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A Study on the Shrinkage of Silk Fabric by $Ca(NO_3)_2$ Solution

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Abstract

The phenomenon of the shrinkage of silk fibers induced by inorganic salts including LiBr, $Ca(NO_3)_2$, and $CaCl_2$, has been studied up to the present as one of the finishing methods of silk. It is expected that the shrinkage phenomenon may greatly contribute to the realization of the high sensibility of silk fibers. Especially the shrinkage enables the expression of three-dimensional appearance of silk fabrics along with the improvements in dimensional stability, resilience in stretching, and comfort.

Numerous theoretical studies on the contraction phenomenon by $Ca(NO_3)_2$ have been conducted so far. These studies have focused mostly on the silk fibers. It is difficult to find studies on silk fabrics. The negative aspects of the finishing are such as strength drop, yellowish discoloration, and fiber damage. These should also be considered as well as the positive aspects.

In this study, the phenomenon of salt shrinkage is diversely reviewed by applying $Ca(NO_3)_2$ solution for the silk fabrics as objects. The changes in the air permeability, thickness, and color were investigated with focus on the shrinkage of the silk fabrics according to the changes in treatment conditions.

Some findings from this study are as follows: Within short period of time at the initiation of salt shrinkage, the salt shrinkage proceeds effectively. In the case of concentration of 47.4%, or 46.3% of $Ca(NO_3)_2$ solution, appropriate treatment time seems to be 20seconds, or 2~8minutes, respectively. Excessive shrinkage is obtained when lower liquor ratio is adopted. As a result, the condition is acting extremely disadvantageously against the thickness and yellow discoloration aspects.

Key Words : silk, salt shrinkage, $Ca(NO_3)_2$, air permeability

Ⅰ. Introduction

Silk fiber, compared to other fibers such as cotton and wool fibers, has various applications due to its luxurious luster and subtle feeling. The fiber exhibits not only excellent affinity for dyes, but also the sense of vitality which is not readily felt in other fibers since it belongs to the animal fibers. Silk fiber, however, has demerits as follows: low dimensional stability, high sus-

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ceptibility to damages by acid and alkali, yellow discoloration due to ultraviolet rays, and discolorations due to salts including perspiration have been presented.

Novel finishing methods have been developed continuously in order to create the high sensibility out of silk fibers. Salt shrinkage finishing has a long history of utilizing the property of contraction caused by inorganic salts. Most of the accompanying changes by the shrinkage finishing procedures are the increase of shrinkage rate, the decrease of tenacity and Young's modulus, the increase of elongation, and the increase of resilience of elasticity.

Since the late 1990's, the three-dimensional constructions of textile fabrics have been of prime importance as satisfying factors for high sensibility textile materials. The three-dimensional constructions have been naturally implemented as the silk fibers are contracted by the salt shrinkage finishing.

One of the previous studies reported the shrinkage rate values, the changes of strength and elongation, and the swelling after treating silk fibers with LiBr, $Ca(NO_3)_2$, $CaCl_2$.[1] This study reviewed the results according to the changes of salt concentration, treatment time, treatment temperature. The specific gravity of $Ca(NO_3)_2$ solutions were selected as 1.44, 1.45, and 1.46, with the range of treatment time being 5~10 minutes, and with the range of treatment temperature of 80, 85, and 90℃.

It was reported that the shrinkage rate reached around 35% at the conditions of the specific gravity 1.45 and 90℃, and the specific gravity 1.46 and 80℃. According to this report, the optimum condition was evaluated as being specific gravity range of 1.45~1.46, and temperature range of 80~90℃. Also this study accentuated the fact that inappropriate selection of the treatment conditions would lead to the irregular effects thereof. It is judged that the establishment of the accurate treatment conditions is important in order to have reproducible and even treatment.

Other study[2] reported on an experimentation in the silk contraction phenomenon in order to find applications of the silk fibers for various purposes as well as apparel product end-uses. Experimental results included the fibroin contractions seeking applications other than those for formal suiting fabrics. Salt shrinkage experimentation was also on the 21 denier raw silk fibers. In order to measure effects of the salt shrinkage more accurately, in the study, the selected specific gravity levels were 1.42, 1.43, 1.44, 1.45, 1.46, 1.47, 1.48 for the $Ca(NO_3)_2$ solutions. The shrinkage rates of the silk yarns after treatment of 5 minutes at 85℃ were investigated. It was expected that accurate shrinkage results were obtainable since the concentration levels of $Ca(NO_3)_2$ solutions were diversely varied.

