An investigation into the functional properties of Kevlar and Dyneema fabrics used as bulletproof

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Abstract:

Bulletproof fabrics are usually used as create jackets to protect the user from being shot. These jackets are varied write as according to the degree of expected risks and required levels of protection. Different types of materials and fibers could be used for achieving many properties and different levels of protections. The type and number of materials were affected on the required protection. The current market is looking to reduce the weight and thickness of these fabrics, in addition to low cost. In all bulletproof protective clothing, there is a certain basic material that contributes to stopping the bullet in a noticeable way. Currently, materials made of high molecular weight polyethylene (UHMWPE) and aramid fibers are widely used for this purpose. Aramid fibers are developed by upgrading ballistic nylon fibers while UHMWPE is developed from polyester. Kevlar 29 and Kevlar 149 are the dominant body armor material belonging to the aramid fibers. Dyneema is another UHMWPE. The molecular formula of this polymer is the same as common polyethylene but differs greatly due to its very high molecular weight, 10 to 100 times higher than that of commercial polyethylene resin.

This research paper goals to investigation into Kevlar and Dyneema fabrics to obtain the best functional properties of bulletproof fabrics. The samples were produced with a plain 1/1 structure. After the fabric samples were produced, tests were carried out to evaluate the samples produced such as, Tensile Strength, UV resistance, Heat Conductivity, Abrasion Resistance, washability, Chemical Resistance, Thermal Properties, the results revealed the superiority of Dyneema fabrics in terms of functional properties over Kevlar fabrics, as it has many properties that qualify it to be a bulletproof fabric.

Keywords:

Bulletproof fabrics
Dyneema fabrics
Kevlar fabrics

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1. Introduction

Bulletproof fabrics for vests divided into three main types according to the final designation of the jacket, each one of them has a specific purpose. The First; bulletproof vests. Which used mainly to protect the wearer of gunshots from close range It is usually hidden inside the external clothes. It was protecting the chest, neck, and upper part of the body from shooting. The Second; Bulletproof jackets which protect the body from explosive fragments and gunfire from short range and this type was used by military personnel. The Third; Bulletproof armor, which used to protect the body from huge fire. Developing countries are usually faced many problems with bulletproof vests which due to their manufacture technique which leads to heavy weight and uncomfortable for the user. There are many of high-performance fibers that were used for bulletproof fabrics The most famous of them are Kevlar and Dyneema fibers. [1]

Dyneema is a type of polyolefin which made from extremely long chain of polyethylene. Since the molecule does not have any subgroups in the structure, it is highly crystalline. Even though there are weaker Vander Vaal bonds between molecules, high degree of crystallinity may increase the strength of the fiber. Degree of crystallinity of the fiber goes up to 85% to 95%. But Aramid fibers such as Kevlar have Hydrogen bonds with a very short molecular length compared to Dyneema. [1] Therefore, this research paper focused on the comparison between Kevlar and Dyneema properties as a most famous and important two materials that used for bulletproof fabrics in the world.

2. Materials and Methods

2.1. Materials

2.1.1 Kevlar Fibers.

They are synthetic fibers like aramid. after spinning, it becomes very high strength fibers. So it is consider one of the most popular fibers that are used in lead jackets. Kevlar fibers consist of long molecular chains made of PPTA (poly-Para phenylene terephthalamide), 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 [2].

2.1.2 Dyneema Fibers.

Dyneema fibers. belong to high- performance polyethylene fibers and the molecular formula of this polymer is the same as the common molecular formula of polyethylene, Dyneema fibers have high molecular weight comparing to polyethylene fibers about 10:100 times [1]. Figure 1. shows the difference between the molecular Chains arrangement of ordinary polyethylene (PE) and Dyneema (HPPE) when was spinning by melt spun, it was noticed it was noticed Chain alignment can be reached by unfolding PE crystals. Structural perfection is possible by using long molecules with a low number of side groups [3].

Table 1. shows the mechanical properties for commercial polyethylene (PE), Dyneema (HPPE) and aramids materials, where the table shows no difference in theoretical properties between polyethylene (PE) and to Dyneema (HPPE) However, it was noticed the difference significant in the commercial properties value between Dyneema and polyethylene polymers there are the difference significant between the mechanical properties of aramid polymer and polyethylene polymer [3].

