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Protection from Ballistic Threats: An Exploration of Textile Materials for Bullet-Resistant Outerwear

ABSTRACT

Bullet-resistant jackets are one of the innovations that demonstrate how textile engineering and technology can work together to protect people from ballistic threats. To improve the protective qualities of bulletproof jackets, it is imperative to comprehend the wide variety of textile materials that are used in them. This study aims to clarify the complex interplay between protection, flexibility, and comfort that is inherent in these kinds of clothes by a thorough analysis of a variety of fibers, fabricsand composites, each offering unique characteristics that contribute to the overall effectiveness of these types of garments. Important factors were determined to take into account when choosing the best material based on particular needs like flexibility, comfort, weight, and degree of protection through careful analysis and comparison. This exploration shall provide valuable insights for researchers, manufacturers, and consumers alike, fostering advancements in protective garment design and promoting informed decision-making in the realm of personal safety.

Keywords: *Bullet-resistant jacket, protective garment, degree of protection, flexibility, comfort, safety*

1. INTRODUCTION

In a time when people place a greater value on personal safety, developing protective gear has become critical. Bullet-resistant jackets are one of these innovations that demonstrate how textile engineering and technology can work together to protect people from ballistic.The concept of threat levels encompasses a range of ballistic hazards, including handgun rounds, rifle ammunition, and specialized projectiles. These threats are typically classified based on their kinetic energy, velocity, and penetrating capabilities, with standardized testing protocols employed to evaluate the performance of bullet-resistant materials against them. The materials used in the construction of these jackets have a major impact on their efficacy. Therefore, to improve the protective qualities of bullet-resistant jackets, it is imperative to comprehend the wide variety of textiles that are used in them[1]. To analyze the characteristics, advantages, and disadvantages of the textile materials used in bullet-resistant jackets, this study has been undertaken. After a thorough analysis of a variety of textiles, from conventional choices to state-of-the-art inventions, we aim to clarify the complex interplay between protection, flexibility, and comfort that is inherent in these kinds of clothes.The evolution of bullet-resistant materials has seen a transition from rigid and cumbersome armour to lightweight, flexible solutions, thanks to advancements in textile technology[2]. Today, an array of fibers, fabrics, and composites are utilized, each offering unique characteristics that contribute to the overall effectiveness of bullet-resistant jackets. From traditional aramid fibers like Kevlar® to high-performance polyethylene fibers such as Dyneema®, the market presents a diverse spectrum of options for manufacturers and consumers alike[3].Moreover, the study examines the manufacturing processes involved in integrating these materials into wearable garments.

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Techniques such as weaving, knitting, laminating, and layering play pivotal roles in optimizing the protective capabilities of bullet-resistant jackets while ensuring wearer comfort and mobility.Not only that, but factors go beyond choosing the right materials and production methods. To give a comprehensive picture of the textile landscape in bulletproof clothing, factors like durability, cost-effectiveness, and environmental impact are also carefully considered. In the end, this research aims to clarify the complex interactions that occur between textile composition and the level of protection provided by jackets resistant to bullets[4]. Continuous effort is required to improve individual safety in an unpredictable world by combining current knowledge and investigating cutting-edge innovations.Through this exploration, we endeavour to provide valuable insights for researchers, manufacturers, and consumers alike, fostering advancements in protective garment design and promoting informed decision-making in the realm of personal safety.The specific textile materials commonly employed in bullet-resistant jackets were studied, analyzed their properties, applications, and potential avenues for future development.

2. PURPOSE OF BULLET RESISTANCE JACKET

A bullet-resistant jacket's main goal is to shield its wearer from ballistic threats that could cause harm or even death. The jacket lessens the severity of trauma to critical organs and aids in preventing penetration by absorbing and dispersing the kinetic energy of incoming bullets or projectiles.Bullet-resistant jackets are essential safety equipment for law enforcement officers, military personnel, and security professionals who may be exposed to firearms and other weapons in the line of duty[5]. These jackets help mitigate the risks associated with confrontational situations and provide a critical layer of protection for individuals serving in high-risk environments.In addition to professionals, civilians in a variety of settings and occupations where there is an increased chance of coming into contact with firearms—security guards, private investigators, journalists covering hostilities—also wear bulletproof jackets[6]. In addition, when they feel that their safety is in danger, civilians may decide to arm themselves with bulletproof jackets for personal defence.

