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Effects of Cultivating Methods and Area on the Mechanical Properties of Cotton Fiber and Yarn

Abstract Two kinds of cotton fibers cultivated by different methods were measured and the mechanical properties of these fibers were compared with the mechanical properties of cotton yarns made of organic cotton fiber and non-organic cotton fiber. In this study, the mechanical properties of single cotton fibers and cotton yarns the authors measured and the moduli were calculated by assuming that the cross-section of the cotton fiber is elliptical. It was also found that the strains and stresses of breaking point of organic cotton fibers were larger than those of non-organic cotton fibers. Cotton fibers cultivated in different areas were then examined and it was found that the moduli of cotton fibers cultivated in the northern or southern hemisphere (USA and Australian cottons in this study) were very similar, and the yarn properties for yarns made from cotton fibers from both areas were also very similar. However, the yarn consisting of a mixture of cottons in the northern and southern hemispheres had larger strain, torsional stiffness and hysteresis. It was concluded that the deterioration of fibers consisting of a mixture of cotton contributes to the yarn properties, because the rules of surface orientation differ for cotton fibrils cultivated in the northern and the southern hemisphere as shown in Onogi's study (*Textile Res. J.* **66**, 406–410 (1996)).

Key words cotton fiber, cotton yarn, tensile property, shear property, compression property

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It is important to study the performance of cotton fiber products with respect to the environment in which they are used, but it is also difficult to study the mechanical properties of cotton fiber because of its irregular cross-section. In this study, the objectives were to clarify the differences in the fundamental mechanical properties of single cotton fibers in terms of how the fibers are affected by the following two points. First, the effect of the cultivating method, namely comparing cotton fiber grown using agricultural chemicals with organically grown cotton fiber, and comparing cotton yarns made of non-organic or organic cotton fibers. The sec-

ond point is the effect of the area of cultivation, namely whether the fiber was cultivated in the northern or southern hemisphere. This point of view is based on research by Onogi [1]. It has been reported that the rules of surface orientation differ for cotton fibril cultivated in the northern and southern hemispheres, regardless of the growing regions and the kinds of cotton. On the basis of these rules, the authors supposed that the mechanical properties of the yarns which made up

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the mixture of cotton fibers cultivated in the northern and southern hemispheres would be different from the yarn made entirely of fibers cultivated in the same area.

Experimental

Samples

The samples used to study the effects of cultivating methods were non-organic (TS), organic supima (OS), organic regular cotton (OG), and the samples used to study the effects of cultivating areas were USA cotton (US), as representative of cotton from the northern hemisphere, and Australian cotton (AU), as representative of cotton from the southern hemisphere. Both US and AU samples were considered non-organic. In this study, it was assumed that the cross-section of the cotton fiber was elliptical, and the longer and shorter diameters of each cotton fiber were individually measured using an optical microscope. The mechanical properties of the cotton fibers were measured using a tensile tester (KES-G1) and torsion tester developed by Kawabata [2].

All of the yarn samples were processed by the same ginning and spinning in a mill and had the same yarn counts. The symbols used for the yarn samples are a “Y” plus the symbol for each of the cotton fibers and sample “YMI” was also added. The YMI sample was a blend using both US and AU fibers. The mechanical properties of the cotton yarns were measured using a tensile, torsion and compression tester developed by Kawabata [3, 4] at 25°C and 65% relative humidity.

Longitudinal Modulus E_L

A single fiber approximately 5 mm in length was reinforced at both ends by gluing pieces of paper to the ends, so that the fiber could be clamped by the chucks of a tensile tester. A constant strain rate of 0.4% per second was applied to test the tensile strength of the single fiber with the KES-G1 tensile tester. Figure 1 shows an example of the load–extension property of a fiber at constant rate of extension. Young’s modulus E_L , strains and stresses of yielding point and breaking point were obtained from the slope of the stress–strain curve.

Shear Modulus G_{LT}

The shear modulus G_{LT} is obtained from the torsion of the fiber about the fiber axis. For an elliptical rod, the G_{LT} is obtained as follows:

$$G_{LT} = TL/(\theta I_p), \quad (1)$$

where T is torque, L is the length of the specimen, θ is the torsional angle (radian), and I_p is the torsional moment of

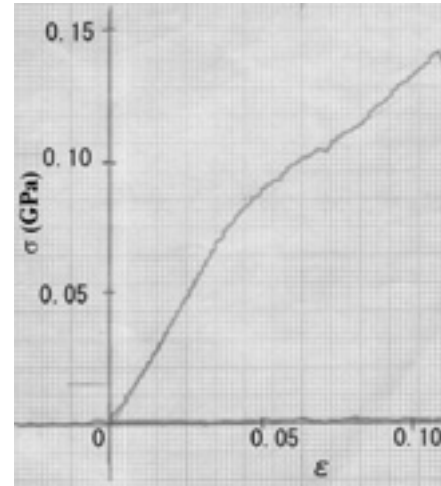


Figure 1 Tensile property of a single cotton fiber (TS).

the inertia of the area of cross-section, given for a elliptical rod by

$$I_p = \pi(a^3 b^3)/(a^2 + b^2), \quad (2)$$

where a is the longer radius and b is the shorter radius.

