Binding Property Evaluation of Low Melting Point Filaments with Conventional Filaments in Weft-Knitted Fabrics

Qiaoqiao Lin[1], Jiali Jiang[1], Shuangxi Xu[2], Yueping Chen[2], Yuanchao Hu[1], Xiuhua Wang[1]

[1]Zhejiang Sci-Tech University, Hangzhou, Zhejiang CHINA

[2]Shaoxing Global Chemical Fiber Co. Ltd., Shaoxing, Zhejiang CHINA

Correspondence to:
Xiuhua Wang email: wxiuhua@126.com

ABSTRACT
In this paper, low melting point polyamide (LMPA) filaments and low melting point polyethylene terephthalate (LMPET) filaments were blended with conventional filaments, including polyamide (PA), polyethylene terephthalate (PET) and polypropylene (PP), to prepare weft-knitted fabrics. The binding properties of low the melting point filaments in weft-knitted fabrics after heat treatment were investigated by testing mechanical properties and observing the morphology. The effect of heat treatment on the binding properties of the low melting point filaments is discussed. Tensile stress at small deformations and Young's moduli of all fabrics increased and then decreased with increasing heat treatment temperature or time. Thus, an optimal heat treatment process is obtained. LMPA/PA fabric shows better binding properties than LMPET/PET fabric. Both are better than other fabrics considered in this study. This could lead to commercial application of these fabrics.

Keywords: low melting point filaments, binding property, fabric, tensile stress, strain

INTRODUCTION
Fibers with lower melting points than conventional fibers are possible through introduction of branch comonomers [1-3]. Low melting point fibers (including staple fibers and filaments) are environment-friendly and have high binding strength, controllable melting points, and good processability [4]. In the past half century, low melting point staple fibers were successfully fabricated and drew great interest earlier than low melting point filaments [5]. However, low melting point staple fibers must be produced fabrics using a spinning process, while low melting point filaments can be directly knitted. At present, low melting point staple fibers like "ethylene-propylene side By side" (ES) staple fibers [6-8] are used to fabricate non-woven fabrics for medicinal applications. Low melting point filaments are blended with conventional filaments to yield adhesive fabrics or yarns used in sports shoe soles [9], chenille yarn [10-11] and binding thread [12-13].

Most studies focus on modification of low melting point fibers by altering processing conditions and compositions of fibers to achieve better processability and higher tensile stress. Lin [14] prepared non-woven blended fabrics by blending tencel staple fibers with low melting point polyethylene terephthalate (LMPET) staple fibers. By testing mechanical the properties, optimal parameters were obtained to prepare a good dressing covering material. Zhou [15] prepared low melting point polyamide filaments (LMPA) with good mechanical properties by analyzing spinning technology. Though binding property evaluations of low melting point staple fibers in non-woven fabrics ve been conducted, such studies of low melting point filaments have not been reported yet. According to the work of Bankar [16], a process for blending low melting point filaments with a continuous filament base yarn to form a blended yarn had been proposed. This work put forward a new way to evaluate the binding properties of low melting point filaments when with conventional filaments in weft-knitted fabrics (short for fabrics) [17-19].

The work reported here involves the evaluation of the binding properties of low melting point of fabrics knitted from blends of low melting point filaments with conventional filaments. Low melting point polyamide (LMPA) filaments and low melting point polyethylene terephthalate (LMPET) filaments were blended with conventional filaments like polyamide (PA), polyethylene terephthalate (PET), polypropylene (PP), and fabrics were knitted. These fabrics were heated to temperatures between melting point of LMPA or (LMPET) and the melting point of the conventional filaments. The low melting point filaments melt during heat treatment and forming binding points on the surface of the conventional filaments after cooling. The effects of heat treatment conditions and type of conventional filament on the binding property were further investigated via tensile testing and microscopy, and optimal processing conditions and filament compositions were determined.

EXPERIMENTAL

Materials

LMPA filaments, LMPET filaments and conventional PA, PET and PP filaments were obtained from Shaoxing Global Chemical Filaments Corporation. Melting points of all samples were tested using a differential scanning calorimeter (DSC). Mechanical properties were investigated with an electronic yarn strength tester at a speed of 500 mm/min and a gauge length of 250 mm. Basic properties of these filaments are shown in *Table I*.

TABLE I. Basic properties of filaments.

