Study on manufacturing and mechanical properties of UHMWPE knitted structural reinforcement in composites

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Abstract. In this paper, four kinds of UHMWPE knitted reinforcement with plain, interlock, swiss pique and purl stitches were prepared respectively to explore the influence of different knitted structures on the mechanical properties of reinforcement. The properties of each UHMWPE knitted structural reinforcement were compared by tensile, tear and puncture tests. The results show that interlock has obvious advantages over other structures in various mechanical experiments, which provides a good choice for preparing knitted structure reinforcement for composites.

1. Introduction
The density of UHMWPE fiber [1-2] is very small, only 0.97g/cm³, and its specific strength and specific modulus are considerably higher than other high-performance fibers [3-4]. It has excellent abrasive resistance, corrosive resistance, impact resistance, low temperature resistance, tensile resistance and light stability [4-5], low elongation at break, greater fracture work, good energy absorption, and shearing resistance. Due to the above excellent performance, UHMWPE fiber is widely used in navigation, aerospace (tail and wing), military defense equipment (protective suit, helmet) and sports goods (tennis racket, battledore), etc. In recent years, researchers have found that knitted reinforcements with good extensibility and high tensile strength can be used as composite reinforcements [6-7]. Weft knitted structural reinforcements can provide good formability, impact resistance and energy absorption properties.

This paper focus on the mechanical properties of UHMWPE knitted structure reinforcements in composites. UHMWPE knitted structural reinforcements with plain, interlock, swiss pique and purl stitch were prepared respectively, and the mechanical properties of these four structures were tested. The mechanical properties of different tissues were compared by the experimental results, which provided reference for the preparation of UHMWPE reinforced composite.

2. Experimental

2.1. Materials
UHMWPE filament yarns (Qingdao Zhongfu Fiber Co., Ltd.) have a fineness of 600 denier. Tensile property of yarns was tested according to ASTM D2256 with an UTM5105 electronic universal testing machine. Basalt filament yarn with the same fineness was selected for tensile testing in order to compare the mechanical properties. The results are shown in table 1 that UHMWPE filament yarn exhibited ultra-high strength than other high performance fibers.
Table 1. Specifications of filament yarns

|              | linear Density(tex) | Breaking Tenacity (cN/dtex) | Breaking Strength (N) | Breaking Elongation (%) |
|--------------|----------------------|-----------------------------|-----------------------|-------------------------|
| UHMWPE       | 66.7                 | 23.08                       | 153.92                | 4.33                    |
| Basalt       | 66.6                 | 2.27                        | 14.96                 | 1.50                    |

2.2. Preparation and specification of reinforcement

UHMWPE filament yarn reinforcements are fabricated with four different knitted structures, including plain, interlock, swiss pique and purl stitches. Manufacturing on STOLL CMS 530 HP computerized flat knitting machine at a knitting speed of 0.4 and sinking depth of 10.5 mm, ensuring consistent knitting parameters for easy comparison between fabrics. The loop diagram of the four knitted fabrics is shown in Figure 1. The basic parameters of four different knitted fabrics were tested. The fabric thickness was measured on an fabric thickness meter (YG 141). The density of the four reinforcements was characterized using a fabric analysing glass(Y511-B). The mass of the fabric sample block was measured by a 0.001 precision laboratory electronic scale and its square gram weight was calculated, and the number of specimens is 5.

Table 2. Basic properties of four UHMWPE knitted structural reinforcements

|                | Plain     | Interlock | Swiss pique | Purl stitch |
|----------------|-----------|-----------|-------------|-------------|
| Thickness(mm)  | 0.88      | 1.73      | 1.70        | 1.06        |
| Courses(number/5cm) | 31       | 64        | 60          | 30          |
| Wales(number/5cm)  | 42       | 82        | 56          | 64          |
| Loop length(mm)  | 5.9       | 6.4       | 5.6         | 7.2         |
| Areal density(g/m²) | 226.48    | 453.67    | 351.89      | 238.52      |
2.3. Mechanical Testing

The tensile testing of the four UHMWPE knitted structural reinforcements was carried out in accordance with the standard ASTM D5035. Five specimens were tested for each test condition. The testing of the samples were characterized using a material testing machine (UTM5105, Sans, Shenzhen).

