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Physical Properties of Ultra-fine Denier Filament Yarn Fabric

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Abstract

Various high-touch textile products have been developed recently including ultra-fine denier filament yarn fabrics. The touch or hand of high value-added products is of prime importance. Physical and mechanical properties of fabric specimens, ultra-fine denier filament yarn fabric specimen, 100% wool fabric and wool/polyester 50:50 fabric,were measured using the KES. Compressibility of the ultra-fine denier fabric is recommendable, possibly due to the good bulk property of the specimen.

Overall, the THV of the ultra-fine denier fabric is positioned between those of the 100% wool fabric and wool/polyester 50:50 fabric. Observed differences in the physical and mechanical properties explain the fabric specimen characteristics reasonably.

Key Words : Ultra-fine fiber, Polyester, Hand Value, Tensile, Compression

I. Introduction

High-touch fiber is defined as a fiber that appeals to human sensitivity, including the tactile sense, visual sense, and auditory sense. As one of the high-touch fibers, the ultra-fine fiber technology was developed first to produce artificial leather, and further developed for such applications as a wiping cloth and a high-density fabric.[1] The touch of a fiber is determined by the mechanical properties, softness, warmth, smoothness or clinginess. Ultra-fine fiber fabric has the characteristics of excellent soft touch, bulkiness, and unique color. Visual characteristics may include hue, luster, shape, and pattern factors.[2] Rustling sound of silk fabric is another factor that pleases our ears.

Numerous textile fiber manufacturers have been developing and supplying micro fiber or ultra-fine fiber textile products. One of the manufacturers, for example, Toray, created polymer patterns as early as 1968 through the island-in-the-sea type composite fiber spinning technology. The company has applied the technology to various ultra-fine fiber products including nonwoven synthetic suede, multipurpose wiping cloth, and high precision filter media. With the advent of ultra-fine fibers, the diameter of fibers was further reduced to the order of micrometers.

While the island-in-the-sea type ultra-fine fiber fabrics need subsequent splitting processes, direct spinning type ultra-fine fiber fabrics do not require additional splitting processes. In the finishing process, direct spinning type ultra-fine fiber fabrics do not need a weight-reduction finishing process, thereby leading to a more environment-friendly process.

The ultra-fine fibers have found niche market in the range of artificial leather. One of the examples: the leather includes ultra-fine polyamide fibers, and the textile product is processed to have a grained surface, bright color, and delicate touch free from rubber-like feeling, and durability. An entangled fiber base is provided comprising ultra-fine polyamide fibers and bundles; polyurethane including polyoxyethylene of molecular weight of 500-5,000 may be applied. The polyamide ultra-fine fibers are dyed with a metal-dye complex and a fixing agent.[3)] Interesting use of the micro fibers includes a bathrobe comprising a nonwoven micro fiber fabric, having a high water absorption capability, a low volume and a bathrobe weight from 200 to 400 grams for a standard user size bathrobe. The micro fiber product may comprise 50% polyester micro fibers and 50% nylon micro fibers so blended as to provide a nonwoven construction absorbing a water weight up to 400% of the bathrobe weight.[4)]

When comparing an ultra-fine single filament fiber with a regular single filament fiber in terms of mechanical properties, the bending rigidity of the fiber reduces most notably. The bending rigidity or stiffness of a fiber is defined as the couple required to bend the fiber to unit radius of curvature.[5)]

$$\text{Bending rigidity} = \frac{1}{4\pi}\frac{\eta E T^2}{\rho} \times 10^{-5}\,\text{gfcm}^2$$

<Equation 1>

where η = shape factor (1 for a circular fiber),

ρ = density in g/cm^3,

T = tex of filament,

E = modulus in gf/tex.

As shown in <Equation 1>, as the T^2 value decreases, the bending rigidity also decreases. Therefore, ultra-fine fiber exhibits much less bending rigidity and becomes pliable compared to the regular polyester fiber. This will eventually lead to a soft-touch fabric after a number of subsequent processes. However, there are other factors to consider due to the increased number of single filaments in a yarn, such as fiber-to-fiber friction and/or hysteresis factors related to some deformation in a fabric.

