STUDIES ON THE GATHERING OF FILAMENTS FORMING RAW SILK

by

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I INTRODUCTION

Silk fabrics have the important characteristic of fine and elegant touch and are distinguished in it from the other textile fabrics. It is said that Japanese silk fabrics have lately been degraded in this point. Since this comes from the manufacturing processes, however, further researches into them are necessary to solve this problem.

The researches are divided into two stages, one the process of making raw silk, an intermediate, and the other the subsequent. Either of them is important, but the first one is above all important in Japan where raw silk is transacted as an article of commerce. These studies belong to the first one. It is assumed that the touch of a silk fabric will vary with the behavior that its silk fibers show when it is subjected to slight forces and has something to do with the gathering of cocoon filaments. These studies were performed with some supplementary aid of the Ministry of Education of Japan.

II DISCUSSION ON THE BULKY NATURE OF RAW SILK AND THE TOUCH OF ITS FABRIC

There are formal or mechanical qualities and chemical qualities such as reactions on chemicals in raw silk. The process of making raw silk as an article of commerce has been so far studied chiefly with a view to improving the former qualities. Improvement was made, for examples, in breaking strength, elongation, evenness, etc. But these qualities have no influence on the touch of silk fabrics. It is thought, however, that the touch of the fabric has something to do with the special behavior that the cocoon filaments show as slight forces are applied to them. When a slight force is applied to a raw silk fiber, the filaments constituting it are gummed together by sericin and so individual filaments are kept immovable. So their special behavior does not appear for it. It is reasonable that there has been reported very little relationship between the mechanical qualities of raw silk and the touch of the fabric therof.

Raw silk in real silk fabrics is separated in filaments by degumming treatment. So individual filaments are gathered together in a movable state and are allowed to behave themselves peculiarly toward slight forces. They originally have the properties of crimping. If the properties are left, the special behavior is still much increased. The degree of degumming is a control of the behavior and will vary the touch of the silk fabric.

The degumming resistance varies with the amount and properties of sericin. and also will vary according to the structure of sericin adherence, which is determined by the structure of gathering of the filaments. Eventually in the same kind of raw silk, it can be said that the structure of gathering of the filaments will influence the touch of the silk fabric made from them. It should be considered that the slight forces mentioned above are applied in the two directions, the fiber axis and its rectangular.

It is experientially assumed that the high bulkiness of raw silk will improve the touch of its fabric. Since the bulkiness is determined by whether the gathering structure of the filaments is fine or rough, the above assumption may be correct.

To prove that the assumption is correct, relationship between the degumming resistance and the bulkiness must be found out and the method of expressing the bulkiness quantitatively must be obtained, and at the same time the fact that the bulkiness i. e. the gathering structure of the filaments is changed by the process of making raw silk must be shown.

The cocoon filaments originally have crimping properties. Tension is necessary to draw out the filaments from the cocoon. This tention is named "drawing tension". This degree of tension is in most cases at a critical point where the crimps of the filaments are removed or not. This tension can be measured with a special device.

A group of filaments is subjected to frictional force because of gathering up. The total tention which the group of filaments have immediately after their gathering up is named "gathering tension". The filaments are stuck together with sericin when they have finished gather up. The drawing tension of each filaments always changes in a vibratile way, but, as all the drawing tension has no chance of becoming zero, the raw silk after being stuck together has not any crimp seemingly.

The raw silk obtained is wound on a reel through the croissieur system and some thread guides. The tension of raw silk increases gradually. The tension of raw silk immediately before winding on a reel is named "winding tension".

The others but the drawing tension can be measured freely during the actual reeling. All of the tension is called "reeling tension".

As it has not proved that the gathering structure of the filaments i. e. the bulkiness of raw silk varies with the reeling tension, raw silk has been made only in an effort to promote productivity. Consequently, it is thougt that raw silk has inclined to resist the treatment of improving the touch of the fabric thereof. These studies are performed in an effort to increase the bulkiness of raw silk.

III THE METHOD OF MEASURING THE APPARENT DENSITY OF THE UNITED COCOON FILAMENTS

The apparent density of the united cocoon filaments is determined by the size of apertures formed by fibroin and the amount of sericin filling the apertures. The size of the aperture is determined by the number of the filament crimps too. As it is thought that it is the apparent density that physically controls the degumming resistance of raw silk, the gathering degree of the filaments was represented by the apparent density.

