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Compressional Properties of Fabrics at Low Pressure to Assess Real Fabric Handle

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직물의 태 예측에 근접한 직물의 저응력 압축특성 측정

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Abstract : Twenty-three fabrics of varying thicknesses and weights were subjected to the maximum pressures of 10, 20, 35, 50 and 70 gf/cm^2 to yield pressure-thickness curves. Compression property values were plotted according to the amount of pressure applied to the samples. Pressure increases resulted in decreases in LC (compressional curve linearity), increases in WC (compressional energy) and no change in RC (compressional resilience). The best-fit lines are found separately according to pressures. The thickest fabrics exhibited the highest LC and WC values. The slopes varied different according to the pressure applied, with a pressure 50 gf/cm^2 exhibiting the steepest slope at WC. The pressure of 20 gf/cm^2 correlated most closely with the hand-evaluation test results, yielding Spearmans correlation coefficients of .86 and .82 respectively for the LC and WC.

Key words : low load, compression property, handle, subjective evaluation, correlation

1. Introduction

Subjective assessments are obtained from touch-evaluation tests of textile materials. Usually, qualitative sensorial evaluations of fabrics are carried out by taking advantage of finger sensitivity. The thickness, or resilience, of textiles depends upon the pressure applied to the surface of the specimen. Also, tactile sensations are felt differently as finger pressure changes. Measurement of fabric thicknesses at different pressures, and terms and equations representing the relationship between thickness and pressure, have been previously studied (Shiefer, 1933; Fourt, 1970). Compressional properties are among the simplest parameters which can predict subjective hand-evaluation test results (Subramaniam, 1990).

Both the Schiefer compressometer and the KES-F3 (Schiefer, 1933; Kawabata *et al*, 1980) use a loaded pressure foot, determining pressure from the compression of the foot. Loading to different pressures, starting at low load and then returning to a high load, obtain thickness-pressure curves. The thickness of the specimen is the distance between the foot and the anvil when the pressure has been increased to a stated amount. According to Scheifer, the standard thickness of the specimen is at a pressure of 70 gf/cm^2 (1 lb/in^2). The compressibility of the specimen is the ratio of the rate of decrease in thickness to the rate of increase in pressure from 0 to 70 gf/cm^2. The compressional resilience of the specimen is the amount of work recovered from the specimen when the pressure is decreased from 140 to 7 g/cm^2. And the order of increas-ing compressional resilience was different from that of compressibility.

Most studies which have assessed the handle of fabrics were done by using KES-F3 "default" maximum pressure value of 50 gf/cm^2 , without any consideration of optimum pressure, even in the case of yarns (Radhakrishnaiah *et al*, 1993). Only one study was found that used the KES-F3 system to evaluate the hand of nappy at 10 gf/cm^2 (Yokura *et al*, 1997). Actually, Bogaty *et al.* (1958, 1953) used a series of blended wool fabrics at three low pressures, .14, .7, 7 gf/cm^2, to simulate the range experienced in actual use, and one high load, 70 gf/cm^2. More attempts have been made at low pressures, particularly regarding the behavior of lofty fabrics, such as wool serge and blanket. Hollies (1964, 1970) tested smooth cotton structures and found some relationships between compressional energy and fabric properties under the pressure range of 0 through 36 gf/cm^2. A maximum load of 36 gf/cm^2 is capable of dem-

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onstrations the three-stage process of compression, namely, flattening of the fibers that protrude from the surface of the fabric, flattening of buckles in the fabric (including those areas of the fabric that are thicker than average), and compression of the main body of the fabric (Fourt *et al.*, 1970). According to ASTM (1986), the thickness of soft materials, such as blankets, fleeces, knits, lofty nonwovens and woolens must be measured at low pressures, .35 through 35 gf/cm^2, while moderately soft fabrics such as worsteds, sheetings and carpets at pressures of 1.4 to 144 gf/cm^2, and firm fabrics, such as ducks and felts at pressures from 7 to 700 gf/cm^2.

