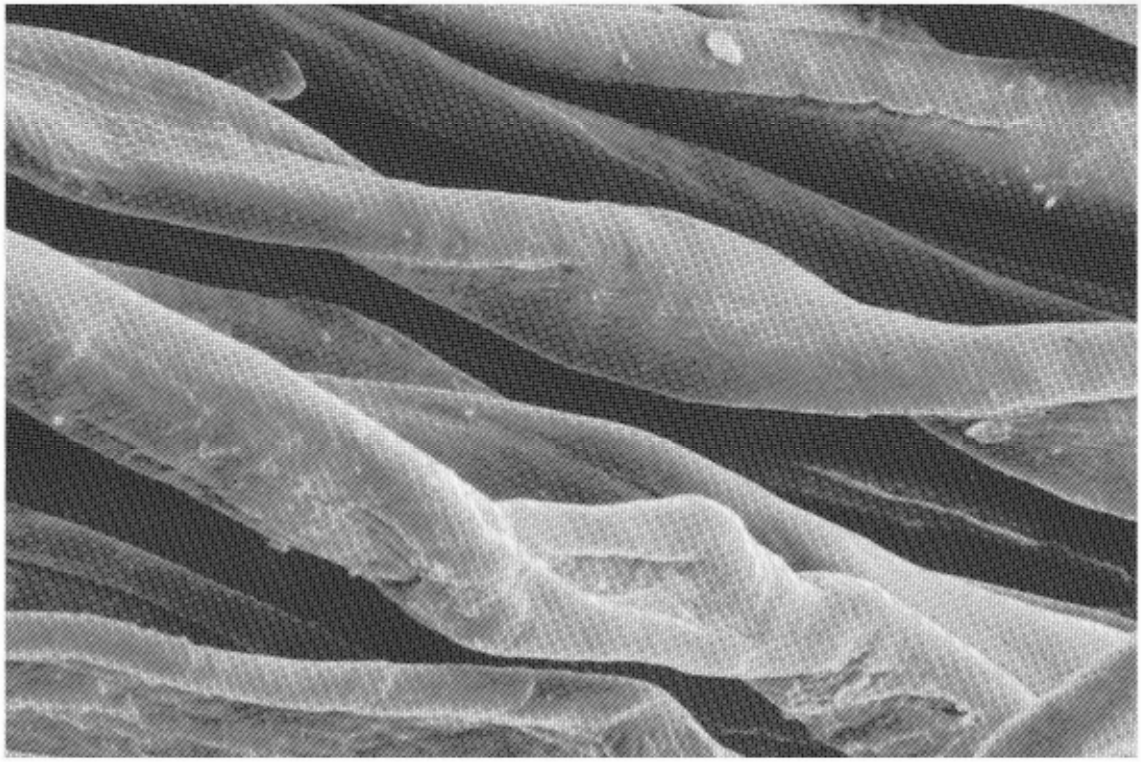
The meaning and assessment of cotton fibre fineness

by H.H. RAMEY Jr.



Technical Research Division

INTERNATIONAL INSTITUTE FOR COTTON

THE MEANING AND ASSESSMENT OF COTTON FIBRE FINENESS

H.H. Ramey, Jr.

Southern Regional Research Center
U.S. Department of Agriculture

This is a revised edition of the booklet published in 1982. Dr Ramey's revised text was received at the IIC shortly before it closed down and, therefore was never published. Only recently (2018) has Dr Ramey's new text been worked up into this document. IIC had already published an extended and revised edition of the companion booklet entitled "The Origin and Assessment of Cotton Fibre Maturity." The reader is strongly advised to consult the maturity booklet because of the considerable interrelationship between these two important fibre properties.

1. Physical Meaning of Fibre Fineness

The term "fibre fineness" can be defined in various ways. Lord (15) lists five measures that may be used: perimeter, diameter, area of cross-section, mass per unit length and specific fibre surface. Some of these measures are interrelated while others introduce other parameters such as maturity and density of the fibre substance.

For most practical purposes it is necessary to consider only two definitions, *Gravimetric Fineness* and *Biological Fineness*.

Gravimetric fineness can be expressed as the mass per unit length of a fibre. The traditional units for *linear density* or mass per unit length of cotton fibres have been micrograms per inch in the USA and micrograms per centimetre in Europe. More recently the tex system has been adopted for linear density of fibres and yarns. *Tex* is grams per kilometre or milligrams per metre. The linear density of fibres is usually expressed as *millitex* or micrograms per metre.

Biological fineness is defined either as the perimeter of the cross-section of the fibre or the diameter of the equivalent circle, i.e. the circle having the same perimeter as that of the cross-section of the fibre. The perimeter is of course π times the diameter. Gravimetric fineness can be related to biological fineness if the wall thickness or maturity of the fibre is known (see later). A range of linear densities is given in Table 1.

Although the variation is more than twofold, it is within that encountered among the various cottons, from the Egyptian to the Asiatic types. In order to see how variations of this magnitude can occur, an understanding of the stages of the development of the cotton fibre is helpful.

Table 1

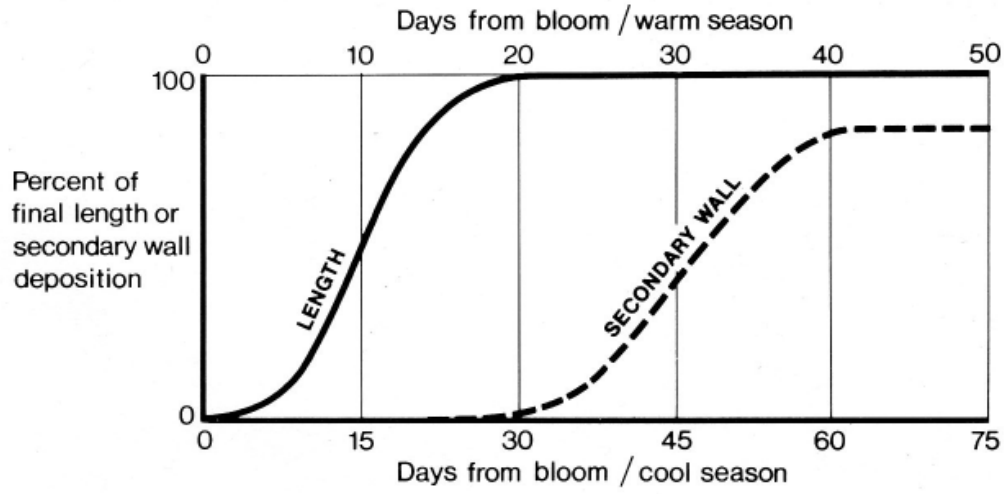
Linear density and the total length of the fibres in a standard 218 kg bale of cotton.

