Polyvinyl Alcohol Yarn Prepared into a Biodegradable Vascular Stent: Effects of Plied Number, Twist Factor on Yarn Structure and Mechanical Properties

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ABSTRACT

This study purposes to discuss effects of plied number and twist factor on polyvinyl alcohol (PVA) yarn and fabricate a degradable PVA vascular stent by the braiding process. PVA yarn was evaluated by stereoscopic microscope, tensile tenacity, tensile elongation, twist angle, force and elongation efficiency. Research result shows that yarn after plying and twisting effectively improves the mechanical strength by stereoscopic microscopic observation. After PVA yarn was made into stent by braiding technique, stent presents the network and tubular structure. This study verifies that the mechanical property of PVA yarn can be improved via plying and twisting process, and PVA yarn can be successfully made into vascular stent.

INTRODUCTION

The main function of heart coronary artery is to provide heart for oxygen and nutrient. However, due to changes of diet and living habit, fat and cholesterol accumulation possibly cause coronary occlusion and arteriosclerosis. The inner diameter of coronary artery becomes narrower due to lesion, which further results in blood vessel unable to offer oxygen and nutrient to heart and leads to sudden death to human.
In order to cure cardiovascular diseases and reduce the sudden death probability, developments for resolving this disease and lowering side-effect of cardiovascular stent become the research subject in the medical. 316 L stainless steel, nitinol and cobalt-chromium alloy are the common materials for fabrication of bare-metal stent. However, these materials produce inflammation after implantation, and then make the blood vessel restenosis. Therefore, drug-eluting stent is made by coating drug on the bare-metal stent. It can lower the restenosis via drug release. Nevertheless, in the therapeutic process, drug release leads to intravascular coagulation system unbalance, which then results high-mortality in thrombus. In addition, metal still belongs to permanent implant. Once the drug is released completely, a part of metal is still exposed [1], and it cannot thoroughly solve the permanent problem to foreign matter.

Degradable cardiovascular stent can not only cure lesion position of blood vessel, but also decompose in vivo and then discharge via human metabolism. Degradable stent substantially lowers the side-effects [2]. However, current related processing technique for degradable stent is macromolecule injection moulding which is limited by mould type and difficult to customization. This study plans to develop a new material as intravascular stent using biodegradable PVA material [3] through plying and twisting, and braiding processing. The optimal stent yarn is selected by changing plying and twisting parameters. PVA yarns are finally made into a stent holder using a braiding technique. This stent holder can reach the consequence of dimension change and processing customization. Experimental sample is evaluated via tensile tenacity, elongation, twist angle, force and elongation efficiency as well as stereoscopic microscopic examination.

EXPERIMENTAL

Materials
The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph).

PVA Plied Yarn Preparation
Single-ply, double-ply and triple-ply PVA twined on paper bobbin respectively, were firstly plied into 75 D, 150 D and 225 D PVA fibers using plying machine, and then twisted into three denier of plied yarn using rotor twisting machine. During twisting, roller take-up speed was 90 rpm, and the rotor speed was changed, so that twist factor (\( \alpha \)) was varied. Twist factor is expressed in Equation (1). After twisting, PVA fiber was twisted into PVA plied yarn. The twist factor of PVA plied yarn was 2, 4 and 6. PVA plied yarn was finally put on the oven for thermoforming at 140 °C for 30 min.

\[
\alpha = t \left( \frac{T}{1000} \right)^{1/2}
\]

where \( \alpha \)-twist factor; \( t \)-twist degree (turns/m); \( T \)-yarn density.
Braid Fabric Preparation.

PVA plied yarns winded on 16 carriers using automatic winding machine, were placed on 16-spindle braiding machine to made PVA braid fabric. For the continuous production, PVA plied yarns were winded on 3 mm-diameter tube, forming tubular hollow braid.

MEASUREMENTS

Tenacity and Elongation of PVA Plied Yarn.

Tensile tenacity (cN/dtex) and elongation (%) of SS/PET PVA plied yarns were measured by Automatic Yarn Tester (FPA /M, Textechno H. Stein GmbH & Co., Germany) in accordance with ASTM D2256. Gauge length was 250 mm, and tensile speed was 300 mm/min. Twenty times were conducted for the mean value of tenacity and elongation.

Force and Elongation Efficiency of PVA Plied Yarn.

Force and elongation efficiency were determined in the Equation (2).

\[
\text{Force Efficiency} = \frac{\text{Yarn max. breaking tenacity}}{\text{Fiber max. breaking tenacity}} \times 100\% \quad (2)
\]

\[
\text{Elongation Efficiency} = \frac{\text{Yarn maximum elongation}}{\text{Fiber minimum elongation}} \times 100\% \quad (3)
\]

Stereoscopic Microscope Observation. PVA plied yarns and stent pattern were observed using stereomicroscope (SMZ-10A, Nikon Instruments Inc., Japan). Motic Images Plus 2.0 software (Motic Group Co., Ltd., USA) was used to produce image. Twist angle of braid stent was measured by Image Pro Plus software (Media Cybernetics, Inc., USA).

RESULTS AND DISCUSSION

Surface Observation

Figure 1 shows that changing twist factor affected the fineness of the yarn. It displays that fineness of single-ply, double-ply and triple-ply PVA yarn all decrease with twist factor. This is because at a certain length of yarn, more twisting circles applied on this length with increase in twist factor. Yarn appearance shows that when twist factor was 2 and 4, yarn diameter increases with ply number. While twist factor reaches 6, the yarn fineness changes insignificantly even with different ply number. It is because at per length, yarn with 6 turns has stronger twist effect.
Tensile Tenacity of the Yarn

It is found from Figure 2 that changing twist factor has an influence on tensile tenacity. Figure 2 shows that compared to untwisted yarn, twisted yarn has stronger tensile tenacity. This is due to the fact that during tensile test, the main force applied along fiber axis, and twist circles per length and fiber content increase with twisting, and thus more fibers produce torsion along fiber axis due to cohesion [4]. In addition, it is also found that with increase of ply number, tensile tenacity increases accordingly. This is because the ply number of PVA yarn increases, and triple-plied yarn contained higher fiber and thus the number of fibers along axis is higher during stretch.

