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〈硏究論文(學術)〉

Study on the Structure and the Physical Properties of Synthetic Fibers Treated with Organic Solvents (V)
—The Shrinkage Behavior and Property Change of Woven Fabric Composed of Nylon 6 Filaments by Formic Acid Treatment—

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溶劑處理에 依한 合成纖維의 構造와 物性에 關한 硏究(V)
—Formic Acid 處理에 의한 Nylon 6 Filament 織物의 收縮擧動 및 性質變化—

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Abstract—The woven fabric composed of nylon 6 filaments was treated with aqueous solutions (20, 30, 40, 50, 60%) of formic acid at 30°C for 10 minutes under unrestrained condition, and the shrinkage behavior and some kinds of properties were examined.

The shrinkages of the constituent yarns and fabric were increased with formic acid concentration, but they were lower than that of the original filaments because of fabric-structural factors. And the shrinkage of the warp was lower than that of the weft because of the residual stress from weaving process.

By the restraint forces such as fabric-structural factors and residual stress, the constituent filaments were damaged partially at 60% of formic acid concentration and the degree of damage on the warp was greater than on the weft. And though the fabric count were increased overall, the spacing between the warps was decreased prior to the weft and eliminated nearly at 60% of formic acid concentration.

The thickness, tensile strength, elongation, and handle value of fabric were increased overall with formic acid concentration excepting that the tensile strength for both the warp and weft directions and the elongation for the warp direction were decreased instead by the damage of yarns. But the crease recovery was decreased except the case of the weft direction at 60% of formic acid concentration.

Introduction

A fiber bears specific characters owing to its chemical composition and fine structure, but it may demonstrate its performance as an aggregate in practical use. It is, therfore, important to examine the structure and properties of not only the fiber itself but also the ultimate aggregate of fibers.

The changes in fine structure and properties of nylon 6 filament treated with aqueous solution of formic acid were examined and discussed already focusing on the relation between fine structure and mechanical properties through some papers of this series.[1-4]

In this study, the shrinkage behavior of the yarn and fabric and some properties of fabric were examined after the woven fabric composed of nylon 6 filaments was treated with aqueous solution of formic acid; hereby it was attempted to extend the study area on the acting mechanism of organic solvents from only fiber (filament) to fabric and to search the scheme to utilize the organic solvents for improvement of fabric properties.

Experimental

Sample

The nylon 6 woven fabric (obtained by courtesy of Jin Il Dyeing Co.) was treated with the aqueous solution of formic acid under unrestrained condition in the same way as Part I of this series. In order to make the analysis of shrinkage behavior easy by minimizing the variation factors related to the structure of fabric and/or yarns, the plain weave fabric composed of untwisted filament yarns was selected as the sample. The characteristics of the sample were indicated in Table. 1.

Table 1. Characteristics of the sample fabric.

Yarn denier (Filaments)	Weave	Fabric count (ends×picks /2.54 cm)	Thickness (mm)
70 (24)	Plain	116×93	0.118

Shrinkage

The shrinkage of fabrics and yarns for warp and weft directions was determined respectively by following equation.

$$S = \frac{l_0 - l_1}{l_0} \times 100$$

where, S is shrinkage (%), l_0 and l_1 are lengths (cm) of original and treated samples respectively.

Besides, the filaments identical with the constituent yarns of sample fabric was treated under the same conditions, and the shrinkage was determined by the same equation.

Structural characteristics

The fabric count per 2.54 cm, thickness and crimp ratio were determined under the provisions of KS K 0511, KS K 0506, and KS K 0545, respectively.

SEM photography

The magnified photographs of samples were taken with Scanning Electron Microscope (SEM; JSM 35 CF, Jeol, Japan). And those of the damaged part on the warp yarn, which was damaged severely in comparison with the weft yarn, were also taken.

Properties of fabric

The handle value was determined by Handle-O-Meter (Type No. 226, Yasuda Seiki, Japan) under following conditions.

Slot openning : 1 cm
Full scale : 100 gf
Chart speed : 12 mm/min
Sample size : 20×20 (cm^2)

The tensile strength and elongation were determined by Autograph (S-500, Shimadzu, Japan) under the provision of KS K 0522 and following conditions.

Full scale : 100 kg
Crosshead speed : 20 cm/min
Chart speed : 40 cm/min

The crease recovery was determined under the provision of KS K 0550.

