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Development of Silk Yarns for Knitted Fabrics

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Abstract

The mechanical characteristics of knitted silk fabrics prepared using salt-shrunk, fiber-dispersed and resin-treated silk yarns were determined based on the Kawabata Evaluation System for Fabrics (KES-FB). These knitted fabrics had a very feel and were fluffy and light. The amount of starting material yarn needed to obtain a knitted fabric of the same thickness was smaller in the case of the processed yarns compared with the unprocessed control yarn. Among the mechanical properties determined, the fabrics made from the processed yarns had higher values for the LT, WT, B, 2HB, LC, WC, MMD and SMD parameters, and lower values for the G, 2HG and 2HG3 parameters than fabrics made from the control yarn. These changes in mechanical characteristics suggest that knitted fabrics made from the processed silk yarns are flexible and elastic, have a higher resilience, and are soft and stretching. Although the primary hand feel (HV) parameters like 'Koshi' (stiffness), 'Fukurami' (fullness and softness), and 'Numeri' (smoothness) of the knitted fabrics made for winter outer garments from the processed silk yarns were about the same as those of knitted fabrics made from the control yarn, the former had a higher total hand feel value (THV) which is used for assessing fabric quality. Based on the determination of the various mechanical properties and the results of evaluation by users who wore the silk sweaters, it is considered that the salt-shrunk, fiber-dispersed and resin-treated silk yarns have a good potential as yarns for knitted fabrics.

Discipline: Sericulture/Agricultural environment
Additional key words: silk

Introduction

Larger amounts of apparel fibers are currently used for making knitted fabrics than woven fabrics. However, in the case of silk yarns, more than 80% is used as material for Japanese dresses which are made of woven fabrics. Only several percent of the total is used for the manufacture of western style woven or knitted products like dresses, women's undergarments, ties, etc. Various attempts have been made to produce silk yarns with a crimped shape, as in the case of cotton, wool, and synthetic spun yarns, in order to expand the use of silk yarns for making knitted products[3].

The present author attempted to develop a crimped silk yarn with good fiber dispersion characteristics by applying the salt-shrinking technique[11]. By immersing twisted silk yarn with a twist coefficient of 1,500–2,500 in a hot (80°C) concentrated solution of calcium nitrate with a specific gravity of about 1.42 for about 1 min, the fiber shrank by 10–40%. Then, by applying the fiber dispersion treatment and resin treatment to the surface, very fine irregular crimping could be obtained in the yarn provided that the fibers were well dispersed. Knitted silk fabrics made from these processed yarns were bulky and showed a high resilience against deformation, while being flexible and elastic.

Materials and methods

1) Materials

(1) Raw silk (27d × 6, Z200T/m) × 5, S150T/m, first twist coefficient = 2,546
(2) Raw silk (27d × 4, Z200T/m) × 3, S150T/m, first twist coefficient = 2,078, 25 skeins
(3) Raw silk (27d × 4, Z150T/m) × 3, S100T/m, first twist coefficient = 1,559, 16 skeins

Samples (2) and (3) consisting of a total of 41 skeins of raw twisted yarn, were placed in a cotton fabric sack and degummed in the sack, in a 10 g/L solution of Marseille soap. The degumming was performed at 95°C to the boiling temperature, for 60 min, and the degumming operation was repeated twice. Thereafter, the silk yarn samples were soaped and washed in warm water. The degumming loss was 24.2%. Sample (1) was used as unprocessed yarn (control) for making knitted fabrics. This yarn was also boiled in a sack for degumming, under the same conditions.

2) Preparation of salt-shrunk, fiber-dispersed and resin-treated yarn

The degummed twisted yarn samples (2) and (3) were soaked and treated for about 30 to 60 sec at 80°C in a concentrated calcium nitrate solution with a specific gravity of 1.415 to obtain a shrinkage scatter in the range of 30–50%. Thereafter, the yarn samples were washed, subjected to fiber dispersion, surface-treated with resin, and treated with an antistatic agent, in that order. Processed yarns Nos. 2 and 3 with salt shrinkage values of 32.3 and 48.8%, respectively, were prepared from sample (2) and processed yarn No. 4 with a salt shrinkage of 39.0% was prepared from sample (3) (Table 1). The shrinkage level was calculated from the original length of the yarn and the yarn length after the treatment, i.e. after soaking in the calcium nitrate solution, washing with warm water to remove the calcium nitrate, washing, and drying, according to the formula given below.

Salt shrinkage (%) =

[(Original yarn length – Yarn length after treatment) / Original yarn length] × 100

3) Electron micrographs

The processed silk yarn was coated with gold and observed at an acceleration voltage of 15 kV using a scanning electron microscope JXA-733S (Nihon Denshi).

