Indian Journal of Fibre & Textile Research
Vol. 42, March 2017, pp. 57-63

Comfort limit and heat protection properties of single layer cotton/ nylon-Kermel blended fabrics

Ali Kakvan[1], Saeed Shaikhzadeh Najar[1,a], Agnes Psikuta[2] & Farshid Sharifnejad[3]

[1]Department of Textile Engineering, Amirkabir University of Technology, Tehran 15875-4413 , Iran

[2]Laboratory for Protection and Physiology, Empa Swiss Federal Laboratories for Materials Science & Technology, Lerchenfeldstr 5, 9014 St Gallen, Switzerland

[3]Department of Textile Engineering, Kar Higher Education Institute, Qazvin, Iran

Received 6 October 2014; revised received and accepted 28 January 2015

Fire and heat protection and thermal comfort properties of cotton/nylon-Kermel blended fabrics have been studied to predict thermal comfort and protection limit of this fabric structure. The results indicate that the cotton/nylon blended with Kermel fabrics, particularly with 30% Kermel fibres, exhibits the highest upper thermal comfort limit and also the widest range of fabric metabolic activity level. The obtained result indicates that all the sample fabrics consisting of 50% cotton fibres have close drying times. The result also shows that the increase in Kermel fibres ratio in blended fabrics has a pronounced effect on prevention of fire diffusion. An increase of Kermel fibres have significant effect on radiant protective performance of fabric samples. The results of vertical wicking and MMT tests show that the addition of Kermel fibres up to 10% significantly detracts these thermal comfort properties. However, the increase of Kermel fibres ratio from 10% to 100% have no significant effect on wicking as well as moisture management properties. The study shows that the blending of Kermel fibre at 30% blend ratio with cotton and nylon enhances thermal comfort limit and heat protection of blended fabrics.

Keywords: Comfort limit, Fire protection, Kermel fibre, Moisture management properties, Nylon, Radiant protective performance, Wicking

1 Introduction

The desired heat protection has negative effect on comfort and work efficiency of wearer[1,2] . Although thermal protective and comfort properties have conflicting characteristics, these are essential factors in thermal protective clothing and it is important to use proper fabrics which have optimal level of both thermal protection and reduction of heat stress[3,4] . The most critical factor in comfort perception is the body temperature and clothing is an essential support for its regulation. Also, it is necessary to find the relationship between fibre characteristics (chemical composition, morphological characteristics, fineness, cross section, porosity and water content of fibre components) , yarn and fabric structure, and finishing treatments along with the resultant comfort of protective clothing [5-9] .

In order to keep the wearer comfortable, clothing has to be able to deal with the perspiration produced by different body activities. Consequently, liquid moisture transfer in clothing, wicking properties of fabric and drying time of next to the skin fabric influence significantly the wearer’s perception of thermal comfort sensation[10-13] .

Barker *et al*.[6-8,14-17] studied the thermal performance of protective fabrics and clothing systems. Their studies indicated that there was no correlation among thermal protective performance (TPP), air permeability, and density of wide range of selected protective fabrics. The studies also indicated that the differences in fabric thickness and weight significantly affect the TPP of single layer protective fabrics than the difference in fibre content.

One of the most important requirements of flame protective clothing is that fabrics should not continue to burn after the fire is removed. In addition clothing must provide thermal resistance against convective and radiant heat transfer. By utilizing a tight weave thicker, and hence, heavier fabric, these two specifications can be improved. Additionally, protective fabrics should also be permeable to water vapour[18]. Furthermore, without flame contact, exposure to hot environment must be considered

[a]Corresponding author.
E-mail: saeed@aut.ac.ir

particularly in terms of radiant heat. The radiant protective performance (RPP) of single layer fabrics is affected by the type of fibres, along with the fabric weight, thickness and structure [3] .

The fabrics made from organic polymers have the disadvantage that they will burn and contribute to the thermal energy generated by fire. But they have significant advantages to improve wearer comfort in protective clothing and indicate good thermal insulation properties[18]. Kermel fibre maintains maximal short-term protection against high temperature and does not melt or burn when exposed to high temperature. This fibre begins to char at about 400º C and has good mechanical properties at elevated temperatures [4, 19-21] .