Micrograms per inch	Millitex µg/m	Metres of fibre per bale (x 10^9)
3.0	118	1.85
3.5	138	1.58
3.8	150	1.45
4.0	158	1.38
4.3	170	1.28
4.5	177	1.23
5.0	197	1.11
5.5	217	1.00
6.0	236	0.92
6.5	256	0.85

A cotton fibre is a biological product. The limits of its development are set by the genetic constitution (genotype) of the variety grown but growing conditions determine whether that limit is realised.

Cotton fibres are borne on seeds within capsules or bolls. A cotton fibre is a tubular outgrowth of a single cell on the surface of a seed (2, 34). On the day the flower opens (anthesis), the fibres begin to elongate in the form of hollow tubes. They grow in length for 15 to 25 days postanthesis (Figure 1).

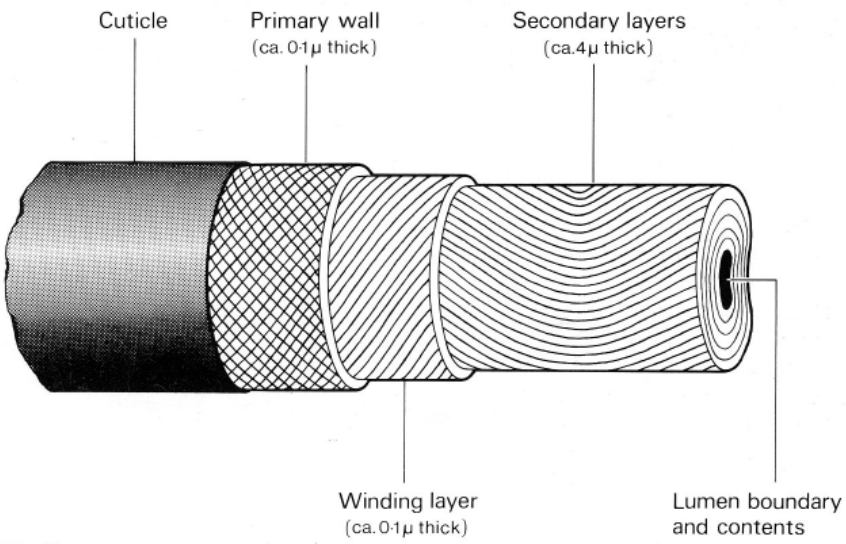
Figure 1



The ultimate length may be as much as 3,000 times the diameter. During the elongation phase, the cell consists of a primary wall filled with a semifluid, semi-transparent substance (protoplasm). As the elongation ceases, secondary wall formation begins (28, 32) and continues for an additional 20 or more days. The actual time required for elongation and for secondary wall deposition to occur depends on the variety and growth conditions (5, 6, 7, 8, 10). The elongation and secondary wall deposition take a longer time in Egyptian varieties than in upland varieties. Both phases will occur in a shorter time period in a warm season than in a cool season. The upper time axis label in Figure 1 is for a warmer area such as Jackson, Tennessee. In an area having cooler temperatures, such as Lubbock, Texas, the pattern of development will be the same but the number of days postanthesis to reach each development step will be greater, as shown by the lower time axis label in Figure 1, with 70 or more days postanthesis being required to complete boll development.

Biological maturation occurs during the final few days depicted in Figure 1, although secondary wall deposition never proceeds to the point where the entire tube is completely filled. There is always a central canal or lumen left in the centre of the fibre. A schematic diagram of a cotton fibre is shown in Figure 2.

Figure 2

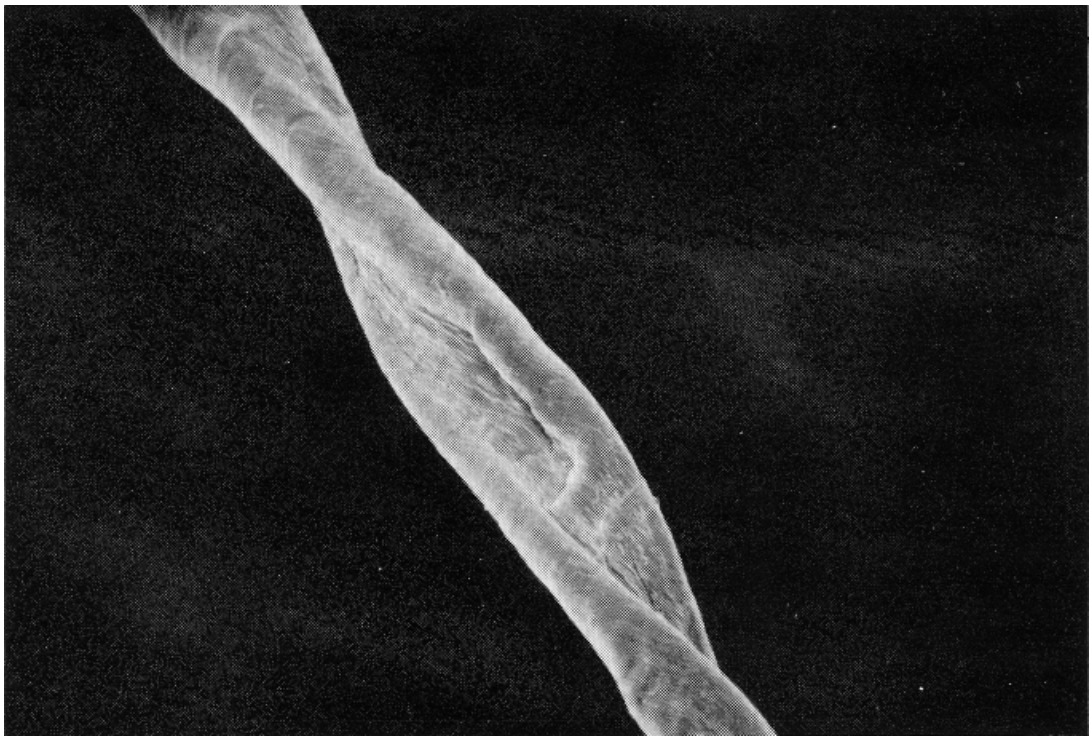


During the final phase of maturation, certain physiological events occur which lead to boll opening. A major event is the sealing-off of the boll from the transpiration stream of the plant and the subsequent opening and drying-out of the boll and its contents. In the initial dehydration, the cotton fibre collapses from the circular cross-section to one of flat, bean or horseshoe shape (Figure 3), depending upon the thickness of the fibre wall. The final cross-sectional shape is rarely circular. If it is, it usually indicates microbial damage (18).