4) Preparation of knitted fabrics

The fabric samples were machine-knitted and set by applying a steam iron for several minutes after placing a piece of cotton cloth over the fabric. The processed yarn samples Nos. 2–4 listed in Table 1 were used for making the knitted products. Two lady's sweaters were prepared from each type of yarn, with a total of 6 sweaters, and evaluated by wearing. Separately, one piece of knitted fabric each, with about the same thickness, was made from the processed yarns Nos. 1–4 (Table 1) for determining the mechanical properties.

To maintain uniform knitting conditions, it is generally desirable to keep the same gauge number for all the yarns (Nos. 1–4). However, since the thickness of the processed yarns varied depending on the extent of shrinkage, for measuring the Kawabata Evaluation System (KES) hand values, it was deemed necessary to obtain fabrics with about the same thickness, rather than using the same gauge number for knitting. Therefore, the person who operated the knitting machine set the gauge number (yarn density) at 48 to 52 rows × 36 to 38 stitches (10 × 10 cm), by observing the processed yarn (Table 1). The knitting machine operator had a high level of professional skill and a long experience.

5) Determination of mechanical properties of the knitted fabrics

Five groups of mechanical properties were determined, each 3 times, with a sample of the knitted fabric, using the "KPM-3-M" program for knitted fabrics[4,5,8]. The means of the values along the wale direction and the course direction were used to express the tensile, bending, shearing, and surface characteristics of the knitted fabrics.

Table 1. Salt shrinkage, resin uptake of yarns and weight of knitted silk fabric used for making measurements

Yarn	Degumming loss (%)	Salt shrinkage (%)	Resin uptake (%)	Gauge No.[a] (Rows × stitches)	Wale No.	Course No.	Weight (g)
No. 1 (Raw silk, 27d × 6, Z200) × 5, S150	25.4	—	—	48 × 36	56	36	13.74 (5.50)[b]
No. 2 (Raw silk, 27d × 4, Z200) × 3, S150	24.2	32.3	9.5	50 × 36	60	36	6.27
No. 3 (Raw silk, 27d × 4, Z200) × 3, S150	24.2	48.8	9.1	48 × 36	52	36	7.31
No. 4 (Raw silk, 27d × 4, Z150) × 3, S100	24.2	39.0	10.8	52 × 38	60	38	6.13

a): Gauge No., wale No. and course No. refer to a 10 × 10 cm area of fabric.
b): The weight given inside the parenthesis for the yarn No. 1 is the value after conversion to the size (324d) of the processed yarns Nos. 2 and 4.

6) End use tests with the knitted products

Four ordinary consumers in their 30's and 40's were asked to evaluate the knitted sweaters. They used the sweaters for about 4 months after which they were asked to evaluate their performance by answering a questionnaire. Resistance to washing was examined with the sweater samples that were worn and washed repeatedly. The questions included in the questionnaire and the method of testing adopted followed the "Testing of commercial washable silk products" manual prepared by Kokumin Seikatsu Center[7].

Washing and handling were performed as follows: washing for 2 min in warm water by repeatedly pressing down, squeezing out the water by pressing, rinsing for about 2 min, removing the water by placing the sweater in a net and spin drying for 10 sec, and drying by hanging in the shade on a rod. The neutral detergent Acron manufactured by Lion K.K. was used for the washing.

The initial quality evaluation was performed before the first washing, through a questionnaire on the quality and wearing comfort of the sweaters. For quality evaluation after washing, the users were asked to give their opinion about wearing comfort after 5 washings, through a questionnaire. The shrinkage due to washing was measured and the fading of color and gloss was determined using a color computer SM-3-SCH manufactured by Suga Shikenki K.K. For determining the shrinkage, the length and bust size of the sweater before and after washing were measured following JIS L 1018[2] and calculated according to the formula given below.

Shrinkage after washing (%) =
[(Size before washing − Size after washing) / Size after washing] × 100

Results and discussion

1) Properties of knitted fabrics

Electron micrographs showing the surface morphology of salt-shrunk, fiber-dispersed and resin-treated yarn are shown in Fig. 1. The yarns had a very good fiber dispersion and the fibers did not stick together. The twisting and bending of the yarn became more extensive with increased salt shrinkage. The trial products knitted from this type of processed yarn had a very soft hand feel and touch and were very light with good bulkiness and heat retention (Fig. 2).

Table 1 gives the values for the degumming loss, salt shrinkage and resin uptake of the processed yarns, the gauge number, the actually observed wale number and course number of a 10 × 10 cm area, and the weight of a 20 × 20 cm piece of the knitted fabric.

