Mechanisms of Degradation of Cotton and Effects of Mercerization-Stretching upon the Course of These Mechanisms. V. Weathering

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Synopsis

Scoured ply cotton yarn was slack mercerized followed by restretching the cotton yarn to 90–103% of the original length in the mercerizing solution. The scoured and the mercerized cotton yarns were subjected to weathering for up to 14 months. Regardless of the cotton substrates, exposure to weathering was accompanied by an increase in copper number, decrease in both degree of polymerization (DP) and iodine sorption, and a loss in strength properties. No significant change in the carboxyl content of scoured and mercerized cottons could be observed after weathering. However, mercerized cottons retained higher strength in spite of higher degradation as compared to scoured cotton. This was interpreted in terms of removal of structural imperfections or weak links in cotton during the combined as swelling and stretching process evidenced by interrelationships between tenacity and percentage of bonds broken, as well as tensile strength and DP together with measurement of the average distances between crystallite centers in scoured and mercerized degraded cotton.

INTRODUCTION

It is well known that mercerization brings about an increase in the reactivity of cotton and makes it more susceptible to chemical attack. However, mercerization alters the molecular structure of cotton in such a way that mercerized cottons show higher retained strength than the corresponding unmercerized cottons when degraded under identical conditions.[1] The susceptibility to chemical degradation was found to decrease with the increase in the tension applied during the stretching of the slack mercerized yarns beyond their original length.[2]

Mercerization usually dissolves shorter chains[3] and thereby reduce the low polymeric components. The significant fact concerning the effect of molecular length on tensile properties was originated by Staudinger,[4] who demonstrated a linear relation between the reciprocal degree of polymerization (DP) and tensile properties. The slower decrease in tensile strength with DP in the low range has been interpreted as a result of size distribution of the morphological units forming the network structure of the fibers. Rate of hydrolysis[5] is also related to the perfection of order and orientation of microfibrils in the cellulose structure. Inverse relation has been found between them. Hydrolysis results in an improvement of order (crystallization) and degree of orientation. In fact the recrystallization is the primary cause of orientation. This improvement of order and orientation was most pronounced in the case of mercerized cottons than in the unmercerized cottons.

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Over the last two years, we have been working a research project the primary objective of which is to measure the fundamental changes occurring as a consequence of acid, hypochlorite, heat, ultraviolet, and weathering degradative treatments of cotton and slack mercerized-restretched cotton yarns, and to determine the effect of mercerization stretching of yarns upon these fundamental changes in order to identify the structural features that are critical to the improved retention of the strength in mercerized-stretched yarns. The results obtained with acid,[6] hypochlorite,[7] heat,[8] and ultraviolet[9] treatments along with appropriate discussion have been reported. The present communication covers the results obtained with weathering degradative treatment. In addition, the main conclusions arrived at from results of the said previously reported degradative treatments are included. It is hoped that these studies will be useful in understanding the phenomena that accompanying the increased rates of molecular degradation and increased extent of strength retention thereby providing basis for new routes to improve balances in properties of chemically modified cotton fabrics.

EXPERIMENTAL

Cotton Fibers

Egyptian cotton fibers (Giza 75) were used in this investigation. After being combed, these fibers were spun on conventional ring spinning to produce singles yarn of count Ne 60 (twist factor of 4). These singles yarn were then plied to produce Ne 60/2. The twist (twist factor of 2.4) in plying the yarns was made opposite to the twist in the singles yarn. Physicomechanical properties of these cotton fibers as well as those of the ply yarn were given in part I.[6]

The ply yarn was Kier boiled and the scoured yarn so obtained was slack mercerized in caustic soda followed by restretching to various lengths while the yarn was still wet with the mercerizing solution. The scouring and mercerizing processes were described in details in Part I.[6] For convenience, the yarn before and after mercerization will be referred to as:

Substrate I: Scoured yarn.

Substrate II: Mercerization as nearly slack as possible on the machine (with ca. 15% shrinkage) followed by partial restretching to 90% of the original length while the yarn was still wet with the mercerizing solution.

