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Sound Characteristics according to Cross-sectional Shapes of Fibers

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Abstract: In order to investigate the effects of cross-sectional shapes on the sound characteristics of polyester fibers, 10 specimens were woven into a twill structure made of round, hollow, triangular, u-shape, cruciform, and composite cross-sectional (▲/▴, ( )/▴, Y/Y) fibers. Their rustling sounds were recorded, and their sound spectra were obtained from FFT analysis. Physical sound parameters (LPT, ΔL, Δ*f*) and Zwicker's psychoacoustic parameters of the loudness(Z), sharpness(Z), roughness(Z), and fluctuation strength(Z) were calculated from the sound spectra. According to noncircular cross-section fibers, the hollow shaped fiber had the highest value of LPT, ΔL, loudness(Z), and fluctuation strength(Z). The triangular shaped fiber had a lower value of LPT, ΔL, loudness(Z), and roughness(Z) than those of the round shaped fiber. Among composite cross-section fibers, C1 (▲/▴) and C3 (Y/Y) had higher values of LPT, ΔL, Δ*f*, and loudness(Z) but C2 (( )/▴) had lower values. Also the LPT, ΔL, sharpness(Z), and roughness(Z) values of different denier were similar to each other, but the Δ*f* and loudness(Z) values increased as the denier increased.

Keywords: Rustling sound, Physical sound property, Psychoacoustic parameter, Noncircular cross-section, Composite fiber

Introduction

The rustling sound of fabric is the frictional sound generated when fibers or fabrics are rubbed against one another and is increased by increasing the difference between static friction and dynamic friction [1]. Scrooping sound, an inherent property of silk, makes us pleasant, but the rustling sound of coated fabric makes us unpleasant. Thus the auditory sensation of fabric is an important factor of evaluating textile quality along with tactile sensation.

It was reported that the scrooping sound of silk fabrics could be imitated by using ultra-fine fiber and micro-slits in a trilobal-shaped cross section of a polyester fiber [2]. In the studies of comparing the sound wave forms of silk-like polyester fabric and natural silk fabric, the patterns of the forms are very close to each other because they have the same trilobal cross-section [1,3]. Fabrics made of noncircular shaped yarns have less bending and shear rigidity values than those of round ones [4] and have firmer and crisper handle than the very smooth handle of fabrics made from round filament [5]. Fiber cross-sectional shape can change not only tactile sensation but also the rustling sound of fabric as mentioned previously. However, there have been very few studies on how fiber cross-sectional shape can influence the rustling sound of fabrics.

In the study on the relationship between the physical characteristics of fabric sounds and the mechanical properties of fabrics it was reported the rustling sounds of general fabrics were related to their bending, shear, and surface properties [6]. In addition, we investigated the effect of weave differences and yarn type variations on fabric sound [7], and showed weave types change the amplitudes of the sound spectra while the yarn type determines the shapes of the spectra.

Then fabric sound is changed by cross-sectional shape, fiber, yarn, and weaving types. A series of fabric sound studies in the macroscopic views have been approached, but no studies about analyzing the sound characteristics in the microscopic views such as fiber cross-sectional shape have been found. Therefore the purpose of this study is to compare the spectra shapes of fabric sound, and to analyze the physical and psychoacoustic sound parameters of fabric sound generated by various fiber cross-sectional shapes. Furthermore, we compared the sound characteristics according to the denier.

Experimental

Specimens

Ten specimens were 100 % polyester woven fabrics made of different cross-sectional shapes of weft yarns. Eight specimens had a 75 denier weft yarn. One was round, 4 non-circular (triangular, hollow, cruciform, u-shape) and 3 had composite cross-sections (▲ + ▴, ( ) + ▴, Y + Y). And two specimens were of round and triangular shaped fibers with a 50 denier weft yarn to compare sound characteristics according to the denier. Specimens were woven using the same loom and weaving conditions. The characteristics of the specimens are given in Table 1.