Results and Discussion

Shrinkage behavior

As a first step, the shrinkage of original filaments and constituent yarns are indicated in Fig. 1 and discussed. The figure shows that the shrinkage is increased overall with formic acid concentration, but the tendency for the original filaments is greater than those for the constituent yarns. In general, the facts that the shrinkage of fiber by organic solvent is due to the disordering (orientation decrease) of amorphous chains and

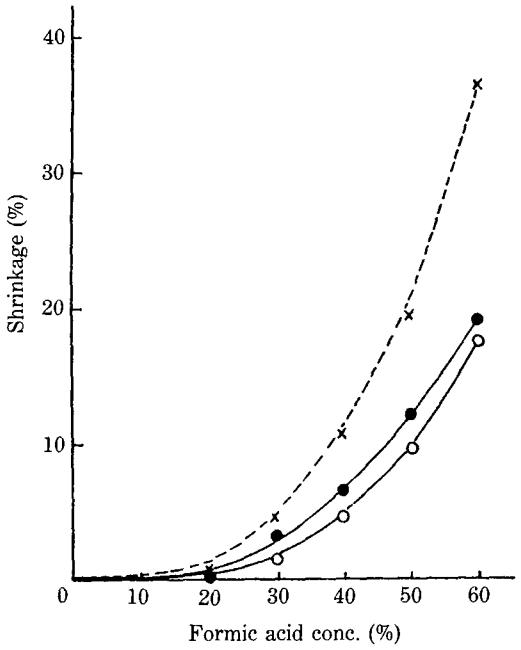

Fig. 1. Relationship between formic acid concentration and shrinkages of original filaments and constituent yarns from sample fabrics.
×; Original filaments, ○; Warp, ●; Weft

crystallites and this effect of organic solvent can be restrained by some external force along the fiber axis direction were identified well in Part I[1] of this series and other reports.[5-7] Judging from this point of view, there may be considerable restraint force, which is resulted from the structural factor of fabric, against the effect of organic solvent. Namely, the constituent yarns are restricted at the points that warp and weft are interlaced to each other, and if yarns for one direction are shrunken the spacing between those for the other direction will be decreased, and consequently the restraint effect will be increased even more. These phenomena may be affected by some factors such as fabric weave, fabric count (cover factor) as well as tension degree on the yarn.

In this experiment, the effects of those factors can be investigated from the fact that, although the warp and weft yarns are identical inherently, the shrinkage of them are different each other. Namely, considering the aspect of fabric count, the shrinkage of the weft may be restrained more than that of the warp. But, in practice, the shrinkage of the weft is greater than that of the warp. This may be resulted from the fact that the warp had considerable quantity of residual stress from the weaving process in spite of some subsequent relaxation procedure such as desizing, scouring, etc.

The relation between the shrinkages of the constituent yarns and the original filaments is illustrated in Fig. 2. First, the facts from the figure that the values of samples and the warps are smaller than those on the straight line of 1:1 and of the wefts respectively establish well the abovementioned subject. In addition, although both the warp and the weft demonstrate direct proportional lines ($r_{wp}=0.9955$, $r_{wf}=0.9995$; $Y_{wp}=0.0177+0.5002X$, $Y_{wf}=0.0276+0.6248X$) up to 50% of formic acid concentration, at 60% of formic acid concentration the value for warp is brought in that line but the value for weft is smaller than that on the line. This may be resulted from the difference of the fabric count between warp and weft. That is, although the counts of warp and weft are increased continuously (Fig. 3), the spacing between

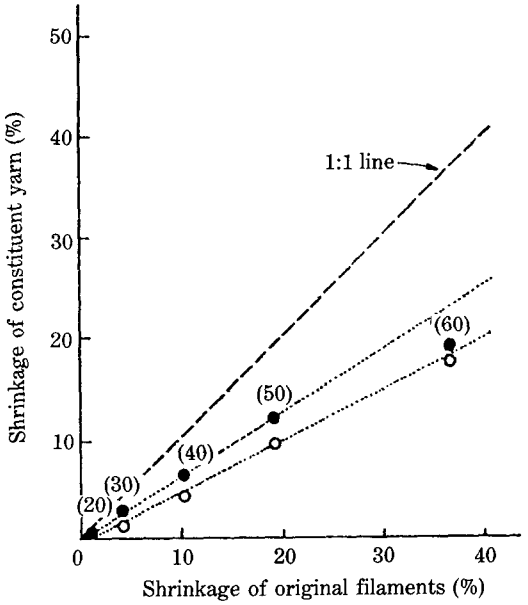

Fig. 2. Relationship between shrinkages of original filaments and constituent yarns from sample fabrics.
○; Warp, ●; Weft, ( ); Formic acid conc.

