APPLICATIONS OF OPTICAL AND ELECTRON MICROSCOPY TO STUDIES OF TEXTILE FIBERS

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APPLICATIONS OF OPTICAL AND ELECTRON MICROSCOPY TO STUDIES OF TEXTILE FIBERS

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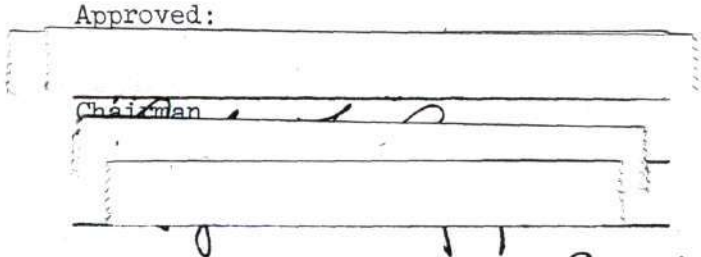

Chairman

Date approved by Chairman: 16 August 1966

Dedicated to

My Father

Ben L. House

(July 4, 1897 - March 27, 1959)

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SUMMARY

The purpose of this research was to investigate and evaluate the applications of optical and electron microscopy to the examination and measurement of textile fibers. A further purpose was to present a catalog of micrographs describing the features of cotton, wool, and man-made fibers of pertinence to the textile industry.

Techniques of microscopy generally employed in micrographic examination of fibers, including mounting, sectioning, and replication, were evaluated and selected methods, after some modification, were applied to this problem. By the use of the Hardy Microtome and the Bausch and Lomb mechanical microtome sections were prepared of 10 cotton specimens grown in Georgia, 14 cotton specimens from a world wide collection furnished by Mr. J. N. Grant of the USDA, SURDD, 2 wool specimens, and 14 man-made fibers. These were then examined and photographed using optical microscopy. Similar studies were made of fiber configurations by views of a length of the fiber made normal to the axis. The fiber surfaces were further characterized by electron microscopy using a carbon replica technique. The combined studies of each fiber were then assembled into a single display (in the appendix of this report).

Using information acquired from the fiber sections, the denier (tex) values were calculated for the cotton fibers and compared to denier measurement of previous workers made by other methods. Excellent agreement was found. Data of denier versus upper quartile length produced essentially a straight line plot with large data scatter at the shorter

fiber lengths.

Convolution counts were made of all the cottons using the 5 mm center section of the fiber as recommended by Betrabet. Counts of one specimen, Dixie King, were made before and after heating in a Gin Dryer Simulator to selected temperatures in the range 22 to 200°C. Convolution counts increased at all temperatures immediately after heating but underwent restoration to the original value when heated to temperatures less than 120°C (250°F). Above this temperature long term deformation of as high as 27 percent occurred.

Crimp frequency for the various cotton fibers was determined and plotted against upper quartile length. A straight line relation was found as for denier. By the method of Pillay maturity coefficients were determined. Fracture interfaces of cotton fibers broken in tension were examined; three of five fibers broke at reversals.

In conclusion, methods of microscopy have been employed to catalog surface and sectional features of the principal cotton and man-made fibers and two specimens of wool.

Presentation of these measurements in graphical form has exhibited interesting relationships between denier, convolution count, crimp frequency and upper quartile lengths.

CHAPTER I

INTRODUCTION

Anyone who attacks a problem in textile science, particularly fiber physics, without the aid of microscopic equipment will soon realize the usefulness of these tools of research. By the very nature of the characteristics of textile fibers, their study by methods of optical and electron microscopy is imperative.

Cotton fibers may vary in length from less than 0.5 inch to greater than 2.5 inches. Generally, the average staple length used in fabric manufacture is greater than 0.75 inch. But, since the average width of a cotton fiber is approximately 0.0008 inch, a one inch fiber is about 1250 times longer than it is wide. Man-made fibers may of course be varied over greater ranges of length and diameter. But the majority of man-made fibers are cut into staple lengths of one to three inches and are manufactured with diameters similar to cotton for blending purposes.

In both cases the researcher has an obvious problem. With materials so small, they must be magnified in order that surface features and other important characteristics may be examined. Models may be constructed but there is no more rapid or reliable method than observing the material itself at the desired magnification. Photomicrography enables the textile researcher to have a permanent record of what he sees. Photomicrographs also prove valuable for analysis and comparison of previous views of similar fibers.

Electron microscopy and electron micrographs can also be an invaluable aid to the textile researcher. With electron microscopy, surface features of fibers can be examined at magnifications much higher than are possible with conventional optical microscopes. Electron wavelengths are much shorter than ultraviolet radiation. Electron microscopes give a high limit of resolving power and a large depth of focus.

Uses of Microscopy in Textile Fields

The application of microscopy to the study of textiles has many possibilities. Probably the oldest application of textile microscopy is in textile fiber identification. It can be used to determine quantities of component fibers in blends. Another use is in grading or determining the quality of fibers. This could include determining the fineness of wool, the maturity of cottons and the deniers of cottons and man-made fibers.

The microscope can be a useful tool in determining various types of damage to textile fibers during textile processing, storage and handling. Mechanical and microbiological as well as chemical damages may be examined. Detection of impurities, foreign matter, and adulteration on and in the fibers is often accomplished by microscopy.

Demonstration of the various effects and treatments of fibers such as mercerization and treatments with resins is another use. By differential dyeing, the cross sections of the fibers show the location of the dyes and resins. Another use is in man-made fiber production process control. Continuous microscopical checks for defects in the spinning processes are quite common in the man-made fiber industry.

Fiber microscopy in its various forms is the primary concern of the writer but other areas such as yarns and fabrics can be analyzed for problems in yarn and fabric construction. Other areas for study could be warp sizing, dye penetration and crease proofing finishes.

Purpose

A continuing need exists in the area of fiber physics for descriptions and recorded data of various fibers in order that research on the fibers can be entered into with a thorough knowledge of the history and characteristics of the sample. The descriptions should include photographs and/or diagrams showing surface characteristics as well as cross sectional area. Recorded data should include length, density, crimp, convolutions and other items that would be useful in the particular research.

The purpose of this research was threefold. The first objective was to evaluate methods of optical and electron microscopy applicable to the study of textile fibers. This involved experimental work and observations as well as a thorough study of the related literature. Secondly, selected methods of microscopy were to be used to characterize a variety of textile fibers. Finally, a study was to be made of the effects of certain processing methods, in particular, heating, on cotton fibers. Textile fibers used in this study included wools, polyamides, polyesters, acrylics, modacrylics, rayons and various cottons.

CHAPTER II

FIBER DESCRIPTION AND CHARACTERIZATION

Characterization of the various textile fibers was the key to this study. "Characterize" is defined by Webster's Seventh New Collegiate Dictionary as "describing, indicating and/or delineating the character of, to be characteristic of, to distinguish as a trait." In this study, character is further defined as an attribute, quality, or property.

Characterization of a fiber consists of learning such things as (1) length of fiber if applicable, (2) cross section to include a description of appearance and measurements, (3) behavior of the fibers under physical, chemical, and mechanical processing, (4) longitudinal appearance descriptions, and (5) in the case of cottons, crimp and convolution per unit length are needed.

Length determination, of course, is not a difficult task. It involves viewing the fiber under low magnifications and measuring it with a standard ruler. When a large amount of the sample is available, instruments such as the digital Fibrograph or the Suter-Webb sorter can be used.

Crimp is definitely an important parameter in the characterization of fibers. Crimp can best be defined as the waviness of a fiber. It is a characteristic feature of nearly all staple fibers. It has a great deal to do with the capacity of fibers to cohere under light pressure. Crimp in man-made fibers is put in the fibers mechanically or through chemical characteristics of the skin of the fiber. In wool, crimp exists due

to the cortical bilateral structure of the fiber. But, in cotton the occurrence of crimp cannot be so easily explained. Crimp in cotton fibers is non-uniform. It appears as gentle waves in the fiber. Also present at random are sharp kinks. In this study only the waves were to be counted as crimp.

Convolutions result during the maturing of the cotton fiber as drying and resulting shrinkage occur when the boll opens, the lumen or central canal flattens and the original cylindrical wall flattens out and collapses. The degree of collapse will depend on the thickness of the cell wall, the thinner the cell wall, the greater the collapse or flattening. During this process the flat ribbon of the collapsed fiber is twisted around its axis. This twisting is a result of the spiral orientation of the cellulose molecules and the microcrystallites of the secondary wall of the fiber. Convolutions vary in number from fiber to fiber. They are one reason for the uniqueness of cotton as a fiber. Though crimp has been duplicated in synthetic fibers mechanically, convolutions are much more difficult to duplicate and may be economically unfeasible.

A convolution either goes through a 180 degree twist to a reversal point from whence it continues in the same twisting direction for another 180 degrees to the next reversal point or at the reversal point the twisting direction may reverse and go in the opposite direction for 180 degrees or more. In either case, a full 360 degrees of twist is defined as one convolution for the purposes of this study.

Cross sections refer to transverse cuts across the width of the fiber. The sections are generally taken near the center of the fiber but may be taken at any point desired along the length of the fiber. Two

methods of cross sectioning fibers are discussed and used in this study. They are the hand sectioning technique using the Hardy Microtome and the mechanical method using the Bausch and Lomb rotary microtome.

After cross sections are made and observed microscopically, a permanent record of the observation must be made. Drawing the area viewed is a possibility but photomicrography certainly is the best method. In this study, photomicrography was decided upon as the method to be used.

Measurements can be taken directly from the photographs and considering the magnification used can be converted into the correct natural dimensions. Major and minor axes are measured for all fibers and in the case of cottons, wall thickness, the distance to the center or lumen, should also be measured.

Much can be learned from observations of cross sections. Mature cotton fibers can be distinguished from immature fibers which are round and uncollapsed. Internal characteristics can be observed at high magnifications. Examples of this would be the growth rings where cellulose is deposited daily during the growth of cotton fibers and in the case of man-made fibers, added chemicals such as titanium dioxide, a delusterant.

The measurements taken from cotton fibers can be used to construct models of the fibers on graph paper. The area covered by the fiber model can be used to calculate the denier of the fiber. Denier information is useful when doing experiments in tenacity and elongation of individual fibers.

Longitudinal studies, views of a length of the fiber, normal to the fiber axis, are useful primarily in that the general shape and surface features of the fibers are distinguishable. Any roughness or adulteration

can be determined. Again photomicrography is the best method available for permanent record. If the fiber is shadowed with a thin film of a metal like chromium, the surface features are easily viewed with a reflected light microscope at powers of 75X or more.

Electron micrographs, as explained earlier, show greater detail due to the much higher resolving power capabilities. Smaller areas can be observed. Reversals in the fibrils and the surface roughness which is characteristic of the fibers can be observed with electron microscopy.

Textile fibers are subjected to many processes. These include physical handling, mechanical and thermodynamic action, and chemical processing. The effects of the processes on individual fibers must be observed by microscopic methods in order to determine and evaluate the changes which occur.

For instance, effects of temperature cycling on fiber shape and configuration were investigated as were fracture interfaces of fibers broken under tension.

CHAPTER III

A STUDY OF THE LITERATURE

Origins and History of Textile Microscopy

Microscopy is the study of the world of nature too small to be visible to the unaided eye. It is a science of optics and of lenses. Roger Bacon (1214-1294), an early English philosopher, who was one of the first to explore the laws of refraction, learned much of the nature of a lens. To many, he is considered the father of microscopy (1).

One of the earliest references to textile microscopy was in Micrographia (2) by Robert Hooke (1635-1703) which was published in 1665. Hooke described linen (flax) cloth and fine waled silk cloth. He included illustrations to supplement his written observations. Hooke also forecasted the production of synthetic fibers (3).

Perhaps the first reference to the microscopy of cotton was the studies of Leuwenhoek (4) in 1678. Thompson (5) in 1834 used artists to make illustrations of mummy cloths found in Egypt.

Denham (6) reported that the first mention of convolutions or striations as surface characteristics of cotton was by Ure in 1836. Ure gave drawings of several cottons illustrating these features as viewed microscopically.

Denham (6) also stated that Crum in 1846-1863 was the first scientist to write of the use of the microscope in dyeing research as he produced figures of longitudinal and transverse sections of cotton in various

stages of maturity and in the dyed state. O'Neill, according to Denham (6), was the first to report of swelling the fiber to elucidate its anatomy. Using cupramonium, he differentiated four regions. The outside region, the cellulose beneath, spiral fibrous material situated on or close to the outside membrane, and the lumen were the four regions he found.

Clegg and Harland (7) in 1923 used the microscope extensively in their research on convolutions of the cotton fiber. They reported the convolutions per millimeter of eight types of cotton and stated that after wetting and boiling the convolutions would leave the fiber but would return upon drying. They also stated that tension caused the pulling out of some convolutions but the reversals remained largely unaffected.

Denham (8) also in 1923 presented a study on the structure of the cotton fiber with particular emphasis on convolutions and striations. He reported that the striations (spiral fibrillar structure) occur in all parts of the fiber. He also stated that convolutions follow the direction of the primary wall striations.

In 1928 one of the first books dealing exclusively with textile microscopy was published. It was L. G. Lawrie's Textile Microscopy. J. M. Preston published his Modern Textile Microscopy in 1933 and was closely followed by E. R. Schwarz and his Textiles and the Microscope in 1934. Of all the early works on this subject the book of Schwarz seems to be the most significant. This is based on the fact that this book is cited as a reference for many papers dealing with textile microscopy after 1934.

Electron Microscopy

Electron microscopy in comparison to optical microscopy is a relative newcomer to the field. Most of the foundation work of electron microscopy was done by men such as J. J. Thompson (1897), Weichert (1899) and Ryan in 1903. These early workers did research in manipulation of electrons using cathode ray tubes.

The formal foundation of geometrical electron optics was set down in 1926 by H. A. Busch (9). Busch discovered the lens property of axially symmetric electric and magnetic fields (10). After this, a beam of electrons could be focused by the lens to produce an enlarged image of the object being viewed. The first electron microscopes were built in 1931-1932 (11).

Early workers in electron microscopy whose findings were useful to those in the textile field were L. C. Martin (12), G. D. Preston (13), D. G. Drummond (14), and E. F. Fullam and A. E. Gessler (15).

With the advent of the use of electron microscopy in textile research during the 1940's, many improvements in research of the individual fiber were realized. It had been known for many years that cellulose fibers when swollen exhibit a fibrillar structure which is just visible under an optical microscope. Electron microscopy confirmed and extended this information (16).

Mary L. Rollins of the Southern Utilization Research and Development Division of the United States Department of Agriculture is one of the most well known and respected electron microscopists in the textile field. The work of Miss Rollins and her associates (17, 18, 19, 20, 21, 22, 23, 24, 25, 26) from 1945 to the present has touched on many facets of textile re-

search but has been particularly oriented towards cotton fiber structure and modifications.

Bailey and Rollins (17) discussed use of the Hardy microtome for hand cross sectioning and illustrated various sections of tire cords. They discussed the usefulness of cross sections for determining degree of impregnation for different chemical compounds that can be added to fibers and fabrics.

Tripp, Moore, and Rollins (26) in a study of the surface of cotton fibers reported that in selected native fibers there is a system of roughly parallel ridges and grooves spiraling around the fiber at an acute angle (usually 20-30°) to its axis. The average height and distance between ridges was shown to be approximately 0.5 micron with many ridges ten microns or more in length. In general, they showed that the surface of native cottons has a relatively uniform appearance.

Characterization

Hock (27) made a study on the degradation of cellulose fibrils. It is well known that cellulose is composed of poorly reactive crystalline regions and readily reactive amorphous regions. After observing chemical reactions, he reported that many reactions proceed more easily in the regions between the fibrils than within the fibrils themselves. It appears that the crystalline cellulose is located principally in the fibrils, and the interfibrillar regions for the most part, form the amorphous fraction.

Three experimental acrylic fibers were characterized by several microscopical methods in a study (28) conducted by Botty et al. The results of the study primarily show that microscopic properties such as size, shape, and structure are related to ultimate physical properties.

Crimp and Convolutions in Textile Fibers

Significant work in defining and measuring crimp has been completed by Alexander, Lewin, Shiloh, et al. at the Institute for Fibres and Forest Products Research, Jerusalem, Israel. In their published work (29, 30, 31, 32, 33, 34) and a final report (35), they define effective crimp diameter and effective wave number from a plane projection of fiber which is being rotated (29). Later, a special apparatus was built for measuring coordinates at points along the axis of the fiber in two perpendicular planes (30). For their study (32, 33), crimp was defined using two parameters, static and dynamic. Shiloh, Fuchs, and Nettler (34) disclosed that they had developed a technique using an analog computer to measure the crimp of cotton fibers whereby the fibers were first photographed. Then the photographs were traced with a device that fed voltage to the computer. The computer traced a curve, calculating least mean square deviation and determining the crimp diameter. All of this work is summarized by Shiloh and Alexander (35).

Ecochard (36) discussed a simple method for counting crimp whereby the fibers are held lightly to a slide by traces of Vaseline. Snyman (37) discussed the cross section of wool fibers in relation to its crimp.

Betrabet et al. conducted a four part research program (38, 39, 40, 41) on the structural properties of cotton fibers. The study dealt mainly with convolution angle, the angle formed by the convolutions at the reversal point in relation to the longitudinal axis of the fiber, and its relation to tensile strength of the cotton fiber. These workers based much of their work on that of Meredith (42, 43). Betrabet (38, 40) reported that there was a high correlation between Pressley strength and convolution

angle for ten Indian cottons tested. Later birefringence and structural reversals (39) were reported to be significantly correlated with strength and toughness. Finally, it was reported (41) that cell wall thickening was compared to convolution angle and birefringence. Though the latter varied appreciably, the bundle strength varied very little.

Of primary interest to this study was a technique developed and described by Betrabet (38) for determining convolutions per unit length. The method consisted of taking a small amount of the specimen and mounting the fibers straight and parallel on a glass slide. Then the convolutions were counted for the entire length and for the central 5 millimeter region only. A high correlation was shown between the two results so the central 5 millimeter region method was chosen. It was reported to be much quicker with quantities of 15 fibers per hour examined under the former method being increased to 100 fibers per hour.

The Transverse Sectioning of Textile Fibers

The area of cross sectioning is an important one in optical and electron microscopy. Generally the term microtomy is used since most techniques involve instruments known as microtomes whether they be hand operated or mechanical.

The original reference to the use of the Hardy hand microtome was by Hardy (44). The Hardy microtome has remained the same, with few modifications, through the years. Hardy reported a similar device (45) for determining wool fineness in 1932.

The Schwarz method was first discussed by the inventor, E. R. Schwarz (46) in 1936. The device uses a solid base for the plate and a micrometer screw beneath the plate attached to a plunger. The Schwarz

microtome is still used extensively.

A microtome designed primarily for the wool industry is discussed by De Cuenca (47). The single microtome is similar to the Hardy. A multiple microtome that allows 11 fiber sections to be made at a time is also described.

Another method for making hand cross sections was described by Mennerich (48). It involved a device that closely resembled the Hardy microtome except a lever device was used to push up the fibers.

In mechanical sectioning the specimen must be embedded in a resin or plastic so it will be extremely rigid thus making it easier to shave off thin sections. A technique for embedding fibers in a clean plastic, polybutyl methacrylate has been described (49). The technique for using gelatin capsules for holding the fibers while the monomer is poured in the capsule is described by Sanders (50).

Microscopical Observations of Fibers Subjected to Textile Processing

During the ginning process in which the cotton fibers are removed from the seed, a certain amount of drying is necessary to remove moisture from immature and damp cotton. A typical method is for the cotton to tumble down a tower which has hot air rising in it.

Berriman (51, 52) reported that at temperatures above the range 230-250 degrees F. the fiber shape and number of convolutions per inch are changed irreversibly. Below these temperatures, shape changes do occur but the changes are reversible on cooling.

Berriman based this statement on a series of experiments using a microdryer system. This system consisted of a microscope with equipment

for polarized and/or phase contrast viewing and a hot stage, electrically heated and water cooled. The heater power was supplied by a variable voltage transformer.

The experiments showed that as fibers dry, the number of convolutions present in a single fiber increases.

Some other very fine work has been produced by Nelson et al. (53) and Grant et al. (54) in their studies of heat effects on fiber length and other physical properties.

Maturity of Cotton Fibers

In studies of cotton, one microscopic examination that is frequently used is that for maturity. Immature cottons (very thin walled) form neps, which are small tightly rolled up entanglements of fiber, and unless they are removed, form specks in the fabric. Morton and Hearle (55) use a method described by Stoves (56) whereby the fibers are laid on a glass slide, covered with a coverslip and irrigated with 18 percent sodium hydroxide. The fibers are swollen by the caustic. According to Stoves, normal walled fibers lose their convolutions, thick walled fibers remain untwisted, while the thin-walled type develop convolutions. Stoves called these thin-walled fibers "dead" fibers. Morton and Hearle defined "dead" fibers as those in which, after the treatment with caustic, the wall thickness is one-third or less of the apparent lumen width. They stated that normal fibers are those which are deconvoluted and by swelling have virtually obliterated the lumen. Between the latter and the former is a third class which they called thin-walled. Obviously there is some difference in their terminology.

A formula used by Pillay and Shankaranarayana (57) is used in this

study where mature, half-mature, and immature fibers are used as percentages. It was decided that for the purposes of this study those fibers which convolute will be considered to be immature, those that become rod-like and deconvoluted will be considered mature, and all others will be considered half-mature. The formula is:

$$MC = (M + 0.6H + 0.4I)$$

where MC = Maturity coefficient

M = Percent mature

H = Percent half-mature

I = Percent immature

CHAPTER IV

SPECIMENS AND EQUIPMENT

Selection of the Specimens

In a concurrent study on the effects of ginning on the properties of cotton, a group of cotton fibers was collected by A. Goldfarb (58). These fibers are representative of cottons grown in central Georgia and are of particular interest with respect to the characterization of fibers produced in the southeastern United States. These cottons are listed in Table 1 as specimens one through ten.

Mr. James N. Grant of the Southern Utilization Research and Development Division, United States Department of Agriculture was kind enough to furnish the balance of the cottons examined. These cottons represent a broad spectrum of world cotton types. In particular they are valuable in that studies by Shiloh et al. (35) and Grant et al. (53, 54) mentioned earlier included specimens of many of these same cottons. Thus, much important data characterizing these fibers has already been gathered. A paper on the spiral structure of cotton by Orr et al. (64) summarized many of the physical properties of these cottons. The properties of the fibers pertinent to this study are shown in Table 5. These cottons are listed in Table 1 as specimens 11-24.

To supplement the data and photomicrographs collected on the cottons a number of man-made fibers as well as two specimens of wool fibers were collected. The man-made specimens are listed in Table 1 as specimens 25 through 38. The wools are listed as specimens 39 and 40.

Table 1. Fiber Specimens Examined

Specimen Number	Fiber Name
1.	Empire WR Hand Ginned (Experiment, Ga.)
2.	Empire WR Ginned Lint (Experiment, Ga.)
3.	Empire WR Hand Ginned (Locust Grove, Ga.)
4.	Empire WR Ginned Lint (Locust Grove, Ga.)
5.	Dixie King Hand Ginned
6.	Dixie King Ginned Lint
7.	Carolina Queen Hand Ginned
8.	Carolina Queen Ginned Lint
9.	Carolina Queen Hand Ginned (Hand Picked)
10.	Carolina Queen Ginned Lint (Hand Picked)
11.	Wilds 5
12.	Delfos
13.	Mexican Big Boll
14.	Rowden
15.	Pima S-1 (Silver)
16.	St. Vincent Sea Island (Silver)
17.	SXP
18.	Bobshaw (1951 crop)
19.	Hopi Acala 54
20.	Pima S-1
21.	Deltapine 15
22.	Bobshaw (1955 crop)
23.	Stoneville
24.	Deltapine (1955 crop)
25.	Dacron Polyester
26.	Celanese Dull Triacetate
27.	Avisco Rayon
28.	Avisco Bright Rayon
29.	Avisco Dull Rayon
30.	Avisco Bright Fiber 40 Rayon
31.	Enka Rayon
32.	Dupont Semi-Dull Nylon Polyamide
33.	Herculon Polypropylene
34.	Kodel Polyester II Semi-Dull
35.	Kodel Polyester IV Semi-Dull
36.	Eastman Verel Modacrylic Bright
37.	Eastman Verel Modacrylic Dull
38.	Dupont Orlon 72 Acrylic
39.	Wool-unscoured
40.	Wool-scoured

Since the surface characteristics and cross sections of man-made textile fibers are quite distinctive, a study of them by methods of optical and electron microscopy was considered to be of value. All the man-made fibers selected were cut staple of 1.5 inch to two inch lengths in the 1.5 to three denier range. These staple lengths and deniers were thought to approximate closely the measurements of the cottons.