Sample	Melting point (°C)	Linear density (dtex)	Tensile strength (cN/dtex)
LMPA	110	108	2.9
LMPET	110	122	1.9
PA	220	372	3.8
PET	254	335	3.1
PP	160	352	3.7

Preparation of Weft-Knitted Fabrics

LMPA filaments and LMPET filaments were blended with PA, PET and PP filaments, respectively at 1:1 blend ratios. These yarns were used to prepare fabrics via single-jersey weft knitting on a knitting machine (z652, Red Flags Company, China). The warp density and weft densities of weft plain fabrics were 0.67 per 5 cm.

Heat Treatment

Fabrics 100×200 mm^2 in size were heated to a given temperature or time on a dual high-voltage shaking pyro graph machine (STC-SD02, STC Machinery Equipment Company, China). Fabrics are denoted as LMPA/PA, LMPA/PET, LMPA/PP, LMPET/PA, LMPET/PET and LMPET/PP, respectively.

Mechanical Properties

The longitudinal tensile properties of the heat treated fabrics were tested on a multifunctional electronic fabric strength tester (YG026D, Chang Yi Fang Yi, China) at a tensile speed of 100 mm/min and a gauge length of 100 mm. Before characterization, all fabrics were cut to 50 mm in length and 150 mm in width, and conditioned at 25 °C and 65 % relative humidity for 24 h according to GB 3923.1-1997. The tensile test was conducted in the warp direction. Each tensile test was run three times and one of the curves was selected for further analysis.

Optical Microscope

The morphology of LMPET/PET fabric after heat treatment for 120s at different given temperatures was observed by using a model stereoscopic microscope (X-2, Shanghai Bimu Instrument Company, China) at a magnification of 25 times.

RESULTS AND DISCUSSION

Mechanical Properties of Fabrics After Heat Treatment

The tensile curves of fabrics before and after heat treatment are shown in *Figure 1*. As shown in *Figure 1(a)*, the tensile curves of original fabrics are flat until the strain reaches 50 percent. In contrast *Figure 1(b)* shows that the initial parts of tensile curves are steeper after heat treatment with higher tensile stress and higher Young's moduli. This is the result of binding points caused by the melting of low melting point filaments during heat treatment. With increasing strain, the binding points between low melting point filaments and conventional filaments are destroyed by the application of tensile stress. The conventional filaments then contribute increasingly to the latter parts of the tensile curves. Low melting point filaments have an impact on tensile stress low deformation range (about 0-10 %), while conventional filaments dominate the tensile stress curves at larger deformations (from 10% to break). Thus, the binding properties of low melting point filaments may be evaluated based on the tensile curves of the fabrics at the small deformations. The higher Young's modulus, the better dimensional stability of fabric.

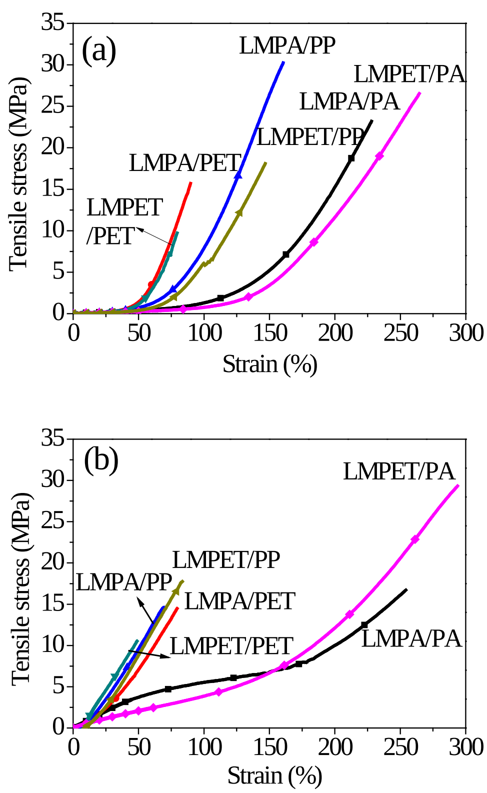

FIGURE 1. The tensile curves of fabrics before (a) and after (b) heat treatment at 140 °C for 120 s.