The shrinkage rates were suggested to be 10, 25.8, 46.3, and 62.8%, respectively at the specific gravity levels of 1.44, 1.45, 1.46, and 1.47 of the $Ca(NO_3)_2$ solutions. Based on the shrinkage rate, effective shrinkage is reported to be obtained at 1.45 and above. This study also observed the changes of crystallinity of the fibers using an infrared spectroscopy. The crystallinity changes were negligible under the specific gravity, 1.44, of the $Ca(NO_3)_2$ solutions, however, over the level, the crystallinity decreased gradually. Severe decrease of the crystallinity is accompanied by the treatment over the specific gravity of 1.47. The results shown above suggest that the optimum range of the $Ca(NO_3)_2$ solutions is between 1.44 and 1.46 as the specific gravity level, and between 45.3% and 47.6% as the concentration level.

The appearance of the treated silk fibroin was observed using a scanning electron microscope. The surface damage became quite noticeable as the cracks on the fiber surface developed over the specific gravity of 1.45 of the $Ca(NO_3)_2$ solution. This may be interpreted that the specific gravity of 1.45 initiated morphological changes inside the fibril of the fiber core as well as surface changes.

The specific gravity of 1.45, or so, may be accepted as being the gravity range for effective salt shrinkage finishing treatment.

Separate study[3] dealt with the dynamic viscoelastic behavior of the shrunk silk yarns, analyses using a differential scanning calorimeter and thermogravimetric analyzer, and tensile properties. The study reported sudden increase of elongation around the specific gravity of 1.45 together with severe decrease of the Young's modulus. This demonstrates that the optimum condition for the salt shrinkage finishing is the specific gravity range of 1.45 or so.

In this study we examined the following aspects and proceeded salt shrinkage finishing.

1) It is surmised that a desirable salt shrinkage finishing be implemented directly on the silk fabrics rather than on the silk fibers in order to obtain high sensibility textile fabrics. The studies up to the present mainly focused on the salt shrinkage finishing of the silk yarns. However, it is impossible to predict the effects on the silk fabrics relying only on the salt shrinkage effects of silk yarns.

2) The behavior of salt shrinkage finishing is immensely sensitive to the changes of finishing conditions. Since negative effects accompany the shrinking of silk fabric, some methods to minimize these negative effects should be sought for. The establishment of immaculate finishing conditions require the visual observation of the salt shrinkage effects of the silk fabrics. At the same time, the change of the area of silk fabrics, and the changes of thickness, air permeability, and color should all be reviewed comprehensively. Excessive salt shrinkage finishing might induce yellowish discoloration of the silk fabric and unduly thick fabric.

3) Even if most of the studies up to the present designated the specific gravity as representative unit of concentration of the $Ca(NO_3)_2$ solutions, it is impossible to represent exact concentration by utilizing the value of the specific gravity. Since the concentration of the $Ca(NO_3)_2$ solution is maintained extremely high, the specific gravity would not change very much even though the change in the % concentration become substantial. It is postulated that the % concentration expression should be needed in order to establish accurate control of the concentration of salt solution for the salt shrinkage finishing.

4) Mention on the liquor ratio has hardly been found so far for the salt shrinkage finishing. However, it is expected, as in the case of dyeing, that the liquor ratio could affect the finishing. The drying methods also might induce different effects after the salt shrinkage treatment. Since the effect of the residual $Ca(NO_3)_2$ on the finished fabric after the salt shrinkage might not be excluded, it is predicted that differences might be incurred by the drying methods.

In this study, considering several aspects mentioned above comprehensively, the silk fabric instead of the silk yarn was employed in the salt shrinkage finishing. Two levels of concentration of $Ca(NO_3)_2$ solutions were selected as % concentration in order to accurately adjust the condition of salt shrinkage. The effect of the temperature was also treated quantitatively by adjusting the temperature of salt shrinkage finishing within the range of 70~100℃. Relatively low temperature treatment was introduced together with longer treatment time in order to gauge the possibility of realistic industrial applications. The evaluation of the effect of salt shrinkage was not only based on the shrinkage rate of the silk fabric, but also on the changes of thickness, air permeability, and the color comprehensively. Lastly, the effect of the liquor ratio change in the salt shrinkage treatment was investigated.

II. Experimentals

1. Specimens and chemicals

1) Fabric Specimens

The fabric specimen used for the experiment was the white silk fabric for dye fastness testing conforming to the KS0905 specifications as described in <Table 1>.

The specimens for the salt shrinkage finishing were cut to the size of 13x13cm.

2) Reagents

$Ca(NO_3)_2 \cdot 4H_2O$ was used for the salt shrinkage finishing. The reagent was dissolved in the deionized water to reach the % concentrations of 46.3% and 47.4%.