The measurement of the handle of fabrics by objective methods has been studies very often because it is assumed to be more reliable, rapid and reproducible than subjective methods. There are relatively few studies that have considered the relationships between objective compressional property measures obtained at low pressures and subjective hand-evaluation test results. This study tested the compressional behavior of fabrics at 5 low pressures (10, 20, 35, 50, and 70 gf/cm^2) using the KES system, and compared these results with fabric thickness and compressional-resilience measures obtained from hand-evaluation tests. The purposes of this "correlation" study are to decide whether LC, WC, or RC is most closely related to the subjective compressional resilience of fabrics, and to determine the optimum pressure at which compressional measures can be used to predict the qualities of compressional resilience determined through hand-evaluation testing.

2. Materials and Methods

2.1. Objective compressional properties

Compressional properties were obtained using the KES-F3 tester at 3 maximum loads (10 , 20, and 50 gf/cm^2) at a speed of 0.02 mm/sec (Kawabata, S., 1980). The values obtained were the linearity of pressure-thickness curve (LC), the energy required for the compression (WC), the resilience (RC), and the fabric thickness at .5 gf/cm^2 (To), that is, uncrushed thickness. The behavior of compressional properties of rayon-blend and wool-blend fabrics were examined in terms of their thickness.

2.2. Materials

The materials used in the study were 8 rayon fabrics (3 composed of filament yarns, and 5 of spun yarns), 4 rayon/cotton blend-fabrics and 11 wool and wool/nylon-blend fabrics. Tests were carried out in equilibrium with an atmosphere of 65%RH at a temperature of 20°C, the standard conditions for textile testing. Table 1 shows the specimens used in this study.

Table 1. Fabric construction characteristics

Fabric composition	Weight (g/m^2)	Yarn type & finishing (for short)	Thickness (mm)	
			At .5 gf/cm^2 (uncrushed)	At 50 gf/cm^2
Rayon 100	70	Filament (F)	.208	.104
Rayon 100	80	Filament (F)	.235	.133
Rayon 100	110	Filament (F)	.269	.169
Rayon 100	120	Spun (S)	.435	.233
Rayon 100	130	Spun (S)	.525	.255
Rayon 100	150	Spun (S)	.600	.251
Rayon 100	160	Spun (S)	.559	.295
Rayon 100	180	Spun (S)	.637	.333
Rayon/Cotton 65/35	100	Spun (C)	.818	.302
Rayon/Cotton 65/35	210	Spun (C)	.851	.485
Rayon/Cotton 65/35	240	Spun (C)	.834	.488
Rayon/Cotton 35/65	400	Spun (C)	1.77	1.22
Wool/Nylon 80/20	215	Napped (N)	2.40	1.54
Wool/Silk/Nylon 60/30/10	270	Normal (W)	1.42	1.01
Wool/Nylon 90/10	290	Napped (N)	1.58	1.17
Wool/Nylon/Angora 65/20/15	300	Boucle yarn (B)	2.60	1.49
Wool/Nylon 95/5	300	Napped (N)	3.38	1.89
Wool/Nylon/Alpaca 75/5/20	310	Napped (N)	2.61	1.72
Wool 100	310	Napped (N)	3.59	2.05
Wool/Cashmere 85/15	330	Napped (N)	2.13	1.36
Wool/Nylon 80/20	360	Normal (W)	2.56	1.73
Wool/Nylon 90/10	430	Napped (N), double	2.63	1.98
Wool/Nylon 80/20	500	Normal (W)	2.18	1.51

2.3. Hand-evaluation test

Hand-evaluation measures of the thickness and compressional resilience of the samples were collected independently from 4 judges. Eleven wool blend fabrics and the heaviest of the R/C fabrics were evaluated and ranked from thinnest (1) to thickest(12), and from least resilient (1) to most resilient (12). Since rayon and wool are very heterogeneous in thickness and compression, the 11 thinnest fabrics (of the 23-fabric sample) were excluded from evaluation to increase the accuracy of the statistics. Pressures of 35 and 70 gf/cm^2, as well as the three maximum pressures (10,20 and 50), were applied to determine which pressures correlates most closely with subjective hand-evaluation test results. The medians of 4 ranks from 4 judges were correlated with the objective measures using PC SAS to yield plot, regression and Spearman rank order data.

