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Small-diameter vascular grafts composed of polyester/spandex fibers: Manufacturing techniques and property evaluations

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A B S T R A C T

This study aims to examine the properties of the small-diameter vascular grafts that are made by incorporating polyester (PET) yarns and spandex fibers. PET and spandex fibers are warp-knitted or weft-knitted into tubular knits. These two tubular knits are combined with polyvinyl alcohol (PVA) by applying a freezing-thawing method in order to create vascular grafts. The physical properties of vascular grafts are tested by performing tensile tests and a compliance test. The test results indicate that the incorporation of spandex fibers increases the deformation level along the axial direction of the warp-knitted tubular knits. In addition, the vascular grafts that are made of spandex fibers have a greater compliance than that of the commercially available vascular grafts (i.e., ePTFE) and natural blood vessels.

1. Introduction

Vascular grafts are essential for the replacement of damaged blood vessels and the treatment of cardiovascular diseases. The common large-diameter vascular grafts that have been commercially available include three types: knitted fabrics and woven fabrics mostly made of PET fibers, as well as tubular grafts made of expanded PTFE (ePTFE) [1–4]. The major challenge to the study is for small-diameter vascular grafts, as they are susceptible to thrombosis and anastomotic intimal hyperplasia as a result of blood pressures, blood flow rates, and their compliance [5]. As a result, determining how to improve the compliance between vascular grafts and blood vessels has become important.

The incorporation of a physical cross-link via a freezing-thawing method can transform polyvinyl alcohol (PVA) into a hydrogel that has good elasticity and a prolonged degradation duration. In addition, using a physical treatment for cross-linking prevents the use of solvents and the possible effects of residual nuclear radiation. Such results suggest the great feasibility of using physical cross-linking while producing vascular grafts [6–8].

Spandex is a highly elastic fiber with a light weight, and it is soft and smooth. Thus, spandex has been commonly used in clothes in order to provide them with high deformation and good elasticity. In contrast, PET fiber has good strength, but does not have high deformation and elasticity. Therefore, in this study, PET yarns or spandex fibers are wrapped in other PET yarns in order to form wrapped yarns. Wrapped yarns are then warp-knitted or weft-knitted into tubular knits. The two tubular knits are respectively combined with PVA in order to form the composite vascular grafts. Finally, the influences of yarn types and knit types on the compliance of the vascular grafts are evaluated.

2. Experimental

2.1. Preparation of tubular knit as vascular grafts

70 D spandex fibers and 75 D PET yarns are respectively wrapped in 75 D PET yarns with incorporation of a constant twist coefficient of 3, in order to form the wrapped yarns. The wrapped yarns are then thermally treated at 140 °C for 30 min, after which

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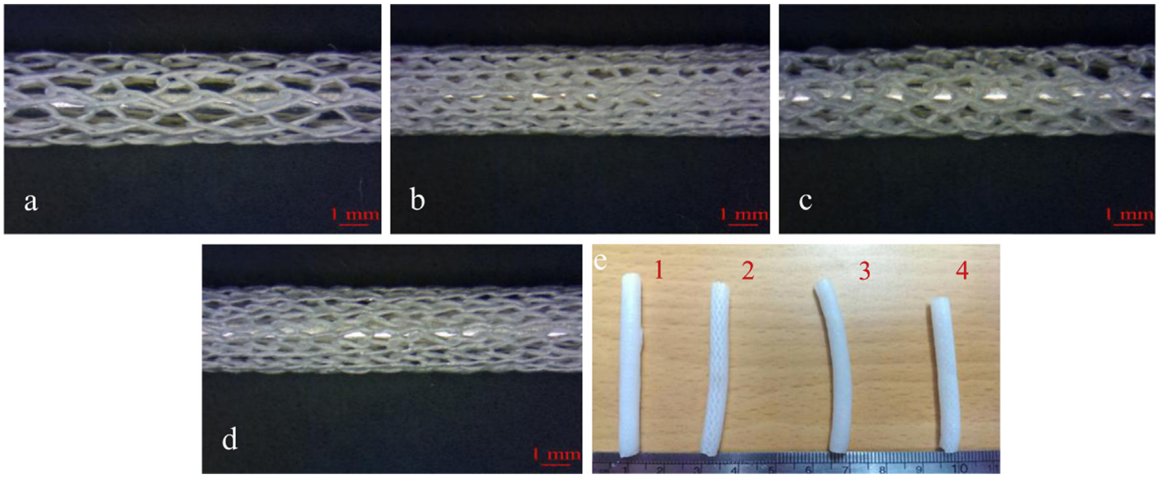

Fig. 1. Stereomicroscopic images (6.7 ×) of (a) The PP warp knit, (b) PP weft knit, (c) PS warp knit, (d) PS weft knits, and (e) four vascular grafts (from left to right are 1) PP_Weft_VG, 2) PP_Warp_VG, 3) PS_Weft_VG, and 4) PS_Warp_VG.).