In recent years, Kermel fibre, as high-performance fibre, is used in heat protective clothing[21,22] . In particular, it is shown that when the Kermel fibre is added to a mixture of cotton/nylon fibres the fabric porosity, air permeability and thermal resistance are increased[22] . However, there is no systematic study on thermal comfort properties of cotton/nylon blended fabrics with high protection Kermel fibre. Therefore, the objective of this research is to investigate thermal comfort limit and the heat radiant protection performance of single layer cotton/nylon-Kermel woven fabrics for their application as functional protective clothing.

2 Materials and Methods

2.1 Sample Preparation

In this study, six Ripstop woven blended fabrics were used. The properties and characteristics of fibres used in this study have been reported earlier[22]. Six different single spun yarns [Kermel(100%), cotton/nylon (50:50), and four blends of 50% cotton fibres with nylon + Kermel (40:10, 30:20, 20:30 and 10:40)] were produced separately at the same linear density of 20 tex (30 Ne) (Table 1). These single yarns were then twisted into two-folded yarns with the same yarn linear density of 40 tex (30/2 Ne) and twist level of 560 TPM for their use as warp and weft yarns. All the fabric specimens were produced on a sampling loom machine (SL8900, CCI Tech Inc., Taiwan) and they have the same number of ends and picks. The fabrics were kept for 24h under standard ambient conditions of 20±2 °C temp. and 65±2% R.H. for conditioning and relaxation. The thermal comfort and physical properties of the fabrics were measured in our previous work [22] .

Table 1—Sample details

Sample No.	Fibre blend ratio, %
1	50:50 cotton/nylon
2	50:40:10 cotton/nylon-Kermel
3	50:30:20 cotton/nylon-Kermel
4	50:20:30 cotton/cylon-Kermel
5	50:10:40 cotton/nylon-Kermel
6	100 Kermel

2.2 Test Methods

The following test methods were used for measuring fire and heat protective performance as well as comfort performance of fabrics.

2.2.1 IR Comfort Test

The objective method was developed in-house to assess the drying process by measuring the temperature course of a wetted textile with an infrared camera. The IR comfort test (determination of cooling performance and drying time) was conducted using infrared camera (Thermo Vision A40 M, FLIR Systems, Frankfurt am Main, Germany)[23] . The temperature course always shows two important and distinct points, namely $t_{5\%}$ and $t_{95\%}$ at which the fabric is fully wet and fully dry respectively. The measurement is based on wetting of a fabric on one side with a defined amount (4 drops) of distilled water with total weight of 200± 2 mg and temperature of 35 °C. The temperature of sample decreases due to evaporative cooling phase until the sample is dried. This temperature course reflects the absorption of moisture and its transport through the sample material. The whole system was placed in a climatic chamber at controlled temperature of 35 °C, relative humidity of 40% and wind speed of < 0.5 m/s. Three measurements were conducted for each fabric and average values of $t_{5\%}$, $t_{95\%}$ and drying time (difference between $t_{95\%}$ and $t_{5\%}$) were calculated therefrom.

2.2.2 Vertical Fire

According to ISO 11612:2009 (clothing protection against heat and flame), a test specimen was positioned vertically above a controlled flame and exposed for a specified period of time. Measurements were made during the length of time when the specimen is exposed to the flame and the time afterglow after the flame source has been removed was noted. Char length, or visible damage to the test specimen after application of a specified tearing force, was determined. Six vertically oriented (3 in warp and

3 in weft direction) samples were brought into contact with 40± 2 mm long propane flame for 10s ignition time at the edge of outer side of sample. For each fabric sample, the test was repeated six times.

