# ASPECTS REGARDING THE USE OF POLYETHYLENE FIBERS FOR PERSONAL ARMOR

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***Abstract:*** *The last few decades represented a revolution for the ballistic protection industry, by introducing the aramids, the world-known Kevlar, into the protective structures, especially body armour and lightweight armour. This accomplishment also introduced the opportunity for other polymers to make their way into ballistic protection domain. Nowadays, high-perfomance polyethylene is the real competitor of aramid. This articles offers a global view over the state-of-the-art of the development of this type of polyethylenes in the ballistic protection domain, mentioning some local recent research that has been made on this subject.*

***Keywords:*** *high-performance polyethlylene, ballistic protection, lightweight armour*

## 1. Introduction

Ballistic protection is known as a very dynamic field which, from the very battlefield point of view, is constantly competing against the development of ammunition, pyrotechnics and, more recently, improvised explosive devices (IED). Personal armor items are also comercialised as ballistic clothing, therefore we may say that fibers play a very important role in this industry. There are many natural and synthetic fibers which are used for ballistic protection, but only two types of synthetic fibers can be regarded as high-performance – aramid and UHMWPE (Ultra High Molecular Weight Polyethylene) fibers. [1] The modern bulletproof vest using Kevlar fibers emerged in the 1970s and since then, many materials made their way into enhancing the ballistic protection or even replacing standard materials, such as metal and ceramics, resulting in lighter, more comfortable to wear protection equipment, the so called ”lightweight armour”.

## 2. General aspects regarding the properties of high-performance polyethylene

Ultra-high-molecular-weight polyethylene (UHMWPE, UHMW) is a subset of the thermoplastic polyethylene. Also known as high-modulus polyethylene (HMPE), or high-performance polyethylene (HPPE), it has extremely long chains, with a molecular mass usually between 2 and 6 million g/mol, that is up to 10-100 times higher than standard grades of high density polyethilene. [2], [3] The longer chains

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serve to transfer load more effectively to the polymer backbone by strengthening intermolecular interactions. This results in a very tough material, with the highest impact strength of any thermoplastic presently made. [2] The essential difference between HPPE and regular polyethylene is illustrated in Figure 1.

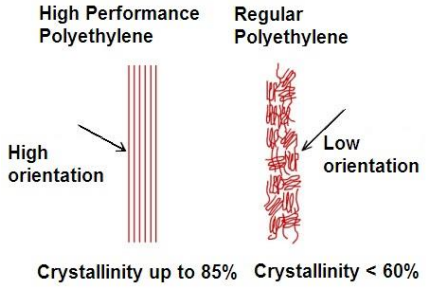



***Figure 1***. *Ideal orientation of polymer chains in HPPE and regular PE [4]*

The HPPE molecules are weak in bonding with each other, but since they are very long, UHMWPE derives its strength largely from the individual chains. The weak bonding between molecules sustains, nevertheless, a particular disadvantage for the UHMWPE fibers, which is the low melting temperature: 135-138°C. [3]

However, this type of high density polyethylene fibers are known as the strongest fibers in the world, their commercial succes being due to their outstanding mechanical properties, their unmatched damage tolerance, fatigue resistance and their ability to fail in shear or compression without losing great amount of tensile strength. On the weight basis, they are the strongest and almost the stiffest commercially available material offering the highest percentage of absorbed energy versus total impact energy. [5]

Evenmore, it is extensively used in ballistic items (helmets, vests, plates) for personal protection. Thus, the UHMWPE fibers may become part of a composite material or may be processed further in different solid forms in order to be used in ballistic protection structures. The majority of the composites used in body armor systems take the form of textile fabrics or unidirectional tape of high modulus and high strength fibers embedded in a variety of matrix resins.

**3. Dyneema and Spectra**

There are two leading high modulus, high performance polyethylenes that are widely used in ballistic protection field. These are Dyneema and Spectra fibers.

