarn that spans two weft yarns by going over them in the Twill (2/1), which is commonly understood as a ‘two up, one down twill’, and a denominator indicates the warp yarn that fits under the next weft yarn, etc. The satin fabric is distinguished by the warp threads floating over the fabric threads. Floats are missing with warp yarn in the warp face satin or vice versa at the top of the weft.

The quasi-static puncture test was measured using the Universal Test Instron 5565 (Instron, USA) connected to a sample and developed in line with GBT 12017-1989 standard. A test apparatus was fitted with a sample.

In each fabric type, three examples were measured. The variation among the quasi-static puncture test findings of the same material is illustrated. The height between the points shows the difference in the punch strength when the sample tip has just pierced the material. The radius of the point is small. When the tip hits on the fabric, there could be a different spot. It is not simple for the probe to penetrate the textile when the tip is only on the top of the yarn. On the other hand, if the end pierces the distance between the yarns, the power of puncture is relatively easy, and smaller. Thus, paragraph b is not appropriate to show the property of a fabric with puncture resistance. the maximum punching force is nearly the same, therefore the near-static punching-resistance characteristic of several materials is assessed.[43]

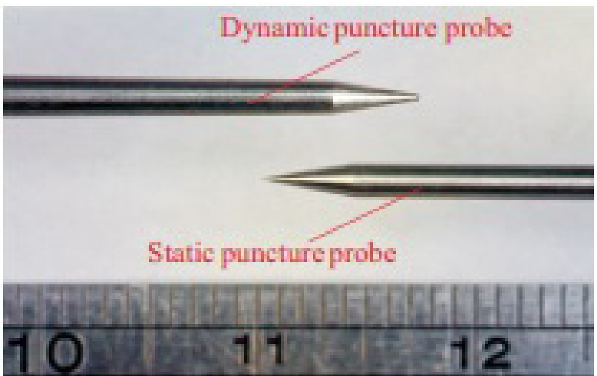

Fig.11. Probes for static and dynamic punctures.

Conclusion

The Triaxial fabric (TWF) is superior to the TWF multiple-layer silk fabric over the para-aramid fabric. Kevlar strands have been proven to be a good strengthening to improve tensile and explosive strengths. Furthermore, the nonwovens of polyester/low-melting polyester help increase the strength of puncture. All the composite components have a thermal conductivity of 0.015-0.025 W/m•K. A variety of cost-effective, flexible materials has been made using high-fit polyester yarns with different material topologies, weft densities, and several layers. The maximum penetration strength and puncture energy of 160 yarn/10 cm plain fabrics obtained the maximum values of 107,43 N and 0,44 J. The biggest obstacle was the contact pressure and friction between the probe and the fibers.

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خصائص مقاومة الثقوب للأقمشة الطبيعية والاصطناعية

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تعتمد آلية التأثير الباليستي بشكل أساسي على سمك وقوة وليونة ومتانة وكثافة المادة المستهدفة. تقنية النانو هي تقنية متطورة تؤدي إلى اختلافات كبيرة في سلوك المنتج. يتم استخدام المواد النانوية بشكل متزايد في المنسوجات لزيادة الأداء وتوفير وظائف نسيج لا مثيل لها. من المتوقع أن يتم تعزيز المواد مثل الأوساخ والعزل المائي ، والتهوية ، والحماية من الأشعة فوق البنفسجية ، والتوصيل ، والصفات المضادة للكهرباء الساكنة ، ومقاومة التآكل والتجاعيد ، ومقاومة البقع ، والبكتيريا بواسطة المواد النانوية أو إضافة ميزات جديدة. من خلال دمج الجسيمات النانوية في الألياف ، يمكن تقوية الصفات الميكانيكية لألياف النسيج.

الكلمات الرئيسية: مقاومة البزل ، أقمشة الباليستية تكنولوجيا النانو ، أقمشة طبيعية وصناعية.