Substrate III: Mercerization nearly slack (ca. 15% shrinkage), followed by restretching the yarn in the mercerizing solution to 94% of the original length.

Substrate IV: Mercerization nearly slack (ca. 15% shrinkage), followed by restretching the yarn in the mercerizing solution to 96% of the original length.

Substrate V: Mercerization nearly slack (ca. 15% shrinkage), followed by restretching the yarn in the mercerizing solution to 100% of the original length.

Substrate VI: Mercerization nearly slack (ca. 15% shrinkage), followed by restretching to 103% of the original length while the yarn was still wet with the mercerizing solution.

Weathering Treatments

Weathering was carried out in Cairo, Egypt by exposing the scoured cotton yarns (Substrate I) and mercerized cotton yarns (Substrates II–VI) to outdoor weather during the period from March 1, 1978 to April 30, 1979. The cotton samples were placed on frames facing the south by an angle of 45°.

Determination of Copper Number (CuNo)

The copper number was determined according to a Micro-Briady method as modified by Heyes.[10]

Determination of Carboxylic Groups

The calcium acetate method described by Lüdtke was used for determination of carboxylic groups.[11] Another method based on methylene blue absorption[12] was also used for the same determination.

Determination of Iodine Sorption Value

The iodine sorption value was determined as per a reported method.[13]

Determination of Degree of Polymerization (DP)

The DP was determined viscometrically in ethyl acetate after converting cotton cellulose to cellulose nitrate as per a method described elsewhere.[14]

Evaluation of Mechanical Properties

Mechanical properties viz. breaking load, tenacity, strength variation, extension at break, etc. were monitored according to standard methods.[15]

RESULTS AND DISCUSSION

Weathering is an inclusive term describing the aggregate effect of environmental factors of sunlight, microorganisms, industrial fumes, rain, and wind.[16] When textile are used outdoors, deterioration in both strength and appearance takes place. Deterioration of textiles from weathering may be classified as chemical or physical. The chief agencies causing chemical deterioration are sunlight, photochemical or actinic degradation, and mildew or rot (microbial attack). Other chemical factors such as airborne acids and alternate wetting and drying may also contribute, but have less of an effect.[16–20]

In this investigation, the effect of weathering on scoured cotton yarn and slack mercerized variably stretched cotton yarns was studied with a view of determining the fundamental changes occurring in cotton structure as a consequence of weathering degradative action.

Copper Number

The scoured cotton yarn (Substrate I) and the five mercerized cotton yarns (Substrates II–VI) were exposed to weathering, starting on March 1, 1978. Exposure was continued for 14 months during which samples were taken at different periods of time. All samples were conditioned for 24 h in an atmosphere of 65% r.h. and 25°C before testing.

Table I shows the effect of weathering on copper number of scoured cotton (Substrate I) and mercerized cottons (Substrates II–VI). It is clear that exposure to weathering is accompanied by an increase in copper number; being dependent upon the duration of exposure. The copper number increases significantly as duration of weathering increases from 2 to 9 months. Thereafter, there is an increase in copper number but to a much lower extent as compared with the first 9 months. Stated in other words, the copper number increases in the first 9 months of weathering, slows down with time and reaches almost a constant value, which is not affected significantly by prolonging the duration of weathering. This is observed regardless of the substrate used. However, for a given duration of weathering, scoured cotton (Substrate I) shows much lower copper number than mercerized cottons (Substrates II–VI), indicating that the latter substrates undergo more weathering degradation than the scoured cotton (Substrate I). The increase in copper number is essentially due to liberation of more and more end reducing groups as well as side reducing groups via hydrolytic cleavage of cellulose glucosidic bonds by enzymes, which the microorganisms (present in the atmospheric environment) release and oxidation of cellulose hydroxyls by light in presence of moisture and oxygen.

It is as well to emphasize that no clear-cut relation is found as far as the effect of tension applied during mercerization since the differences in copper number (Table I) of the five mercerized cottons (Substrates II–VI) after weathering are not significant.