The tearing testing of the samples were carried out in accordance with the standard ASTM D5587. Five specimens were tested for each test condition with the material testing machine. The specimen was trapezoid, with a gap of 15 mm in the middle of the upper and lower clamps. (upper side length: 25mm, lower side length: 100 mm, height: 75 mm).

The puncture testing of the four UHMWPE knitted structural reinforcement was carried out in accordance with the standard ASTM D751-2006. In this experiment, the impact velocity was 1000 mm/min and the puncture angle was 0°. Sample size was 100 mm×100 mm, and five specimens were tested for each test condition with the universal strength tester.

3. Results and analysis

3.1. Tensile property analysis

The UHMWPE knitted structural reinforcements were subjected to a large extent of tensile deformation in transverse and longitudinal directions. The breaking points of the fabric distributed at both ends of the clamps, causing serious deformation in the middle section by the fibers fracture and slippage between fibers. From the perspective of longitudinal observation, there was a distinct difference in the fracture between each fabric structure. The damage degree of interlock structure was the lowest, the purl stitch reinforcement exhibited more obvious fractures and the other two kinds of reinforcements were fractured to some extent at both ends of the clamps.

The tensile strain of the four kinds of knitted structure reinforcement in longitudinal direction was lower than that in the transverse. The weft knitted structure had a series of coils in the longitudinal direction, which made the longitudinal coil withstand greater tension as shown in Figure 2. The yarn was bent in a loop in the transverse direction. When the transverse direction was stretched, the yarns were stretched and deformed, causing severe elongation and deformation of the reinforcements (Figure 2(a)). Due to the close structure and great tensile strength of the interlock stitch, both the transverse and longitudinal tensile strength were very high, which was approximate 4 times than that of purl stitch. The swiss pique exhibited higher tensile elongation but lower tensile strength. Therefore, the interlock structural reinforcement showed the best tensile properties among the four structural reinforcements.

Figure 2. Stress-Strain curves of Tensile testing (a: Transverse, b: Longitudinal)
3.2. Tear performance analysis
Because of the high strength of UHMWPE, the fabric is impossible to fractured by tearing directly, however, the transverse tear is accompanied by the longitudinal stretch of the reinforcement. As can be seen from Figure 3, interlock stitch had the greatest tear-resistance ability compared with other stitches in transverse and longitudinal directions. The tear strength of the interlock was about two times than that of the purl stitch while the elongation was lower than the purl stitch. The tearing strength of swiss pique transverse and longitudinal directions were generally consistent, and the tearing deformation in longitudinal direction was more serious than in transverse direction because it was accompanied by the transverse stretching of the fabric. Compared with other stitches, the tear strength of plain stitch was much lower. In a comprehensive consideration, the interlock stitch exhibited the highest tearing resistance among the four structures.

![Figure 3. Load-displacement curves of tear strength (a: transverse, b: longitudinal)](image)

3.3. Puncture resistance analysis
When being punctured at a certain rate, the puncture strength of the interlock stitch is the highest, and that of the purl stitch is the lowest. Due to its tight structure and good puncture resistance, the fabric was extended much longer during puncture process (Figure 4). On the contrary, the plain stitch had poor puncture resistance and small deformation. The puncture resistance of swiss pique was better, but it was not as close and thick as the air layer of interlock, so the puncture distance was longer. Therefore, the interlock stitch exhibited the highest puncture resistance.

![Figure 4. Peak load of puncture strength](image)
4. Conclusions
In this paper, plain, interlock, swiss pique and purl stitch fabricated with UHMWPE fiber were respectively prepared to explore the influence of different knitted structures on the mechanical properties of UHMWPE knitted structural reinforcements. The results showed that the interlock stitch exhibited the highest mechanical properties and could be fabricated for composites which were utilized for various industrial applications.

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