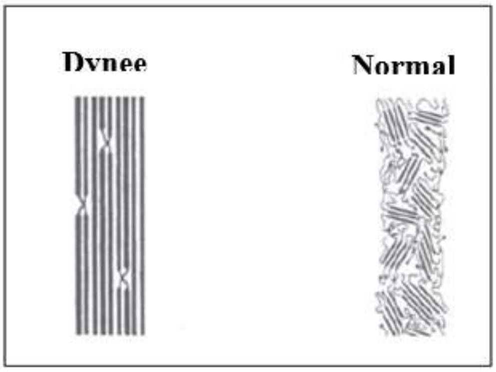

Figure 1. The difference between the molecular Chains arrangement of ordinary polyethylene (PE) and Dyneema (HPPE) [3]

Table 1. Mechanical properties of polymer materials [3]

Material	Theoretical values		Commercial values	
	Modulus (N/tex)	Strength(N/tex)	Modulus (N/tex)	Strength(N/tex)
Polyethylene (PE)	250 - 300	27 -33	10	0.8
Dyneema (HPPE)	250 - 300	27 - 33	90	2.7
Aramids	130	33	100	2.3

2.2 Properties of Kevlar and Dyneema fibers.

Table 2. shows the properties of Dyneema and Kevlar fibers used. when it was used the same yarn count for each materials. However, the Dyneema material was superior in elongation, tenacity and modulus. Also; Kevlar has density of 1.43 g/cm^2, which resulting a heavier and bulkier material , which Dyneema material has a density of 0.97 g/m2, which allowing for a light weight and comfortable bulletproof vests.

Table 2. Properties Kevlar and Dyneema Materials

Material	Yarn count		Tenacity		Modulus g /D	Elongation at Break %	Density g/cm^2
	Denier	Tex.	N/tex.	g/D			
Dyneema	1500	1670	33	37	1200	4.5	0.97
Kevlar	1500	1670	19	22	1100	3.3	1.43

2.3 Fabric Structure.

Two Samples of woven fabrics were produced with by Dyneema and Kevlar using Plain 1/1 structure, the Plain 1/1 was chosen because it has high coveted factor of factor. So, it reduces the bullet penetration compared to other weave structures with less inter sections points. Table 3. shows the specifications of the produced fabric samples. Figure 2. shows Plain 1/1 woven structure.

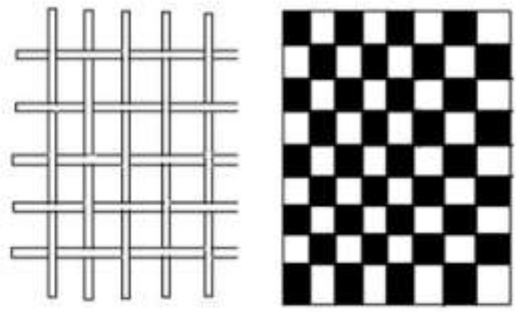

Figure 2. Plain 1/1 woven

Table 3. Specifications of fabrics

Material	Structure	Yarn count/ warp	Yarn count/ weft	Warp density/cm²	Weft density/cm²	weight (g/m²)	Thickness (mm)
Dyneema	Plain 1/1	1500 D	1500 D	10	7.5	345	0.72
Kevlar		1500 D	1500 D	10	8.5	320	0.37

2.4 Finishing of fabrics.

the Kevlar fabric was washed and rinsed well to remove the oily substances, where the Kevlar consists of O-H and benzene groups. While Dyneema fabric does not need any process before the final use, which reduce the time, efforts and costs. Figure 3. shows the visual photo microscopic views of produced Dyneema fabrics and Kevlar fabrics.