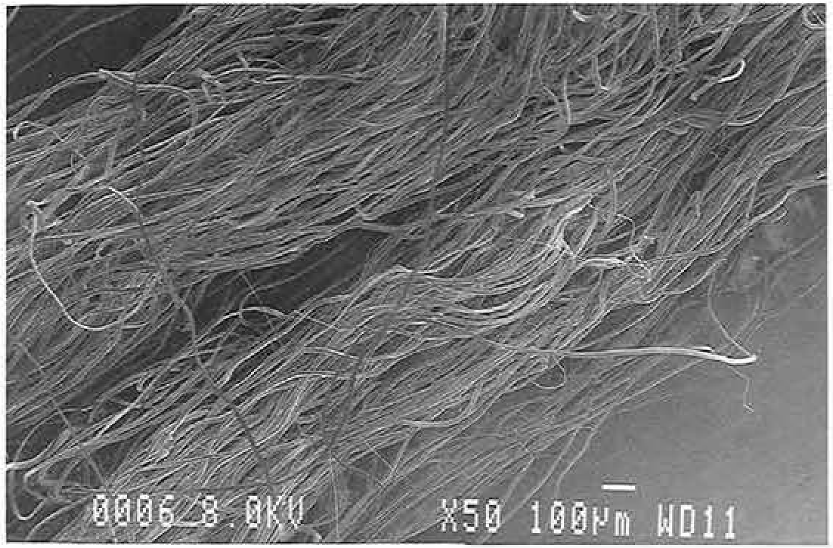
The weight and thickness of the knitted fabric were closely related to the denier and yarn density. The weight of the fabric knitted from the unprocessed yarn (No. 1) was, on the average, 2.1 times larger than that of the fabric samples made from the processed yarns (Nos. 2–4). This is a reflection of the fact that the total denier of the raw twisted yarn used for making the unprocessed yarn was 810d (27d × 30), while it was 324d (27d × 12) in the raw untwisted yarn used for making the processed yarns. Thus, the former showed a 2.5 times larger weight, to begin with.

In the case of the processed yarns, because of the resin treatment of the yarn surface, about 10% of the weight is due to resin uptake. Fig. 1 clearly indicated that the yarn structure is crimped and not straight. Even though the structure of the crystalline region of the silk fiber was destroyed and became amorphous during the salt shrinkage treatment, and the degree of molecular orientation in the amorphous part, which is considerably higher in silk compared to other fibers, was also lowered by the salt shrinkage treatment, leading to a reduction of the specific gravity of the silk, the 2.1 times larger weight of the knitted fabric made from the unprocessed yarn was within an acceptable range.

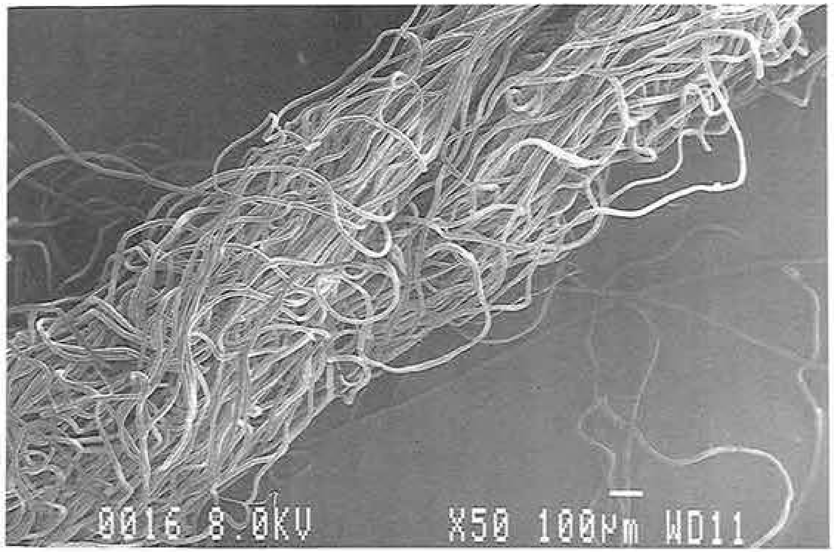
In spite of the 2.5 times difference in denier to begin with, when the initial pressure of 0.5 g/cm^2 was applied to the knitted fabric and its thickness was measured using the KES-FB4 device, the thickness of the knitted fabric made from the unprocessed yarn was 1.91 mm and that made from the processed yarns was in the range of 1.85–2.03 mm. The difference between the 2 types of fabrics was very small, being only 0.03–0.12 mm (1.6–6.3%) (Table 2), presumably because after salt shrinkage, fiber dispersion and resin treatments, the silk fiber became slightly thicker, the twisted yarn itself became well-dispersed, crimped and bulky, and the knitted fabric made from it was very fluffy and light. Therefore, although the processed yarn experienced a salt shrinkage of about 40%, a much smaller amount of processed yarn was needed for preparing a knitted fabric that was quite bulky.