Figure 3

Convolutions are formed along the length of the fibre during the collapse. The final result is the characteristic complex shape (Figure 4). This general description of cotton fibre cell elongation and maturation provides an understanding of how the two major concepts of fineness arise.

Figure 4



The perimeter or diameter of the fibre are measures of the biological fineness and each variety produces fibre having a typical perimeter (26). However, the perimeter can be affected to a small extent by the cultural conditions under which the cotton is grown (25) and also by the magnitude of the secondary wall development of the fibre. This latter effect may be due to the influence which wall thickness has on the collapse of the fibre during the initial drying. Within a given variety, fibres which have the least amount of secondary wall development appear to have the smallest perimeters (4).

The interrelation between gravimetric fineness and biological fineness on the stresses generated during the initial collapse of the fibre also influences the frequency of the convolutions produced. Indeed, for many varieties, there is a close relationship between the gravimetric fineness and the spiral angle of the convolution (4).

Typical fibre diameters, for a range of cotton types, both during fibre elongation (8 to 16 days postanthesis) and after drying, are given in Table 2 (23, 24). The shrinkage in diameter of the cross-section in the initial drying is from 32 to 42 percent (4, 23, 24). The shrinkage is not constant; the diameter of the elongating fibre influences the diameter of the dried fibre.

The primary wall is approximately 0.1 µm thick. The cross-sectional area of the primary wall and, thus, the mass, will vary with the cell diameter. For a fibre 16 µm in diameter, the cross-sectional area of the primary wall will be 5 μm^2. The gravimetric fineness of this fibre, assuming a density of 1.52 g/cm^3, will be 7.6 millitex. With only primary wall and no secondary wall, fibres which range from the smallest to largest diameter listed above will vary from 5.4 to 9.0 millitex or 0.14 to 0.23 ug/in. Clearly, the mass of the primary wall will vary with the diameter of the cell.

Table 2

Typical Fibre Diameters, µm

Cotton type	during elongation	after drying
Egyptian, American Pima and Sea Island	17 to 20	11.5 to 13.0
Long staple upland	21 to 23	13.0 to 14.7
Medium staple upland	23 to 26	14.2 to 16.8
Short staple upland (coarse)	28 to 29	17.5 to 19.0

The second factor in the biological development of the fibre that influences gravimetric fineness is the extent of the deposition of the secondary wall. Beginning as the cell elongation ceases, the secondary wall is laid down inside the primary wall but outside the protoplasm. Growth conditions affect the amount of secondary wall laid down (5, 6, 10). Drought or cool temperatures, including early frost will slow down cell wall deposition. Higher than average temperatures can cause thicker cell walls. The usual range in cell wall thickness is from 1.8 to 4.0 µm, but this will be influenced by the diameter of the cell.

Tables 3 and 4 illustrate the effect of wall thickness and cell diameter on gravimetric fineness of an idealised cotton fibre, assuming the density of the cell wall material to be 1.52 g/cm^3.

Table 3

Fineness in Millitex of Cotton Fibres

Wall thickness µm	Cell diameter, µm			
	12	14	16	18
0.1	5.7	6.6	7.6	8.5
0.5	27.5	32.2	37.0	41.8
1.0	52.5	62.1	71.6	81.2
1.5	75.2	89.5	103.9	118.2
1.8	87.7	104.9	122.0	139.2
2.0	95.5	114.6	133.7	152.8
2.3	107.7	130.0	152.3	174.5
2.7	118.9	144.3	169.8	195.3
3.0	128.9	157.6	186.2	214.9
3.5	142.1	175.5	208.9	242.3
4.0	152.8	191.0	229.2	267.4
4.5	161.2	204.1	247.1	290.1
5.0	167.1	214.9	262.6	310.4

The 0.1 µm wall thickness is primary wall only and is included to illustrate the small

contribution to mass per unit length that this important structural component makes. Wall thicknesses of 4.5 and 5.0 µm will be encountered only rarely in 18 µm diameter fibres and almost never in fibres having smaller diameters. Among the four cell-diameter groups, fibres can be found which have practically the same gravimetric fineness but widely differing wall thicknesses. For example, a gravimetric fineness of 152 to 157 millitex can be found together with a wall thickness of 2.0 to 4.0 µm. Conversely, for a given wall thickness, the gravimetric fineness varies substantially between the four diameter groups.

Table 4

Fineness in Micrograms per inch of Cotton Fibres

	Cell diameter, µm			
Wall thickness µm	**12**	**14**	**16**	**18**
0.1	0.14	0.17	0.19	0.22
0.5	0.70	0.82	0.94	1.06
1.0	1.33	1.58	1.82	2.06
1.5	1.91	2.27	2.64	3.00
1.8	2.23	2.66	3.10	3.53
2.0	2.42	2.91	3.39	3.88
2.3	2.73	3.30	3.86	4.33
2.7	3.02	3.66	4.31	4.96
3.0	3.27	4.00	4.73	5.45
3.5	3.61	4.45	5.30	6.15
4.0	3.88	4.85	5.82	6.79
4.5	4.09	5.18	6.27	7.36
5.0	4.24	5.45	6.67	7.88

2. Technological Importance of Fibre Fineness

Fibre fineness is an important factor in determining the stiffness of a fabric or, conversely, its softness of handle and its draping quality. For example, coarse Peruvian Tanguis cotton is often selected by knitters to give "bulky" characteristics to their fabrics. Fineness also plays an important part in determining the ease with which fibres can be twisted together during yarn formation (21).

The finer the fibres incorporated in a fabric, the greater is the number of individual reflecting surfaces per unit area of that fabric. Thus, fibre fineness has an influence on yarn and fabric lustre. Also, other things being equal, the finer the fibre, the lighter is the apparent shade of a dyed fabric, for a given concentration of dyestuff. Since the rate at which dyes are absorbed into a fibre is dependent on how much surface is accessible to the dye liquor for a given volume of the fibre substance, it follows that the time required to exhaust a dye bath is shorter for fine fibres than for coarse fibres.

It should also be noted that nep formation becomes more frequent and more detrimental in its

consequences with the spinning of fine yarns from fine fibres. Neps are more noticeable in fine yarns because their size becomes comparable to that of the yarn diameter.

More importantly for the spinner, the strength and uniformity of a yarn is very largely determined by the average number of fibres in the cross-section. For a given yarn count, the finer the fibres, the more uniform is the yarn. Improved yarn uniformity not only improves yarn appearance but also introduces other important consequences including greater strength, extensibility, and lustre; fewer end breakages in spinning, winding, warping and weaving; greater resistance to surface abrasion.