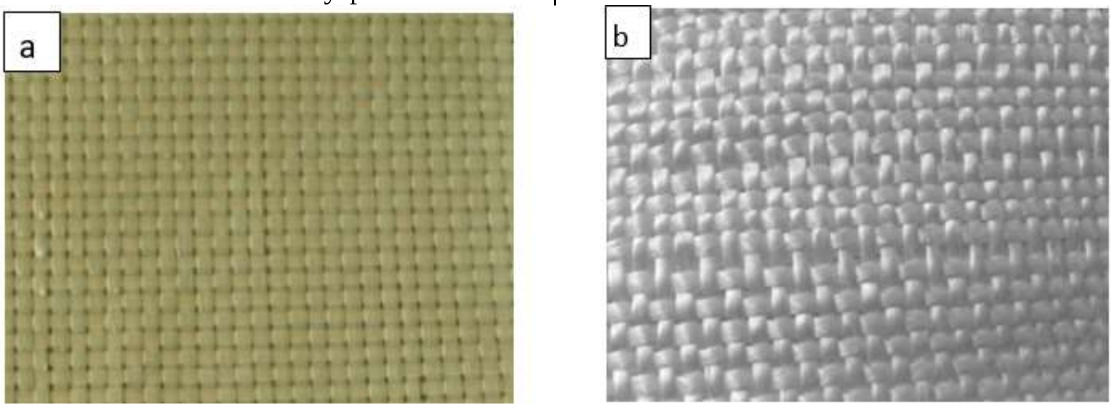

Figure 3. Visual photo of fabrics; (a) Kevlar (b) Dyneema

3. Results and Dissections.

Fabric structures are engineered structures that meet the load resistance requirements of most bulletproof fabrics. Where the fabric is subjected to constant biaxial stress from the pressure or applied tension during use. So, the fabric shall be resistant to slippage and stress, therefor the opportunity for accidental damage is minimized, in addition to the careful detailed design for fibers which support the strength properties. Kevlar is considered 7 times stronger than steel, while Dyneema is 15 times stronger than steel. Therefore, they were making them the world's strongest fibers.

3.1 Tensile Strength Test.

Table 4. shows the tensile strength results for Kevlar and Dyneema fabrics. The results were carried out on 40cm of produced fabric for warp and weft direction. The results were carried out on 40cm of produced fabric for warp and weft direction. The Dyneema fibers don't have Amorphous regions in the structure, so, it characterized with highly crystalline. Although there was weaker Vander Vaal bonds between molecules, but the highly degree of crystallinity may increase the strength of the fiber. While Kevlar fibers such as Aramid that has Hydrogen bonds with a very short molecular length compared to Dyneema. Therefore, Kevlar has lower strength than the Dyneema. Both fibers materials have higher tensile strength per its weight as a ratio.

Table 4. Tensile Strength of fabrics

Material	Warp			Average	Weft			Average
	1	2	3		1	2	3	
Kevlar	151.9	155.5	153.7	**153.7**	125.7	129.4	127	**127.3**
Dyneema	255.8	258	259.3	**257.7**	238	236.9	239	**237.9**

3.2 UV resistance Test.

UV resistance is defined as the ability of a material to resist ultraviolet (UV) light or sunlight. UV light, or sunlight, will cause non-resistant materials and surfaces to fade or discolor. The UV accelerated weathering tester reproduces the damage caused by sunlight: in a few days or weeks, the UV tester can reproduce the damage that occurs over months or years outdoors. The test was performed according to the standard (ASTM D6544 –12) This practice leads to measurement of the residual level of UV-protection in fabrics or garments labeled as sun- or UV-protective, after exposure to conditions that relate to about two years of seasonal use. After being exposed to UV radiation during three consecutive days, Kevlar began to degrade and lost about 35% of its strength. While the Dyneema fabric lost only about 10% of its strength. Table 5. shows the tensile strength test results for Kevlar and Dyneema fabrics after UV exposure. Figure 4. shows warp Tensile strength test before and after UV exposure. Figure 5. shows weft Tensile strength test before and after UV exposure.

Table 5. Tensile strength test of produced fabric after UV exposure

Material	Warp			Average	Weft			Average
	1	2	3		1	2	3	
Kevlar	99.9	99	100	**99.63**	83	84.4	82.9	**83.43**
Dyneema	233.8	232	231.3	**232.3**	212.5	213.9	215	**213.8**