Carboxylic Groups

The carboxylic groups in scoured cotton yarn (Substrate I) as well as in the five mercerized cotton yarns (Substrates II–VI) before and after weathering for different durations were determined as per two methods. While the first method is based on calcium acetate, the second method is based on methylene blue absorption. The results obtained with the two methods are shown in Table II.

It is observed (Table II) that the calcium acetate method failed to detect any carboxylic groups in any of the substrates in question even after 2 months ex-

TABLE I
Effect of Weathering on Copper Number of Scoured and Mercerized Cotton Yarns

	Weathering (months)									
Substrate	Untreated	2	3	5	6	8	9	11	12	14
I	0.02	0.04	0.07	0.46	0.52	0.62	0.68	0.72	0.77	0.77
II	0.02	0.06	0.09	0.75	0.88	0.93	0.92	0.95	1.02	1.10
III	0.02	0.06	0.09	0.70	0.85	0.86	0.96	0.97	1.12	1.11
IV	0.02	0.06	0.09	0.67	0.82	0.84	0.94	0.96	1.02	1.04
V	0.03	0.06	0.09	0.66	0.82	0.87	0.98	0.94	1.13	1.09
VI	0.03	0.06	0.09	0.62	0.81	0.83	0.99	0.93	1.14	1.08

TABLE II
Effect of Weathering on Carboxyl Groups as Determined by Two Different Methods

Substrate	mequiv. COOH/100-g cellulose after duration (months) of									
	Untreated	2	3	5	6	8	9	11	12	14[a]
I	0.0	0.0	0.6	1.0	1.0	1.0	1.1	1.0	1.1	
II	0.0	0.0	0.7	1.0	0.8	1.4	1.1	1.0	1.1	
III	0.0	0.0	0.7	0.9	0.6	1.3	1.0	0.9	1.0	
IV	0.0	0.0	0.8	0.8	1.0	1.1	0.9	0.9	0.9	
V	0.0	0.0	0.8	1.1	1.0	1.1	0.9	1.0	0.9	
VI	0.0	0.0	0.9	1.1	1.0	1.1	1.1	0.8	0.8	
I	3.1	3.8	3.6	3.2	3.8	3.6	4.2	3.6	4.0	3.7[b]
II	3.1	3.8	3.7	3.3	3.8	3.5	4.4	3.3	4.2	3.9
III	3.2	3.2	3.7	3.6	3.3	3.3	3.8	3.3	3.6	3.9
IV	3.0	3.7	3.5	3.6	3.4	3.6	4.0	3.1	3.4	3.8
V	3.3	3.8	3.6	3.8	3.2	3.1	4.0	3.3	3.6	3.7
VI	3.3	3.7	3.8	3.8	3.4	3.4	4.2	3.6	3.9	3.7

[a] Calcium acetate method.
[b] Methylene blue absorption method.

posure to weathering. Furthermore, the values of carboxylic groups determined by this method in samples exposed to weathering for one year are as low as 1-mequiv. COOH/100-g cellulose. The second method, on the other hand, brings about a value for carboxylic groups that amounts to ca. 3-mequiv. COOH/100-g cellulose and ca. 4-M.E. COOH/100-g cellulose before and after one year exposure to weathering, respectively (Table III).

Obviously then weathering degradative treatment has a very marginal effect on carboxylic groups of scoured and mercerized cottons, indicating that no further oxidation of the aldehydic groups to carboxylic groups occurs. Weathering treatment results in reducing-type oxidized cellulose as shown by the copper number measurements given above.