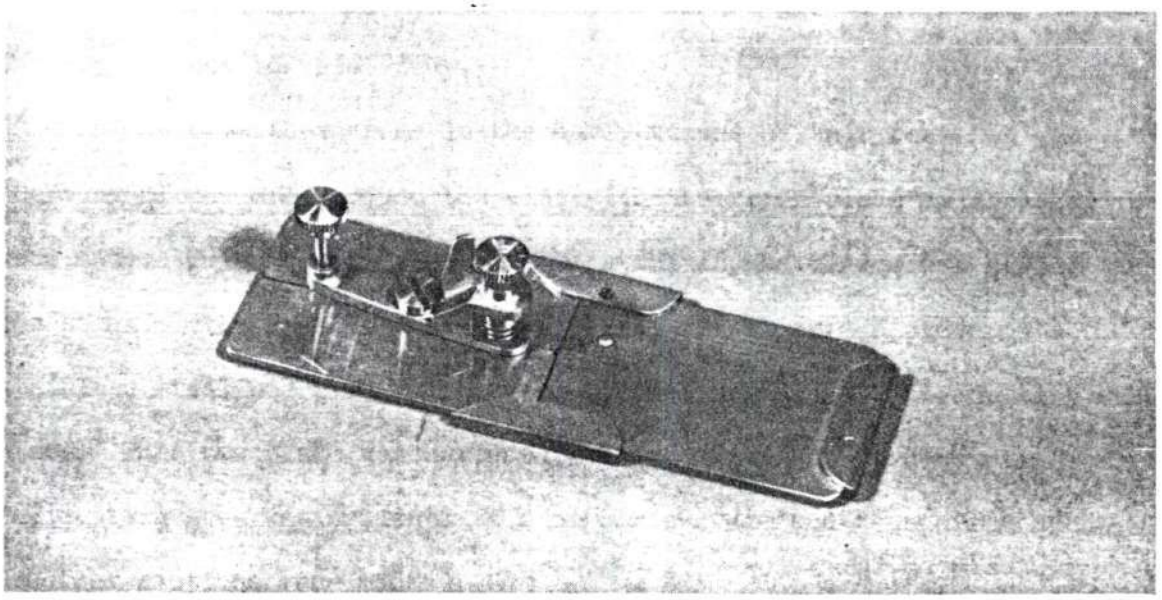
Cross Sectioning Equipment

A hand sectioning device, the Hardy microtome, was used for all the fibers in the study with the exception of the rayons. A Bausch and Lomb mechanical microtome was used for the rayons.

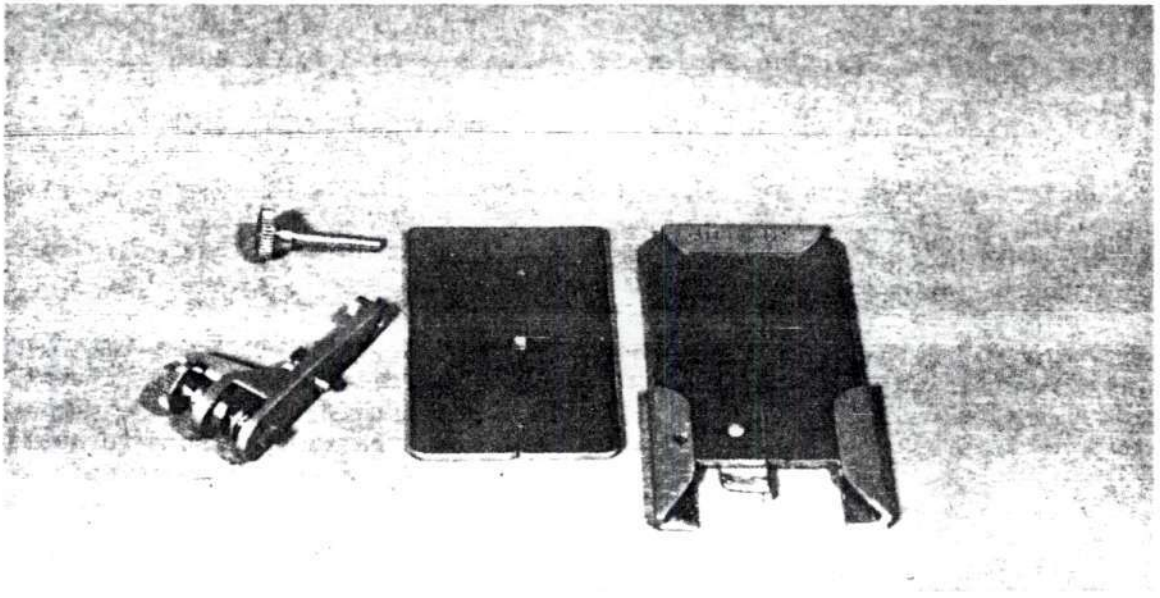
The Hardy microtome, illustrated in Figure 1, furnishes usable sections for optical microscopy. This microtome consists of two rectangular metal plates which are held together and aligned in the same plane by means of two brass guides on each side of one of the plates. On one end of one of the plates is a slot, centrally located and parallel to the longitudinal axis of the plate. When the other plate is fitted to this plate a brass tongue on the second plate fits into the slot leaving a small opening about .10 inch long. This slot is for the fibers that are to be cut in cross sections.

A feeder mechanism, provided for adjusting the thickness of the cross sections, fits onto the first plate. The feeder mechanism has a screw driven plunger which fits in the slot. This plunger is the means by which the bundle of fibers is pushed up through the slot. (See Chapter V for description of procedure.)

The other equipment needed for hand sectioning is a very sharp razor blade and a stereo binocular microscope of low power. After much experi-



A. ASSEMBLED AND IN THE INVERTED POSITION



B. DISASSEMBLED SHOWING VARIOUS PARTS

Figure 1. Views of the Hardy Microtome

mentation Gem single edge stainless steel blades proved to be most satisfactory for use in this study.

A problem that arose in the early stages of this research was scarring of the area around the slot with the razor blade as the sections were made. This occurred because the steel in the blades was harder than the steel of the cutting stage area of the microtome. A piece of 440 C stainless steel was procured and a duplicate was made of the cutting stage plate. This new plate was hardened by heat treatment to Rockwell C 62. The cutting area was polished to a mirror surface and thereafter much smoother sections were made.

The microscope used for the cross-sectioning portion was a Lietz Stereo binocular microscope at 30X. This is just enough magnification to insure correct positioning of the microtome and blade.

The Bausch and Lomb mechanical microtome utilized a fixed position for the embedded fibers. A small vise that holds the embedded mass is raised in one to 50 micron increments depending on the setting of the gauge. The knife, which in this case was glass, prepared by evenly breaking a piece of plate glass, slides back and forth in a fixed plane and slices the embedded fibers placed in its path. The slicing operation is driven by a hand operated crank.

Optical Equipment

For optically viewing the cross sections, a Leitz binocular biological microscope was used. The microscope was equipped with a 10X eyepiece. The binocular attachment increased the magnification by a factor of 1.6X. For this study, a 24X objective was used and resulted in a total magnification of 384X.

In preparation of the fiber specimens for longitudinal views, a Kinney vacuum evaporator was used. The metal used for shadowing the specimens was chromium.

Photographic equipment for the optical cross sections and longitudinal views was set up on the same Leitz binocular biological microscope mentioned above. The camera used was a Tenacte 35 millimeter, Type IV S made by the Tanake Optical Company, Ltd., Japan. The objective was changed to 10X and the binocular attachment was removed. Positioning of column extensions into the barrel of the microscope yielded a final magnification of 170X.

For the evaluation of convolutions and the fiber maturity study, a Reichert Visopan projection microscope was used. This microscope projects the image onto a viewing screen. The fibers in both studies were viewed at a final magnification of 315X.

In the crimp studies the same binocular stereo microscope employed in the cross section study was used. Glass slides and double faced cellophane tape acted as the fiber support system.

In the experiment on effects of heat on cotton fibers, a Model M-209 Dazor floating fixture fluorescent illuminated magnifying glass was employed to aid in mounting the fibers on glass slides. The fibers were later viewed with an American Optical Spencer Sixty Microscope utilizing a 10X eyepiece and a 10X objective for a total magnification of 100X.

The electron microscope used in this research was the Phillips EM200. The EM200 was operated at 60,000 volts with single condenser. The resolution capability of this instrument is normally 10 angstrons. Magnifications for 35 millimeter film range from 460X to 86,500X. Print magnifications

normally range from 2,900X to 554,000X.

Gin Dryer Simulator

Heat provided by a moving stream of air was a desirable feature for a drying oven to be used for the study of effects of a range of high temperatures on individual fibers but no such oven was available. The writer and A. Goldfarb devised an apparatus based around the use of an electrically operated heat gun capable of producing a forced air stream at temperatures up to 300 degrees centigrade to be used as an oven. This apparatus is shown in Figure 2. A pyrex tube, 70 centimeters in length, 4.75 centimeters inside diameter and inclined at an angle of 7.5 degrees to the horizontal, was mounted over the nozzle of the heat gun. A variac supplied the heating elements with a controllable voltage so that the output temperature could be varied over a range of 22 degrees centigrade to greater than 300 degrees centigrade.

A device for lowering the fibers into the heat chamber was constructed by placing a glass tube through two corks. One cork was mounted on each end of the tube. A small clamp style clip was attached to the end of one cork. This clip held the glass slide on which the fibers were mounted. Since high temperatures were to be used, an adhesive was needed that could be quickly applied and easily handled. General Electric Silicone rubber cement RTV-106, which is damage resistant up to temperatures of 300 degrees centigrade, was chosen. A calibrated thermometer with a measurement range from 0 to 200 degrees centigrade was lowered into the tube and fixed in a position such that the bulb was next to the fibers.

For use in the above study and in the convolution characterization study, a method was needed for determining the central five millimeter por-

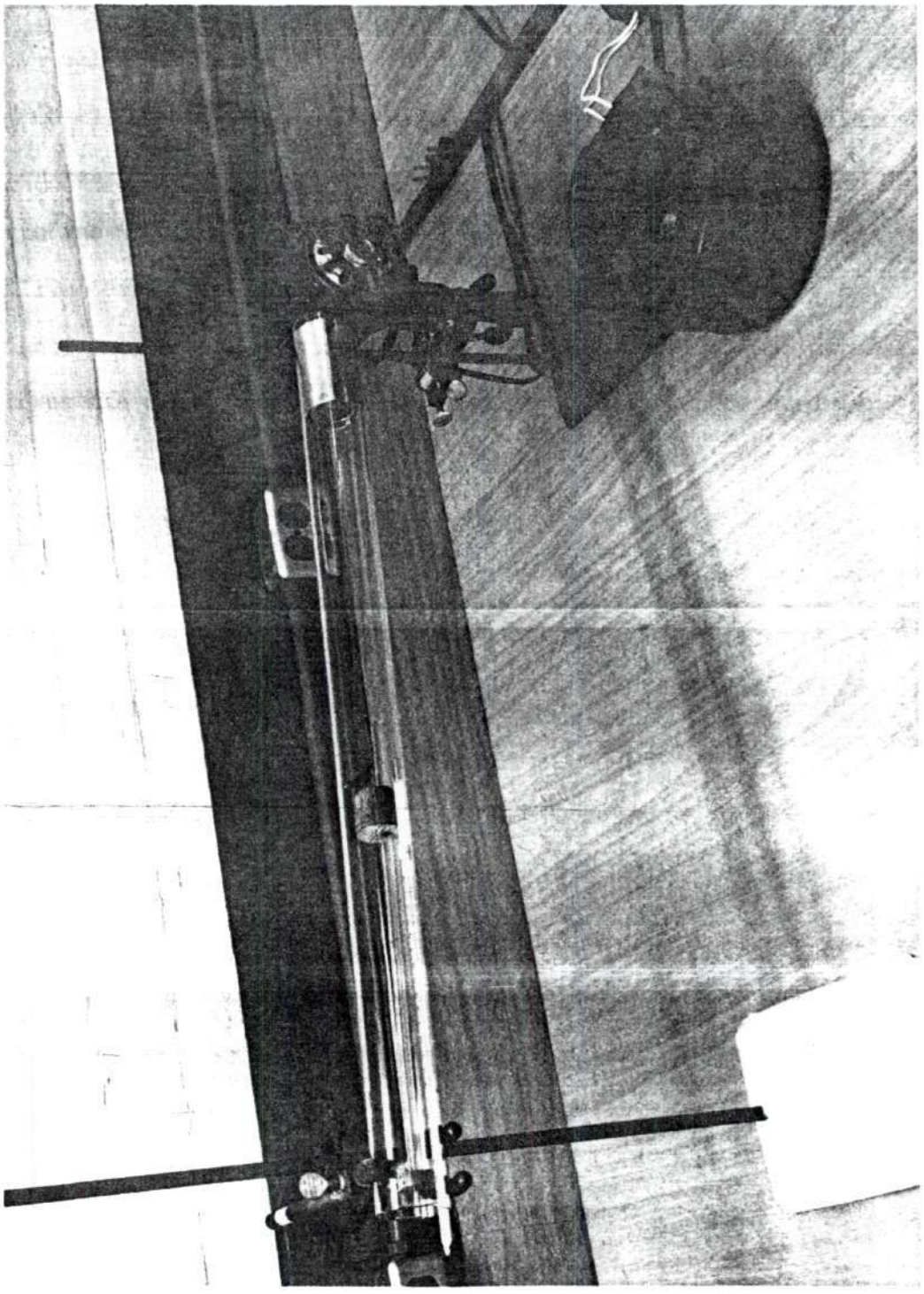


Figure 2. Gin Dryer Simulator

tion of the fibers. Betrabet et al. (38) did not specify exactly how this five millimeter area was determined for their study. Some 24 millimeter by 60 millimeter glass coverslips were procured. A five millimeter portion was carefully measured and marked on the coverslip. Then masking tape was used to mask out all the area of the coverslip leaving the five millimeter portion open. When viewed under a microscope by transmitted light, only the fibers in the open area can be seen. The tape also improves the durability of the coverslips so they can be used many times.

CHAPTER V

SPECIMEN PREPARATION AND PROCEDURES

Fiber Cross Sections

Cross sections of a fiber for optical study are slices of the fiber ade generally perpendicular to the axis in thicknesses varying from 10 o 25 microns. For study by electron microscopy, slices of thicknesses n the range .01 to .03 micron are employed. To make any of the sections uitable for viewing requires great care and the use of hand operated or echanical microtomes.

Fiber Sectioning with the Hardy Microtome

The Hardy microtome was described in Chapter IV. The procedure sed was to first take a small tuft of the fibers from the specimen. This uft was then combed with the combs from a Suter-Webb fiber sorter until he fibers were parallelized and any trash or neps were removed. This mall bundle of fibers was then placed in the slot of the microtome and he two pieces were fitted together so that the brass tongue pressed the iber bundle tightly into the slot. The bundle was centered so the center f the fibers would be the area to be cross sectioned.

The bundle was determined to be the proper size when the tongue ressed it tightly enough so that it would barely move when pulled through he slot. The ends of the fibers protruding from the slot were then cut ith scissors as closely as possible to the plate. The remaining protrud-ng ends were then coated with a mixture of 50 percent Neg-o-Lac nitrocellu-

lose lacquer and 50 percent acetone. After the Neg-o-Lac hardened (which usually took 10-15 minutes), the ends of the fibers were cut with a razor blade flush with the surface of the plate. The feeder mechanism was then fitted to the proper plate and screwed into place. The bundle was pushed up a small amount, barely noticeable under a stereomicroscope, and coated with Neg-o-Lac. Then an initial thick section was cut using a new razor blade.

Subsequent sections were made for examination by turning the plunger screw through one-half of one of the marked divisions on the head of the screw, coating the protruding fibers with Neg-o-Lac and then cutting proceeded with an unused portion of a razor blade.

The blade used for cutting had to be held firmly against the plate during the cut. The angle of the blade to the surface of the plate was 20 degrees, and the angle between the cutting edge of the blade and the slot was about 40 degrees. This insured that the blade would not ride up over the bundle and that the cut would be smooth and uniform. The cut had to be one continuous slicing motion as any pause would leave a gap in the section.

The thin film of Neg-o-Lac with the fibers in it was then lifted carefully from the microtome with tweezers and placed gently on a standard glass microscope slide. A drop of mineral oil (refractive index - 1.47) was added and a coverslip was placed over the cross section. The slide was then placed on the stage of the Leitz binocular biological microscope and viewed at 384X.

The key to successful fiber sectioning with the Bausch and Lomb microtome is rigidness of specimen so that a very thin cut can be made.

This is especially true in mechanical sectioning. The sample must be mounted in a hard medium and then held rigidly so that the edge of a piece of glass can slice off very thin sections. For this study the plastic used was araldite.

A small tuft of fibers (30 to 50) was parallelized in the same manner as mentioned above. A small cardboard frame was prepared by cutting rectangles .2 inch wide and .7 inch long from a piece of manila folder. Then, a rectangular opening about .1 inch by .5 inch was cut in the piece of cardboard. This frame was placed down and the fibers were laid across it parallel to the longitudinal axis. Then a drop of Duco cement was placed at each end of the frame to hold the fibers in place. After the cement dried, the ends of the fibers protruding past the ends of the frame were cut off and the frame was placed in a gelatin capsule.

The plastic mixture was then prepared. Five cc of Cargile Araldite 6005 resin A, five cc of Araldite epoxy resin hardener (Dodecenyl Succinic Anhydrine), 25 drops of Araldite accelerator (N-Benzyl Dimethylamine), and 20 drops of Araldite platicizer (Di-Butyl Pthalate) were mixed together in a small container. Using an eyedropper the gelatin capsules were filled with the araldite mixture. The capsules were then put in a small laboratory oven and left overnight at 60 degrees centigrade.

The hardened capsules were removed from the ovens the next day. The gelatin was chipped away from the sides of the araldite. Using a laboratory grinding wheel, a portion of the capsule was ground away. The abrasion was considered sufficient when the top portion of the cardboard frame had been ground away. This left only the fibers embedded in the plastic to be cut. The total thickness of one end of the bundle was further

reduced by grinding to form it in the shape of a tiny trapezoid with a base of approximately .1 inch and a width of approximately .05 inch. The fibers were then ready to be sectioned.

The embedded mass was placed in the vise nolder with the wider base of the trapezoid nearest the knife. The knife and the area to be cut were coated with a light film of mineral oil so that the sections would be easier to handle. The gauge was set at 25 microns and some initial thick sections were cut. The operation worked best if the section freshly cut was removed after each slice of the blade. After several thick cuts were made, the gauge was set at ten microns. The first few cuts at this thickness were discarded. Then, the next five or six cuts that were salvageable were removed with a fine artist brush and placed on a glass slide.

Examination of Cross Sections

Using the stereo binocular microscope at low power, the sections were flattened out with tweezers. A drop of mineral oil was added and a coverslip was carefully placed over the sections. Viewing continued in the same manner as described earlier.

Besides the rayon cross sections made by the mechanical microtome method, several of the cotton samples were made by this method to compare with the Hardy cross sections. All the cross sections, both Hardy and mechanical, were set aside for microphotography.

The same Leitz biological microscope used above was prepared for photography by adding column tubes and a Tenacte 35 millimeter camera. Transmitted light was used for the photography.

Studies of Fiber Shape and Surface

In viewing fibers with an optical microscope the near transparency of the fibers makes surface features such as texture and topography difficult to observe. One method of accentuating the surface features is by shadowing the surface with a thin metal film evaporated onto the fiber in vacuo. This method was employed.

To prepare the fibers, a glass slide was prepared by laying a piece of double face cellophane tape on the slide. Small tufts of five or ten fibers each were combed and parallelized as for the cross sections. The fibers were carefully laid down across the width of the slide. They were allowed to touch the tape at four or five positions along the fiber. Five specimens were put on each slide.

Several of the slides were then put into a Kinney vacuum evaporator. The glass bell jar was evacuated until a vacuum existed around the fibers. The chromium was evaporated from a tungsten basket at an angle to the fibers of approximately 18.5 degrees. The chromium was evaporated until a film thickness of approximately 50 percent optical transmission (250 angstroms) was deposited.

Photography techniques were identical to those described above except that reflection microscopy instead of transmission was employed. The shadowed and unshadowed areas give good contrast by this method.

Electron Microscopy Techniques

Whereas optical methods suffice for many textile examinations, magnifications of about 1000X are the maximum feasibly employable. Optical methods are also severely limited as to depth of focus. The electron microscope increases useful magnifications to approximately 10^6 and has tremen-

dous depth of focus. However, parameters intrinsic to the normal electron microscope limit its direct application to organic materials and replication techniques of fiber shapes and surfaces become necessary. The methods of preparing these are outlined below. A standard method was first employed in making surface replicas. A solution of approximately 20 percent polystyrene in xylene was placed on a glass slide and allowed to dry, thus forming a thin film. A few fibers were laid on the film and a second glass slide was laid on top of the fibers. The polystyrene was then softened by placing on a hot plate at a temperature of 150 degrees centigrade. The fibers were pressed down into the soft polystyrene by the pressure of the top plate. The slides were then set aside to let the polystyrene harden.

After the polystyrene had hardened, the fibers were removed using tweezers. The plastic replicas of the surface of the fibers were placed in the vacuum system and a thin layer of carbon was evaporated onto the replicas. They were then removed and cut into several one-eighth inch squares. Small wire bridges were placed in petri dishes which were filled with xylene just to the bottom of the bridges. The small squares were placed on 100 mesh copper microscope grids and were placed carbon side down on the wire bridges. The petri dishes were covered and left overnight in order that the plastic would dissolve leaving the carbon replica. These carbon replicas were removed, allowed to dry, and placed back in the vacuum system for shadowing. For the second shadowing, a thin film of platinum was evaporated from a position on a line making about a 30 degree angle with the surface of the grids.

A second method which can be attributed to Sayre (59) has been adapted to this study and has given better results than the first one. The primary

features of the Sayre method follow. A mixture of 20 drops of 2.5 percent polystyrene in xylene was mixed with .5 percent Dibutyl Pthalate (plasticizer). This mixture was spread on a glass slide and allowed to dry.

The fibers were prepared by carefully taping several fibers to a glass slide applying the tape at each end leaving 1/2 inch or more of the center section of the fiber exposed. The film prepared above was then peeled off the slide and laid on top of the fibers. A layer of Saran wrap was then placed on top of the first film. A rectangular piece of packing foam about 1/4 inch thick, typical of the type found in photographic shipping cartons, was placed on top of the Saran wrap. Another glass slide was placed on top of this and the entire sandwich was clamped together with just enough pressure to cause the foam to slightly compress. The sandwich was then placed in a laboratory oven for one hour at 60 - 70 degrees centigrade. The film was then peeled off and placed on a glass slide replica side up.

The replica was placed in the vacuum system and shadowed at an angle of 18.5 degrees with platinum. It was then coated with a thin film of carbon. The procedure for dissolving the plastic in the petri dish was exactly the same. It generally took 3 - 4 hours for the plastic to be removed. The grids were viewed and photographed in the Phillips EM200.

One problem arose with the Sayre method. It worked fine for the wools and the man-made fibers but cotton, probably due to the convolutions and its kinked configuration, was not making good replicas. It was found that by laying the prepared film on the fibers and placing the slide on a

hot plate for a few minutes the film could be melted down over the fibers and that this procedure produced good replicas.

Maturity Study

Seed cotton was employed for the maturity study. Tufts of fibers were pulled from the seeds by hand. These tufts were then combed and parallelized. Small amounts (approximately 150) of the fibers were laid carefully on a glass slide. Using an eyedropper, 18 percent sodium hydroxide was irrigated onto the fibers. The fibers were covered with a coverslip and set aside for four minutes. Each slide was than placed on the stage of a Reichert Visopan projection microscope and viewed at 315X. Using the stage movement control a point at the top of the slide was chosen. Then the slide was traversed from top to bottom so only one position on each of the fibers could be seen on the viewing screen. The first pass over the fibers was for the purpose of counting all the fibers. A second pass was made and those fibers that showed a highly convoluted appearance were counted and recorded as "dead" or immature fibers. In a third pass over the slides the rod like unconvoluted fibers were counted and recorded as fully mature fibers. Subtraction yielded the one-half mature fibers or those with some small amount of convolutions. Four slides for each type fiber were prepared and observed.