3. Results

3.1. Objective compressional properties according to fabric thickness

Linearity of curve (LC) : The LC of three rayon fabrics of filament yarn was frequently above 1; however, the measurement range is limited to values ≤1. Therefore, the KES-F3 system has limited utility for measuring LC, especially under low pressures for filament-yarn fabrics. Plotted without rayon filament fabrics, the results showed a linear relationship between LC and To, uncrushed thickness (Fig. 1). The points which are shown in Fig. 1 plot

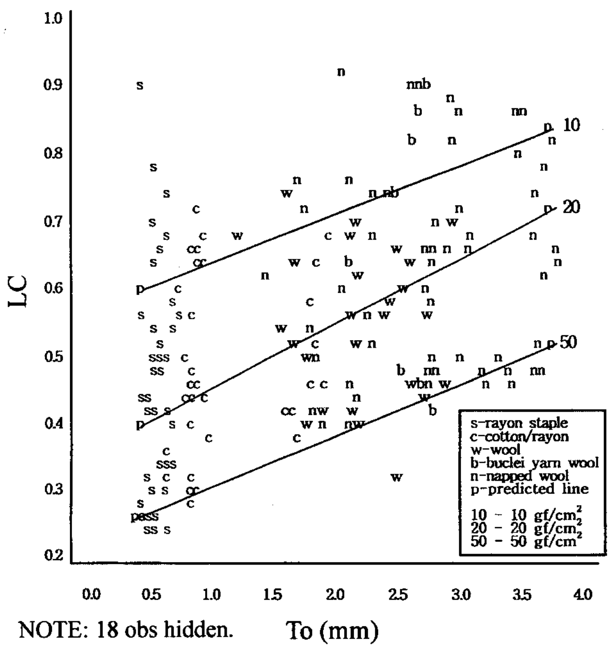

Fig. 1. The relationship between compressional linearity (LC) and uncrushed thickness (To).

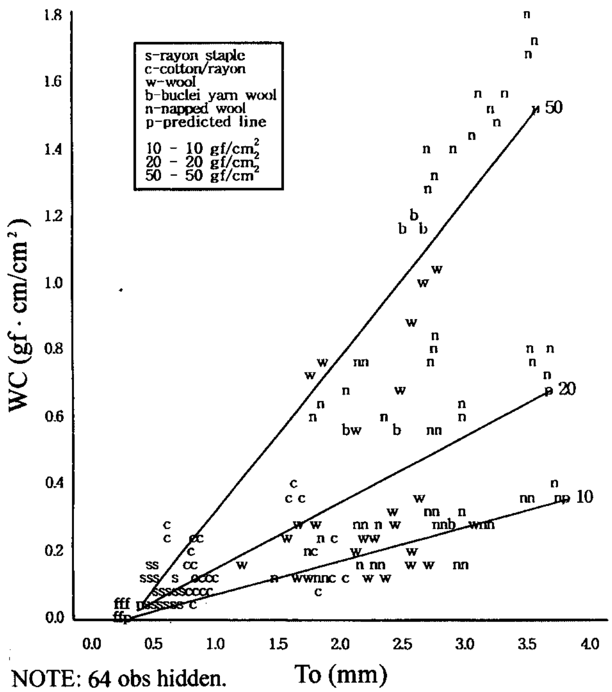

Fig. 2. The relationship between compressional energy (WC) and uncrushed thickness (To).

the results of 3 repeated measurements. The 'note' at the bottom of figure represents the number of hidden measurement observations. The slopes are similar, and the intercepts are different according to the loads used. The thicker fabrics (wool blends represented as "w", and napped wool as "n") show higher linearity than the thinner fabrics (rayon fabrics of spun yarns as "s", and rayon/cotton blends as "c"). Napped wool fabrics are at the top of the scale, followed by unnapped wool blends, R/C blends, and rayon spun yarns. The LC regression lines at 10, 20 and 50 gf/cm^2 were calculated as follows:

$$LC_{10} = .57+.08\ To\ (r^2=.48,\ Pr<.0001)$$

$$LC_{20} = .37+.10\ To\ (r^2=.70,\ Pr<.0001)$$

$$LC_{50} = .24+.08\ To\ (r^2=.71,\ Pr<.0001)$$

Compressional energy (WC) : The thicker the fabric, the higher the compressional energy value (WC) it exhibits (Fig. 2). The same types of fabrics are clustered together on the graph. The thickest napped wool fabrics have the highest WC, followed in order by the unnapped wool blends, R/C, rayon spun yarns and rayon filaments (shown as "f"). The WC of rayon filaments is the lowest, regardless of the pressure applied. The slopes varied different according to the pressure applied, with a pressure 50 gf/cm^2 exhibiting the steepest slope. The best fit lines are found separately. The regression equations are shown below:

