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Physical Properties of Ultrahigh Molecular Weight Polyethylene(UHMWPE) Tape Yarns Produced by the Compaction/Drawing Method

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1. INTRODUCTION

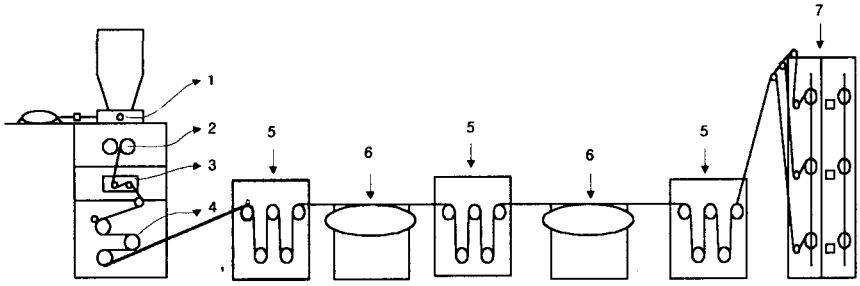
Since early of 1980's, high performance fiber has been developed by processing of ultrahigh molecular weight polyethylene(UHMWPE). UHMWPE fibers have high strength, high modulus and excellent impact properties due to the strong C-C bond.[1] Furthermore, the specific gravity of UHMWPE fibers is less than 1.0g/cm^2, which makes it possible to produce composites that combine good mechanical properties with low specific mass.[2] On the contrary, UHMWPE fibers also have some disadvantages such as low melting point(150℃) and low surface energy from lack of polar groups on the surface.[3] Recently commercialized UHMWPE fiber has been manufactured by gel spinning process. However, this complicated gel spinning method of UHMWPE fiber leads very high production cost. In addition, the environmental problem is occurred from the use of hazardous organic solvents during the manufacturing process.[4]

Thus, solid state processing for UHMWPE fibers is desirable in order to have competitive power in price and environmental affinity. Solid state processing of UHMWPE fiber is accomplished by a simple process as the compaction of UHMWPE powder and drawing of the compacted film under the melting point without any organic solvents. Whether gel spun or solid state processed, The UHMWPE fiber has poor wettability which cause the weak interfacial bonding in composite fabrication. So, the plasma treatment is essential to change the surface properties of UHMWPE fibers.[5-6]

In this study, the characteristics of UHMWPE tape yarns produced by the compaction/drawing method as a solid state processing was analyzed in terms of tensile properties and draw ratio. And the surface properties of UHMWPE yarns were investigated with plasma surface treatments related to the interfacial adhesion.

2. EXPERIMENTAL

2.1 UHMWPE tape yarn preparation



1. powder extrusion 2. compaction 3. slitting part
4. first drawing 5. preheating 6. secondary drawing 7. winding

Figure 1. Schematic diagram for the manufacturing process of UHMWPE tape yarns.

The manufacturing process of UHMWPE tape yarns can be divided by four steps as shown in Figure 1 : i)compaction step(using a slit under pressure 200-1000MPa, temperature 80-135

℃), ii)tape splitting step with the knives which were arranged to pre-determined distance, iii) first drawing step(drawing under temperature 130-140℃, draw ratio 1.1-10), second drawing step(using heated rollers as draw ratio 1.1-15), and iv)winding step. Specimens of tape yarn were supplied by Hanwha chemicals Inc. in variation with the draw rate.(8.5, 9.5, 10.7, 37, 45, 104, 108, 208)

2.2 Measurement of tensile properties

In order to measure tensile properties of UHMWPE yarn, Instron 8250 tensile tester was used with special yarn grips. Test conditions were fixed at gauge length of 100mm and cross-head speed of 10mm/min in room temperature. Tensile strength, modulus, and strain were tested under variation of draw ratio(8.5, 9.5, 10.7, 37, 45, 104, 108, 208). The values of the test result were compared with gel spun UHMWPE fiber(Spectra-900 from Allied Signal. Co.). In addition, we observed the fracture surface of tested yarns using SEM.