Effects of Heat Treatment Temperature on Binding Properties

In this study, the heat treatment temperatures for fabrics were set as 110, 120, 130, 140 and 150 °C and all fabrics were treated for 120 s. Tensile curves of fabrics at 0-10% deformation at different heat treatment temperatures are shown in *Figure 2*. It can be seen that tensile stress at the initial part of tensile curves is linearly correlated with strain. This indicates that the Young's modulus of fabrics after heat treatment are significantly increased, showing that the low melting point filaments after heat treatment have a significant effect on the binding properties. In *Figure 2 (a)*, Young's modulus of LMPA/PA fabric is firstly increased and then decreased with increasing heat treatment temperature, and reached the maximum at 140 °C. At lower temperatures, the LMPA filaments do not melt completely and develop limited binding points on the surface of the PA filaments. However, more LMPA filaments melt at the temperature of 140°C and the binding of fabrics increases. When the temperature is raised to 150°C, the molten LMPA filaments flow excessively and do not attach uniformly to the surface of PA filaments, as evidenced by the lower tensile properties of the fabric. In *Figure 2 (e)*, the Young's modulus of LMPET/PET fabric was still increasing at the maximum heat treatment temperature used in this study. The tensile responses of the other fabrics have similar behaviors (*Figures 2(b)-2(d)*).

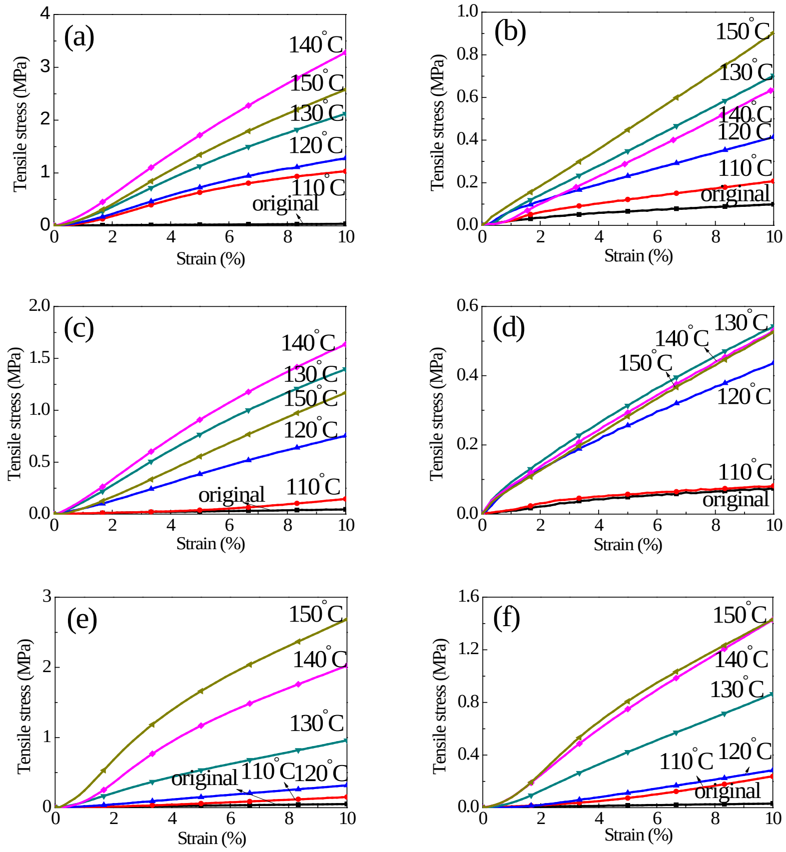

FIGURE 2. The tensile curves of fabrics after heat treatment at different given temperature: (a) LMPA/PA; (b) LMPA/PET; (c) LMPA/PP; (d) LMPET/PA; (e) LMPET/PET; (f) LMPET/PP.

Effects of Heat Treatment Time on the Binding Property

The tensile curves of the fabrics at 0-10% deformation as a function of heat treatment time are shown in *Figure 3*. It can be seen that Young's moduli of fabrics substantially increase to 120s and then decrease as time increases to 150 and 180s.. The reason is that the number of binding points between the filaments gradually increases until the filaments melt completely and flow rather than adhere to the PA, PP or PET filaments.

Contributions of Conventional Filaments to the Binding Properties of Fabrics

The tensile stress of the fabrics at a strain of 10 %a treatment time of 120s over the range of heat treatment temperatures is shown in *Figure 4*. The tensile stress of the untreated fabrics lies in the range of 0.04~0.1 MPa. However, the tensile stress of the fabrics after heat treatment has a wide range. For example, after heat treatment 140°C, LMPA/PA fabric shows a tensile stress of 3.3 MPa, which is higher than that of the other five fabrics. It is possible that the tensile stress of LMPA/PA fabric is higher than that of the LMPA/PET and LMPA/PP fabrics due to hydrogen bonds formed between LMPA filaments and PA filaments of the LMPA/PA fabric in addition to the mechanical binding [20]. LMPET/PET fabric shows similar behavior. These results indicate that the binding is achieved between filaments of when the chemical structures of the two fibers are most compatible [21].