Fabric Sound Recording

The rustling sounds of the specimens were generated by a measuring apparatus for fabric noise (MAFN, patent no. 2001-0073360) [8] and were recorded using a Sound Quality System (Type 7698, B&K). This was calibrated with a sound level calibrator (Type 4231, B&K) before the recording. Two

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Table 1. Characteristics of specimens

Fiber cross-section		Weft yarn density (d/f)	Woven structure	Fabric density (warp/cm×weft/cm)
Round	(●)	75/36$^+$	2/1 twill	45 × 45
Triangular	(▲)	75/36$^+$	2/1 twill	45 × 45
Hollow	(◎)	75/24$^+$	2/1 twill	45 × 45
Cruciform	(+)	75/36$^+$	2/1 twill	45 × 45
U-shape	(U)	75/48$^+$	2/1 twill	45 × 45
C1	(▲ + ▲)	75/48$^+$	2/1 twill	45 × 45
C2	(( ) + ▲)	75/48$^+$	2/1 twill	45 × 45
C3	(Y + Y)	75/48$^+$	2/1 twill	45 × 45
Round1	(●)	50/24^{++}	2/1 twill	45 × 45
Triangular1	(▲)	50/24^{++}	2/1 twill	45 × 45

$^+$ warp yarns were 75 denier and round shapes.
$^{++}$ warp yarns were 50 denier and round shapes.

pieces of each specimen were rubbed against each other in selvage direction.

Fabric Sound Analysis

The sound spectrum was analyzed by a FFT at frequencies ranging from 0 to 17 250 Hz using the Sound Quality Program (ver 3.2, B&K). The sound color of the specimens such as the values of the level pressure of total sound (LPT), the level range (ΔL), and the frequency difference (Δf) were quantified using equations mentioned in previous studies [6]. In addition, the psychoacoustic Zwicker's loudness parameters [9]; loudness(Z), sharpness(Z), roughness(Z) and fluctuation strength(Z) were calculated with the BZ5652 software [10].

Statistical Analysis

We analyzed the data with Pearson's correlation to identify the relationship between physical sound properties and psychoacoustic parameters according to cross-sectional shapes using the SPSS package (ver. 11.0).

Results and Discussion

Sound Characteristics according to Fiber Cross-sectional Shapes

Sound Spectra according to Cross-sectional Shapes of Fibers

The sound spectra from round and noncircular cross-section fibers with 75 denier are presented in Figure 1. Their amplitudes ranged between 20 (cruciform)~44.3 dB (hollow). The curve shapes of specimens increased from about 3 000 Hz but decreased after about 10 000 Hz. The curve of the spectrum of hollow shaped fiber was the highest and those of u- and cruciform shaped fibers were similar to each other, so they are thought to have similar fabric sound properties.

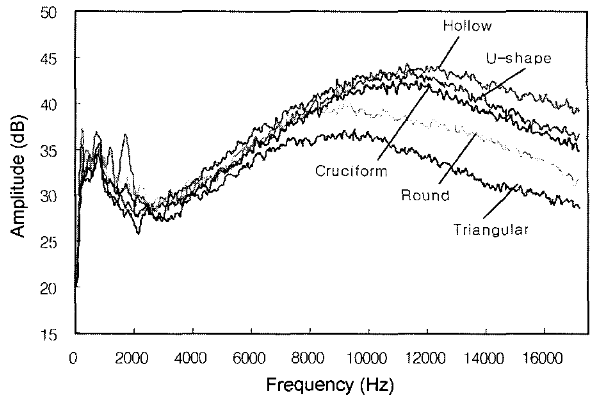

Figure 1. Sound spectra of round and non-circular cross-section fibers.

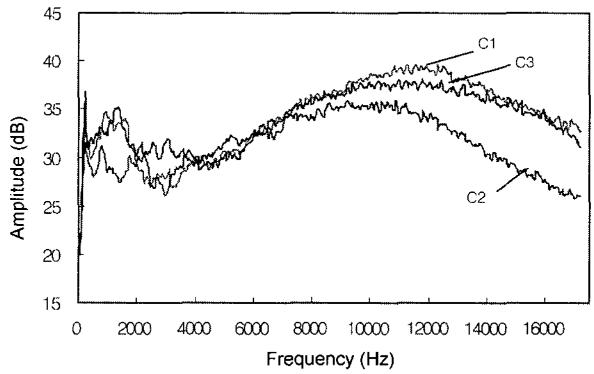

Figure 2. Sound spectra of composite fibers.

Comparing noncircular shaped fibers to the round one, the curve of spectrum of the triangular shaped fiber was lower than that of the round one, but those of the cruciform, u-shape, and hollow shaped fibers were higher.

