Characteristics of Mechanical Properties and Handles of Silk Filament Weaves

CHARACTERISTICS OF MECHANICAL PROPERTIES AND HANDLES OF SILK FILAMENT WEAVES

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ABSTRACT

In order to investigate peculiar characteristics of mechanical properties and fabric handles of silk filament weaves, objective evaluation method was applied to the silk weaves comparing with other fiber weaves. The basic mechanical properties such as tensile, bending, shearing, compressional and surface properties were measured by KES-FB system and fabric handles were calculated by transformation equations developed by Kawabata. Following conclusions were obtained: Peculiar characteristics of silk filament weaves appear in compressional and tensile properties at a small deformation region, and silk weaves are very soft in compression and stretchy compared with other filament weaves such as polyester, rayon, cupra, acetate and nylon. Shear stiffness and hysteresis in shear force of silk weaves are extremely small in relatively small strain region, however, they become larger with the increase of shear strain. Degummed silk weaves show hard shearing property. One of the peculiar features of silk weaves in fabric handle is high FUKURAMI.

1. Introduction

Silk weaves are traditional fabrics which have been used widely in Japan for a long period for their beautiful and soft handle and also for their comfortable touch. Although a great deal of efforts have been made by many synthetic fiber producers in order to produce silk-like weaves by synthetic fibers, natural silk weaves are still preferred by many consumers because of its superiority in fabric handle. Silk weaves continue to be prized by consumer even though some man-made fibers now have some qualities such as fiber fineness or strength that were formerly possessed only by silk[1].

Although the structure of silk fibroin fiber in molecular level have been investigated precisely[2-6], the difference in the fabric handle between silk weaves and the other weaves has not been clearly explained until today because of the difficulty of expressing fabric handle objectively. Fabric handle of silk weaves has been discussed only by subjective evaluation[7-11]. Recently, the method of objective evaluation of fabric handle has been developed by Kawabata[12] and the progress has enabled objective evaluation of fabric handle of silk weaves. In the objective evaluation method, mechanical properties of fabric are measured precisely in the range of small load region related to fabric handle. Then fabric handle is calculated objectively from the mechanical properties using transformation equations[12]. In these days,

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mechanical properties of fabrics have been studied widely and explicitly and fabric handle has been analyzed clearly using precise mechanical data and the method of objective evaluation[13-15].

In such a background of the development of the objective evaluation of fabric handle, this new technique is applied to silk filament weaves to explain their characteristics. The objective of this paper is to study mechanical properties and fabric handles of silk filament weaves identifying those from other filament weaves.

There are two major kinds of silk filament weaves. One is the filament fiber weave which is the typical silk weave called generally "silk weave". This fabric is characterized by the sericine removal process. The sericine of raw silk fiber is removed in the fabric state after weaving. This type of silk weaves have been used widely for Japanese traditional costume "Kimono" and women's thin dress fabrics[16] such as blouses, one-pieces, shirts, etc. The other kind of the silk weave is also the filament weave, but the sericine is removed before weaving in the yarn state. This weave is called "degummed silk weave" which has been used mainly for Japanese "Obi" (bands), neckties, etc. which are stiffer fabrics. In addition to these two kinds of fabrics, the silk weave woven by spun silk yarns have been used also for women's dress fabrics or Japanese Kimono, however they are minor in quantity.

In this paper, analysis is made by using the typical silk filament weaves which are characterized by their sericine removal process where the sericine of silk fiber is removed after the weaving in the woven state to produce typical silk handle of the fabric.

2. Method of Analysis

The basic mechanical properties such as tensile, bending, shearing and compressional properties and surface properties of silk filament weaves are measured by using KES-FB system[17]. These properties are measured by "high sensitivity conditions"[18], which is mainly applied to thin fabrics as following conditions:

Tensile ; maximum tensile load is 50 gf/cm.
Bending ; maximum curvature is ± 2.5 cm^{-1}.
Shearing ; maximum shear angle is ± 8 degree.
Compression; maximum pressure is 10 gf/cm^2.
Surface ; surface contour under 10 gf pressure,
surface friction under 50 gf pressure.

Details are shown in Appendix A. The graphic curves of the output signals from these testings are recorded and also made inspections to identify the characteristic properties of the silk weaves.

The primary hand values (HV)[12] of weaves and the total hand value (THV)[12] which gives grades of fabric quality are obtained objectively by using the transformation equations from the raw mechanical properties. For this identification of silk filament weaves, mechanical properties and fabric handles of the silk weaves are compared with those of other fabrics, such as polyester, viscose rayon, cupra rayon, acetate and nylon. All of these fabrics are used for similar type of garments and the fabric structure of those are similar to each other.

3. Experimental

The basic mechanical and surface properties are measured by using KES-FB system for the following properties under the "high sensitivity conditions". Mechanical parameters are defined as follows:

Tensile property:
- LT ; tensile linearity
- WT ; tensile energy
- RT ; tensile resilience

Bending property:
- B ; bending rigidity
- 2HB ; hysteresis of bending moment

Shearing property:
- G ; shear stiffness
- 2HG ; hysteresis of shear force at 0.5 degree
- 2HG5 ; hysteresis of shear force at 5.0 degree

Compressional property:
- LC ; linearity of compression
- WC ; compressional energy
- RC ; compressional resilience

Surface property:
- MIU ; coefficient of friction
- MMD ; mean deviation of MIU
- SMD ; geometrical roughness

Details are shown in Appendix B.