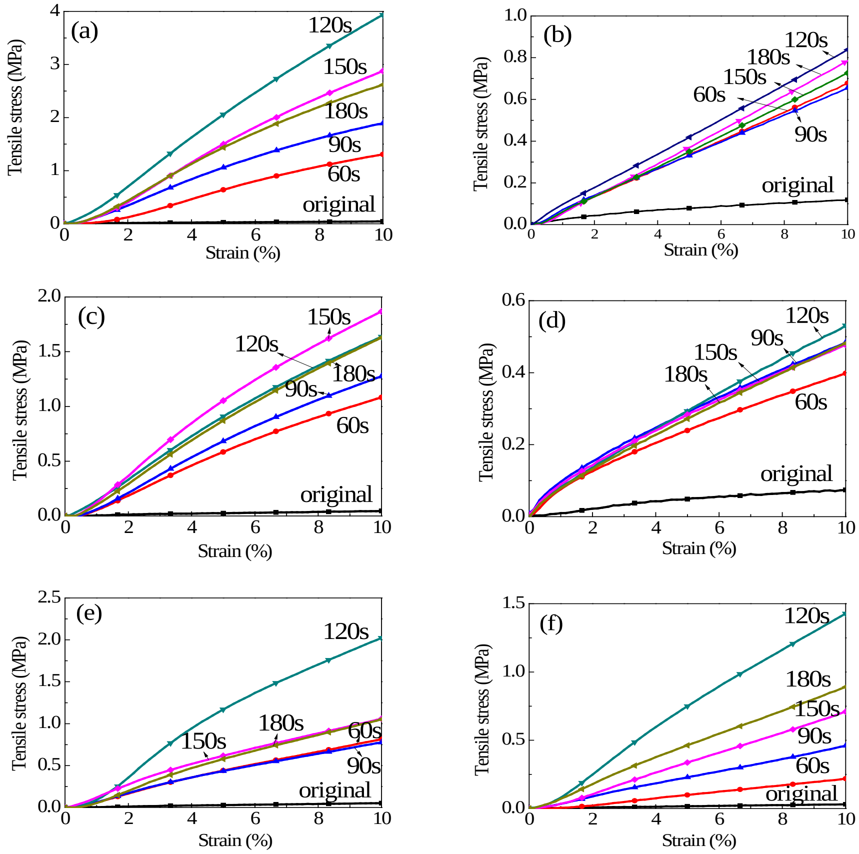

FIGURE 3. The tensile curves of fabrics at different heat treatment time: (a) LMPA/PA； (b) LMPA/PET；(c) LMPA/PP； (d) LMPET/PA； (e) LMPET/PET； (f) LMPET/PP.

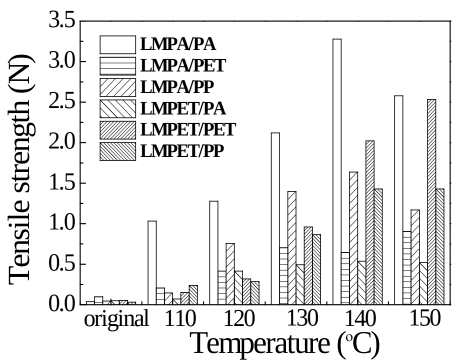

FIGURE 4. The tensile stress of fabrics at the strain of 10 %.

Melting Behavior of Low Melting Point Filaments

Morphology of LMPET/PET fabric at different heat treatment temperatures is shown in *Figure 5*. The LMPET filaments are pictured in white and the PET filaments are shown in black color). As temperature increases, LMPET filaments (white) gradually melt and attach to the surface of PET filaments (black), and form binding points which restrain deformation under the action of external forces [22]. When the melting of LMPET filamentsin the LMPET/PET fabric is sufficient the LMPET filaments become adhered to the surface of PET filaments *(Figures 5(e) and 5(f)).*

