Structural Analysis of UHMWPE Knitwear

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Abstract
The article presents the results of studying the structural properties of knitted fabrics produced from ultra-high molecular weight polyethylene (UHMWPE) fibers. The influence of knitting technological parameters on surface mass, thickness, and volumetric density was investigated. It was found that variation in loop length and knitting density significantly affects the fabric structure and performance characteristics. UHMWPE knitted fabrics demonstrate high tensile strength, low density, and excellent abrasion resistance, making them promising materials for technical and protective textiles.
Keywords: UHMWPE, knitted fabric, structure, surface density, volumetric density, technical textiles, protective materials.

Introduction

Ultra-high molecular weight polyethylene (UHMWPE) is one of the strongest synthetic fibers known today. The material possesses a unique combination of properties such as high tensile strength (up to 3 GPa), low density (0.97 g/cm³), chemical inertness, and excellent resistance to abrasion and ultraviolet radiation.

Due to these properties, UHMWPE is widely used in the production of ballistic fabrics, ropes, medical implants, sportswear, and protective clothing. However, the structure and behavior of UHMWPE yarns in knitted systems have not been sufficiently studied, particularly regarding the influence of knitting technological parameters on fabric properties.

Literature Review

UHMWPE yarn is based on ultra-high molecular weight polyethylene, which is a subtype of high-density thermoplastic polyethylene. It is odorless, tasteless, and non-toxic. It combines all the characteristics of high-density polyethylene with additional resistance to concentrated acids, alkalis, and many organic solvents. UHMWPE fibers have high resistance to aggressive chemicals (except oxidizing acids), low moisture absorption, a low coefficient of friction, and outstanding abrasion resistance—up to 15 times greater than that of carbon steel. Its melting point is approximately 130–136°C, and it is not recommended for long-term use above 80–100°C. At temperatures below −150°C, it becomes brittle [1].

In addition to high strength, UHMWPE fibers are extremely lightweight and resistant to ultraviolet radiation [2].

One of the most well-known UHMWPE fiber producers in Europe is **DSM Dyneema** (Netherlands). These fibers have a diameter of 12–21 μm and are manufactured in three strength grades and various linear densities [3]. DSM Dyneema has branches in the USA, Singapore, Russia, and Brazil. The **Braskem** company produces UHMWPE fibers and textiles under the **UTEC®** trademark [4].

In Asia, several Chinese companies dominate UHMWPE fiber production and supply their products to global markets. For example, **Jiangsu Dongrun Safety Technology Co., Ltd.** manufactures UHMWPE fabrics with surface densities of 80–160 g/m² for soft armor and 130 g/m² for hard armor [5].

Beijing Protech New Material Science Co., Ltd. produces UHMWPE-based fabrics with surface densities of 50–300 g/m² for use in light bulletproof armor, puncture-resistant clothing, ballistic shields, helmets, explosion-proof barriers, and armored vehicles [6].

Jiangxi Great Wall Protection Equipment Industry Co., Ltd. specializes in UHMWPE-based tactical and lightweight concealed bulletproof vests [7].

Sinty Sci-Tech Co., Ltd. (Sinty Fiber) manufactures UHMWPE fibers (XT grade) and fabrics with surface densities of 75, 130, and 160 g/m², as well as UHMWPE cut-resistant gloves [8]. The company collaborates with high-tech equipment manufacturers in the Netherlands and Italy and conducts research jointly with Shandong Polytechnic University and Donghua University to enhance product quality.

Table 1. Fiber composition of blended UHMWPE yarns [9]

№	Yarn code	Composition	Linear density (den/tex)
1	UB-WH10	400 den white polyethylene + 140 den black nylon + 130 den spandex + 100 den white polyester ×2 + 100 den fiberglass	970 den / 107.8 tex
2	UB-0615B	200 den white polyethylene + 100 den black polyester ×2 + 100 den fiberglass	500 den / 55.6 tex

Materials and Research Methodology

The study used UHMWPE yarn of two linear densities – 107.8 tex and 55.6 tex. Knitting was carried out on a flat knitting machine of gauge 12, with variations in loop length and course height [10].

The evaluated structural characteristics included surface mass (Ms), thickness (T), and volumetric density (δ).

№	Yarn brand	Linear density, tex	Loop pitch A (mm)	Loop height B (mm)	Horizontal density Rg	Vertical density Rv	Loop length L (mm)	Surface mass Ms (g/m²)	Thickness T (mm)	Volumetric density δ (mg/cm³)
1	UHMWPE	107.8	1.43	0.90	35	55	5.0	412.2	1.2	343.5
2	UHMWPE	107.8	1.43	0.83	35	60	4.8	712.0	1.8	395.6
3	UHMWPE	107.8	1.70	1.11	30	45	5.8	704.3	2.3	306.2
4	UHMWPE	55.6	1.00	0.83	50	60	3.0	649.0	1.6	393.1
5	UHMWPE	55.6	1.11	0.90	45	55	3.6	629.4	1.7	370.2

Table 2. Results of structural parameters of UHMWPE knitted fabrics

Results and Discussion

The diagram in Figure 1 illustrates changes in loop pitch (A), course height (B), loop length (L), and thickness (T) of the knitted samples.