I) Method of Measuring

The apparent density of raw silk was adopted as a quantitative indicator of the bulkiness—— the gathering structure of the filaments. This measurement is simple and speedy. This is absolutely necessary for the study.

The special raw silk of outerlayer filaments only or of middlelayer filaments only or inner-layer filaments only is made. After the raw silk has been re-reeled, sizing skeins of 100 round threads, each of them 112.5 meters in length, are taken from it. This is done so that partial differences in sericin contained in filaments may not influence the results of measurement. This precaution will be unnecessary if a great amount of sampling is allowed to be used as in the actual production of raw silk.

A bandle of 800 threads is measured as a sample. The number of threads is definite for convenience sake. The shape of the cross-section of a bundle is made diamond-shaped by compressing it at right angles to the fiber axis. The angle of one opposite in the diamond is set at 60°. When the total sum of the true cross-section areas of the bundled raw silk is the greatest in proportion to the area of the diamond, the opposite angle is calculated at 60°. In this case the cross-section of one thread of raw silk was assumed to be circular. The bundled raw silk is consequently very easy to be compacted and compressed.

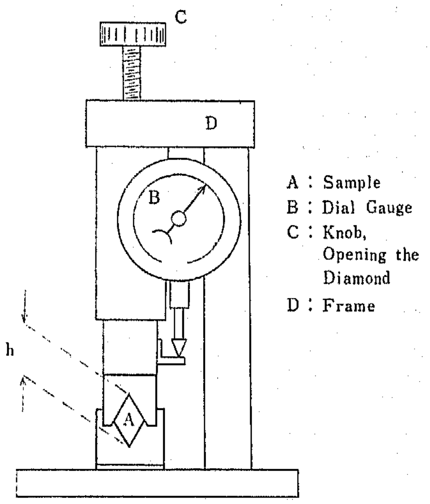

Fig 1 Apparatus of Measurement
h is obtained with B

Compressive force is given with a weight of 150 gr from the direction of the opposite angle of 60°. The apparent density is obtained from the distance h between the opposite apexes of the diamond. The apparatus of measurement is outlined at Fig. 1. h can be read up to 1/100mm with a dial gauge.

Let the diameter of raw silk be D, the number of threads in a bundled raw silk be n, and then the length of a side of the diamond is given geometrically. n is generally many and so the elliptical formula is like this:

$$h \doteqdot \sqrt{3n}\, D$$

As the total of the cross-section areas of raw silk is $\pi h^2/12$, the apparent density of raw silk is given in the following formula:

$$\rho \doteqdot \frac{12nd}{9000\pi h^2}$$

d is the thickness in denier of one thread of raw silk. As for this sample, it is

$$\rho \doteqdot \frac{0.34d}{h^2}$$

As shown in the above formula, d being definite in the same sample, the relation between ρ and h is in a parabola. In this study, using this formula the apparent density i. e. the gathering structure of the cocoon filaments is given.

2) The Utility of the Apparent Density

It is necessary to recognize the utility of the apparent density in connection with this study. It is also necessary to know whether there is any relationship between the gathering structure of the filaments represented by the apparent density, and the degumming resistance of the raw silk or not. To obtain the relationship is to show the utility of the apparent density too, and so the following researches were performed.

The apparent density of the samples of raw silk was measured and then they were boiled for 20 minutes in the distilled water weighing their 100 times, as a very slight degumming treatment. After the treatment, changes in weight were sought. The results are shown in Table I.

Table 1 Rate of Loss in Weight

Apparent Density	Outer-layer Raw Silk	Middle-layer Raw Silk	Inner-layer Raw Silk
0.803	1.29%	1.25	1.10
0.954	1.14	1.10	1.00

The rate of loss in weight varies according to parts of cocoon layers and is lower for the raw silk of higher apparent density. Here outer-layer raw silk is made of outlayer filaments only. Decrease in the apparent density of raw silk makes the degumming resistance slightly low. This is significant because it is thought that the touch of silk fabrics changes by a slight cause. It is recognized that relationship exists between the bulkiness of raw silk and the touch of the fabric thereof. And at the same time it can be said that the expression by the apparent density is useful.