The KES(Kawabata Evaluation System), developed by Prof. Kawabata, Japan, is a testing methodology that has been used with considerable success for predicting the hand and tailor ability of apparel fabrics. Peirce[6)] reported that physical and mechanical properties of fabrics are closely related to the hand of fabrics. Hoffmann and Beste[7)] identified the contribution made by compressional properties to softness. These properties are associated with the attributes of fabric leanness and bulk. Brand[8)] reported fabric bulk is an important factor in the aesthetic evaluation of fabrics.

This study used the KES equipment to measure the mechanical and surface properties of ultra-fine denier polyester filament yarn fabric, 100% wool fabric, and wool/polyester 50:50 fabric specimens in order to evaluate the primary hand values together with the total hand value(THV).

II. Experiments

1. Measurement

The KES system comprises four precision instruments designed to measure important mechanical properties related to the hand, drap ability, and formability of fabrics. All samples were tested in both warp and filling directions for tensile and shearing properties, pure bending properties, and surface smoothness and frictional properties, except for compression properties.

The KES tensile tester hold the specimen between two grips and extends until a specified maximum force (F_{max}=500gf/cm) is exerted on the specimen during the cycle of tensile deformation. In KES bending test, the specimen is bent in the range of K=−2.5 ~ +2.5cm^{-1}. KES surface tester uses two different sensors to register the geometric roughness and the coefficient of friction of the fabric surface. In compression test, the sample is positioned on a platform equipped with a force transducer covering an area of 2cm^2. A motor-driven plunger, descending at a rate of 0.02mm/sec, compresses the fabric sample. Plunger displacement is registered by a potentiometer.

From the generated charts, constants characterizing the fabric mechanical and surface properties were calculated. These charts also permit study of the recovery properties or hysteresis behavior in stretching, shearing, bending and compression. All the test were carried out at small degrees of deformation, similar to what happens when the fabrics are handled or when they are spread, cut, fused, sewn, or shaped and molded.

From the physical/mechanical parameters measured using the KES, translational equations were used to estimate the primary hand values, KOSHI, NUMERI, FUKURAMI, and SOFUTOSA, based on KN-201-MDY women's winter suiting, and the THV(Total Hand Value) for winter suiting based on KN-301-Winter.

The primary hand values are defined as follows:

KOSHI(Stiffness): Stiff and springy property in bending deformation. Stiff in shearing and the compressional properties. Thin fabric in proportion to its weight increases KOSHI.

NUMERI(Smoothness) : Smoothness which comes from smaller variations of frictional force and smooth surface. Each of bending, shearing and compressional properties has small rigidity and is springy.

FUKURAMI(Fullness and Softness) : Softness in the compressional property. Smooth surface and soft extensibility.

SOFUTOSA(Soft Feeling) : Soft feeling comprising voluminous feeling and smoothness.

2. Fabric specimens

In order to compare the hand-related physical/mechanical properties of fabrics, ultra-fine denier polyester filament yarn fabric, whose ultra-fine denier yarn is heat-treated and twisted together with highly shrinkable polyester flat yarn to impart needed fabric property, developed by Hyosung Corp., commercially available wool fabric(high price) and wool/polyester fabric(medium price) specimens for women's winter weight were selected.

<Table 1> List of fabric specimens

Sample No.	Material	Fabric count (ends/cm x picks/cm)	Weight(g/m^2)
1	Wool 100%	39 x 39	181.2
2	Wool 50% / polyester 50%	24 x 23	181.4
3	Polyester 100% (Ultra-fine denier)	60 x 34	155.1

III. Results and Discussion

1. Measured KES parameters

The physical and mechanical properties measured using the KES are listed in Tables 2 through 6.