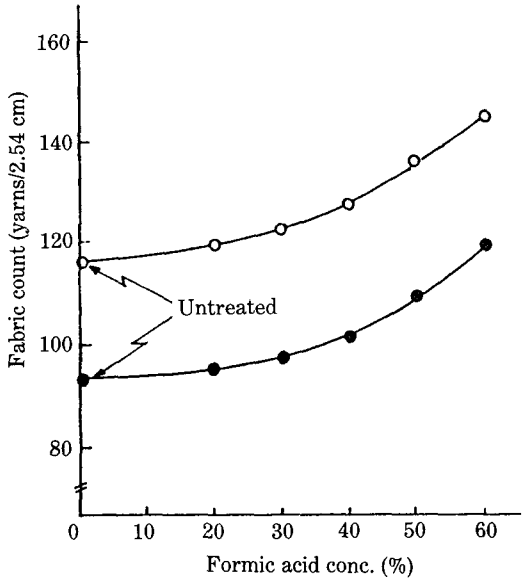

Fig. 3. Relationship between formic acid concentration and fabric count of samples.
○; Warp, ●; Weft

the warps, of which original count had been greater than that of weft, arrives at almost zero earlier than that between the wefts. This will be discussed again in the SEM photographs.

Fig. 4 shows that the tendency of fabric shrinkage is similar to that of the constituent yarns on the whole, but over the 50% of formic acid concentration the shrinkage for the weft direction become smaller than that for the warp direction. This phenomenon indicates the shrinkage of fabric was not affected consistently by that of yarns, and can be accounted in Fig. 5 which indicates the change of the crimp ratio of the constituent yarns. For the untreated sample, the crimp ratio of the weft is greater than that of the warp because both the residual stress and count of the warp are greater than those of the weft. But over the 40% of formic acid concentration, the crimp ratio of the weft is decreased a little while that of the warp is increased rapidly; consequently the values for the warp and weft are reversed each other. It is thought that this is resulted from the increasing tension by the prior shrinkage of the weft, therefore the shrinkage for the weft direction of the fabric become smaller than that for the warp.

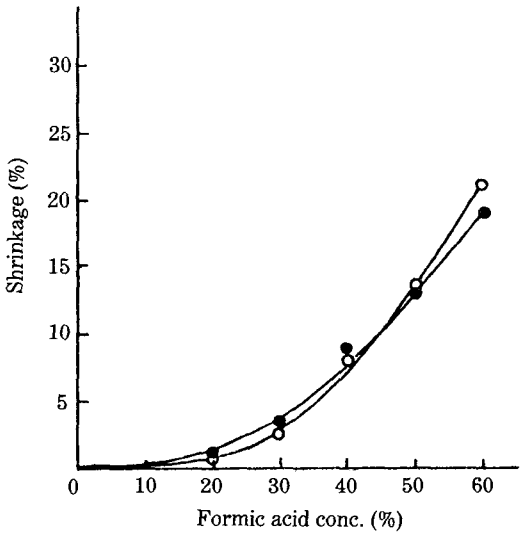

Fig. 4. Relationship between formic acid concentration and shrinkage of sample fabrics.
○; Warp direction, ●; Weft direction

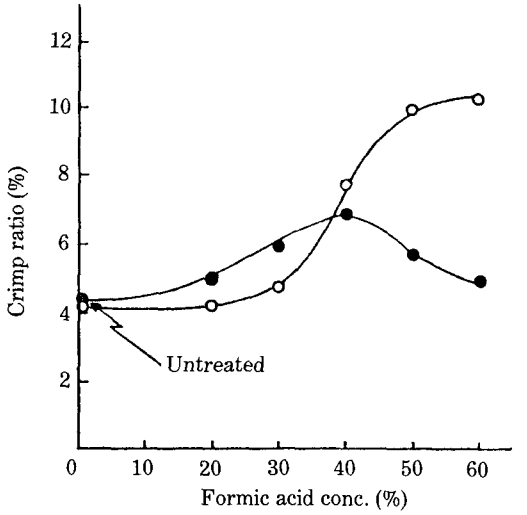

Fig. 5. Relationship between formic acid concentration and crimp ratio of constituent yarns from sample fabrics.
○; Warp, ●; Weft