2. Experimental methods

1) Changes of concentration of $Ca(NO_3)_2$ aqueous solution, treatment time, and treatment temperature

In the case of 47.4% of $Ca(NO_3)_2$ in % concentration, fabric specimens were treated for 20, 40, 60, and 80 seconds, while maintaining liquor ratio of 1:100 and treatment temperature of 90℃. In the case of 46.3% of $Ca(NO_3)_2$ in % concentration, fabric specimens were treated for 2, 4, 6, 8, 10, 20, and 30 minutes, while maintaining liquor ratio of 1:100 and treatment temperature of 90℃. After the treatment, specimens were dried under cool air mode.

2) Effect of liquor ratio change on the salt shrinkage

The effect of liquor ratio on the salt shrinkage was investigated using a $Ca(NO_3)_2$ solution of 46.3% concentration with liquor ratio of 1:50 and 1:100. Specimens were dried under cool air mode.

3) Change of salt shrinkage treatment temperature and differentiation of drying methods after the salt shrinkage treatment

Fabric specimens were treated for 20, 40, 60, and 80 seconds, at the temperature of 70, 80, 90, and 100℃, while maintaining liquor ratio of 1:100 using the solution of $Ca(NO_3)_2$ of 47.4%

<Table 1> Characteristics of the fabric specimen.

Fabric composition	Fabric weave	Thickness (mm)	Air permeability ($cm^3/min/cm^2$)	Color values		
				L^*	a^*	b^*
Silk 100%	Plain	0.105 ±0.01	24.1	92.93	0.47	-0.16

concentration. At the predetermined intervals, two specimens were taken out of the bath. One specimen was dried under hot air drying mode, the other under cool air drying mode. The changes in specimen area, air permeability, thickness, and color was measured for the dried specimens.

3. Measurement and Analysis

1) Measurement of shrinkage of specimens treated with salt shrinkage finishing

Salt shrinkage rate, X, was determined as follows by comparing the area of the shrunk specimen with that of untreated specimen.

$$X = (A/169)\times 100$$

A : area of the shrunk specimen after the salt shrinkage finishing

2) Measurement of air permeability

An air permeability tester (Model: Textest FX 3300) was employed to measure the air permeability at the condition of 125Pa pressure. Average value of four readings of air permeability of fabric specimens was calculated.

3) Measurement of thickness of fabric speci mens treated with salt shrinkage finishing

A thickness tester was employed to measure the thickness of the fabric specimens treated with salt shrinkage finishing.

4) Measurement of color and color difference

Chroma Meter (CR-200, Minolta, Japan) was used for the color measurement of the specimens treated with salt shrinkage finishing. Hunter L^*, a^*, b^* values were measured, where L^*(Whiteness), a^*(Redness), b^*(Yellowness) are points in a 3-dimensional spatial coordinates, in which the distance between two color points is represented as color difference, ⊿E. The ⊿E , color difference between control fabric(untreated original) and the treated specimen, was calculated from the measured L^*, a^*, b^* values. 3~5 color measurements and their average were made for different points on the same specimen.

The color difference between reference color, (L^*1 , a^*1 , b^*1), and comparison color, (L^*2 , a^*2 , $b*2$), is calculated using the following equation.

$$\Delta E = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)}$$

III. Results and Discussion

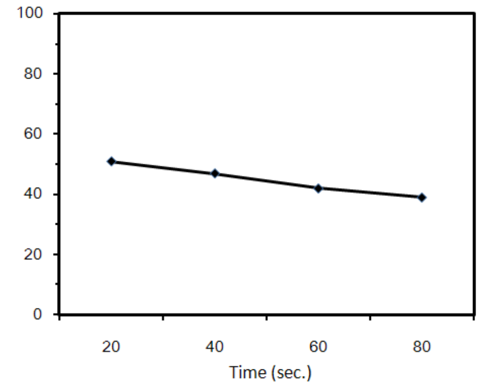
1. Change of concentration of $Ca(NO_3)_2$ solution, treatment time, and treatment temperature

1) Case of concentration 47.4% of $Ca(NO_3)_2$ solution

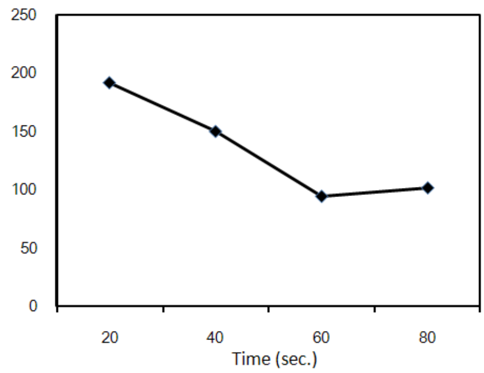
<Fig. 1>, <Fig. 2>, <Fig. 3>, and <Fig. 4> show the results of the treatment under the condition maintaining liquor ratio of 1:100 and temperature of 90℃.

