Convolutions in cotton fibers

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Cotton is a versatile fiber. Amongst the various natural fibers such as linen, sisal, hemp, ramie etc. cotton still holds the market value in textile manufacturing industries right from spinning to medical textiles due to its inherent physical properties like flexibility and ease of blending with other synthetic and regenerated fibers. Similarly, the versatility of the cotton fiber has been found that it excels in many consumer goods than all of the other textile fibers concerned.

Cellulose constituent in cotton fibers is around 90-95 %, purest form of cellulose and has considerable economic significance. In general, cotton fibers develop in 4 stages, viz, initiation, propagation or elongation, secondary cell wall thickening and maturation. Cotton fibers grow in length, then in thickness. The physical properties like length, fineness and cell wall structures are governed by genetics and of course it is subject to changes in weather conditions also during their growth period. During the growth period, the fiber length is established first before the cell wall thickening starts, the cell wall structure is influenced independently. Changes in the weather conditions more frequently, may result, for example, short, weak fiber or long strong fibers.

Growth of cotton fiber

The origin of the cotton fiber is a single cell which forms the outer covering of the cotton seed. The fiber develops by an expansion of the outer wall, that is, the exposed surface of the cell. The appearance of the first fiber initials appear at the broad outer end of the chalazal seed (Fig. 1). As they elongate, more fiber initials appear, and they appear more progressively nearer the tip of the seed (Fig. 2).

The growth of the fiber initials continues to appear for 3-5 days, or even longer in some varieties depending upon the adverse weather conditions may prolong the period for all cottons. Cotton fibers grow in length slowly for the first 2-5 days, then more rapidly for the next 8-10 days, and then again more slowly, until at about 16-20 days, development of fiber length ceases. However, the growth rate is determined by the cotton variety and the environment in which it grows.

In general, short staple cotton varieties grow more slowly than the long staple varieties and vice versa. However, short staple varieties reach its full length in fewer days than that of its counterpart. When the fiber first emerges from the seed, its diameter is too small – about 1 mm in diameter. There may be around 15,000-20,000 fibers on a seed. At maturity stage, the average fiber diameter is much greater than that of the initial stage when it first emerges. Cotton fibers resemble a club shape – in other words, they increase in diameter for some distance, then reaches the maximum after which no changes occur, and then gradually tapers relatively to a small tip. Fiber initiation begins during flowering and fibers arise from the epidermal cells on the ovule surface; days after flowering are referred to as days post anthesis (dpa). Fiber elongation begins on the day of flowering by spherical expansion above the ovular surface and continues with primary cell wall deposition for 20-25 days, until reaching final fiber lengths of 22-35 mm. Secondary cell wall synthesis begins around 15-22 dpa and continues for 30-40 days. Fiber maturation is evident by a twisted ribbon-like structure beginning 45-60 dpa. While cells are growing, cellulose is synthesized by the condensation of glucose molecules at enzyme complexes, each of which generates 36 cellulose molecules; these lie in the same direction and crystallize into long microfibrils. The cotton boll starts to open and fibers become flattened and twisted. After dehydration, the cross-section of cotton fibers is kidney bean shaped, however the shape is near circular in fully developed, thick-walled, mature fibers and curled in thin-walled, immature fibers.

Convolutions or crimps in cotton fibers

The development of convolutions in cotton fibers occurs during the collapse of the fiber as it dries. In 1951 Meredith has defined convolution as twist of the fibers through 180° about its axis [3]. When we look at the longitudinal image of a convoluted fiber it looks like a twisted fiber with a series of bobbin-like segments. The shape of the bobbin-like segments reflects how much the fiber is convoluted. In image processing method, the bobbin-like segment was bordered by 2 neighboring convolutions. Hence, according to the definition, convoluted fiber is defined by a chain of convoluted segments. In the modern-day image processing technique, convolutions are characterized by the convolutions

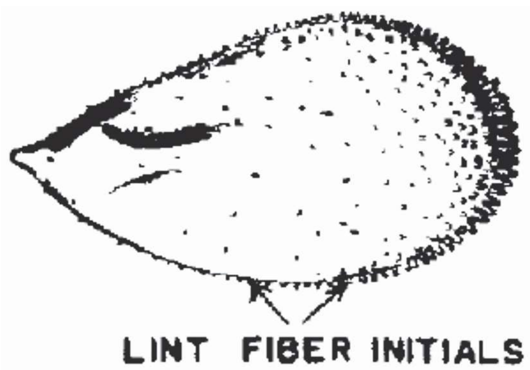

Fig. 1
Fiber initials

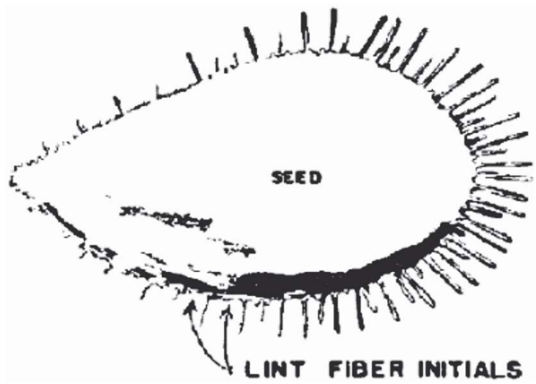

Fig. 2
Fiber initials after 2 days

per mm, size and shape of each individual convolution segment. The number of convolution segments per mm, average width, and the shape factor of each segment were derived from the area, perimeter and length as:

N = 1000/La

Wa = A/L

Fs = P2/(4πA)

where, N: number of convolution segments/mm

La: average length of convolution segments in a fiber (μm)

Wa: average width of a convolution segment (μm)

A: area of a convolution segment (μm^2)

L: length of a convolution segment (μm)

Fs: shape factor

P: perimeter of a convolution segment (μm)

The shape factor (Fs) indicates the elongation of a convolution segment. It varies from minimal and equal to 1 for a circle. It has a non-linear negative relationship with convolution angle. In other words, the larger the shape factor smaller the convolution angle. The maximum width (Wm) of a convoluted segment can be calculated as Wm = 4A/πL, assuming that the convoluted segment as an ellipse.