IV COCOON DRYING AND THE APPARENT DENSITY

In making raw silk, cocoons are first dried. So it is necessary to seek what relation exists between the dryness and the bulkiness of raw silk. The dryness consists chiefly in drying pupas and at the same time in setting filament-crimps on cocoon-shells by means of heating.

1) The Effect of Heat-setting

The crimps of filaments are made by the worm beforehand. During the drying of cocoons, the filaments are subjected to the actions of both heat and vapour, which will given them the effect of heat-setting. The crimps of the filaments drawn out of dried cocoons were examined and the results are as follows:

Even in the filaments which have been subjected to the drawing-out tension, crimps are generated about 10% in non-tension. In this case the tension is only given in a very short time. The generation varies according to cocoon layers, the thickness of a filament, and the tension given. The work of extension to remove the crimps generated is determined by the thickness of a filament.

To know the heat-setting effect of the filament of the cocoons which have been dried by various drying methods requires to compare the amount of the work of removing the crimps of the filaments of the same thickness. Filaments were drawn under the same conditions out of the cocoons dried by three methods of drying and then the amount of the work of removing their crimps by extension was obtained and the results are shown in Table 2.

Tcdle 2 Amount of Removal Work of the Crimps

Method of Drying	Amount of Crimps	Amount of Removal Work
2	9.24%	116mm.mg
1	9.61	114
3	9.00	118

The fiqures showing methods of drying also indicate the ordering of solubility of sericin contained in the cocoons. The amount of the work becomes slightly high, of removing the crimps of the filaments of the cocoons dried under the conditions in which sericin solubility lowers; Namely, such a drying method means that the effect of heat-setting is somewhat high. As the drawing tension is small, the crimps remain even a little for this degree of effect and enter into the filaments united together, Thus increasing the bulkiness of raw silk.

2) The Apparent Density and the Degrees of Drying

There are filatures in which cocoons are dried to various degrees of dryness to be reeled off. The more the degrees of dryness, the less the solubility of sericin is. And this will increase the heat-setting effect on the filaments. In this case what will be the relation between the degrees of dryness and the bulkiness of the raw silk?

The degrees of dryness were controled by the time of drying under the normal conditions. Raw silk was produced from these cocoons under the definite reeling conditions. The results are shown in Table 3

Table 3 Changes in the Apparent Density

Degrees of Dryness	Outer-layer Raw Silk	Middle-layer Raw Silk	Inner-layer Raw Silk
100%	0.854	0.878	0.878
61	0.869	0.879	0.912
44	0.935	0.848	0.862
38	0.966	0.890	0.930

100% degrees of dryness represent raw cocoons and the smaller the number, the more the degrees of dryness are. As the degrees of dryness proceed, the effect of heat-setting must be higher. However, this indicates, on the contrary, that the apparent density increases with the degrees of dryness, and the bulkiness of raw silk decreases.

The reason for the inverse results of those of Table 2 is thougt to be the definite reeling conditions for all the cocoons. Decrease in sericin solubility causes increase in drawing tension, under the same reeling conditions. Therefore the crimps are more removed. The results of Table 3 show that the effect of increased drawing tension is greater than that of heat-setting planned to keep filament-crimps. Therefore, in order to acquire the effect of heat-setting, the reeling conditions under which drawing tension does not increase must be established for each group of cocoons.

Drawing tension is also controled by cocoon-cooking, but in this case the apparent density is changeable for another reason. as the degree of cocoon cooking advances, the amount of sericin contained in the filaments is decreased. This lowers the percentage in the amount of sericin which fills the aperture in the raw silk and so makes the apparent density of raw silk low.

V SILK REELING AND THE APPARENT DENSITY

As silk reeling is considered to be a process which directly influences the apparent density of raw silk, this relation was investigated in detail. The process of silk reeling involves gathering filaments and removing moisture in raw silk and other functions. As reeling tension is said to influence the bulkiness of raw silk, this relation was especially researched.

1) Winding Tension

The apparent density of raw silk was investigated in connection with the definite drawing and gathering tension, and with the some other conditions but with varied winding tension. The method was that raw silk just before winding on a reel is subjected to frictional force and so winding tension only is increased. The result are shown in Table 4.