2.2.3 Radiant Protective Performance (RPP)

Test was done according to ISO 6942:2002 [protection against heat and fire (method of test: evaluation of material assemblies when exposed to a source of radiant heat)]. For radiant protective performance (RPP) test method, the typical heat flux ranges from 21 kW/m^2 to 84 kW/m^2 (refs 18,24) . Based on ISO 6942, the samples were conditioned for at least 24h at 20±2 ºC and 65±2 % RH. The sample was mounted onto a defined curved copper plate calorimeter and exposed to a defined radiant heat source. The time needed for temperature rise by 12 °C and 24 °C in the calorimeter was recorded and expressed as radiant heat transfer indexes. Also the difference between two indexes was observed and the heat transmission factor was calculated. The level of incident heat flux density was found at medium level of 40.8 kW/m^2. The measured time for producing an increase in temperature of the calorimeter corresponds to the time when the person starts feeling pain with second degree burns[24] . The RPP value is the product of the incident heat flux and the recorded tolerance time to second degree burn (kW/m^2). The transmitted heat flux density (Q_c) in kW/m^2 is calculated using the following equation:

$$Q_c = \frac{M \times C_p \times 12}{A \times (t_{24} - t_{12})} \qquad \dots(1)$$

where M is the mass of copper plate in kg; C_p, the specific heat of copper 0.385 [kJ/kg.ºC]; $12/(t_{24}-t_{12})$, the mean rate of rise in calorimeter temperature in ºC/s in the region between a 12 ºC and a 24 ºC rise; and A, the area of the copper plate in m^2.

The heat transmission factor [TF (Q_0)] for the incident heat flux density level (Q_0) was calculated by the following equation:

$$\mathrm{TF}(Q_0) = \frac{Q_c}{Q_0} \qquad \dots(2)$$

The radiant heat transfer index [RHTI (Q_0)] for the incident heat flux density level (Q_0) was determined as the mean of t_{24}, the time in 0.1s, for a temperature rise in the calorimeter of 24±0.2 ºC.

2.2.4 Vertical Wicking

The test was carried out according to DIN 53 924 [determination of water absorption velocity of textile fabrics (capillary rise method)]. In vertical strip wicking test, the wicking heights of water at 10, 30, 60 and 300s on fabric samples were measured. Ten (5 in warp and 5 in weft directions) specimens were prepared and immersed in distilled water at their bottom edge. The bottom edge of the sample was clamped 15 mm from the lower end with a 1.4 g clip, in order to ensure that the fabric sample will contact the water [10, 25] .

2.2.5 Liquid Moisture Management Properties

The test was done according to AATCC test method 195-2009. In the moisture management tester (MMT), the specimen was horizontally held flat under fixed pressure between the upper and the lower concentric surfaces with moisture sensors, while standard test solution (0.15 g sodium chloride 0.9%) was introduced onto the center top surface of the fabric (skin side). All the samples were conditioned and tested at 23±2 °C and 50±5 % relative humidity. The one-way-transport capacity (OWTC) of fabric or the difference between the area of the liquid moisture content curves of the top and bottom surfaces of specimen with respect to time and its overall moisture management capacity (OMMC) are two important output results of this test [26] .

2.3 Comfort Limit Model

In the present study, the comfort limit of blended fabric samples was calculated. Woo and Barker [27] derived this comfort limit range from an application of the first law of thermodynamics concerning the law of energy conservation; as given below:

Energy storage within body (J)
= Energy production (Mn)-Energy dissipation(G) ... (3)

If there is neither heat loss nor heat storage in the body (J=0 or G=0), it leads to the sensation of thermal comfort. The energy dissipation from body into an ambient environment can be expressed as follows [28, 29] :

$$\text{Total energy dissipation}(\mathrm{Q}) = \text{Dry heat transfer}(\mathrm{H}) + \text{Evaporative heat transfer}(\mathrm{E})$$

The heat balance equation is defined as follows:

$$Mn = Q = \left(\frac{1}{0.155I}\right)[(Ts - Ta) + 16.5 i_m (Ps - Pa)] \quad \dots(5)$$

where Mn is the net metabolic rate (W/m^2); Q, the total energy dissipation (W/m^2); Ts and Ta, the temperature of skin and ambient respectively (°C); *Ps*, the saturated water vapour pressure at skin temperature (kPa); *Pa*, the water vapour pressure at ambient temperature (kPa); *I*, the clothing thermal resistance (clo); and i_m, the permeability index which is the ratio of thermal and evaporative resistance of the ensemble.

