The Scientist Looks at Cotton

James N. Grant

Cottons grown in the different parts of the world vary in color, maturity, size, length, and strength of fibers. Soil, climate, and the species of cotton cause the variations.

Fibers may be short and coarse, as in the Asiatic varieties. They may be long and fine, as in Egyptian and sea-island varieties. They may be intermediate in length and size, as in the American upland varieties, which constitute the great bulk of cotton produced in the United States.

This diversity and the demand on textile products to meet definite requirements in specific uses necessitate the classification of cotton by quality.

The conception of quality depends somewhat on individual interests. In the trade, the cotton classer judges quality by what he can see with his eyes or feel with his hands. The textile-mill superintendent thinks of quality in terms of fibers that meet requirements of his special product. The consumer judges quality by the appearance or serviceability of the product manufactured from the cotton.

In the laboratory, the textile technologist thinks of quality in terms of the chemical or physical properties of the fibers and the potentialities of those properties in putting out superior products. Because the chemical composition of most cotton fibers is nearly the same, quality is usually defined in terms of the physical properties of the fibers—length, strength, fineness, maturity, or color.

Qualities of raw cotton fibers evaluated in commercial classification are identified under such terms as staple length, character, and grade. The values assigned according to accepted scales of measurements or specified terms of description determine the relative market worth of the cotton and denote its useful attributes.

Of the many physical properties of cotton fibers, staple length is the only one assigned a concrete value in commercial classification. To the cotton classer, staple length represents the length of only a typical part of fibers he has segregated and straightened between his thumb and forefinger. From the several thousand fibers in his hands he estimates the staple length of a cotton. Uniformity in making this selection requires great skill. Evaluation is made by comparison with official standards provided for three types of cottons—American upland, American Egyptian, and sea-island. Official standards of length for American upland are available in 20 intervals over the range from 3/4 to 1 1/2 inches. American Egyptian and sea-island have 4 intervals over the range from 1 1/2 to 1 3/4 inches, with provision for estimating beyond the official standards. The length evaluation is the basis for international classification of cotton for export and import. Such a selection is reasonable, because length often imparts fundamental information on other properties of the fiber, such as strength and fineness. The general tendency, for instance, is for long fibers to be very fine, with high tensile strength. The uses of fibers depend upon these basic properties.

Character of cotton fiber is based on strength, fineness, maturity, elasticity, and many other inherent physical properties, together with uniformity of fiber-length distribution. Some terms that designate character are weak, strong, soft, wasty, perished, irregular, and normal—depending on the deviation from the normal cotton. Character terms are relative rather than absolute as compared to staple length, but they provide essential information where strength, dyeing qualities, or spinning properties of the fibers are the critical factors.

Evaluations of cotton fiber under grade are associated with the history of the fiber from opening of the boll until packing in the bale. Grade combines a visual classification of the color, the amount of foreign substances entangled in the fibers before and during harvest, and the evenness with which the fibers were ginned. Long exposure to intense sunlight produces changes in color and gloss. Stalks, hulls, leaves, or other foreign material entangled in the fibers may increase cleaning damage and cost before processing. High moisture content of seed cotton at the gin, as well as improperly operated ginning equipment, can result in gin damage or cause the fibers to be left in small matted tufts.

THE THREE GENERAL classifications are satisfactory in the evaluation of cotton for purchase or selection for general uses. But that type of information is of little use to breeders, who desire specific values for many physical properties of their cottons, or to manufacturers, who require correlation of physical properties of fibers with product performance. Definite values for individual fiber characteristics, such as strength, fineness, surface characteristics, maturity, and length uniformity, as well as detailed knowledge of chemical structure of the fiber, are essential to an understanding of the mechanical behavior of cotton. The characteristics determine durability, appearance, dyeing properties, and other qualities of interest to consumers.

The desire for specific values indicative of fiber-length distribution in a sample to replace dependence on judgment from visual examination has resulted in the development of several instruments for the purpose. Mechanical separation of fibers into groups of 1/8-inch intervals is more time-consuming than optically scanning the fibers in a beam of light, but results from the mechanical method give more detailed information. Both methods are extensively used in breeding programs, in which knowledge of lengths of individual fibers and the distributions of the fibers by length is helpful in predicting the demand for a new variety. Length of individual fibers in samples of cotton range from a small part of an inch to more than the staple length. The greater part by weight is always less than the designated length. Individual fibers in varieties of American upland cottons often exceed 2 inches and in sea-island 3½ inches, but the number ever attaining these unusual lengths is small. Cottons with the higher proportion of fibers of the same length group have better manufacturing characteristics—the breakage due to long fibers is lessened. Experience indicates that an increase in lengths of fibers of the same weight fineness (weight of cellulose per inch of fiber), without change in strength, increases the strength of yarns by reducing the number of discontinuities between fiber ends, and that interspacing short fibers with longer ones increases yarn size without proportionally increasing its strength or durability. Extremely long fibers, however, add to processing difficulty because they have a greater tendency toward neppiness and are more difficult to separate and parallelize on textile machinery without breakage of individual fibers.