Iodine Sorption

Table III shows the effect of weathering degradative treatment on iodine sorption values of the scoured yarn (Substrate I) and the five mercerized cotton yarns (Substrates II–VI). It is clear that the iodine sorption value for the scoured cotton yarn remains practically intact after exposure to the weather for a period of up to 5 months. Thereafter, the iodine sorption value substantially decreases by prolonging the duration of exposure up to 9 months then attains almost a

TABLE III
Effect of Weathering on Iodine Sorption

Substrate	mequiv. I_2/g cellulose after a duration (months) of									
	Zero	2	3	5	6	8	9	11	12	14
I	26.0	25.7	25.9	26.3	22.9	21.3	18.9	18.9	18.9	18.8
II	92.7	68.2	61.8	51.0	45.4	43.5	41.9	40.1	34.0	33.5
III	92.0	66.7	52.5	60.1	45.9	43.0	42.8	40.8	34.8	34.1
IV	91.8	66.4	51.8	59.1	45.1	43.2	42.8	40.2	34.4	33.4
V	91.6	66.2	59.8	51.9	45.3	43.4	42.8	39.8	34.4	32.9
VI	91.6	64.1	58.1	51.1	45.0	43.0	42.0	40.1	34.2	33.4

constant value. With mercerized cottons (Substrates II–VI), on the other hand, the iodine sorption value rapidly decreases during the first 6 months exposure and continues to decrease, but with a much slower rate, by further prolonging the duration of exposure up to 14 months.

It is also seen (Table III) that no significant differences are observed between the values of iodine sorption obtained with the five mercerized cotton yarns after weathering. This indicates that the magnitude of tension applied during mercerization does not alter the susceptibility of the mercerized yarns toward weathering. However, in comparison with the scoured cotton, the mercerized cottons proved to be much more amenable to weathering degradation than scoured cotton, in accordance with previous reports concerning with acid,[6] hypochlorite,[7] thermal,[8] and ultraviolet[9] degradative treatments.

Degree of Polymerization (DP)

The effect of weathering on the DP of the scoured cotton (Substrate I) and mercerized cottons (Substrates II–VI) is shown in Table IV and Figure 1. It is clear that the DP decreases significantly as the duration of weathering increases though the decrease in DP is more progressive in the initial than in the later stages of weathering. This is observed regardless of the substrate used. However, the decrease in DP for mercerized cottons (Substrates II–VI) is higher than that of scoured cotton (Substrate I). The implication of this is that mercerized cotton yarns are more amenable to weathering degradation than scoured cotton yarn; in accordance with the data of copper number discussed above as well as with previous studies.[6–9]

A close examination of the data given in Table IV would indicate that under the hydrolytic–oxidative action of weathering cellulose chain scission occurs, and the DP falls from 2412 to 1725 and 550 in case of Substrate I and from 2342 to 1714 and 490 in case of substrate II and from 2396 to 1390 and 519 in case of Substrate IV and from 2504 to 1593 and 464 in case of Substrate VI after 2 and 14 months, respectively. Thus if the original DP of each substrate before weathering is taken into consideration, it will be apparent that the magnitude of tension applied during mercerization has little effect on degradation of the cellulosic chains of mercerized cotton by the attack of weathering. However, there is a tendency that yarns mercerized under high tension acquire slightly higher DPs after weathering for relatively short periods (up to 3 months).

TABLE IV
Effect of Weathering on the Degree of Polymerization (DP)

Substrate	Weathering (months)									
	Zero	2	3	5	6	8	9	11	12	14
I	2410	1730	1500	1150	1050	850	800	700	610	550
II	2340	1710	1280	1000	950	850	710	610	540	490
III	2360	1230	1040	1110	850	800	650	600	550	350
IV	2400	1390	1290	1100	920	860	800	600	530	520
V	2500	1440	1370	1020	1000	880	770	590	540	370
VI	2500	1590	1420	1090	970	830	800	590	490	460