Growth analysis of cotton fiber states that around 50-80 % of the mature bundle fiber strength is determined in 15-20 days and also in 25-30 days after the post anthesis period. It means that a major portion of the fiber strength is attributed to the early development of the secondary cell growth. It is also found that the convolutions of cotton fibers are known to affect the fiber strength. Meredith has found the true spiral angle by eliminating the effect of convolution angle by subtracting the convolution angle from the optical spiral angle and arrived at a constant value of 22° for undried cotton which is irrespective of any genetic variety. However, the fibrils in the cotton fiber are not parallel to the fiber axis but spiral around the fiber as a coiled helix. Spiral angle measured by refractive measurements is affected by fiber convolutions and if a suitable correction factor is arrived, the true spiral angle can be found out.

Spiral angle of some few cotton varieties such as American upland, Egyptian and Indian cotton varieties showed that the spiral angle of cotton fibers is 21.7 ± 0.25°.

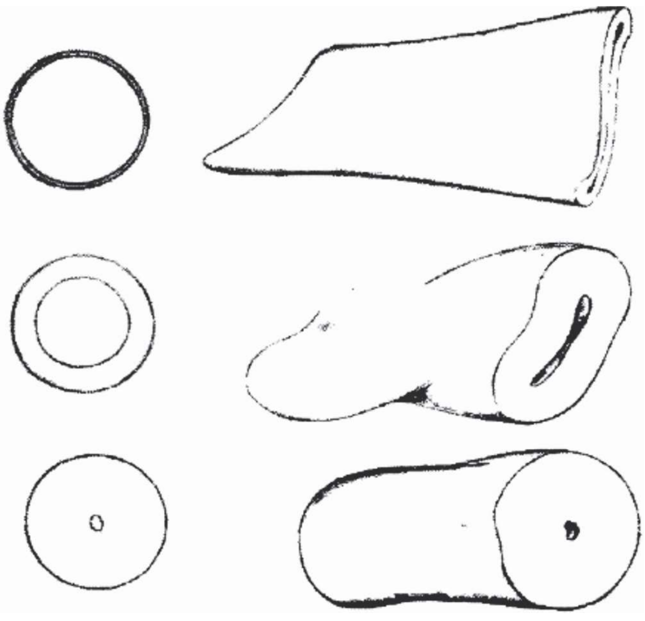

Fig. 3
Cotton fiber before, during and after drying

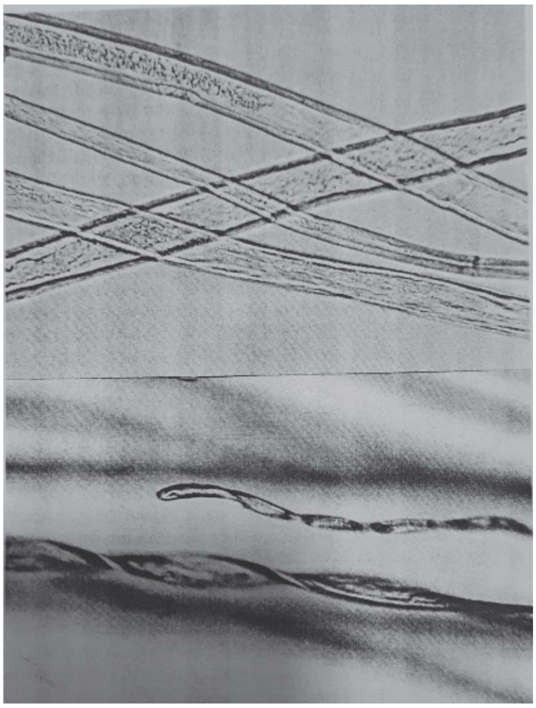

Fig. 4
Fully hydrated cotton fibers (top) and dried cotton fibers (bottom)

Impact of convolutions on cotton fiber strength

Environmental factors, growth conditions, degree of cell wall thickening have profound influence on the fiber strength. The convolution interval and the number of convolutions/mm are dependent upon several factors, the one being the degree of cell wall thickening. It is found that some varieties of cotton have been found to have more convolutions than others, and very thick-walled fibers and very thin walled fibers are devoid of these natural convolutions. Very thick-walled fibers would convolute little since they do not collapse. Similarly, very thin-walled fibers such as with primary wall and with few layers of secondary wall thickening do not convolute until it is swollen in caustic solution. The greatest number of convolutions occurs with wall of intermediate thickness.

Fig. 3 shows a cotton fiber before, during and after drying. Convolutions can be seen in the middle.

All cells which have spiral structure would twist upon drying if separated one from another. Most of the plant cells spiral in one direction only. However, cotton fiber cells differ from other plant cells by twisting in one direction in one part of the fiber and in the opposite direction in another segment, that is, the convolutions reverse at the spiral reversals.

Conclusions

Although there is a tremendous growth of synthetic fibers in the world, cotton still holds around 60-70 % of the world fiber production market. Undoubtedly, it is one of the versatile fibers used in all commercial applications way back to its antiquity, its properties and characteristics are still not completely known. Microscopes and image analyzers have been developed which clearly reveal the internal structure and their relationship with the other fiber properties.

References

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