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Effect of treatment temperature on mechanical properties of silk textiles made with silk/polyurethane core-spun yarn

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Abstract

Silk has been used extensively in textile applications because of its good luster and feel. However, the low elongation and elastic recovery of silk has limited its use in a wider variety of textile applications. In this study, silk textile samples were made with a highly twisted silk/polyurethane core-spun yarn. They were immersed in water and dried at different temperatures, and the effect of treatment temperature on the mechanical properties of the silk textile was examined. It was found that the water temperature strongly affected the morphology and mechanical properties of the silk textile, whereas the drying temperature did not. As the water temperature was increased, the weft silk yarn became tangled and the interval between warp yarns decreased, resulting in shrinkage of the silk textile. When the silk textile was immersed in water at high temperature (i.e., 100°C), the elongation of the textile increased eight-fold as compared to an untreated silk textile. The maximum elastic recovery ratio of the silk textile was 96.7%.

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Introduction

Silk has been considered an excellent textile material for a long time because it has good luster and feel (Lee *et al*., 2016). However, unlike synthetic textiles, silk textiles have limited elongation and elasticity, which restrict their further use in textile applications. Therefore, it is necessary to develop a new silk textile with better elongation and elasticity to meet customer demand and market needs.

Core-spun yarn is made by spinning a sheath of fibers around a central core. In core-stretched yarn, the core is an elastic filament (usually under tension) surrounded by a fiber sheath. Such yarn has all the characteristics of the predominant fiber, together with the added advantage of stretch and recovery, depending on the tension of the elastic core filament (Shi and Xuling, 2012). Polyurethane filament has been extensively used as a core filament for core-spun yarn because of its excellent elasticity (Bo, 2007; Shi and Xuling, 2012; Helali *et al*., 2012).

In this study, a highly twisted silk/polyurethane core-spun yarn was used to weave a silk textile to improve the elasticity of the silk textile. Samples of the woven silk textile were immersed in water at different temperatures and dried at various temperatures to examine the effect of treatment temperature on the morphological structure and mechanical properties of the silk textile.

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Table 1. Sample codes of silk textiles treated at different water and drying temperatures.

Water temp. (°C) \ Drying temp.(°C)	25	40	60	80	100
25	SS 25/25	SS 25/40	SS 25/60	SS 25/80	SS 25/100
40	SS 40/25	SS 40/40	SS 40/60	SS 40/80	SS 40/100
60	SS 60/25	SS 60/40	SS 60/60	SS 60/80	SS 60/100
80	SS 80/25	SS 80/40	SS 80/60	SS 80/80	SS 80/100
100	SS 100/25	SS 100/40	SS 100/60	SS 100/80	SS 100/100

Materials and Methods

Preparation

A silk/polyurethane core-spun yarn consisting of two silk yarns (sheath) made by twisting four 21-denier silk filaments around a polyurethane filament (core) was used as the weft yarn and two 42-denier silk yarns were used as the warp yarn to weave the silk textile. The degree of twist of the weft yarn was 4000 turns per inch (TPM). The silk textile samples were then immersed in water at different temperatures (25–100°C) for 10 min and dried in a drying oven at different temperatures (25–100°C) for 6 h. The sample codes are listed in Table 1.

Measurement and characterization

The morphology of the silk textiles was studied by field emission electron microscopy (FE-SEM, S-4800, Hitachi, Japan). The samples were coated with Pt–Pd prior to FE-SEM imaging.

The shrinkage of the silk textiles after immersion in water and drying was calculated by Eq. 1.

$$\text{Shrinkage (\%)} = (L_1 - L_2)/L_1 \times 100 \quad \text{(Eq. 1)}$$

L_1: Length of textile before the treatment

L_2: Length of textile after the treatment

To evaluate the mechanical properties of the silk textiles, their tensile strength, tensile elongation, and initial Young's modulus were obtained using a universal test machine (OTT-03, Oriental TM, South Korea). The tensile tests were performed using a 200 kgf load cell at an extension rate of 50 mm/min for the silk textile. The silk textiles were cut into 70 mm × 25 mm pieces and fixed by clamps. The gauge length (length between the clamps) was 50 mm. All samples were preconditioned at 20°C and 65% relative humidity (R.H.). Five samples for each condition were tested and the average and standard deviation of the measurement results were used.