3. THREAT LEVEL

Major threats faced by the Indian armedforces, paramilitary, state police forces, and other law and enforcement agencies shall be classified into 6 threatlevels. Bullet-resistant jackets, also known as ballistic vests or body armour, are designed to protect the wearer from various ballistic threats, including bullets and projectiles. These jackets are typically classified into different threat levels based on their ability to withstand different types of ammunition and the kinetic energy they carry. The threat levels are often standardized by organizations like the Bureau of Indian Standards (BIS) (Table 1) or international standards bodies like the National Institute of Justice (NIJ) in the United States[7].

Table 1: Threat levels standardized by Bureau of Indian Standards (BIS)[8]

Sl no.	Threat Level	Ammunition	bullet Weight (see note) g	Bullet type	Impact velocity m/s	Distance of impact m	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	1	9x19 mm	7.4-8.2	FMJ/Pb	430±15	5±0.5	For all flexible panels
	2	7.62x39 mm	7.45-8.05	FMJ/MSC	710±15	10±0.5	
	3	7.62x51 mm	9.4-9.6	FMJ/Pb	840±15	10±0.5	In addition, shall be in compliance with threat level 2
	4	5.56x45 mm	3.5-4.0	FMJ(SI+Pb)	890±15	10±0.5	In addition, shall be in compliance with threat level 3
	5	7.62x39 mm	7.45-8.05	HSC	700±15	10±0.5	In addition, shall be in compliance with threat level 3
	6	7.62x52 R	10.3-10.5	API	830±15	10±0.5	In addition, shall be in compliance with threat level 3
	special	Any other requirement by the user. Complete details of ammunition shall be stored for future up gradation of the standard.					
NOTE - Routine ballistic evaluation may use service ammunition where bullet weight is not considered. Bullet weight shall be considered for reloaded ammunition. FMJ: Full Metal Jacket Pb: Lead Core MSC: Mild Steel Core SI: Steel InsertHSC: Hard Steel Core API: Armour Piercing Incendiary							

3. COMPONENTS OF JACKET

The two primary components of a bullet-resistant jacket are:

Soft armour panel “SAP” and Hard armour panel “HAP” typically refer to different levels of protection against ballistic threats

3.1. Soft Armour Panel:

Soft armour panels are inserts that are flexible and usually composed of materials such as Aramid fibers and Ultra-high molecular weight polyethylene (UHMWPE). These panels lessen the chance of penetration and wearer injury by absorbing and dispersing the kinetic energy of incoming projectiles. Soft armour panels can withstand bullets from handguns and some rifle ammunition with a lower muzzle velocity. Wearers can move freely and the armour can be bent or flexed at will while still being protected from ballistic threats thanks to the balance of protection and flexibility they offer.Minimum coverage areas of components of Soft Armour Panel I shown in Table 2.

Table 2: Minimum Coverage Areas of Components of Soft Armour Panel[9].

Sl. no	Size	Total protection area for sap (including Torso, Neck, Shoulders, and groin) m^2	Total protection area for shoulders only m^2	Total protection area for groin only m^2	Total protection area for neck and collar only m^2
(1)	(2)	(3)	(4)	(5)	(6)
	XS	0.45	0.035	0.05	0.05
	S	0.50	0.035	0.05	0.05
	M	0.55	0.035	0.05	0.05
	L	0.60	0.04	0.06	0.06
	XL	0.65	0.04	0.06	0.06