The primary hand values (HV) of fabrics are objectively evaluated using the equation converting these mechanical parameters into HV. The equations used here are KN-202-Filament[19] and KN-203[20]. Primary hand values are as follows:

KOSHI	; stiffness
HARI	; anti-drape stiffness
SHARI	; crispness
FUKURAMI	; fullness and softness
KISHIMI	; scrooping feeling
SHINAYAKASA	; flexibility with soft feeling
NUMERI	; smoothness

These feeling intensity is given by the number from 0 (weak) to 10 (strong).

The quality of fabric is given by the total hand value (THV) using transformation equation

KN-302 (W)[20] coverting these primary hand values into THV. The qualty is given by the number from 1 to 5 as following:

THV= 5 ; excellent
4 ; good
3 ; average
2 ; below average
1 ; poor

All the measurements were carried out at conditions of 65 ±2% relative humudity and 20±1°C temperature.

4. Samples

The filament yarn weaves of silk are classified into the following three types of weaves:

(1) Habutae; consisting of twistless yarns in both warp and weft yarns.

(2) Dechine; consisting of weft yarns having strong twist (1000-3000 turns/m) and warp yarns having no twist.

(3) Georgette; consisting of strong twist (2000-3000 turns/m) yarns in both warp and weft yarns.

In this paper, the first "Habutae" structure is compared with different fiber "Habutae" weaves to draw distinctive features of the silk weaves in their mechanical properties and fabric handles. Secondly, it is inspected whether this distinctive feature appears also in the other type of weave, Dechine and Georgette.

The samples used in this inspection are shown in Table 1. These samples were selected from ordinary commercial weaves. The range of fabric weight is between 3 mg/cm^2 and 16 mg/cm^2 and the use of these fabrics is mainly for women's thin dress fabrics such as blouses,

Table 1 Outlines of Samples

Weave	Name	Structure	Yarn	Number of Sample	Thickmess (mm)**	Weight (mg/cm^2)
Silk	Habutae	Plain	Filament	8	0.12−0.25	5−12
	Dechine	Plain	Filament	8	0.19−0.29	5−9
	Georgette	Plain	Filament	6	0.17−0.26	3−6
Degummed Silk	Habutae	Plain	Filament	6	0.22−0.71	10−16
Polyester	Habutae	Plain	Filament	5	0.09−0.22	4−12
	Habutae*	Plain	Filament	10	0.09−0.23	5−11
	Dechine*	Plain	Filament	8	0.22−0.29	6−11
	Georgette*	Plain	Filament	7	0.20−0.60	6−16
Rayon	Habutae	Plain	Filament	5	0.09−0.22	4−12
Cupra	Habutae	Plain	Fialment	6	0.09−0.15	6−9
Acetate	Habutae	Plain	Filament	5	0.12−0.16	6−10
Nylon	Habutae	Plain	Filament	7	0.09−0.12	5−7

*These polyester weaves are called silk-like polyester weaves in Japan.
**The thickness is measured under the pressure 0.5 gf/cm^2.

one-pieces, shirts, etc.

5. Results

5.1 Mechanical Characteristics and Hand Values of Silk Weaves

Results of mechanical characteristics and hand values of silk and other weaves are listed in Table 2. In order to find out mechanical peculiarities of silk filament weaves, mechanical characteristics of polyester "Habutae" are plotted on the basis of those of silk "Habutae" and shown in Fig. 1, where the mean value and the standard deviation of each mechanical characteristics of the polyester weave is normalized by those of he silk weave as follows:

Table 2-(1) Results of Mechanical Parameters and Hand Values of Silk Filament Weaves.

		Habutae(8)		Dechine(8)		Georgette(6)		Degummed(6)	
		X	σ	X	σ	X	σ	X	σ
Tensile	LT	0.818	0.071	0.760	0.048	0.730	0.037	0.810	0.070
	log WT	−0.716	0.149	−0.209	0.197	−0.145	0.175	−1.377	0.176
	RT	77.5	6.27	77.0	6.00	68.6	9.20	73.0	11.30
Bending	log B	−1.571	0.204	−1.940	0.087	−2.220	0.145	−0.741	0.149
	log 2HB	−2.025	0.154	−2.385	0.147	−2.633	0.167	−0.743	0.182
Shearing	log G	−0.698	0.038	−0.700	0.040	−0.710	0.023	0.200	0.066
	log 2HG	−1.075	0.137	−0.962	0.160	−1.017	0.164	0.834	0.070
	log 2HG5	−0.427	0.132	−0.769	0.217	−0.781	0.195	1.052	0.060
Compress.	LC	0.394	0.070	0.380	0.080	0.460	0.047	0.340	0.077
	log WC	−2.103	0.122	−1.978	0.085	−1.894	0.151	−1.703	0.313
	RC	48.6	3.7	48.0	4.7	67.5	2.6	56.0	7.0
Surface	MIU	0.184	0.015	0.206	0.023	0.172	0.009	0.185	0.022
	log MMD	−1.958	0.181	−1,750	0.052	−1.704	0.078	−1.531	0.119
	log SMD	0.404	0.166	0.463	0.066	0.513	0.174	0.629	0.103
Thickness	log T	−0.721	0.074	−0.626	0.056	−0.651	0.095	−0.398	0.205
Weight	log W	0.803	0.114	0.826	0.064	0.589	0.137	1.056	0.076
Hand Value by KN-202 Fil.	KOSHI	6.37	0.83	4.63	0.28	4.03	0.45	7.47	0.44
	HARI	6.69	1.26	4.70	0.46	3.30	1.14	11.14	0.33
	SHINAYA-KA	5.86	0.88	7.19	0.59	7.36	1.06	0.22	0.38
	FUKUR-AMI	6.48	0.94	6.29	1.04	1.80	0.53	5.85	1.00
	SHARI	4.19	1.07	5.02	0.61	6.57	0.83	4.55	0.85
	KISHIMI	6.75	0.62	5.35	0.79	3.84	0.86	6.26	0.50
by KN-203	KOSHI	6.10	0.53	5.08	0.25	4.28	0.53	8.95	0.76
	NUMERI	6.38	1.52	6.04	0.72	6.32	0.86	3.72	1.14
	FUKUR-AMI	5.28	0.90	5.48	0.45	6.06	0.58	4.92	1.02
by KN-302(W)	THV	3.63	0.70	3.43	0.30	3.20	0.25	0.33	1.47