Linear density is important, therefore, in determining the finest yarn that can be spun before the irregularity becomes so great that neither acceptable strength nor reasonable end-breakage rates can be maintained. A minimum number of fibres is required in the yarn cross-section for satisfactory performance. This minimum number varies with staple length. For medium staple cotton, about 80 fibres per cross-section are required in ring spun yarn and about 110 in open end spun yarn.

Table 5 shows the finest yarns that can be spun satisfactorily from fibres of specific linear densities in tex and cotton count, on ring and open-end equipment assuming that the minimum number of fibres required per yarn cross section is 80 for ring and 110 for open-end spun yarns. In a particular factory, the actual minimum number of fibres in the yarn cross-section may be more or fewer than these, depending on the type and condition of the preparation and the spinning machinery. Longer staple cotton fibres can be spun into yarns finer than these. Combed cotton can be spun out finer than only-carded material.

Table 5

Theoretical Number of Fibres in the Yarn Cross-section

Millitex	Ring spun		Open-end spun	
	tex	**cotton count**	**tex**	**cotton count**
118	9.4	63	13.0	45
138	11.0	54	15.2	39
150	12.0	50	16.5	36
158	12.6	47	17.4	34
170	13.6	43	18.7	32
177	14.2	41	19.5	30
197	15.8	37	21.7	27
217	17.4	34	23.9	24
236	18.8	32	26.0	22
256	20.5	29	28.2	21

These considerations assume a much greater importance as the amount of yarn produced on rotor spinning systems increases and as machinery manufacturers and spinners work towards the production of ever finer rotor spun yarns. To achieve this objective, finer cotton fibres are

required but these fibres also need to be mature in order to avoid subsequent dyeing problems. Regrettably, these requirements are sometimes expressed in terms which reflect the confusion which can be caused by the use of the Micronaire test. For example, calls have been made for "low Micronaire reading but mature" fibres. The difficulties which arise from this description can be illustrated in the following example.

Most US cotton has a biological fineness of 15-18 μm (see Table 2). A maturity ratio of greater than 0.9 is considered mature and hence mature fibres would be found with a gravimetric fineness of 140 - 220 millitex (see Figure 5). From this same figure, it can be seen that the lowest Micronaire value that can be achieved within these parameters is about 3.5, corresponding to a biological fineness of 15 μm and a maturity ratio of 0.9.

Considering that 15 μm is the practical lower limit of biological fineness in American upland cotton, a "low Micronaire value, mature" cotton is scarcely possible. For any maturity ratio greater than 0.9 and any biological fineness greater than 15 μm, the Micronaire reading will be greater than 3.5.

3. Interrelationship of Fineness, Maturity and Surface Area

As mentioned previously, gravimetric and biological fineness can be related if the maturity of the fibre is known. A knowledge of the wall thickness alone does not provide a measure of the extent to which the secondary wall fills the space inside the primary wall because the proportion filled by a given wall thickness depend upon the diameter of the fibre.

In order to provide a measure of this proportion that is independent of cell diameter, the ratio θ was introduced (27). It is defined as:

$$\textit{Degree of thickening} = \theta = \textit{(area of cell wall) / (area of circle having same perimeter)}$$

The effect of cell diameter and cell wall thickness on θ is given in Table 6. The values of θ usually encountered range from about 0.4 to about 0.75. It is interesting to examine two cases in Table 6 where θ is constant for different cell diameters (θ = 0.556 and 0.75). In both cases, millitex fineness (taken from Table 3) increases by the same proportion (2.25 times) as the cell diameter increases from 12 to 18 μm.

The maturity ratio obtained from the sodium hydroxide swelling test provides an estimate of θ (27). The relationship is:

$$\theta = 0.577M$$ where M is the maturity ratio.

The effect of cell diameter and cell wall thickness on maturity ratio is given in Table 7. For example, if the maturity ratio is 1.0 and the cell wall diameter is 16 μm, the wall thickness will be about 2.8 μm and the gravimetric fineness (from Table 2) about 176 millitex.

These relationships are illustrated in Figure 5. Biological fineness can also be determined from this graph since it is related to the diameter and therefore surface area of the fibre.

Table 6

The Ratio, θ, of the Area of Cotton Fibre Cell Wall to the Area of a Circle Having the Same Perimeter