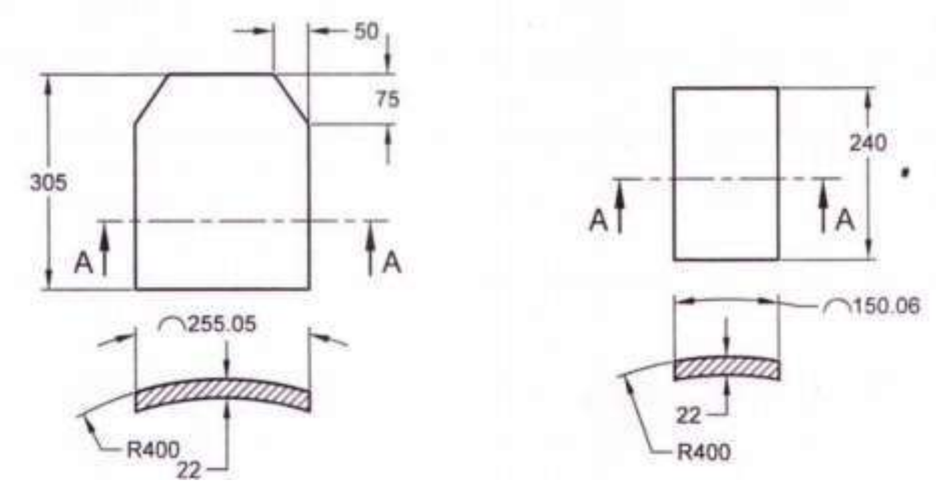
3.2. Hard armour panel:

Hard armour plates are inflexible inserts composed of steel, ceramic, or composite materials that are designed to withstand the impact of heavy projectiles like rifle rounds fired at high speeds. To provide additional ballistic resistance against rifle fire, hard armour plates are usually inserted into specially made pockets or carriers within the bulletproof jacket. Hard armour plates are vital components for scenarios where there is a high risk of coming into contact with rifle fire, even though they are less flexible and heavier than soft armour panels. Minimum coverage areas of components of Hard Armour Panel / Hard armour plates also provide better protection against more powerful threats[10] as shown in Table 3.

Table 3: Minimum Coverage Areas of Components of Hard Armour Panel (m’)[11]

size / Panel	XS	S	M	L	XL
Front/back	0.0667	0.0700	0.0735	0.0772	0.0810
Side (optional)	0.0326	0.0342	0.0359	0.0377	0.0396
Groin (optional)	0.0370	0.0370	0.0370	0.0370	0.0370
Throat (optional)	0.0245	0.0257	0.0270	0.0284	0.0298
Total (considering front and back, two sides throat and groin)	0.260	0.271	0.283	0.295	0.308
Total (considering front and back)	0.133	0.140	0.147	0.154	0.162

Together, soft armour panels and hard armour plates form the dual protection system within a bullet-resistant jacket, providing wearers with comprehensive protection against a wide range of ballistic threats.Design example of front and side plate (medium size) is given in figure 1.



a) b)

Figure 1.Design example of front(a) and side plate(b) (medium size)

4. MATERIAL REQUIREMENTS

Differentiating their functions and performance characteristics, Hard Armor Plates (HAP) and Soft Armour Panels (SAP) in bulletproof jackets require different materials.

1. Materials in SAP:

1. Ultra high molecular weight polyethylene (UHMWPE):

The thermoplastic polyethylene subclass includes ultra-high-molecular-weight polyethylene (UHMWPE, UHMW). It is also referred to as high-modulus polyethylene (HMPE), and it is characterized by incredibly long chains that typically have a molecular mass of 3–7 million amu. Through the strengthening of intermolecular interactions, the longer chain helps to transfer the load to the polymer backbone more effectively [12] . As a result, this material is incredibly durable and has the highest impact strength of any thermoplastic currently in use.

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

UHMWPEfibers are commonly used in soft body armour and have contributed to vast improvements when compared with p-aramid fibers making them 40% stronger. For body armour, the fibers are aligned and bonded into sheets, which are then layered at various angles to give the resulting composite material strength in all directions[13]. Dyneema ® is the trade name of ultra-high molecular weight polyethylene (UHMWPE), manufactured exclusively by Netherland based DSM[14].Chemical formula of UHMWPE is given in Figure 2.