2) Mechanical properties

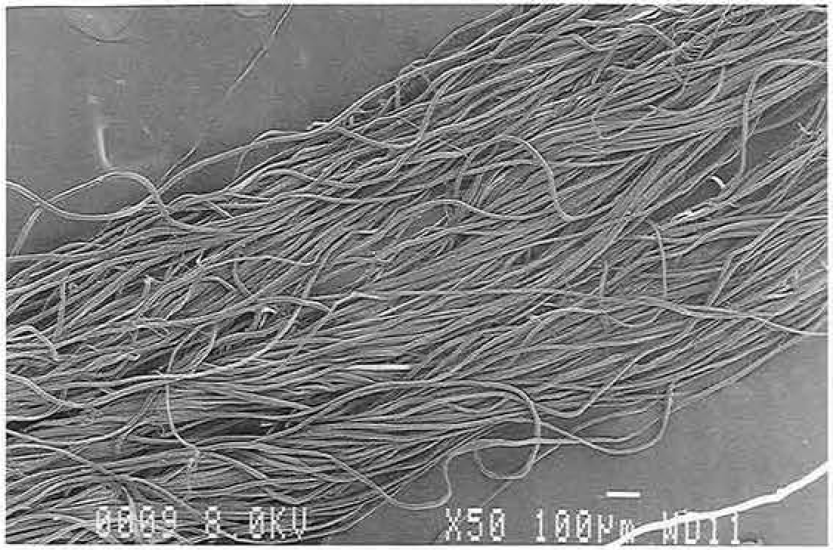
Only in very few cases has the fabric quality been evaluated through the measurement of the primary



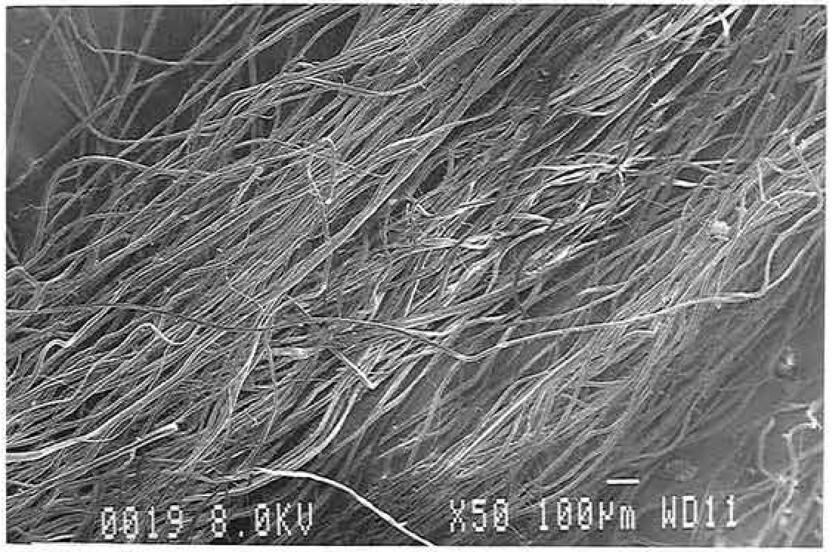
Yarn No. 1, salt shrinkage 32.3%, resin uptake 0%



Yarn No. 3, salt shrinkage 48.8%, resin uptake 9.1%



Yarn No. 2, salt shrinkage 32.3%, resin uptake 9.5%



Yarn No. 4, salt shrinkage 39.0%, resin uptake 10.8%

Fig. 1. Scanning electron micrographs of salt-shrunk, fiber-dispersed and resin-finished silk yarns and an unprocessed control silk yarn
Yarns Nos. 1, 2 & 3: (27d × 4, Z200T/m) × 3, S150T/m,
Yarn No. 4: (27d × 4, Z150T/m) × 3, S100T/m.

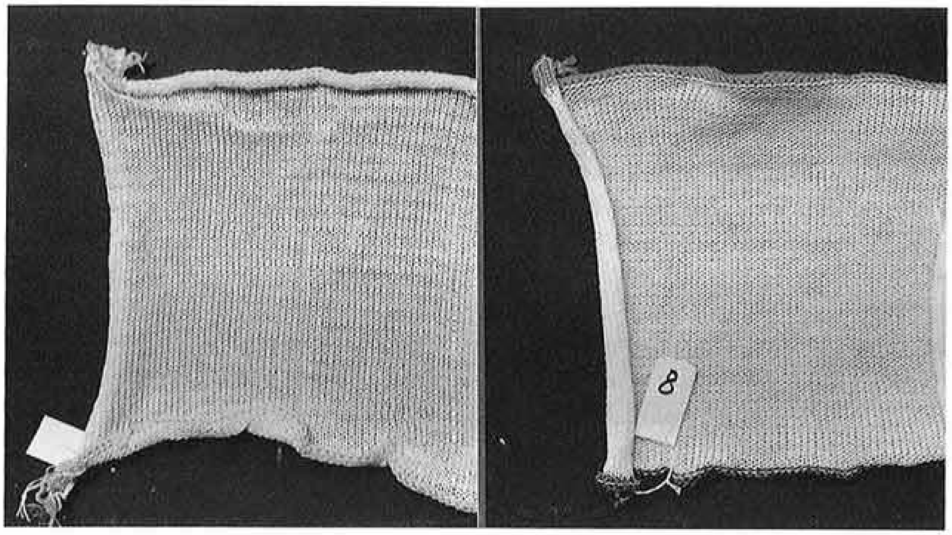


Fig. 2. Trial knitted products made from salt-shrunk, fiber-dispersed and resin-treated silk yarn
Left: Resin-treated, Right: Not treated with resin.