2.3 Plasma treatment and fiber pull-out test

Before plasma treatment, UHMWPE tape yarns were cleaned with the soxhlet extractor for 6 hours with n-hexane followed by drying under vacuum for 6 hours. Then they were treated with O_2 gas plasma by using parallel electrode type plasma treatment device from Vacuum Science Co.. Treatment conditions were controled at vacuum of 50-100mtorr and O_2 gas flow rate of 10sccm with varied treatment power such as 50W, 100W and 150W for 5minutes. We have compared the chemical composition of plasma treated UHMWPE yarn surface with that of untreated one by the data from XPS analysis. ESCALAB MK II(V.G. Scientific Co.) model equipment was used in XPS analysis.

For preparing fiber pull-out test specimen, vinylester(XSR-10 from Saewon Whasung) resin was used with 20parts of DAP(diallyl phthalate) and 2parts of BPO(benzoyl peroxide) as a hardner and initiator, respectively. The formulated resin was dropped on the UHMWPE yarns which were treated by O_2 plasma to fabricate the microdroplet specimen for pull-out test. Then the specimen were cured in the oven at 110℃ for 30minutes. Interfacial shear strength of the microdroplet specimen was measured with a special pull-out fixture in Instron 4467 model.

3. RESULTS AND DISCUSSION

3.1 Tensile properties and Fracture behavior

Figure 2 shows the relationship between draw ratio and tensile strength of UHMWPE tape yarns. Tensile strength of UHMWPE yarns rapidly increased with increasing draw ratio.

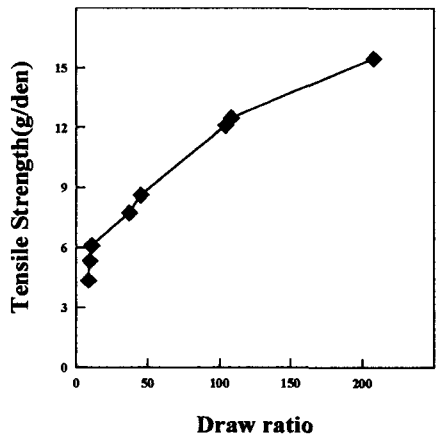


Figure 2. Tensile strength of UHMWPE tape yarns as draw ratio.

Figure 3 shows fracture surface of UHMWPE tape yarns observed by SEM. From the observation of fracture surface, the fracture procedure of UHMWPE yarns were progressed as following steps : at initial time, yarns were extended in yarn axis direction with applying tensile force, and then the yarns were separated as many fibrils by transverse shear force. Degree of the fibrillation has increased with increasing draw ratio easily observed in enlarged microphotographs magnified in 1500 times. They showed the separations between the fibrils distinctly and the breakages of the inter-fibrils more in highly drawn specimen. These fracture behavior is due to the increase of molecular orientation of UHMWPE yarn toward yarn direction with increasing draw ratio. Thus, many fibrils were found in highly extended tape yarns(Figure 3(d)), while a few fibril in low extended tape yarns.