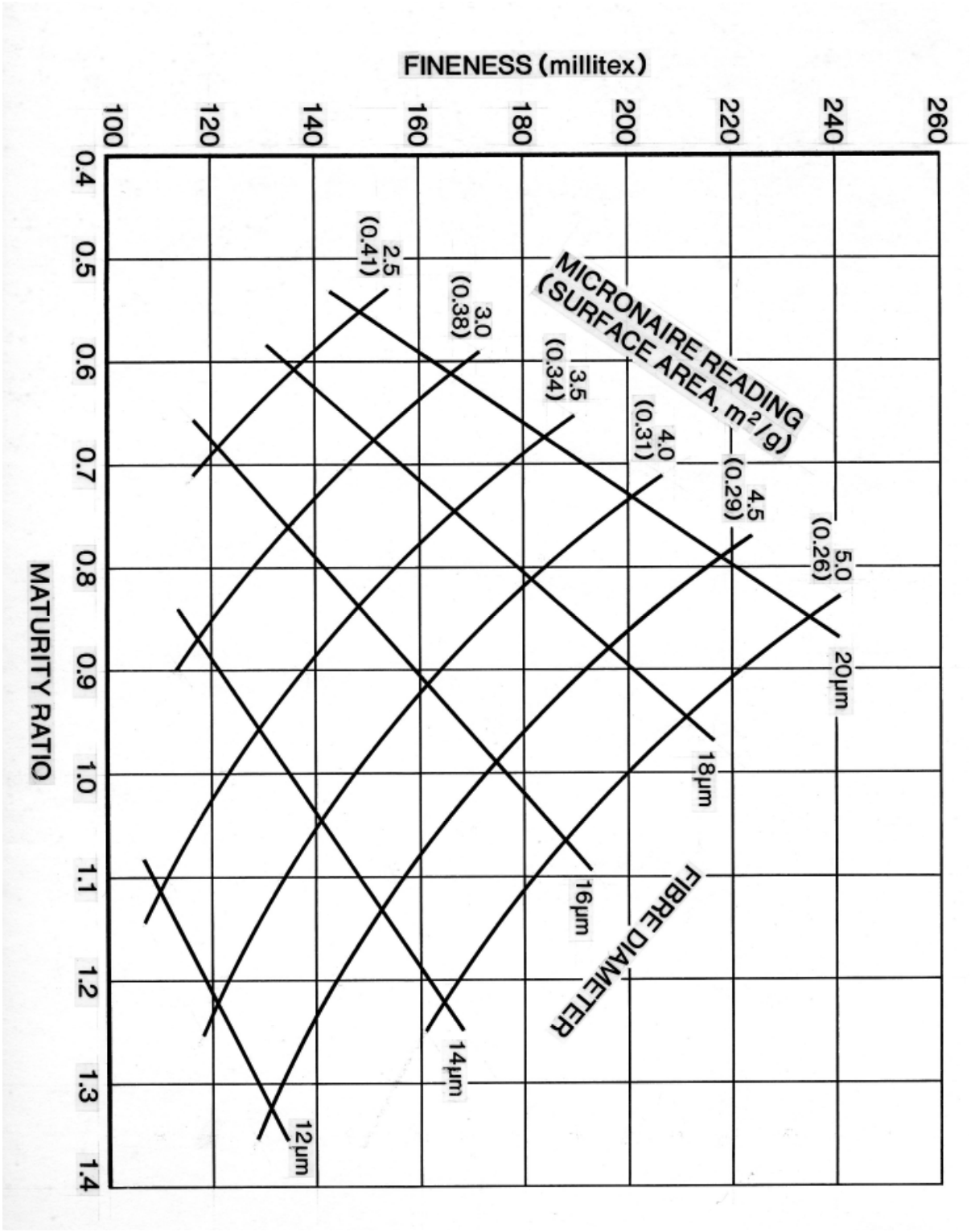
	Cell diameter, µm			
Wall thickness µm	**12**	**14**	**16**	**18**
0.1	0.0331	0.0284	0.0248	0.0221
0.5	0.1597	0.1378	0.1211	0.1080
1.0	0.3056	0.2653	0.2344	0.2099
1.5	0.4375	0.3827	0.3398	0.3056
1.8	0.5100	0.4482	0.3994	0.3600
2.0	0.5556	0.4898	0.4375	0.3951
2.3	0.6265	0.5555	0.4982	0.4512
2.7	0.6914	0.6168	0.5556	0.5049
3.0	0.7500	0.6735	0.6094	0.5556
3.5	0.8264	0.7500	0.6834	0.6265
4.0	0.8889	0.8163	0.7500	0.6914
4.5	0.9375	0.8724	0.8086	0.7500
5.0	0.9722	0.9184	0.8594	0.8025

Table 7

Maturity ratio of cotton fibres. The maturity ratio is θ / 0.577

	Cell diameter, µm			
Wall thickness µm	**12**	**14**	**16**	**18**
0.1	0.057	0.049	0.043	0.038
0.5	0.277	0.239	0.210	0.187
1.0	0.530	0.460	0.406	0.364
1.5	0.758	0.663	0.589	0.530
1.8	0.884	0.777	0.692	0.624
2.0	0.963	0.849	0.758	0.685
2.3	1.086	0.963	0.863	0.782
2.7	1.198	1.069	0.963	0.875
3.0	1.300	1.167	1.056	0.963
3.5	1.432	1.300	1.184	1.086
4.0	1.541	1.415	1.300	1.198
4.5	1.625	1.512	1.401	1.300
5.0	1.685	1.592	1.489	1.391

Figure 5: Millitex versus Maturity Ratio for Cell Diameters from 10 to 20 µm



Surface area can be expressed either as area per unit volume or as area per unit mass (35) (Tables 8 and 9). The former definition is usually called the specific surface area and can be estimated directly with an instrument of the airflow type. Surface area per unit mass requires a separate estimate of the mass per unit volume of the fibre. The mass per unit volume can be measured independently or a typical value can be used. For cotton fibres the variation in mass per unit volume is from about 1.50 to 1.56 g/cm^3 and, therefore, using a value of 1.52 g/cm^3 would introduce no more than a 3% error in the calculation of surface area per unit mass. These figures refer to the substance of the wall of the fibre; the overall density of fibre including lumen is about 1.35 g/cm^3 (21).

The 176 millitex fibre described above would have a surface area of about 0.286 m^2/g, a specific surface area of 434 mm^2/mm^3 and a Micronaire reading of 4.6.

Figure 5 also shows how the Micronaire value is related to both the fibre fineness and maturity and illustrates clearly the comment made previously; that to achieve "low Micronaire value, mature" cottons, it is necessary to work with cultivars having cell diameters of less than 15 µm.

Table 8

Fibre Surface Area per Volume (mm^2/mm^3 or mm^{-1}) of Cotton Fibres

	Cell diameter, µm			
Wall thickness µm	**12**	**14**	**16**	**18**
0.1	10084	10072	10063	10056
0.5	2087	2074	2065	2057
1.0	1091	1079	1067	1059
1.5	762	747	736	727
1.8	654	638	626	617
2.0	600	583	571	562
2.3	532	514	502	492
2.7	482	463	450	440
3.0	444	424	410	400
3.5	403	381	366	355
4.0	375	350	333	323
4.5	356	327	309	296
5.0	343	311	291	277

Table 9

Fibre Surface Area per Mass (m^2/g) of cotton fibres
(cell-wall density is assumed to be 1.52g/cm^3)

	Cell diameter, µm			
Wall thickness µm	**12**	**14**	**16**	**18**
0.1	6.634	6.626	6.620	6.616
0.5	1.373	1.365	1.358	1.353
1.0	0.718	0.709	0.702	0.697
1.5	0.501	0.491	0.484	0.478
1.8	0.430	0.419	0.412	0.406
2.0	0.395	0.384	0.376	0.370
2.3	0.350	0.338	0.330	0.324
2.7	0.317	0.305	0.296	0.290
3.0	0.292	0.279	0.270	0.263
3.5	0.265	0.251	0.241	0.233
4.0	0.236	0.230	0.219	0.211
4.5	0.234	0.215	0.203	0.195
5.0	0.226	0.205	0.191	0.182

4. Measurement of Fineness

Direct measurement of gravimetric fineness

The measurement of mass per unit length is simple and straightforward. A small sample of fibres, say 300, can be weighted individually and the length of each determined.

Gravimetric fineness is then calculated as $\Sigma W / \Sigma L$

where W is the weight of an individual fibre

and L is the corresponding length

Because the mass of each fibre is small, the error associated with weighing each fibre individually is great relative to its mass and hence this procedure is of doubtful accuracy. Other methods have been developed to overcome the difficulties of weighing individual fibres and to reduce the time required for each determination.