To examine the elastic recovery of the silk textiles, silk samples with the same dimensions were extended to 10 mm at an extension rate of 1 mm/s. Before the extension, the boundary lines between the clamps were marked. The extended silk textile at the clamps was maintained for 1 min after extension. The clamps were then removed from the silk textile to allow the silk textile to recover to its original state (i.e., the state before extension). The elastic recovery ratio was calculated by Eq. 2.

$$\text{Elastic recovery ratio (\%)} = (10 - Y)/10 \times 100 \quad \text{(Eq. 2)}$$

$Y \text{ (mm)} = X - 50 \text{ mm}$

X (mm) = length between the marked boundary lines

Results and Discussion

Shrinkage and morphology of silk textile

Silk textiles shrink when immersed in water and dried. Therefore, the shrinkage ratio of silk textiles dried at various temperatures as a function of water temperature was measured and the results are shown in Fig. 1. As the water temperature increased, the shrinkage ratio of the silk textiles increased. However, the drying temperature showed almost no effect on the shrinkage ratio of the silk textiles. These results indicate that the water temperature determines the degree of shrinkage of silk textiles and that shrinkage of silk textiles occurs during immersion in water.

To examine the reason for the shrinkage of silk textiles in more detail, the morphology of the silk textiles was observed by FE-

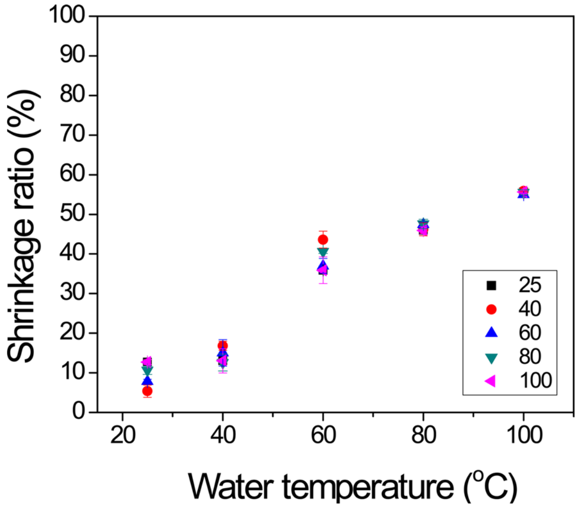

Fig. 1. Effect of treatment temperature on the shrinkage ratio of the silk textiles.

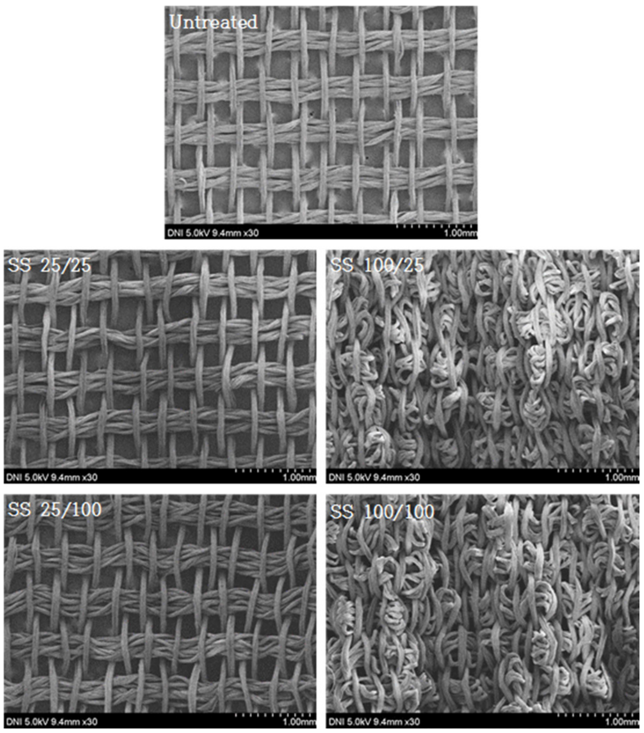

Fig. 2. Effect of treatment temperature on the morphology of the silk textiles.