As shown in <Fig. 1>, the area of silk fabric decreased with the treatment time. It is found that the effect of salt shrinkage is extremely sensitive to the treatment time. Treatment of 20 seconds reduced the original down to almost half the size.

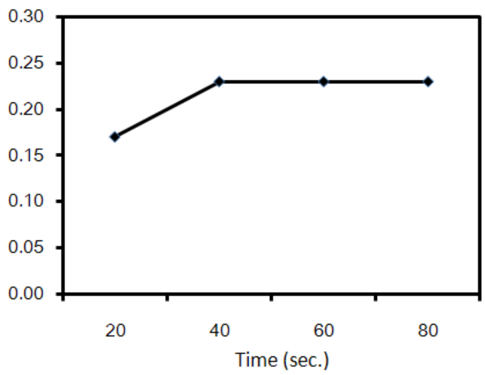
Shrinkage of about 30% is generated lengthwise.



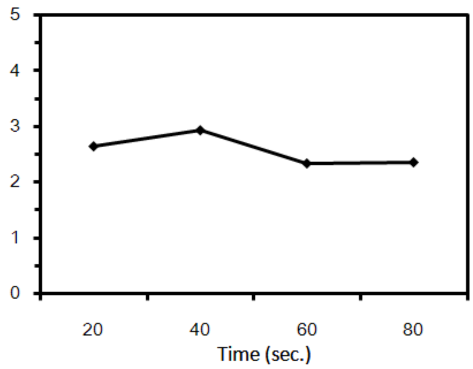
<Fig. 1> Shrinkage with time



<Fig. 2> Air permeability with time



<Fig. 3> Thickness with time



<Fig. 4> △E with time

In terms of fabric's convention, area reduction down to half the size after finishing is a very high shrinkage rate. It seems to be an highly excessive treatment condition.

When we reviewed the 40seconds and 60seconds treatment results, the shrinkage rates are not so high as we had expected. From this fact, it seems that the shrinkage is almost completed between the 20~40 seconds initial period in the case of 90℃ treatment.

The change of air permeability of specimens treated with salt shrinkage is shown In <Fig. 2>. The air permeability is regarded as an immensely important factor since it is related to the com fort in high sensibility fabrics. We might expect that the air permeability would decrease naturally, since the fabric shrinks due to the salt shrinkage treatment. Contrary to our expectation, as shown in <Fig. 2>, the air permeability rose up to 192 with the 20 seconds treatment. The rise is almost 8 times that of untreated original. This stiff increase of air permeability is highly desirable in terms of comfort. However, prolonged salt shrinkage treatment decreased abruptly. From the point of air permeability, it seems that it is advisable not to prolong the treatment time. It is surmised that there is some relationship between the increase of air permeability and the stiffness increase of silk fabrics after the salt shrinkage treatment. After the treatment, the silk fabric feels mostly stiffer and harder. This increase of air permeability is a desirable aspect for summer clothing material in terms of comfort along with the improvement in hand touch.

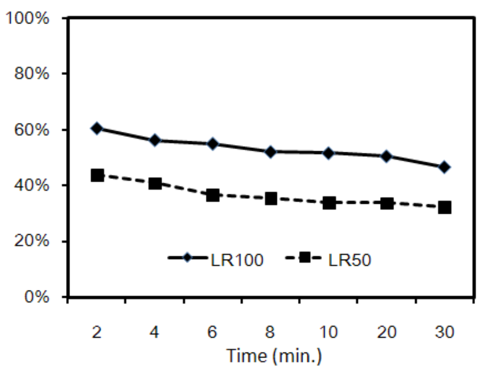
Thickness change of the silk fabric specimens after the salt shrinkage treatment is shown in <Fig. 3>. The thickness of 20seconds treatment increased a little to 0.17 compared to that of original untreated fabric, 0.105mm. However, over the 40seconds, there is no thickness change.

<Fig. 4> shows the color change of the treated fabrics. 20seconds, and 40 seconds treatments resulted in rather larger color difference values than those of 60seconds and 80 seconds treatments in △E values. This suggests that some discoloration is accompanied by the salt shrinkage treatment. This conforms to the general fact that silk fabric may be discolored toward yellowish color by perspiration. In terms of silk fiber maintenance, considering the yellow discoloration is the most important problem, it is needed to establish optimum condition to minimize the yellow discoloration due to the salt shrinkage finishing. On a close examination of the yellow discoloration, the b^* values are −0.16, 2.95, 4.41, 3.92, 3.83 for silk fabrics of untreated original, 20seconds, 40seconds, 60seconds, and 80 seconds, respectively. Compared to the original untreated fabric, the discoloration became larger after the treatment. Since the increase of b^* values of the other fabrics except for 20seconds treatment are large, it is judged that treatment more than 20seconds is not desirable.