The USA procedure (ASTM Method D1769) involves the use of fibres previously sorted for length measurement by the array method (ASTM Method D1440). Tufts of 75 or more fibres are taken from each length class except for the two shortest ones. The tufts so taken are weighed and the number of fibres in each tuft counted. Since the length of each tuft is known from sorting, the gravimetric fineness of the sample can be calculated as

$$\text{Sample gravimetric fineness} = \Sigma M / \Sigma(LMN/W)$$

and the gravimetric fineness of each length group can be calculated as

$$\text{Length group gravimetric fineness} = W / NL$$

where M is the mass of the length group,
L is the length of the length group,
N is the number of fibres counted,
W is the mass of fibres counted.

This procedure provides a measure of the average gravimetric fineness of the sample or of the length group.

The cotton fibre is tapered at the ends; more so at the end away from the seed coat. The tapered extremity may have less secondary wall deposition and thus be more readily damaged or broken during ginning and subsequent processing into yarn. For this and other reasons, the practice in Great Britain and many other countries is to measure gravimetric fineness on only the centre portions of the fibres (27). The procedure involves parallelising a bundle of fibres clamped at one end by combing; cutting a set length, say 1 cm, from the centre of the bundle; weighing the cut length bundle and counting the number of fibres.

$$\text{Gravimetric fineness} = W / NL$$

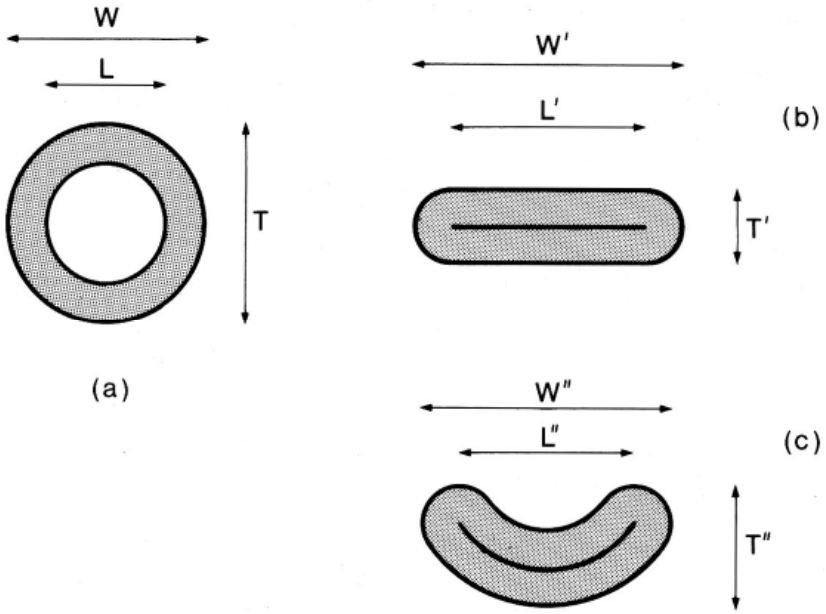
where W is the weight of cut bundle of fibre,
N is the number of fibres in cut bundle,
L is the length of fibre bundle.

These direct methods of measuring gravimetric fineness are useful for research purposes but they are too slow for use as practical measures for monitoring cotton quality and, as previously discussed, are of limited usefulness unless a measure of the biological fineness of the fibres is available.

Direct measurement of biological fineness

Measurement of the width of a cotton fibre can be used to provide an estimate of the diameter. A tuft of fibres is placed on a microscope slide and the dimensions at the widest and narrowest points of a convolution near the centre of each fibre are measured by means of an ocular micrometer or by micro-projection. The two measurements are averaged to obtain an estimate of the diameter.

Figure 6 Diagrams of Idealised Fibre Cross-sections



Errors of measurement occur because of the complex shape of the cotton fibre (15) (Figure 6). When the cross-sectional shape is a circular tube (Figure 6a), the width (W) and thickness (T) are equal and are equal to the diameter. If the fibre collapses into a flat ribbon (Figure 6b), the width (W') and the thickness (T') are unequal. Even when measured exactly, (W' + T') / 2 underestimates the diameter. The underestimate depends on the wall thickness and may be as great as 15 percent.

If the fibre collapses into a bean-shaped cross section (Figure 6c), the width (W'') and thickness (T'') are again unequal. (W'' + T'') / 2 underestimates the diameter but the underestimate is not as much as when the cross-sectional shape is a flat ribbon. In most cases, therefore, this method of measurement underestimates the biological fineness.

Another technique for obtaining diameter involves measuring fibre width and lumen width (33). In a circular cross-section (Figure 6a) W is the diameter of the fibre and L is the diameter of the lumen. When the fibre collapses upon drying into a flat ribbon (Figure 6b), the fibre width increases to W' and the lumen width increases to L'.

$$\text{In complete collapse} \qquad L' = \pi L/2 \qquad \text{and} \qquad W' = W - L + \pi L/2.$$

$$\text{Therefore } W = W' + L - L'.$$

Tufts of fibre must be carefully prepared and mounted in a minimal quantity of a clearing & mounting medium for the fibre and lumen widths to be determined. The clearing & mounting medium must clear the fibre sufficiently for the lumen to be visualized but must not distort the fibre dimensions by swelling. Also, the medium should allow for a flattening of the non-flat

cross-sectional shapes. If the cross-sectional shape remains other than flat, the widths measured will be underestimates (compare Figures 6b and 6c). Although this has the potential for accurately determining biological fineness, the amount of error associated with it has not been assessed.

The cross-sectional characteristics of cotton fibres can be measured directly from fibre cross-sections. A bundle of fibres is suitably embedded and sectioned. The cross-section is projected on to a surface or a photo-micrograph is made. The image is measured for cross-sectional area and perimeter using a planimeter and map measuring device (ASTM method D1444). Alternatively, the image can be measured with a data digitizer (11). Techniques have been developed for the use of an image analyser to obtain cross- sectional area (3, 9).

In all cases care has to be taken to avoid errors which arise from measuring outside rather than on the edge of the image (27).

Recently workers at the University of Leuven have carried out very detailed studies on the dimensions of never-dried cotton fibres (25). They have developed suitable embedding techniques and have confirmed the circularity of the fibre cross-sectional shape. Thus, a good estimate of biological fineness can be obtained from a relatively small number of measurements.

They recognize that tests made on dried fibres will always be of importance to technologists and traders but suggest that breeders and growers can derive further useful information from measurement on never-dried fibres, especially since the techniques are relatively simple.