The above-mentioned subjects can be investigated in Fig. 6 and 7 of SEM photographs. The existance of the restraint forces against shrinkage from the fabric-structural factors and of the residual stress in the warp were established from Fig. 6. That is, the fabric was damaged partially while the original filaments was not damaged (Fig. 7) by treatment with 60% aqueous solution of formic acid, and the degree of damage on the

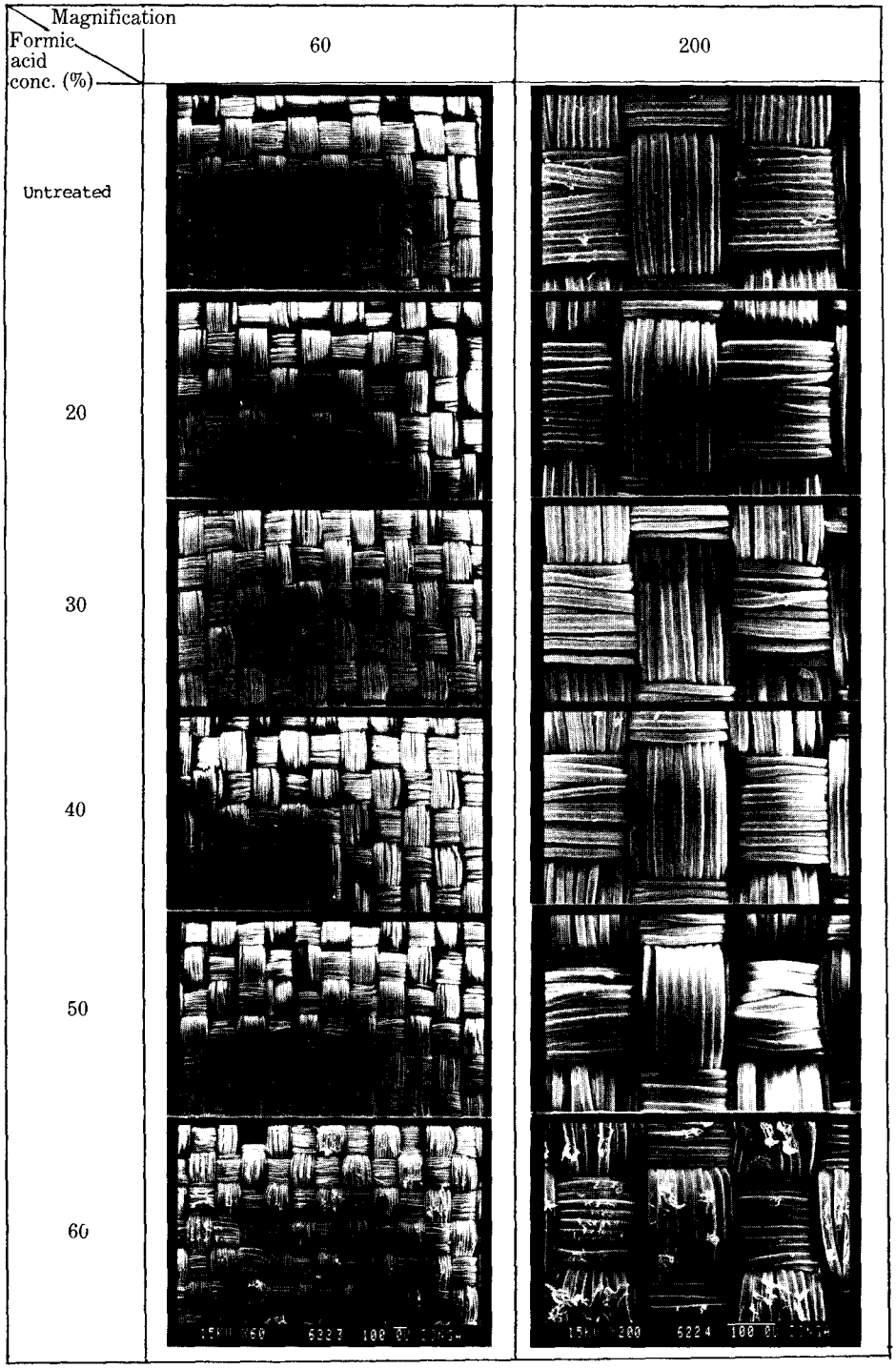

Fig. 6. SEM photographs of samples.