Yarn strength mostly constitutes of slipping fiber force and breaking fiber force. Different structure of yarn has various slipping length. After twisting, fibers produce cohesion, and fibers among yarn cohere tightly due to twisting which reduces fiber fracture and fiber slipping in the breaking process. In addition, although twisting of long fibers affect the strength of raw materials, it attaches more function on the long fibers. The yarn maximum breaking tenacity is lower than the fibers. Therefore, the force efficiency is used to discuss the efficiency of fibers in the yarn.

Figure 2. Tensile tenacity of PVA yarn with different plying and twisting parameters.
Table 1. Force efficiency of PVA plied yarn after different plying and twisting parameters.

| Force efficiency (%) | Control | Twist factor=2 | Twist factor=4 | Twist factor=6 |
|----------------------|---------|----------------|----------------|---------------|
| Single               | 100     | 167.7115       | 160.3118       | 158.1724      |
| Double               | 100     | 156.4903       | 151.9401       | 145.3149      |
| Triple               | 100     | 141.9833       | 138.6762       | 136.7997      |

Table 1 shows that twist factor have an influence on yarn tenacity. With increase of twist factor, force efficient decreases. PVA yarn went through twisting has 100% force efficiency, which is assumable because single PVA yarn was mostly selected and better winding was produced during twisting. When twist factor increases, force efficiency decreases. This result from the fact that, torsion produced after twisting which leads to bigger twist angle along axis and then larger component force than twisting torsion.

Tensile Elongation of the Yarn

Figure 3 shows that twist factor has a slight influence on tensile elongation, which is because PVA yarn has multifilament and nonuniform structure. It is also found that with increase of ply number, tensile elongation is stable. This is because for tripe-plied yarn, it has higher compactness than single-plied and double-plied ones.

Maximum breaking elongation of twisted filament is larger than combinations of untwisted yarns. Bigger twist factor produces higher twist angle, namely bigger slope; sloped fibers arrange along fiber axis after tensile, which increases the slipping length between total yarn and fiber and further improves the maximum breaking elongation of PVA yarn. Other tensile elongation, yarn elongation efficiency is also discussed.

Table 2. Elongation efficiency of PVA plied yarn after different plying and twisting parameters.

| Elongation efficiency (%) | Control | Twist factor=2 | Twist factor=4 | Twist factor=6 |
|---------------------------|---------|----------------|----------------|---------------|
| Single                    | 100     | 79.6112        | 94.0499        | 90.4107       |
| Double                    | 100     | 111.4355       | 82.1147        | 96.1527       |
| Triple                    | 100     | 94.5487        | 100.9902       | 97.2305       |

Table 2 shows that twist factor affects yarn elongation efficiency not obviously. After twisting, the elongation efficiency of PVA plied yarn reaches 79-100 %, showing that PVA yarn has a better physical combination. This is because PVA yarn has multifilament and ply structure, which makes better friction and cohesion forces for PVA yarn after torsion.
Twist Angle

Table 3. Mechanical properties and twist angle of PVA plied yarn with different plying and twisting parameters.

| Ply yarns-Twist factor | Tenacity (cN/dtex) | Elongation (%) | Twist angle (°) |
|------------------------|--------------------|----------------|-----------------|
| Single-control         | 2.08               | 11.86          | 0               |
| Single-2               | 3.49               | 9.44           | 13.98           |
| Single-4               | 3.34               | 11.15          | 15.19           |
| Single-6               | 3.29               | 10.72          | 21.72           |
| Double-control         | 2.19               | 15.28          | 0               |
| Double-2               | 3.43               | 17.03          | 12.76           |
| Double-4               | 3.33               | 12.55          | 13.62           |
| Double-6               | 3.18               | 14.70          | 24.30           |
| Triple-control         | 2.37               | 14.97          | 0               |
| Triple-2               | 3.37               | 14.15          | 13.71           |
| Triple-4               | 3.29               | 15.12          | 21.15           |
| Triple-6               | 3.25               | 14.55          | 25.49           |

Table 3 shows that twist factor affects the twist angle, and twist angle increases with twist factor. This is because increasing twist factor makes fibers and turns content higher at per length, and increases the angle between fiber axis and, which means that increasing twist factor improves the yarn compactness. In addition, twist angle affects the tensile tenacity, because yarn produced torsion during twisting which generates higher component force and higher tenacity. This phenomenon is inferred as the identical materials in the plied yarn.

Stereoscopic Observation of PVA Vascular Braid Stent

It is found from Figure 4 that hollow braiding processing can successfully fabricate stent holder. The braid stent has tubular appearance and connected pores, and can circulate the blood smoothly, which possesses the base requirement for vascular stents [5-7].

CONCLUSION

This study successfully prepares a tubular vascular stent holder using hollow braiding technique. Research result shows that plying and twisting process improve the mechanical strength and dimension stability of yarn. Tensile tenacity via twisting technique can be improved by 46.72 %. Single PVA fibers produce better physical connection via twisting, and fabricated stent holder satisfies the requirement for stent. This study chooses PVA yarn as the main material which is different from the commercial metal materials. Using fabricated tubular braid as the base, can effectively retard the side-effects of stent implant to human body, which conforms to the requirement of modern stent.
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