Table 2-(2) Results of Mechanical Parameters and Hand Values of Polyester Filament Weaves

		Habutae(5)		Habutae(10)*		Dechine(8)*		Georgette(7)*	
		X	σ	X	σ	X	σ	X	σ
Tensile	LT	0.970	0.042	0.855	0.055	0.800	0.065	0.740	0.023
	log WT	−1.267	0.091	−0.855	0.198	−0.466	0.130	−0.247	0.060
	RT	63.4	14.8	77.2	11.5	74.0	4.7	61.0	9.0
Bending	log B	−1.248	0.250	−1.685	0.117	−1.935	0.126	−2.068	0.165
	log 2HB	−1.634	0.403	−2.192	0.250	−2.564	0.196	−2.583	0.241
Shearing	log G	−0.331	0.198	−0.619	0.076	−0.618	0.031	−0.632	0.055
	log 2HG	−0.135	0.396	−0.665	0.237	−0.625	0.141	−0.580	0.231
	log 2HG5	0.361	0.189	−0.138	0.242	−0.388	0.153	−0.444	0.220

Compress. log	LC	0.48	0.087	0.459	0.070	0.52	0.049	0.52	0.103
	WC	−2.467	0.076	−2.210	0.154	−1.998	0.122	−1.951	0.186
	RC	68.0	4.7	51.5	5.9	54.0	5.5	69.0	5.7
Surface	MIU	0.177	0.023	0.194	0.028	0.206	0.022	0.191	0.024
	log MMD	−1.525	0.272	−1.767	0.306	−1.759	0.106	−1.589	0.148
	log SMD	0.640	0.147	0.398	0.143	0.477	0.093	0.686	0.140
Thickness	log T	−0.933	0.155	−0.789	0.123	−0.592	0.033	−0.455	0.142
Weight	log W	0.752	0.163	0.790	0.046	0.893	0.117	0.957	0.130
Hand	KOSHI	7.71	0.89	6.25	0.53	5.14	0.49	4.64	0.38
Value	HARI	9.28	1.53	6.60	0.75	4.56	0.77	4.26	0.79
by	SHINAYAKA	1.78	1.88	5.39	0.86	6.67	0.74	6.21	0.76
KN-	FUKURAMI	1.23	0.62	4.91	1.32	4.67	0.96	1.30	1.15
202	SHARI	6.09	1.23	5.18	1.71	5.34	0.86	7.65	0.82
Fil.	KISHIMI	3.11	0.94	6.62	0.51	4.71	0.45	3.30	0.25
by	KOSHI	7.45	0.67	6.10	0.31	5.42	0.34	4.91	0.42
KN-	NUMERI	3.30	1.12	5.07	1.45	5.39	0.46	5.22	0.67
203	FUKURAMI	2.78	0.79	4.12	0.81	4.86	0.50	5.26	0.60
by KN-	302(W) THV	1.89	0.80	3.13	0.53	3.18	0.20	3.05	0.22

*These polyester weaves are called silk-like polyster weaves in Japan.

Table 2-(3) Results of Mechanical Parameters and Hand Values of Other Filament Weaves

		Nylon(7)		Rayon(5)		Cupra(6)		Acetate(5)	
		X	σ	X	σ	X	σ	X	σ
Tensile	LT	0.880	0.070	0.840	0.032	0.790	0.022	0.840	0.066
	log WT	−1.056	0.126	−0.954	0.083	−0.937	0.058	−0.880	0.067
	RT	80.0	4.7	92.0	2.7	88.0	2.5	87.0	2.9
Bending	log B	−1.401	0.151	−1.479	0.115	−1.362	0.070	−1.460	0.140
	log 2HB	−1.658	0.109	−2.027	0.159	−1.972	0.157	−1.736	0.076
Shearing	log G	−0.374	0.098	−0.692	0.055	−0.701	0.029	−0.515	0.059
	log 2HG	−0.182	0.300	−1.112	0.259	−1.078	0.312	−1.058	0.286
	log 2HG5	0.545	0.186	−0.543	0.176	−0.575	0.182	0.082	0.103
Compress. log	LC	0.45	0.031	0.40	0.031	0.44	0.050	0.38	0.050
	WC	−2.481	0.039	−2.470	0.055	−2.468	0.055	−2.501	0.097
	RC	71.7	9.5	81.2	6.4	68.5	5.2	75.3	4.8
Surface	MIU	0.210	0.018	0.172	0.017	0.175	0.011	0.183	0.007
	log MMD	−1.655	0.182	−1.618	0.201	−1.889	0.178	−1.573	0.193
	log SMD	0.598	0.031	0.65	0.093	0.480	0.114	0.757	0.036
Thickness	log T	−0.991	0.038	−0.974	0.086	−0.977	0.048	−0.899	0.028
Weight	log W	0.755	0.035	0.818	0.056	0.867	0.063	0.848	0.042
Hand	KOSHI	7.23	0.66	8.14	0.31	8.04	0.31	7.31	0.39
Value	HARI	8.56	0.83	8.10	0.61	8.27	0.27	8.01	0.85
by	SHINAYAKA	2.83	0.77	3.72	0.68	3.90	0.21	3.54	0.88
KN-	FUKURAMI	1.87	1.00	0.73	0.75	3.12	0.76	1.60	0.65
202	SHARI	5.54	0.95	7.31	1.04	5.49	0.91	6.62	0.71
Fil.	KISHIMI	2.99	0.67	4.85	0.27	5.68	0.38	3.57	0.61
by	KOSHI	7.19	0.48	6.85	0.45	7.16	0.38	6.95	0.44
KN-	NUMERI	3.68	0.97	4.52	0.73	5.61	0.85	3.78	0.82
203	FUKURAMI	3.25	0.81	3.78	0.81	4.26	0.56	3.52	0.77
by KN-	302(W) THV	2.20	0.64	2.59	0.59	2.84	0.43	2.42	0.49