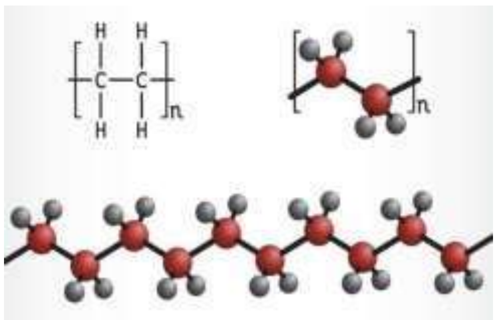


Figure 2.Chemical formula of UHMWPE

4.1.2. Kevlar:

Kevlar is a synthetic fiber known for its remarkable strength and heat resistance. It is a type of aramid fiber, which are long-chain synthetic polyamide molecules with strong bonds between individual molecules they are synthetic fibers like aramid. After spinning, it becomes very high-strength fibers. So it is considered one of the most popular fibers that are used in lead jackets. Kevlar fibers consist of long molecular chains made of PPTA [poly (p-phenyleneterephthalamide)] and the Strength property of Kevlar fibers lies in the multiple chemical bonds between their chains molecular as well as hydrogen bonds of adjacent polymer chains[15]. Kevlar has strength, high stiffness, high tensile, and high modulus. They have low weight and density. It is unidirectionallywoven into textile materials and is extremely strong and lightweight, with resistance to corrosion and heat. It is used in vast applications such as aerospace engineering (such as the body of the aircraft), body armour, bulletproof vests, car brakes, and boats[16]. Chemical structure of Kevlar is given in Figure 3.

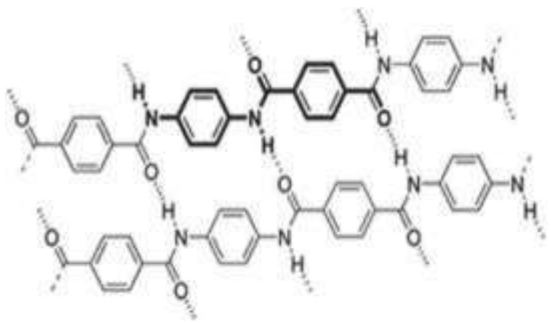


Figure 3.Chemical structure of Kevlar

4.1.3. Polycarbonate sheet:

In a bullet-resistant jacket, multiple layers of different materials are often used to create a composite structure. Polycarbonate sheets may be integrated into this layered structure to provide additional protection against certain types of ballistic threats. Polycarbonate material is used in bullet resistance jackets because of its good impact resistance. The use of polymers is increasing across many industries due to their low weight, low cost, and even straightforward manufacturing processes [17]. One of the main reasons polycarbonate might be used in bullet-resistant jackets is for its spall protection properties. Spall refers to the fragments or splinters that can break off from the back face of a material when it's struck by a projectile. Polycarbonate can help contain or minimize the spall created by the impact of a bullet, reducing the risk of secondary injuries to the wearer.Chemical structure of Polycarbonate sheet is given in Figure 4.

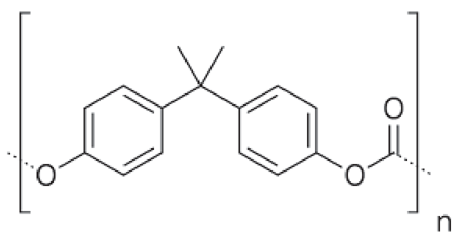


Figure 4.Repeating unit of Polycarbonate polymer

4.1.4. Polyurethane (pu) composite foam:

Polyurethane (PU) composite foam can be utilized in bullet-resistant jackets as part of the protective material system. However, it's important to note that while PU foam can provide cushioning and impact absorption, it's typically not used as the primary material for bullet resistance. Instead, PU foam is often incorporated into the design of bullet-resistant jackets for comfort, flexibility, and shock absorption[18]. Figure 5 representsPolyurethane (PU) composite foam.