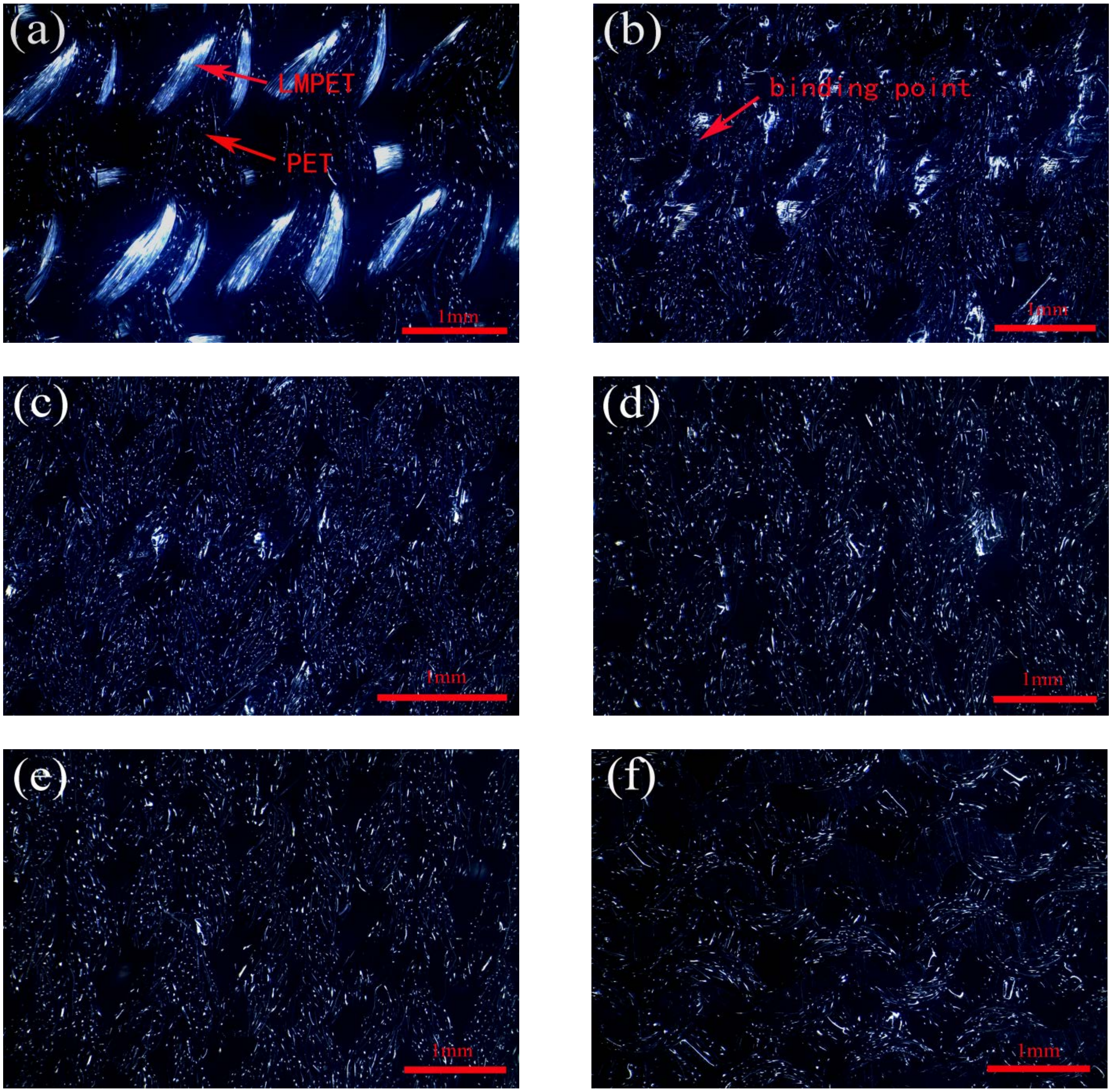

FIGURE 5. Morphology (25X) of LMPET/PET fabric after heat treatment at different temperature：(a) original；(b) 110 ˚C；(c) 120 ˚C；(d) 130 ˚C；(e) 140 ˚C；(f) 150 ˚C.

CONCLUSION

The binding properties of low melting point filaments in weft-knitted fabrics were evaluated by tensile testing and microscopy. Young's moduli of heat treated fabrics first increased and then decreased with increasing temperature or time. Based on the mechanical properties, heat treatment at 140 °C for 120 s was found to be optimum optimum for all 5 fabrics studied. Melting behavior of the low melting point filaments was observed via micrographs. Low melting point filaments gradually melted and attached to the surface of the conventional filaments. Binding points began to form with increasing heat treatment temperature. Both LMPET and LMPA filaments show good binding properties when blended with filaments of similar molecular structure. LMPA/PA fabric shows better binding properties than LMPET/PET fabric. Both are superior to the other fabrics considered in this study.

REFERENCES

[1] Lu, H.J., Preparation of Low Melting Point of PET, *Journal of synthetic fiber industry*, Vol. 28, No.6,2005, pp. 40-41.