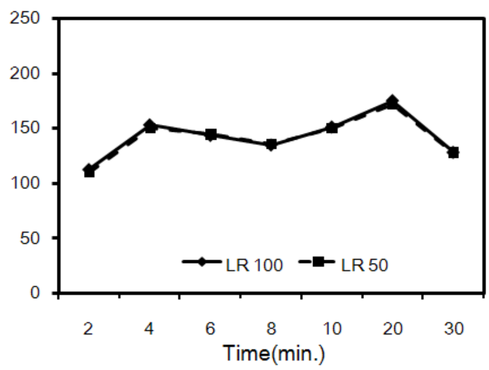
As reviewed above, it seems that the case of concentration 47.4% of $Ca(NO_3)_2$ solution and treatment temperature of 90℃, the treatment accompanies abrupt shrinkage. Treatments except for the 20seconds seem to result in too high shrinkage rate.

2) Case of concentration 46.3% of $Ca(NO_3)_2$ solution

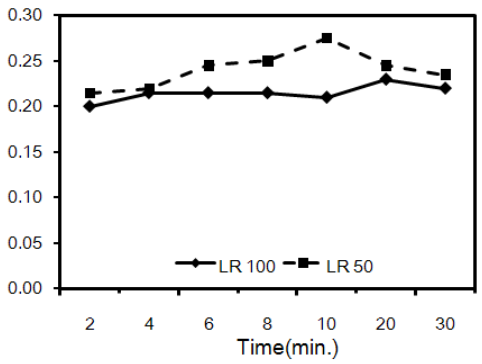
<Fig. 5>, <Fig. 6>, <Fig. 7>, and <Fig. 8> show the treatment results for the conditions of liquor ratio 1:100, 1:50 and temperature of 90℃.



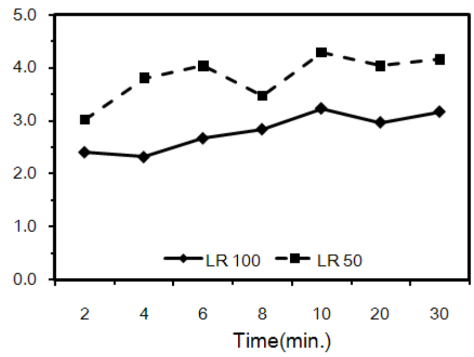
<Fig. 5> Shrinkage with time and L.R



<Fig. 6> Air permeability with time and L.R



<Fig. 7> Thickness with time and L.R



<Fig. 8> △E with time and L.R

Review on the case of liquor ratio 1:100 is described first. Comparing <Fig. 5> and <Fig. 1> shows significant difference in shrinkage rate. Previous treatment condition of 47.4% concentration $Ca(NO_3)_2$ solution encompassed treatment time ranges of seconds. On the other hand, <Fig. 5> shows the results for the treatment of minutes range.

It took 20seconds for treatment for the shrinkage rate to reach 50% in <Fig. 1>, compared to 8minutes in <Fig. 5>. This exemplifies the high sensitivity of the $Ca(NO_3)_2$ concentration's role on the salt shrinkage. The concentration difference of mere 1% between 47.4% and 46.3% resulted in treatment time change from seconds to minutes. In view of this fact, it is regarded that the use of % concentration instead of the specific gravity unit offers better accuracy in terms of $Ca(NO_3)_2$ solution representation.

In <Fig. 5>, unlike <Fig. 1>, the shrinkage trend slope becomes quite gentle. For the 4~20 minutes period, shrinkage rate is maintained at 50% or so. As mentioned previously, the salt shrinkage is completed within short period along with the initiation of salt shrinkage. It is desirable to reduce the concentration down to 46.3% in view of the fact control of the shrinkage amount is manageable. Since the areal shrinkage is 56% at 4minutes treatment, the lengthwise shrinkage is about 25%. This range of shrinkage is evaluated as being adequate.

Air permeability data in <Fig. 6> shows that the value of about 150 is maintained between the 4 and 10minutes range corresponding to 50% shrinkage rate. In the case of 47.4% concentration of $Ca(NO_3)_2$ solution, 47% shrinkage was obtained in 40seconds resulting in air permeability of 150. Results show that similar shrinkage rate offers similar air permeability value.