Figure 5.Polyurethane (PU) composite foam

4.2. Materials in HAP:

Hard armour panels are made of steel, polyethylene, or ceramic materials. They are designed to survive impacts from projectiles with high velocity, such as rifle bullets. HAPs are also often referred to as Level III and Level IV panels to denote their degree of defence against ballistic threats.

4.2.1. Ceramic plates:

Many fields have been using ceramic materials for decades because of their high compressive strength, low density, and high hardness; even though they can be brittle. Silicon carbide is highly effective in stopping various types of ballistic threats, including rifle rounds and armour-piercing ammunition. When used in combination with other materials such as aramid fibers or UHMWPE, silicon carbide can provide multi-hit protection against high-velocity projectiles[18]. The projectile and the target configuration with dimensions in mm is given in figure 6.

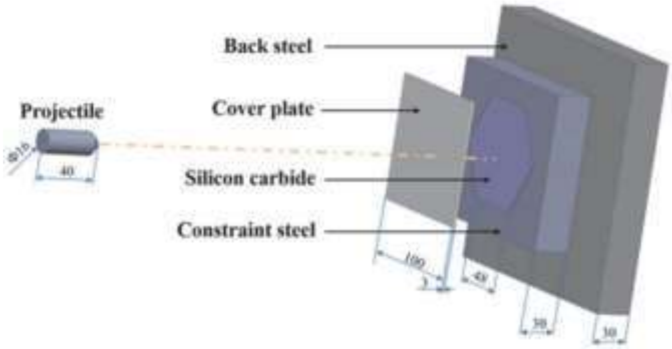


Figure 6.The projectile and the target configuration with dimensions in mm

4.2.2. Steel plates:

In order to save energy and improve mobility, it is crucial for defence systems against ballistic threats to use lightweight armour. Steels have a long history of use in armour applications due to their vast technological database and ability to be produced at a comparatively lower cost. They can also have a very broad range of mechanical properties[20]. However, due to its relatively high density, steel is not a good choice for use as lightweight armour. Because steel armour is heavier than other materials and does not provide the same level of protection in defence systems, researchers are looking into lighter alternativesteel plates for hard armour panel is given in Figure 7.

Figure 7 Steel plates for hard armour panel

4.2.3. UHMWPE with ceramic plates:

UHMWPE has an exceptional strength-to-weight ratio, making it lightweight compared to traditional materials like steel. This property allows for the construction of lightweight hard armour panels that provide high levels of protection without significant added weight.UHMWPE has a low density, typically around 0.93 to 0.94 g/cm³, which contributes to the lightweight nature of hard armour panels[21] . This low density minimizes the overall weight burden on the wearer while maintaining high levels of protection. When combined with ceramic plates, UHMWPE is typically used as a backing material or as a composite layer to provide additional strength and support to the ceramic tiles. The combination of UHMWPE with ceramic plates offers a synergistic effect, with the ceramic providing high hardness and fracture resistance to defeat incoming projectiles, while the UHMWPE helps to absorb and disperse the impact energy[22]. UHMWPE with ceramic plates is shown in Figure 8.

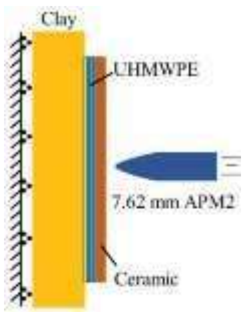


Figure 8.UHMWPE with ceramic plates

4.2.4. Backing face material clay:

The clay material used in bullet-resistant jackets is typically a type of ballistic clay, which is a specially formulated mixture designed to simulate human tissue for ballistic testing purposes. It usually consists of a combination of clay, water, and other additives to achieve the desired density and mechanical properties. It is used as backing material in ballistic tests. Backing material in ballistic tests is given in Figure 9.