Convolution Study

In the convolution study a large number of fibers were to be observed. To examine the complete length of each fiber individually would have required a prohibitive time period. Since only a convolution per unit length value was desired the method of Betrabet *et al.* (38) was

adopted after examining its validity.

The fibers were prepared by first spreading a small amount of vaseline petroleum jelly on a glass slide until a thin film of jelly covered the slides. Then, ten or more fibers were placed on the slide and stretched out gently with fingers and tweezers until most of the crimp was removed.

The slide with the fibers was then placed on the stage of the Reichert Visopan projection microscope and a quick observation determined if there were any very immature (round, thin walled) fibers present or any fibers that were broken at both ends, indicating a break after the initial removal from the seed. Both these types of fibers were discarded as being untypical of a convoluted cotton fiber.

The prepared coverslip with the five millimeter opening was then placed gently on top of the fibers. The slide was then put on the stage of the Reichert Visopan projection microscope and viewed at 315X. Convolutions were counted in the five millimeter open area and recorded. Fibers were observed until twenty-five values for each sample were determined and recorded.

Crimp Study

It was desired in the crimp study that fibers of similar staple lengths be examined. In most cases fibers of one inch lengths were observed. For some of the cottons of longer staple, fibers of greater lengths were observed, and the values were converted to crimps per inch.

For study of crimp a factor concerning crimp must be considered. Crimp is three-dimensional and if a fiber is pressed flat under a coverslip only two dimensions will be visible. Since the waves of the crimp

are visible under a stereo microscope at 30X, a method described by Boys (60) was used. A glass slide was prepared by putting a piece of double face cellophane tape on it. The individual fibers were taken gently with tweezers and laid on the tape so that contact was made only at the first places where the fiber touched. The fibers were not pressed down in order that the natural configuration of the fiber was preserved as much as possible.

Ten fibers for each sample were observed with the stereomicroscope and the number of crimps was counted and recorded for subsequent statistical analysis.

A Study of Fiber Breaks

In a concurrent study by H. Levy (61) of the effects of opening and cleaning on the physical properties of cotton fibers, single fibers broken by tension were examined. The fiber was glued to small pieces of cardboard which were then fitted in the jaws of the Instron tester. The fibers were then broken. Photomicrographs of these fibers showing the point of breakage were made.

To prepare the fibers for viewing the pasteboard holding the fiber was cut away until a very small piece was left. Then, using tweezers, the ends of the fibers were positioned very close together and a tiny drop of mineral oil was added. A small chip of coverslip glass was placed gently over the ends of the fibers. After ascertaining that the ends of the fibers were close enough to be included in the field of the microscope by viewing the slide with the Visopan projection microscope, the fibers were photographed using the same photographic equipment employed previously.

Effects of Heating on Cotton Fibers

A study on the effects of heating cotton over a range of temperatures was conducted on Dixie King seed cotton utilizing the gin dryer simulator described in Chapter IV. Glass slides were prepared to hold the fibers by coating one end with a light layer of General Electric silicone rubber cement RTV-106 squared off at one end with a razor blade. To this layer of cement the fibers were mounted. The squared edge provided a means of aligning a coverslip over the fibers insuring that the same length of the fibers would be examined before and after heating.

Individual fibers were removed from the cottonseed and one end of each was pressed into the cement. As an optical aid to this process a model M-209 Dazor magnifying glass was used. After five to eight fibers were mounted on the slide, another small amount of cement was applied to the already cemented ends of the fibers to insure that they were thoroughly attached to the slide.

The slides were set aside for 24 hours to cure the adhesive. The cement hardened in 15 minutes but the instructions for usage stated that when high temperatures were to be used, a thorough cure was advisable.

After 24 hours the slides were placed on the stage of an American Optical Spencer Sixty Microscope and viewed at 100X. Prepared coverslips were then placed on the slides so that only the central five millimeter region of the fiber would be exposed. When the coverslip was in place, the number of convolutions observed were counted and recorded.

Individual specimens were then subjected to temperatures of 22 degrees centigrade to 200 degrees centigrade as noted in Table 9.

After the fibers were subjected to the hot air for 30 seconds they were removed and set aside for 15 minutes. The convolutions for each specimen were then counted in the same manner as before and recorded. After 24 hours the fibers were again examined and the results were recorded.

CHAPTER VI

EXPERIMENTAL WORK

General

Ten specimens of three cotton varieties, gathered in Georgia, were extensively examined by methods of optical and electron microscopy to determine fiber configuration, cross sections, and surfaces. The specific factors studied were fiber sectional dimensions, convolutions per unit length, crimp per unit length, fiber maturity, and fiber surfaces. Less extensive investigations of 14 other cotton specimens supplied by Mr. J. N. Grant of the Southern Utilization Research and Development Division, United States Department of Agriculture, were made. In a similar manner a limited study of a series of man-made fibers and two wool specimens was conducted.

Procedures for each operation are outlined in detail in Chapter V preceding. However, short refresher summaries will be given in the pertinent paragraph where considered desirable.

Fiber Shapes, Sections, and Surfaces

As noted above ten cotton specimens from central Georgia and 14 specimens from a world wide collection were procured and examined by optical and electron microscopy. Since the fiber has three important geometrical aspects, (1) the general shape along its fiber axis, (2) its cross section, and (3) its surface, these were examined by a suitable method. For the shape and section studies optical microscopy was em-

ployed and for the surface, electron microscopy, using replication techniques, was employed.

Photographic views of each fiber normal to the axis were made at 170 power. In addition, extensive visual studies were made with both the binocular and stereomicroscope. Representative photomicrographs of each fiber were made and exhibited in Figures 12 through 35 for the cotton specimens and in Figures 36 through 51 for the man-made fibers and wool. Examination shows that the shape of the various cotton fibers varies considerably and that extensive analysis of convolution count, fiber dimensions, and surface appearance, may prove profitable.

A similar examination of the man-made fibers reveals greater straightness and less variation but some possess striations and wrinkles related to the extrusion orifices employed. These features are also apparent in the sections.

For the same fiber specimens extensive sections were prepared with the Hardy microtome principally, and with the Bausch and Lomb mechanical microtome. Since a large number of fibers were included in each bundle prepared for the Hardy microtome, statistically valid dimensions could be obtained from a few studies of each fiber group. Examples of typical sections obtained for each specimen are shown in Figures 12 through 51.

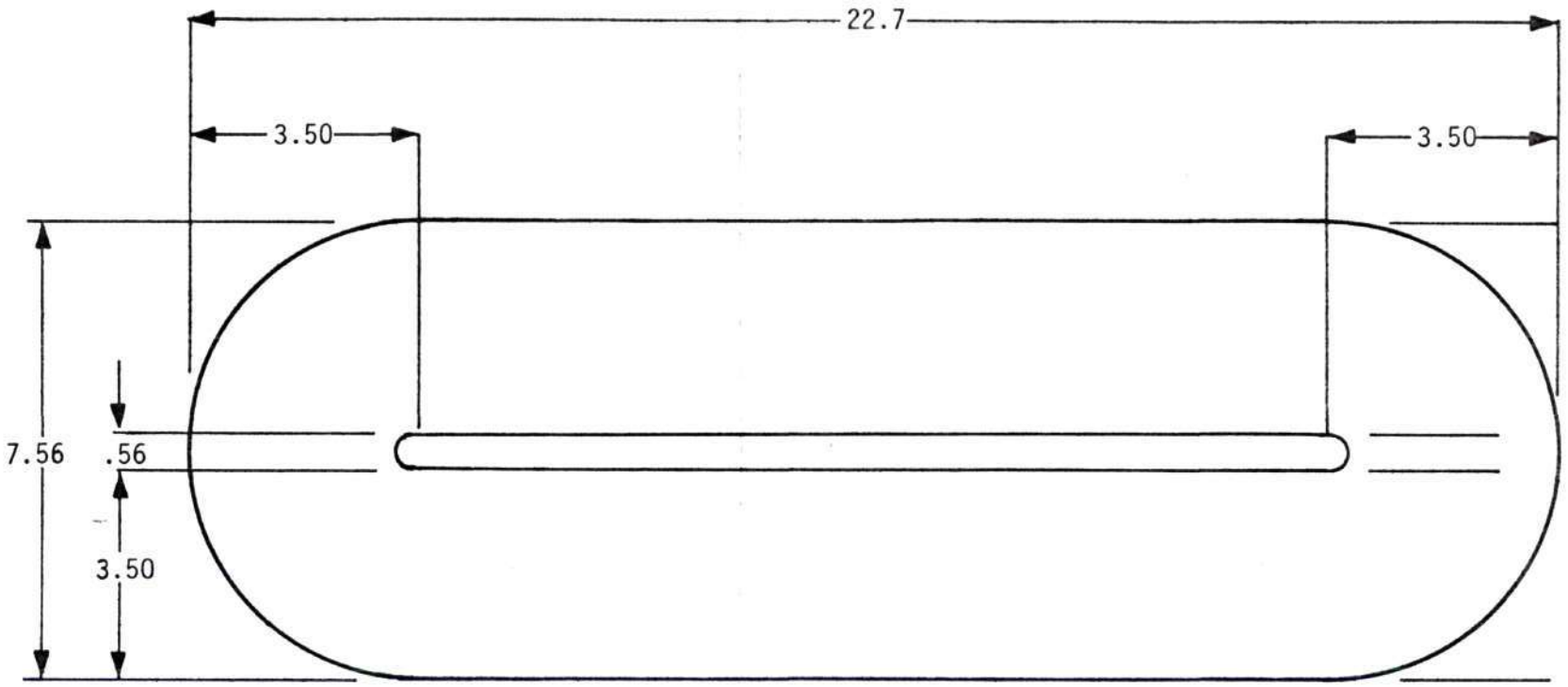
Measurements of the sections made provided data for statistically valid information concerning major and minor fiber dimensions, the ratio of major to minor dimensions, and calculations of fiber denier by means of fiber models constructed from these dimensions. The data obtained is exhibited in Tables 2, 3, and 4. An example of a constructed fiber model

is shown in Figure 3.

Of considerable interest also is that certain data obtained by Orr et al. for cotton as outlined in Table 5 can be plotted as shown in Figure 4 to exhibit the relation of fineness (denier, tex) to fiber length (upper quartile), giving essentially a straight line. Fibers of similar character group in specific localities along the plot. In Figure 5 a plot of fineness (denier, tex), which was calculated using constructed models, versus upper quartile length taken from Tables 5 and 6 is given. Plots of this data group similarly to those of Figure 4 with few random excursions. There is more scatter in the 1.15 to 1.20 inch region. At this time, it is undetermined whether this is real or experimental.

Although a considerable amount of surface topography of fibers can be observed optically and by means of optical micrographs, the fine detail of surface structure can only be obtained by electron microscopy. Replicas were made as outlined in Chapter V. Most of the replicas were made by the method of Sayre (59) which reduced preparation time and number of undesired artifacts present in the replica. Typical electron micrographs of all the fibers are shown along with the other micrographs of the particular fibers in Figures 12 through 51. The enlarged views of the surface features of the various fibers provided by the electron micrographs indicate the complex nature of the surface of the cotton. Fibrils, reversals, fibrillar angles with the fiber axis, and structural features are resolved. The man-made fibers are less complex but still indicate reasonably complex structure in a number of instances.

This latter study has been prepared principally to exhibit the fine detail appearances and variation of the various fiber surfaces for pos-



SCALE: 1 INCH = 3 MICRONS

AREA = 17.74 IN^2

159.66 μ^2

DENIER

159.66 x $10^{-8} cm^2$ x 900000 x 1.50 = 2.15 DEN.

Figure 3. Example of Construction of Fiber Model

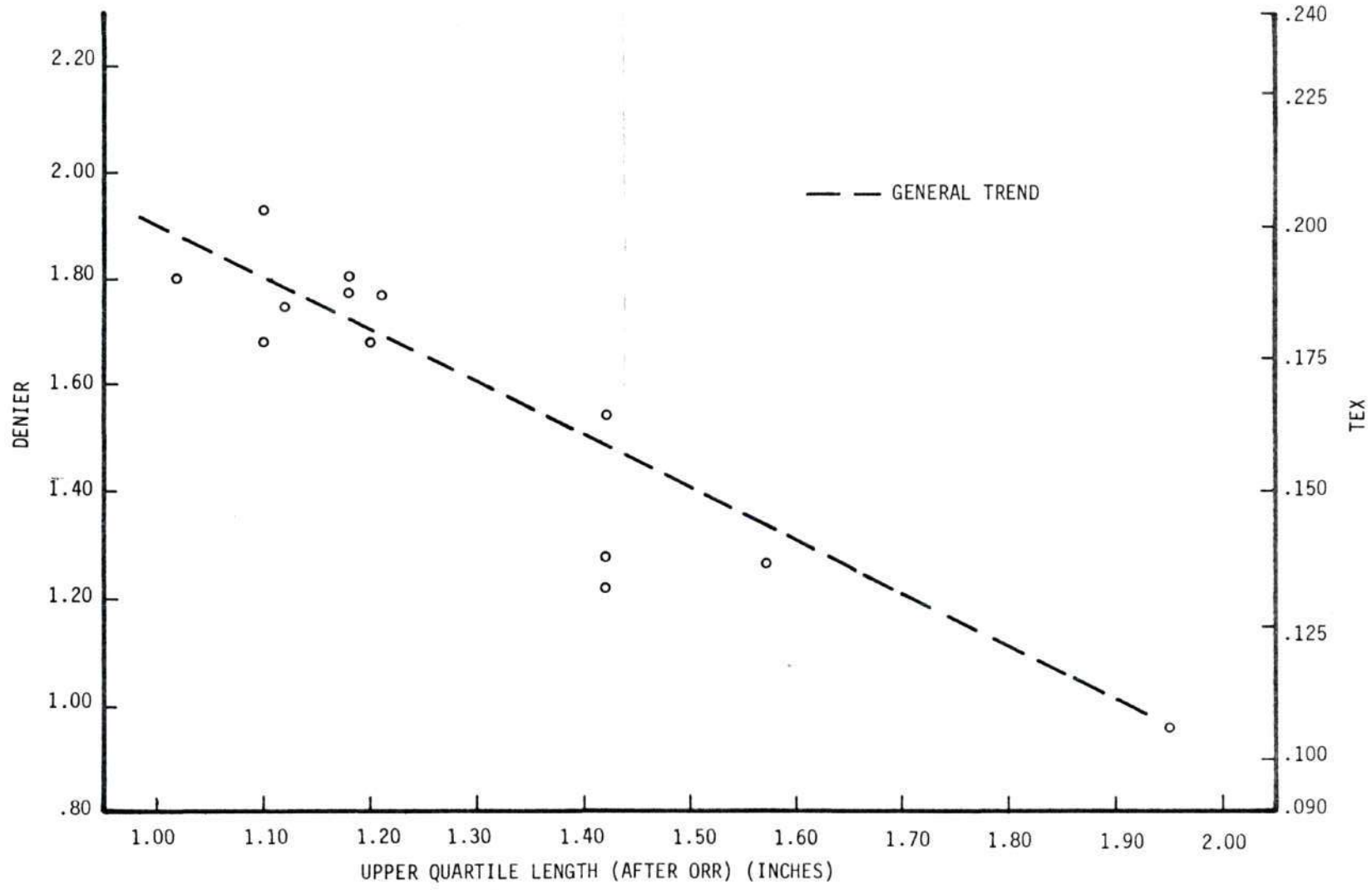


Figure 4. Fineness versus Staple Length (Upper Quartile) for Various Cottons After Data by Orr et al. (Table 5)

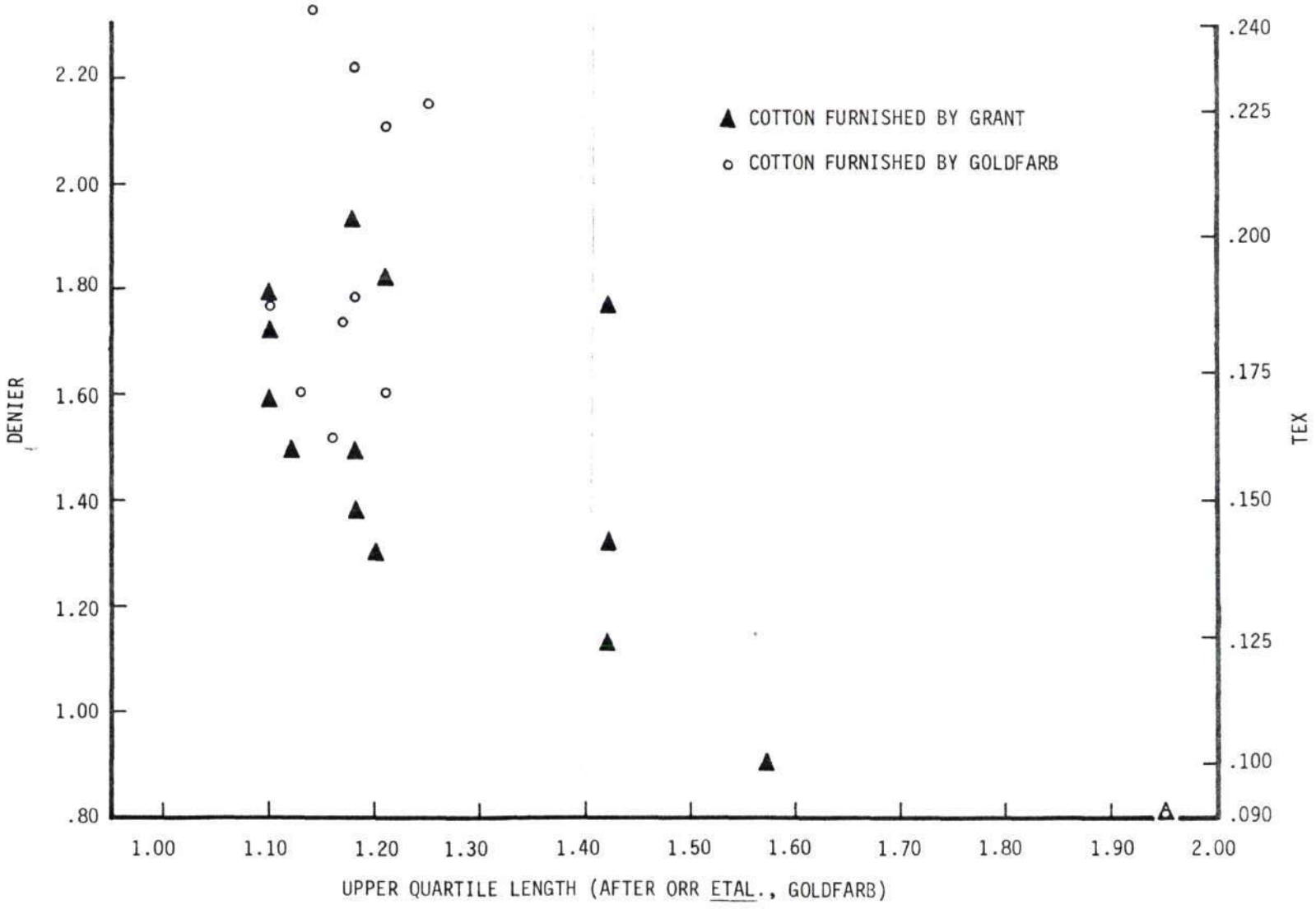


Figure 5. Calculated Fineness (Table 4) versus Staple Length (Upper Quartile) for Various Cottons Using Quartile Length Data by Orr et al. (Table 5), Goldfarb (Table 6)

sible use in identification or explanation of fiber behavior. A more detailed analysis of the specimens will undoubtedly result in additional valuable information.

Further discussions concerning the data obtained in this study and the analysis thereof appear in Chapter VII.

Convolution Studies

To verify the method of Betrabel et al. (38) for determining convolutions per millimeter, a trial experiment on a specimen of Dixie King seed cotton was conducted as shown in Table 7. The lengths of the ten fibers examined ranged over a wide spectrum of staple length to insure that the method would apply to all fibers. The results of this experiment showed an average value of 2.64 convolutions per millimeter for the full length and 2.92 convolutions per millimeter for the central five millimeter region. This is a correlation of 0.87. The results also show more convolutions in the central five millimeter region. This is logical since the ends of the fibers are always less convoluted. The number of convolutions per millimeter in the central five millimeter region of the fibers was then considered a reasonable representative of the number of the entire fiber.

The convolutions per five millimeter central portion for 25 fibers of each of the 24 cotton specimens were counted. The convolutions per five millimeter value was converted to convolutions per millimeter. The 25 values for each fiber specimen were averaged and are presented in column two of Table 8. Confidence intervals for the convolutions per millimeter for each fiber specimen were calculated and are shown in column four of Table 8. Confidence interval can be spoken of as a method of statistical

Table 8. Computed Data for Convolutions per Millimeter for Various Cotton Specimens

Cotton Name	Average Conv/mm	Standard Deviation	Confidence Interval	Tolerance Limits
Empire Hand Gin (Experiment)	3.56	.62	3.56 ± .21	3.56 ± 1.37
Empire Gin Lint (Experiment)	3.31	.482	3.31 ± .16	3.31 ± 1.06
Empire Hand Gin (Locust Grove)	3.26	.577	3.26 ± .20	3.26 ± 1.27
Empire Gin Lint (Locust Grove)	3.36	.692	3.36 ± .24	3.36 ± 1.53
Dixie King Hand Ginned	3.82	.462	3.82 ± .16	3.82 ± 1.02
Dixie King Ginned Lint	3.28	.623	3.28 ± .22	3.28 ± 1.38
Carolina Queen Hand Gin (Mech Harv)	2.44	.31	2.44 ± .11	2.44 ± .68
Carolian Queen Ginned Lint (Mech Harv)	2.59	.338	2.59 ± .12	2.59 ± .75
Carolina Queen Hand Gin, Hand Picked	2.90	.368	2.90 ± .13	2.90 ± .81
Carolina Queen Ginned Lint, Hand Picked	2.54	.295	2.54 ± .10	2.54 ± .65
Wilds Five	2.47	.266	2.47 ± .09	2.47 ± .59
Delfos	3.22	.47	3.22 ± .16	3.22 ± 1.04
Mexican Big Boll	3.48	.504	3.48 ± .17	3.48 ± 1.11
Rowden	2.80	.266	2.80 ± .09	2.80 ± .59
Pima S-1 (Sliver)	3.25	.508	3.25 ± .17	3.25 ± 1.12
St. Vincent Sea Island (Sliver)	3.07	.338	3.07 ± .12	3.07 ± .75
SXP	3.17	.378	3.17 ± .13	3.17 ± .83
Bobshaw (1951)	3.14	.294	3.14 ± .10	3.14 ± .65
Hopi Acala 54	3.20	.40	3.20 ± .14	3.20 ± .88
Pima S-1	3.40	.325	3.40 ± .11	3.40 ± .72
Deltapine 15	2.90	.280	2.90 ± .10	2.90 ± .64
Bobshaw 1955	3.22	.809	3.22 ± .28	3.22 ± 1.79
Stoneville	3.20	.347	3.20 ± .12	3.20 ± .77
Deltapine (1955)	3.07	.292	3.07 ± .10	3.07 ± .74

estimation (62). In this case the interval calculated indicates that the true mean of the entire sample of which the examined specimen is a small part will fall within the limits of the interval 95 percent of the time.

Tolerance limits for the convolutions per millimeter for each fiber specimen were also calculated and are shown in column five of Table 8. Tolerance limits are the end points of a tolerance interval. A tolerance interval covers a fixed portion of the population of values with a specified confidence (63).

In this case the limits were selected to include 90 percent of all values of convolutions per millimeter. The probability that the values would fall within the limits was 0.95.

An example of all the calculations for convolutions results is shown in Table 9.

Crimp Study

The crimp was counted in ten fibers from each of the 24 cotton specimens. One inch fibers (± 1/16 inch) were used for all the fibers except Wilds Five, Pima S-1, Sea Island, SXP, Hopi Acala, Deltapine 15, in which lengths of 1-1/4, 1-1/4, 1-5/8, 1-1/8, 1-1/8, and 1-1/8 inches respectively were used. All values obtained were converted to crimps per inch. The values for each of the cotton specimens were averaged and presented as column two of Table 10.