The sound spectra from composite cross-section fibers are shown Figure 2. Their amplitudes ranged between 20.8 (C2) ~ 42 dB (C1). These showed deep curves at a frequency of about 3000 Hz as well as in the spectra of noncircular shaped fibers. The curve shapes of C1 and C3 were similar in high frequency. The curve of spectrum of C2 was similar to the curve of the triangular shaped fiber. And the spectra of C1 and C3 showed higher curve than that of the triangular shaped fiber above 9 000 Hz.

The results show that the sound spectra of fiber cross-sectional shapes were generally S-shaped and only had different heights to the curves at high frequencies. The peak of the curve of sound spectra of polyester fabrics made of various fiber cross-sectional shapes appeared in high frequency while those of silk fabrics according to weave structure appeared in low frequency [7]. These differences would affect the sound characteristics, and we confirmed that the curve shape of sound spectrum could be designed by changing their cross-sectional shapes.

Table 2. Physical sound parameters of fabric made of various fiber cross-sectional shapes

Fiber cross-section	LPT (dB)	ΔL (dB)	Δ*f* (Hz)
Round	60.4	19.3	9173
Triangular	57.5	16.5	9518
Hollow	64.3	23.4	11327
Cruciform	62.4	22.5	10857
U-shape	63.5	22.5	11367
C1	59.9	19.9	12277
C2	56.4	15.2	9130
C3	59.2	17.1	11717

Physical Sound Properties according to Cross-sectional Shapes

The values of LPT, ΔL, and Δ*f* for fabrics made of various fiber cross-sectional shapes with 75 denier are shown Table 2. According to the results of the round and noncircular shaped fibers, the LPT values ranged from 57.5 (triangular) to 64.3 dB (hollow), which corresponded to those of normal conversation at 1 m (50~60 dB). Noncircular shaped fibers except the triangular fiber had higher values of LPT, ΔL, and Δ*f* than those of the round fiber. The hollow shaped fiber had the highest value of LPT and ΔL, followed by the u-shape, cruciform, round, and triangular. The order of their amplitudes from highest to lowest was the same as that of their sound spectra. The Δ*f* value of u-shaped fiber (11 367 Hz) was the highest, and that of the round shaped fiber (9 173 Hz) was the lowest.

Among the composite cross-section fibers, the LPT value ranged from 56.4 (C2) to 62.3 dB (C1). The values of LPT, ΔL of C1 were the highest due to more bending and shear rigidity values compared to the others [11], but those of C2 were the lowest. The LPT, ΔL, and Δ*f* values of C1 and C3 were higher than those of the triangular shaped fiber but those of C2 were similar. From these results we could confirm that physical sound properties were affected for cross-section shapes as well as the weave structure [7].

Psychoacoustics Properties according to Cross-sectional Shapes

The loudness(Z), sharpness(Z), roughness(Z), and fluctuation strength(Z) values for the cross-sectional shaped fibers with 75 denier are shown in Table 3. The loudness(Z) of the round and noncircular shaped fibers ranged from 9.03 (triangular) to 11.2 sone (hollow). The hollow shaped fiber was the loudest because of its higher bending and compression properties [12], followed by the u-, round, cruciform, and triangular shaped fiber. The round shaped fiber was louder than the triangular shaped fiber because the frictional coefficients and the bending rigidity of the fabrics made of triangular shaped fiber were lower than those of the round one [4]. Sharpness(Z) held a tight range of 3.32 (triangular) to 3.66 acum (u-shape), and the triangular shaped fiber was the lowest among them. The

Table 3. Psychoacoustic parameters of fabric made of various fiber cross-sectional shapes

Fiber cross-section	Loudness (Z) (sone)	Sharpness (Z) (acum)	Roughness (Z) (asper)	Fluctuation strength(Z) (vacil)
Round	10.30	3.38	1.95	1.57
Triangular	9.03	3.32	1.81	1.84
Hollow	11.20	3.54	1.70	2.08
Cruciform	10.20	3.61	1.82	1.45
U-shape	10.90	3.66	1.87	1.93
C1	9.45	3.38	1.83	1.84
C2	8.21	3.37	1.94	2.18
C3	9.75	3.24	1.78	1.80

roughness(Z) of the round shaped fiber had the highest value (1.95 asper) and the noncircular shaped fibers ranged between 1.70 (hollow) ~1.87 asper (u-shape). Fluctuation strength(Z) ranged from 1.45 (cruciform) to 2.08 vacil (hollow).

