Journal of Zhejiang University SCIENCE A
ISSN 1673-565X (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Shape memory behavior of SMPU knitted fabric*

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Received Oct. 19, 2006; revision accepted Jan. 21, 2007

Abstract: A preliminary investigation of shape memory (SM) effects of SMPU (shape memory polyurethane) knitting fabric is presented in this paper. Three SMPU knitted fabrics series with different content of SMPU fibers: 100% SMPU, 50% SMPU and 50% cotton, 16% SMPU and 84% cotton are designed and manufactured in our lab. Their shape memory behaviors at different temperatures are characterized in terms of bagging. Our experimental results showed that shape memory effect can be improved with increasing content of SMPU fibers. A comparison between Lycra and SMPU knitted fabrics was also made to validate the shape memory effects of SMPU knitted fabrics.

Key words: SMPU (shape memory polyurethane) fiber, Shape memory (SM), Bagging, Recovery
doi:10.1631/jzus.2007.A0830 **Document code:** A **CLC number:** TQ343.2

INTRODUCTION

Shape memory (SM) means that the special material could memorize its original shape or state. No matter what happened during its changing process, it still recovers its original shape or state under suitable condition. Now shape memory materials (Hu *et al*., 2005; Hyashi, 1993; Tobushi *et al*., 1996; Gall *et al*., 2002; Wei *et al*., 1998; Lin and Chen, 1998a; 1998b; Jeong *et al*., 2000) are widely used in different fields, such as textile, space, biomedical and engineering. Some shape memory materials are used for daily commodities and industrial products (Mitsubishi Heavy Industries Ltd., http://www.diaplex.com; Micro-Tech (Nanjing) Co., Ltd., http://www.microtech.com.cn). In textiles, shape memory material is often used as fiber divided into shape memory alloy fiber and shape memory polymer (SMP) fiber. Shape memory alloy fiber can be used as intimate apparel by Memory Corporation (http://www.memry.com). Italy Luotaliyani designed "lazy shirt" fabric joined with nickel, titanium and nylon fiber, these shape memory alloy fibers have shape memory function. During high outside temperature, the shirts sleeve can willingly wind up from wrist to elbow volumes in short time when the temperature becomes lower, automatically return to original shape. The clothing also has super wrinkle free capacity, regardless of massage pressures, and can return to its original status in 30 s (http://www.dhu.edu.cn/textile/lab/research-032.htm). Heriot-Watt University designs many different fancy yarns; shape memory alloy fiber could be made into wire and spun to shape memory yarn, the interior textiles and textiles for fashion knitted and woven by it showed shape memory function, however, SMP is difficult to spin into filament, because the experiment showed that the mechanical properties of the SMP failed to produce a competent yarn to be applied for the end applications, although some other polymer is selected to blend with the SMP, the SMP filament cannot be spun well yet because of poor viscosity, uneven cross-section, poor strength and low yield point. Although they wove fabric using shape memory fiber interlaced with nylon monofilament by machine and knitted the fabric by hand, they did not study the SMP fabric in details. We also do not know how to use the SMP fiber in common life (Chan *et al*., 2002) and how SMP fabric shows its shape memory function.

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Now spinning good performance SMP fiber and how to take advantage of its shape memory effect is very interesting research. In order to develop new product and decrease its cost, shape memory polyurethane (SMPU) fiber and its application to the knitting fabric were studied in this work. The bagging of knitting fabric is used to test the shape memory performance because of its special and obvious shape (Zhang *et al*., 1999).

In this work, all the SMPU fiber used was made directly by conventional wet-spinning method. An innovation in this work is that SM fiber need not be embedded by SMP or shape memory alloy need not be embedded by other resins, as it is knitted strongly. The fiber's switch temperature is 60 °C. The finer shape memory fibers are from 8 tex to 36 tex. The max strain is from 101% to 204%.

EXPERIMENTAL DESIGN

Spinning yarns

Table 1 lists the yarn specifications in our research. As shown here, the cotton selected was combined with shape memory filament, because it is common material of different spinning system and the yarns could be endowed with natural fiber's good effect. Also the elastic polyurethane fiber—Lycra was spun with shape memory fiber and cotton, because its temperature response has bright contrast to the shape memory yarn.

To prepare the shape memory yarns, four facilities (Table 2) are used and four types of shape memory yarns and one Lycra yarn were designed in experiments: (1) Three-ply yarn; (2) Friction spinning yarn; (3) Ring spinning yarn; (4) Lycra yarn.

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Knitting fabrics

Knitting fabrics can easily be used to form bagging, and so can exhibit bagging very well. Table 3 shows all the knitting fabrics in our experiment. Knitting machine characteristics are described in Table 4. All the knitting fabrics were jersey.