hand values, which is considered to be an objective method of quality evaluation[12]. If the warp and weft directions of woven fabrics are considered, respectively, to be equivalent to the wale and course directions of knitted fabrics, the primary hand values calculated from the mechanical properties determined in feel testing may enable to evaluate the performance of the fabric[4]. On the basis of this assumption, we determined the mechanical properties of knitted fabric samples, all having about the same thickness (Table 2).

(1) Tensile characteristics

Tensile energy (WT) of the fabric was higher in the processed fiber, i.e. the salt-shrunk, fiber-dispersed and resin-treated yarn fabric, compared with the unprocessed fiber. The greater the shrinkage and the lower the number of twists in the yarn, the higher was the WT value of the fabric. The resilience (RT), i.e. the force of recovery from a deformative load, was more affected by the number of twists than by the processing of the yarn. When we compared the processed yarns Nos. 2 and 3 (Z200/S150) with the

Table 2. Mechanical properties of test-made knitted silk fabrics

Group	Parameter	Unit	No. 1	No. 2	No. 3	No. 4
Strength	LT	none	0.45	0.54	0.52	0.51
	WT	gf × cm/cm^2	40.1	48.1	55.3	56.5
	RT	%	22.7	22.8	21.5	15.7
	EMT	%	35.46	35.6	44.0	44.2
Bending	B	gf × cm^2/cm	0.079	0.054	0.088	0.049
	2HB	gf × cm/cm	0.087	0.077	0.122	0.073
Shearing	G	gf/cm × deg	0.33	0.38	0.23	0.19
	2HG	gf/cm	1.38	1.66	0.85	0.75
	2HG3	gf/cm	1.98	1.71	1.07	0.89
Compression	LC	none	0.57	0.52	0.75	0.56
	WC	gf × cm/cm^2	0.65	0.73	0.74	0.79
	RC	%	40.8	42.2	37.9	42.1
Surface	MIU	none	0.24	0.27	0.30	0.26
	MMD	none	0.0089	0.9124	0.0144	0.0128
	SMD	μm	4.86	4.31	5.06	4.42
Thickness	T[a)]	mm	1.91	1.85	2.03	1.88
Weight	W	mg/cm^2	34.3	15.8	18.3	15.3

a): T is the thickness of the fabric when 0.5 gf/cm^2 pressure was applied, calculated from the compression characteristics.

processed yarn No. 4 (Z150/S100), the former showed about the same RT value of the fabric as the unprocessed yarn, while the latter had a clearly lower fabric RT value. Apart from this, the value of the LT parameter which is a measure of tensile rigidity, was slightly increased by the processing of the yarn. Therefore, the fabric knitted from the processed yarn had smaller spaces in the knitted structure, with increased inter-fiber and inter-yarn contact, compared with the fabric made from unprocessed yarn. In spite of this, the fabric knitted from the processed yarn showed a high EMT (elongation or strain) against tensile force and therefore could be easily stretched. The results suggest that tensile recovery and tensile elasticity can be retained at the same levels as in the fabrics made from the unprocessed yarn, if the number of twists is not very low and the salt shrinkage is about 40%. All these findings suggest that soft, flexible and stretching knitted fabric can be prepared from the processed yarns.

(2) Bending characteristics

The values of the B and 2HB parameters were higher in the fabric made from processed yarn No. 3, which exhibited a greater salt shrinkage, than in the fabric made from yarn No. 2. Crimping induced by processing was optimum when the silk yarn had a twist coefficient of 1,500–2,500 and a salt shrinkage of 30–40%. Even when the original yarn had the same twist coefficient, the degree of twisting increased with increased salt shrinkage and resulted in greater final twisting, which affected the crimping and the processed yarn became somewhat hard in hand feel and lacked fluffiness and bulkiness. These characteristics may account for the increased resistance torque against the bending deformation and the increased bending strength and hysteresis in this type of fabric.

On the other hand, fabrics made from the processed yarns Nos. 2 and 4 showed about the same values for the B and 2HB parameters, which were lower than in the fabric made from the unprocessed yarn. These results suggest that knitted fabrics made from the processed yarns displayed a greater ease of bending and bending recovery. Therefore, if salt shrinkage and the twist number are controlled in a suitable range, well-crimped processed yarn can be obtained. It was found that processing enabled the fiber and yarn to move easily in response to bending deformation and the fabric had a flexible and smooth feel during bending. Based on these results, salt shrinkage of 48.8% for the yarn No. 3 appears to be excessive.