Indirect measurement

In order to provide an estimate of fineness which can be obtained rapidly for monitoring fibre quality, various indirect measures have been developed (1). The more important of these are based on the air permeability of a test specimen of specified mass held in a test chamber of specified dimensions (13). From the basic theory of fluid flow, it can be shown that the parameter measured is the fibre surface area (14).

Micronaire

The Micronaire is the most widely used instrumental test. Several different instruments are used that differ in the chamber dimensions and the specimen mass required. Results from the various instruments are given in Micronaire scale units. The Micronaire scale was originally calibrated by using the measured linear density of a group of test cottons. The instrument readings were assumed to indicate gravimetric fineness in µg/in. Experience with the instrument on a broader range of samples has shown that its scale does not represent gravimetric fineness. Fibre surface is the property measured by the instrument. The relationship between the Micronaire scale and fibre surface area per unit volume, mm^2/mm^3, was shown to be (36):

$$A(mm^2/mm^3) = 1904.8 + 169.32\ mic - 1047.4\ mic^{0.5}$$

where mic = Micronaire scale reading.

The Micronaire test is relatively insensitive to specimen preparation techniques and to modest

changes in atmospheric conditions. When the range of samples being tested all have the same biological fineness (perimeter of cross-section), the Micronaire reading reflects differences in wall thickness or maturity. Because of the relative insensitivity to test conditions the Micronaire is a useful test for assessing maturity (and thereby gravimetric fineness) when it is known that the samples do not vary appreciably in biological fineness; for example, in samples from the San Joaquin Valley of California. However, when the biological fineness among the samples being tested is variable, Micronaire readings are misleading (14). For example, within the dimensions in Tables 3 and 8, a surface area of 400 mm^2/mm^3 could be obtained from fibres ranging in gravimetric fineness from 140 to 215 millitex.

Dual compression instruments

Because cotton fibres vary in biological fineness and in maturity, a single airflow measurement cannot provide sufficient information for adequate estimation of both properties (16, 17). Compression of fibres in the test chamber affects the airflow and thus the indication of fibre surface area (12, 22). A higher compression causes an apparent increase in the fibre surface area. The difference between the air permeabilities at two different compressions has been shown to be related to fibre maturity or more specifically to $1/\theta$.

The IIC-Shirley Fineness & Maturity Tester (FMT) operates on the dual compression principle. The instrument registers pressure drops across the specimen under two defined conditions of airflow and sample density (16). Use of the readings in the following empirically established equations permits the estimation of maturity and fineness.

$$\text{Maturity ratio} \qquad MAT = 0.247(P_L)^{0.125} \cdot (P_L/P_H)^2$$

$$\text{Fineness, (millitex)} \qquad FIN = (60000/P_L) \cdot (P_H/P_L)^{1.75}$$

where P_L is the pressure drop at lower sample density and higher flow rate,

P_H is the pressure drop at higher sample density and lower flow rate.

For a group of 100 cotton samples having a wide range of fineness and maturity, the correlations between the fibre parameters calculated from pressure drop readings and those obtained by direct measurement were $r = 0.934$ for maturity ratio and $r = 0.994$ for average linear density.

The results are sensitive to specimen preparation. The test specimen must be opened thoroughly and the fibres must be orientated randomly. An opener-blender which has a similar action to that of a carding machine or Shirley Analyser is preferred.

Since the first edition of this monograph was published, in 1982, there has been considerable research with, and commercial interest in the FMT instrument. A detailed description of the research activities is given in reference 17 to which the reader is referred.

The use of the instrument is recommended by the International Committee on Cotton Testing Methods (31) and a standard test method has been issued (ASTM Method D 3818). One model is being used in High Volume Instrument testing lines. Another model is a stand-alone unit.

Although the FMT was developed for estimating maturity and gravimetric fineness, Ramey (30) points out that biological fineness can also be estimated. The calculation is:

$$\text{Fibre diameter} = 1.452\ \text{FIN} / \text{MAT}$$

Wall thickness can also be established from the same parameters, thus:

$$\text{Lumen diameter} = 1.452\ \text{FIN} / \text{MAT} - 0.838\ \text{FIN}$$

$$\text{Wall thickness} = 1/2\ (\text{fibre diameter} - \text{lumen diameter})$$

Reflectance measurements

Near infra-red reflectance (NIR) can be used to estimate the cross-sectional area and the specific surface of cotton fibres (29). However, in the initial work, the instrument required slightly more than one minute for a scan of the specimen. This time is not compatible with High Volume Instrument (HVI) systems. Because of the time differential, no follow up work was done with NIR measurement of fineness and maturity for several years.

Recently, NIR instruments having a reduced scan time have become available. Perimeter and wall thickness can be estimated with these reduced scan instruments (19).

5. Summary

1. Cotton fibre fineness is a complex characteristic which can be defined in at least two ways.

   - Gravimetric fineness is mass per unit length.

   - Biological fineness is the perimeter of the fibre cross-section or the diameter of the equivalent circle.

2. Biological fineness is a characteristic of the variety or species. The fibre diameter (in the dried state) may be as small as 11.5 µm in Sea Island or Egyptian cottons or as large as 19.0 µm in short staple upland types.

3. Fibre fineness influences handle, lustre, fibre cohesion, yarn strength and uniformity, and colour. Because a minimum number of fibres is required for satisfactory spinning and yarn properties, the fineness of those fibres determines the finest count which can be spun.

4. Gravimetric fineness can be measured directly by a count, measure and weigh procedure or can be estimated from airflow readings on a double-compression instrument. The widely used Micronaire test is difficult to interpret. When the samples being tested all have the same biological fineness, differences in Micronaire readings do reflect

differences in fibre maturity but, if the samples differ in biological fineness, there is no good interpretation of the Micronaire readings unless the biological fineness or the maturity of the individual samples is known.

5. Biological fineness can be measured directly on cross-sections of either dried or never-dried fibres.

6. Gravimetric fineness and biological fineness can be related if wall thickness, maturity or fibre surface area are known.

7. Direct methods of determination for both parameters are too slow for commercial monitoring of cotton quality. Both values have limited usefulness in the absence of additional data on fibre wall thickness or maturity.

8. The interrelationships between the above-mentioned fibre properties are illustrated in a chart (Figure 5) which covers a range of diameters from 12 to 20 µm .

The basic equations used to prepare Figure 5 are:

$$MH = 3.86(mic)^2 + 18.16(mic) + 13$$

$$Surface\ area = 3.78 / MH$$

$$Fibre\ diameter = 1.21\ H / M$$

Where M is maturity ratio,

H is fineness,

mic is Micronaire reading.