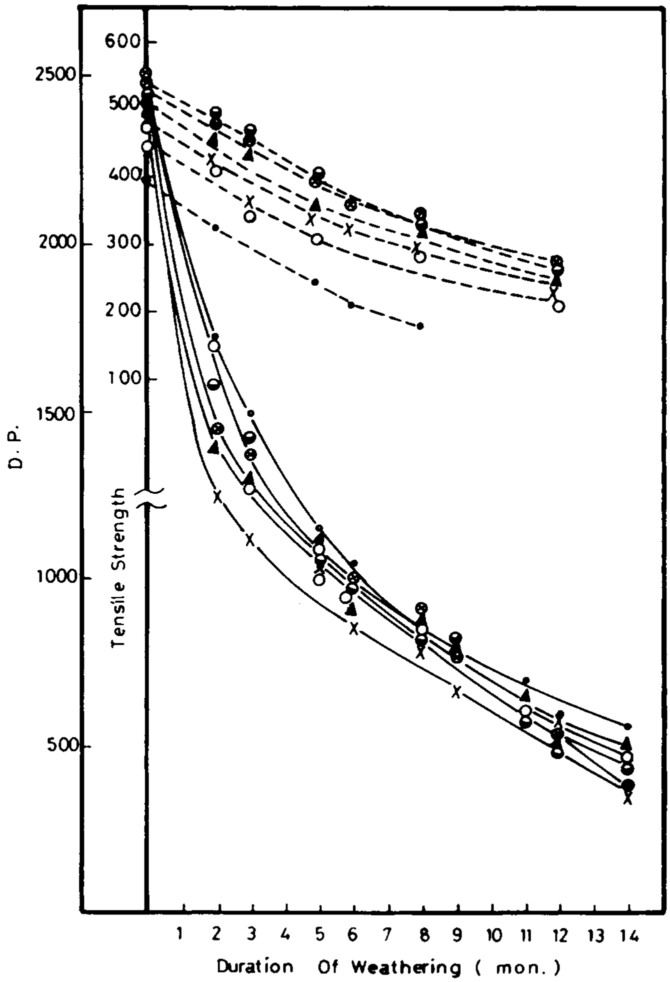

Fig. 1. Variation of DP and tensile strength with duration of weathering. (- - - -) Tensile strength (g): (—–) DP. ●, Substrate I; ○, Substrate II; ×, Substrate III; ▲, Substrate IV; ⊗, Substrate V; ⊖, Substrate VI.

Strength

When the scoured cotton yarn (Substrate I) and the five mercerized cotton yarns (Substrates II–VI) were exposed to the weather, the yarn strength decreases substantially. This is shown in Table V and Figure 1. The loss in strength increases by increasing the duration of weathering irrespective of the substrate used. However, the losses in strength for mercerized cotton yarns (Substrates II–VI) are much less than those of scoured cotton yarn (Substrate I).

The effect of tension applied during mercerization on the strength of the yarn after weathering may be realized from Figure 1. It is apparent that yarns that were slack mercerized followed by stretching under high tension retain more strength than their mates that were slack mercerized and then stretched under low tension. Figure 1 also brings out the anomalous behavior of mercerized and unmercerized yarns. The mercerized yarns retain higher strength inspite of higher degradation as compared to the unmercerized yarns; in accordance with

TABLE V
Effect of Weathering on Yarn Strength (Tensile Strength in g and Tenacity in g/tex) and Elongation at Break (E%)

Duration (months)	Properties	Substrate I	II	III	IV	V	VI
Zero	g	392	444	492	508	514	532
	g/tex	22.0	24.6	25.5	26.0	27.1	29.8
	E%	8.8	7.2	5.4	4.8	4.8	4.8
2	g	344	462	418	452	484	486
	g/tex	17.9	23.6	24.2	24.8	26.7	27.0
	E%	6.6	7.4	5.8	4.8	6.4	4.4
3	g	311	434	411	434	561	449
	g/tex	15.8	19.5	22.5	24.5	24.3	25.5
	E%	4.8	5.5	5.4	4.4	4.2	4.2
5	g	292	349	408	359	385	380
	g/tex	13.6	17.0	21.4	19.9	22.8	22.0
	E%	4.1	5.1	4.9	4.2	3.8	4.1
6	g	220	307	395	350	368	471
	g/tex	13.1	19.7	20.1	15.4	20.7	20.2
	E%	4.0	4.2	4.8	4.1	3.2	3.9
8	g	201	308	389	312	367	316
	g/tex	12.3	16.9	20.1	13.2	16.8	19.8
	E%	3.9	4.0	4.7	4.0	2.9	3.1
11	g	—	291	341	293	311	298
	g/tex	—	12.4	18.7	12.3	16.6	17.3
	E%	—	3.8	4.1	4.0	2.9	2.9
12	g	—	285	272	270	277	244
	g/tex	—	11.2	14.5	11.9	13.4	13.4
	E%	—	3.6	3.9	4.1	2.8	2.9

the results of earlier reports on acid,[6] hypochlorite,[7] thermal,[8] and ultraviolet[9] treatments.