The mechanism of the torsion tester [2] developed by Kawabata is shown in Figure 2. A typical torque–torsional angle relation for a cotton single fiber is shown in Figure 2.

A constant rate of torsion was applied to a single fiber at a rate of 0.5π radian/second using the fiber torsion tester. The sample length was about 3 mm. The shear modulus was obtained from the initial slope of the curve.

Tensile Property of Yarn

A piece of yarn approximately 100 mm in length was reinforced at both ends by gluing pieces of paper to the ends, so that the yarn could be clamped by the chucks of a tensile tester. A constant strain rate of 0.4% per second was applied to test the tensile strength of the single fiber with the KES-G1 tensile tester. After the tensile force attains at maximum force of 10N/tex, the recovery process was also measured and the maximum values of strain (EMT), tensile energy per unit area (WT) and resilience (RT) were obtained. The breaking force and strain were obtained from the strain–force curve at the point of fracture.

Torsion Property of Yarn

The torsion property of the yarn was measured using a torsion tester [4]. A constant rate of torsion was applied at a rate of 0.2π radian per second to a yarn specimen, using

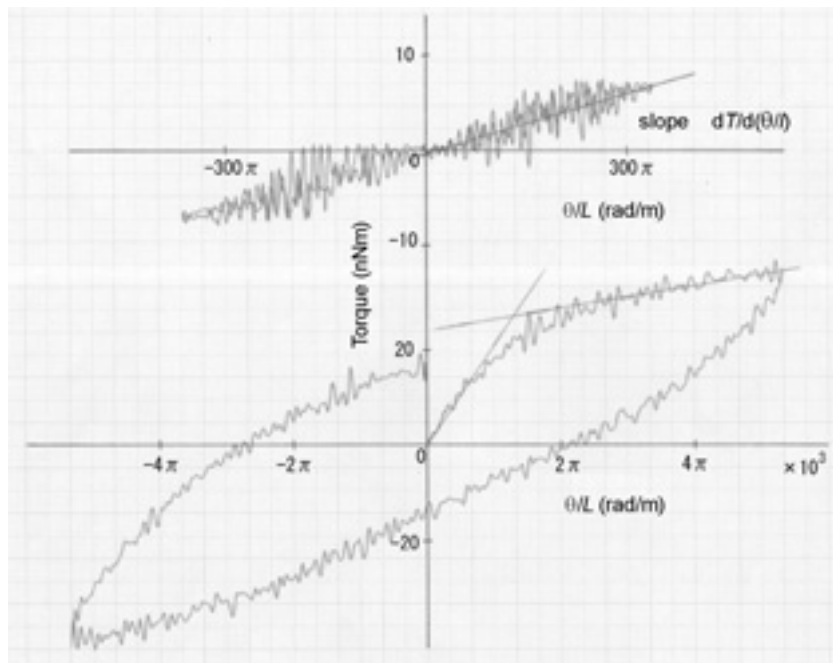


Figure 2 Shear property of a single cotton fiber (TS).

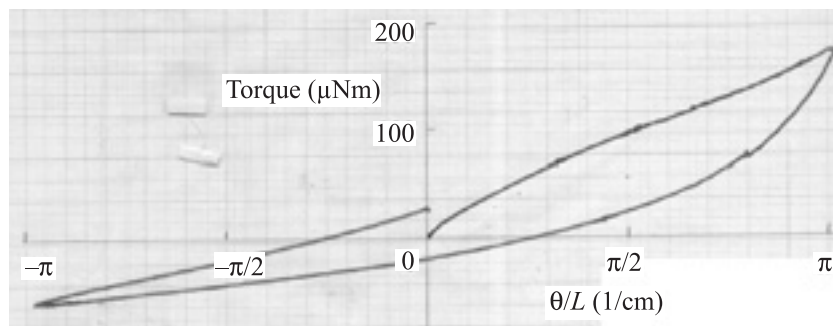


Figure 3 Torsion property of YOS (organic supima cotton).

the fiber torsion tester. The sample length was approximately 10 mm. A constant tension was applied by 2 g weights during the measurement. The maximum torsion angle is $+0.2\pi/\text{mm}$.