Table 4 Changes in the Apparent Density

Winding Tension	Outer-layer Raw Silk	Middle-layer Raw Silk	Inner-layer Raw Silk
0.351g/d	0.962	0.858	1.120
0.239	0.938	0.836	1.130

Contrary to expectation, the apparent density of raw silk increases in a low proportion to increased winding tension. It proves that the apparent density of the raw silk which has had croissieur effect is considerably stable against more or less tension given thereafter.

2) **Gathering Tension**

Instruments, in general use, for gathering cocoon-filaments into a group are a button or a rotary ends-feeder or a fixed ends-feeder. These rub filaments in gathering them. The degree of rubbing varies with the instruments. The apparent density of raw silk manufactured with the three kinds of instruments was obtained and shown in Table 5. The raw silk manufuctured with a rotary ends-feeder is the greatest in gathering tension and highest in apparent density. . The gathering tension strongly influences the apparent density.

Table 5 Differences of the Apparent Density

Reeling Conditions		Button		Rotary Ends-feeder		Fixed Ends-feeder	
Winding Speed	Reeling Temperature	gathering Tension	Apparent Density	Gathering Tension	Apparent Density	Gathering Tension	Apparent Density
77m/min	22°C	0.257g/d	0.890	0.328g/d	0.981	0.240g/d	0.863
46	68	0.144	0.743	0.230	0.866	—	—

The button has a circular hole having a little larger area than the cross-sectional area of a group of cocoon-filaments. The hole is very short in length. The filaments as a group are firmly bundled and united by passing through it. Some filaments do not rub with the inner wall of the hole in passing through it, because of a rate of the total cross-sectional area of a group of filaments to the area of the hole.

The fixed ends-feeder has a metal plate of V letter shape. This plate is so fixed that cocoon-filaments are gathered up and united at the point bottom, where there are few filaments rubbed with it as in the case of the button.

The rotary ends-feeder has a threading pipe of 2mm in inner diameter and 3cm in length. A group of filaments are gathered by passing through the threading pipe. However, the inner diameter of the pipe is very great as compared with the total cross-sectional area of the filaments as a group and so they are all rubbed with the entrance of the pipe and are subjected to insufficient gathering action, and are united at the exit after it. Gathering action and uniting action do not take place at the same time, differently from the other two. The filaments have chances to have their crimps removed between the two actions.

It is thought that the above differences in the construction gave the results of Table 5. The fittest as a means of raw silk production is at pressent the rotary ends-feeder. Therefore the action of this feeder was furthermore analyzed for investigation.

The influences of the length of the pipe were examined in order to shorten the distance in which filament-crimps are liable to be removed. The results are shown in Table 6.

Table 6 Influences of the Pipe Length

Length of Pipe	Gathering Tension	Apparent Density
7cm	0.257g/d	1.000
4	0.200	0.988

The reeling conditions under which apparent density is increased were adopted to make results well shown. As a sticking friction is made between the pipe and the cocoon filaments, there is relationship between the pipe length and the gathering tension. But those lengths of the pipe do not influence the apparent density.

Relationship between the gathering pressure acting between the pipe entrance and the filaments, and the apparent density of raw silk was sought. If a special action is given to the filaments before they are gathered and to the cocoons, changes in drawing tension take place. This must not be done. Therefore the following method was adopted to change the pressure between the filaments and the pipe entrance.

The area of the cocoons occupying the surface of hot water in the reeling basin is generally fixed. The filaments are drawn in a cone. When the height of the cone is varied, the angle of the pipe axis with the filaments is also varied and thus changes in the pressure are achieved. The distance between the pipe entrance and the surface of the reeling water is equal to the height of the cone. The results are shown in Table 7. This lowered the gathering tension a little and the apparent density beyond expectation. The reeling conditions are the same as in Table 6.

Table 7 Influences of the Gathering Pressure

Distance between Cocoons and Pipe Entrance	Gathering Tension	Apparent Density
10cm	0.184g/d	0.989
75	0.173	0.892

As this lowering in gathering tension can not influence the apparent density, as shown in Table 6, it is thought that there are other causes for the results of Table 7.

3 Mean Drawing Tension on Each Cocoon Filament

There is, as shown in Table 3, some relationship between the total values of the mean drawing tension on each filament and the apparent density of raw silk. But the mean drawing tension on each filament is not always equal. An investigation was made of the case where the mean drawing tension of a filament is different from each other and their total values are fixed.