Thickness change after salt shrinkage is shown in <Fig. 7>. 51% of shrinkage was obtained within 20 seconds resulting in the increase of thickness to 0.17 in <Fig. 3>. On the other hand, 61% of shrinkage was obtained within 2minutes with the thickness increase up to 0.20. General expectation is that as the shrinkage rate increases, the thickness increases together. Contrary to this expectation, in the case of 46.3% concentration of $Ca(NO_3)_2$, thickness becomes higher even though the shrinkage rate becomes lower. However, after 4minutes, the thickness is maintained almost constant at 0.22. In view of general trend, the concentration of the $Ca(NO_3)_2$ solution does not seem to affect the thickness. △E change is shown in <Fig. 8>. △E value of 2.84 and b^* value of 3.66 are shown at the treatment of 8minutes where 51% shrinkage occurs. Considering the fact that △E value of 2.64 and b^* value of 2.95 are shown in <Fig 4>, where shrinkage of 51% occurs, the reduction of concentration of $Ca(NO_3)_2$ solution does not seem to act favorably for the color change.

Based on these reviews, the concentration of $Ca(NO_3)_2$ solution mainly affect the speed of salt shrinkage. However, it does not affect other physical changes of silk fabrics treated with salt shrinkage.

Salt shrinkage is proceeded within short period from the initiation of the salt shrinkage. As a result, the optimum salt shrinkage time range for the concentration of 47.4%, or 46.3% of $Ca(NO_3)_2$ solution seems to be 20seconds, or 2~8minutes, respectively. Based on visual inspection of damages to the salt shrunk fabric, 46.3% seems to be superior to the 47.4%.

Review on the case of liquor ratio 1:50 is described next. The shrinkage rate reaches 44% after the initiation of salt shrinkage, and 37% after 6minutes. Sudden shrinkage is obtained with lower liquor ratio. It seems to be practically meaningless since the shrinkage over 40% is too excessive. Another characteristics is that after 6minutes, the salt shrinkage does not proceed. As mentioned beforehand, it is confirmed that the shrinkage is completed as soon as the silk fabric is in contact with the solution of $Ca(NO_3)_2$. The air permeability values coincide perfectly regardless of the liquor ratio in <Fig. 6>. This phenomenon shows that there is no correlation between the air permeability and the shrinkage rate. Excessive shrinkage rate accompanies the thickness increase and the yellowish discoloration extensively in <Fig. 7> and <Fig. 8>

Based on a general trend, in the case of lower liquor ratio condition, initial excessive shrinkage under 50% proceeds. As a result, the condition is acting extremely unfavorably towards the thickness and yellow discoloration aspects. It will be mild salt shrinkage condition to increase the liquor ratio more than 1:100.

2. Change of salt shrinkage temperature and differentiation between drying methods after salt shrinkage treatment

1) Shrinkage rate of silk fabric treated with salt shrinkage

<Fig. 9> and <Fig. 10> show the shrinkage rate of silk fabrics treated with salt shrinkage dried under cool air drying or hot air drying mode. When we first review the effect of temperature, regardless of drying methods, salt shrinkage is not proceeded at 70℃. At 80℃, 60% shrinkage rate is obtained for 60seconds treatment. 100℃ treatment offers a little higher shrinkage, even though similar to 90℃ treatment. It is judged that 80℃ treatment would be the most appropriate one. 80℃ and 90℃ treatments give significantly lower shrinkage rate in cool air drying mode than that in hot air drying. From this fact, it is supposed that secondary shrinkage occurs in hot air drying mode.

2) Air permeability of silk fabric treated with salt shrinkage

Air permeability is shown in <Fig. 11> and <Fig. 12>. In air permeability, the effect according to the change of salt shrinkage temperature exhibits significantly. The air permeability becomes significantly lower due to the excessive shrinkage. The lower air permeability trend at 70℃ is due to the fact that salt shrinkage barely proceeds. At 90℃, with the increase of time of salt shrinkage, the air permeability drops suddenly. The air permeability at 80℃ is the highest. 60 seconds treatment, where 60% shrinkage is obtained, maintains the highest value. At 80℃, even if the shrinkage is increased, lowering of the air permeability is not very significant.

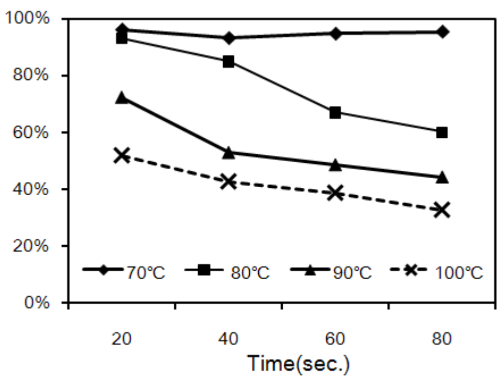
As a general trend, the air permeability is maintained higher in the case of hot air drying mode than in the case of cool air drying mode. However, this does not seem to be a desirable condition from the point of view of damage to the silk fabrics of salt shrinkage finishing. This seems to be attributable to the secondary degeneration accompanied by the hot air drying after the first degeneration due to $Ca(NO_3)_2$ solution. In actual appearance evaluation, significant damage is observed in the case of hot air dried specimens.