Thick line ; $(X-\bar{X}_{silk})/\sigma_{silk}$
Broken line ; σ/σ_{silk}

Almost all the mechanical characteristics of the polyester weave are separated from those of the silk weave. In shearing property, shear stiffness ; G and its hysteresis ; 2HG, 2HG5 of the polyester weave are extremely large and it is clear that silk weave is soft and elastic in shear deformation. Compressional energy ; WC is small and linearity of compression ; LC and resilience ; RC are large for the polyester weave. Therefore, it can be said that silk weave is easy to compress and soft in compression. In tensile property, linearity ; LT is large and tensile energy ; WT is small for the polyester weave. Silk weave is considered to be more stretchy than polyester weave. Bending rigidity ; B and its hysteresis ; 2HB of the polyester weave are larger than those of silk weave in bending property. This means silk weave is soft in bending and good recovery from bending deformation. In surface property, frictional coefficient ; MIU of the polyester weave is similar to that of the silk weave, but mean deviation of the frictional coefficient ; MMD is larger. Silk weave can be considered to have smooth surface.

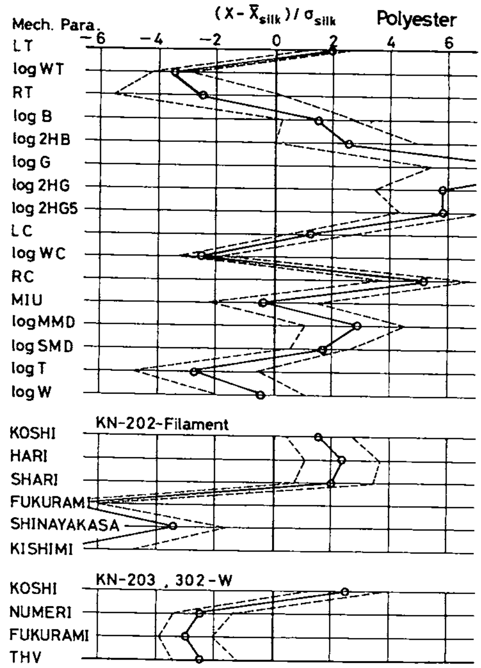

Fig. 1 Deviations of the mechanical parameters and the primary hand values of polyester filament weaves from those of silk filament weaves.

As the results mentioned above, HVs of the polyester weave also deviate remarkably from those of the silk weave. By the result of KN-202-Filament equation, KOSHI, HARI and SHARI of the polyester weave are larger, but FUKURAMI and KISHIMI are more smaller than those of the silk weave. FUKURAMI is also smaller by the calculation of KN-203 equation. Therefore, THV of the polyester "Habutae" is very small.

Result of the polyester "Habutae" which is made to simulate silk weave, which are called silk-like polyester weave[21-23] in Japan is shown in Fig. 2 as the same manner as Fig. 1. Deviation of mechanical characteristics is not so large as that of the polyester weave. However, in shearing property, shear stiffness and its hysteresis of the silk-like polyester weave are still larger than those of the silk weave. Further, there is a similar tendency in compressional property as the polyester weave. That is, linearity and resilience are large and energy is small for the silk-like polyester weave. Mean deviation of the frictional coefficient of the silk-like polyester weave is still larger than that of the silk weave. So, although KOSHI, HARI and SHINAYAKASA are quite same as those of the silk weave, FUKURAMI and KISHIMI are still smaller and SHARI is a little larger.

Mechanical properties and hand values of viscose rayon, cupra rayon, acetate and nylon filament weaves "Habutae" are plotted as the same manner as Fig. 1 and Fig. 2 and shown in

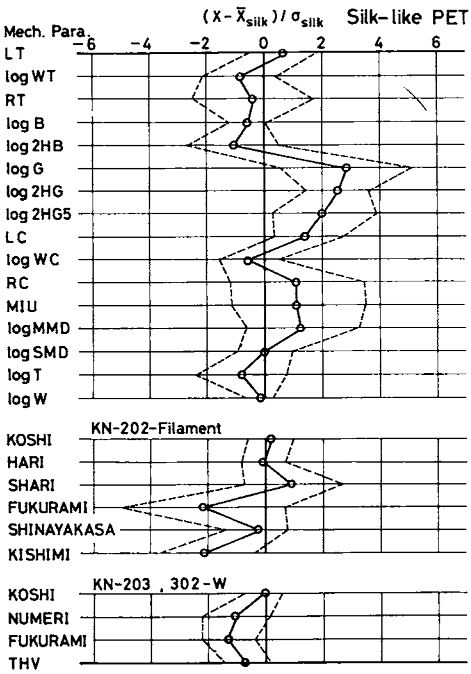

Fig. 2 Deviations of the mechanical parameters and the primary hand values of silk-like polyester weaves from those of silk filament weaves.

