NOTES

A Quantitative Evaluation of NaOH Swelling and Its Effect on Maturity of Cotton Fibers

This article presents the results of an investigation carried out to quantify the changes in the wall thickness–ribbon width ratio of cotton fibers from different varieties during swelling in 18% NaOH. While measuring the wall thickness and ribbon width before and after swelling, the identity of individual fibers was maintained such that changes could be followed up with precision. The data indicate not only varietal differences in the response to alkali but also a strong dependence of the extent of swelling on the initial wall thickness for fibers in a given variety. Thin-walled fibers seem to have a tendency to swell more than mature hairs. This tendency would cast doubt on the accuracy of maturity measured by the alkali swelling method, especially when the concerned variety has a substantial percentage of fibers having a wall–ribbon ratio falling in the 0.15–0.25 range before swelling.

INTRODUCTION

Fiber maturity is one of the important physiological attributes of cotton related to cell wall development. The true estimate of fiber maturity is equally useful to the breeder, the technologist, and the textile chemist. The presence of immature fibers has the potential to increase the fiber entanglement during processing, leading to neps and unevenness in the yarns. These show up as imperfections in the finished fabric, as immature fibers have relatively low dye affinity.

Several direct[1-4] and indirect[5-12] methods have been suggested from time to time for measuring the maturity of cotton fibers. In the most popular direct method[4] that uses the light microscope, fibers are irrigated with 18% NaOH and classified as mature or immature from the relative dimensions of wall and lumen, following standard norms. This is the method followed at the Central Institute for Research on Cotton Technology (CIRCOT). The various indirect methods of determining maturity are all based on some secondary characteristic that depends on cell wall thickness. Measurements are usually made on raw fibers. The results obtained by indirect methods can be converted into equivalent maturity values obtainable by the alkali swelling method using regression equations. However the maturity obtained after swelling may not represent the true biological maturity, as different cottons tend to swell differently[13-15] in NaOH. In other words, it is possible that samples that show the same extent of wall development may fall into different maturity groups after swelling. Alternative procedures[16-17] of measuring maturity have been explored where the direct measurements do not involve NaOH swelling, although these are yet to become routine methods.

Although there are studies indicating that swelling of cotton in NaOH is a variety-dependent phenomenon, not much is known as to exactly how swelling varies with wall thickness when field-opened fibers of different varieties are examined. This prompted us to examine from an entirely different angle the problem of maturity measurement by swelling fibers in caustic soda. Results of our experiments are presented here and the likely reasons for anomalies in the measurement of maturity with 18% NaOH are discussed briefly.

EXPERIMENTAL

Materials

About 50 g lint of four hirsutum/hybrid and two arboreum/herbaceum cottons were obtained from the respective regions where they are grown. The varieties were selected to cover a wide range of maturity. After proper sampling, a thoroughly mixed silver was prepared for each variety and used throughout the study.

Methods

For each variety, ribbon width (R) and lumen width (L) were measured at the widest portion at ten different places along the length of each fiber. One hundred fibers drawn from different length groups were tested from each variety. Measurements were carried out on the same set of fibers both in the raw and alkali swollen states, maintaining fiber identity by taking appropriate precautions.

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Table I Data on Raw and Swollen Fibers for Six Varieties

Name of Cotton	Ribbon Width (μms) Control (R)	Ribbon Width (μms) 18% NaOH (R')	Wall Thickness (μms) Control (W)	Wall Thickness (μms) 18% NaOH (W')	Wall–Ribbon Ratio Control (W/R)	Wall–Ribbon Ratio 18% NaOH (W'/R')	% Increase in W/R on Swelling	Correlation Coefficient (r)
DCH.32	18.53	21.97	4.27	7.07	0.234	0.327	39.70	0.84
GCot.10	19.79	24.54	4.60	7.77	0.238	0.319	34.00	0.84
MCU.5	18.81	23.88	5.04	8.30	0.271	0.348	28.40	0.68
GCot H.6	19.53	24.69	5.17	8.87	0.268	0.359	33.90	0.80
GCot.11	22.16	28.80	5.75	9.30	0.261	0.323	23.70	0.63
AKH.4	20.46	27.66	5.88	10.12	0.290	0.367	26.60	0.71

From the measured values of ribbon and lumen widths, the wall thickness (W) and wall-ribbon ratio were calculated for both raw (W/R) and swollen (W'/R') fibers. A parameter called "swelling coefficient" defined as

$$SC = \frac{(W'/R' - W/R)}{(W/R)}$$

has been evaluated in all cases.

Percent of mature fibres (P_M) was estimated for different cutoff values of W/R and W'/R'.