[2] Wang, S.B., Wang, C.S., Wang, S.B., et al. Preparation of Low Melting Point Polyester by PET/PBT Reactive Blending, *China Synthetic Fiber Industry*, Vol.5, No.22,2015,pp.23-26.

[3] Xie, G.Q., Li, X.L., Zhai, J., et al. Preparation of Low Melting Point Copolyamide Hot Melt Adhesive, CN104559909A, 2015.

[4] Mao, X.F., Qian, Y., Wang, X.H., et al. Preparation and Characterization of Low Melting Point Polyamide, *Journal of textile*, Vol. 3, No.1, 2016,pp.6-10 .

[5] Li, G., Low Melting Point Fibers and Hot-rolled Non-woven Cloth, *Journal of Beijing textile*, Vol.3, 1997, pp. 12-14.

[6] Mizukami, Y., Tomikawa, T., Double -knitted Fabric and Moldings and Mouse Pads Made Thereof: US, US 5962349 A [P], 1999.

[7] Yang, G. K., Antibacterial, waterproof, and absorbent composite cloth: US, US20090081911. 2009.

[8] Suzuki, M., Sheet Elastic Complex Used in Sanitary Products its Manufacturing Process, and its Usages: US, US 5576090 A, 1996.

[9] Wang, X.L., Low Melting Point Heat Binding Filaments, *Journal of synthetic filaments*, Vol.4, 1990, pp.40-47.

[10] Liu, R.Q., Product and Development of Chenille Line, *Journal of China textile*, Vol.8, 1998, pp.40-41.

[11] Ilhan, I., Babaarslan, O., A Theoretical Approach to Pile Yarn-shedding Mechanism of Chenille Yarn. *Journal of the Textile Institute*, Vol. 98, No.1, 2005, pp.23-30.

[12] Jiang, S.Y., Jin, X., Fang, Y., Household Textile Material, S*hanghai: Donghua University press*, 2013, pp.195 -196.

[13] Xie, J.S., Zhong, J.Q., Yang, B.C., et al. Analysis of Thermal Stress of Au Bonding Thread in CSP. *Electronic Product Reliability & Environmental Testing*, 2005.

[14] Lin, J.H., Lu, C.T, Chen, W.C., et al. Preparation and Property Evaluation of Tencel/LMPET Dressing Fabric Coated by UV Cross-linked Chitosan,2011, pp.3 32-334 .

[15] Zhou, J.P., He, W.X., Preparation of Low Melting Point Polyamide Filaments, *Journal of Tianjin textile science and technology*, 2011,Vol. 4 , pp. 25-27.

[16] Bankar, V.G., On Line Interlacing of Bulked Continuous Filament Yarns and Low-melting Binder Fibers: EP, EP0444637, 1994.

[17] Chang, H.S., Kim, S.G., Fabric including Low-melting Fiber: US, EP2261405, 2010.

[18] Fukuoka, K., Nishio, K., Yamahara, S., et al. Weft Knitted Fabric including Polyurethane Elastomer Fiber and Process for Producing the Same: US, US 8173558 B2, 2012.

[19] Ji, M.G., Lee, S.H., Dyeing of Thermal Bonded Polyester Fabric by Using Low Melting Point Bicomponent Filament Yarn -Head tie, *Fashion & Textile Research Journa*l, Vol. 11 ,No.4,2009.

[20] Sun, B., Hot Melt Adhesive Composite Filaments Materials, *China's individual protective equipment*, Vol. 4, 2001, pp.9-15.

[21] Zhang, X.H., Zhao, G.L., Yin, R.X., Anti-felting Properties of Wool Low Melting Point Bi-component Sheath-core Filaments Blended Fabrics, *Journal of textile*, Vol. 4,2007, pp.30-33.

[22] Li, G., Low melting point filaments and hot-rolled non-woven cloth , *Journal of Beijing textile*, Vol. 3,1997, pp.12-14.

AUTHORS' ADDRESSES
Qiaoqiao Lin
Jiali Jiang
Yuanchao Hu
Xiuhua Wang
Zhejiang Sci-Tech University
Higher Education Park No. 2 on 5th Avenue
Zhejiang Sci-Tech University
Building 18,406
Hangzhou, Zhejiang 310018
China

Shuangxi Xu
Yueping Chen
Shaoxing Global Chemical Fiber Co. Ltd
No. 1435 East Renmin Road,
Shaoxing, Zhejiang 312000
CHINA