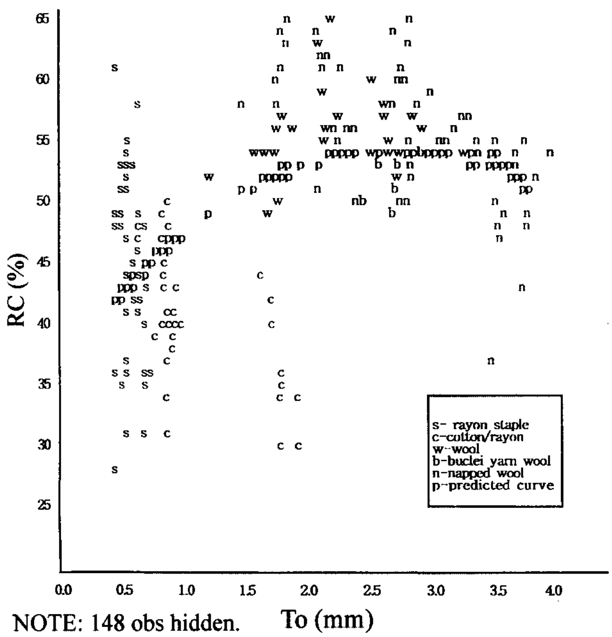

Fig. 3. The relationship between compressional resilience (RC) and uncrushed thickness (to).

$$WC_{10}=-.01+.10\ To\ (r^2=.88,\ Pr<.0001)$$

$$WC_{20}=-.06+.21\ To\ (r^2=.86,\ Pr<.0001)$$

$$WC_{50}=-.15+.49\ To\ (r^2=.85,\ Pr<.0001)$$

Compressional resilience (RC) : As shown in Fig. 3, fabrics of mid-range thickness have the highest RC values. This result implies that the long surface hairs of napped wool fabrics displayed weak recovery from compression. According to Scheifer (1933) the compressional resilience was found to increase with the thickness of the specimen. This is because Schiefer used pressures of 7-140 gf/cm^2 to measure compressional resilience while this study used pressures of 0.5-10, 20, or 50 gf/cm^2. Also, Schiefer used 70 gf/cm^2 to measure fabric thickness, but this study used .5 gf/cm^2 (i.e. 'uncrushed').

Since there the RCs remained constant under three loads, only one regression equation was obtained. The RC and the fabric thickness have a curved relationship.

$$RC=37.2+13.3\ To-2.61\ To^2\ (r^2=.28,\ Pr<.0001)$$

3.2. Thicknesses and subjective senses of thickness

Hand-evaluation rankings of thickness and compressional resilience for the twelve fabrics were correlated thicknesses measured using the KES-F3 system at various pressures. The median ranks obtained from the 4 panels were run correlated with objective thickness values. The Spearman rank correlation coefficient between subjective thickness and subject compressional resilience was .81 (P<.01). Table 2 represents Spearman rank correlation coefficients between objective thickness and subjective thickness and compressional resilience. The subjective thickness values are correlated more closely with objective fabric thickness obtained ≥ at 20 gf/cm^2 than at ≤10 gf/cm^2, while the subjective compressional resilience values showed a higher correlation with objectively measured thicknesses at ≤10 gf/cm^2 than ≥20 gf/cm^2.

3.3. Compressional properties and subjective compressional resilience

Table 3 shows that subjective thickness is not related to objective compressional properties, but subjective compression resilience is closely related to the compressional properties (with the exception of RC). This is because RC shows a curved relationship with fabric thickness. LC measured at 20 gf/cm^2 and WC measured at 10 gf/cm^2 have the highest correlation coefficients, .86, .83 respectively, in predicting of the subjective compressional resilience.