SEM and the results are shown in Fig. 2. In case of the SS 25/25 sample (25°C water and 25°C drying temperature), the weft silk yarn became slightly bent as compared to the weft silk yarn of the untreated sample. When the drying temperature increased to 100°C, the weft yarn became more bent. A significant morphological change was observed in the silk textiles immersed in water at 100°C (SS 100/25 and SS 100/100). The weft yarns became tangled, showing a rounded appearance rather than lying flat, and the distance between the warp yarns decreased. It is thought that the shrinkage of silk textiles is because of the decreased distance between the warp yarns as a result of the tangled weft yarn.

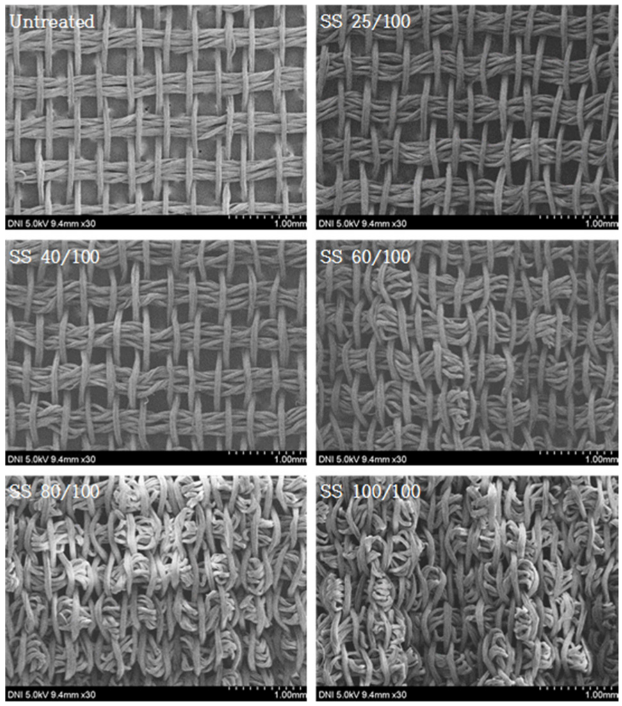

Fig. 3. Effect of water temperature on the morphology of the silk textile dried at 100°C.

Considering that the water temperature had a more significant role than the drying temperature, the effect of water temperature on the morphology of the silk textiles dried at 100°C was evaluated and the results are shown in Fig. 3. As the water temperature increased up to 60°C, the weft yarn became uneven. When the water temperature was increased to 80 and 100°C, the weft yarn tangled, which may have been related to the highly twisted yarn state. That is, the weft yarn was highly twisted (4,000 TPM), and it is thought that the twisted yarn became untwisted and contracted upon immersion in water, causing the yarn to tangle. The contraction of the silk yarn is thus accelerated by increasing water temperature.

Mechanical properties of silk textiles

Fig. 4 shows the effect of water temperature on the mechanical properties of the silk textile dried at 100°C. At a