Confidence intervals and tolerance limits for crimp per inch of the cotton specimens were calculated using the same conditions outlined above. These values are reported as columns four and five, respectively, of Table 10. An example of the calculation for crimp for a typical cotton specimen is shown in Table 11.

Table 10. Computed Data for Crimp of Various Cottons Specimens

Name of Cotton	Average Crimps Per Inch	Standard Deviation	Confidence Intervals	Tolerance Limits
Empire Hand Ginned (Experiment)	16.5	1.08	16.5 ± .63	16.5 ± 3.07
Empire Ginned Lint (Experiment)	16.3	1.52	16.3 ± .88	16.3 ± 4.32
Empire Hand Ginned (Locust Grove)	16.6	1.41	16.6 ± .82	16.6 ± 4.00
Empire Ginned Lint (Locust Grove)	15.9	1.66	15.9 ± 1.60	15.9 ± 4.71
Dixie King Hand Ginned	16.8	1.39	16.8 ± .81	16.8 ± 3.95
Dixie King Ginned Lint	16.7	1.06	16.7 ± .62	16.7 ± 3.01
Carolina Queen Hand Gin (Mech Harvested)	17.0	1.25	17.0 ± .73	17.0 ± 3.55
Carolina Queen Gin Lint (Mech Harvested)	16.4	1.35	16.4 ± .78	16.4 ± 3.83
Carolina Queen Hand Gin, Hand Picked	14.9	.738	14.9 ± .43	14.9 ± 2.10
Carolina Queen Gin Lint, Hand Picked	14.6	.966	14.6 ± .56	14.6 ± 2.74
Wilds Five	11.4	1.07	11.4 ± .62	11.4 ± 3.04
Delfos	15.4	.699	15.4 ± .41	15.4 ± 1.98
Mexican Big Boll	13.6	1.31	13.6 ± .76	13.6 ± 3.72
Rowden	12.8	1.23	12.8 ± .71	12.8 ± 3.49
Pima S-1 (Sliver)	12.6	1.41	12.6 ± .82	12.6 ± 4.00
St. Vincent Sea Island (Sliver)	7.4	.819	7.4 ± .48	7.4 ± 2.33
SXP	13.2	1.35	13.2 ± .78	13.2 ± 3.83
Bobshaw	13.4	.966	13.4 ± .56	13.4 ± 2.74
Hopi Acala 54	10.1	.814	10.1 ± .47	10.1 ± 2.31
Pima S-1	12.9	1.09	12.9 ± .63	12.9 ± 3.09
Deltapine 15	9.8	1.06	9.8 ± .62	9.8 ± 3.01
Bobshaw (1955)	12.9	.994	12.9 ± .58	12.9 ± 2.82
Stoneville	15.0	1.34	15.0 ± .78	15.0 ± 3.80
Deltapine (1955)	11.9	.738	11.9 ± .43	11.9 ± 2.10

Maturity Study

In the maturity study a number of fibers from each of the five specimens tested were examined. Four samples of each specimen were investigated. The total number of fibers viewed was recorded. Then, number of mature, one-half mature, and immature fibers were counted. Percentages of each type of fiber found were calculated against the sum of all fibers examined. Finally, a maturity coefficient was calculated for each specimen.

The results of this study are summarized and shown in Table 12. An example of the breakdown of values and calculations is given in Table 13.

Fiber Breaks

As noted in Chapter V, a microscopic examination of fiber break interfaces was needed in conjunction with a current study in which fibers were broken under tension. Five fibers were mounted and viewed microscopically as outlined in Chapter V.

Two typical breaks are presented as Figures 6 and 7. The fiber in Figure 6 appears to have broken at a reversal point and it sheared primarily along the path of the reversal.

The fiber shown in Figure 7 broke at a straight area between reversals. The characteristics of this break differ in that the edges of the break are jagged planes with small protrusions. This is due to successive breaking of fibrils instead of a tear along a curved path.

Additional investigations in this area will be of much value.

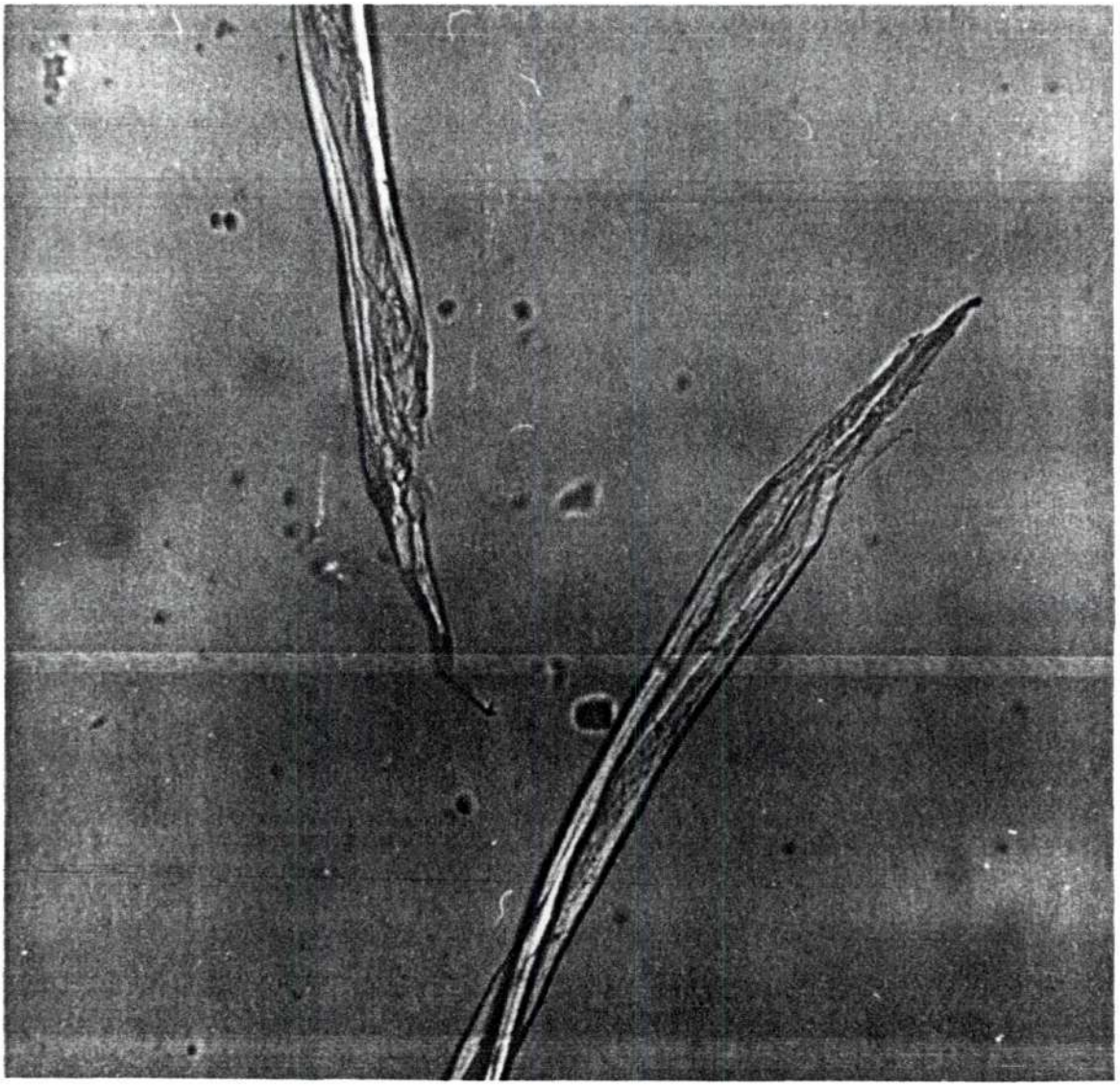


Figure 6. Micrograph of Typical Fiber Broken at Reversal (515X)

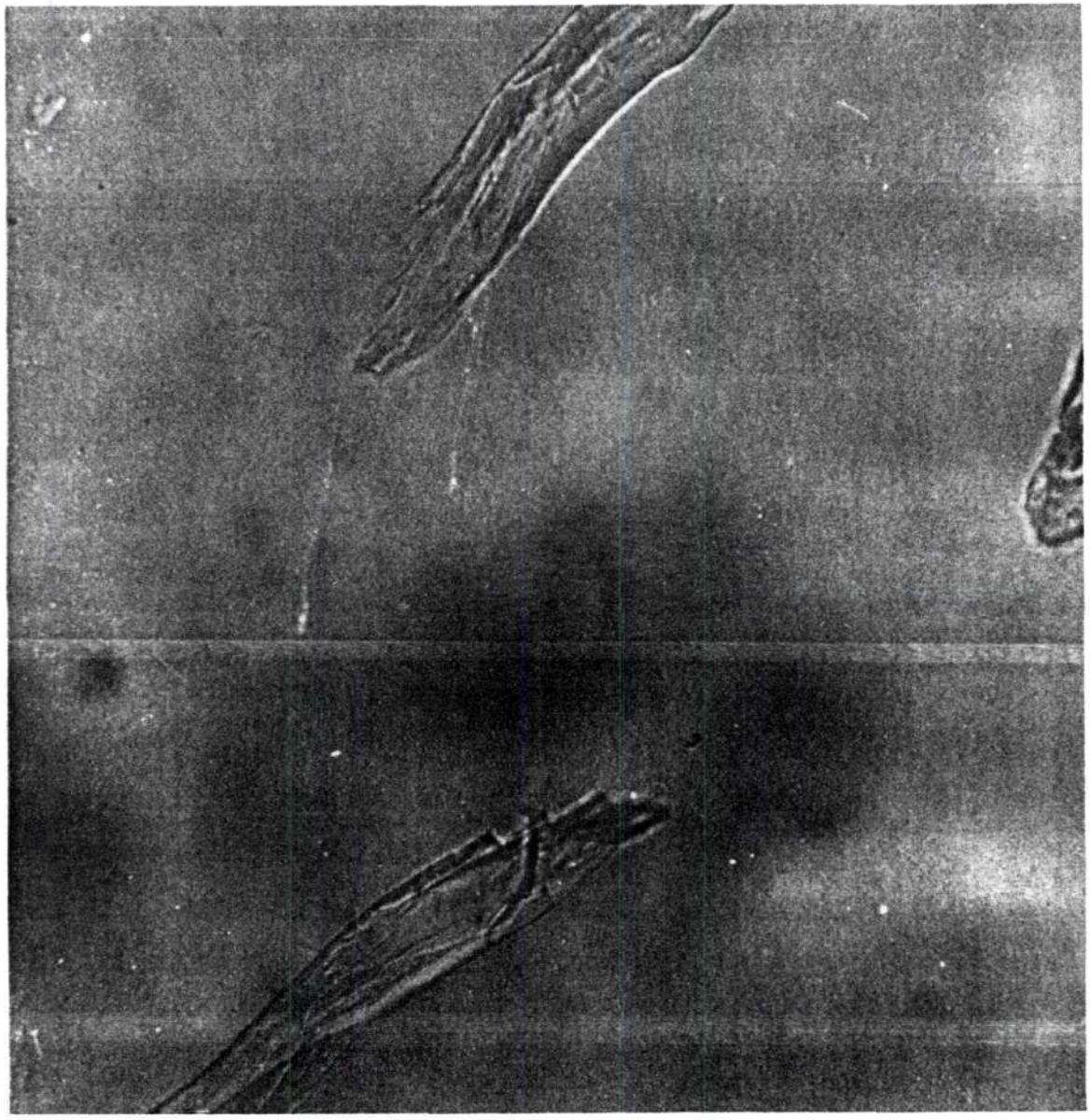


Figure 7. Micrograph of Typical Fiber Broken in Straight Zone Between 180 Degree Turns of Fiber (515X)

Effects of Heating on Cotton Fibers

In this study, five to eight fibers were placed on a glass slide using procedures outlined in Chapter V. Then each of the twelve samples was examined and the number of convolutions per five millimeters were counted. The value for each sample is averaged and shown in column three of Table 14. After exposure to heat, each sample was examined 15 minutes later. The average value for the observations is shown in column four of Table 14. Finally, 24 hours after the exposure to the heating the fibers were again examined. The values obtained were averaged and presented in column five of Table 14. Percentage change for number of convolutions per five millimeters for 15 minutes after heating and for 24 hours after heating were calculated and are given in columns six and seven, respectively, of Table 14. The data for this study are presented graphically as Figure 8.

Measurements and Analysis of Photomicrographs

In analyzing the cross sectional photographs prepared during this study, several approaches were taken. In the man-made and wool fibers, major and minor axis measurements were made. Since the magnification of the photographs was 560X, one millimeter equals 0.56 micron. Average values of these measurements are presented in Table 2. The cross sectional shapes of the fibers are of course governed by the configuration of the spinneret through which they are extruded. Of the round fibers, the Enka rayon, Figure 42, is most uniform. The polyesters, Figures 26, 45, and 46, are reasonably uniform but the nylon shown in Figure 43, although very circular, varies a great deal in diameter.

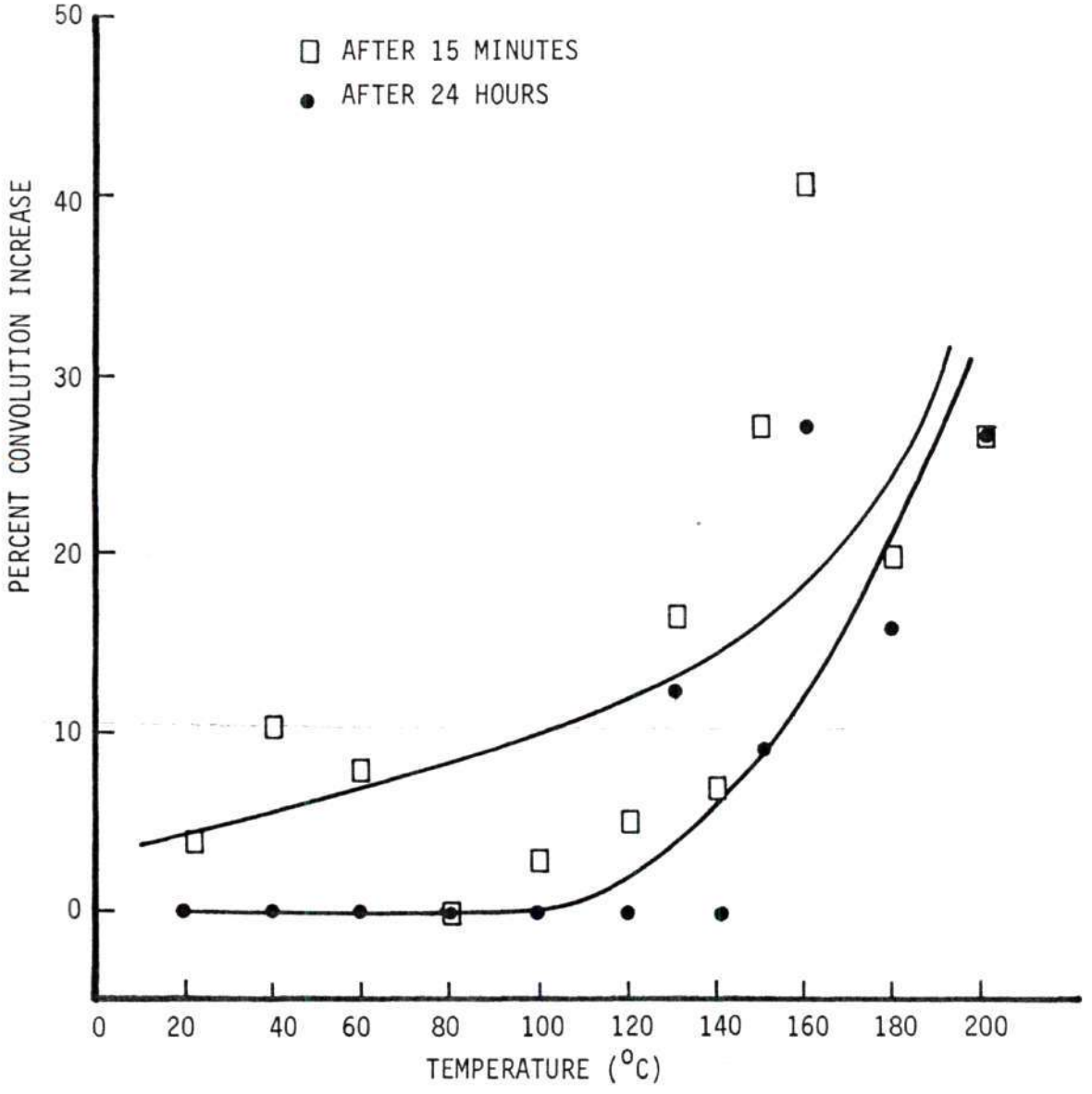


Figure 8. Convolution Change versus Temperature

The crenulated shape of the other rayons, Figures 37 through 41, is possibly an attempt by the manufacturer to duplicate the convoluted shape of the cotton fiber. The polypropylene fibers, Figure 44, seem to have a somewhat oblong configuration. The dogbone shape of the modacrylics, Figures 47 and 48, and the acrylic, Figure 49, is probably the reason these fibers are used in fabrics where bulkiness is desired. These fibers, when spun into a yarn, would not let a great amount of air through the fabric. The dark spots that appear in the cross sections of many of the fibers are titanium dioxide which is used as a delusterant. The percentage of titanium dioxide used as filler determines whether the fiber is dull or semi-dull. See pages 161 to 170 for further comments.

The wools, Figures 50 and 51, show an irregular cross section varying from round to oblong.

The cottons, though easily identifiable by the elliptical shape and the lumen canal, vary somewhat. Measurements of the major and minor axes and the wall thicknesses were averaged and summarized in Table 3. Major variances apparently only exist between cottons belonging to different botanical species. Most of the cottons in this study are of the American Upland variety which is part of the Gossypium Hirsutum species. The Pima S-1 specimens are part of the Vitifolium form of the Gossypium Barbadense species. The St. Vincent Sea Island cotton is among the longest and finest cotton available. It belongs to the Gossypium Barbadense species.

The American Upland cottons are a coarse cotton generally in the one inch staple range. The other cottons in this study are finer and longer with staple lengths greater than 1.5 inches.

The measurements of Table 3 were used to construct models of each

of the cotton specimens used in this study. An assumption was made that ideally, the cross section of cotton is an elongated ellipse. A rectangle was constructed using the measurements of the major and minor axes. Then the lumen was constructed from the wall thickness measurements. The angles of the corners of the rectangle were bisected and the intersection points were used as center points for constructing a semicircle. The radius of the semicircle was one-half the minor axis. From the same point, a semicircle was constructed for the end of the lumen using one-half the lumen width as the radius. An example of this construction is shown in Figure 3.

The area of the fiber cross section was then measured in square inches with a Keuffel and Esser planimeter. The measurements were converted to square microns. Then, using a formula given in Heyn (67) and Stoves (68) which is

$$D = a \times 900,000 \times \Delta$$

where D = Denier (the weight in grams of 9,000 meters of fiber)

a = area in square centimeters

Δ = specific gravity of fiber

the denier of each fiber was calculated. Square microns were converted to square centimeters by multiplication by 10^{-8}. A specific gravity of 1.50 for cotton given by Heyn (69) was used. Tex (grams per 1,000 meters) was also calculated by substituting 100,000 for 900,000 in the formula. The results are summarized and presented in Table 4.

Most of the American Upland cottons are in the 1.75 to 2.00 denier range. The Pima-1 cottons and the Sea Island cotton are 1.00 denier or

CHAPTER VII

DISCUSSION

Cross Section, Optical Surface Study, and Electron Microscopy Photographs

Figures 12 through 51 represent the first collection of photomicrographs exhibiting sections, surface features, and electron micrographs of a large number of economically important fibers in a single study. Visual comparison of the photomicrographs with others of similar specimens in the literature shows that, for detail and technique, these compare very favorably. In addition, many are exhibited for the first time to the public.

Comparison of the photographs of typical cross sections (Figure 9) made by the Hardy Hand microtome and the Bausch and Lomb mechanical microtome shows that the mechanical method gives very thin sections which for the most part show good detail. However, the relative times for obtaining usable cross sections were the deciding factor in this study, since the mechanical methods require 24 or more hours and the Hardy method one hour or less. The mechanical microtome, by its consistency does give very thin sections and is superior for single fiber studies.

Denier and tex calculations made from constructed models of cotton fibers are, to the knowledge of the author, presented in this paper for the first time. The formula given in Chapter VI was intended to be used where the cross section of a fiber was projected onto a screen which had

(a)

(b)

Figure 9. Comparison of Micrographs of Cross Sections Made by (a) Hardy Microtome and (b) Bausch and Lomb Mechanical Microtome

grid squares on it. The area was to be figured by calculating number of squares covered.

Denier and tex may be obtained using a vibrascope. Unfortunately, one was not available for this study. Orr et al. (64) reported the tex values for many of the same cotton specimens used in this study. These values are shown in Table 5. Orr reported only one value for Empire which was .190 tex. The average for the four Empire specimens in this study was .202. These values are very close. Mexican Big Boll, which calculated to .199 tex in this study, was reported to be .203 tex in the Orr study. Pima S-1 Sliver and Pima S-1 cotton compared favorably for calculation between the two studies. The sliver was calculated at .146 and the raw cotton at .125. Orr reported values of .138 and .132. The St. Vincent Sea Island compared favorably with .097 (calculated) compared to .106 (reported by Orr). Deltapine also was very close with an average value of 1.71 for two specimens calculated compared to 1.81 average for two specimens reported by Orr.

The denier measurements also support an earlier statement on length and fineness. Pima S-1, SXP, and St. Vincent Sea Island, while having the lowest tex values (.125, .107, and .097), also were the longest staple cottons. This was shown by observation earlier in the study in crimp determination and is verified by Orr et al. in Table 5, where the upper quartile lengths, 1.42, 1.57, and 1.95 inches, respectively, are recorded.

From Table 3, which is a summary of the average measurements of major and minor axes and wall thicknesses in microns and inches, two interesting points may be made in connection with the above. Most of the specimens with the exception of a few of the very long staple cottons have

major axis measurements of .0008 to .0009 inch. Also, the average major to minor axis remains fairly constant throughout (about 3.0). The long staple cottons had markedly smaller major axes and denier.

Crimp Results

Boys (65) gave a value of 16.4 crimps per inch for a one inch Empire WR cotton fiber. For the four Empire WR specimens examined in this study, an average of crimps per inch was 16.3, thus supporting Boys' measurements. Two crimp parameters defined by Shiloh (35), the crimp-diameter and the specific uncrimping energy, were shown by Shiloh to be significantly correlatable with upper quartile length. Fineness is also shown to be significantly correlatable to crimp diameter and specific uncrimping energy. The report of Shiloh thus indicates that cottons with longer staple and finer fiber have lower crimp parameters.

Using the upper quartile lengths of Orr et al. and Goldfarb, given in Tables 5 and 6, crimp per inch from Table 10 was plotted versus quartile length and presented as Figure 10. It can be seen that large variations in crimp per unit length exist for the shorter cottons. However, there are a great deal more data for these cottons. The dotted line on the graph shows the approximate general trend.

An interesting point is shown in Table 10. The hand picked samples of Carolina Queen averaged 14.8 crimps per inch, while the mechanically harvested averaged 16.7 crimps per inch. This probably is a result of the hand picked fiber being longer on an average than the mechanically harvested cotton, thus having less crimp per length.