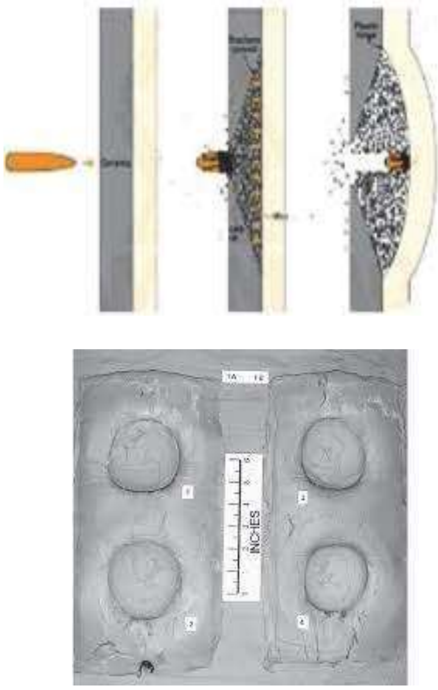


Figure 9. Backing material in ballistic tests

3. Physical requirements of non-ballistic components:

The outer-carrier fabric, hook and loop fasteners, belt loop, trauma pad, water-repellent SAP and HAP covers, webbings, buckles, and other items are examples of non-ballistic materials.

1. Outer carrier fabric:

The outer carrier fabric made of woven fabric, and the color/print can be customized according to the purchaser's needs.Nylon 66 is known for its high durability, which means it can withstand wear and tear over time, maintaining the integrity of the bullet-resistant jacket.It is relatively lightweight compared to other materials, which can make the bullet-resistant jacket more comfortable for the wearer. But the effectiveness of a bullet-resistant jacket depends not only on the outer carrier material but also on the ballistic panels and overall design of the jacket.This fabric is coated with a layer of polyurethane (PU)[23]. PU coating adds several beneficial properties to the fabric, including water resistance, abrasion resistance, flexibility, and improved durability. The fabric is designed to be heat sealable, meaning it can be bonded or sealed using heat. This feature allows manufacturers to create seams and join different pieces of fabric together without the need for stitching[24].PU coated nylon 66 fabric is shown in figure 10. Requirement of outer carrier fabric is shown in Table 4.

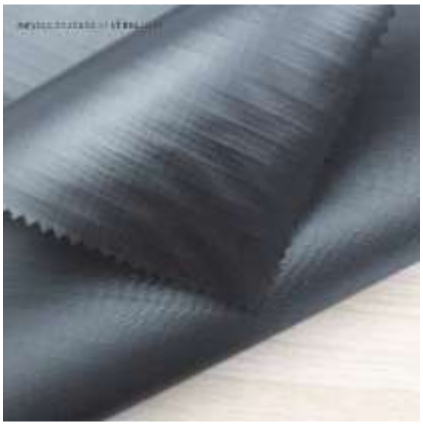


Figure 10.PU coated nylon 66 fabrics

Table 4.Requirement of Outer Carrier Fabric[25]

Sl. No	Test parameter	Requirements	Method of test, Refer to
(1)	(2)	(3)	(4)
i.	Mass, g/m', Max	160	IS 7016 (Part I)
ii.	Tensile strength, N, Min: a) Warp wise b) Weft wise	 1150 900	IS 7016 (Part II)
iii.	Tear strength, N, Min: a) Warp wise b) Weft wise	 160 140	IS 7016 (Part 3), Method A2, Trouser shaped test piece, Single tear method
iv.	Flame resistance test: a) Duration of flame (After flame time), s, Max b) Duration of afterglow, s, Max	 5 5	IS 11871, Method A
v.	Resistance to water penetration at hydrostatic pressure head of 30 cm water column height for 30 minutes	There shall be no water penetration	IS 7016 (Part 7)
vi.	Colour fastness rating to light (Change in colour on blue wool), Min	4	IS 2454

4.3.2. Hook and loop fastener:

All the clothing flaps of the jackets shall be provided with hook and loop fastener, so that it can be worn and taken off easily and quickly. Hook and loop is made to withstand the rigors of military use. It is frequently constructed from premium materials like nylon that are resistant to deterioration. Two parts make up the hook and loop system: hooks and loops. By holding onto the loops, the hooks form a dependable and safe fastening mechanism. Unintentional detachment during demanding activities is avoided by this design[26]. In certain military applications, the quiet operation and lack of noisy hook-and-loop separation sounds that could jeopardize operational security are critical requirements for hook-and-loop fasteners.