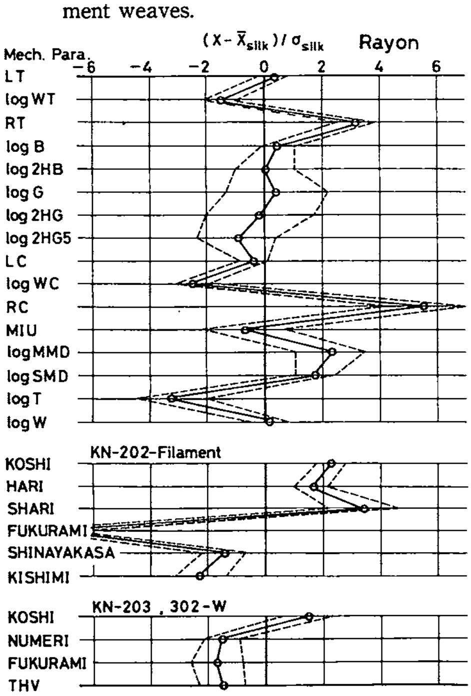

Fig. 3 Deviations of the mechanical parameters and the primary hand values of viscose rayon filament weaves from those of silk filament weaves.

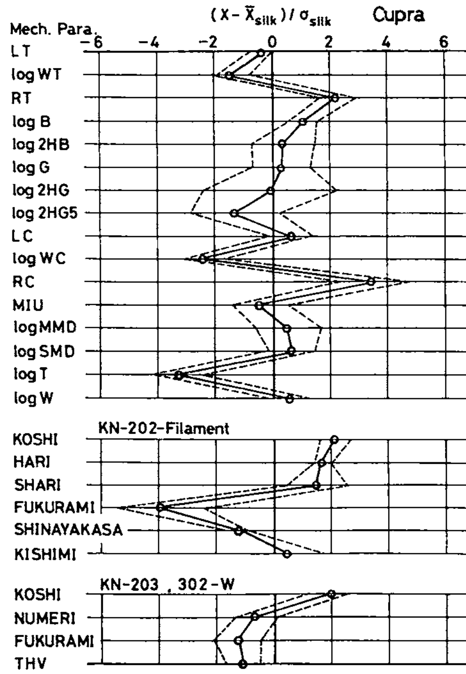

Fig. 4 Deviations of the mechanical parameters and the primary hand values of cupra rayon filament weaves from those of silk filament weaves.

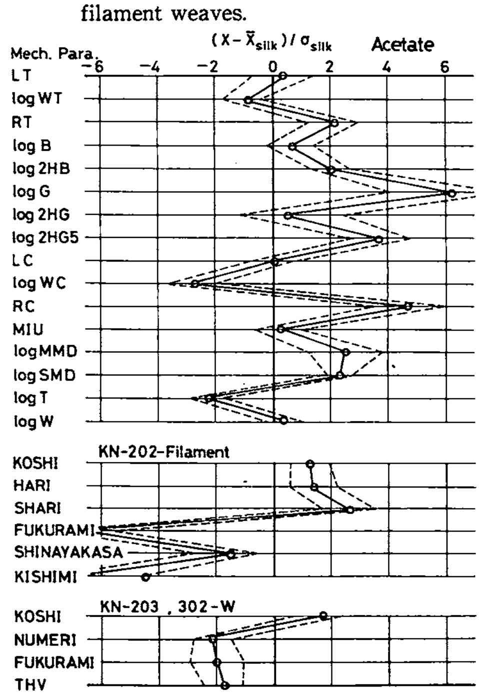

Fig. 5 Deviations of the mechanical parameters and the primary hand values of acetate filament weaves from those of silk filament weaves.

Fig. 3, 4, 5 and 6, respectively. Deviations of both properties are basically similar to those of polyester or silk-like polyester weaves. That is, these weaves show hard in tensile, bending, shearing and compressional properties and rough in surface properties. KOSHI, HARI and SHARI are large, but FUKURAMI is very small. Therefore, it can be concluded that silk filament weave has high FUKURAMI compared with other filament weaves. This may be peculiar characteristics of silk filament weave.

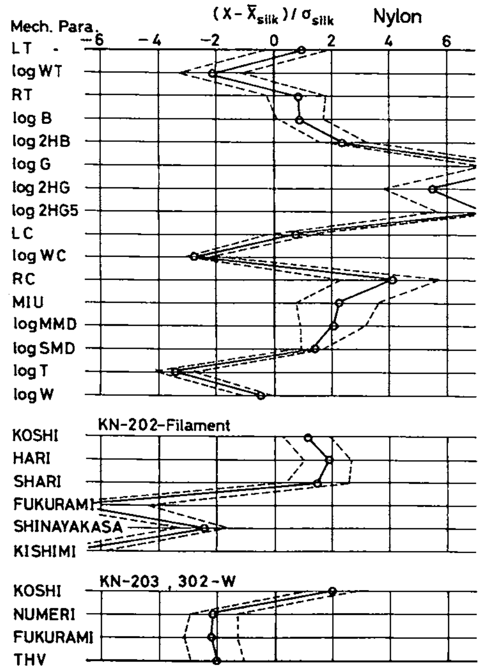

Fig. 6 Deviations of the mechanical parameters and the primary hand values of nylon filament weaves from those of silk filament weaves.

5. 2 Graphic Presentation of Mechanical Properties

In order to clarify each mechanical property of silk weave, graphic curves of each mechanical property measured by KES-FB system are shown comparing with polyester and silk-like polyester weave. The polyester weave and the silk-like polyester weave are two representative weaves being the most different from the silk weave and the most similar to the silk weave, respectively.