Spectra®, a product manufactured by Honeywell International (previous AlliedSignal - USA), is an ultra high strength polyethylene fiber. The UHMWPE is dissolved in a solvent and then spun through a series of small openings called spinnerets. The solution is then made solid by cooling, and the cooled fiber has a gel like look. This Spectra fiber is then used to make what they call ”Spectra Shield”. The Spectra Shield has two unidirectional layers of the fiber that cross each other at 0 and 90 degree angles and are held in place by a flexible resin. The resin and fiber layers are then sealed between two thin sheets of polyethylene film. Honeywell says that the resulting no woven fabric is very strong and light weight with excellent ballistic protection. Spectra Shield is made in several styles, and in both hard armor and concealable armor styles. [6]

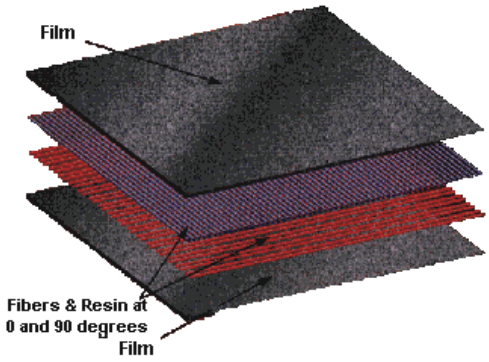



***Figure 2**. Spectra Shield structure [7]*

Honeywell International also manufactures a product called Gold Shield. This product is made by using aramid fibers instead of the Spectra fibers. In the image bellow there is a composite product made of both the Spectra and Gold shield, used to enhance the ballistic protection of helmets in Asia since 2011, according to their website [8].

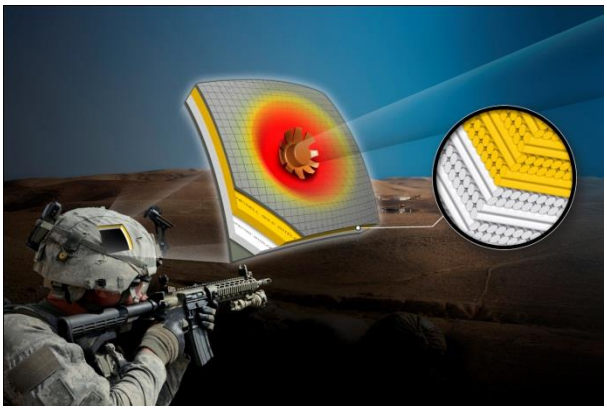


***Figure 3**. Structure of Honeywell combat helmets in Asia [8]*

Spectra Shield products are also applicable in armour for the Humvee, US Marine helicopters, protective vests, ESAPI and ESBI plates and Blastshield fabric. [9]

The other leading high modulus, high performance polyethylene (HPPE) fibre is Dyneema from DSM, produced in the Netherlands, USA and Japan.

Dyneema has a very high strength to weight ratio, and is light enough to float on water. A 1 mm diameter rope of Dyneema can hold up to a 240 kg load, and it also has a high energy absorption rate. [5] On a weight-for-weight basis, Dyneema is 15 times stronger than steel and is 40 percent stronger than aramid fibers. [10]

One of Dyneema's main uses is for armored vehicle protection. Its incredible strength and resistance to extreme and changing weather conditions make it an ideal addition to vehicles in dangerous situations. Its ability to be molded to various forms allows Dyneema to be used in a variety of vehicles for military, law enforcement and civilian protection applications. Depending on the type of situations that Dyneema will be used for, it can be obtained for either soft ballistics, like handguns, or hard ballistics, like antitank projectiles, land mines.

Dyneema can be used in two different ways for vehicle protection, as either spall liner or as a panel. In its form as spall liner, Dyneema works as an extra layer of

protection against a ballistic threat to a vehicle. Spall liner is used to protect vehicle occupants by catching and absorbing the ballistic itself, or metal fragments that came off of the vehicle due to the explosion. When Dyneema is used as panel it can protect against stronger ballistic threats such as antitank projectiles and tank-penetrating projectiles. The panels can be custom shaped and easily cut to the design specifications of the vehicle.

By themselves or combined Dyneema has the potential to protect against a range of ballistic threats including direct gunfire from an AK47, IEDs, rocket-propelled grenades, land mines or explosively formed penetrators.

Compared to armor plating, armor made with Dyneema that has a steel or ceramic strike plate is 50 to 75 percent less dense than steel armor. Because it is extremely light and moldable, a vehicle equipped with Dyneema doesn't have to sacrifice maneuverability or design, or change the center of gravity in order to protect against an explosion or gunfire.