Table 8 Influences of Filaments Given Tension

Number of Filaments Given Tension	Apparent Density
0	0.752
1	0.804
2	0.794
3	0.809
4	0.761
5	0.738
6	0.748
7	0.742

Raw silk was made in such a way that some of the filaments being reeled are given some tension especially by rubbing.

The number of filaments given tension is varied and then relation between the number and the apparent density was sought.

The results are shown in Table 8. That is, a large proportion of tension-given filaments does not influence the apparent density much. The total number of filaments is 7.

4) Vibrating Width of Drawing Tension on a Cocoon Filament

There was an unexpected cause in the results of Table 7. It is assumed through experimental observation that the cause is this: The component of drawing tension on the surface of the reeling hot water is smaller as the height of the cone of filaments is higher. This makes the gathering force of the cocoons small. Consequently the cocoons bob freely and then the vibration of drawing tension grow in width. If there are many chances to make the drawing tension very small, filament-crimps tend to blend in the raw silk.

To prove this assumption a special rotary ends-feeder was made by the writer. The structure is outlined at Fig. 2. Two parallel bars closing each other are established and the cocoon filaments pass between them. The bars are always at right angles with the filaments and revolve around the filaments. They imaginally form a very small circular hole while revolving. The hole gathers the filaments, acting as the pipe entrance of the traditional ends-feeder. But this device helps to shake every filaments positively and also make a great vibration.

A comparison is made between the trial type and the traditional type ends-feeder to prove the above assumption. Using each of the two ends-feeders raw silk was made with the gathering tension and the winding tension equal. The results are shown in Table 9.

The apparent density of raw silk made with the trial type ends-feeder is obviously lower. Therefore it can be said that the vibrating width of drawing tension influences the apparent density of raw silk strongly.

Table 9 Apparent Density on the Two Feeders

Type of Ends-Feeder	Outer-layer Raw silk	Middle-layer Raw silk	Inner-layer Raw Silk
Traditional	0.958	0.874	0.895
Trial	0.898	0.792	0.852

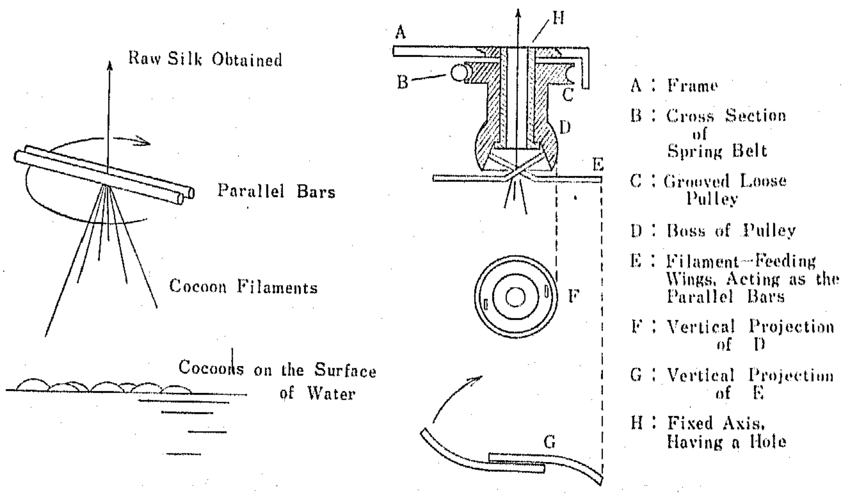

Fig 2 Trial Type Ends-feeder Made by the Writer to Prove the Assumption

5) Croissieur or Twisting Device

The croissieur or twisting device has the function of removing moisture from raw silk and of making raw silk compact and rounding its cross-section. So it is thought that the action of croissieur influences the apparent density of raw silk strongly. The effect of croissieur was examined under the same reeling tension and Table 10 was obtained from this. As the same kinds of studies has already been reported, some of the results are omitted here.

Table 10 Variations in the Apparent Density

No. of Twists	Outer-layer Raw Silk	Middle-layer Raw Silk	Inner-layer Raw Silk
0	0.742	0.816	0.858
1	0.950	0.946	0.913
20	0.961	0.955	0.916

That the number of twists is zero shows that there was no croissieur. Whether the apparent density is high or low is determind only by whether there is croissieur or not, and it is not much influenced by the number of twists.