RESULTS AND DISCUSSION

Effect of Swelling on W/R

The average values of ribbon width, wall thickness, and wall–ribbon ratio for different varieties of cotton are given in Table I. The correlation coefficients between W/R and W'/R', as well as the percentage increase in the wall–ribbon ratio brought about by swelling, are also included in the table. If W'/R' is decided only by the original value of W/R, we would expect a correlation of unity between the two parameters. But wall thickness and ribbon width measurements can be affected by convolutions and deformities. Further, swelling itself may be influenced by wall structure, void space, damage to primary wall, etc. It may be noted from the table that correlation coefficients are not only low but different for different varieties. To a first approximation, the different r values can be taken to be indicative of the differential swelling that occurs among the varieties, either due to structural or morphological variations, or both.[15] The percentage increase in the wall–ribbon ratio (see last column of Table I) also demonstrates the varietal response to swelling.

Figure 1 gives the relation between W/R and W'/R' for the variety DCH.32. W'/R' increases with increase in W/R, although there is considerable scattering of points. It is obvious from the figure that W'/R' is decided mainly by the initial value of W/R.

Table II gives the swelling coefficients together with values of W/R and W'/R' for all six varieties. For each

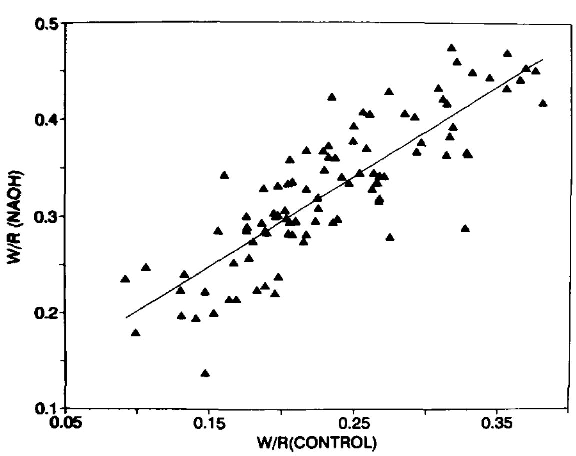

Figure 1 Relationship between wall-ribbon ratios (W/R) for the raw and the corresponding swollen fibers (cotton : hybrid variety DCH.32).

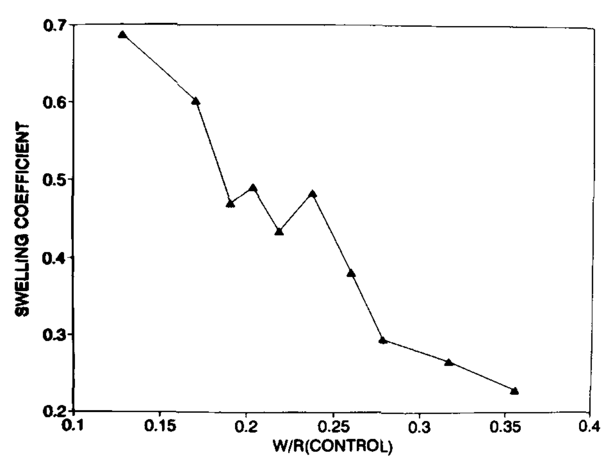

Figure 2 Dependence of swelling coefficient on the wall–ribbon ratio of the raw fibers (cotton : hybrid variety DCH.32).

variety, data are presented as group averages, each group comprising ten fibers. Since ten readings are taken for each fiber, a total of 100 values of ribbon width and wall thickness are averaged for each group. Note that in each variety the swelling coefficient decreases with increases in W/R. The difference in W/R and W'/R' for the most thin-walled fibers (first row in Table II) is nearly double that for thick-walled fibres (last row). This is made more evident in Figure 2, where swelling coefficient values of class averages are plotted against W/R for one variety (DCH.32). This figure shows that the swelling coefficient decreases with increased wall–ribbon ratio, initially very quickly and then rather slowly. Ultimately, when the wall thickness is much higher than the lumen width, the swelling coefficient approaches zero.

It would appear that when lumen size is large, considerable swelling in the cell wall can occur toward the interior, in addition to the outward swelling. With a decrease in lumen width the inward swelling becomes difficult, and at very high wall thickness there is very little room for inward swelling. Swelling now must occur more toward the periphery. At the same time, since the primary wall exerts a restrictive influence on swelling towards the periphery, the net swelling would tend to become negligible.

Effect of Swelling on Maturity

The shift of some fibers from the immature to the mature category as a result of swelling would upset maturity measurements. This is demonstrated by the data given in Table III. For raw cotton, mature fiber percentage (P_M) has been calculated for two cutoff values of W/R, namely 0.20 and 0.25. For swollen fibers, the chosen cutoff values were 0.25 and 0.30. The choice of these values was arbitrary. The increase in P_M values due to swelling has also been calculated in each case.