3) Thickness of silk fabric treated with salt shrinkage

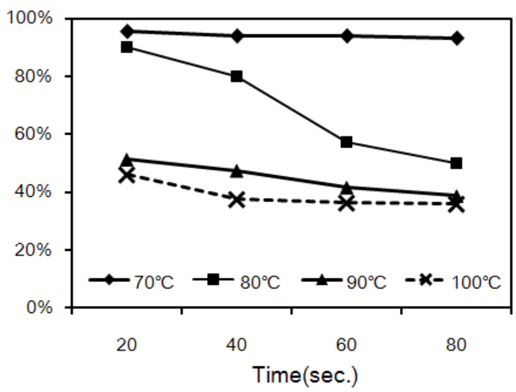
Thickness change is shown in <Fig. 13> and <Fig. 14>. As the temperature of salt shrinkage treatment increases, the thickness of the fabric increases. It seems that the thickness increases along with the increase of shrinkage. The condition of 80℃ treatment seems to be excellent condition since the thickness at the condition is maintained at 0.2 or so. Even if the salt shrinkage time is extended, constant thickness is maintained in the case of cool air drying mode than in the case of hot air drying.

4) Color change of finished fabric

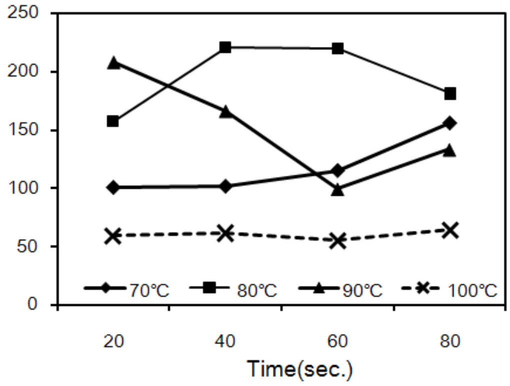
<Fig. 15> and <Fig. 16> show the color difference of silk fabrics treated with salt shrinkage. Generally, △E value increased in the case of hot air drying mode than in the case of cool air drying. At 90℃ treatment, even if regularity does not show, △E value decreases in the case of cool air drying mode. At 100℃ treatment, due to the damages to the silk fabric, significant yellow discoloration accompanies the hot air drying mode. Cool air drying mode is found to be absolutely superior in the drying procedure after the salt shrinkage treatment.



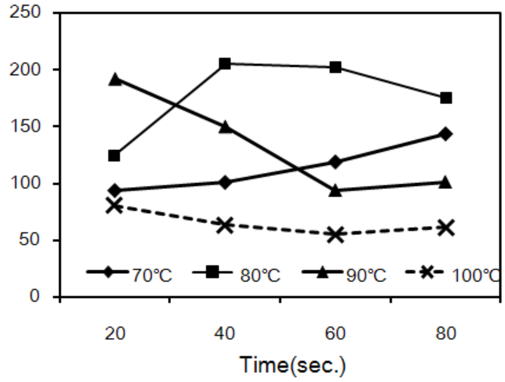
<Fig. 9> Shrinkage with time and temp (hot air drying)



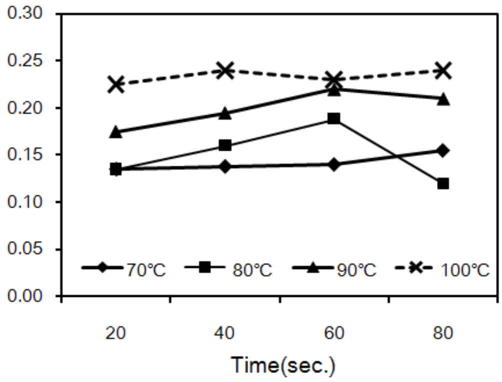
<Fig. 10> Shrinkage with time and temp (cool air drying)



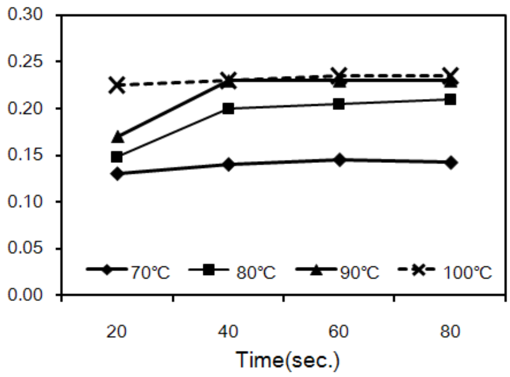
<Fig. 11> Air perm. with time and temp (hot air drying)