Measured at different loads, the relationship between subjective compressional resilience and WC was greater at 10 (r=.84) or 20 gf/cm^2 (r=.82), than at 50 gf/cm^2 (r=.78) or at 70 gf/cm^2 (r=.79). LC measured at 20 gf/cm^2 was most highly related to subjective compressional resilience (r=.86), followed in order by LCs measured at 35 gf/cm^2 (r=.82) and 50 gf/cm^2 (r=.78). Therefore, to predict the

Table 2. Spearman rank correlation coefficients between fabric thicknesses and the ranks of subjective hand for thickness and compressional resilience

Coefficient	Thickness measured at _gf/cm^2					
Significance # of samples	.5	10	20	35	50	70
	.79	.84	.93	.92	.91	.92
Subjective Thickness	.0024	.0006	.0001	.0001	.0001	.0001
	12	12	12	12	12	12
Subjective	.89	.89	.84	.86	.83	.81
Compressional	.0001	.0001	.0006	.0004	.0009	.001
Resilience	12	12	12	12	12	12

Table 3. Spearman rank correlation coefficients between objective compressional properties and the ranks of subjective thickness and compressional resilience

Coefficient Significance # of samples	LC (at__gf/cm²)					WC (at__gf/cm²)					RC (at__gf/cm²)				
	10	20	35	50	70	10	20	35	50	70	10	20	35	50	70
Subjective thickness	.20 N.S. 12	.49 N.S. 12	.65 * 12	.60 * 12	.69 * 12	.62 * 12	.54 N.S. 12	.51 N.S. 12	.50 N.S. 12	.51 N.S. 12	.36 N.S. 12	.20 N.S. 12	-.03 N.S. 12	.26 N.S. 12	-.06 N.S. 12
Subjective compressional resilience	.64 * 12	.86 *** 12	.82 ** 12	.78 ** 12	.71 ** 12	.84 *** 12	.82 ** 12	.80 ** 12	.78 ** 12	.79 ** 12	.09 N.S. 12	-.01 N.S. 12	-.11 N.S. 12	.04 N.S. 12	-.11 N.S. 12

N.S.: statistically insignificant *represents <.05, **<.01, ***<.001

subjective handle of fabrics, objective measures should be obtained at pressures lower than 50 gf/cm^2.

4. Conclusions

To find out the compressional behavior of fabrics ranging from rayon through wool double fabrics, compressional property measures were plotted according to the uncrushed specimen thickness. Thick fabrics (wool blends and napped wool blends) had higher LC and WC values than thin fabrics (rayon, and rayon blends). Pressure increases applied to the specimens, increased LC values, and decreased WC values, without affecting RC values. The load effects on WC were greater for thick fabrics than for thin fabrics. The LC of rayon filaments under a pressure of 10 gf/cm^2 was frequently larger than 1. Thus, LC for very thin fabrics at 10 gf/cm^2 maximum pressure is not recommended. Higher RCs were obtained for medium-thickness fabrics because their napped hair had low latent recovery power.

Objective fabric thickness measurements obtained at 20 gf/cm^2 were closely related to subjective thickness rankings, objective thickness measurements obtained at 10 gf/cm^2 were closely related to subjective compressional resilience rankings. WC and LC are more closely related than RC to subjective compressional resilience. Also, pressures of 10 gf/cm^2 and 20 gf/cm^2 are most closely related values to subjective compression hand rankings. Of the 5 pressures tested, compressional properties obtained at 20 gf/cm^2 were most closely related to subjective compressional resilience measures, because LC at 10 showed lower correlation coefficients. Thus, to predict hand rankings of fabrics practically, the maximum load for compression must be lower than 50 gf/cm^2.

국문요약 : 두께와 무게가 다양한 23종의 직물을 대상으로 최대하중 10, 20, 35, 50, 70 gf/cm^{2}의 5종류 다양한 조건하에서 압축-두께곡선을 측정함으로써 저응력에서 압축특성과 두께, 태를 분석하였다. 최대하중이 증가함에 따라 LC(curve linearity)는 증가하였으며 WC(compressional energy)는 감소하였다. 또한, 최대하중에 따라 RC(compressional resilience)는 변화가 없었다. LC와 WC는 직물이 두꺼울수록 크게 나타났으며 RC는 중간 두께의 직물에서 가장 크게 나타났다. 최대하중 20 gf/cm^{2}에서 측정한 LC와 WC가 주관적 태 평가결과와 가장 상관이 깊었으며 Spearman's rho는 .86과 .82였다.

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