Elongation

Table V shows the effect of weathering on elongation at break of scoured cotton yarn (Substrate I) and the five mercerized cotton yarns (Substrates II–VI). It is seen that weathering causes a significant reduction in elongation of scoured cotton yarn (Substrate I). This reduction increases by prolonging the duration of weathering. With mercerized cotton yarns (Substrates II–VI), on the other hand, there is no reduction in elongation in the initial stages of weathering and the decrease in elongation found in the later stages of weathering is not that striking.

The finding that mercerized cotton yarns retain higher values of their original elongation at break as compared with scoured cotton yarn after weathering could be associated with chain breakage in the amorphous regions, accompanied by a relief of stress on some of the cellulose chains.[1] As it will also be shown later, the fraction of bonds broken is much higher with mercerized cotton yarns than with scoured cotton yarn. This might also be accompanied by relief of stress on some of the cellulose chains thereby favouring elongation.

It may be further noted that increasing the magnitude of applied tension during mercerization has no significant effect on elongation at break of mercerized cotton yarns after weathering (Table V).

Other Mechanical Properties

Table VI contains the results of turn per inch (twist), yarn number and evenness obtained with scoured cotton yarn (Substrate I) and five mercerized cotton yarns (Substrates II–VI) before and after these substrates have been exposed to weathering. It is clear that irrespective of the substrate used: weathering leaves these yarn properties practically unimpaired. Thus it is obvious that the loss in yarn strength resulting from weathering as shown above is due to degradation of cotton cellulose rather than changes in twist, yarn number, and/or evenness.

Interrelationship

Figure 2 shows the relation between strength (tenacity, g/tex) and the percentage of bonds broken when scoured cotton yarn (Substrate I) and the five mercerized yarns (Substrates II–VI) were exposed to weathering for different durations (2–14 months). The percentage of bonds broken was computed for weathering degraded yarns by making use of DP measurements on the said substrates and by following the route previously described.[6–9]

It is clear (Fig. 2) that the strength decreases considerably as the percentage of bonds broken increases. This is observed regardless of the substrate used. Nevertheless, for a given percentage of bonds broken, the strength of mercerized

TABLE VI
Effect of Weathering on Twist [turns/inch (TPI)], Yarn Number (tex), and Evenness (CV %).

Duration (months)	Properties	Substrate					
		I	II	III	IV	V	VI
Zero	TPI	14.7	13.8	12.8	13.0	12.4	13.0
	C.V.%	14.5	13.8	14.4	12.8	14.4	13.4
	Tex	18.2	20.0	17.5	17.7	18.0	18.5
2	TPI	12.8	13.7	12.9	13.3	12.4	12.9
	CV %	14.8	15.5	15.5	14.5	15.4	14.7
	Tex	19.2	19.6	18.6	18.5	18.6	18.0
3	TPI	13.7	15.2	14.5	13.9	14.3	13.7
	CV %	13.3	14.0	16.0	15.0	12.6	14.8
	Tex	18.8	17.9	18.3	17.5	17.8	17.6
5	TPI	12.8	13.7	12.9	13.0	12.4	12.9
	CV %	14.8	15.5	15.0	14.5	15.6	14.7
	Tex	17.3	18.8	17.9	18.4	18.1	15.4
6	TPI	13.7	15.4	14.5	13.9	14.3	13.7
	CV %	13.3	13.8	16.0	14.8	12.6	14.8
	Tex	18.5	19.0	18.9	18.1	18.1	17.4
8	TPI	13.7	14.0	12.6	11.8	14.3	—
	CV %	13.9	14.9	15.3	15.2	15.1	—
	Tex	17.9	20.6	18.8	18.4	18.4	—