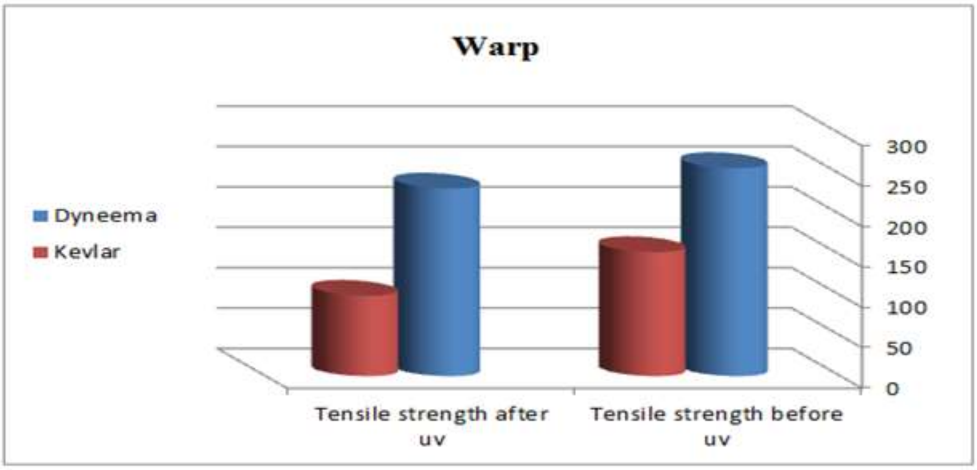

Figure 4. warp Tensile strength test before and after UV exposure

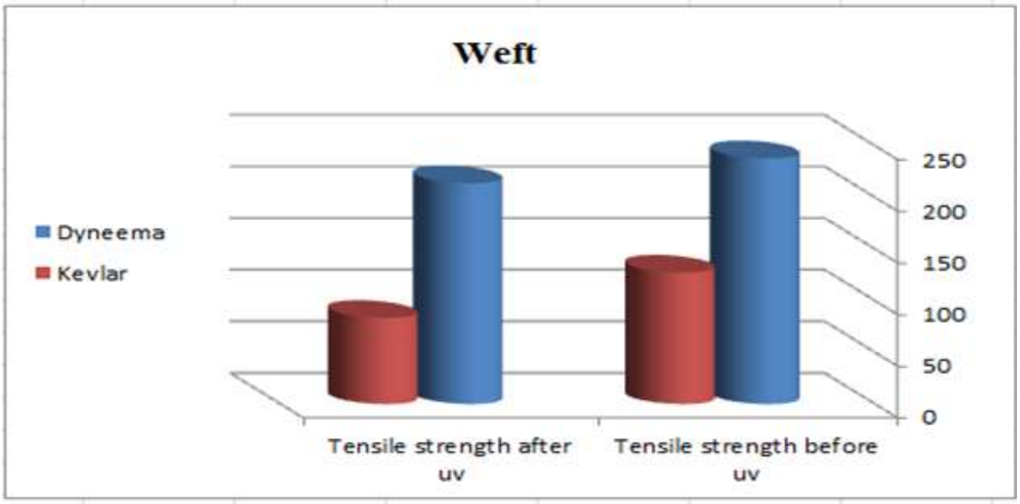

Figure 5. weft Tensile strength test before and after UV exposure

3.3 Water Resistance Test.

The test was performed according to the standard (ISO 4920/ 2012) This International Standard specifies a spray test method for determining the resistance of any fabric, which might or might not have been given a water-resistant or water-repellent finish, to surface wetting by water. The test was performed accordingly Standard atmospheres for conditioning and testing (ISO 139: 2005). After exposing the Kevlar fabric, absorbed about 4% of the weight of the water, while the Dyneema fabric didn't absorb any amount of water and maintaining its properties in humid conditions. Table 6. shows the Water Resistance Test Results for Kevlar and Dyneema fabrics. Figure 6. shows Weight before and after Water Resistance Test.

Table 6. Water Resistance Test Results

Material	Weight before testing (g/m^2)	Weight after testing (g/m^2)			Average (g/m^2)
		1	2	3	
Dyneema	345	345	345.1	345.3	**345.1**
Kevlar	320	332.9	333	332.8	**332.9**