Although an increase in fiber length is often associated with an increase in yarn strength (through the fact that use is made of a higher proportion of the fiber strength corresponding to the greater length), it is the inherent strength of the fiber that is fundamental to strength in a yarn or manufactured product.

The inherent strength of the fiber depends on the deposition of spiral layers of cellulose in the cell wall during the growth of the fiber. The angle of these spiral layers of cellulose with the fiber axis, determined from X-ray patterns of masses of fibers, is closely associated with fiber strength.

Individual fiber strengths range from $\frac{1}{400}$ to $\frac{1}{30}$ pound; the average is about $\frac{1}{100}$ pound. When fibers are tested in small compressed bundles, however, their bundle tensile strengths range between 50,000 and 100,000 pounds to the square inch, the higher strength being commensurate with the tensile strength of steel. American upland varieties produce fibers intermediate in this range, with strength averaging about 78,000 pounds to the square inch.

The three common mechanical methods for determining strength are round-bundle, flat-bundle, and individual-fiber breaking load. In the round-bundle test, comparison of cottons is based on the strength per unit of the cross-sectional area of the bundle, expressed as pounds per square inch. From the flat-bundle method, the ratio of breaking load to weight of fiber tested furnishes essentially the same information as the round-bundle test but in less time. Neither of these methods gives the fundamental knowledge of elastic properties or variation between fibers obtained in the individual-fiber method.

As a complement of strength, the elastic properties of cotton fibers (determined on the individual fiber) influence their usefulness. The individual fiber elongates rapidly when load (less than $\frac{1}{1000}$ pound) is first applied, because of its natural twists and convolutions and the kinks that result from the condition of the fiber in the boll. After the rapid initial elongation, the fiber elongates very slowly and finally breaks. At break, the length increase may be as much as 6 to 10 percent. If the load is removed before break, only a fractional part of the elongation is recovered. Strength and elongation of cotton fiber depend in general upon the variety of the plant and growth conditions. The longer fibers in a variety usually have greater strength and elongation.

In contrast to elongation and recovery, which are considered in a direction parallel to the fiber axis, such properties as flexibility and brittleness are judged by ability of the cotton fiber to bend in directions perpendicular to the axis. Performance tests on the textile product indicate that the flexibility of cotton fiber is satisfactory and superior to that of other natural cellulosic textile fibers. However, this evaluation is a composite with other fiber properties and fabric construction.

Closely associated with other properties, but undesirable in a textile fiber, is the lack of resilience, or inability of the cotton fiber to recover rapidly from deformation, such as bending or compression.

The sizes of fibers are difficult to determine if the fiber diameter is taken as the measure, because shapes of dry fibers are highly irregular. The cross-sectional shapes assumed by fibers on exposure to the air depend on the thickness of the cellulose wall. Thick-walled fibers remain almost circular. Thin-walled fibers are approximately elliptical. Internal stresses within the walls cause the fibers to twist. The twisting produces convolutions. Such variations make fiber diameter unreliable as a measure of size.

Instead of diameter, the weight of cellulose per inch of fiber, called weight fineness, is generally accepted as a good measure of cellulose content, closely associated with size. The range in weight fineness of commercial cotton extends from 2.5 micrograms per inch in sea-island to 8.8 micrograms per inch in Asiatic varieties. American upland cottons range from 3.2 to 6.0 micrograms per inch. Special varieties, such as S×P, or United States sea-island, have weight fineness as low as 3.0 micrograms per inch, while varieties of Chinese cotton show values up to 11 micrograms per inch. A rapid approximation of weight fineness can be obtained from instruments that measure the resistance to air flow. This measure is more accurately one of fiber surface, because passage of air between fibers depends on both the fiber shape and the cross-sectional perimeter.

Textile fibers, natural or synthetic, differ in many physical and mechanical properties. Length and size of hemp, jute, and ramie fibers depend partly upon the separation of cells in the retting process, whereas the cotton fiber is a single cell. In contrast, synthetic fibers are extruded to the size and cut to the length desired by the manufacturer.

The relative thickness of the cell wall as compared to total fiber diameter when a fiber is swollen in sodium hydroxide is generally accepted as an expression of the maturity of the fiber. Cottons with total wall thickness more or less than half the diameter of the swollen fiber are arbitrarily referred to as mature and immature, respectively. Cell-wall thickness influences such properties of the fiber as strength, elongation, and absorption of dyes. The usual evaluation of fiber maturity has depended on microscopical examination of a fiber swollen with sodium hydroxide, or of its color when the fiber is viewed through polarizing crystals in the microscope. A newer test for maturity is based on the different reactions of mature and immature fibers to a mixture of a green and a red dye; those with thick walls dye shades of red and those with thin walls dye green shades.