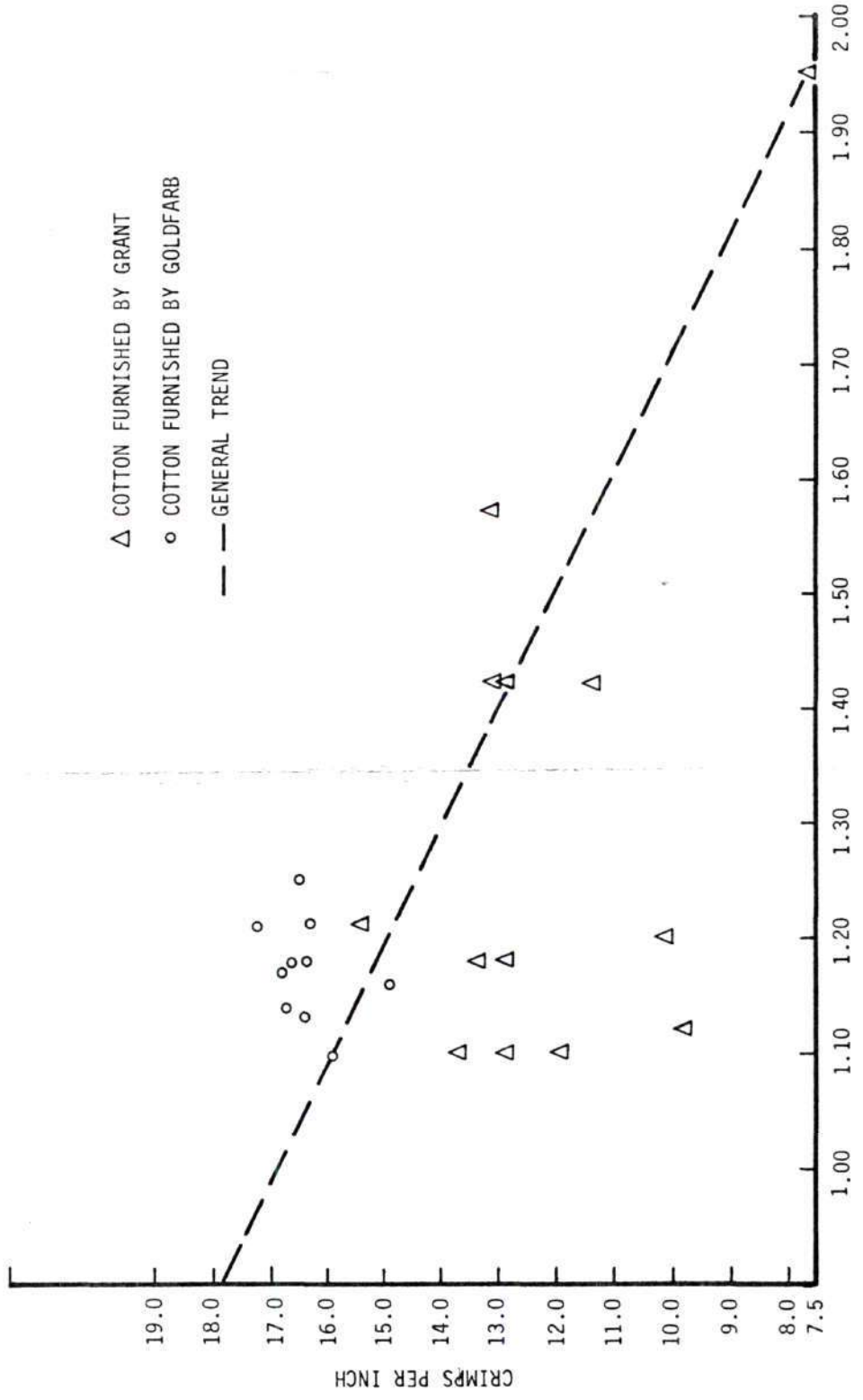


Figure 10. Crimp Per Inch versus Upper Quartile Length for Various Cottons

Convolution Results

Boys (66) showed an average value of 84.6 convolutions per inch for Empire WR cotton fiber. The average convolution per millimeter of the four specimens of Empire used in this study was 3.56, 3.31, 3.26, and 3.36. Boys, of course, used the entire fiber and determined length of each fiber examined, while this study used only the central five millimeter portion and considered only fibers that appeared to be "average," i.e., very long, short or broken fibers were not counted. However, the values obtained by this study convert to 90.5, 84.1, 82.7, and 85.4 convolutions per inch. All these values fall within the tolerance limits set by Boys (84.58 ± 28.00) and only one value, 90.5, for the Empire hand ginned from Experiment, falls outside his confidence interval (84.58 ± 4.34).

It appears that the method described and used in this study for determining convolutions per millimeter is both quick and relatively accurate within tolerances.

Meredith (43) defined a convolution as a 180 degree turn of the fiber. This study of course has considered a convolution as a 360 degree turn. With this in mind, the data of Betrabet et al. (40) are considered. Betrabet obtained convolutions (Meredith's definition) per centimeter for 67 cottons, five of which are similar to five included in this study. The cottons and the values which have been converted to convolutions per millimeter are Delfos 2.92, Deltapine 3.40, Stoneville 3.17, Acala 2.69, and Bobshaw 2.14. Values obtained in this study were Delfos 3.22, Deltapine 2.90, Stoneville 3.20, Hopi Acala 54 3.20, and Bobshaw 3.18 (average). For the most part, these values are not necessarily correlatable but, since there are many varieties and crops of each of the above named specimens,

this is understandable. There is a good agreement between the Stoneville specimens, however.

Using the upper quartile lengths of Orr et al. and Goldfarb from Tables 5 and 6, a plot of convolutions per millimeter from Table 8 versus upper quartile length is presented as Figure 11. It can be seen that there is tremendous scatter at most of the lengths. When the confidence interval is added for the longer staple cottons, a gentle downward slope can be approximated.

Orr et al. (64) and Table 5 report reversals per millimeter instead of convolutions. Since a reversal is a point where the winding of the fibrils changes direction, these data are not necessarily correlatable to convolutions. It is interesting to note that for Rowden the value for reversals, 2.74, is very near that for convolutions, 2.80. The other specimens follow a pattern of reversals per millimeter being somewhat less than convolutions per millimeter.

Fiber Breaks

The analysis of the five photographs of fibers which had been broken gave interesting results. Three of the fibers broke at what was considered to be a reversal point or the point where the convolution formed an acute angle with the fiber axis. The other two broke at points along the straight unconvoluted portion of the fiber. An example of a fiber which broke at a reversal point is shown in Figure 6. A fiber which broke in between reversals and convolutions is shown in Figure 7. An interesting point is learned from the photographs. The breaks appear to be of two types. The one of the reversal is essentially a shear or tear whereas the other appears to be a tensile break in which little shear was involved, re-

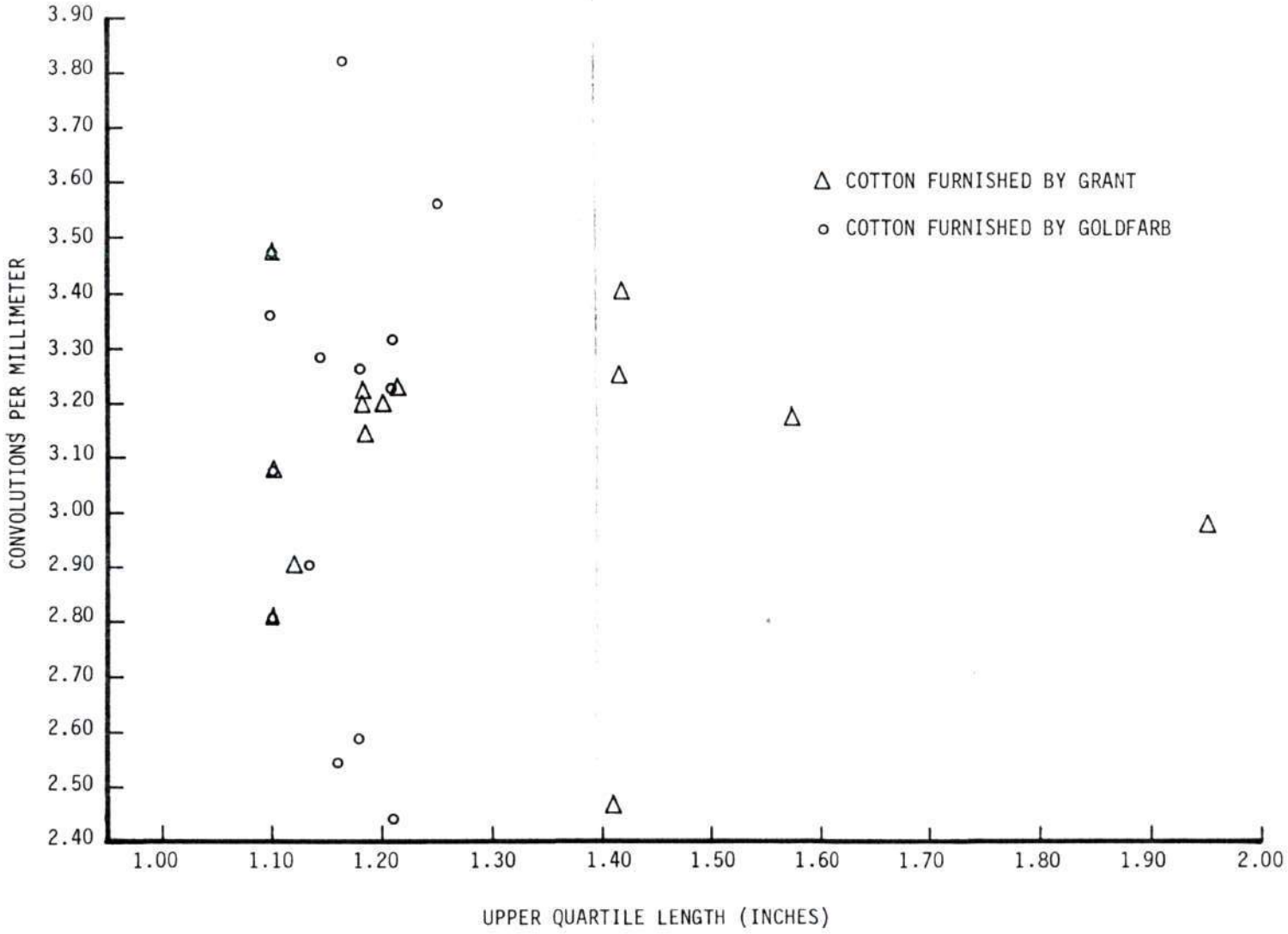


Figure 11. Convolution Per Millimeter versus Upper Quartile Length for Various Cottons

sulting in somewhat jagged interface.

Maturity Study

No data are available in the literature on the specimens used in this study for comparison of the maturity coefficients derived and presented in Table 12. The study (57), in which the formula used was presented, separated the fibers studied into various length groups. The four groups consisted of all the fibers from the specimens tested including very short and very long fibers. In the present study, only one group was used without regard to length. The average in the previous work for cotton in the Gossypium Hirsutum class was .892. This is the class in which the specimens used in this study belong. The values for the cottons used in this study are Empire hand ginned (Experiment) .785, Empire hand ginned (Locust Grove) .793, Dixie King hand ginned .759, Carolina Queen hand ginned, mechanically harvested .740, and Carolina Queen hand ginned, hand picked .783.

It is readily evident that there is not a high degree of correlation between this study and work reported by Pillay (57). However, the cottons being compared are not of the same varieties or location. There is good correlation between the values obtained for the various species examined in this study.

Effect of Heating on Cotton Fibers

The results of heating the cotton to simulate gin drying effects showed that there was a convolution increase of some degree at all temperatures above 70 degrees Fahrenheit except one. From Table 14 it is evident that even at the lowest temperature (70 degrees Fahrenheit) there

was a convolution increase after 15 minutes (3.6 percent). Increases after 15 minutes were noted at all temperatures except 176 degrees Fahrenheit. Highest increase was at 320 degrees (40.9 percent), while the lowest was at 212 degrees (3.0 percent). The failure to increase at 176 degrees can be discounted as experimental error, since increases were noted up to that point.

Permanent changes (existing after 24 hours) were first noted at the 266 degrees Fahrenheit mark (12.5 percent). Changes of a permanent nature existed at all other temperatures higher except 284 degrees in which there was no change. Highest percentage of permanent change occurred at 320 degrees Fahrenheit (27.3 percent). These data are presented graphically in Figure 8. Observation of this graph shows clearly the relationship between temporary and permanent change.

The fact that permanent changes in single fibers did not occur until the fibers were exposed to temperatures greater than approximately 248 degrees Fahrenheit agrees very closely with the work of Berriman (51) which showed that permanent changes begin to occur in the range 230-250 degrees Fahrenheit.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The collection of fiber specimens used in this study represents a broad sampling of natural and man-made fibers. This collection will be useful in further studies of fiber properties since these fibers have been well characterized by photomicrography and electron microscopy.

The Hardy method for hand microtomy is a valuable device. Sections prepared by this method are acceptable for analysis of fiber cross section shape by optical microscopy. The Bausch and Lomb mechanical microtome produces ultra-thin sections which are more useful for certain examinations and for specific fibers. On the other hand, the Hardy method is a much more rapid one, in that sections may be prepared in less than an hour as compared to 24 hours for the mechanical method; hence, its employment in large scale experiments is desirable.

The Sayre (59) method for electron microscopy replicas produces excellent replicas in a shorter time with less difficulty than the standard method.

Denier and tex calculations made from fiber models constructed from cross section measurements correlate well with previous results obtained by other methods. The method of constructing models by assuming an elongated elliptical shape for the cotton fiber is an interesting and valuable research technique. A denier versus fiber length plot could furnish a use-

ful classification method for unknown cotton specimens.

Crimps per inch and convolutions per millimeter determined in this study compare favorably with available earlier data. The method proposed by Betrabet for quickly determining convolutions per millimeter by examining the central five millimeter portion was shown to be satisfactory for this determination of convolution counts.

It has been shown that cotton fibers, after being exposed to temperatures of approximately 248 degrees Fahrenheit and higher, have permanent increases in number of convolutions per unit length. Changes of 12.5 percent were noted at 266 degrees Fahrenheit.

The maturity coefficients for five of the cotton specimens included in this study are in the range 0.740 to 0.793. Although length of fibers was not considered, a value of 0.78 can be accepted as a valid figure for these specimens.

Fiber breaks, in a limited study, were found to occur at reversal points in three out of five cases. Breaks appeared to be sheared smoothly when occurring at these positions and more raggedly when at in-between positions.

The data collected and methods outlined should benefit future investigators of fiber properties.

Recommendations

It is recommended that a continuing program of research by techniques of optical and electron microscopy be a part of the future textile research program at Georgia Tech.

In particular, certain programs now underway should be implemented

to the degree possible by these methods. These programs include specifically, (1) a method of cross sectioning single fibers and a program to relate such observations to other measurements of the physical properties of the fibers; (2) more aggressive application of micrography techniques to the current studies of the frictional properties of fibers; (3) additional studies of fiber break positions and character and correlation of these with tensile strength or other properties.

An equipment supplement for current and future work that would be of assistance is a vibrascope. In the field of electron microscopy, a reflection or scanning microscope and a high energy (1 MeV) microscope appear to hold great promise in fiber research, and their procurement at the earliest feasible date is recommended.

APPENDIX

Table 2. Summary of Average Major and Minor Axis Measurements for Wools and Man-Made Fiber Cross Sections in Microns and (Inches)

Fiber Name	Major	Minor
Wool (Unscoured)	15.86 (.00062)	13.46 (.00053)
Wool (Scoured)	23.64 (.00093)	20.07 (.00079)
Dacron Polyester	18.03 (.00071)	16.13 (.00064)
Celanese Dull Triacetate	19.19 (.00076)	12.50 (.00049)
Avisco Rayon	22.07 (.00087)	12.82 (.00050)
Avisco Bright Rayon	18.23 (.00072)	13.25 (.00052)
Avisco Dull Rayon	19.55 (.00077)	15.13 (.00060)
Avisco Bright Fiber 40 Rayon	18.64 (.00073)	13.70 (.00084)
Elka Rayon	12.50 (.00049)	11.61 (.00046)
Dupont Nylon Semi-Dull	18.55 (.00073)	17.87 (.00070)
Herculon Polypropylene	20.57 (.00081)	18.50 (.00073)
Kodel Polyester II Semi-Dull	19.87 (.00078)	19.03 (.00075)
Kodel Polyester IV Semi-Dull	17.71 (.00070)	17.11 (.00067)
Verel Modacrylic Bright	27.54 (.00108)	9.91 (.00039)
Verel Moclacrylic Dull	27.16 (.00106)	9.66 (.00038)
Orlon 72 Acrylic	20.30 (.00080)	6.70 (.00026)

Table 3. Summary of Average Measurements of Major and Minor Axes and Wall Thicknesses for Cottons in Microns and (Inches)

Cotton Name	Major Axis	Minor Axis	Wall Thickness	Ratio Major/Minor
Empire WR Hand Ginned (Experiment, Ga.)	22.7 (.00089)	7.56 (.00030)	3.50 (.00014)	3.0
Empire WR Ginned Lint (Experiment, Ga.)	21.04 (.00084)	6.84 (.00027)	2.94 (.00012)	3.08
Empire WR Hand Ginned (Locust Grove, Ga.)	22.39 (.00088)	6.38 (.00025)	3.02 (.00012)	3.51
Empire WR Ginned Lint (Locust Grove, Ga.)	21.66 (.00085)	7.59 (.00030)	3.28 (.00013)	2.86
Dixie King Hand Ginned	21.95 (.00086)	7.36 (.00029)	3.20 (.00012)	2.97
Dixie King Ginned Lint	24.21 (.00095)	8.15 (.00032)	3.52 (.00014)	2.97
Carolina Queen Hand Ginned	24.18 (.00095)	8.02 (.00031)	3.44 (.00014)	3.03
Carolina Queen Ginned Lint	24.02 (.00094)	7.92 (.00031)	3.38 (.00013)	3.04
Carolina Queen Hand Ginned	22.58 (.00089)	5.04 (.00020)	2.41 (.00010)	4.48
Carolina Queen Ginned Lint	22.62 (.00089)	5.77 (.00023)	2.54 (.00010)	3.92
Wilds Five	21.42 (.00084)	5.50 (.00021)	2.48 (.00010)	3.90
Delfos	21.90 (.00086)	6.85 (.00027)	3.20 (.00013)	3.20
Mexican Big Boll	22.42 (.00088)	6.94 (.00027)	2.95 (.00012)	3.24
Rowden	22.22 (.00087)	6.74 (.00026)	3.04 (.00012)	3.31

Table 3. Summary of Average Measurements of Major and Minor Axes and Wall Thicknesses for Cottons in Microns and (Inches) (Concluded)

Cotton Name	Major Axis	Minor Axis	Wall Thickness	Ratio Major/Minor
Pima S-1 (Sliver)	16.29 (.00064)	6.79 (.00027)	3.06 (.00012)	2.40
St. Vincent Sea Island (Sliver)	15.29 (.00063)	4.47 (.00018)	2.16 (.00009)	3.56
SXP	16.42 (.00065)	4.47 (.00018)	2.12 (.00008)	3.67
Bobshaw (1951)	20.98 (.00082)	6.79 (.00027)	3.04 (.00012)	3.09
Hop. Acala 54	16.88 (.00067)	6.86 (.00027)	3.16 (.00012)	2.46
Pima S-1	17.77 (.00070)	5.18 (.00020)	2.39 (.00009)	3.42
Deltapine 15	19.95 (.00079)	6.03 (.00024)	2.68 (.00011)	3.30
Bobshaw (1955)	19.52 (.00077)	6.36 (.00025)	2.84 (.00011)	3.06
Stoneville	22.02 (.00087)	5.54 (.00022)	2.68 (.00011)	3.98
Deltapine (1955)	20.62 (.00081)	6.90 (.00027)	3.16 (.00012)	2.99

Table 4. Summary of Denier and Tex Calculated for Cotton Specimens

Cotton Name	Area $(Microns)^2$	Tex	Denier
Empire WR Hand Ginned (Experiment)	159.66	.239	2.15
Empire WR Ginned Lint (Experiment)	118.20	.177	1.60
Empire WR Hand Ginned (Locust Grove)	131.70	.197	1.78
Empire WR Ginned Lint (Locust Grove)	130.90	.196	1.77
Dixie King Hand Ginned	127.80	.192	1.73
Dixie King Ginned Lint	172.90	.258	2.33
Carolina Queen Hand Ginned	156.10	.234	2.11
Carolina Queen Ginned Lint	164.20	.246	2.22
Carolina Queen Hand Ginned (Hand Picked)	111.80	.167	1.50
Carolina Queen Ginned Lint (Hand Picked)	112.20	.168	1.51
Wilds Five	130.00	.195	1.76
Delfos	135.00	.202	1.82
Mexican Big Boll	132.30	.199	1.79
Rowden	126.60	.190	1.71
Pima S-1 (Sliver)	97.90	.146	1.32
St. Vincent Sea Island (Sliver)	64.80	.097	.87
SXP	71.80	.107	.97
Bobshaw (1951)	110.30	.165	1.49
Hopi Acala 54	96.10	.143	1.30
Pima S-1	83.40	.125	1.13
Deltapine 15	110.25	.165	1.49
Bobshaw (1955)	102.50	.153	1.38
Stoneville	143.10	.214	1.93
Deltapine (1955)	117.90	.177	1.59

Table 5. Cotton Samples with Wide Ranges in Physical Properties (After Orr et al.)

Sample Name	Upper Quartile Length In.	Fineness (Center) Tex	Reversals/mm
1. Empire	1.12	.190	3.13
2. Wilds Five	1.42	.164	2.25
3. Delfos	1.21	.187	2.01
4. Mexican Big Boll	1.10	.203	2.69
5. Rowden	1.10	.253	2.74
6. Pima S-1	1.42	.138	2.47
7. Sea Island (St. V.)	1.95	.106	2.78
8. SXP	1.57	.137	2.22
9. Bobshaw	1.18	.190	2.54
10. Hopi Acala	1.20	.178	2.47
11. Pima S-1	1.42	.132	2.64
12. Deltapine	1.12	.184	2.90
13. Bobshaw	1.18	.187	2.01
14. Stoneville 2B	1.18	.190	2.71
15. Deltapine	1.10	.178	2.47

Table 6. Upper Quartile Length of Cotton Specimens Gathered in Georgia (After Goldfarb)

Cotton Name	Upper Quartile Length (inches)
Empire WR Hand Ginned (Experiment)	1.25
Empire WR Ginned Lint (Experiment)	1.21
Empire WR Hand Ginned (Locust Grove)	1.18
Empire WR Ginned Ling (Locust Grove)	1.10
Dixie King Hand Ginned	1.17
Dixie King Ginned Lint	1.14
Carolina Queen Hand Ginned	1.21
Carolina Queen Ginned Lint	1.18
Carolina Queen Hand Ginned (Hand Picked)	1.13
Carolina Queen Ginned Lint (Hand Picked)	1.16

Table 7. Comparison of Convolutions Along Entire Length and Central Five Millimeter Portion Only

Sample Number	Fiber Length Inches	Convolutions	Conv./in	Conv./mm	Central 5 mm Conv./mm
1	1/2	26	52.0	2.05	2.40
2	3/4	64	85.0	3.34	3.45
3	7/8	69	80.0	3.14	3.39
4	1	85	85.0	3.34	3.10
5	1-1/4	54	43.2	1.70	2.00
6	1-1/4	66	52.8	2.08	1.80
7	1-1/4	87	70.5	2.77	3.00
8	1-3/8	95	69.1	2.72	3.10
9	1-1/2	101	67.3	2.65	3.65
10	1-1/2	107	71.3	2.81	3.30
			Average	2.64	2.92

Table 9. Example of Calculations of Convolutions

Fiber Specimen	Cotton	Empire	Ginned Lint (Experiment, Ga.)
Sample Number	Conv/5mm	Conv/mm	
1	18	3.6	$\Sigma X = 82.7$
2	13	2.6	$\bar{X} = 3.31$
3	17	3.4	
4	18.5	3.7	$\Sigma X^2 = 279.3$
5	22	4.4	
6	18	3.6	$(\Sigma X)^2 = 6839.3$
7	15	3.0	
8	16	3.2	$n = 25$
9	20	4.0	
10	14	2.8	
11	17	3.4	$SD^2 = \frac{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}{n-1}$ $SD^2 = \frac{279.3-273.6}{24}$
12	13.5	2.7	
13	16	3.2	
14	12.5	2.5	$SD^2 = .237$ $SD = .482$
15	13	2.6	
16	18	3.6	Confidence Interval - 95% Confidence
17	17	3.4	
18	18	3.6	
19	20	4.0	$\bar{X} \pm t$ (one tailed for n-1) $\frac{S}{n}$
20	14	2.8	
21	16	3.2	
22	17	3.4	$3.31 \pm 1.711 \frac{.48}{5.0} = 3.31 \pm .164$
23	15	3.0	
24	18	3.6	Tolerance Limits - 95% Confidence 90%
25	17.5	3.5	
			$\bar{X} \pm KS$ $K = 2.208$
			$3.31 \pm 2.208\ (.48) = 3.31 \pm 1.06$

Table 11. Examples of Calculations for Crimp

Fiber Specimen: Cotton Empire WR Ginned Lint (Experiment, Georgia)

Sample Number	Crimps Per Inch
1	15
2	19
3	17
4	16
5	16
6	18
7	15
8	17
9	14
10	16

$\Sigma X = 163$

$\bar{X} + 16.3$

$\Sigma X^2 = 2677.0$

$(\Sigma X)^2 = 26569.0$

$n = 10.0$

$$SD^2 = \Sigma X^2 - \frac{\frac{(\Sigma X)^2}{n}}{n-1}$$

$$SD^2 = \frac{2677 - 2656.9}{9}$$

$SD^2 = 2.33$ $\quad SD = 1.52$

Confidence Interval 95% Confidence

$$\bar{X} \pm t \text{ (one tailed for } n-1) \frac{s}{n}$$

$$16.3 \pm 1.833 \frac{1.52}{3.16} = 16.3 \pm .882$$

Tolerance Limits 95% confidence
90%

$\bar{X} \pm KS$ $\quad K = 2.839$

$16.3 \pm 2.839\ (1.52) = 16.3 \pm 4.32$

Table 12. Maturity Study of Five Cotton Specimens

Cotton Name	Number Fibers Examined (Percentage) 1/2 Mature	Mature	Total	Maturity Coefficient*
Empire WR Hand Ginned (Experiment, Ga)	45 (5.93)	342 (45.02)	372 (49.05)	759 (100.00)	.785
Empire WR Hand Ginned (Locust Grove,Ga)	38 (5.25)	321 (44.48)	363 (50.25)	722 (100.00)	.793
Dixie King Hand Ginned	30 (5.92)	329 (53.84)	252 (41.24)	611 (100.00)	.759
Carolina Queen Hand Ginned (Mech. Harvested)	33 (5.68)	327 (56.28)	221 (38.04	581 (100.00)	.740
Carolina Queen Hand Ginned (Hand Picked)	11 (2.68)	207 (50.36)	193 (46.96)	411 (100.00)	.783

*See Table 13 for formula for maturity coefficient.