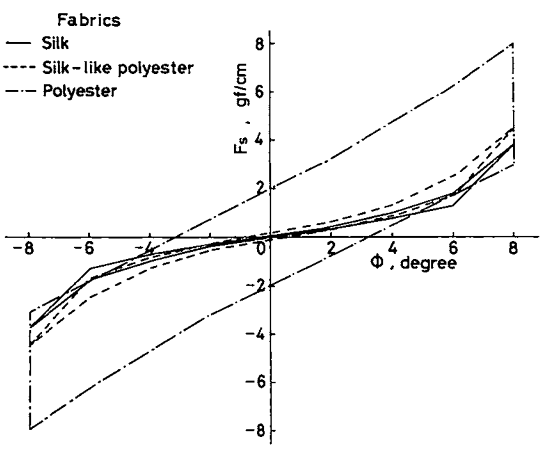

Fig. 7 Shear properties of silk, silk-like polyester and polyester weaves ; curves show the averaged shear force versus shear angle relations measured by KESF system for each three groups.

Shearing properties are shown in Fig. 7 as shear force versus shear angle relation. Silk weave shows extremely low shear force and its hysteresis in relatively small shear strain region. However, they become larger with the increase of shear angle. Shear force of silk-like polyester weave is also very small in relatively small shear strain region, but its hysteresis is larger than that of silk weave. Difference between silk and silk-like polyester weave becomes more clear if small shear strain region is more enlarged. Therefore, it can be said that low shear force and hysteresis at small shear strain region is peculiar characteristics of silk weave.

Compressional properties of the three kinds of weaves are shown in Fig. 8 as logarithms of compressional force versus changes of weave thickness at two different maximum pressure, namely 50 gf/cm² in left and 10 gf/cm² in right. Horizontal line at the maximum pressure

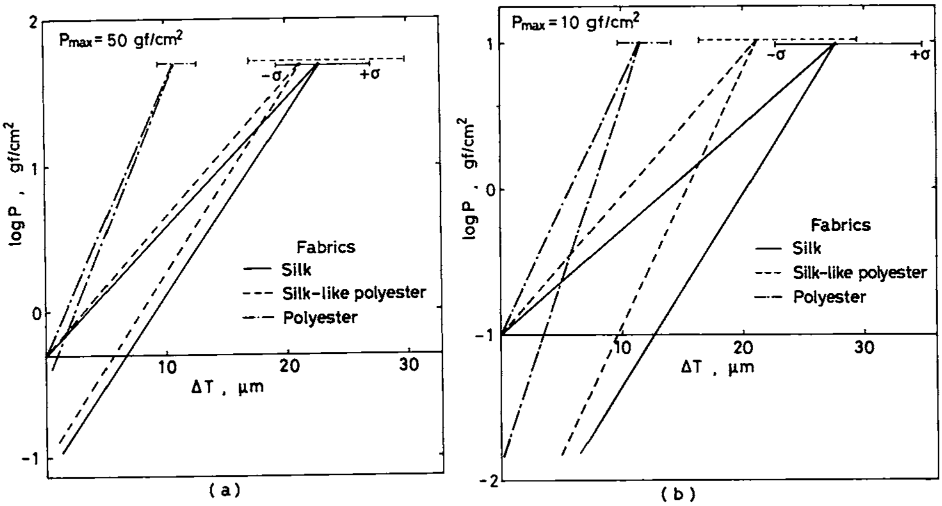

Fig. 8 Compressional properties of silk, silk-like polyester and polyester weaves; curves show the averaged lagarithms of pressure versus thickness change relations for each three groups. (a); the maximum pressure is 50 gf/cm², (b); the maximum pressure is 10 gf/cm².

means a standard deviation of data within each group. Although the difference between silk and silk-like polyester weave is not clear in the left figure, it becomes distinct if the maximum pressure is small as shown in right figure. This means that silk weave is very soft in small pressure region. So, peculiar characteristics of silk weave in compressional property appear at small level of pressure and that thickness change is considerably large in this region. This property is closely related with soft feeling of silk weave.

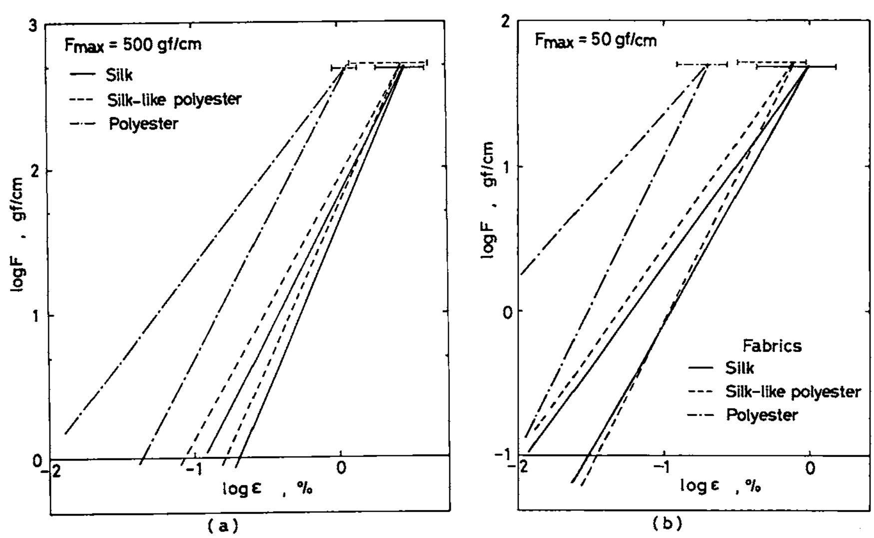

Fig. 9 Tensile properties of silk, silk-like polyester and polyester weaves; curves show the averaged logarithms of tensile force versus logarithms of strain relations for each three groups. (a); the maximum force is 500 gf/cm, (b); the maximum force is 50 gf/cm.