THE RANGES in strength and elastic properties overlap for natural and synthetic fibers. Jute fiber has a cross section 10 times the size of that of the cotton fiber, but its tensile strength per unit of weight fineness is the same as that of cotton. Flax, hemp, and ramie, also larger in cross section than cotton, have strengths almost twice that of cotton, but their elongation under load is far less. Silk filaments, 30 percent smaller than cotton fibers, have 40 percent more tensile strength and about 300 percent greater elongation, with larger relative recovery when the load is removed. Wool fiber, recognized as an inherently weak fiber, with a tensile strength about half that of cotton, increases in length as much as 34 percent before breaking and has excellent recovery of length. Protein fibers are weaker than wool and have comparable elongation at break, but show little recovery at the high elongations. In general, stretched rayon has elongation comparable with that of cotton and with a higher strength. Unstretched rayons, however, have lower strength, with higher elongation and poor recovery from loading.

Synthetic fibers have a much wider range of property differences, depending on the materials used and the mechanical or chemical treatment given the fiber.

NYLON FILAMENT, slightly weaker than ramie, the strongest of the natural fibers, has strength and excellent elongation and recovery after loading, exceeding even that of silk. Such composite properties have made nylon filament in demand for products like parachute cords and hosiery.

Textile fibers differ in flexibility, that is, their ability to bend repeatedly without breaking. Glass fiber, as an extreme, is very brittle. The bast fibers are less brittle. Cotton is considered to have better flexibility properties than bast fibers, as reflected by the behavior of its manufactured products. The flexibility of synthetic fibers is as good as that of cotton and in some fibers is far superior to that of the cotton fiber.

Natural and synthetic fibers respond differently to changes in temperature and moisture. Most natural fibers, notably ramie and cotton, increase in strength with increase in moisture, while synthetic fibers usually decrease in strength with increase in moisture. Natural fibers lose strength with a rise in temperature; synthetic fibers vary in their response to temperature.

Wool, nylon, and silk are superior to cotton in their ability to absorb energy, or work, because they have excellent elongation and good recovery.

The properties of textiles are of immediate interest to the manufacturer and the user. The characteristics of any product depend upon the basic fiber properties and the interaction of the properties in the geometrical structure of the fabric containing large aggregates of fibers. Many of the properties have been evaluated only in the yarn stage.

Differences in physical properties of cotton fibers are recognized in their selection for many textile products. Fibers used in tire cord must be strong and flexible to withstand the strains and bends of the tire as it hits obstacles in its path. Color in these fibers is of secondary importance, because they are concealed in layers of rubber.

Fibers made into a mattress or a rug must have sufficient resilience to recover from bends or other deformations while in use, a property more pronounced in the coarse fibers.

Size, strength, and color are important qualities of the cotton fibers used in fine fabrics, because they add to durability and appearance of the finished products. Immature, or thin-walled, cotton fibers are generally avoided by the manufacturers because they forewarn of processing difficulties. Their strengths are usually insufficient to withstand the mechanical processes of separation and straightening to produce uniform fine yarns without significant decrease in length. These fibers, manufactured into fine yarns produce irregularities in strength and cross-sectional area because of small mats of entangled fibers, called neps. Neps dye to lighter shades of color than does the rest of the yarn.

The thin-walled fibers are especially suitable for the manufacture of products, like fire hose, in which color is unimportant and fine yarns are not required, but in which, rather, fibers that have natural swelling capacity to close the interstices between yarns and fibers are essential to prevent leakage. Many intricate cotton fabrics are constructed from yarns designed to overcome the undesirable elastic properties of the fibers both in extension and compression. An analysis of elastic properties of fibers in these fabrics is often complicated with superimposed properties, such as staple length, twist in the singles yarn, twist in the plied yarns, and weave of the fabric.

Coarser fabrics can be produced from average cotton that has acceptable strength and good spinning characteristics. Most domestic fabrics require cottons with physical properties within the range found in our American upland varieties; special fabrics must be produced from imported cottons or those produced at a higher cost per pound. The demand for cotton with long, strong, and fine fibers is greater than can be met by domestic production. To meet it, quantities of Egyptian cottons are imported each year.

The practice of evaluating the fiber qualities in terms of service of the manufactured products has prevented many properties from being recognized, because processing and fabrication of yarns introduce variables that sometimes overbalance the property under test. The textile technologist is working to meet the needs of the breeder for information on quality characteristics of cottons by developing precise methods and equipment to measure and evaluate properties of textile fibers during stages of processing and product performance.

JAMES N. GRANT *is a native of North Carolina and a graduate of Duke University. He joined the staff of the research and testing division of the cotton branch, Production and Marketing Administration, in 1937, to perform research on physical properties of cotton fibers and devise rapid methods for measuring those properties. He transferred to similar work with the Southern Regional Research Laboratory in 1942.*