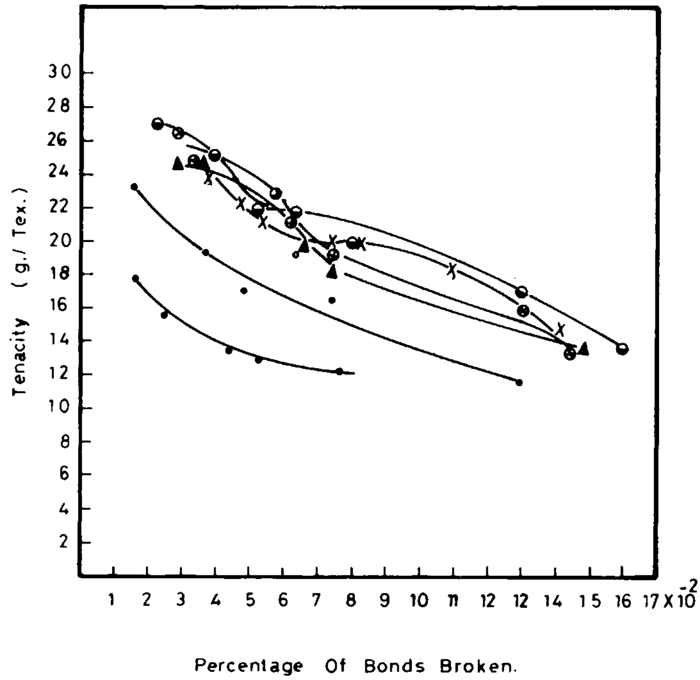

Fig. 2. Relation between percentage of bonds broken and strength of scoured and mercerized cotton yarns after weathering. Duration of treatment from 2 to 12 months. ●, Substrate I; ○, Substrate II; ×, Substrate III; ▲, Substrate IV; ⊗, Substrate V; ⊖, Substrate VI.

cotton is much higher than that of scoured cotton. Furthermore, the strength of highly stretched yarn is greatly higher than those stretched at lower tension provided that the percentage of bonds broken is the same.

Figure 3 shows the relation between DP and strength of scoured cotton yarn (Substrate I) and the mercerized cotton yarns (Substrates II–VI) subjected to weathering. It is clear that the curves of the scoured cotton and mercerized cottons do not overlay, i.e., do not fall on different ends of the same curve. On the contrary, the curves of the mercerized cotton overlay irrespective of the tension applied during mercerization, with the exception of substrate II.

The data (Fig. 3) also indicate that the strength of scoured cotton yarn whose chain length was reduced by weathering treatment decreases almost imperceptibly from about DP 2400 to about DP 1000. Thereafter, there is a sharp decrease in tensile strength with the decrease in DP, in accordance with previous studies.[6–9] A similar trend is observed with the mercerized cottons, but the sharp decrease in DP did not cause a sharp decrease in yarn strength. This reflects the effect of mercerization on: (a) lowering the polydispersity of cotton cellulose, (b) increasing the crystallite orientation along the fibre axis, (c) removing weak points in the scoured cotton yarn brought about perhaps by mechanical damage in processing, by strain set in drying, or by strain at points of reversal in the spiral structure,[21,22] and (d) increasing the frequency of successive regions of high lateral order as shown in Table VII. In short, mercerized cotton exhibits a more uniform structure which improves the distribution of stress along the fiber.