they are made into PET/PET (PP) tubular warp knits and PET/spandex (PS) tubular warp knits by using a DH CK-06 cord knitting machine that has 8 needles of 3-mm outer diameter (Dah Heer Industrial Co., Ltd., Taiwan), as indicated in Fig. 1(a, c), as well as PP tubular weft knits and PS tubular weft knits by using a DH 06-KL circular knitting machine that has 12 needles of 3-mm outer diameter, as indicated in Fig. 1(b, d). The four tubular knit types are then looped around the stainless steel mandrel of a 3-mm diameter, and it is eventually thermally treated at 140 °C for 30 min. Next, PVA powder that has a molecular weight of 146,000–186,000 is stirred with deionized water at 100 °C for 6 h in order to form an 11% PVA solution. The knits with stainless steel mandrel are placed inside a hollow stainless steel tube that has a 6-mm outer diameter and a 4.4-mm inner diameter. After PVA solution fills the tube, the whole structure is placed in a mold, and is frozen at −20 °C for 20 h, and is then thawed for 4 h. The freezing-thawing cycle is repeated three times. Finally, the tubular knits are removed from stainless steel mandrel to form the PP tubular weft knit vascular grafts (hereafter referred as PP_Weft_VG), PP tubular warp knit vascular grafts (hereafter referred as PP_Warp_VG), PS tubular weft knit vascular grafts (hereafter referred as PS_Weft_VG), and PS tubular warp knit vascular grafts (hereafter referred as PS_Warp_VG), as indicated in Fig. 1(e).

2.2. Tests

PET/PET wrapped yarns and PET/spandex wrapped yarns are tested for tensile strength with a material testing machine (HT2402, Hung Ta Instrument Co., Ltd., Taiwan, R.O.C.), with settings as distances between fixtures being 25 mm, the tensile speed being 300 mm/min. Tubular knit axial tensile strength test is performed by employing a HT2402, which has a 10-mm gauge distance and a 10 mm/min tensile speed. Each sample type is tested 10 times to have the mean.

The tube is sealed at one end and is first released with air, followed by being infused with an increasing amount of water, in order to expand the diameter of the vascular grafts. They are then cyclically pressurized between 20 and 200 mmHg three times using a syringe pump at a flow rate of 0.2 ml/min to minimize hysteresis. The preconditioning outer diameter of vascular grafts is recorded with settings of luminal pressure being 0 mmHg and an axial load being 0 mN. The increase in the diameter of the vascular grafts is recorded when the pressure is raised to 200 mmHg. The compliance is computed with the following equation:

$$\text{Compliance}(\%\,\text{per}100\,\text{mmHg}) = P\frac{(D_{sys} - D_{ias})}{(D_{ias}(P_{sys} - P_{ias})} \times 10^4 \quad (1)$$

where P_{sys} means systemic pressure, D_{sys} is the corresponding outer diameter of the scaffold, P_{ias} is the diastolic pressure, and D_{ias} is the corresponding outer diameter of the scaffold. Herein the compliance was calculated between 70 and 120 mmHg [9].

3. Results and discussion

Table 1 indicates that the tensile strength of wrapped yarns. PP wrapped yarns have a 54% higher tensile strength, and a 61% lower elongation than PS wrapped yarns. PS wrapped yarns are a combination of spandex fibers as the core and PET yarns as the sheath, and thereby have a significantly greater elongation. Namely, PS wrapped yarns can form fabrics that have higher deformation and elasticity.

Fig. 2 indicates that the tensile properties of tubular warp knits and tubular weft knits that are composed of PP wrapped yarns or PS wrapped yarns. PP weft knits have tensile strength of 52 N and elongation of 226% while PP warp knits have tensile strength of 22 N and elongation of 94%. Regardless of tensile strength and elongation, PP weft knits outperforms PP warp knits. In comparison to the warp knitting, the weft knitting forms a more dense structure, as indicated in Fig. 1(a, b). Therefore, the axial tensile strength and the axial deformation of PP weft knits are greater than those of PP warp knits. The same trend is not observed for PS warp knits and PS weft knits. PS weft knits have tensile strength of 32 N and elongation of 204% while PS warp knits have a tensile strength of 18 N and an elongation of 263%.

The fiber orientation of warp knits is along the axial direction, while that of weft knits is along the circumferential direction. As a result, the axial elongation of PS wrapped yarns is high, which, at the same time, allows for a greater deformation level while PS warp knits are axially extended. Intriguingly, PS warp knits have a significantly greater deformation than that of PP warp knits. However, PS weft knits have a significantly lower deformation than PP weft knits. Such results are due to the different structures

Table 1
Tensile strength and elongation of various wrapped yarns.

	Tensile strength (N)	Elongation (%)
PP wrap yarn	6.24	25.42
PS wrap yarn	2.86	66.11