Literature

1. Anderson, S.L. *The measurement of fibre fineness and length: The present position.* J. Textile Institute 1976. **67**:175-180.

2. Beasley, C.A. *Developmental morphology of cotton flowers and seed as seen with the scanning microscope.* American Journal of Botany 1975. **62**:584-592.

3. Berlin, J.D., S. Worley, Jr., H.H. Ramey, Jr., and S.S. Linkous. *Measuring the cross-sectional area of cotton fibres with an image analyzer*. Textile Research Journal 1981. **51**:109-113.

4. Duckett, K.E., and H.H. Ramey, Jr. *On the Radial Variation of Spiral Angle in the Cotton Fiber*. Textile Research Journal 1981. **51**:656-664.

5. Gipson, J.R. and H. E. Joham. *Influence of night temperature on growth and development of cotton (Gossypium hirsutum L.) I. Fruiting and boll development*. Agronomy Journal 1968. **60**:292-295.

6. Gipson, J.R. and H. E. Joham. *Influence of night temperature on growth and development of cotton (Gossypium hirsutum L.) Fibre properties*. Agronomy Journal 1968. **60**:296-298.

7. Gipson, J.R. and H. E. Joham. *Influence of night temperature on growth and development of cotton. III. Fibre elongation*. Crop Science 1969. **9**:127-129.

8. Gipson, J.R. and L.L. Ray. *Fibre elongation rates in five varieties of cotton (Gossypium hirsutum L.) as influenced by night temperature*. Crop Science 1969. **9**:339-341.

9. Gilhaus, K. and J. Lunenschloss. *Characterization of cotton fibres by cross section, fineness and maturity grade*. International Textile Bulletin, Spinning 1980. **2**:117-129.

10. Grant, J.N., C.F. Egle, Jr., D. Mitcham, and R.D. Powell. *Structure and properties of cotton fibres from controlled growth environments*. Textile Research Journal 1970. **40**:740- 748.

11. Hebert, J.J., E.K. Boylston, and J.I. Wadsworth. *Cross- sectional parameters of cotton fibres.* Textile Research Journal 1979. **49**:540-542.

12. Hertel, K.L. and C.J. Craven. *Cotton fineness and immaturity as measured by the Arealometer*. Textile Research Journal 1951. **21**:765-774.

13. Lawson, R. and H.H. Ramey Jr. *Comparison of cotton fibre fineness and maturity on air-flow instruments.* Journal of Testing and Evaluation 1978. **6**:248-252.

14. Lord, E. *Airflow through plugs of textile fibres. Part II. The Micronaire test for cotton*. J. Textile Institute 1956. **47**:T16-47.

15. Lord, E. *The Characteristics of Raw Cotton*. Manual of Cotton Spinning. 1961. Vol. II Part 1. The Textile Institute and Butterworths. London, p. 103.

16. Lord, E. *The Origin and Assessment of Cotton Fibre Maturity* 1981. 2nd Ed. The International Institute for Cotton. Manchester, England, 27p.

17. Lord, E. and Heap S.A. *The Origin and Assessment of Cotton Fibre Maturity*. 1988. 3rd Ed. The International Institute of Cotton. Manchester, England, 38p.

18. Marsh, P.B. and T. Kerr. *Uncollapsed fibres associated with boll rot in cotton.* Plant Disease Reporter 1961. **45**:550-551.

19. Montalvo, J., S. Faught, R. Grimball, E. Stark, and K. Luchter; *Measurement of cotton maturity and fineness by a VIS/NIR reflectance HVI.* In Herber, D. J. and D. A. Richter, (ed.) Proc. Beltwide Cotton Confs. 1994. Natl. Cotton Council of America. Memphis, Tennessee, pg 1473-1475.

20. Moore, J.H. *Measuring the diameter of cotton fibre*. Journal of the American Society of Agronomy 1938. **30**:604-609.

21. Morton, W.E. and J.W.S. Hearle. *Physical Properties of Textile Fibres*. 1962. Wm. Heinemann and The Textile Institute. Manchester. pp. 127-145.

22. Morton, W.E. and J. Radhakrishnan. *The performance of the Arealometer in the measurement of fineness and maturity of raw cotton*. J. Textile Institute. 1954. 45:T774-T793.

23. Pearson, N.L. *Perimeter measurements of cotton fibres in the primary-wall stage*. Textile Research Journal 1950. **20**:152-164.

24. Pearson, N.L. *A study of cotton perimeters as calculated from Arealometer values at low and high compression*. Textile Research Journal 1955. **25**:124-136.

25. Peeters. M.C., I. De Langhe, J. Wijsmans, and E. De Langhe. *Never Dried Cotton Fibers as a Meaningful Expression of Maturity*. Textile Research Journal 1986. **56**:621-626.

26. Petkar, B.M., D.V. Mhagut, and P.G. Oka. *Distribution of cross-sectional area, perimeter, circularity, and secondary wall thickness of different cotton fibers during growth*. Textile Research Journal 1986. **56**:642-645.

27. Peirce, F.T. and E. Lord. *The fineness and maturity of cotton*. J. Textile Institute 1939. **30**:T173-T210.

28. Ramey, H.H., Jr. Fibre Crops, Chapter 2 in C.S. Hoveland, editor, *Crop Quality, Storage and Utilization*. 1980. Crop Science Society of America. Madison, Wisconsin, pp. 35-39.

29. Ramey, H.H., Jr. *Estimating quality components of natural fibres by near-infrared reflectance. I. Cotton Fiber cross- sectional area and specific surface.* Textile Research Journal 1982. **52**:20-25.

30. Ramey, H.H., Jr. Unpublished work

31. Report of the Meeting of the International Committee on Cotton Testing Methods 1986. International Textile Manufacturers Federation, Zurich, Switzerland.

32. Schubert, A.M., C.R. Benedict, J.D. Berlin, and R.J. Kohel. *Cotton fibre development - kinetics of cell elongation and secondary wall thickening.* Crop Science 1973. **13**:704-709.

33. Stephens, S.G. *A new method of relating airflow measurements of fineness and maturity to the gravimetrical properties of the cotton fibre.* Textile Research Journal 1976. **46**:835-841.

34. Stewart, J.M. *Fibre initiation on the cotton ovule (Gossypium hirsutum L.)* American Journal Botany 1975. 62:723-730.

35. Sullivan, R.R. *A theoretical approach to the problem of yarn strength.* J. Applied Physics 1942. 13:157-167.

36. Worley, S., Jr., R.S. Krowicki and E.L. Cox. *Conversion of micronaire reading to Arealometer specific-surface-area values in cotton.* Textile Research Journal 1975. **45**:326-327.