Table 1 Specification of yarn specimen

Yarn ID	Fiber content	Yarn type	Yarn count (tex)	T_g (°C)
Y1	SMP A	Filament yarn	36	60
Y2	SMP B	Filament yarn	20	60
Y3	SMP C	Filament yarn	16	60
Y4	SMP D	Filament yarn	8	60
Y5	50% SMP D, 50% cotton	Filament core yarn	16	60
Y6	16% SMP C, 84% cotton	Filament core yarn	97	60
Y7	100% cotton	Two ply yarn	63	−
Y8	84% cotton, 16% Lycra	Filament core yarn	53	−

Table 2 Yarn spinning methods and facilities

Machine	Yarn type	Yarn ID
Two spindles twisting machine (Simet)	Three-ply yarn	Y5
Lab ring spinner (SKF)	Filament core yarn	Y6
Ring spinning machine with Lycra spinning device (Zinser)	Filament core yarn	Y8

Table 3 Knitting fabric description

Group	Fabric code	Fiber content	Yarn type	Yarn count (tex)	Tightness factor	T_g (°C)	Fabric thickness (cm)
1	S2	100% SMP B	Filament yarn	20	12.08	60	0.051
2	C/S 2	50% SMP D, 50% cotton	Filament core yarn	16	10.40	60	0.071
3	C/S 2 R1	16% SMP F, 84% cotton	Filament core yarn	97	13.72	60	0.147
4	C3	100% cotton	Two-ply yarn	63	16.75	−	0.100
5	C/L 2	16% Lycra, 84% cotton	Filament core yarn	53	13.72	−	0.145

Table 4 Knitting machine

Knitting machine	No. of needles	Fabric ID
Lawson-Hemphill FAK 3 1/2″	160	C3, C/S R1, C/L 2
Single jersey machine	300	S2, C/S 2

FAK: fiber analysis knitter

In order to keep the knitting fabrics' dimensional stability, all the tested fabrics were set to form its permanent flat shape at 160 °C in the curing machine.

The details are as follows:

(1) The knitted fabric is fixed on the pin frame and should be placed flat and evenly.

(2) The curing machine temperature was adjusted to 160 °C, after which the fabric was put into it heated for 3.5 min.

(3) The fabric was cooled down under room temperature for 5 min, and taken from the pin frame.

After being pretreated, the fabric is flat and easy to be made into any shape.

Making bagging

Bagging SM fiber into 3D spherical shape involves complex deformations including tension, shearing, bending and compression of the SM cloth into different directions. As the general phenomena of fabrics, the bagging can determine the fabric's performance simply by its shape and height. Then the bagging was made for testing shape memory effect.

The procedure of making bagging (Fig.1) is described bellow:

(1) The sample was fastened on the top of the circular bottom plate (diameter: 5 cm) on the reverse side.

(2) The ground placement was set by subject to the top steel ball (sphere) (diameter: 2.5 cm) on the sample without loading.

(3) The steel ball exerts a force on the specimen at speed of 150 mm/min, and is stopped and held at 3 cm (maximum extension) displacement for 3 min. Then it rises to the ground displacement and the process is repeated 3 times.

Fig.1 Making bagging procedure

Measuring the bagging height

In order to investigate the shape memory behavior of the knitting fabrics, after taking them from the Instron, the bagged specimens were measured by the carpet thickness gauge metric immediately (the height is named unloading height), after which the specimen was relaxed for 3 h on a flat bench under standard condition. And then the height (called bagging height after relaxation) was measured. At last the sample is heated at different temperature (100, 75, 50 and 30 °C). Non-recoverable bagging height is measured every one minute, and then we could get three non-recoverable bagging heights at every temperature.

RESULTS AND ANALYSIS

Behavior of shape memory knitting fabric

From these experiment procedures, we could easily observe the shape memory behavior of the shape memory knitting fabric. As shown in Figs.2~5, just as predicted, the shape memory knitting fabric could change shape according to the temperature's changing, but it did not return to its original shape totally. The shape memory knitting fabric obviously recovered at higher than its transfer temperature, which was about 60 °C.