VI RE-REELING AND THE APPARENT DENSITY

If raw silk of no tension is immersed in boiling water and dried as it is, it will be faulty, so-called shrink-threads which have crimps over all.

1) Decrease in Length of Raw Silk

Raw silk made with the present rotary ends-feeder was immersed in boiling water for 2 minutes and dried in wind. Then it was examined about decrease in length. The original length was 150cm. The lengths of raw silk after treatment were measured as it was stretched so that its crimps were removed. The weight for tension was 0.3gr. No tension was exerted during treatment.

This examination was made in connection with the assumption that the apparent density of raw silk will vary during rereeling. the results are shown in Table 11.

Table 11 Decrease in Length of Raw Silk after Treatment

	Outer-layer Raw Silk	Middle-layer Raw Silk	Inner-layer Raw Silk
Decreased Length	146.6cm	146.3	146.3
Percentage of Derease	97.7%	97.5	97.5

Raw silk will shorten more than 2% according to treating conditions. It will be thicker if it does not lose any sericin. If increasing rates of its cross-sectional area are not in proportion, the apparent density of raw silk must be varied.

2) The Present Rereeling

Rereeling is a process of re-winding raw silk containing much moisture in smaller tension than reeling tension. This can vary the apparent density of raw silk. Raw silk of high apparent density was specially made and variations before and after rereeling were examined. This is for easy inspection. The results are shown in Table 12.

Table 12 Variations of the Apparent Density

	Outer-layer Raw Silk	Middle-layer Raw Silk	Inner-layer Raw Silk
Before Rereeling	1.031	0.998	1.062
After Rereeling	1.018	0.968	1.064

Decrease in the apparent density caused by rereeling is at a low rate. It shows that the apparent density measured by this method is invariable even with rereeled raw silk.

VII RAW SILK TESTING AND THE APPARENT DENSITY

It is the gathering tension and the vibrating width of the drawing tension that influences the apparent density of raw silk strongly. The winding tension and the others in reeling and the rereeling process are second to this. Therfore much raw silk was made using the author's rotary ends-feeder as a trial, which had been used to obtain Table 9. Then its apparent density and the results of its testing were compared. The control was raw silk made with the present type rotary ends-feeder. The results are shown in Table 13.

Table 13 Comparison on Testing

	Control	Bulky Silk
Apparent Density	0.916	0.873
Neatness	93.0	92.5
Cohesion	71.0	68.1
Strength	4.3	4.0
Elongation	18.5	18.1
Young's Modulus	999.	996.

In the case of raw silk of low apparent density, the results of its testing done in accordance with the regulations tend to be degraded. Much care must be taken to work upon this kind of raw silk.

Summary

An investigation was made into the gathering of cocoon filaments forming raw silk and the following results were obtained.

1 The method of measuring the apparent density of raw silk was worked out in order to express the gathering degrees of cocoon filaments in a quantitative way. The apparent density of raw silk indicates its bulkiness and has something to do with the touch of silk fabrics. It was assumed that this will be caused by raw silk's resistance put up in improving the touch of silk fabrics.

2 This measurement is practically useful, because the values obtained from it are changed by degrees of degumming resistance of raw silk.

3 The drying of raw cocoons has the effect of setting filament-crimps by heat and of increasing the drawing tension at the same time. The effect of heat setting is very weak and so it is not easy to lower the apparent density of raw silk by varying cocoon-drying methods.

It is well considered that raw silk of low apparent density can easily better the touch of its fabrics.

4 The winding tension does not influence the apparent density of raw silk much. The gathering tension with various kinds of ends-feeders was examined. This tension does influence the apparent density very much.

It was unsuccessful to lessen the gathering tension and consequently the apparent density by improving in part on the present type ends-feeder.

5 To lessen the total of drawing tension on each of the filaments is to lessen the apparent density of raw silk. But to make their differences in tension greater is not effective.

6 By working out, as a trial, the ends-feeder quite different in structure from the others, the apparent density could be lessened. It can be made very low by making the great vibrating width of drawing tension of each cocoon filament.

7 The function of croissieur is very effective to make the apparent density high. But more or less twists held do not concern it much.

8 When raw silk is boiled in no tension, it will shorten. But the existing rereeling conditions are not very effective to make the apparent density low.

9 Raw silk of low apparent density is degraded in the results tested in accordance with the regulations. These results are only of mechanical properties.

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