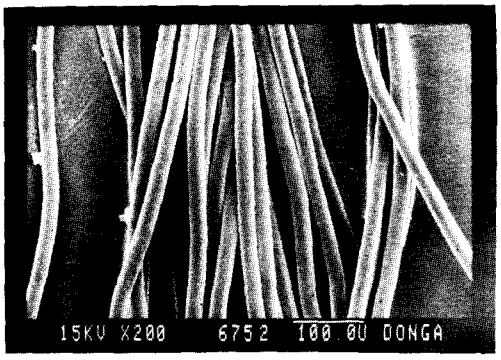

Fig. 7. SEM photograph of the original filaments treated with 60% formic acid solution.

warp was greater than that on the weft. In other words, the above phenomena may be caused by the accelerating effect of those forces on the dissolution action of organic solvent (formic acid) as the case of stress cracking.[8]

And the prior shrinkage and consequent tension of the weft can be proved from the change of filaments arrangement in Fig. 6. The filaments of the warp which have been arranged almost perfectly (in tension state) begin to be relaxed over the 30% of formic acid concentration.

The spacing between yarns is decreased with the increase in formic acid concentration and the decreasing tendency for the warp was greater than that for the weft. This may be resulted also from the prior shrinkage of the weft. At 50% of formic acid concentration, the spacing between the wefts remaines a little but that between the warps is nearly eliminated. Therefore, the shrinkage of the weft would be restrained more than that of the warp at 60% of formic acid concentration. This phenomenon can account for the fact that the value for the weft at 60% of formic acid concentration is not brought in the proportional line in Fig. 2. Besides, the fact which the spacing between the constituent yarns is decreased severely shows good potentiality that the organic solvent treatment can be utilized for "water-proofing with moisture transpiration" by the "high-fabric-count method".[9]

On the other hand, Fig. 8, which are the SEM

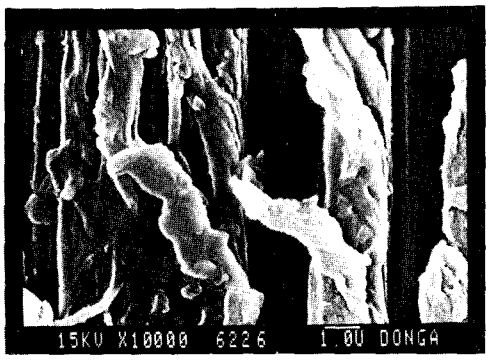

Fig. 8. SEM photographs of damaged part on the warp filament.

photographs of the damaged part of the warp filament, shows the existance of the fibril-structure along the fiber axis more clearly than other cases such as the hydrolysis of fiber by a certain chamicals.

Fig. 9 shows that the thickness of fabric is increased with the formic acid concentration. This may be resulted mainly from the cross-sectional swelling of the constituent filaments by formic acid.

Tensile strength and elongation

Fig. 10 shows that the tensile strength of fabric is increased a little up to 40-50% of formic acid concentration and then decreased considerably at 60%. It is thought that the increase in tensile strength is resulted from the increases in the diameter of filaments and fabric count, although the strength per unit cross-sectional area of each filament was decreased because of the decrease in the orienta-

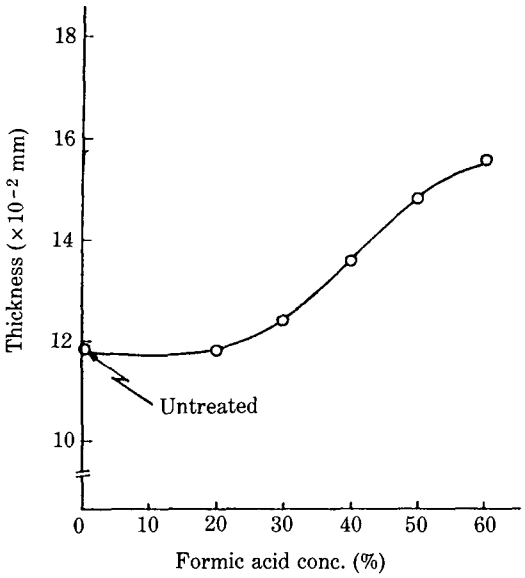

Fig. 9. Relationship between formic acid concentration and thickness of samples.