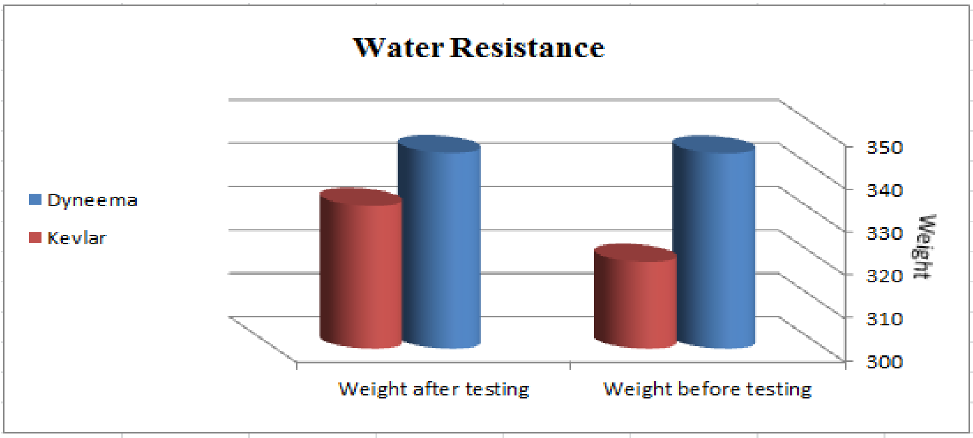

Figure 6. Weight before and after Water Resistance Test

3.4 Heat Conductivity Test.

The test was performed according to the standard (ASTM F955 – 15) Use this test method to measure and describe the properties of materials, products, or assemblies in response to molten substance pour under controlled laboratory conditions and shall not be used to describe or appraise the thermal hazard or fire risk of materials, products, or assemblies under actual conditions. Kevlar fabric tends to insulate the heat where its conductive of 0.06 w/mk, unlike Dyneema fabric that has a conductive heat of 45 w/mk, which leads to disperses the heat quickly. So, Kevlar materials conceder good for cold weather, while Dyneema material provides maximum comfort for warm weather.

3.5 Abrasion Resistance Test.

The test was performed according to the standard (ASTM D3885 – 07) his test method covers the determination of the abrasion resistance of woven or nonwoven textile fabrics using the flexing and abrasion tester. Kevlar fabric fatigued after of 100,000 abrasion cycles and lost about 20% of its weight, while Dyneema fabric lost the same weight after 1,000,000 abrasion cycles. Table 7. shows abrasion resistance test results for Kevlar and Dyneema fabrics. Figure 7. shows Weight for Kevlar and Dyneema fabrics before and after testing.

Table 7. Abrasion Resistance Test Results

Material	Weight before testing (g/m^2)	Weight after 100,000 abrasion cycles (g/m^2)	Weight after 1,000,000 abrasion cycles (g/m^2)
Dyneema	345	345	276
Kevlar	320	256	0

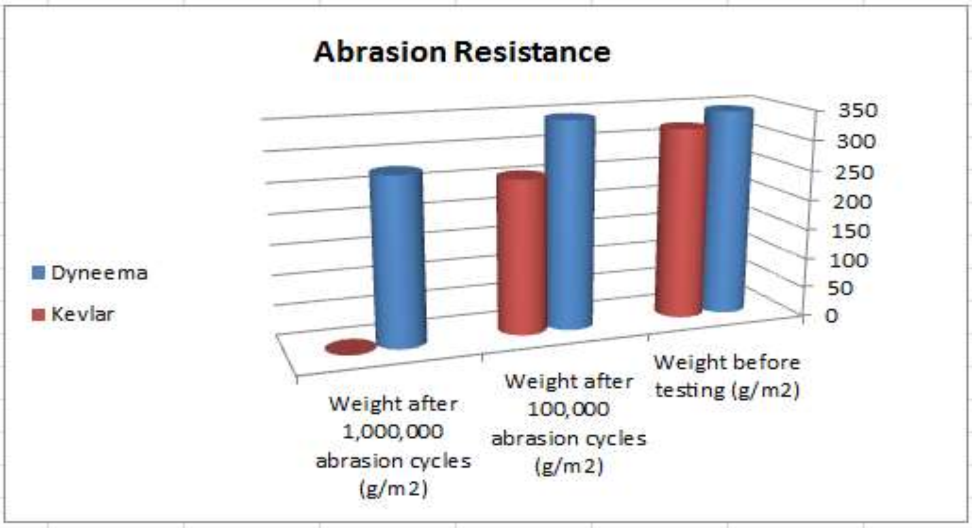

Figure 7. Weight before and after Abrasion Resistance Test

3.6 washability Test.

The test was performed according to the standard (ASTM D6321 / D6321M – 14) This practice covers test methods and procedures used to evaluate important characteristics of machine washable T-shirts. T-shirts may be made of knitted fabric composed of any textile fiber or blend of fibers and intended to be used as underwear or as an outer garment. T-shirts' characteristics may be assessed either as a final product or at any intermediate processing stage. Kevlar fabric lost about 17% of their Weight after three washes. While Dyneema fabrics kept the Weight of their fibers after more than ten time washings. Table 8. shows weight Kevlar and Dyneema fabrics after washing. Figure 8. shows weight Kevlar and Dyneema fabrics before and after washability Test.