Dyneema has also been implemented into an invention that protects not only the occupants of a vehicle but also the vehicle itself from a direct explosion. The structural blast chimney uses Dyneema to take the initial blast of an explosion and channel it towards the center of the vehicle and then up and away from it. The design of the chimney along with the Dyneema's impact absorption allows the vehicle stay firmly planted on the ground and intact during an explosion, protecting occupants from sound, heat and sheer force of the explosion. [11]

Being a non woven fabric, the construction of Dyneema sheets is similar to that of Spectra shield, as observed in Figure 3.

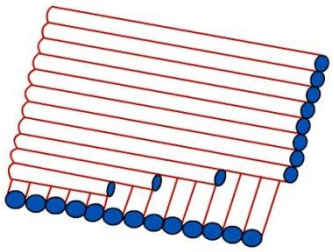


***Figure 4****. Construction of Dyneema and Spectra Shield [4]*

**4. Tensylon and Endumax**

High-performance polyethylene have come to the attention of many manufacturers across the world, some of them even managing to introduce new types of UHMWPE into ballistic protection solutions at even lower costs than previous mentioned brands.

One of these rather new HPPE is Tensylon, produced by DuPont, the same manufacturer of well-known aramid fiber, Kevlar. Tensylon is said to offer similar performance to other high-performance polyethylenes, but at lower cost.

Typical ceramic composite armor solutions use the ceramic element to “break up” or fracture the threat while the exterior laminate “captures” or absorbs the threat. Traditional metallic armoring is monolithic in that it does both breaking up and capturing in one. To this extent, Tensylon has flexural strength, and proprietary composite formulations result in less delamination, which is important in overmatched threat situations. It is ballistically more efficient than typical woven para-aramids used in military ground vehicles.

Offering a reduction in spall quantity and cone angle inside crew compartments, Tensylon ballistic composites can be utilized as a ballistic blanket for military ground vehicles, commercial armored vehicles and aircraft.

Anti-ballistic composites such as Tensylon are made in application-specific widths to maximize material yield, resulting in a cost savings over armor plating, which is purchased by piece, not exact measurement. Individual protection applications include helmets, hybrid and monolithic insert plates, and body armor. [12]

The other high-performance polyethylene that raised attention lately is called Endumax.

Created by Teijin Ltd in Japan, and then further developed by Teijin Aramid in Europe, Endumax is a new, ultra-high-molecular-weight polyethylene tape. It is intended to be used to reinforce and to reduce weight in a range of applications, from anti-ballistic plates to assistive technologies for people with disabilities.

Endumax is produced in a solvent free, patented process by stretching a sheet of pure UHMWPE to a thin, narrow tape. The actual tape is 55 microns thick, but comes in standard widths of 2mm and 133mm.

In many respects, tapes today can be used like a fiber, either twisted, woven or knitted. However, Teijin Aramid envisioned other advantages. Endumax tapes are ideal for constructing thin but strong structures, such as panels and laminates for anti-ballistic applications. In laminates made from fibers, each fiber needs to be fixed, so the final laminate can contain up to 15-20% glue. But one made from Endumax tape would contain just 4% glue – providing the same ballistic protection level. [13]

Currently, although there are already many applications for Endumax, it is still in research phase regarding the ballistic protection, and is taken into account in futuristic projects such as „the world toughest material" obtained by tying the fibers into knots. [14]

5. **Local research**

We have been testing recently some plates for individual ballistic protection based on Endumax. The configuration of the samples tested was similar to that presented in figure 5.