The limit of 20% sweat wetted area (SWA) has been suggested as the comfort limit [5,6,27]. By assuming Ts = 33 °C for which Ps = 5.033 kPa , the comfort equation becomes [27] :

$$\left(\frac{6.46}{I}\right)(33-Ta) \le Mn \le \left(\frac{6.46}{I}\right)\left[(33-Ta)+3.3i_m(5.033-Pa)\right] \quad \ldots(6)$$

This equation contains three groups of parameters that have effect on comfort[27] , viz (i) parameters that are function of materials type and garment design (I, i_m); (ii) parameters that are function of environmental conditions (Ta, Pa); and (iii) a parameter that is a function of body activity (Mn). Our investigation focuses on the effect of material type (Kermel fibre blend ratio) on the predicted level of comfort of cotton/nylon blended Kermel woven fabrics.

3 Results and Discussion

SPSS statistic software was used and One-Way Anova statistical analysis was performed in order to indicate the significant differences between the results (p-value = 0< 0.05). Based on the comfort limit equation [Eq. 6], thermal comfort properties, assumed ambient temperature of 23 °C, relative humidity of 65%, and air velocity of 1m/s[27], we calculated the comfort limit for the test fabrics (Fig. 1.).

Figure 1 shows the predicted thermal comfort limits of fabric samples plotted against net metabolic rate. It is shown that the predicted thermal comfort limit of cotton/nylon and cotton/nylon blended with Kermel fabrics shows little difference and is found related to the cotton fibre content of these fabrics. In addition, cotton/nylon blended with Kermel fabric, particularly with 30% Kermel fibres, exhibits the highest upper comfort limit and also the widest range of metabolic activity level. The model predicts that each of the Kermel 100%, cotton/nylon (50/50) and blended fabrics when worn in a hot environment should be perceived to be thermally comfortable by the wearer who is sweating and involved in moderate levels of physical activity.

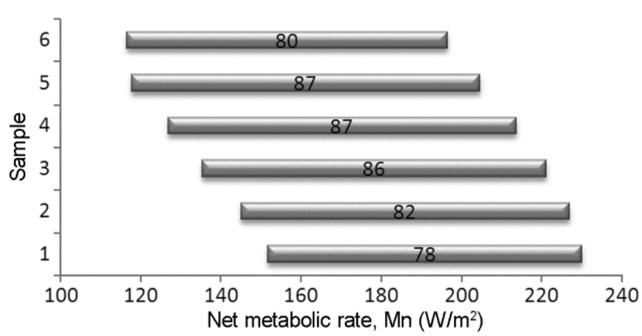

Fig. 1—Thermal comfort limit of cotton/nylon-Kermel blended fabrics against net metabolic rate [numbers on the bars are the difference between upper and lower net metabolic rate limits]

The average values of IR test measurements of fabric drying time ($t_{5\%}$) (drying state of wet fabric = 5% dry) and $t_{95\%}$ (drying state of dry fabric = 95% dry) [23] are shown in Fig. 2. According to the table of moisture regain for textile fibres [(ASTM D1909-04(2012)] and Kermel fibres specifications [21] , nylon 66 and Kermel fibres have the same moisture regain of about 4 - 4.5%. Therefore, the Samples 1 and 2 show the same drying time. By increasing the Kermel fibre percentage in Samples 3,4 and 5, a gradual decrease in drying time is observed that appears likely to be related to the change in porosity of fabric samples. Nevertheless, all the fabric samples that consist of 50% cotton fibres have similar drying times as explained by natural hygroscopic properties of cotton fibres. The drying of cotton content is very slow due to the storage of part of the water in the fibres. Conversely, the 100% Kermel fabric shows lowest drying time and this sample will be more comfortable when worn as a protective clothing. This result indicates that comfort perception is more desirable to have a material that dries faster after absorption of liquid moisture. As shown in Fig. 2, the