Tensile properties are shown in Fig. 9 as logarithms of tensile force versus logarithms of strain at two different maximum force, namely 500 gf/cm in left and 50 gf/cm in right. Difference between silk and silk-like polyester is indistinct in the left figure, but it becomes clear in the right figure. Maximum strain at the maximum load increases polyester weave, silk-like polyester weave and silk weave in the order. Therefore, peculiar characteristics of silk weave in tensile property appear at small level of tensile force and are that tensile strain of silk weave is very large in this region. This property is also concerned with soft feeling of silk weave.

5. 3 Another Filament Weaves: Dechine and Georgette

Mechanical characteristics and hand values of silk-like polyester weave "Dechine" are plotted on the normalized chart by those data of silk Dechine and shown in Fig. 10. In tensile, shearing and compressional properties, the polyester Dechine shows the same tendency as the polyester Habutae, namely, the silk Dechine is soft in shearing, compressional and tensile properties compared with the polyester Dechine. As the result, FUKURAMI of the polyester Dechine calculated by KN-202-Filament equation is lower than that of the silk Dechine. According to the result obtained by KN-203 equation, NUMERI and FUKURAMI of the silk Dechine is higher and KOSHI is lower.

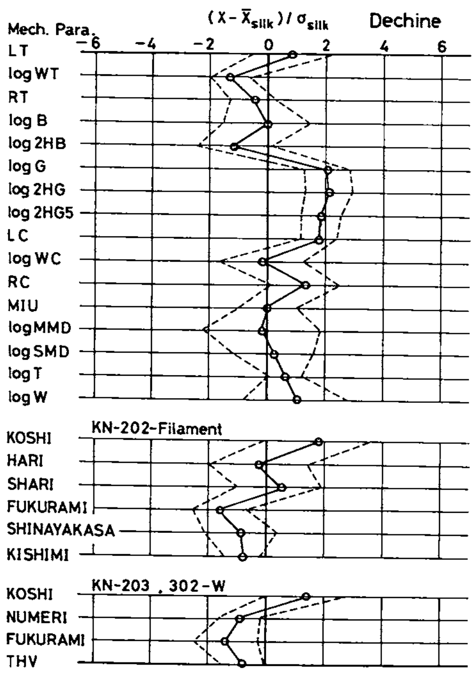

Fig. 10 Deviations of the mechanical parameters and the primary hand values of silk-like polyester weave "Dechine" from those of silk Dechine.

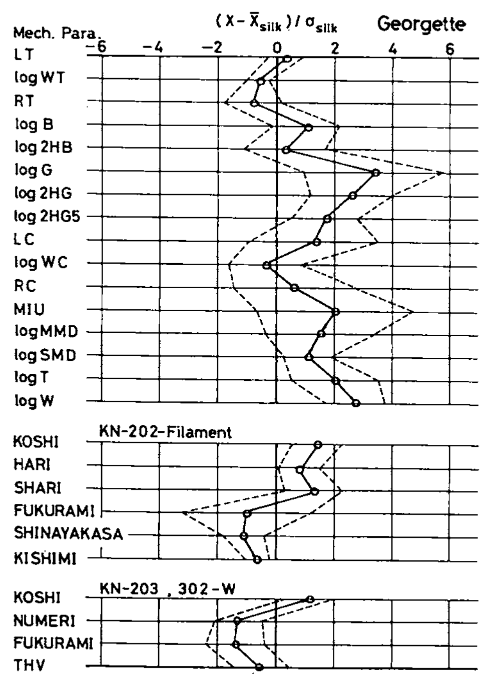

Fig. 11 Deviations of the mechanical parameters and the primary hand values of silk-like polyester weave "Georgette" from those of silk Georgette.

Results of "Georgette" weave are shown in Fig. 11. Deviation of mechanical properties and hand values of the polyester Georgette is similar to that of the polyester Habutae and Dechine. FUKURAMI of the silk Georgette is high.

5. 4 Degummed Silk Weave

Mechanical characteristics and hand values of degummed silk weaves being Habutae structure are plotted on the basis of the silk weave Habutae as shown in Fig. 12. Degummed silk shows very large shear stiffness and its hysteresis. Bending rigidity and its hysteresis are also large. Deviation of mechanical properties is nearly same as that of the standard polyester Habutae except compressional property as shown in Fig. 1. LC of the degummed Habutae is small and WC is large. Consequently, FUKURAMI shows considerably high value as the silk weave. SHINAYAKASA and THV are small.

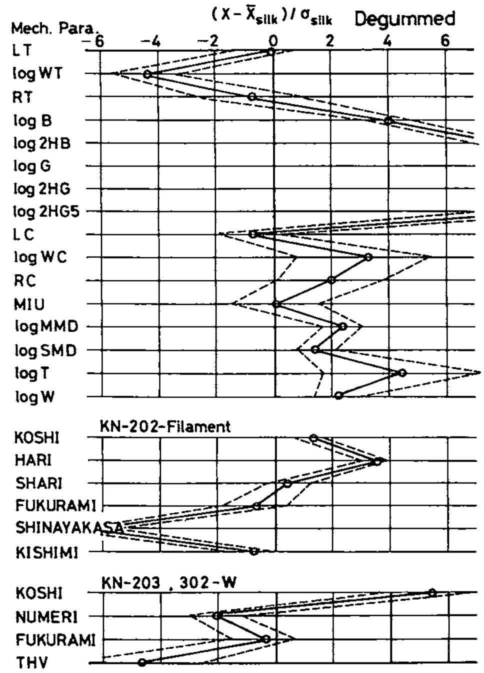

Fig. 12 Deviations of the mechanical parameters and the primary hand values of degummed silk weaves being Habutae structure from those of silk Habutae.