(3) Shearing characteristics

The values for the parameters G, 2HG and 2HG3, which reflect the shearing characteristics of fabrics, all showed a similar response to processing. Compared with the fabric made from the unprocessed yarn, these values were generally lower in processed yarn fabrics, although some of the values were comparable in the 2 types of fabrics (Fig. 3). Shearing

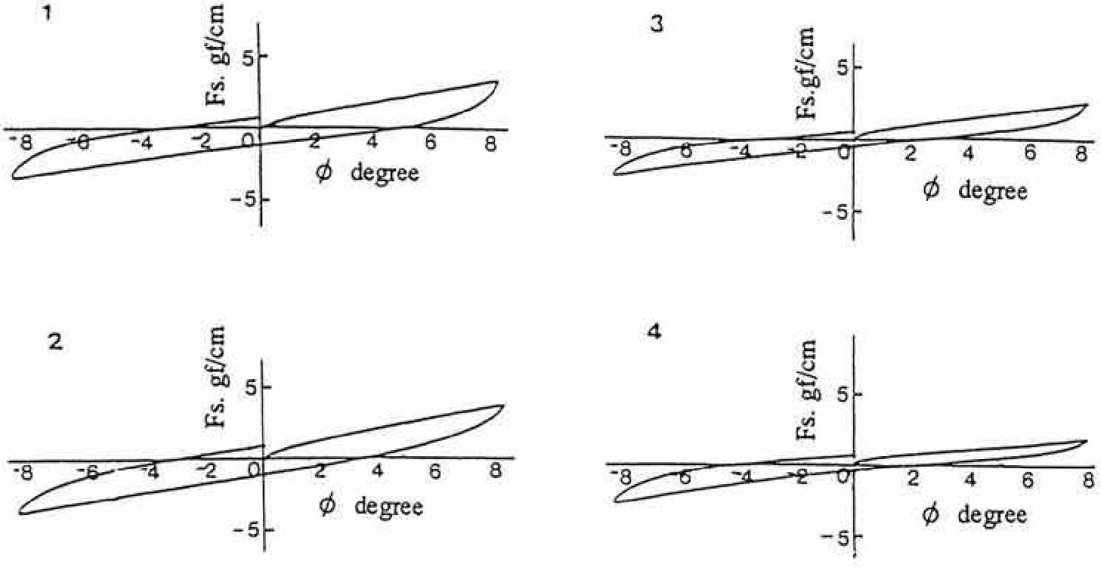


Fig. 3. Shearing characteristics of knitted fabrics made from salt-shrunk, fiber-dispersed and resin-treated silk yarns

Measurements were performed in the wale direction.

The numbers correspond to those given in Table 1.

deformation which is determined by factors like yarn pressure and slipping at the crossing points, bending deformation of the yarn, etc. is generally considered to be closely related to the bending characteristics[9]. In the present study, the fabric samples were produced under the same knitting conditions, to obtain the same knitted structure. Therefore, the effect due to the difference in the knitted structure is considered to be minimal.

The fabric made of unprocessed yarn had a high value of G. It showed a high yarn density and very close contact between yarns. Therefore, when a shearing deformative force was applied, the contact area between the yarns at the crossing points increased and the resistance torque increased making it difficult to change the angle of crossing[10]. Therefore, the knitted fabric was very hard, with little space within the fabric. In contrast, since the processed yarn fabrics had smaller hysteresis values (2HG and 2HG3), the fabric was resilient and fabrics made from yarn with high salt shrinkage had a small G value and the shape easily changed in response to the shearing deformation force. In short, from the point of view of shearing characteristics also, knitted fabrics made from the processed yarns were soft and flexible.

(4) Compression characteristics

In the processed yarns, the values for the WC and RC parameters of the fabric tended to be higher. When we compared the fabrics made from Nos. 2 and 3 processed yarns, the No. 2 yarn fabric which had a lower salt shrinkage showed lower LC and higher RC values, compared with the No. 3 yarn fabric. The WC value was slightly higher in all the processed yarns, including No. 4 which had a small twist number. These results suggest that knitted fabrics made from the processed yarns could be easily compressed and showed a good recovery from compression also. This is believed to be due to effect of fiber intertwining and the increased space in the yarn because of the crimping. However, as discussed in the section on bending characteristics, processed yarn with large salt shrinkage (No. 3 yarn) had high LC and low RC values because it had less crimping, and the fabric was not resilient.

It is known that woven wool fabrics made wholly from untwisted yarn, or in which untwisted yarn is mixed, show smaller LC and greater RC and WC values with an increased proportion of untwisted yarn in the fabric because the untwisted yarn is bulkier and has more space. It is however interesting to note that some of the compression characteristics of the fabrics made from processed yarns in the present study were similar to those of woven wool fabrics.