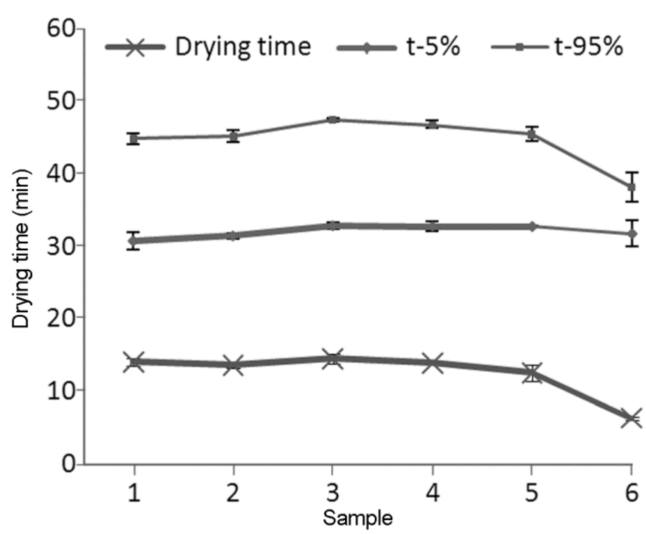

Fig. 2—Average values of IR comfort test of cotton/nylon-Kermel blended fabric samples

100% Kermel fabric sample starts to dry slightly later than cotton and nylon blended fabric but it dries much faster. So blending cotton with other fibres such as nylon and Kermel in fabric samples used in this study leads to faster comfort recovery for wearer.

Figure 3 shows images of fabric samples after the vertical flame test used in this study. From these photos it is obvious that the increase of Kermel fibres ratio in blended fabrics has a pronounced effect on prevention of fire diffusion. Problems arise in blends with natural fibres like cotton which will char and form a supporting structure that will then hold the molten polymer. Kermel fibres are not ignited or burnt, but they provide a coherent char form (without shrinkage) when heated sufficiently to decompose the material. Thus, fabrics made from these fibres continue to be in the charred form as a protective barrier to heat and flame. Because cotton is a highly flammable fibre, the cotton/nylon-Kermel blended fabric containing 50% cotton is not self-extinguishable. It seems that with higher ratio of Kermel fibre the sample is not burnt, which can be a sign for improvement of fire resistance properties of fabric samples.

The requirements according to the standard test method of clothing to protect against heat and flame is (i) no sample may continue to burn to the top or the side edges, (ii) no sample may have hole formation,

Fig. 3—Images of cotton/nylon-Kermel blended fabric samples [(a) Sample 1 (Co50/Ny50), (b) Sample 2 (Co50/Ny40/K10), (c) Sample 3 (Co50/Ny30/K20), (d) Sample 4 (Co50/Ny20/K30), (e) Sample 5 (Co50/Ny10/K40) and (f) Sample 6 (K100)]

(iii) no sample may have burning or melting or melting debris, (iv) the after flame time shall be ≤ 2 s, and (v) the afterglow time must be ≤ 2s. The results show that only Sample 6 (Kermel 100%) fulfill and another samples that consist of cotton fibres do not fulfill their requirement. However, if the fire retardant (FR) cotton fibre is used and blended with nylon and Kermel fibres, it is expected that the blended structure would be more flame retardant.

It can be seen in Fig. 4 that the transmission factor (TF %) of fabric samples against radiant heat flux decreases with the increase in Kermel fibres ratio. This result indicates that Kermel fibres have a significant effect on radiant protective performance (RPP) value of fabrics. RPP value, however, is negatively correlated with fabric air permeability. The results indicate that the cotton/nylon (50/50) fabric shows close RPP values to the cotton/nylon-Kermel blended fabrics, even Sample 5 with 40% Kermel fibre blend ratio is likely to be attributed to the fact of hollow cotton fibre structures [3]. As obviously shown in Fig. 4, the 100% Kermel fabric sample has the lowest transmission factor, indicating that this fabric sample has the highest RPP value.

As shown in Fig. 5, with an increase in Kermel fibre blend ratio, the wicking height of water, compared with cotton/nylon fabric sample, decreases. However, the increase of Kermel fibre blend ratio from 10% up to 40% has no significant effect on wicking height, particularly after a longer wicking time (after 300s). Although the Kermel and nylon fibres have the same moisture regain, it seems likely that blending Kermel with cotton and nylon fibres leads to change in structure of yarn and fabric porosity. Increase in blend ratio of Kermel fibres in samples increases the fabric porosity. Therefore, changing the size and number of pores in structure of blended fabrics prevents water from faster rising through the fabric. The Kermel 100% fabric with highest porosity value, exhibits the lowest wicking height of water, particularly after 60s between the cotton/nylon-Kermel blended fabrics.