Table 13. Example of Calculations for Maturity Study

Cotton: Empire WR Hand Ginned (Experiment, Georgia)

Sample Number	Number of Fibers Examined			
	Dead	1/2 Mature	Mature	Total
1	14	100	107	221
2	12	108	104	224
3	9	54	69	132
4	10	80	92	182
	45	342	372	759

Formula: $MC = \frac{M + 0.6H + 0.4I}{100}$

Percentages

45 - 5.93
342 - 45.02
372 - 49.05
759 100.00

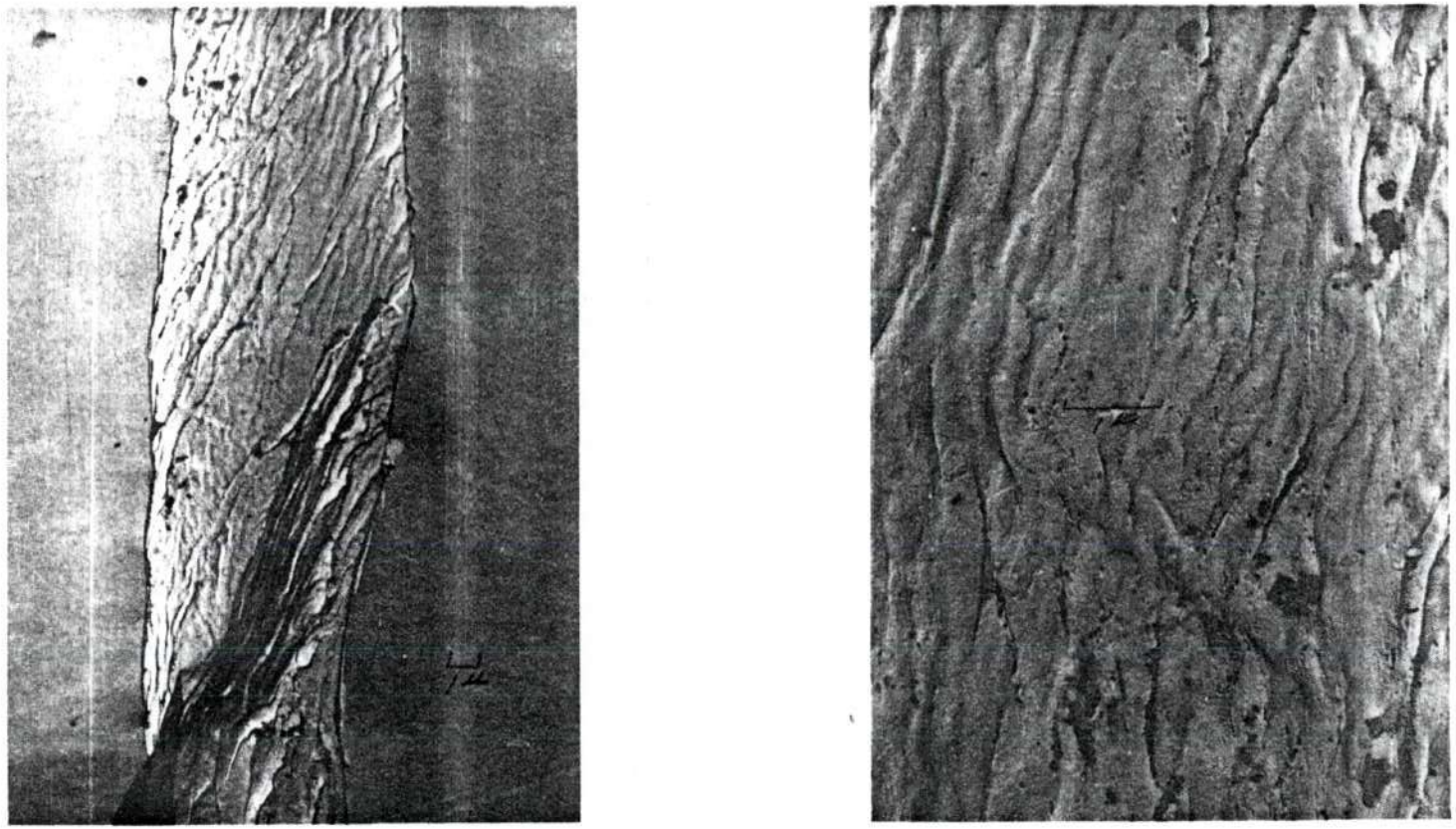
$MC = \frac{49.05 + 27.10 + 2.38}{100}$

$MC = 78.52$

$MC = .785$

Table 14. Effect of Heating Cotton Fibers Showing Percent Change After 15 Minutes and Permanent Change After 24 Hours

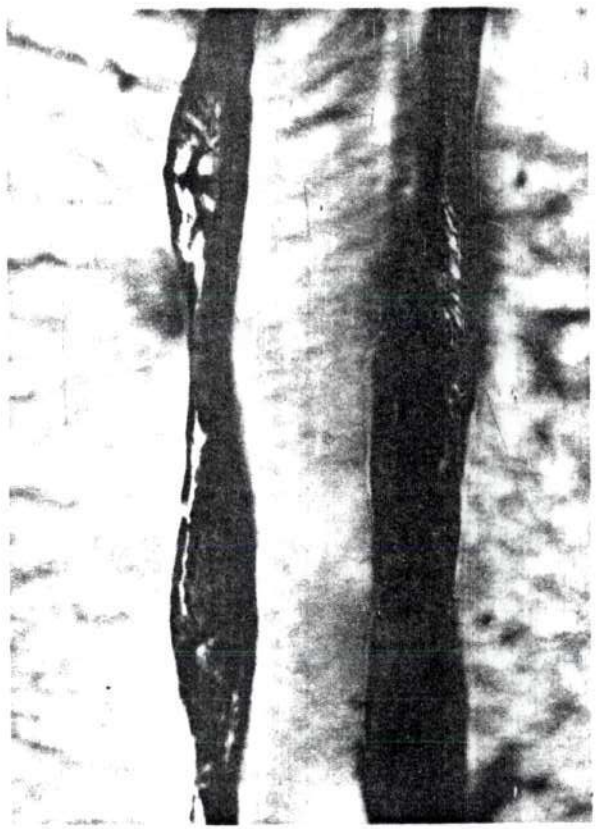
Temperature °C (F)	Sample Number	Original Reading	After 15 Min	After 24 Hr	% Change 15 Min	% Permanent Change 24 Hr
22 (70)	1	14.0	14.5	14.0	3.6	0.0
40 (104)	2	14.0	15.5	14.0	10.7	0.0
60 (140)	3	12.0	13.0	12.0	8.3	0.0
80 (176)	4	14.0	14.0	14.0	0.0	0.0
100 (212)	5	15.0	15.5	15.0	3.0	0.0
120 (248)	6	10.0	10.5	10	5.0	0.0
130 (266)	7	12.0	14.0	13.5	16.7	12.5
140 (284)	8	14.0	15.0	14.0	7.1	0.0
150 (302)	9	11.0	14.0	12.0	27.4	9.1
160 (320)	10	11.0	15.5	14.0	40.9	27.2
180 (356)	11	12.5	15.0	14.5	20.0	16.0
200 (392)	12	15.0	19.0	19.0	26.7	26.7



(a) 3,800X

(b) 12,800X

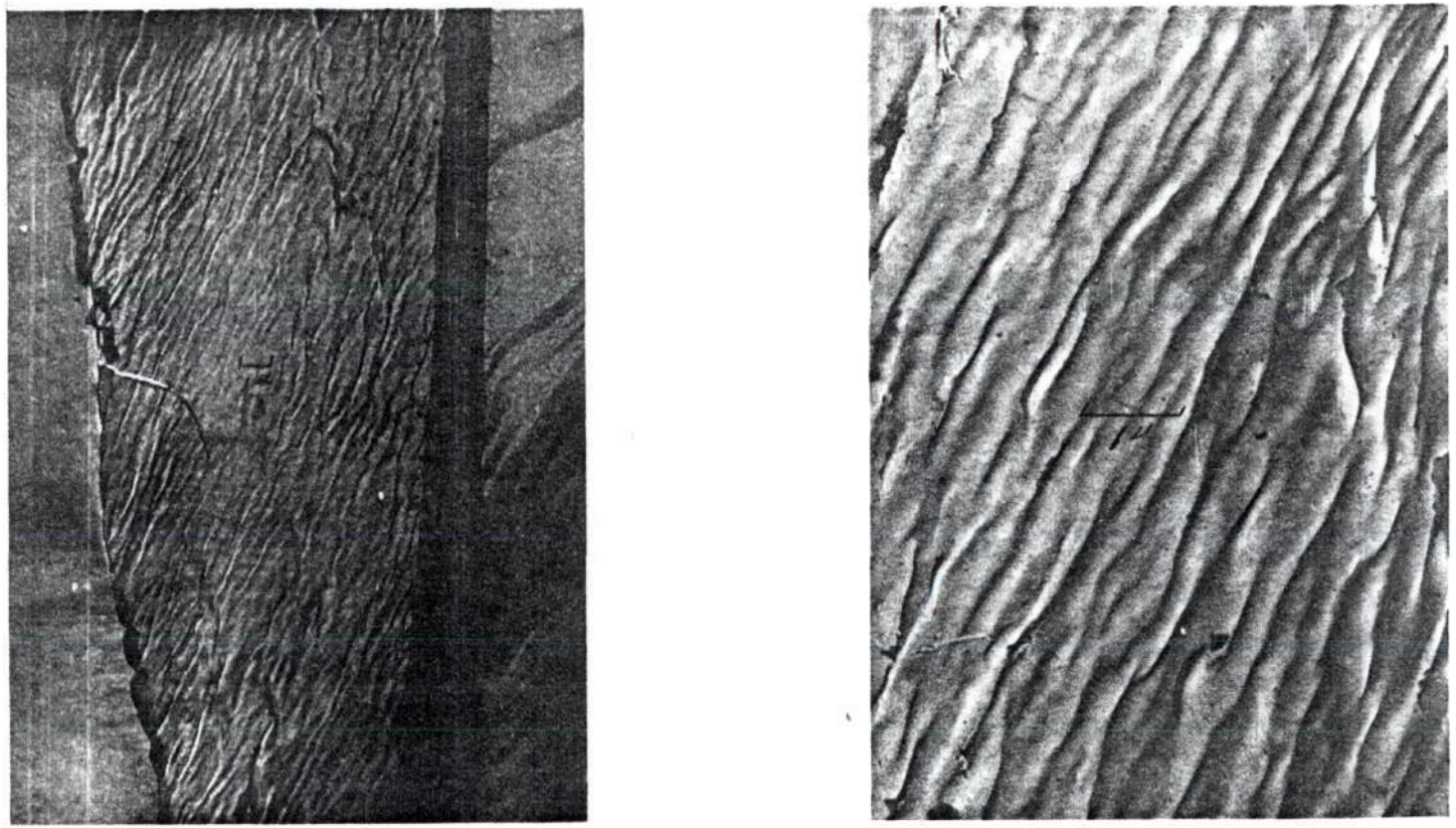
Figure 12. Cotton Empire WR Hand Ginned (Experiment, Georgia), Electron Micrographs of Surface (a) and (b)



(c) 560X

(d) 560X

Figure 12. Continued, Empire WR Hand Ginned (Experiment, Georgia), Optical Micrographs of Surface (c) and Cross Sections (d)



(a) 3,800X

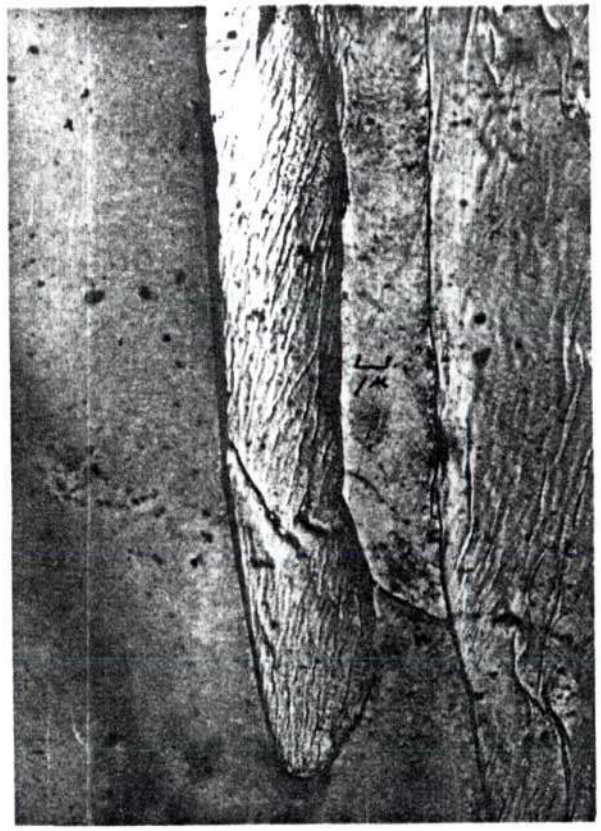
(b) 12,800X

Figure 13. Cotton Empire WR Ginned Lint (Experiment, Georgia), Electron Micrograph of Surface (a) and (b)

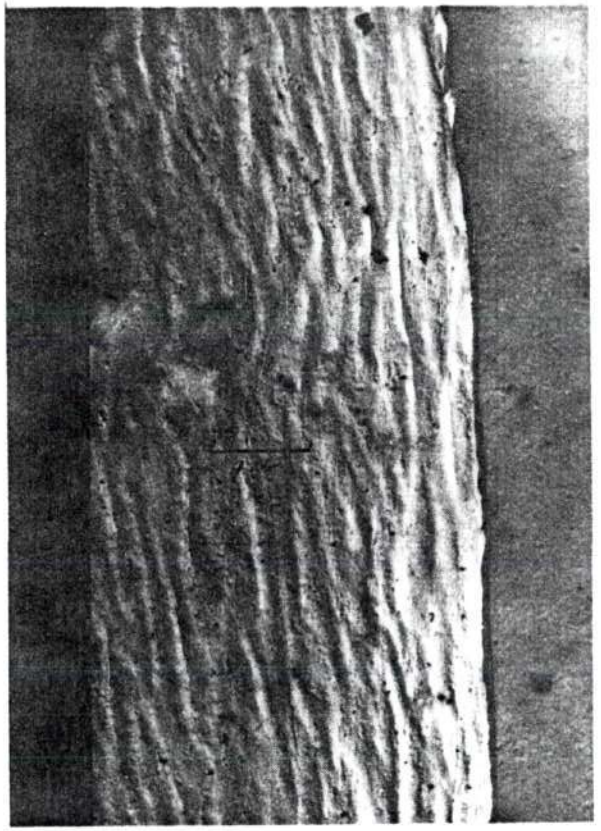
(c) 560X

(d) 560X

Figure 13. Continued, Empire WR Ginned Lint (Experiment, Georgia), Optical Micrographs of Surface (c) and Cross Sections (d)



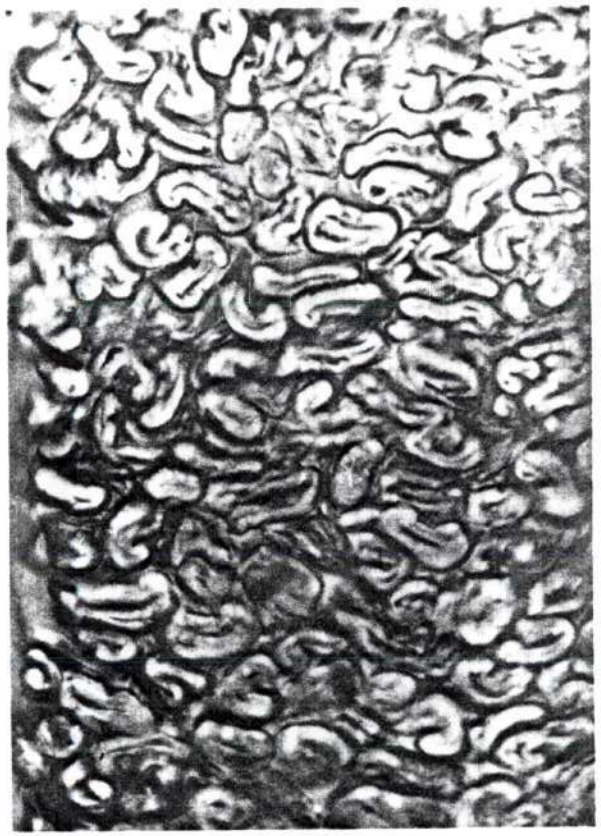
(a) 3,800X



(b) 12,800X

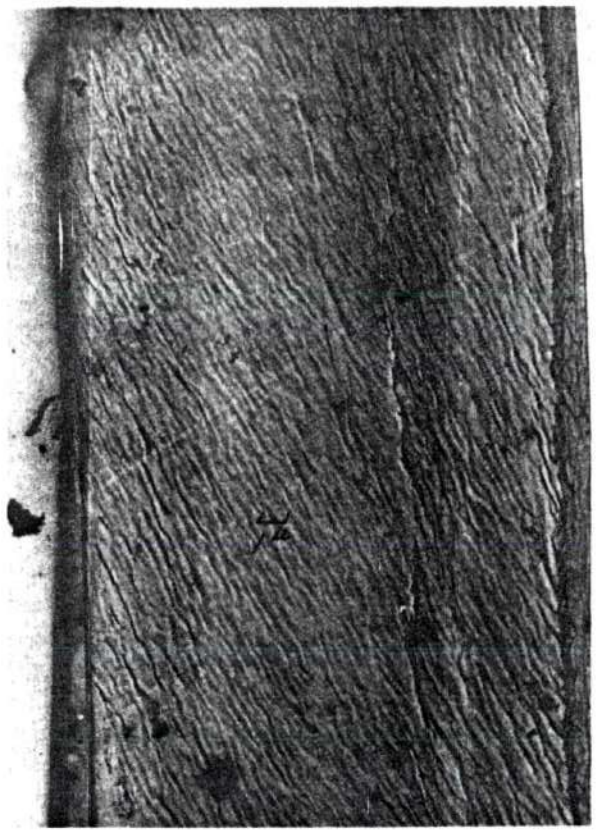
Figure 14. Cotton Empire WR Hand Ginned (Locust Grove, Georgia), Electron Micrographs of Surface (a) and (b)

(c) 560X

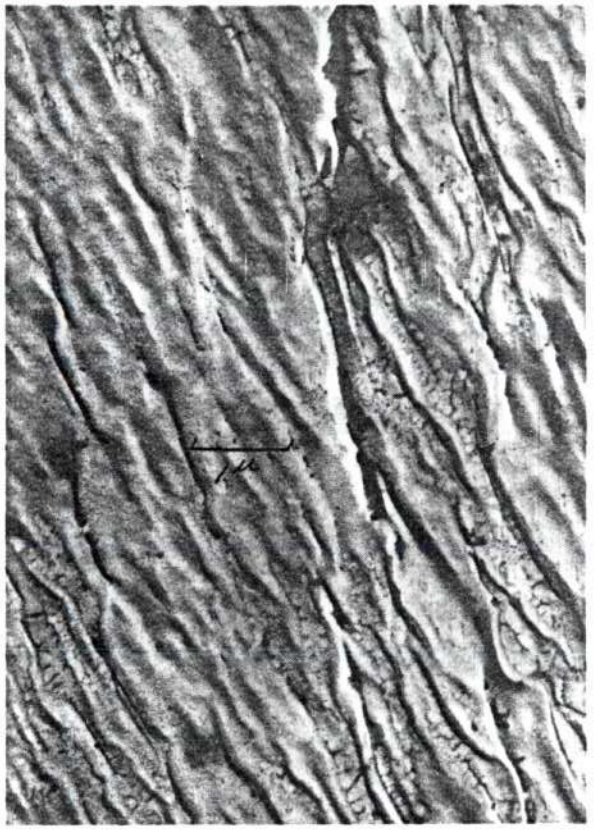


(d) 560X

Figure 14. Continued, Empire WR Hand Ginned (Locust Grove, Georgia), Optical Micrographs of Surface (c) and Cross Sections (d)



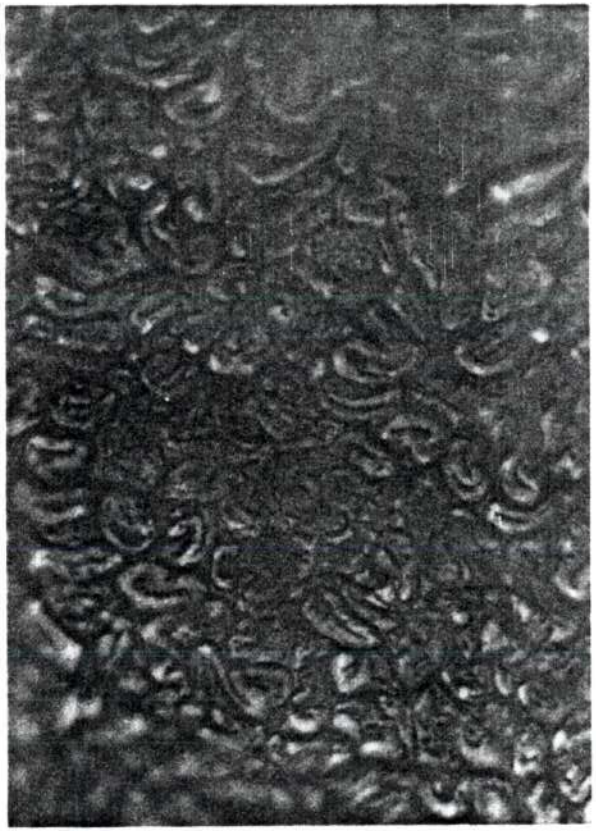
(a) 3,800X



(b) 12,800X

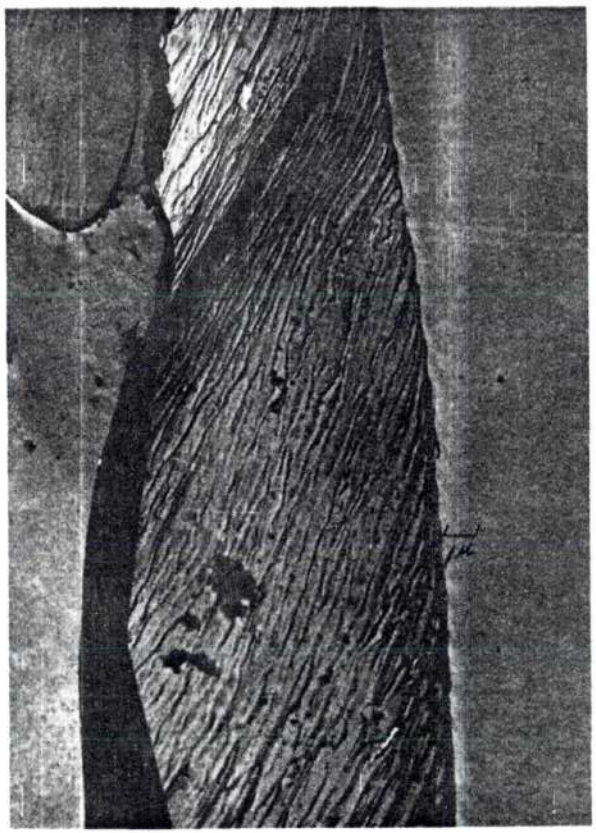
Figure 15. Cotton Empire WR Ginned Lint (Locust Grove, Georgia), Electron Micrographs of Surface (a) and (b)