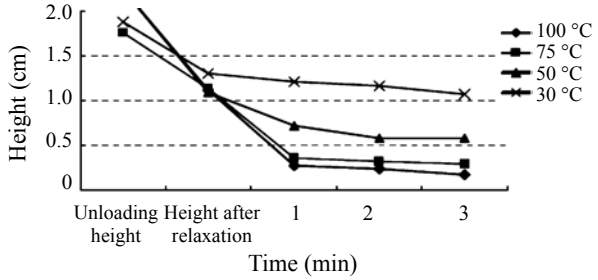

Fig.2 Bagging recovery performance of 100% SMP knitted fabric (S2) under different temperature

In addition, we also found that all the fabrics recovery phenomena included three stages: (1) instant elastic recovery; (2) high elastic recovery; (3) plastic recovery with thermal response. Instant elastic recovery occurs during the unloading process, the shape memory fabric had no obvious changes; the high elastic recovery arises in the course of relaxation, shape memory shows its excellent behavior; and the plastic recovery with thermal response occurs while

the fabric is heated at different temperature. This finding provides better prediction; apparently, the shape memory fiber could show big changes at the third stage.

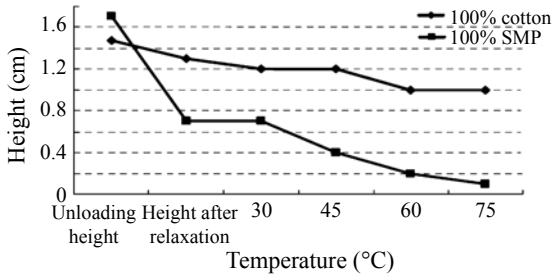

Fig.3 Comparison with cotton fabric

Effect of shape memory fiber content in the fabric

It is also interesting to see the effect of shape memory fiber content on the fabrics. According to Fig.4, S2 has 100% shape memory fiber, C/S 2 fabric has 50% shape memory fiber; C/S R1 has 16% shape memory fiber, the more content of shape memory fiber in the fabric, the more recovery change in the fabric.

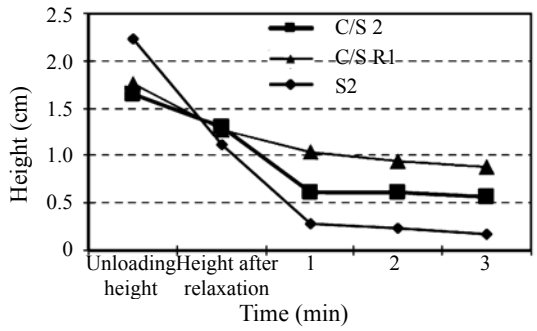

Fig.4 Bagging recovery performance of different fiber content (cotton) at 100 °C

During the bagging recovery process, after unloading, the changing of C/S 2 and C/S R1 are similar, then after relaxation for 3 h, the C/S 2 became different from C/S R1, the shape memory fiber still had high elastic recovery (Fig.4). In the heating process, the C/S 2 changed very fast, maybe the lower cotton contents in the fabric, the faster the heat transfer. The fabric changing depends little on the time.

Compared with elastic fiber

As illustrated by Fig.5, the C/CL 2 has good instant recovery. Because Lycra fiber is elastic fiber, its bagging also has minimal recovery during the heating process; it is better than 100% cotton fabric. The C/S 2 fabric still had the best recovery when it is heated at high temperature, which should be higher than its transfer temperature.

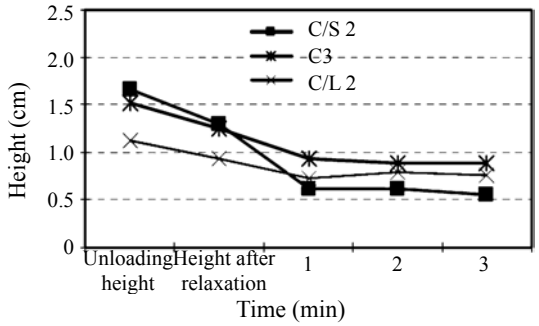

Fig.5 Bagging recovery performance of different fiber content (Lycra) at 100 °C

CONCLUSION

In this work, we selected shape memory fiber whose transfer temperature is about 60 °C, which is the boundary at which the fiber changes obviously. Detailed sampling procedures are shown; the bagging of shape memory knitting fabric could recover better when the transfer temperature is higher than 60 °C, furthermore when the temperature is higher, the SM fabric could recovery to its limit.

In terms of the use value of the shape memory fiber, the shape memory fiber could be used widely, it is easy to be knitted to fabric and the more shape memory fiber be used the more shape memory effect could be shown.

In particular, we knew that Lycra is also polyurethane fiber, but as it is only elastic fiber, it has no obvious response to the temperature. On the contrary, our shape memory fiber has excellent temperature response performance.

ACKNOWLEDGEMENTS

Authors thank the invaluable help given by Mr. JI FengLong, and Mr. Zhu Yong during the progress of this work.

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