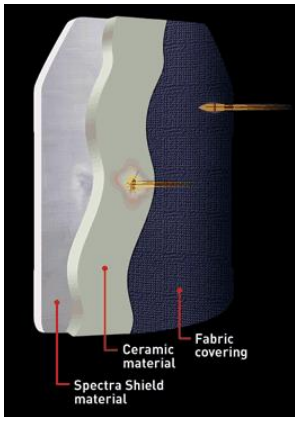



***Figure 5.*** *Configuration of a ballistic protection plate based on ceramic and pressed high-performance polyethylene blocks [14]*

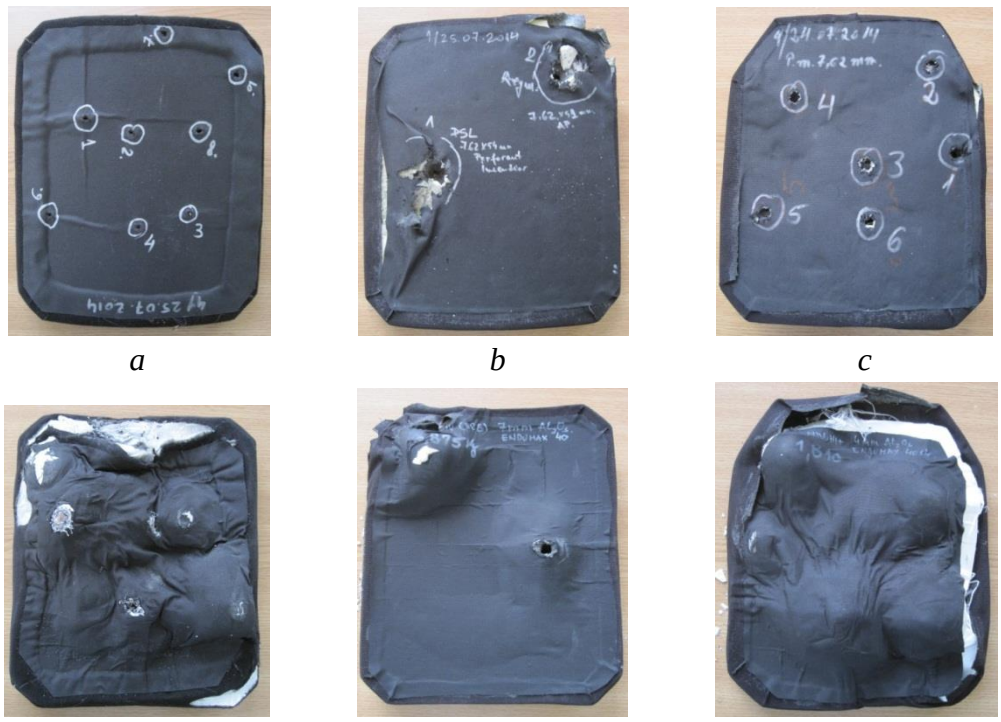
Experimental trials were conducted according to NIJ STANDARD USA 0101.04⁄2000 and Technical Military Standard 40202-99 used in Romania for testing individual ballistic protection items.

We had three plates, one made entirely out of Endumax, level III of protection, and the other two being composites of Endumax and alumina, level IV and III+ of protection. The results were recorded in the table below, followed by some snapshots of the fired plates.

**Table 1.**

Endumax ballistic protection plates - testing results

| **Sample No.** | **Materials** | **Plate type** | **Ammunition** | **No. of shots** | **Impact velocity range [m/s]** | **Penetration** | **Blunt trauma range [mm]** |
|---|---|---|---|---|---|---|---|
| 1 | Endumax | Level III | 7,62 x 51 mm FMJ | 8 | 862-875 | 5 partial | 24 – 32 |
| | | | | | | 3 total | - |
| 2 | ·$Al_2O_3$ 7 mm ·Endumax 40 layers, pressed | Level IV (SR8) | 7,62 x 54 mm | 1 | 881 | total | - |
| | | Level III | 7,62 x 51 mm FMJ | 1 | 823 | partial | 18 |
| 3 | ·$Al_2O_3$ 4 mm ·Endumax 40 layers, pressed | Level III+ | 7,62 x 39 mm | 6 | 698-703 | 6 partial | 11-22 |



*a* *b* *c*

***Figure 5.*** *a. Sample 1; b. Sample 2; c. Sample 3*

## 6. Conclusions

As observed, our local research had promising results. One of the plates tested turned out to be suitable for the envisioned level of protection (Level III+), and the other two are between the line, suggesting more trials are needed for this particular plates.

Generally, we may conclude that high-performance polyethylene represent the future of ballistic protection, having many advantages over aramids or other types of materials. The one disadvantage that needs to be overcome is the low melting temperature but, nevertheless, many applications don't even aproach that temperature.

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