As shown in <Table 2>, LT1 and LT2 represent tensile linearity for warp direction, and that for weft direction, respectively. The numbers,1 and 2, at the end of each parameter represent warp and weft direction, respectively. LT is the average value of LT1 and LT2. WT represents tensile energy or tensile work done during the initial tensile extension up to the F_m(Maximum Load). EMT represents tensile extensibility. RT is the tensile resilience. WT data and EMT data show that sample 1 and sample 2 have extensible property, while sample 3 is not so extensible as the others. This may be attributed to the fact that sample 3 is made from almost linearly structured filament, eventhough the sample 3 has a certain level of crimps developed during the yarn manufacturing process, compared to the spun yarn structure of the other two(wool or wool/polyester spun yarn).

In <Table 3>, G(shear rigidity), 2HG(shear hysteresis at 0.5degree), and 2HG5(shear hysteresis at 5 degrees) of fabric specimens during shearing deformation cycle are presented. As the G value increases, the shear stiffness of the fabric increases. Shear properties are related to the harmony of fabric and wearer's body surface, and drap ability. Shear deformation behavior depends firstly on tensile and shear resistance of the comprising yarns, secondly on the increase of interactions of cross-over points, e.g., warp-weft friction, and on the bending behavior of yarns, and thirdly on the yarn compressions. Since the number of yarns in a unit area of the fabrics specimen is high for the sample 3(ultra-fine denier fabric), the number of cross-over point in a given area is high, leading to the increase of warp-weft friction, and resulting in the increase of G(shear rigidity). At the same time, recovery from the initial shear deformation is also affected by the cross-over points, resulting in the increase of 2HG and 2HG5, meaning the recovery from the initial deformation is low. The other factor may be related to the inherent property differences of yarn structures.

<Table 2> Tensile properties of fabric specimens

Sample	LT1	LT2	WT1 gf·cm/cm^2	WT2 gf·cm/cm^2	RT1 %	RT2 %	EMT1	EMT2	LT	WT gf·cm/cm^2	RT %	EMT
1	0.664	0.601	9.45	12.80	63.49	62.89	5.69	8.52	0.633	11.13	63.19	7.11
2	0.713	0.74	17.30	6.40	61.45	65.63	9.71	3.46	0.727	11.85	63.54	6.59
3	0.902	0.883	8.75	3.60	54.29	52.78	3.88	1.63	0.893	6.18	53.54	2.76

<Table 3> Shear properties of fabric specimens

Sample	G1 gf/cm·deg	G2 gf/cm·deg	2HG1 gf/cm	2HG2 gf/cm	2HG51 gf/cm	2HG52 gf/cm	G gf/cm·deg	2HG gf/cm	2HG5 gf/cm
1	0.61	0.56	0.52	0.52	1.40	1.20	0.59	0.52	1.30
2	0.66	0.64	0.67	0.58	1.83	1.67	0.65	0.63	1.75
3	1.20	0.85	2.20	1.15	4.53	3.45	1.03	1.68	3.99

With some modification in the fabric treatment process, such as softener treatment in order to reduce the yarn-to-yarn friction, the shear property may possibly be improved within some limited range.

In <Table 4>, B(bending rigidity) and 2HB (bending hysteresis) of fabric specimens during bending deformation cycle are given. As the B value increases, the bending stiffness of the fabric increases. Bending property of fabric is influenced by the yarn bending property, and yarn-to-yarn friction properties along with the treatment effect such as softener or other finishing agents. Bending rigidity of sample 3 is low compared to those of the other two specimens as expected. Sample 2, wool/polyester 50:50, shows the highest B value for both warp and weft. 2HB of sample 3 is the highest due to the similar reasons discussed as in the shear hysteresis behavior interpretation. Even thought the B of ultra-fine denier fabric is low, recovery from the fully bent state might possibly be hindered by the friction at the warp-weft cross-over points.