Among the composite cross-section fibers, C3 with two different sized Y-shaped fibers showed a loudness(Z) of 9.75 sone, while C2 with a composite cross-section of Y-shape and ( ) shape had a loudness(Z) of 8.21 sone. C1 and C3 had similar spectra shapes but C3 showed a more higher amplitude around 3 000 Hz, resulting in the highest loudness (Z); humans can respond to this frequency because their hearing ranges from 2 000 to 6 000 Hz [13]. Sharpness(Z) ranged between 3.24~3.38 acum, and fluctuation strength(Z) ranged between 1.78~1.94 asper, with both parameters showing similar values in the composite cross-sections.

Sound Characteristics according to the Denier

Sound Spectra according to the Denier of Round and Triangular Shaped Fibers

The sound spectra according to the denier of round and

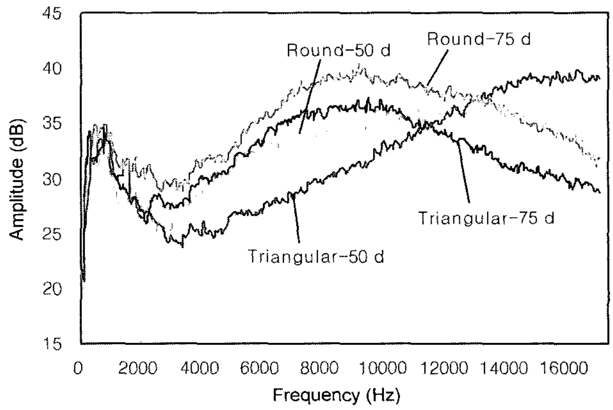

Figure 3. Sound spectra of round and triangular shaped fibers according to the denier.

triangular shaped fibers are showed in Figure 3. Their amplitudes ranged between 20 (round, 50 d)~40.4 (triangular, 75 d). The curve of spectrum of the round shaped fiber with a 50 denier was lower than that of the round fiber with a 75 denier. In the case of the triangular shaped fiber, the curve of spectrum of the 50 denier fiber was lower than that of the 75 denier fiber under 11 000 Hz.

Therefore the sound characteristics may increase by increasing the denier because the sound spectra of round and triangular shaped fibers of 75 denier were higher than those of 50 denier.

Physical Sound Properties according to the Denier of Round and Triangular Shaped Fibers

The values of LPT, ΔL, and Δf for round and triangular shaped fibers with different deniers are shown Figure 4. The LPT and ΔL values of 50 denier were similar to that of 75 denier but Δf of 75 denier was lower than that of 50 denier. And Δf of round shaped fiber was lower than that of the triangular shaped fiber in 50 denier as well as 75 denier.

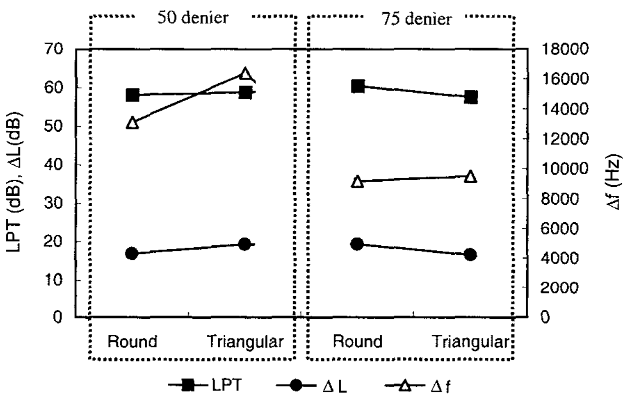

Figure 4. Physical sound properties of round and triangular shaped fibers by the denier.