It was found that the loop pitch varied between 1.43–1.70 mm (by 18.9%), course height between 0.83–1.11 mm (by 33.7%), loop length between 4.8–5.8 mm (by 20.8%), and fabric thickness between 1.2–2.3 mm (by 91.7%).

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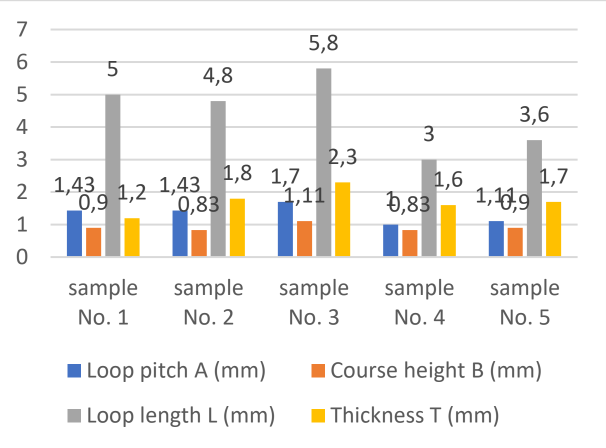

Figure 1. Variation of loop pitch A (mm), course height B (mm), loop length L (mm), and thickness T (mm) for UHMWPE-based knitted fabrics.

Analysis of surface mass (Ms) of UHMWPE knitted fabrics (Figure 2) shows that it ranges from 412.2 to 712 g/m² (a 42% variation relative to the maximum). The main reason for this difference is the structure of the knitted loops. Since surface mass depends primarily on yarn consumption and volumetric density depends on fabric thickness, both indicators must be analyzed together. The volumetric density ranged from 306.2 to 395.6 mg/cm³ (a 22.6% variation).

Among the tested samples, the optimal fabric in terms of minimum surface mass is sample No. 1 (412.2 g/m²). For double-knit structures, sample No. 5 (629.4 g/m²) is the most recommended.

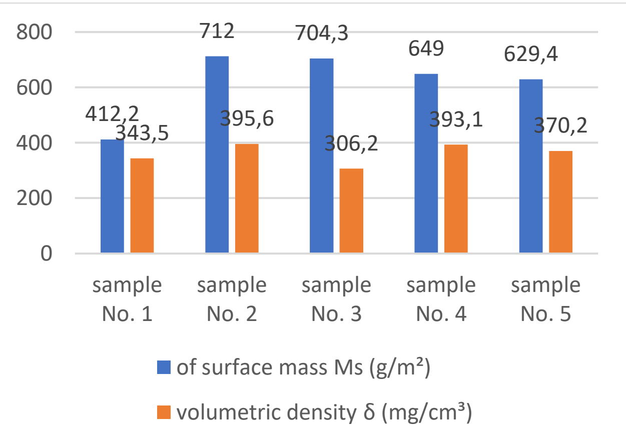

Figure 2. Variation of surface mass Ms (g/m²) and volumetric density δ (mg/cm³) for UHMWPE knitted fabrics.

The highest volumetric density was observed in sample No. 2 (395.6 mg/cm³), while sample No. 3 (306.2 mg/cm³) showed the lowest value and is considered optimal. Comparing samples No. 4 and No. 5, the latter had a 3% lower surface mass and 5.8% lower volumetric density.

Thus, by introducing yarns of different compositions on one side of the fabric, it is possible to achieve a two-sided effect – one side provides external protection while the other enhances thermal comfort. Replacing expensive UHMWPE yarn with less costly fibers (e.g., nylon or polyester) on the inner layer can reduce production costs without compromising functionality, achieving an economic benefit. Therefore, sample No. 5 can be recommended as the most cost-effective variant for special-purpose knitwear.

In general, increasing loop length and reducing vertical density leads to an increase in fabric thickness and a decrease in volumetric density.

Samples No. 2 and 3 (107.8 tex yarn) exhibited the highest surface mass (712 and 704 g/m²) and thickness (1.8–2.3 mm), due to increased loop volume. Fabrics made of finer yarn (55.6 tex) had a denser structure and higher volumetric density (up to 393 mg/cm³).

Figure 3 illustrates the relationship between surface density (Ms, g/m²) **and** volumetric density (δ, mg/cm³) for knitted fabric samples made from UHMWPE yarns intended for special-purpose applications.

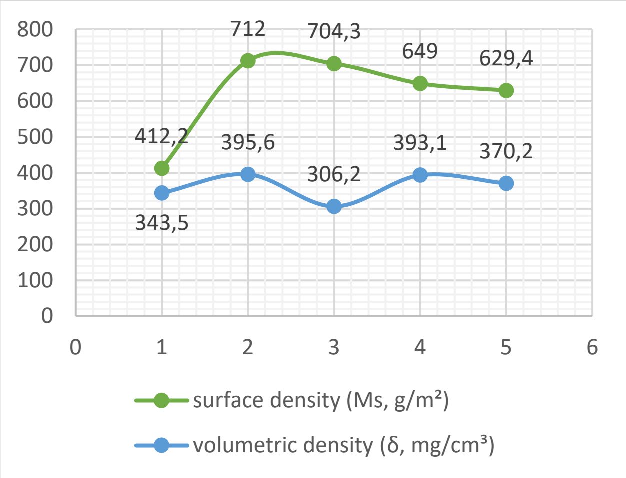

Figure 3. Variation of surface density (Ms, g/m²) and volumetric density (δ, mg/cm³) of UHMWPE knitted fabrics depending on the knitting structure and sample variant.