(5) Surface characteristics

In the surface characteristics of the processed yarn knitted fabrics, the values of both the MIU and MMD parameters (the mean deviation of MIU) were higher than in the fabric made from unprocessed yarn. This increase in the MIU and MMD values in the processed yarn fabrics was ascribed to the fact that the processed yarns had a crimped shape and dispersed fibers and therefore, knitted fabrics made from them did not have a uniform surface. The space within the yarns, the intertwining or misalignment of fibers, fluff formation, etc. all enhanced the surface unevenness of the knitted fabrics.

The results obtained suggest that soft fluffy and resilient knitted fabrics can be produced from salt-shrunk, fiber-dispersed and resin-treated yarns. This is because the twisted silk yarns acquire irregular and minute crimping and good fiber dispersion so that the intertwining of fibers and space in the yarns are increased, giving flexibility and bulkiness to the fabric.

3) Hand feel

The primary hand value (HV) which is a quantified feel parameter calculated based on the determination of the mechanical properties, reflects the stiffness, fullness and softness, crispness, and the anti-drape stiffness. HV is considered to be closely related to the fabric characteristics[5]. We obtained 3 of the HV parameters, 'Koshi' (stiffness), 'Fukurami' (fullness and softness) and 'Numeri' (smoothness), and the total hand value (THV) using the mechanical values > HV and the HV > THV conversion formulae of Kawabata. We used the "KPC-5-N" program for the KES-FB system to carry out these conversions and for preparing the knitted fabric snake charts. Table 3 gives the results of calculations using the criteria for outer winter garments (A) and winter undergarments (B). In the case of undergarments, the thermolab measurements could not be performed because of the limitations of the KES system. We therefore ignored the heat and moisture transfer characteristics that are obtained from thermolab measurements, and calculated HV and THV from the values of the mechanical characteristics KES-FB1 to KES-FB4.

With the criteria for outer winter garments, the values for the 'Koshi', 'Fukurami' and 'Numeri' parameters of the processed yarn fabrics were all about the same as in the unprocessed yarn knitted fabric. However, the values of THV, which is a

Table 3. **Primary hand values of test-made knitted silk fabrics**

Hand values	Criteria[a)]	No. 1	No. 2	No. 3	No. 4
'Koshi'	A	1.7	1.8	2.1	1.1
	B	5.8	5.4	3.8	2.7
'Fukurami'	A	5.0	3.1	3.2	3.2
	B	16.3	16.3	16.6	18.8
'Numeri'	A	8.6	7.9	7.7	7.9
	B	9.6	8.8	9.7	10.9
THV	A	2.2	3.2	3.4	3.2
	B	6.0	2.3	2.2	1.5

a): A; For winter outer garments,
B; For winter undergarments.

parameter used for evaluating the fabric quality, were in the range of 3.2–3.4 in the processed yarn fabrics, compared with 2.2 in the unprocessed yarn fabric. The hand feel values were not affected by the salt shrinkage and number of twists. It became clear from these results that fabrics knitted from the processed yarns were superior in terms of THV, although they were not appreciably different from the unprocessed yarn fabric in terms of 'Koshi', 'Fukurami' and 'Numeri'.

The THV and mechanical properties determined above suggest that knitted fabrics made from processed yarns in the present study had the characteristic properties and good feel of the processed yarns and such yarns have the potential of becoming attractive silk yarns for knitted fabrics, which would expand the range of application of silk products and satisfy the requirements of consumers.

4) End use tests

(1) Evaluation of initial quality

Four users were asked to evaluate the wearing comfort of the sweaters made from the processed yarns before washing. The users answered "Difficult to say," or "Somewhat poor," when asked about the flexibility of the garment. But regarding the feel of the fabric and wearing comfort, 3 out of 4 users answered "Fairly good." No users stated that the initial wearing quality of the sweaters was poor (Table 4). The knitted fabric made from processed yarns with 32.3 to 48.8% salt shrinkage lacked the silky gloss and was more like wool in external appearance. Therefore, all the users thought that the sweaters were made of wool, before they were told that they were made of silk. But after wearing them, many of the users said that they were "Very light and easy to wear" compared to woolen sweaters which are generally considered to have just the opposite characteristics[6)]. In fact, one of the users suggested that perhaps the material was suitable for undergarments like slips and summer blouses because it was light, soft to touch, moisture-absorbing, and not stuffy. The "light feel" of garments is an important feature for summer wear. This is an impression about the fabric which is closely related to the "cool touch."

In one study on the evaluation of knitted fabrics for undergarments involving a group of 18 expert technologists having 1–20 years of experience in undergarment manufacture and a group of 9 ladies consumers in the 22–38 age group, the 2 groups showed no significant difference in the perception of hand feel, with a high inter-group correlation, the evaluation rather differing from person to person[12)]. The 4 users in the present study had a high level of knowledge about garments and acquired a wide experience from managing households. If we take into consideration the report of Sakaguchi et al.[12)], according to which the judgement of consumers was quite reliable, it is clear that the knitted fabrics made from the processed yarns in the present study had a good fabric quality while they were new.