6. Discussions

Silk filament weave in which sericine is memoved after weaving has extremely low shear stiffness and its hysteresis. Intersecting angle between warp and weft yarns changes by shear deformation of weave, so it can be considered that contact of warp and weft yarns is quite loose at the intersecting point. This problem is analysed in detail in another papers[24-26].

Shear stiffness and its hysteresis of degummed silk weave in which sericine removed yarns are woven to make up the weave are very large compared to the silk weave of which sericine is removed after weaving. In degummed silk weave, contact of warp and weft yarns is very complete.

Compressional and tensile property of silk weaves including degummed silk weave are in general, soft and deformable in relatively small strain region. This deformability of silk weave can make high value of FUKURAMI and is considered to be related with fiber crimp of silk fibroin. This is also discussed in another paper[27]. Although KOSHI and HARI of degummed silk weave are very large, FUKURAMI is considerably high. Therefore, it is said that high FUKURAMI is an unique feature of all the silk filament weaves.

Hand values are calculated by two transform equations; KN-202-Filament and KN-203 equations. KOSHI and FUKURAMI are calculated by both equations and the values are alike each oher. So, both equations are good for obtaining hand values objectively. But it is safely said that the former may be suitable for inspecting HARI, SHINAYKKASA and KISHIMI, and the latter is good for KOSHI, NURERI and FUKURAMI.

7. Conclusions

Tensile, bending, shearing, compressional and surface properties of silk filament weaves were measured precisely by KES-FB system, and peculiar characteristics of silk filament weaves in mechanical properties and hand values were extracted. The following conclusions can be made:

(1) Peculiar characteristics of silk filament weaves in compressional and tensile properties appear at a small strain region of compressional or tensile deformation, and silk weaves are very soft in compression and stretchy compared with other filament weaves such as polyester, rayon, cupra, acetate and nylon.

(2) Shear stiffness and the hysteresis in shear force of silk weaves are extremely small in relatively small strain region, however, they become larger with the increase of shear strain. Degummed silk weaves show hard shearing property.

(3) FUKURAMI of silk weaves is very high compared with other filament weaves. The high FUKURAMI is related mainly to compressional and tensile property of the weave.

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Appendix A High Sensitivity Conditions of KESF System

Properties	Measuring Conditions	Parameters
Tensile*	Strip biaxial deformation. Maximum load ; 50 gf/cm. Tensile strain rate ; 0.2 %/s. Sample width ; 20 cm and lenth in the extension direction ; 5 cm. Speed ; 0.1 mm/s.	LT-1, LT-2 WT-1,WT-2 RT-1, RT-2
Bending*	Pure bending. Maximum curvature ; $K_{max}=\pm 2.5$ cm^{-1}. Bending rate ; 0.5 cm^{-1}/s.	B-1, B-2 2HB-1, 2HB-2
Shearing*	Shear deformation under constant tension ; W=10 gf/cm. Maximum shear angle ;$\phi_{max}=\pm 8$ degree. Rate of shear strain ; 0. 00834/s. Sample length ; 5 cm and width ; 20 cm. Shear deformation is applied to the width direction.	G-1, G-2 2HG-1, 2HG-2 2HG5-1, 2HG5-2
Compression	Compression to fabric thickness direction by two circular plates having 2 cm^2 area. Maximum pressure ; 10 gf/cm^2. Rate of compression ; 20/3 μm/s.	LC WC RC
Surface*	Contactor for friction measurement : Ten parallel steel-piano-wires with 0.5 mm diameter and 5 mm length simulating finger skin geometry. Contact force ; 50 gf.	MIU-1, MIU-2 MMD-1, MMD-2
	Contactor for geometrical roughness : A steel-piano-wire, with 0.5 mm diameter and 5 mm length, placed on fabric parallel to fabric surface with contact force of 10 gf. Measured distance ; 2 cm. Speed ; 0.1 cm/s. Tension of specimen ; 20 gf/cm. The signal of wave length being smaller than 1 mm is allowed to pass by a high pass filter of 2nd order.	SMD-1, SMD-2
Thickness	Thickness at 0.5 gf/cm^2 pressure.	T
Weight	Weight of specimen per unit area.	W

Note : At the tensile, bending, shearing and compression measurements, deformation is applied up to the maximum value then recovered with the same velocity.

* The parameters of warp direction is denoted by 1 (LT-1 or B-1) and weft direction by 2. The mean value of warp and weft directions is used for objective handle evaluation.

Appendix B Descriptions of Mechanical Parameters

Properties	Parameters	Descriptions	Unit	Apparatus
Tensile	LT	Linearity of load-extension curve	none	KES-FB1
	WT	Tensile energy	gf cm/cm^2	
	RT	Tensile resilience	%	
Bending	B	Bending rigidity	gf · cm^2/cm	KES-FB2
	2HB	Hysteresis of bending moment	gf · cm/cm	
Shearing	G	Shear stiffness	gf/cm/deg	KES-FB1
	2HG	Hysteresis of shear force at 0.5 deg. of shear angle	gf/cm	
	2HG5	Hysteresis of shear force at 5.0 deg. of shear angle	gf/cm	
Compression	LC	Linearity of compression-thickness curve	none	KES-FB3
	WC	Compressional energy	gf cm/cm^2	
	RC	Compressional resilience	%	
Surface	MIU	Coefficient of friction	none	KES-FB4
	MMD	Mean deviation of MIU	none	
	SMD	Geometrical roughness	μm	
Thickness	T	Fabric thickness	mm	KES-FB3
Weight	W	Fabric weight	mg/cm^2	Balance