Table 8. Abrasion Resistance Test Results

Material	Weight before testing (g/m^2)	Weight after testing (g/m^2)			Average (g/m^2)
		1	2	3	
Dyneema	345	345	345.1	345.3	**345.1**
Kevlar	320	332.9	333	332.8	**332.9**

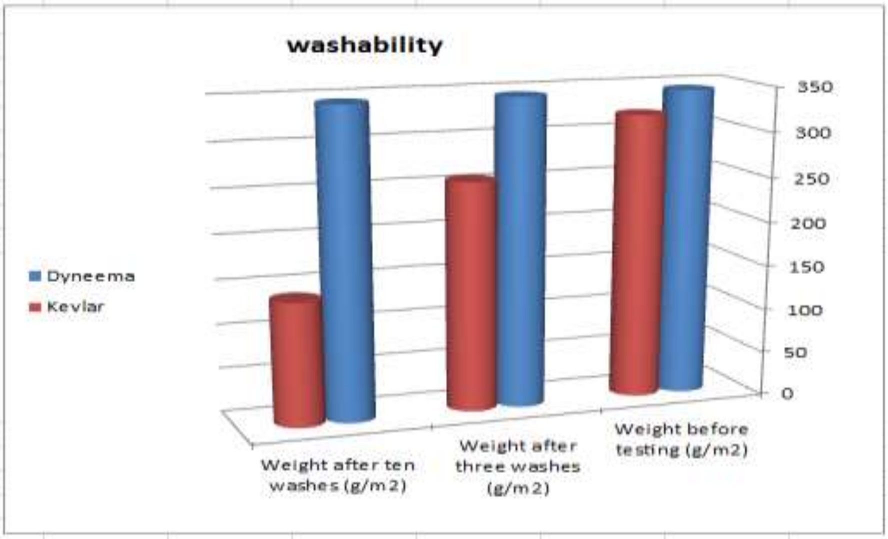

Figure 8. Weight before and after washability Test

3.7 Chemical Resistance Test.

The test was performed according to the standard (ASTM C267 – 01) These test methods are intended to evaluate the chemical resistance of materials, under anticipated service conditions. These test methods provide for the determination of changes in the Weight of specimen properties of the after exposure of the specimens to the medium. Dyneema fabrics have highly resistant to most chemicals and moisture, as they do not contain hydroxyl or amides groups. While the Kevlar fabrics were easily affected by most chemicals because they contain polar groups. Therefore, Kevlar fabrics cannot be used directly as bulletproof fabrics, but they must be treated before use. While Dyneema fabrics do not need to be treated before using chemical bulletproof fabrics and thus will save time and effort as well as cost

3.8 Thermal Properties Test.

The test was performed according to the standard (ASTM D7984 – 16) Test Method for Measurement of Thermal Effusively of Fabrics Using a Modified Transient Plane Source (MTPS) Instrument. When exposed to heat; Kevlar material borne from 160: 200°C and then began to melt. While the Dyneema fabrics borne about 152:155°C and then began to melt. So Kevlar has superior thermal properties, because the impact bullet temperature from 9 mm distance is about 147: 152°C. This value is the same as the melting point of Dyneema fabric. But some research pointed that the outer surface of bullet is hot from while the core is cold.

4. Conclusion.

The low density of the Dyneema fibers with high strength property is the basis for very high tenacity related to their weight. It was presented that Dyneema has a unique combination of properties being the strongest man-made fibers. Also showed Dyneema fabric has good abrasion resistance due to a lower friction coefficient, thus Dyneema tends to bend when it creates a loop or knot, while the Aramid filament tends to break.

Dyneema is more flexible than the Kevlar material, which may result in fewer breakages or problems during weaving or knitting process. In addition, Dyneema fiber is very resistant against almost chemicals. Because it is produced from ultra-high molecular weight polyethylene, but Dyneema has limiting property of thermal because its melting point is lower than Kevlar. Generally, Dyneema material is considered superior in all the properties that qualify it for bulletproof fabrics from its results test.

5. References

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