Four characteristic parameters: the torsion rigidities for increasing and decreasing twist (GP and GN); the average torsional rigidity (GM); and the hysteresis of torque at a torsion angle of zero (ZHG), were obtained from the curve. A typical torque–torsion angle relation for a single cotton fiber is shown in Figure 3.

Compressional Properties (Yarn Thickness Change) caused by Tension, Measured by the Wire Method

The changes in yarn thickness caused by tension were measured using the wire method [4]. A piece of yarn was

hung on the tension arm F_y . The angle between the yarn and the horizontal level was 30° , which was approximately equal to the average yarn intersecting angle in various weaves. The yarn thickness at the crossover point was measured by a linear differential transducer, having a needle sensor that was contacting at the top of the yarn surface with a small compressional force, and the thickness was recorded as a function of yarn tension. The yarn tension was detected by a force transducer and recorded. A typical change of yarn thickness (ΔD)–tension (F_y) relation for the YMI cotton yarn is shown in Figure 4. Three characteristic parameters were obtained from the curve: the linearity (LC); the energy required for compression (WC); and resilience (RC).

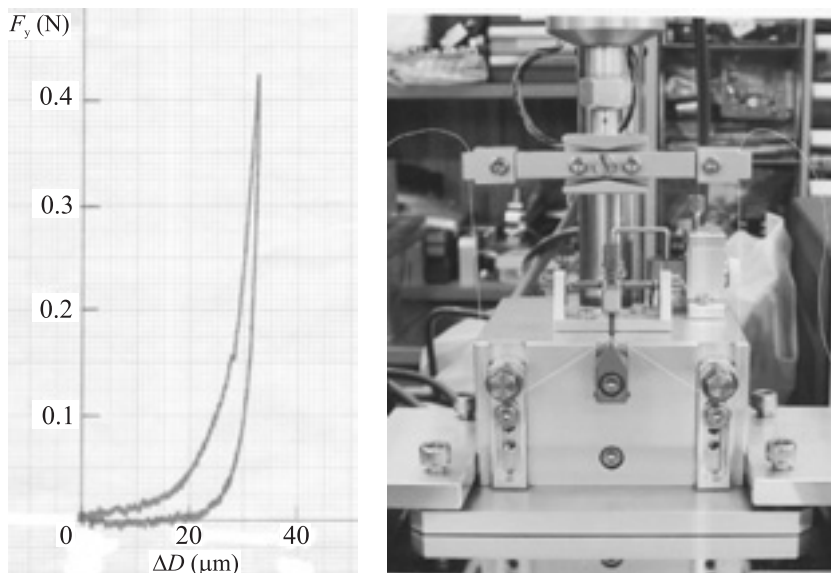


Figure 4 Compression property of cotton yarn and compression tester (wire method).

Results and Discussion

Mechanical Properties of Fibers

The tensile and shear properties of single fiber samples are shown with the major and minor axes of the cross-section of single fiber samples in Table 1. Young's modulus E_L and shear modulus G of the US sample is the largest, and the TS sample is the smallest of all samples. Comparing the differences between cultivating methods, there were no significant differences ($p > 0.05$) between the moduli of non-organic and organic cottons except for E_L (between OG and US, and between OS and US). However, the strains and stresses of breaking point of tensile properties showed significant differences ($p < 0.05$ and $p < 0.10$, respectively) between organic (OS and OG) and non-organic cottons (US, AU, or TS) and the breaking strains of the organic cottons were larger than the non-organic cottons. As for the area, there were no significant differences ($p > 0.05$) between any of the parameters of US cotton and AU cotton.

Mechanical Properties of Yarns

Table 2 shows the tensile, torsion and compression properties of yarns. As WT and RT of the tensile properties and the compression parameters were obtained from the average curve of the fifteen samples, the standard deviations are not shown. The breaking stress for the tensile deformation, the torsion properties and RC of compression properties of organic cotton yarn were the largest of all samples and showed significant differences ($p < 0.05$) when com-

pared with the inorganic cotton yarn. These results show that the yarn properties were directly affected by the single fiber properties.

All parameters of the tensile properties and LC and WC of the compression properties of the blended yarn YMI were larger than YUS or YAU and there were significant differences ($p < 0.05$). The authors supposed that blended yarns were bulkier and tangled more easily because the shapes of the individual fibers cultivated in the northern and the southern hemispheres were different.