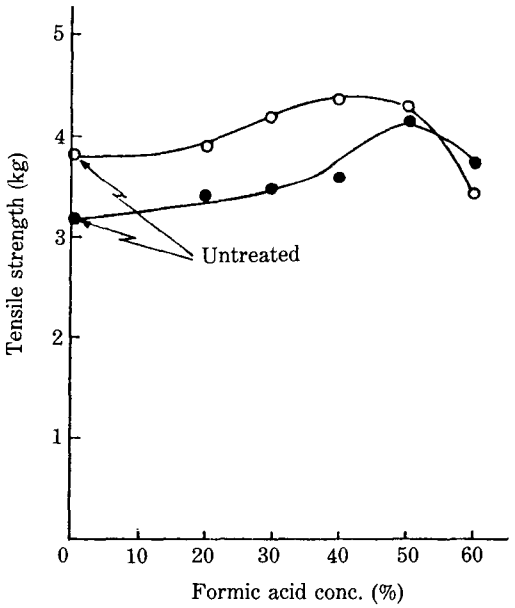

Fig. 10. Relationship between formic acid concentration and tensile strength of samples.
○; Warp direction, ●; Weft direction

tion of molecular chains and crystallites by the action of organic solvent.[2] But the decrease of tensile strength at 60% may be resulted from both the severe decrease in orientation and the partial damage of the constituent yarns.

Fig. 11 shows that the elongation, which is not

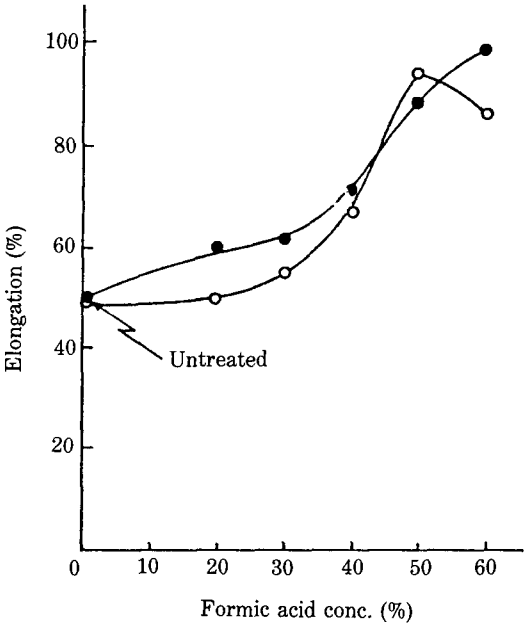

Fig. 11. Relationship between formic acid concentration and elongation of samples.
○; Warp direction, ●; Weft direction

affected by either the diameter of filaments or the fabric count, is increased greatly by the decrease in orientation. However, because the crimp ratio and the tension degree of the constituent yarns must be considered, up to about 40% of formic acid concentration, the elongation of the weft of which crimp ratio and tension degree are relatively low is greater than that of the warp; but beyond that concentration this phenomenon begin to be reversed. Especially, the noticeable decrease in the elongation of the warp may be resulted from the severer damage on the warp.

The change of the handle value obtained by Handle-O-Meter, which measures the compound characteristics related to the handle, such as transverse and surface frictional resistances,[10] is indicated in Fig. 12. The stiffness of fiber itself was decreased by the decrease in molecular orientation owing to organic solvent generally; therefore, the handle value of the fabric would be decreased by organic solvent. But the figure shows that, up to 40% of formic acid concentration, the handle value is not varied almost. This may be resulted from that such decreasing effect of fine-structural factor and the increasing effect of fabric-structural factors