Compression properties are closely related to the thickness, volume, and other factors such as surface fibers protruding from the fabric surface. Compression tester presses the specimen until a specified pressure on the specimen is reached, and resumes to the original position after initial compression, and registers the thickness values along with the pressure signals. In <Table 5>, T_0 value of sample 3 is the highest, followed by those of samples 2 and 1. Considering the fact that the unit area weight of sample 3 is the lowest, this may be interpreted as sample 3 having voluminous feel. The thickness difference value, (T_0-T_m), of samples 2 and 3 is high enough compared to that of sample 1. This may also be interpreted as sample 3 having better compressibility. WC (compression energy) of sample 3 is the highest. This also supports the fact that sample 3 is easily compressible. RC(compression resilience) value of sample 1 is the highest, followed by that of sample 3. RC of sample 2 is the lowest.

Surface texture of apparel fabric is related closely to the surface friction and surface geometrical roughness. As shown in <Table 6>, the MIU (friction coefficient) of sample 3 is the highest. The MMD(mean deviation of MIU) of sample 1 is the lowest, followed by that of sample 3. That of

<Table 4> Bending properties of fabric specimens

Sample	B1 gfcm2/cm	B2 gfcm2/cm	2HB1 gfcm/cm	2HB2 gfcm/cm	B gfcm2/cm	2HB gfcm/cm
1	0.0593	0.0459	0.0182	0.0112	0.0526	0.0147
2	0.0720	0.1027	0.0187	0.0426	0.0874	0.0307
3	0.0398	0.0525	0.0362	0.0358	0.0462	0.0360

<Table 5> Compression properties of fabric specimens

Sample	LC	WC gfcm/cm2	RC %	T_0 mm	T_m mm	(T_0-T_m) mm
1	0.334	0.106	58.49	0.579	0.452	0.127
2	0.375	0.133	47.37	0.630	0.488	0.142
3	0.477	0.168	57.14	0.659	0.518	0.141

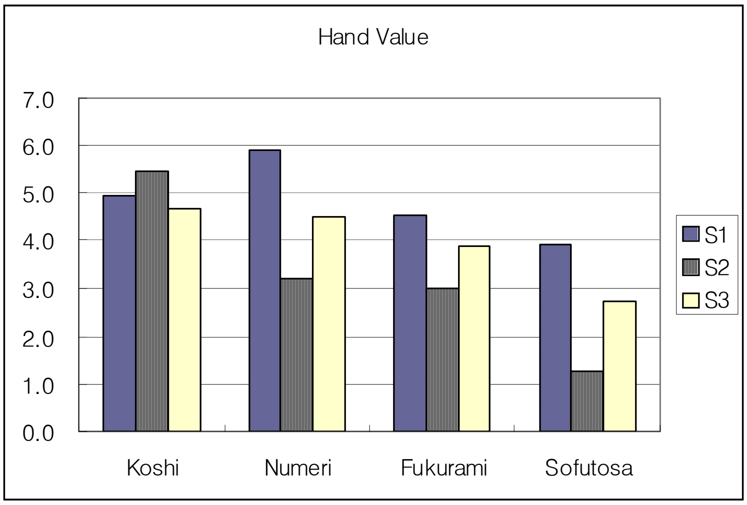
sample 2 is the highest. The SMD(surface roughness) of sample 1 is the lowest, followed by sample 3. That of sample 2 is the highest. This friction and roughness parameters are important factor in predicting NUMERI(Smoothness), one of primary hand values.