(c) 560X

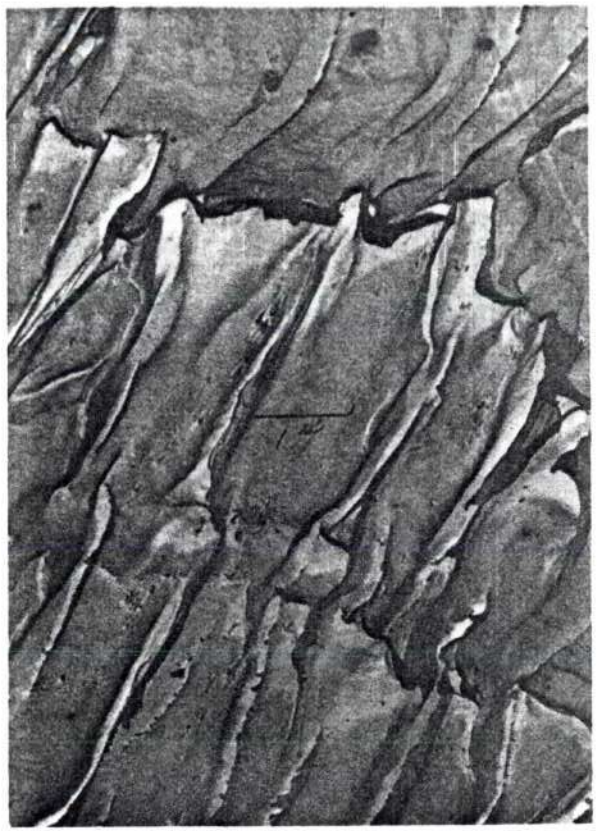


(d) 560X

Figure 15. Continued, Cotton Empire WR Ginned Lint (Locust Grove, Georgia), Optical Micrographs of Surface (c) and Cross Sections (d)



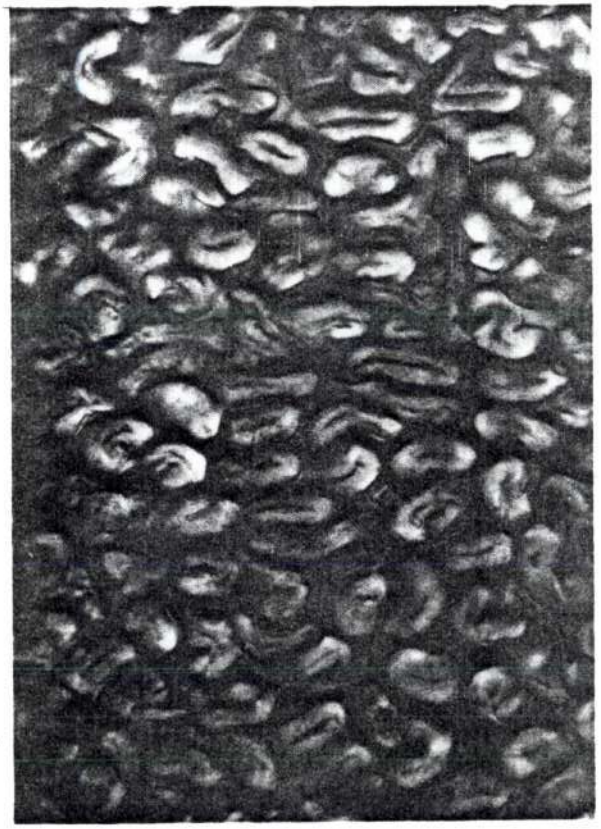
(a) 3,800X



(b) 12,800X

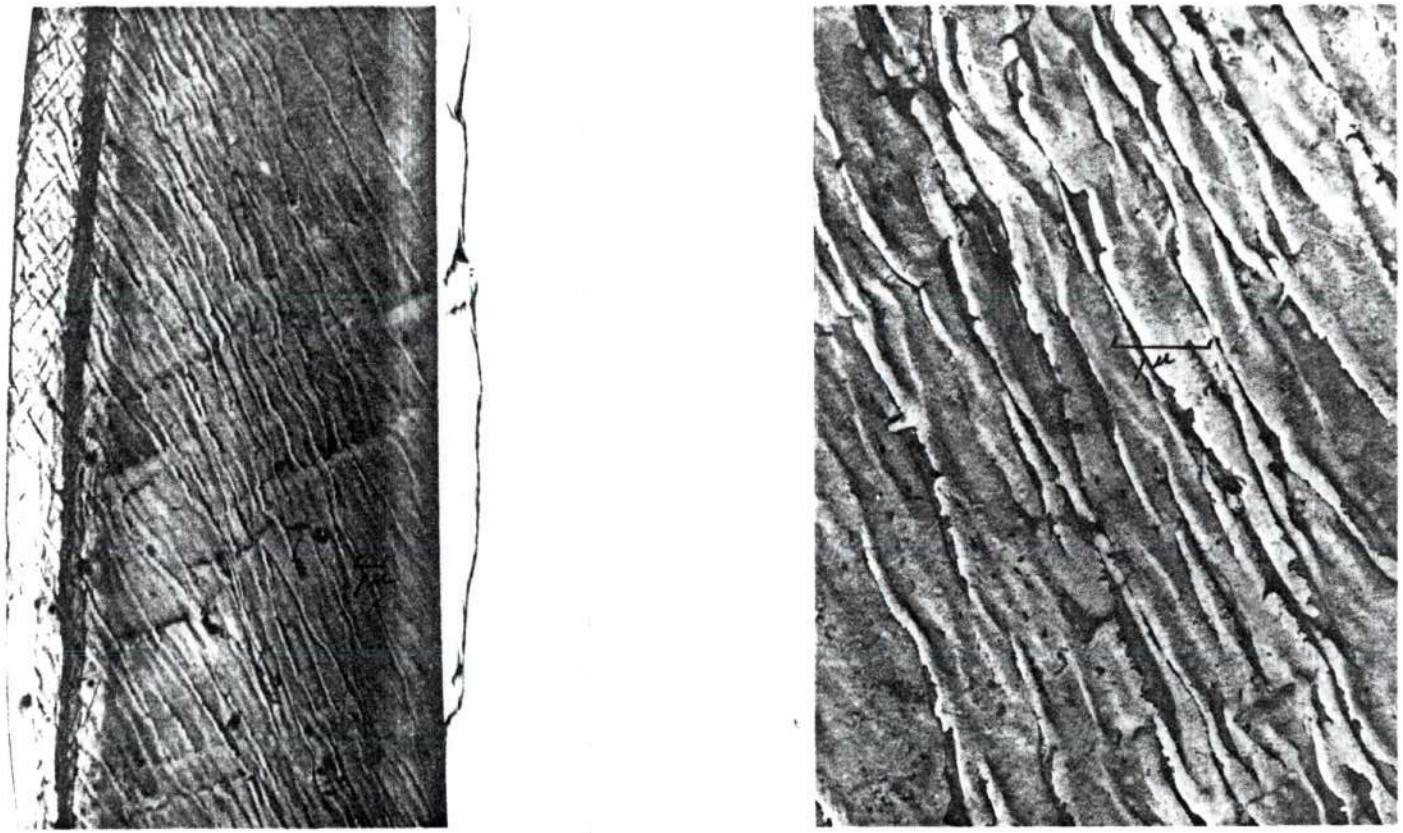
Figure 16. Cotton Dixie King Hand Ginned, Electron Micrographs of Surface (a) and (b)

(c) 560X



(d) 560X

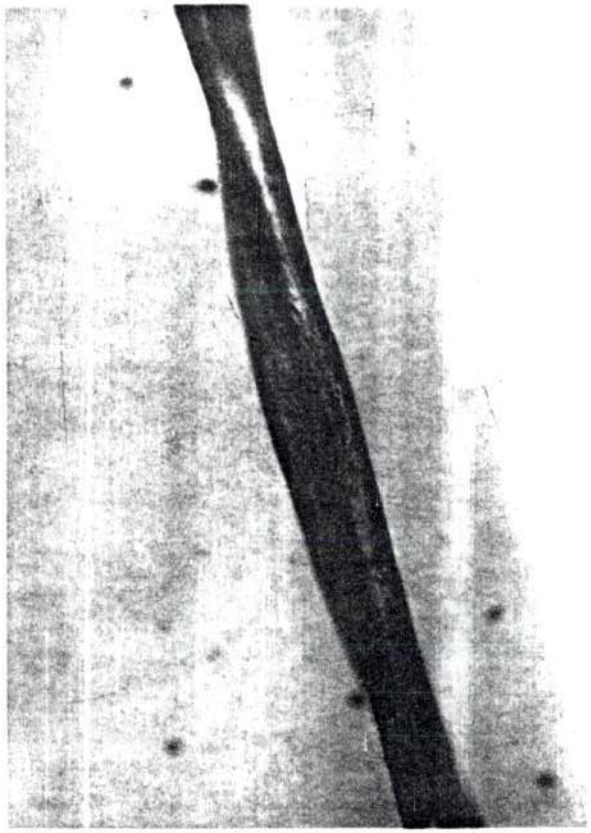
Figure 16. Continued, Cotton Dixie King Hand Ginned, Optical Micrographs of Surface (c) and Cross Sections (d)



(a) 3,800X

(b) 12,800X

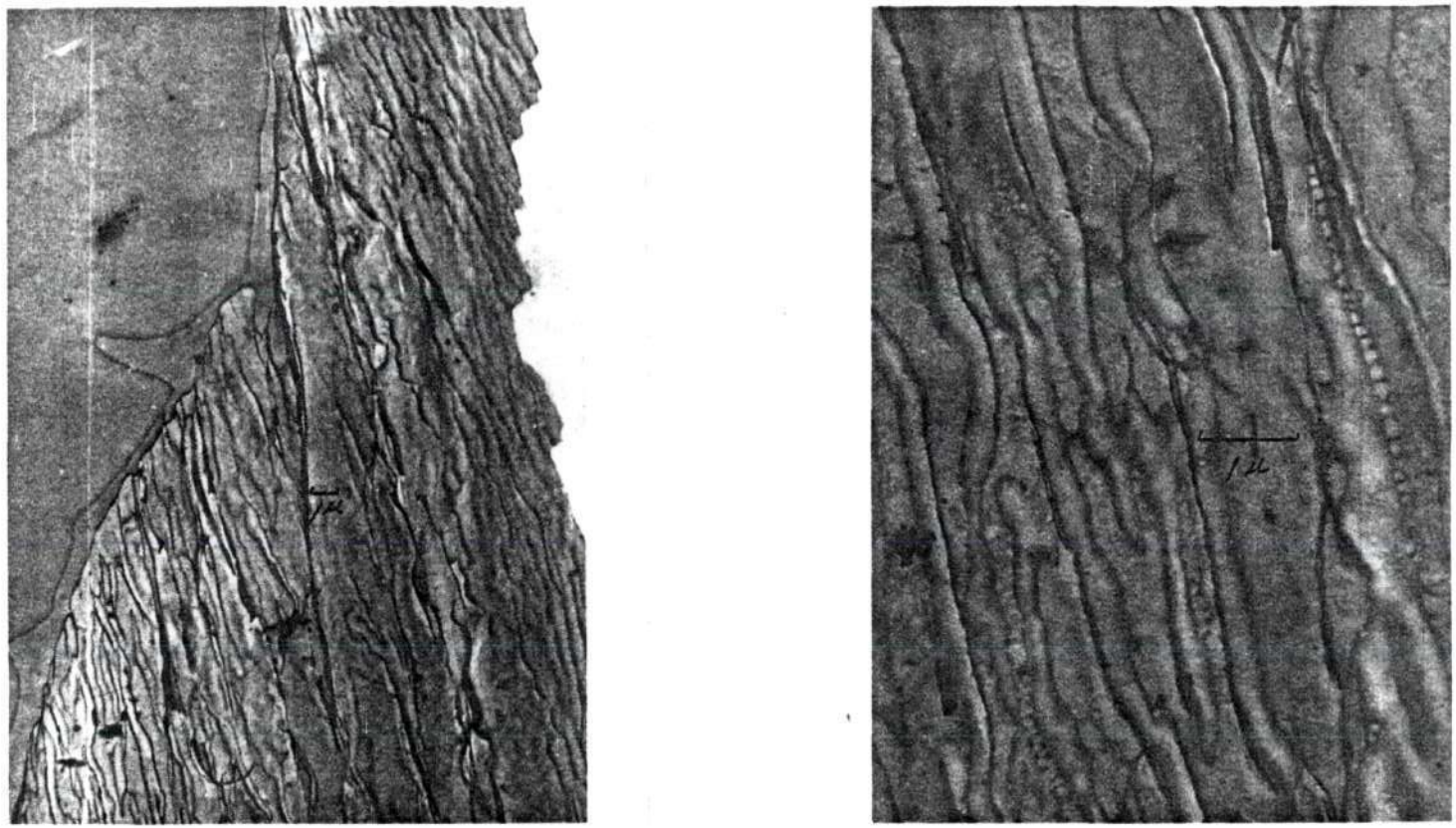
Figure 17. Cotton Dixie King Ginned Lint, Electron Micrographs of Surface (a) and (b)



(c) 560X

(d) 560X

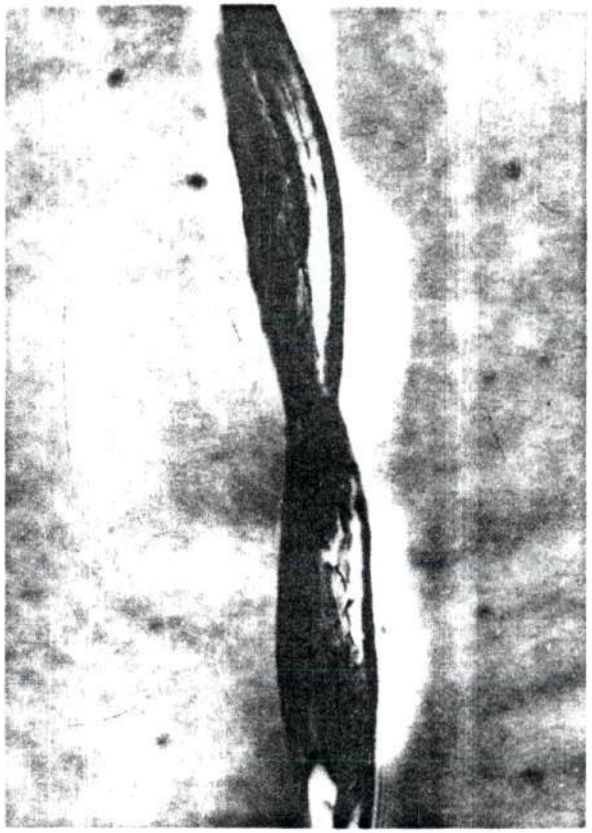
Figure 17. Continued, Cotton Dixie King Ginned Lint, Optical Micrographs of Surface (c) and Cross Sections (d)



(a) 3,800X

(b) 12,800X

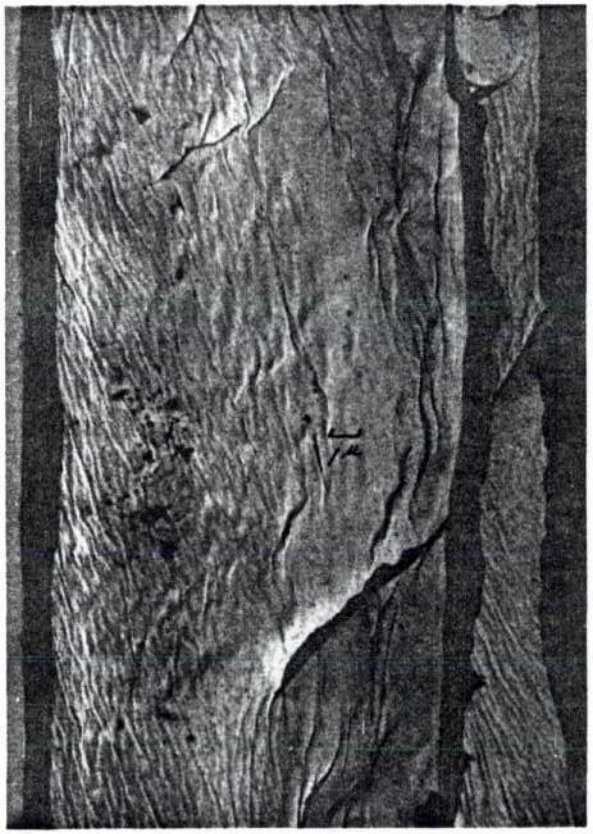
Figure 18. Cotton Carolina Queen Hand Ginned, Electron Micrographs of Surface (a) and (b)



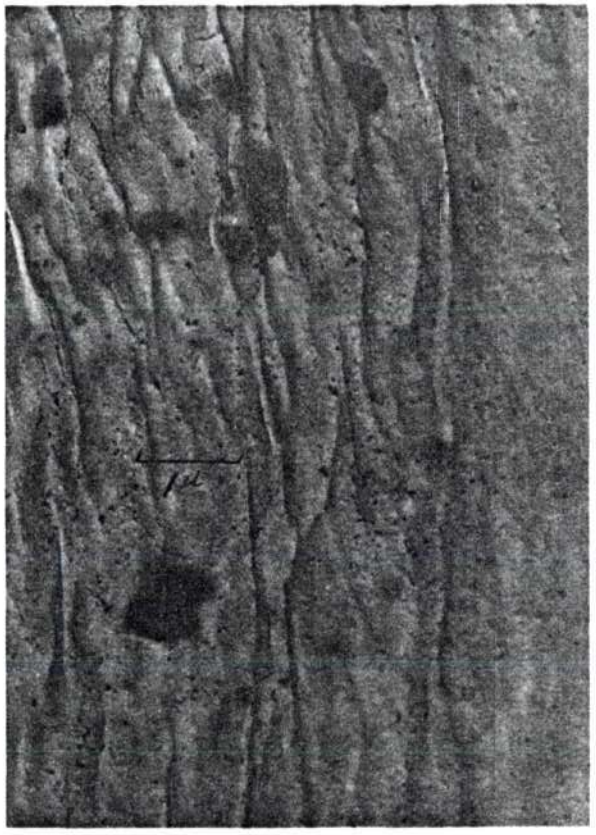
(c) 560X

(d) 560X

Figure 18. Continued, Cotton Carolina Queen Hand Ginned, Optical Micrographs of Surface (c) and Cross Sections (d)

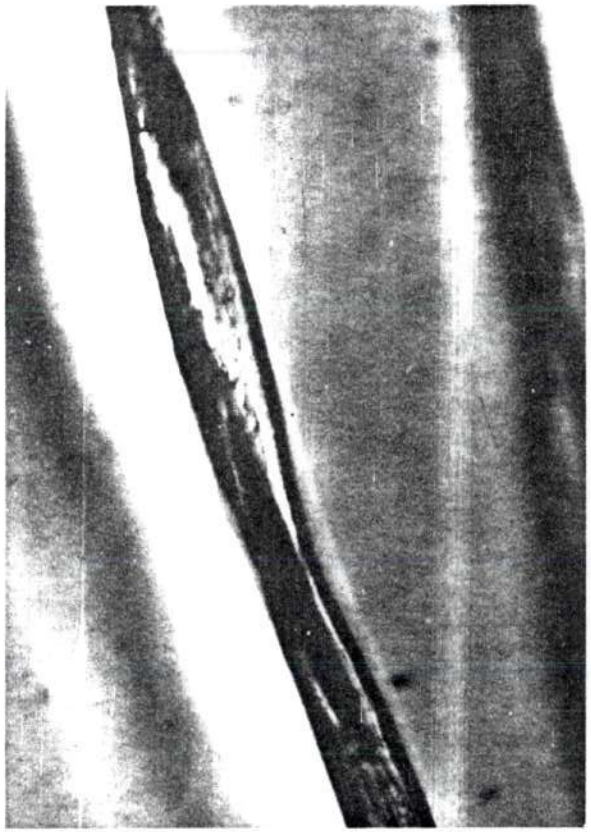


(a) 3,800X



(b) 12,800X

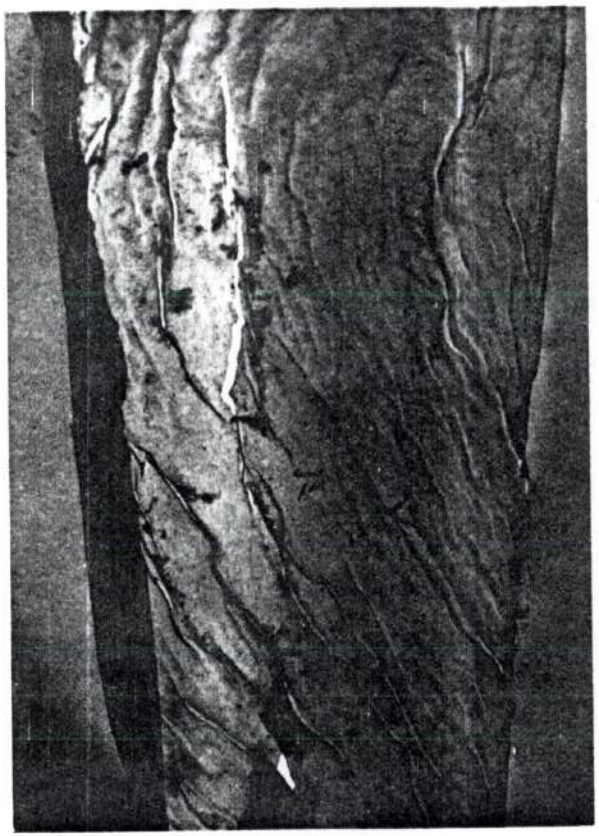
Figure 19. Cotton Carolina Queen Ginned Lint, Electron Micrographs of Surface (a) and (b)



(c) 560X

(d) 560X

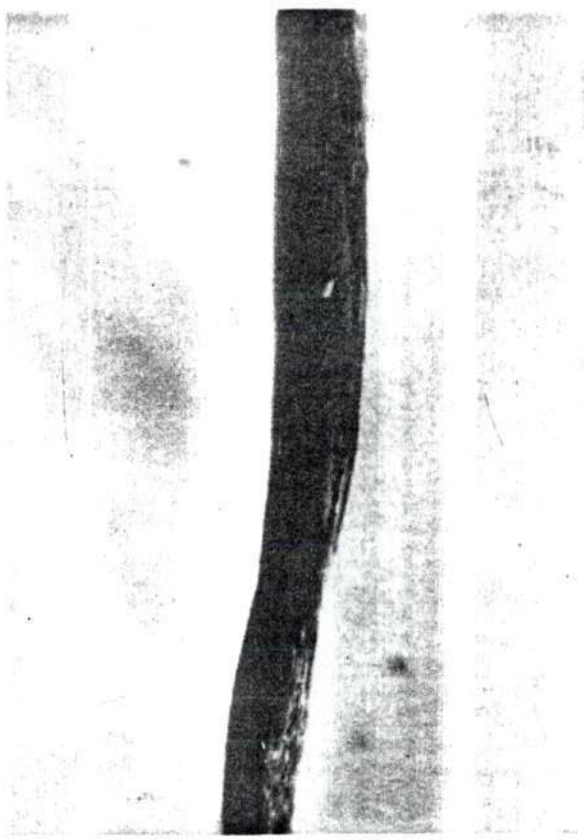
Figure 19. Continued, Cotton Carolina Queen Ginned Lint, Optical Micrographs of Surface (c) and Cross Sections (d)