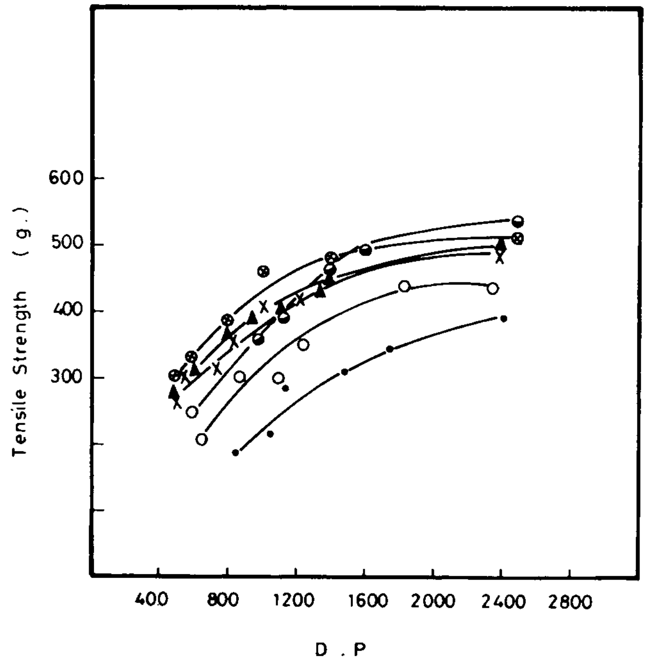

Fig. 3. Relation between tensile strength and DP of scoured and mercerized cotton yarns weathered for 0, 2, 3, 5, 6, 8, 11, and 12 months. ●, Substrate I; ○, Substrate II; ×, Substrate III; ▲, Substrate IV; ⊗, Substrate V; ⊖, Substrate VI.

CONCLUSION

When scoured and slack mercerized-restretched cotton yarns were subjected to acid,[6] hypochlorite,[7] heat,[8] ultraviolet,[9] and weathering degradative treatments, they reveal the following common features:

(1) The mercerized yarns retain higher strength in spite of higher degradation as compared to scoured yarn.

(2) The strength of mercerized yarns after treatment is dependent on the magnitude of stretching; the higher the magnitude of stretching the higher the strength.

TABLE VII
Average Distance between Crystallites Centers (L) for Scoured and Mercerized Cotton Yarns that Have Been Subjected to 8 Months Weathering Degradative Treatment

Substrate	L, from equation (DP)[a]	Reference
I	770	1
II	500	
III	290	
IV	910	
V	640	
VI	590	

[a] $T = T_0e^{-BL}$, where T and T_0 are the tenacities at any given time and at zero time, respectively, B is the fraction of total bonds broken and L is the average distance between crystallite centers. The fraction of bonds broken B was calculated from the relation $B = 1/P_t - 1/P_0$, where P_0 and P_t are the DP of the original cellulose and the degraded cellulose, respectively.

(3) The magnitude of stretching has no significant effect on copper number, carboxyl content, and iodine sorption of the degraded mercerized cottons. On the contrary, there is a tendency that the DP is higher the higher the magnitude of stretching.

(4) The degradative treatments studied have practically no effect on twist, yarn number, and evenness of the scoured and mercerized cottons, indicating that the decrease in yarn strength is due to chemical degradation rather than changes in twist, yarn number, and/or evenness.

(5) The average distances between centers of crystallites in mercerized cotton after any of the degradative treatments in question are much shorter than their mates in scoured cotton, indicating that the frequency of successive regions of high lateral order is much more in mercerized cottons as compared to scoured cotton.

(6) Plotting the DP of degraded yarns against the corresponding tensile strength shows the curve of scoured cotton does not overlay on those of mercerized cottons. The curves of mercerized cotton, on the other hand, overlay irrespective of the magnitude of tension except in one case.

(7) The plots of DP with tensile strength also show that the strength of scoured cotton yarn whose DP was reduced by the treatment to DP below 1000 decreases sharply whereas with mercerized cotton yarns no sharp decrease in strength was observed.

(8) The strength decreases as the percentage of bonds broken increases irrespective of the degradative treatments used within the range studied. However, for a given substrate, the type of the degradative treatment determines the magnitude of the strength loss since at equal percentages of bonds broken, the strength varies considerably with the type of the treatment.

(9) For a given percentage of bonds broken, the strength of the mercerized cotton yarns is greatly higher than that of scoured cotton.

(10) For a given percentage of bonds broken, the strength of the highly stretched yarn (i.e., slack mercerized then stretched under high tension) is significantly higher than those stretched at lower tension.

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