Table 2 indicates accumulative OWTC index and OMMC of fabric samples respectively. The Sample 3 has the highest one-way-transfer capacity (OWTC = 807.548) and also a high liquid moisture management capacity (OMMC = 0.576). It means that liquid sweat can be quickly transferred from next-to-the-skin to the opposite side of the fabric to keep the skin dry and provide better thermal comfort. Samples 1, 2, 5 and 6 have low OWTC and OMMC values, and hence these fabric samples show poor liquid moisture management properties, meaning that the liquid cannot be absorbed easily from the next-to-the-skin side to the outer surface. Sample 4 has the highest liquid moisture management capacity (OMMC = 0.675), whereas it shows the lowest one-way-transfer capacity (OWTC = 456.381), which indicates that the

Table 2—OWTC and OMM indexes of cotton/nylon-Kermel fabric samples

Sample	OWTC, %	OMMC (-)
1	630.43	0.537
2	545.95	0.398
3	807.54	0.576
4	456.38	0.675
5	636.28	0.448
6	497.80	0.401

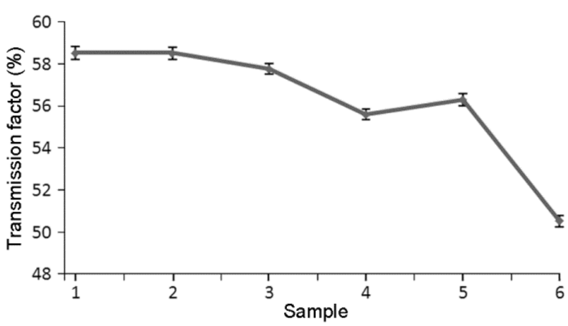

Fig. 4—Radiant protective performance values in form of transmission factor % of cotton/nylon-Kermel blended fabric samples

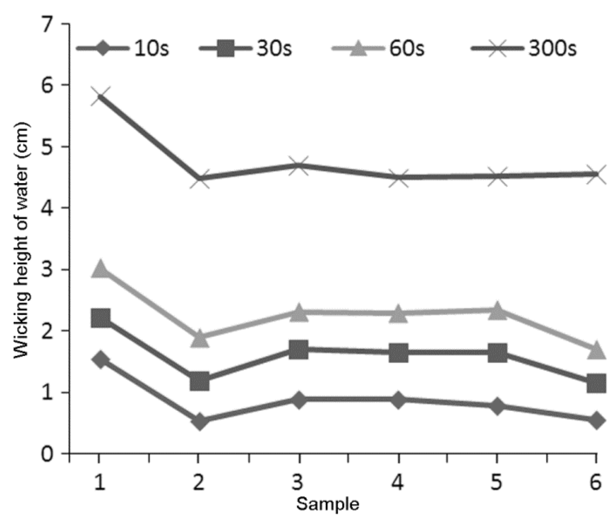

Fig. 5—Wicking height levels of water in the cotton/nylon-Kermel fabric samples at different rising time of 10, 30, 60 and 300s

liquid (sweat) can be transferred from the surface next to the skin to the opposite surface but cannot easily evaporate to the environment.

4 Conclusion

The results show that cotton/nylon blended with Kermel fabrics, particularly with 30% Kermel fibres, exhibit the highest upper thermal comfort limit and also the widest range of net metabolic rate for which the fabric ensures the thermal comfort. The model predicts that each of the sample fabrics when worn in a hot environment should be perceived to be thermally comfortable by the wearer who is involved in moderate levels of physical activity.

The obtained result indicates that all the sample fabrics, consisting of 50% cotton fibres, have close drying times as also explained by their natural hygroscopic properties. However, the increase of Kermel fibres ratio from 10% to 100% has no significant effect on wicking as well as moisture management properties. The 100% Kermel fabric will be more comfortable when worn as protective clothing, because generally a material that dries faster after absorption of liquid moisture provides a better thermal comfort perception.