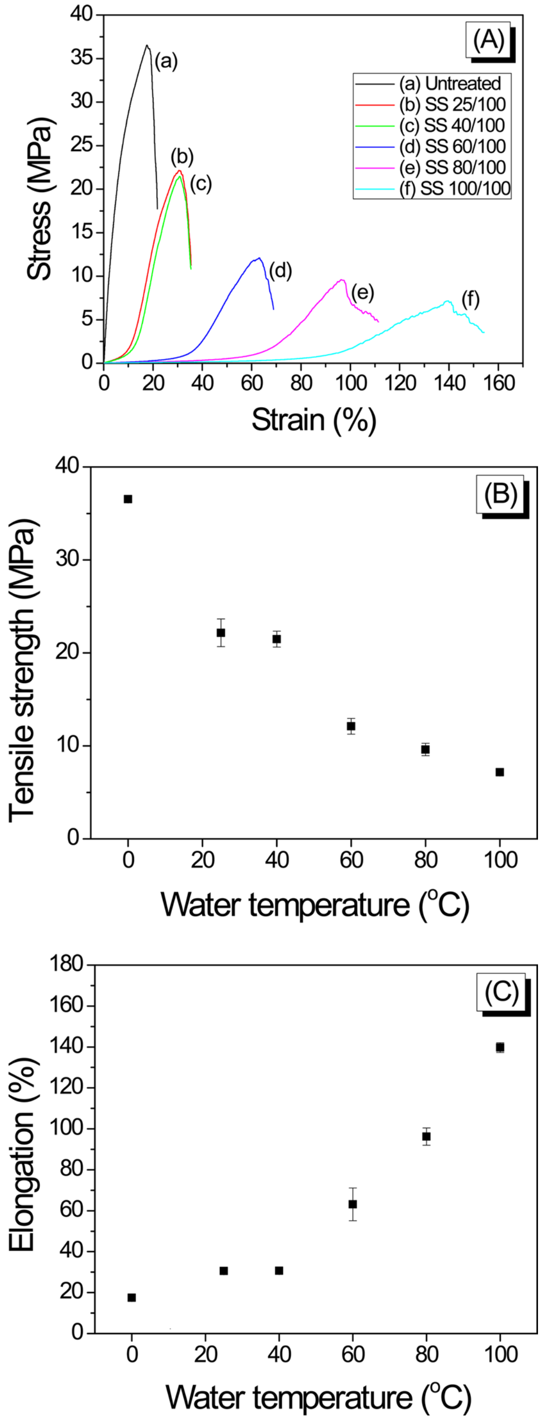

Fig. 4. Effect of water temperature on (A) the stress–strain curve, (B) the tensile strength, and (C) the elongation of the silk textile dried at 100°C.

water temperature was increased, the tensile strength of the silk textile decreased. The elongation increased significantly, reaching approximately 140% at a water temperature of 100°C. As compared to the untreated silk textile, the elongation of the silk textile immersed in water at 100°C increased eight-fold. This

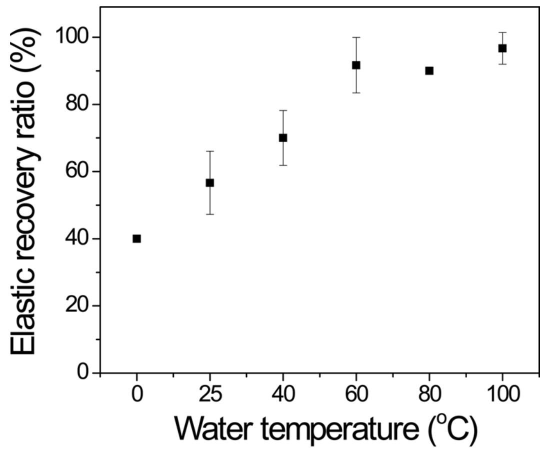

Fig. 5. The effect of water temperature on the elastic recovery ratio of the silk textile dried at 100°C.

significant increase of elongation is because of the easy extension of the shrunk silk textile. That is, as tensile force was applied to the silk textile, the tangled weft yarn became untangled, resulting in the significant increase of elongation.

Because clothing is under repetitive external force in actual use, the elastic recovery of a textile is also important. Therefore, elastic recovery tests were conducted on the silk textiles dried at 100°C and the results are shown in Fig. 5. As the water temperature was increased up to 60°C, the elastic recovery ratio increased linearly. After 60°C, the elastic recovery ratio increased slightly with increasing water temperature. Finally, the silk textile immersed in water at 100°C (SS 100/100) showed a 96.7% elastic recovery ratio.

Overall, controlling the water temperature was effective for improving the elongation and elasticity of the silk textiles, whereas the drying temperature did not have a significant effect. Although the elongation of the silk textiles improved significantly by increasing the water temperature, the elastic recovery ratio of silk textiles has not been satisfactory until now considering that just 20% elongation was used for the elastic recovery ratio measurement. Therefore, it is thought that more studies should be conducted to improve the elastic recovery of silk textiles.

Conclusions

In this study, silk textiles were made with highly twisted silk/polyurethane core-spun yarn and were immersed in water and dried, both at temperatures of 25–100°C. The effect of treatment temperature on the morphology and mechanical properties of the silk textile was examined. The water temperature strongly affected the morphology and mechanical properties of the silk textiles, whereas drying temperature had little influence.

When the silk textile was immersed in water at high temperature (i.e., 100°C), the elongation of the textile increased significantly (eight-fold higher than that of untreated silk textile). However, the maximum elastic recovery ratio of the SS 100/100 silk textile (immersed in water and dried, both at 100°C) was 96.7%. The value is not satisfactory for actual use. Therefore, it is thought that additional studies to improve the elastic recovery ratio of silk textiles should be performed.

Acknowledgements

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