The above data show that the increase in P_M due to swelling is different for each variety. This increase does not seem to be related to W/R obtained for raw fibers in each sample. Maturity percentage based on measurements after swelling the fibers cannot therefore be regarded as accurate. The analysis clearly shows that even the ranking of different samples will be upset if a different cutoff value is chosen for W/R. However it is evident from the table that when W/R itself is lower than 0.25 for a variety, the increase in P_M during swelling is quite substantial. But since with increased W/R the relative change in P_M does not follow any specific pattern for the varieties, there is no exact way of predicting the apparent increase in P_M during swelling.

From the above discussion, it follows that in order to obtain the true fiber maturity, measurements should be made on unswollen fibers. These measurements, however, will be very time-consuming because variation along the length of each fiber in the raw state is much higher than that after swelling. This will necessitate observation at several places to arrive at meaningful wall–ribbon ratios.

Table II Variation of Wall–Ribbon Ratio and Swelling Coefficient during 18% NaOH Swelling

Class No.	G COT 10			MCU.5			G COT H.6		
	Control W/R	NaOH W/R	Swelling Coefficient	Control W/R	NaOH W/R	Swelling Coefficient	Control W/R	NaOH W/R	Swelling Coefficient
1	0.122	0.199	0.642	0.157	0.254	0.627	0.133	0.217	0.633
2	0.145	0.233	0.602	0.204	0.316	0.554	0.171	0.324	0.910
3	0.170	0.226	0.338	0.224	0.311	0.386	0.203	0.296	0.461
4	0.190	0.298	0.566	0.245	0.343	0.403	0.248	0.346	0.392
5	0.213	0.322	0.514	0.262	0.346	0.321	0.276	0.370	0.343
6	0.228	0.340	0.487	0.285	0.351	0.233	0.291	0.378	0.299
7	0.253	0.344	0.361	0.305	0.397	0.302	0.312	0.419	0.344
8	0.290	0.374	0.286	0.323	0.389	0.206	0.332	0.401	0.211
9	0.343	0.401	0.174	0.345	0.374	0.085	0.350	0.424	0.211
10	0.389	0.431	0.109	0.377	0.406	0.077	0.382	0.423	0.112

Class No.	G COT 11			AKH.4			DCH.32		
	Control W/R	NaOH W/R	Swelling Coefficient	Control W/R	NaOH W/R	Swelling Coefficient	Control W/R	NaOH W/R	Swelling Coefficient
1	0.130	0.242	1.052	0.200	0.287	0.460	0.128	0.208	0.686
2	0.191	0.268	0.405	0.229	0.337	0.471	0.170	0.272	0.603
3	0.209	0.286	0.369	0.241	0.333	0.383	0.190	0.280	0.471
4	0.238	0.316	0.329	0.257	0.363	0.411	0.203	0.303	0.492
5	0.258	0.306	0.185	0.277	0.343	0.238	0.218	0.313	0.435
6	0.271	0.338	0.246	0.296	0.374	0.264	0.237	0.351	0.484
7	0.288	0.361	0.254	0.312	0.398	0.274	0.259	0.358	0.383
8	0.308	0.334	0.084	0.333	0.390	0.170	0.278	0.360	0.296
9	0.334	0.398	0.193	0.359	0.427	0.191	0.317	0.400	0.267
10	0.383	0.385	0.007	0.388	0.425	0.097	0.356	0.436	0.228

Table III Relative Increase in Mature Fiber Percent During 18% NaOH Swelling

Name of Variety	(W/R)	Mature Fiber Percent for a Cutoff Value of $W/R \geqq 0.20$ Raw	Mature Fiber Percent for a Cutoff Value of $W/R \geqq 0.25$ Swollen	Increase in Mature Fiber Percent Due to Swelling No.	Increase in Mature Fiber Percent Due to Swelling %	Mature Fiber Percent for a Cutoff Value of $W/R \geqq 0.25$ Raw	Mature Fiber Percent for a Cutoff Value of $W/R \geqq 0.30$ Swollen	Increase in Mature Fiber Percent Due to Swelling No.	Increase in Mature Fiber Percent Due to Swelling %
DCH.32	0.234	68	84	16	24	37	56	19	51
G COT 10	0.238	62	71	9	15	38	57	19	50
MCU.5	0.271	79	85	6	8	62	75	13	21
G COT H.6	0.268	75	90	15	20	63	71	8	13
G COT 11	0.261	81	87	6	7	61	65	4	7
AKH.4	0.29	98	100	2	2	78	91	13	17

The swollen-fiber method, which is relatively fast, may have to be followed until a faster method is developed based on raw fibre measurements. We hope to develop such a method soon with the help of an image analysis system coupled to the microscope.

CONCLUSIONS

1. Swelling of cotton fibres in 18% NaOH causes unequal changes in wall–ribbon ratios in different varieties of cotton.
2. The percentage increase in the wall–ribbon ratio for fibers in a given variety will depend on the initial value of the wall–ribbon ratio.
3. Measurement of maturity based on swollen hair dimensions can lead to higher values of P_M when the variety contains a large number of immature fibers.

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