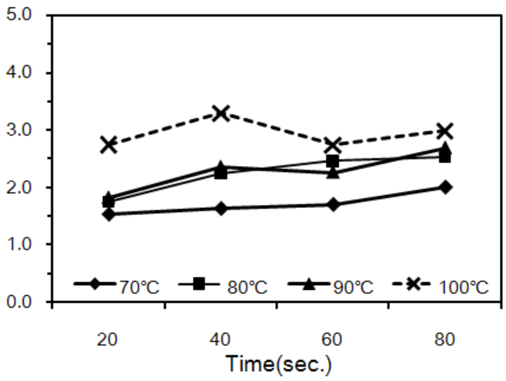
<Fig. 12> Air perm. with time and temp (cool air drying)



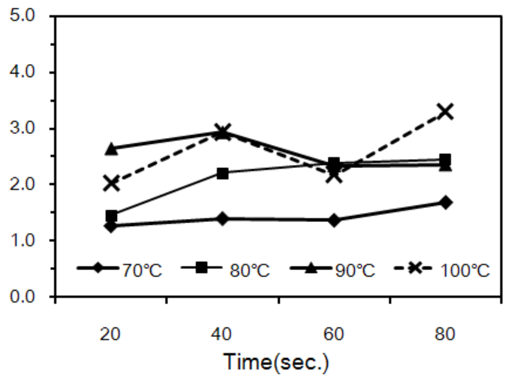
<Fig. 13> Thickness with time and temp (hot air drying)



<Fig. 14> Thickness with time and temp (cool air drying)



<Fig. 15> △E with time and temp (hot air drying)



<Fig. 16> △E with time and temp (cool air drying)

Ⅳ. Conclusions

There have been numerous theoretical researches regarding the shrinkage phenomenon due to $Ca(NO_3)_2$ up to now. Most of the studies have been done regarding silk fibers. It is difficult to find studies regarding silk fabric. The negative aspects, such as strength drop, yellowish discoloration, and fiber damage, of the salt shrinkage finishing should be considered as well as positive aspects.

In this study, various aspects of salt shrinkage phenomenon were reviewed by applying $Ca(NO_3)_2$ on silk fabric as object. Air permeability change, thickness change, and color change were investigated around shrinkage of silk fabric according to the change of treatment conditions.

The experimental results are summarized below.

1) In the case of concentration 47.4% of $Ca(NO_3)_2$ solution, treatment temperature of 90℃, the salt shrinkage is almost completed within initial 20~40seconds. The area of fabric decreases down to less than 50% of that of untreated silk fabric.

2) In the case of concentration 47.4% of $Ca(NO_3)_2$ solution, treatment temperature of 90℃, extremely severe shrinkage accompanies the treatment. Except for 20seconds treatment, shrinkage amount seems to be excessively high. Treatment period is determined within the range of unit of seconds.

3) In the case of concentration 46.3% of $Ca(NO_3)_2$ solution, treatment temperature of 90℃, liquor ratio of 1:100, treatment period needs the range of unit of minutes. It takes about eight minutes for the shrinkage rate to reach 50%, and the slope of shrinkage trend becomes gentle. It is adequate to select a concentration lower than 46.3% from the aspect of the control of salt shrinkage speed.

4) It seems that direct use of % concentration unit, instead of the specific gravity unit, is recommendable. The percent concentration unit is representative of $Ca(NO_3)_2$ solution concentration more accurately.

5) Within short period of time at the initiation of salt shrinkage, effective salt shrinkage proceeds. In the case of concentrations of 47.4%, 46.3% of $Ca(NO_3)_2$ solution, appropriate treatment time seems to be 20seconds or 2~8minutes, respectively.

6) Excessive shrinkage is obtained when lower liquor ratio is adopted. As a result, the condition is acting extremely disadvantageously against the thickness and yellow discoloration aspects. It will be mild salt shrinkage condition to increase the liquor ratio more than 1:100.

7) In the case of concentration 47.4% of $Ca(NO_3)_2$ solution, the effects of treatment temperature are as follows. Regardless of drying methods, salt shrinkage does not occur at 70℃. At 80℃, around 60% shrinkage occurs for the 60 seconds treatment. It is regarded as the most adequate to select 80℃ treatment. 80℃ and 90℃ treatments give significantly lower shrinkage rate in the cool air drying than that in the hot air drying. From this fact, it is supposed that secondary shrinkage proceeds in hot air drying mode.

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