Conclusions

The tensile and shear properties of organic cotton fibers were compared with those of non-organic cotton fibers. Organic cotton fibers had a larger breaking strain and stress than inorganic fibers. The difference in the shear moduli of the fibers was not so clear. Organic cotton yarn had a rigid tensile property in the initial region and had larger rigidity and hysteresis for the torsional property than inorganic cotton yarns. These results show that the fundamental properties of organic cotton contribute to the quality of the final cotton products. Organic cotton is also very valuable from a global environment point of view. There are some problems associated with organic cotton, such as high cost, but the authors hope that organic cotton becomes popular in spite of the higher cost.

The tensile and shear properties of cotton fibers cultivated in the northern and the southern hemispheres were also compared, but there were no significant differences between the two types of cotton. The tensile, torsional and

Table 1 Tensile and shear properties of cotton single fiber samples.

Samples			Diameter		Tensile Properties								Shear properties		
			N	Longer diameter (μm)	Shorter diameter (μm)	N	Area (μm ²)	E _L (GPa)	Yielding point		Breaking point		N	I _p × 10 ²¹ (m ⁴)	G _{LT} (GPa)
									strain (%)	stress (GPa)	strain (%)	stress (GPa)			
OS	Organic Supima (organically, grown)	Average SD	72	19.05 2.51	9.16 1.61	71	154.7 29.8	2.68 1.24	4.21 1.81	0.126 0.071	17.26 8.45	0.473 0.169	37	1.87 0.81	2.76 1.44
OG	Organic regular (organically, grown)	Average SD	79	21.50 2.97	9.33 1.60	72	186.9 14.0	2.53 1.53	3.99 1.63	0.092 0.046	20.56 10.41	0.365 0.177	37	2.01 0.74	3.6 1.57
TS	Non-organic (raised using agricultural chemicals)	Average SD	68	19.86 2.47	9.71 1.38	70	171.6 15.3	2.25 1.44	5.10 2.80	0.109 0.040	11.82 4.78	0.277 0.176	41	2.58 1.16	3.05 1.49
US	Non-organic, cultivated in the northern hemisphere (USA)	Average SD	78	19.83 1.88	9.09 1.69	70	158.3 24.0	3.55 1.50	3.41 1.86	0.114 0.029	9.27 5.19	0.404 0.138	39	2.19 1.21	3.68 2.08
AU	Non-organic, cultivated in the southern hemisphere (Australia)	Average SD	75	20.96 3.01	9.33 1.85	69	181.0 16.4	3.04 1.77	4.18 3.19	0.112 0.079	13.26 8.30	0.433 0.182	42	2.19 1.05	3.42 2.08

N, number of samples; E_L, Young's modulus; G_{LT}, shear modulus.

Table 2 Mechanical properties of yarn samples.

Samples	Fiber	Count	N	EMT (%)	WT (N.m/m)	RT (%)	Breaking point		GP (mNm ²)	GN (mNm ²)	GM (mNm ²)	2HG (mNm ²)	LC (-)	WC (μNm)	RC (%)
							Strain (%)	Stress (N/tex)							
YOS	Organic	1/30's	15	0.95 0.09	24.0	68	6.71 0.47	0.192 0.016	5.55 1.95	1.97 0.47	3.76 1.18	6.60 1.33	0.373	2.20	32.9
YUS	Non-organic made in USA	1/30's	15	1.08 0.09	25.2	69.6	6.81 0.78	0.110 0.023	3.23 1.27	1.98 0.82	2.61 1.03	3.77 1.42	0.397	2.46	20.0
YAU	Non-organic made in Australia	1/30's	15	1.00 0.10	24.8	68.2	6.89 0.62	0.094 0.025	2.92 0.26	1.81 0.25	2.37 0.21	3.23 0.29	0.290	2.02	28.7
YMI	Blended, made in US and AU	1/30's	15	1.18 0.22	28.6	72.9	7.81 0.41	0.140 0.009	3.36 0.66	1.91 0.33	2.63 0.46	4.05 0.57	0.464	3.83	23.9

N, number of samples; EMT, maximum value of strain; WT, tensile energy per unit area; RT, resilience; GP, torsion rigidity for increasing twist; GN, torsion rigidity for decreasing twist; GM, average torsional rigidity; 2HG, hysteresis of torque at a torsion angle of zero; LC, linearity; WC, energy required for compression; RC, resilience.

compression properties of yarn made from fibers cultivated in one area were compared with those of blended yarn made with cotton fibers cultivated in both the northern and the southern hemispheres. The blended yarn had

larger tensile strain, torsional stiffness and hysteresis than yarns made from cotton grown in just one area. These results showed that the blended yarn was bulkier than yarn made from cotton grown in just one area. It appears that

the mechanical properties of cotton yarn could be controlled by adjusting the blending proportions of cotton fibers cultivated in the northern and southern hemispheres.

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