2. Predicted primary hand values(PHV) and total hand value(THV)

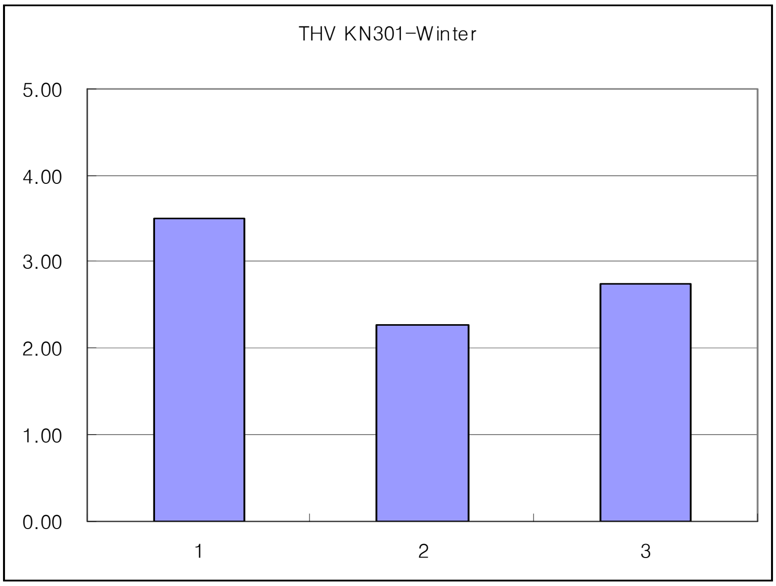
The tactile responses generated in touching fabrics are generally complicated and require intensive interpretation process to be useful. From the physical and mechanical parameters measured using the KES, it is possible to predict subjective responses such as softness, smoothness, etc, based on the translational formulae prepared by Profs. Kawabata, Niwa, and the HESC(Hand Evaluation Stand. Committee), with some limitations. Based on KN-201-MDY, KOSHI, NUMERI, FUKURAMI, and SOFUTOSA values were calculated from the KES data of the fabric specimens as shown in <Fig. 1>.As expected, sample 3(ultra- fine denier) has the lowest KOSHI(Stiffness) value, meaning the sample is somewhat softer. NUMERI(Smoothness) of the sample 3 is positioned between those of the two other fabric specimen's. FUKURAMI(Fullness and Softness) value of the sample 3 is also positioned between those of the two other fabric specimens. SOFUTOSA(Soft Feeling) value of the sample 3 is similar to the trend of FUKURAMI.

<Table 6> Surface properties of fabric specimens

Sample	MIU1	MIU2	MMD1	MMD2	SMD1	SMD2	MIU	MMD	SMD
1	0.124	0.131	0.0115	0.0107	2.260	2.095	0.128	0.0111	2.178
2	0.154	0.228	0.0279	0.0257	7.580	3.495	0.191	0.0268	5.538
3	0.207	0.249	0.0111	0.0185	2.880	2.525	0.228	0.0148	2.703



<Fig. 1> Primary hand of fabrics calculated using KN201-MDY.



<Fig. 2> Total hand value(THV) of fabric specimens.

The THV(Total Hand Value) is an overall evaluation of the fabric specimens, ranging from 0(out-of-use) to 5(excellent). As expected, the sample 1 in <Fig. 2> shows THV of 3.5(average ~ good). THV of sample 3 is 2.75, a little below average, and that of sample 2 is 2.26. Overall, the ultra-fine denier fabric specimen is positioned between the two fabric specimens, 100% wool fabric and wool/polyester 50:50 fabric. With further modified finishing process, some improvement in the hand-related properties may be possible.

Conclusions

Ultra-fine denier filament yarn fabric specimen was compared with 100% wool fabric and wool/polyester 50:50 fabric specimens. Physical and mechanical properties of fabric specimens were measured using the KES. The shear rigidity of the ultra-fine denier fabric is higher than those of the other fabrics. Bending rigidity of the ultra-fine denier fabric is the lowest of all. Bending hysteresis, however, of the ultra-fine denier fabric is higher possibly due to the yarn-to-yarn friction, which could be improved by further softening agent treatment in the finishing process. Compressibility of the ultra-fine denier fabric is recommendable, possibly due to the good bulk property of the specimen.

Overall, the THV of the ultra-fine denier fabric is positioned between those of the 100% wool fabric and wool/polyester 50:50 fabric. Further finishing process parameter considerations might possibly improve the hand-related properties of the ultra-fine denier fabric.

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