The result also shows that the increase of Kermel fibres ratio in blended fabrics has a pronounced effect on prevention of fire diffusion. It can be seen that from the results that with the increase of Kermel fibres blend ratio the transmission factor of fabric samples against radiant heat flux decreases, thus the Kermel fibres have significant effect on RPP.

The findings suggest that blending Kermel fibre at 30% blend ratio with cotton and nylon enhances thermal comfort limit and heat protection of blended fabrics. Also it would be a cost effective if producers use blended fabrics instead of 100% Kermel fabrics in their fire and heat protective clothing productions. In general, only some blends of cotton, nylon and Kermel fibres exhibit proper protection and sufficient thermal comfort properties, related to fibre characteristics, yarn and fabric structure and also complex interaction between physical, mechanical and comfort properties of blended fabrics. Further studies can be done in this area using FR cotton and FR viscose fibres blended with nylon and Kermel fibres.

References

1 Shepherd A M, *ASTM Int* , 9 (2012) 188.
2 Scott R A , *Textiles for Protection* (Woodhead Publishing Ltd.,Cambridge), 2005.
3 Nelson C N & Henry N W, *ASTM Int*, 7 (2000) 33.
4 *Handbook of Technical Textiles*, edited by A R Horrocks & S S Anand (Woodhead Publishing Ltd., Cambridge), 2000.
5 Barker R L , *Int J Clothing Sci Technol*, 14(3/4) (2002) 181.
6 Yoo S. & Barker R L , *Text Res J*, 75(7) (2005) 523.
7 Yoo S & Barker R L , *Text Res J*, 75(7) (2005) 531.
8 Barker R L, Song G & McDonald A, *J Fiber Bioeng Informatics*, 1.1 (3) (2008) 173.
9 Varshney R K, Kothari V K & Dhamija S, *J Text Inst*, 101(6) (2010) 495.
10 Saville B P, *Physical Testing of Textiles* (Woodhead Publishing Ltd.,Cambridge), 1999.
11 Babu R V , Ramakrishnan G , Subramanian V S & Kantha L, *J Eng Fibers Fabrics*, **7**(3) (2012) 28.
12 Junyan H , Yi L , Kwok-Wing Y , Wong A S W & Weilin X, *Text Res J*, 75(1) (2005) 57.
13 Manshahia M & Das A , *J Text Inst*, (2013) 1.
14 Shalev I & Barker R L , *Text Res J*, 54(10) (1984) 648.
15 Lee Y M & Barker R L , *J Fire Sci*, 4(5) (1986) 315.
16 Lee Y M & Barker R L , *Text Res J*, 57(3) (1987) 123.
17 Song G W, Barker R L , Hamouda H , Kuznetsov A V, Chitrphiromsri P & Grimes R V, *Text Res J*, 74(12) (2004) 1033.
18 Harper C A , *Handbook of Building Materials for Fire Protection –Fibers and Fabrics* (The McGraw-Hill Companies, Inc.), 2004, *Chap 5*.
19 Valaseviciute L, Milasius R , Bagdoniene R & Abraitiene A , *Material Sci*, 9(4) (2003) 391.
20 Hearle J W S, *High-Performance Fibers* (The Textile Institute) 2001.
21 *Kermel Performance is Our Profession*. Catalog (2013). www.Kermel.com (accessed on March 2013).
22 Kakvan A , Shaikhzadeh Najar S & Psikuta A , *J Text Inst*, 106(6) (2015) 674.
23 Niedermann R & Rossi R M , *Text Res J*,82(4) (2012) 374.
24 Zhu F , Zhang W & Chen M , *Fibres Text Eastern Eur*, 15(1) (2007) 72.
25 Fangueiro R , Filgueiras A , Soutinho F & Xie M , *Text Res J*, 80(15) (2010) 1522.
26 Hu J , Li Y , Yeung K , Wong A S W & Xu W, *Text Res J*, 75(1) (2005) 57.
27 Barker R L & Woo S S, *Proceedings*, *Fiber Producers Conference* (Greenville, SC.), 1988, 16.
28 Woodcock A H , *Text Res J*, *Part I*, 32 (1962) 628.
29 Woodcock A H , *Text Res J*, *Part II*, 32(1962) 719.