(2) Evaluation of quality after washing

Shrinkage caused by washing of the knitted garments is shown in Fig. 4. There was a considerable scatter in the values, perhaps because of slight variations in the method of taking measurements by the users. However, the overall trend showed that the shrinkage varied depending on the extent of salt shrinkage of the yarn. In sweaters made from yarn

Table 4. **Evaluation of users after wearing the new (unwashed) sweater**

	Poor (−2)	Somewhat poor (−1)	Difficult to say (0)	Moderately good (+1)	Good (+2)
Touch			2[a)]	2[a)]	
Flexibility		3[a)]	1		
Wearing comfort			3	1	

a): The figures refer to the number of users.

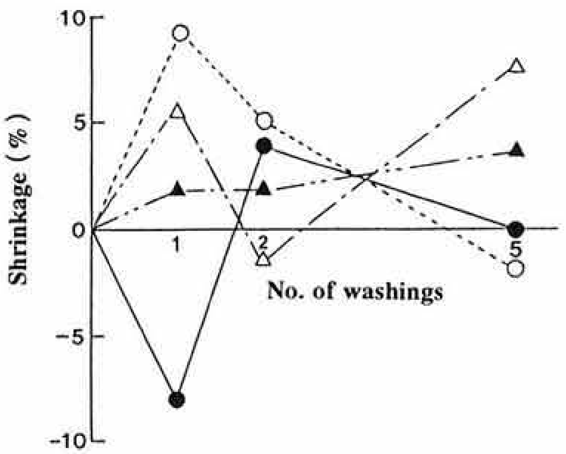


Fig. 4. Changes in shrinkage caused by repeated washing
···○···: Length of garment made from yarn No. 2 (salt shrinkage 32.3%),
—●—: Bust size of garment made from yarn No. 2 (salt shrinkage 32.3%),
—△—: Length of garment made from yarn No. 3 (salt shrinkage 48.8%),
—▲—: Bust size of garment made from yarn No. 3 (salt shrinkage 48.8%).

with a low salt shrinkage (32.3%), after one washing, the length decreased by 5.0 cm while the bust size increased by 4.0 cm, resulting in the change of the shape of the garment. However, after repeated wearing and washing, the dimensions became more or less similar to those of the new sweater. Thus, there was no problem of shrinkage caused by washing. The sweaters made from yarn with a high salt shrinkage (48.8%) showed a reduction in both length and bust size as the garments were washed repeatedly. After 5 washings, the average shrinkage of the 2 sweaters was 7.9% for the length and 2.0% for the bust size, showing significantly higher shrinkage in the length direction. Thus, it may necessary to improve the quality.

The opinion of the users about the qualities of the garments, such as the feel, flexibility, wearing comfort, etc. after 5 washings was that the sweaters were not appreciably different from the new sweaters with respect to shrinkage, color fading, gloss, hand feel, fluff formation, feel, flexibility and wearing comfort (Table 5).

It has been reported that the value of silk blouses and undergarments decreased after washing because of shrinking, yellowing, and changes in gloss and hand feel[7]. In one report[1], it was stated that knitted garments made from spun silk yarns shrank after hand washing with a neutral detergent, their color faded, and the gloss and hand feel were poor, the flexibility characteristic of silk disappeared and the hand feel of the garments became similar to that of garments made from low quality cotton. However, knitted garments made from processed silk yarn in our study showed a lower decrease in quality than anticipated.

The results shown in Figs. 5 and 6 suggest that the sweaters were resistant to washing. However, when asked to give their overall opinion about the sweaters after 5 washings, some users gave comments like "It does not slip well," "It sticks to the body," "It got slightly stretched after repeated use," "It lacks stiffness," "It has a coarse feel," "It lacks smoothness," etc.

There were opinions like "Overall, I do not like the sweater," and "I do not wish to wear this type of sweater." We do not think that all these negative comments can be attributed to the quality of the processed yarns. The sweaters were rather thickly knitted, did not have much gloss which made them look like wool, and had a design that was not very sophisticated. Thus, the fact that samples had just the opposite image to the generally held delicate

Table 5. Evaluation of 4 users for the sweaters after 5 washings

	Poor (−2)	Somewhat poor (−1)	Not different from when the sweater was new (0)	Moderately good (+1)	Good (+2)
Shrinkage			4[a]		
Color fading			4		
Gloss		2[a]	2		
Hand feel		2	2		
Fluff formation		2	2		
Touch			2	2[a]	
Flexibility	1[a]	2	1		
Wearing comfort			3	1	

a): The figures refer to the number of users.

image of silk garments may have exerted an adverse effect.

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