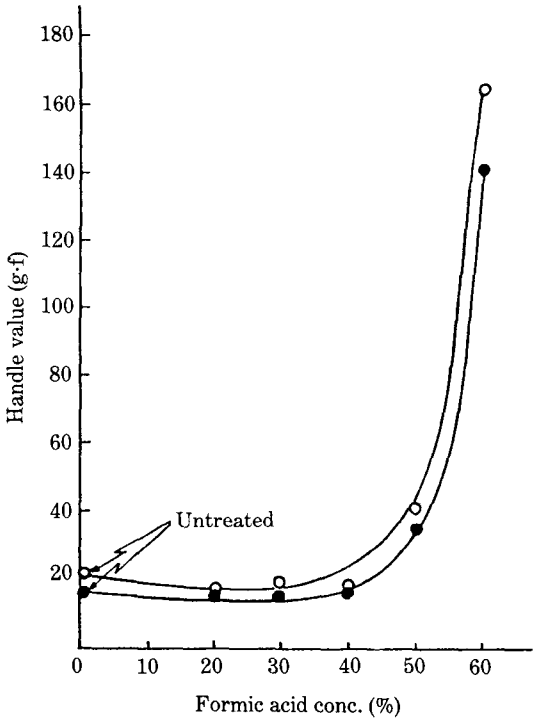

Fig. 12. Relationship between formic acid concentration and handle value of samples.
○; Warp direction, ●; Weft direction

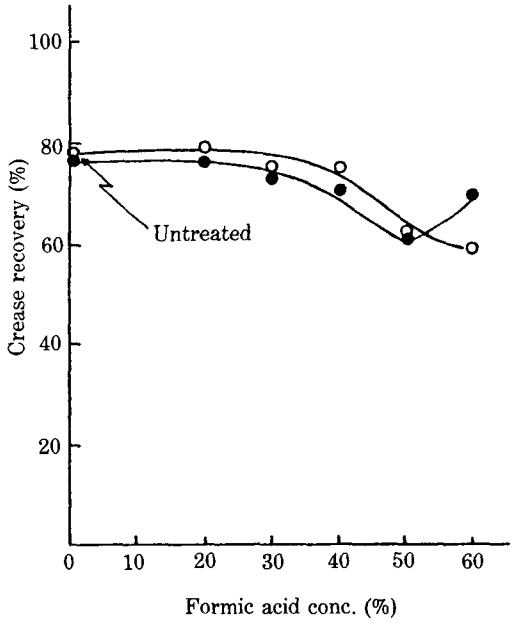

Fig. 13. Relationship between formic acid concentration and crease recovery of samples.
○; Warp direction, ●; Weft direction

such as fabric count, crimp ratio, and tension degree of the constituent yarns, offset each other. However, beyond 50% of formic acid concentration the handle value is increased rapidly by main effect of the strong compressive force among the constituent yarns and among the each and every filaments.

Fig. 13 shows that the crease recovery is decreased with formic acid concentration owing to the increase in the fabric count followed by the decrease in the freedom of the constituent filaments as well as the decrease in elasticity of fiber itself by fine-structural factor (orientation decrease). Perciliarly, the crease recovery of the weft is increased conversely at 60% of formic acid concentration. It is presumed that such increase is due to the high resistivity to the bending of the weft created by severe compression between the warp.

Conclusions

The woven fabric composed of nylon 6 filament yarns were treated with aqueous solutions of formic acid for 10 minutes. And then the shrinkage behavior and some properties were examined and the following conclusions were obtained.

1. The shrinkages of the constituent yarns and the warp are lower than those of the original filaments and the weft because of the fabric-structural factors and the residual stress from weaving process, respectively.
2. The constituent filaments are damaged partially at 60% of formic acid concentration and the degree of damage on the warp is greater than that on the weft because of the above-mentioned reasons.
3. The spacing between the warps is decreased prior to the weft and eliminated nearly at 60% of fomic acid concentration. Therefore, the shrinkage of the weft is still more restraint than that of the warp at the concentration.
4. The changing tendency of the fabric shrinkage is similar to that of the constituent yarns generally, but the fabric shrinkage is affected a little by the crimp ratio of the yarns.

5. The fabric count and thickness are increased with formic acid concentration.
6. The tensile strength and elongation are generally increased with formic acid concentration, but at 60% of formic acid concentration the tensile strength for both warp and weft directions and the elongation for warp direction are decreased because of the damage of the yarns.
7. The handle value is not changed almost up to 40% of formic acid concentration, but beyond that concentration increased rapidly on account of strong compressive force between yarns and each and every filaments.
8. The crease recovery is generally decreased with increase in formic acid concentration, but at 60% of formic acid concentration that for weft direction is increased because of the high resistivity to the bending of the weft created by severe compression between the warps.

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