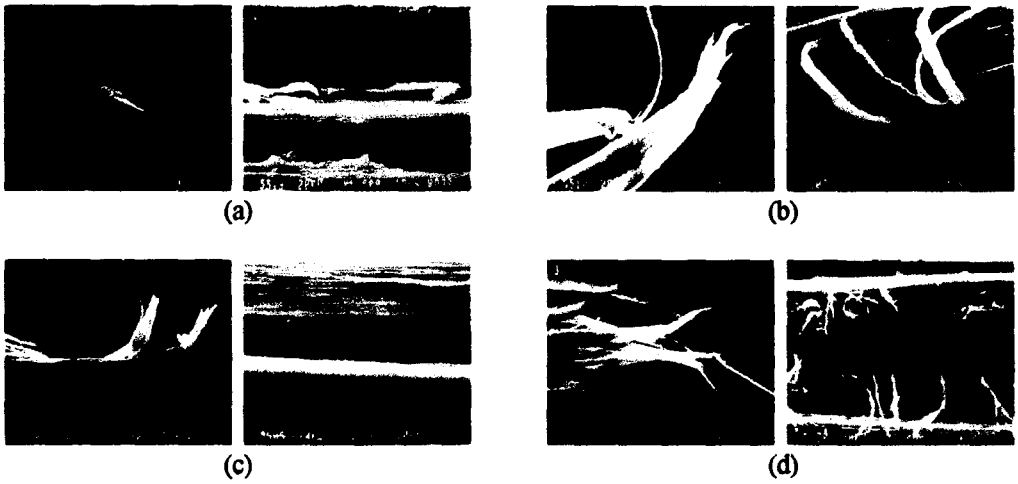


Figure 3. SEM microphotographs of fracture surface in UHMWPE tape yarns .
(a)DR 10.7 (b)DR 37 (c)DR 104 (d)DR 208

3.2 Surface properties of plasma treated UHMWPE yarns

The change in surface chemical composition of UHMWPE tape yarns by O_2 plasma treatment are presented in table I . We can find that the oxygen containing groups, such as hydroxyl(286.15eV), carbonyl(287.5eV), and carboxyl group(288.7eV), were produced on the yarn surface by O_2 plasma treatment. Also, the content of those oxygen containing groups was increased with increasing treatment power, obviously.

Table I The changes in the surface composition of UHMWPE yarns by O_2 plasma treatment

Treatment condition / C_{15} analysis	untreated	100W, 5min	150W, 5min
C	92.6%	77.8%	78%
O	7.4%	22.2%	22%
-C-H(284.6eV)	100	100	100
-C-OH(286.15eV)	5	13	13
=C=O(287.5eV)	2	2.8	4.7
-COOH(288.71eV)	0	4.8	4.0

In particular, untreated UHMWPE tape yarns have no carboxyl group at all, but it was

detected characteristically after O_2 plasma treatment under all treatment power condition in this study. The oxygen containing groups are very important to improve the interfacial bonding between UHMWPE yarn and matrix resins.

3.3 Interfacial shear strength

The results of fiber pull-out test were presented in Figure 4. Obviously, O_2 plasma treated UHMWPE tape yarns showed much higher interfacial shear strength than untreated one. We could get good results even in 50W and 5minutes treated specimen. Thus, plasma surface treatment is necessary for improving the interfacial adhesion of UHMWPE yarn reinforced composites. And we concluded that the optimum treatment condition in this study is 100W and 5minutes considering the results of XPS analysis and interfacial shear strength.

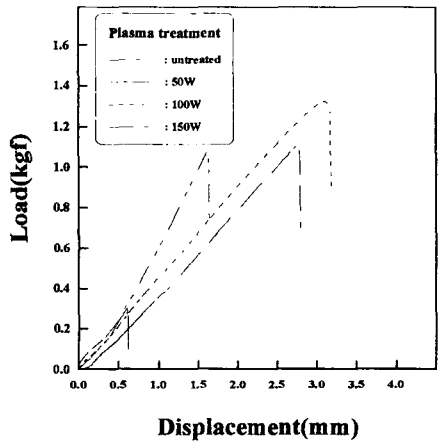


Figure 4. Load-displacement curves of UHMWPE tape yarns in fiber pull-out test.

4. CONCLUSION

We have investigated the physical properties of UHMWPE tape yarns produced by the compaction/drawing method. In particular, we evaluated the relationship between tensile strength and draw ratio, the changes in surface properties by O_2 plasma treatment, and interfacial shear strength of UHMWPE tape yarns. From this study, the following results can be obtained.

1. Tensile strength of UHMWPE tape yarns has increased with increasing the draw ratio.
2. The highly drawn UHMWPE tape yarn showed more fibrillar fracture behavior than the less drawn one
3. By O_2 plasma treatment, oxygen containing groups are created on the surface of UHMWPE tape yarns. Thus, interfacial shear strength of UHMWPE tape yarns increased by O_2 plasma treatment evidenced by fiber pull-out test. Maximum interfacial shear strength was obtained in the plasma treatment condition of 100W and 5min treating time.

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