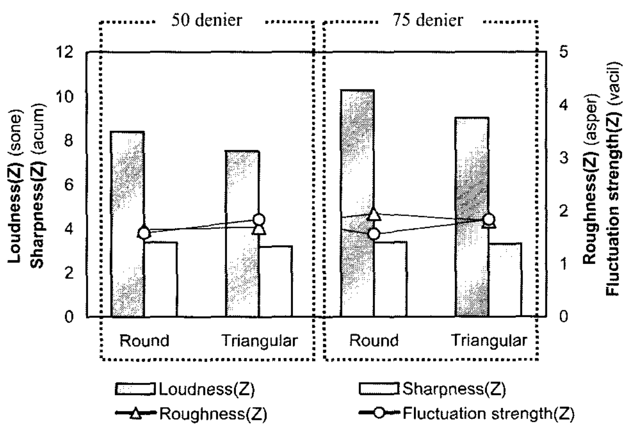

Figure 5. Psychoacoustics properties of composite shaped fibers according to the denier.

Table 4. Correlation coefficients between physical sound properties and psychoacoustic parameters by fiber cross-sectional shapes

	Loudness (Z)	Sharpness (Z)	Roughness (Z)	Fluctuation strength(Z)
LPT	0.86^{**}	0.76^{**}	–0.08	–0.08
ΔL	0.73^{**}	0.72^{*}	–0.11	–0.12
Δf	–0.44	–0.33	-0.72^{*}	–0.09

* p<0.1, **p<0.01.

Thus it can be said that the Δf is the factor to illustrate the difference of sound color between triangular and round shaped fibers.

Psychoacoustics Properties according to Denier of Round and Triangular Shaped Fibers

The loudness(Z), sharpness(Z), roughness(Z), and fluctuation strength(Z) values for the round and triangular shaped fibers with different denier are shown in Figure 5. Loudness(Z) of round and triangular shaped fibers with 75 denier were higher than that with 50 denier, which implies that the more increase in the denier, the louder the fabric sound. But the sharpness(Z), roughness(Z), and fluctuation strength(Z) were similar to each other and had no connection with the denier.

Relationship between Physical Sound Properties and Psychoacoustic Parameters by Cross-sectional Shaped Fibers

The correlation between physical sound properties and psychoacoustic parameters of fabric sound by various fiber cross-sectional shapes is shown in Table 4. Loudness(Z) was positively correlated with LPT and ΔL (p<0.01). Sharpness (Z) was also positively correlated with LPT (p<0.01) and ΔL (p<0.1). Roughness(Z) was related negatively to Δf (p<0. 1). Fluctuation strength(Z) was not related to any physical sound properties. Therefore, the higher LPT and ΔL, the louder and sharper the fabric sound of fiber cross-sectional shapes is, but the lower Δf, the rougher it is.

Conclusions

In this study, we obtained the rustling sounds of polyester fabrics made of various fiber cross-sectional shapes, such as round, hollow, triangular, u-shape, cruciform, and composite cross-sections (▲/▲, ( )/▲, Y/Y) using a measuring apparatus for fabric noise (MAFN). And we investigated the sound spectra of their rustling sounds by FFT and analyzed their physical sound properties and psychoacoustic parameters and compared the sound characteristics by the denier.

In the case of round and noncircular shaped fibers, the hollow shaped fiber had the highest value of LPT, ΔL, loudness(Z), and fluctuation strength(Z), but the triangular shaped fiber had a lower value of LPT, ΔL, loudness(Z), and roughness(Z) than those of the round shaped fiber. Therefore the hollow shaped fiber was louder and had a higher value of fluctuation strength than the others, while the triangular shaped fiber was less loud and rough than the others.

Among composite cross-section fibers, C1 (▲/▲) and C3 (**Y**/Y) had higher values of LPT, ΔL, Δf and loudness(Z) but C2 (( )/▲) had lower values of them. The rustling sound of C3 with two Y-shaped cross-sections of different size was louder than that of C1 with two triangular cross-sections of different size. But the rustling sound of C1 (▲/▲) was shaper than that of C3 (**Y**/Y).

In round and triangular shaped fibers with different deniers, Δf and loudness(Z) were increased by increasing the denier but LPT, ΔL, sharpness(Z), roughness(Z), and fluctuation strength(Z) values were similar to each other.

From these results it can be drawn that fiber cross-sectional shapes have an affect on loudness(Z) and sharpness(Z) but have hardly any effect on roughness(Z) and fluctuation strength (Z), and that the denier only influences loudness(Z). Therefore it is necessary to consider not only fabric structure and finishing but also fiber cross-sectional shapes and the denier to design a pleasant fabric sound or to reduce fabric noise.

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