Variation of Surface Density (green curve):

The surface density shows a distinct upward trend from sample No. 1 (412.2 g/m²) to sample No. 2 (712 g/m²), where it reaches its maximum value, followed by a gradual decrease down to 629.4 g/m² for sample No. 5.

This behavior is associated with the structural characteristics of the knitted loops. Increasing the vertical loop density and decreasing the loop length (sample No. 2) result in a tighter structure and higher surface mass. As the loop length increases and stitch density decreases (samples No. 3–5), the structure becomes looser, leading to a reduction in surface density.

Thus, the curve exhibits a clear peak, which reflects the optimal combination of knitting parameters at which the maximum mass per unit area is achieved.

Variation of Volumetric Density (blue curve):

The volumetric density varies less sharply than the surface density. The minimum value is observed in sample No. 3 (306.2 mg/cm³), while the maximum occurs in sample No. 2 (395.6 mg/cm³).

A consistent trend is noted: as the fabric thickness increases (samples No. 3–5), the volumetric density decreases due to the increase in internal loop volume and higher porosity of the knitted structure.

Correlation Between the Curves:

A comparison of both curves reveals an inverse correlation between surface and volumetric density.

Where the surface density reaches its maximum (sample No. 2), the volumetric density also attains relatively high values due to the compact loop structure.

However, as the loop length increases further (sample No. 3), surface density decreases slightly, while volumetric density drops more noticeably — indicating increased looseness and internal volume within the fabric structure. So, we can conclude:

- Surface density varies within **412.2–712 g/m²**, and volumetric density within **306.2–395.6 mg/cm³**.
- Both dependencies exhibit a **nonlinear character** with a pronounced maximum in the region of tighter knitting structures.
- With increasing loop length, both surface and volumetric densities tend to decrease, especially the latter.
- The **optimal structure** in terms of technological and physical parameters is **sample No. 2**, which demonstrates the highest surface mass and satisfactory structural compactness.

Hence, controlling loop parameters allows purposeful regulation of mass, thickness, and density of UHMWPE knitwear, which is crucial for designing functional textiles for protective and technical purposes. UHMWPE knitwear combines low weight, high tensile strength, and excellent abrasion resistance, making it competitive with aramid and carbon fabrics while being significantly lighter.

Comparative Analysis

To evaluate the practical significance of UHMWPE knitted fabrics, a comparative analysis was carried out against commonly used aramid (e.g., Kevlar®, Twaron®) and polyester knitted structures under similar conditions.

Table 3. Comparative Analysis of Structural and Performance Parameters of Knitted Materials

Property	UHMWPE Knit	Aramid Knit	Polyester Knit
Fiber density (g/cm³)	0.97	1.44	1.38
Tensile strength (GPa)	2.8–3.0	2.5–3.5	0.8
Modulus of elasticity (GPa)	80–120	70–130	10–20
Abrasion resistance (cycles, Martindale)	>25,000	10,000–15,000	8,000
Surface mass of knit (g/m²)	412–712	520–780	600–850
Thermal stability (°C)	up to 100	up to 250	150
UV resistance	Medium–High	High	Medium
Cost (relative)	Low–Medium	High	Low

Analysis of the data demonstrates that UHMWPE knitted fabrics have several key advantages over aramid and polyester analogues:

- The density of UHMWPE fibers is 30–35% lower than aramid and polyester, resulting in lighter fabrics with comparable strength.
- The abrasion resistance of UHMWPE is significantly higher (up to 2.5× that of aramid knits), providing longer service life in protective gear.
- Although UHMWPE has lower thermal resistance (melting point ~136°C) than aramid (decomposition above 400°C), it remains stable under moderate working temperatures (up to 100°C), suitable for mechanical and ballistic applications.
- Considering the cost-to-performance ratio, UHMWPE fabrics are more economically efficient**,** enabling the development of lightweight, affordable protective textiles.

These characteristics highlight UHMWPE knitwear as an optimal material for hybrid protective structures — for example, when combined with aramid layers or flame-retardant coatings to achieve both heat and impact resistance.

Conclusions

1. The change in loop parameters (loop length, horizontal and vertical density) significantly influences the geometric and structural characteristics of UHMWPE knitted fabrics.
2. Increasing loop length leads to greater thickness and lower volumetric density of fabrics.
3. Comparative analysis shows that UHMWPE knitted fabrics combine low mass, high strength, and excellent abrasion resistance**,** outperforming polyester and approaching aramid materials in strength while remaining more economical.
4. These properties make UHMWPE knitwear a promising material for lightweight ballistic textiles, protective sportswear, and technical clothing**.**

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