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〈研究論文(學術)〉

아라미드 직물의 열적 성질과 역학 성질에 관한 연구

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A Study on Thermal and Mechanical Properties of Aramid Fabrics

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요 약－본 연구는 노멕스 직물과 일반 방염직물의 쾌적성에 영향을 주는 중요한 인자를 찾기 위하여 직물의 열적 성질과 역학 성질에 관하여 연구한 것이다. 사용된 직물은 재해를 일으킬 수 있는 환경에서 방호용 의복으로 사용되는 노멕스 직물이 주를 이루며, 비교를 위하여 방염직물과 쾌적성이 좋은 일반직물을 포함시켰다. 직물의 물리적 성질과 열 특성을 측정하였으며, 역학 성질을 측정하여 노멕스 직물과 다른 직물을 서로 비교 분석하였다. 노멕스 직물은 파이버 자체가 뻣뻣하기 때문에 쾌적성을 향상시키기 위해서는 소프트감을 높이는 것이 중요한 요소라는 것을 확인할 수 있었다. 같은 노멕스 직물이라도 쾌적성 면에서 서로 차이를 보여주므로 직물의 구조적 성질이 직물을 구성하고 있는 파이버 성질보다 쾌적성에 더 영향을 미치는 것을 알 수 있었다.

1. Introduction

Comfort is an important consideration determining the acceptability of fabrics used in workwear garments. The tactile comfort is related to mechanical interaction between the clothing material and the human body. The opportunity to explore the relationship between mechanical properties of fabrics and contact sensation has been developing over the last two decades.

Yoon, et al.[1] investigated the low stress mechanical behavior of polyester and polyester blend knits. Gibson and Postle[2] included a polyester jersey in a similar study. Postle[3] also defined the optimal combinations of mechanical/surface parameters for maximizing overall handle of men's suiting fabrics. Kim and Oh[4~6] reported the changes of mechanical properties of polyester fabrics according to the fabric construction, density, and twist level.

Tactile comfort is essentially a result of how much load is generated in the fabric and how it is distributed on the skin. Kirk and Ibrahim[7] reported that fabric stretch about a knee during deep bending could be larger than 50%. The ease of body motion and the level of the load generated in the fabric during a body movement are obviously related to the mechanical properties of fabrics, and therefore a study of clothing comfort must take into account these properties.

A human body is a complicated thermodynamic system in which energy is constantly produced by its metabolic activity, and from which energy must be continuously dissipated into the surroundings by dry thermal transport or latent heat loss accompanying water evaporation. Clothing will modify this heat dissipation process.

This research compared Nomex and other flame resistant fabrics on the basis of structural properties that influenced their tactile comfort and thermal comfort. Non-flame resistant polyester/cotton fabric, which was superior in comfort, was included. Wicking properties of those fabrics were also compared.

2. Experimental

2.1 Materials

The shirting fabrics that were tested were shown in Table 1. Each fabric has its own particular function, classified according to the end-use of the clothing in which materials might be used. Five are Nomex fabrics used in military and industrial shirting applications (N1-N5). Three are control fabrics. One material is a lightweight non-FR polyester/cotton used in ordinary clothing (C6). Topically treated FR materials include a FR cotton sample (C7) and a Flamex shirting fabric (C8).

2.2 Measurement of Physical Properties

The thickness was measured with KES-FB-3 compression tester. Pressure-thickness curves were produced at 0.5 gf/㎠. The 0.5 gf was used to provide the standard measurement of fabric thickness and the calculation of volume fraction. Air permeability was measured according to ASTM D-737, using a Frazier tester. The actual volume of fibers in the fabric was measured, using an air comparison Pycnometer, Beckman Model 930. Optical porosity was measured at 500 nm wavelength with Perkin Elmer UV-Visible Spectrophotometer Model 559.

2.3 Measurements of Wicking and Thermal Properties

Water transport rate was measured with the vertical wicking strip test (BS3424) to determine

Table 1. Characteristics of fabrics

Fabric no.	Fiber type	Construction	Warp×Filling (threads/inch)	Weight (g/㎡)
N1	Nomex	plain	70×47	155.3
N2	Nomex	plain	44×44	164.8
N3	Nomex	plain	86×54	199.4
N4	Nomex	plain	124×47	203.1
N5	80/20 Nomex/PBI	plain	66×48	170.8
C6	65/35 non-FR* polyester/cotton	plain	104×54	142.8
C7	FR cotton	plain	76×50	182.4
C8	50/50 FR polyester/cotton	twill	108×44	204.8

*FR : flame resistant

wickability parallel to the fabric plane. A fabric strip was vertically placed with one end immersed into the water and the rise of water was determined after ten minutes.