4.3.3. Pocket with flaps

The jacket shall be provided with minimum two externalpockets in outer carrier fabric tohouse two magazinesof self-carried assault rifle in each pocket. Two pocketsshall also be provided to accommodate one grenade ineach pocket.Pattern for pocket with flaps is given in figure 11.

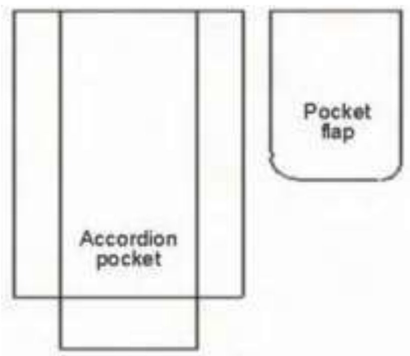


Figure 11. Pattern for pocket with flaps

4.3.4. Beltlkamarband

In order to properly secure the bulletproof jacket with the wearer's body around the waist and distribute the weight of the jacket across the waist and shoulders, an additional belt made of nylon material with a minimum width of 10 mm must be provided[27]. A hook and loop fastener for double jacket locking is included with the belt/kamarband.Strong and long-lasting nylon webbing is frequently used for belts and straps in outdoor and tactical equipment. It is appropriate for usage in harsh environments because of its strong tensile strength and abrasion resistance.

5. CONCLUDING REMARKS

Wide range of textile materials, each with special qualities and benefits that are used to make bulletproof jackets.Important factors to take into account when choosing the best material based on particular needs like flexibility, comfort, weight, and degree of protection through careful analysis and comparison. The variety of materials available in the field of ballistic protection is impressive, ranging from conventional materials like Kevlar® aramid fibers to advanced composites that incorporate ceramics and ultra-high-molecular-weight polyethylene (UHMWPE). It is crucial to strike a balance between material characteristics in order to maximize performance and satisfy the needs of practical applications by providing insights that can guide the development and selection of textile materials for bullet-resistant jackets in a variety of environments and scenarios of ballistic protection. Safer and more durable protective clothing for people in high-risk occupations and circumstances is continuing to push the boundaries of material science and ballistic engineering.

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IZVOD

ZAŠTITA OD BALISTIČKIH PRETNJI: ISTRAŽIVANJE TEKSTILNIH MATERIJALA ZA GORNJU ODEĆU OTPORNU NA METKE

Jakne otporne na metke su jedna od inovacija koje pokazuju kako tekstilni inženjering i tehnologija mogu da rade zajedno da zaštite ljude od balističkih pretnji. Da bi se poboljšali zaštitni kvaliteti neprobojnih jakni, neophodno je razumeti širok spektar tekstilnih materijala koji se koriste u njima. Ova studija ima za cilj da razjasni složenu interakciju između zaštite, fleksibilnosti i udobnosti koja je svojstvena ovim vrstama odeće kroz detaljnu analizu različitih vlakana, tkanina i kompozita, od kojih svaki nudi jedinstvene karakteristike koje doprinose ukupnoj efikasnosti ovih vrsta odeće. odevnih predmeta. Određeni su važni faktori koje treba uzeti u obzir pri izboru najboljeg materijala na osnovu posebnih potreba kao što su fleksibilnost, udobnost, težina i stepen zaštite kroz pažljivu analizu i poređenje. Ovo istraživanje će pružiti vredne uvide istraživačima, proizvođačima i potrošačima, podstičući napredak u dizajnu zaštitne odeće i promovišući informisano donošenje odluka u oblasti lične bezbednosti.

Ključne reči: *jakna otporna na metke, zaštitna odeća, stepen zaštite, fleksibilnost, udobnost, bezbednost*

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