Q_{max} (warm/cool feeling) is defined as the peak value of the rate of flow of heat from the heat capacitor to the surface of a fabric specimen, measured from the moment the capacitor and surface come into contact. T-box of Thermolabo II was used as a heat source and the insulator styrofoam was used as sample support base for measuring q_{max} with 10℃ temperature difference. Thermal conductance was measured with Thermolabo II equipment which included a small guarded hot plate as a heat source and a water cooled bath as a heat sink. Thermal resistance (clo) was measured with a large guarded hot plate in standard (21℃, 65% RH) environmental condition.

2.4 Measurement of Mechanical Properties

Mechanical properties were measured with Kawabata Evaluation System[8] (KES-FB). Tensile and shear, bending, compression, and surface testing instruments were used to characterize the mechanical and surface properties of the test fabrics.

3. Results and Discussion

3.1 Physical Properties of Nomex fabrics

The observations based on the data from the laboratory testing provided insight into factors which might be responsible for differences in properties of those five Nomex and three control shirting fabrics. The physical properties of these shirting materials (thickness, permeability to light and air, volume fraction) were shown in Table 2. These data showed that the N4 was the thinnest of Nomex samples, comparable in thickness to the polyester/cotton shirting sample (C6). However, this same Nomex fabric had the lowest air permeability, due to the tightness of the fabric weave. The Nomex fabric used in industrial shirting (N2), because of the relative openness of the weave construction, had the highest air permeability of all the tested fabrics.

When physical properties were compared with fiber content, there was generally great differences among the five Nomex shirtings. This strongly suggested that other factors, probably structural properties, were more responsible for comfort than fiber content. There was close alignment on many test results for N2 and N3 Nomex shirtings. These were among the thickest of the eight shirtings with lower fiber volume fractions, and the highest air

Table 2. Physical properties of fabrics

Fabric no.	Thickness (mm)	Air Permeability ($ft^3/ft^2 \cdot min$)	Optical Porosity (%)	Volume Fraction (%)
N1	0.47	80.1	0.9	23.5
N2	0.73	230.5	4.4	16.5
N3	0.74	87.5	0.5	19.2
N4	0.42	6.2	0	33.8
N5	0.77	94.3	1.2	15.3
C6	0.39	49.6	0.6	23.2
C7	0.55	69.4	1.3	19.5
C8	0.53	61.6	0.5	24.4

permeability. However, N2 (more open construction) had almost three times the air permeability capacity of N3.

The N4, with the highest warp count, was among the heaviest of the samples but it also was among the thinnest structures. It had the highest fiber volume fraction and the lowest of the eight shirtings on the transport properties of optical porosity and air permeability. The Nomex/PBI (N5) fabric had the highest thickness of the eight samples. The non-flame retardant polyester/cotton (C6) control fabric, considered to be a typical fabric used in workwear shirting, was found to be the lightest and thinnest of the eight samples.

3.2 Wicking and Thermal Properties of Nomex fabrics

Table 3 showed that, based on measurement in a vertical wicking test, Nomex shirting fabrics had a capability to wick liquid moisture that was equal to regular non-FR polyester/cotton shirting fabric (C6). N3 showed superior wicking ability in a vertical test, and N5 had the highest wicking ability due to the presence of the high absorbing PBI component. All Nomex fabrics had far greater vertical wickability than the flame retardant polyester/cotton fabric (C8).

An expected strong correlation between thermal conductance and fabric thickness was shown in Fig. 1. N2 and N3 provided the lower levels of dry heat transfer (high similar clo values in Table 3) than the other six shirtings in standard condition. Thermal resistance of clo value is the reciprocal of the dry heat transfer rate. N4 had the coolest touch of q_{max}, and it was among the two best in heat conductance. It's clo value was lowest, indicating it had ability to conduct heat to maintain comfort in standard environment equal to that of the cotton control (C6).

On most heat transfer properties, N5 exhibited mid-range of the Nomex fabrics, and C6 exhibited

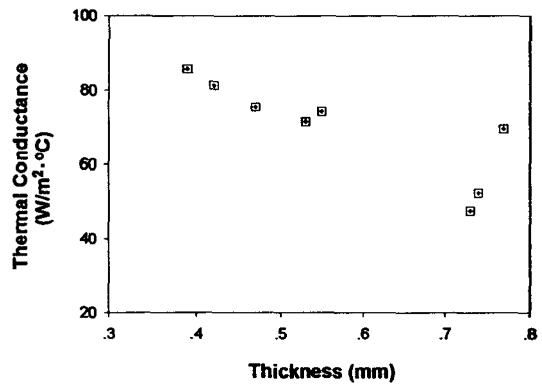

Fig. 1 The relation between thermal conductance and thickness of fabrics.

Table 3. Wicking and thermal properties of fabrics

Fabric no.	Wicking (cm/10 mins)	Q_{max} (W/m²·℃)	Thermal Conductance (W/m²·℃)	Thermal Resistance (clo ; m²·℃/W)
N1	7.5	15.03	75.56	0.324
N2	7.3	10.02	47.50	0.360
N3	11.7	10.93	52.33	0.357
N4	5.2	17.34	81.35	0.321
N5	12.1	11.30	69.80	0.358
C6	7.6	14.85	85.81	0.324
C7	5.3	14.97	74.39	0.321
C8	1.0	16.87	71.67	0.321

Q_{max} : warmness/coolness

superior performance to the Nomex fabrics and other cotton controls, having the highest heat conductance of all samples. The observed similarity in the thermal insulation (clo value) of the test fabrics was attributed to the dominating influence of boundary air layers that contributed to the effective thermal thickness of the sample. This means that, for the range of woven constructions, differences in bulk fabric thickness had lesser impact on total insulation.

3.3 Mechanical Properties of Nomex fabrics

The surface and mechanical properties of fabrics are important determinants of comfort since they influence the physiological reaction of the skin to fabric contact and may control the degree of skin-fabric contact. The prominent tactile properties of fabrics on the comfort were B (bending rigidity), G (shear stiffness), and SMD (geometrical roughness) of all KES data. Table 4 showed that the cotton and polyester/cotton blends were generally smoother (lower SMD) than Nomex shirtings.

The higher the q_{max} values, the cooler the fabric was likely to be perceived ; q_{max} is a function of fabric smoothness and heat capacity. On surface qualities, N2 and N3 Nomex shirtings had the lower q_{max} values than other Nomex and control fabrics, indicating the warmer touch sensation with initial contact of the fabric surface, while they had the roughest surfaces (highest SMD) of all shirtings. Fig. 2 showed a correlation between q_{max} and surface roughness of tested fabrics. The greater the surface area of contact, the greater the expected flow of heat from the skin, and therefore the cooler the fabric should feel[9].

Measurement of KES mechanical properties showed that Nomex shirtings were much stiffer in extension, bending and shearing than comparable control materials (Table 4). On surface and

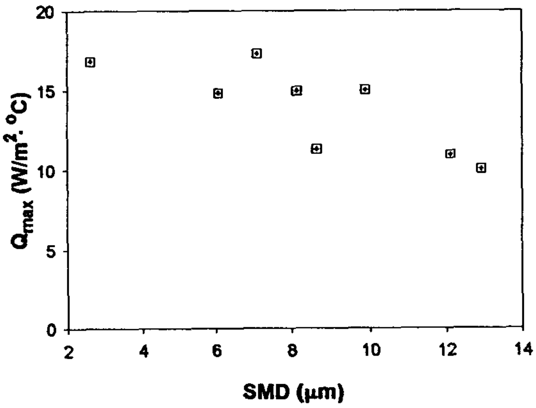

Fig. 2 The relation between q_{max} and surface roughness of fabrics.

Table 4. Mechanical properties of fabrics

Fabric no.	SMD (μ)	EM (%)	G (gf/cm·degree)	2HG (gf/cm)	B (gf·cm2/cm)
N1	9.88	2.15	1.98	2.14	0.319
N2	12.93	1.35	1.91	2.07	1.390
N3	12.11	2.92	0.52	1.05	0.222
N4	7.11	1.70	5.28	7.84	0.361
N5	8.63	2.30	3.12	5.18	0.346
C6	6.07	3.89	2.07	2.47	0.098
C7	8.14	9.95	1.50	2.54	0.106
C8	2.61	5.12	2.11	1.79	0.230

SMD : geometrical roughness, EM : fabric extensibility, G : shear stiffness
2HG : shear hysteresis at $\phi=0.5°$, B : bending rigidity

other KES hand properties, C6 was second smoothest (SMD) with lowest bending rigidity (B). N4 had the highest shear rigidity and bending rigidity. This indicated that Nomex shirtings might be perceived as stiff in skin-fabric contact. On the other hand, since these same properties also controled the limpness of the fabric, a lack of crispness might contribute to cling and closer contact between the fabric and the skin, especially when the fabric was wet. However, N3 Nomex fabric had flexible properties (low G and B).

4. Conclusions

Differences in physical and transport properties were revealed which may ultimately explain the differences perceived in these materials when worn in shirts. Nomex shirting fabrics had a capability to wick liquid moisture that was equal to regular non-FR polyester/cotton shirting fabric (7.6cm/10 mins). N1 and N4 fabrics had almost equal thermal conductance properties with comparable control materials. Nomex shirtings were much stiffer in extension, bending and shearing than comparable control materials.

Wearer reactions to the comfort of Nomex and control fabrics were not based on differences in the thermal insulation properties of these materials. Comfort reactions in those fabrics were more likely due to differences in softness related to fabric mechanical and surface properties. Therefore, improvements in the physical properties of fabric that predict softness was a major factor to enhanced comfort.

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