(a) 3,800X

(b) 12,800X

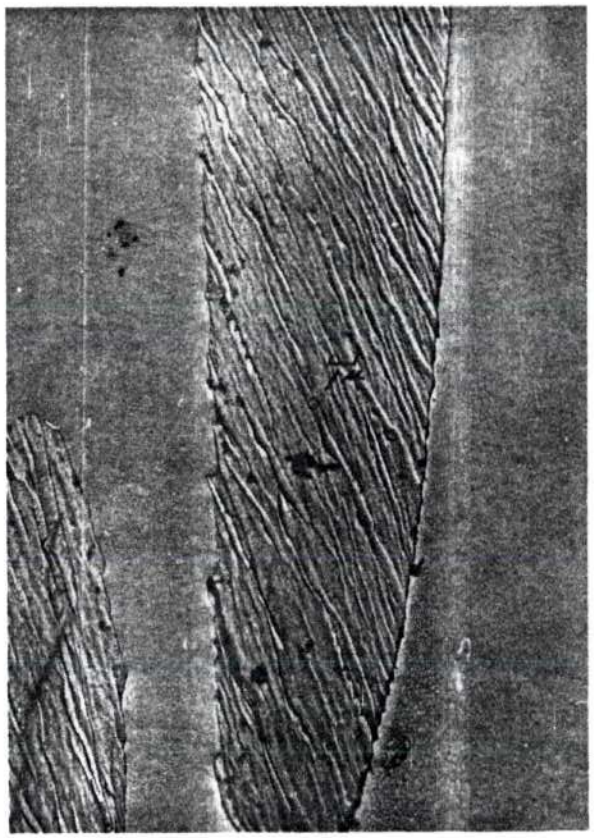
Figure 20. Cotton Carolina Queen Hand Ginned (Hand Picked), Electron Micrographs of Surface (a) and (b)



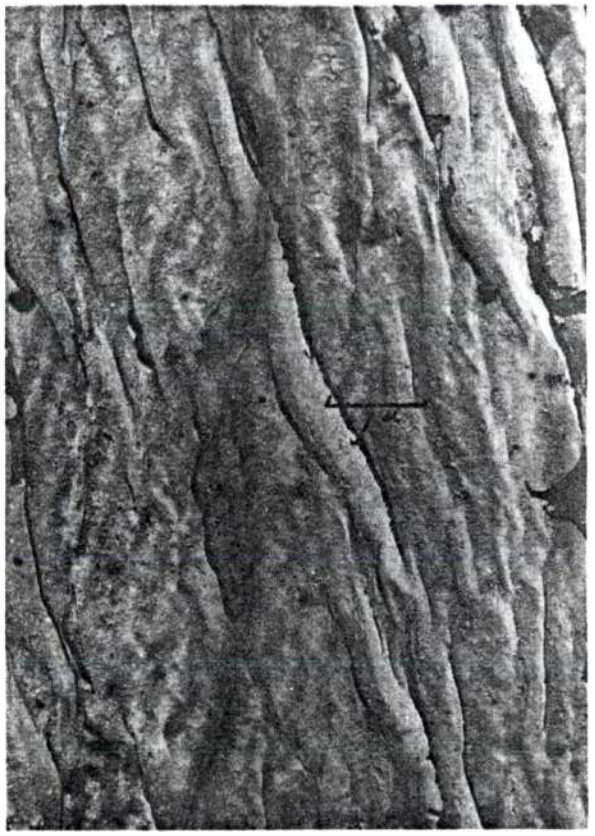
(c) 560X

(d) 560X

Figure 20. Continued, Cotton Carolina Queen Hand Ginned (Hand Picked), Optical Micrographs of Surface (c) and Cross Sections (d)

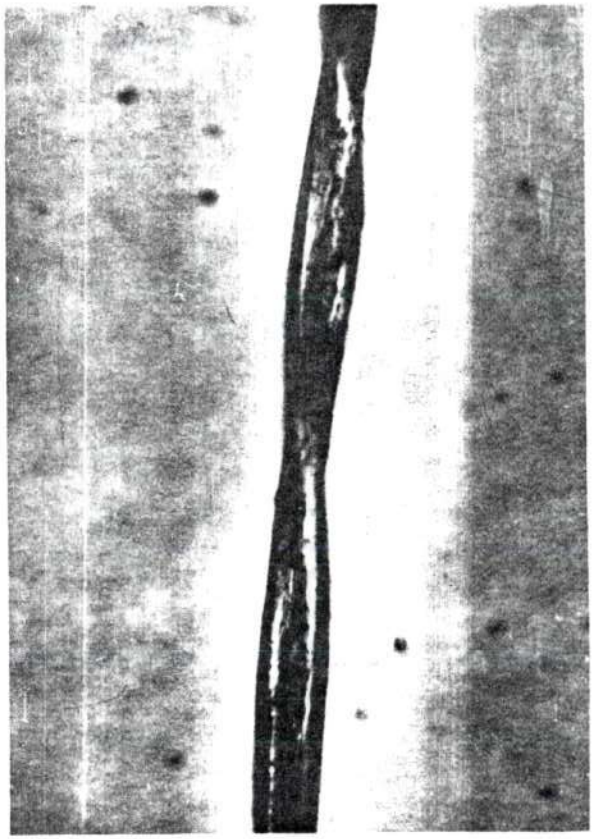


(a) 3,800X



(b) 12,800X

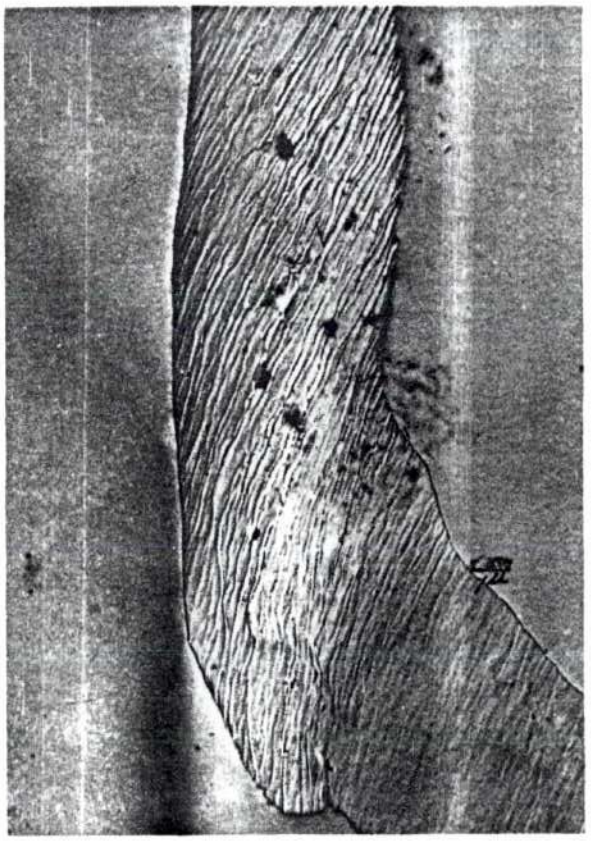
Figure 21. Cotton Carolina Queen Ginned Lint (Hand Picked), Electron Micrographs of Surface (a) and (b)



(c) 560X

(d) 560X

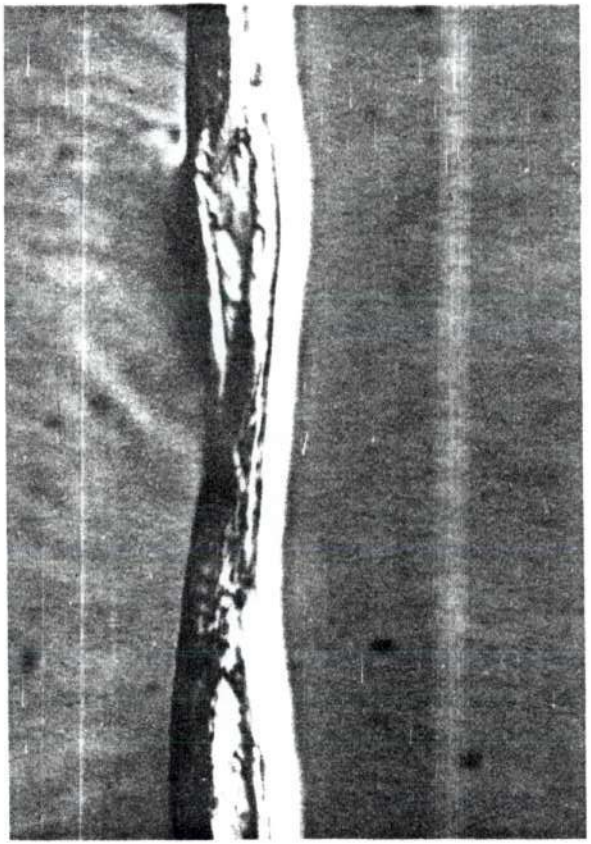
Figure 21. Continued, Cotton Carolina Queen Ginned Lint (Hand Picked), Optical Micrographs of Surface (c) and Cross Sections (d)



(a) 3,800X

(b) 12,800X

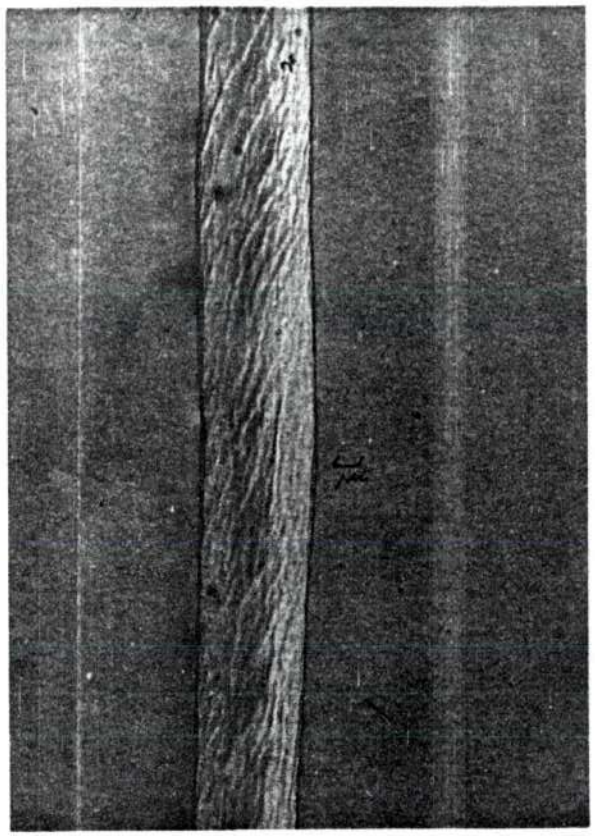
Figure 22. Cotton Wilds 5, Electron Micrographs of Surface (a) and (b)



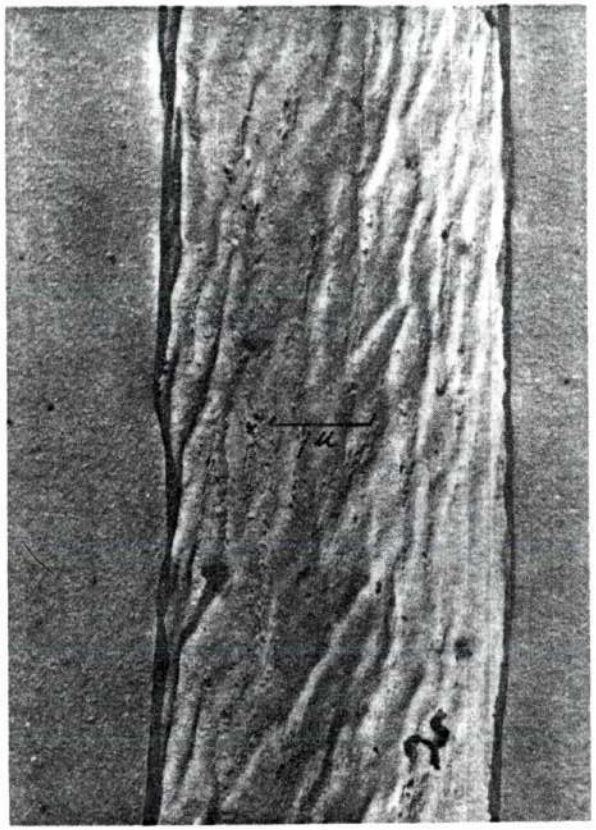
(c) 560X

(d) 560X

Figure 22. Continued, Cotton Wilds 5, Optical Micrographs of Surface (c) and Cross Sections (d)

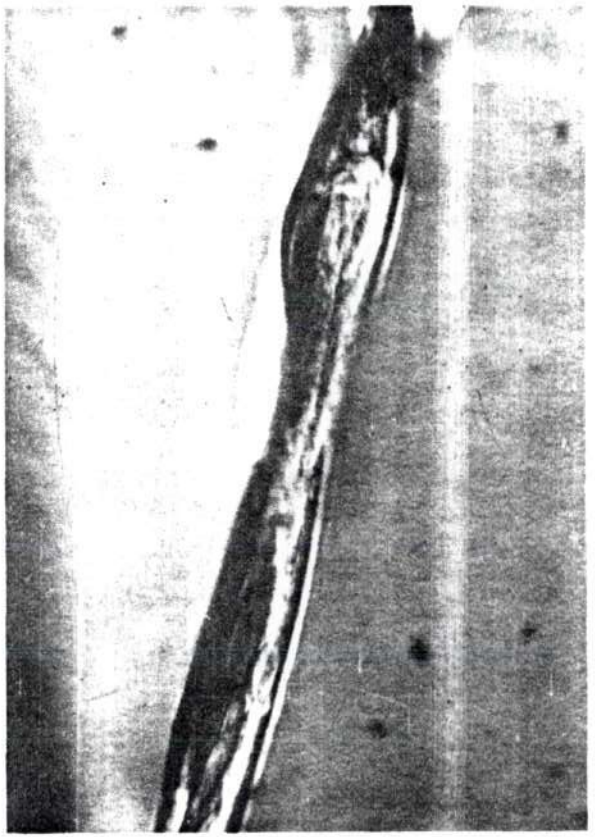


(a) 3,800X



(b) 12,800X

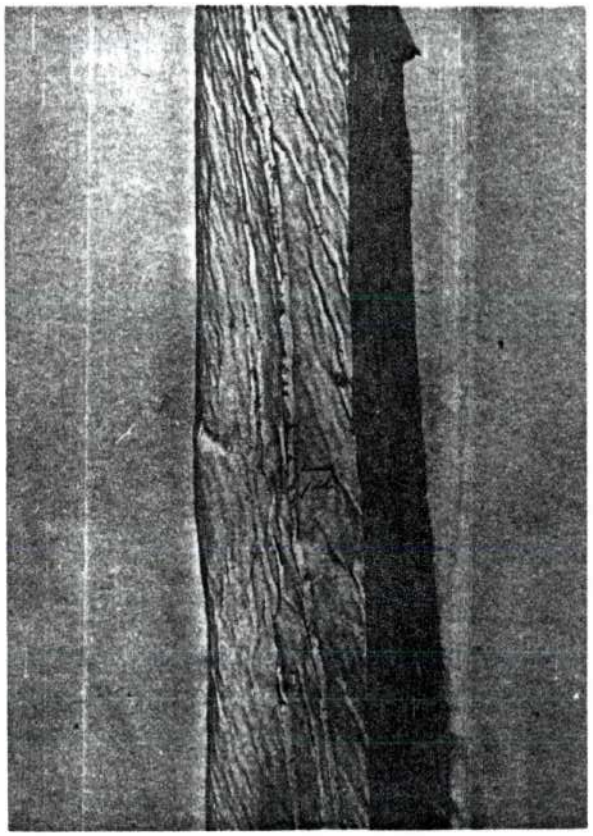
Figure 23. Cotton Delfos, Electron Micrographs of Surface (a) and (b)



(c) 560X

(d) 560X

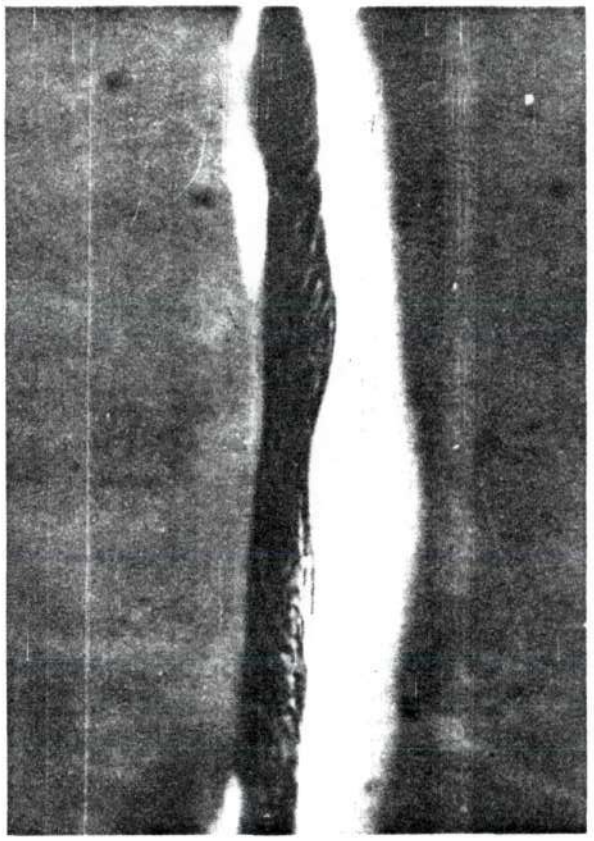
Figure 23. Continued, Cotton Delfos, Optical Micrographs of Surface (c) and Cross Sections (d)



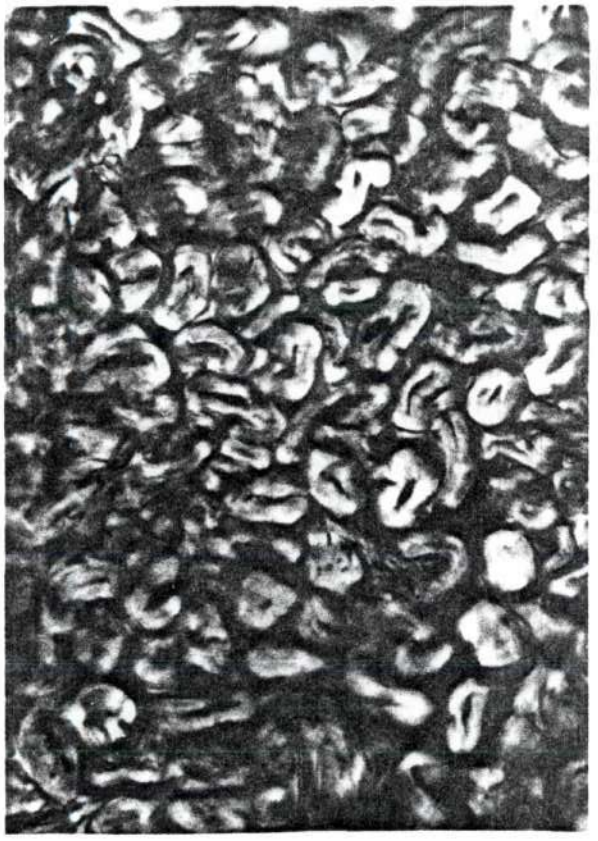
(a) 3,800X

(b) 12,800X

Figure 24. Cotton Mexican Big Boll, Electron Micrographs of Surface (a) and (b)

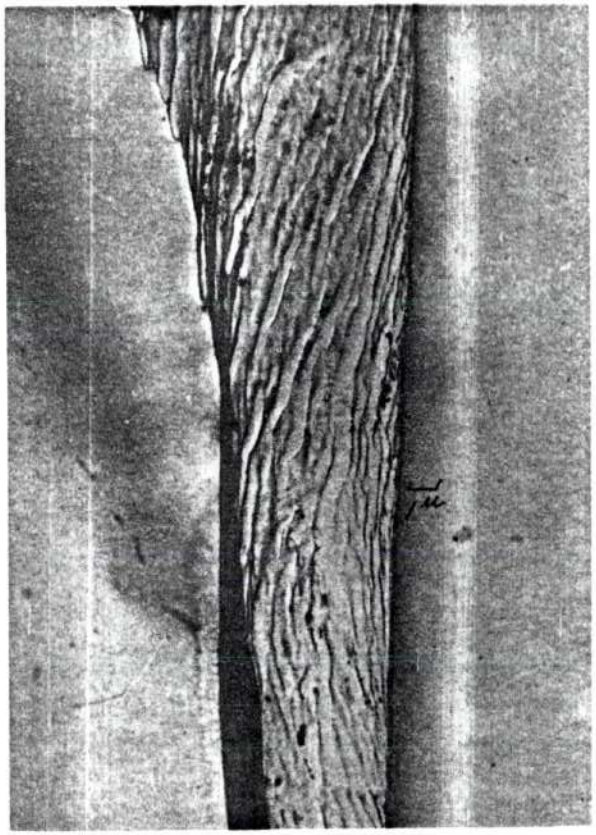


(c) 560X



(d) 560X

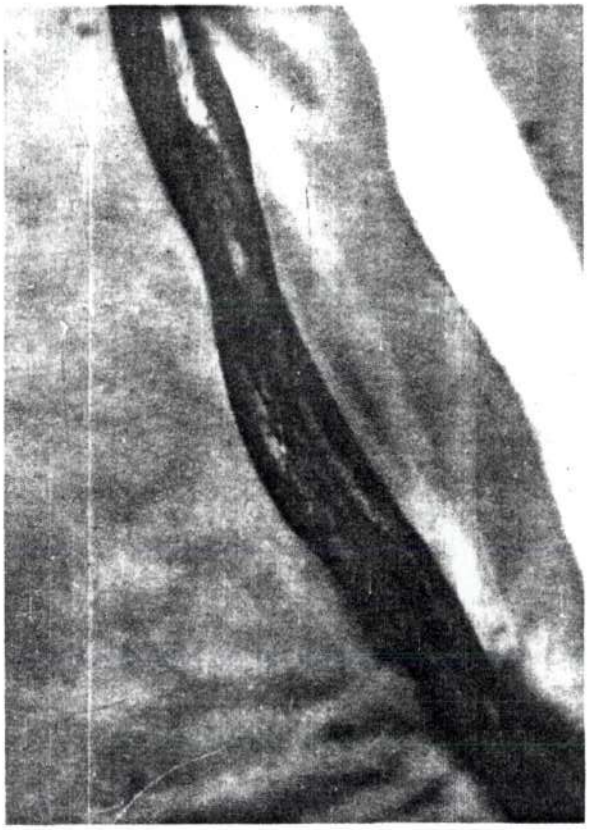
Figure 24. Continued, Cotton Mexican Big Boll, Optical Micrographs of Surface (c) and Cross Sections (d)



(a) 3,800X

(b) 12,800X

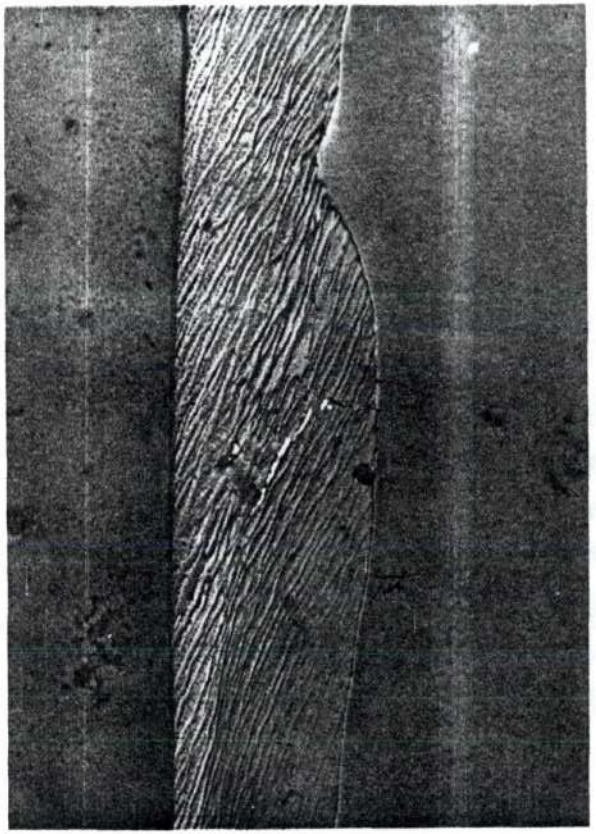
Figure 25. Cotton Rowden, Electron Micrographs of Surface (a) and (b)



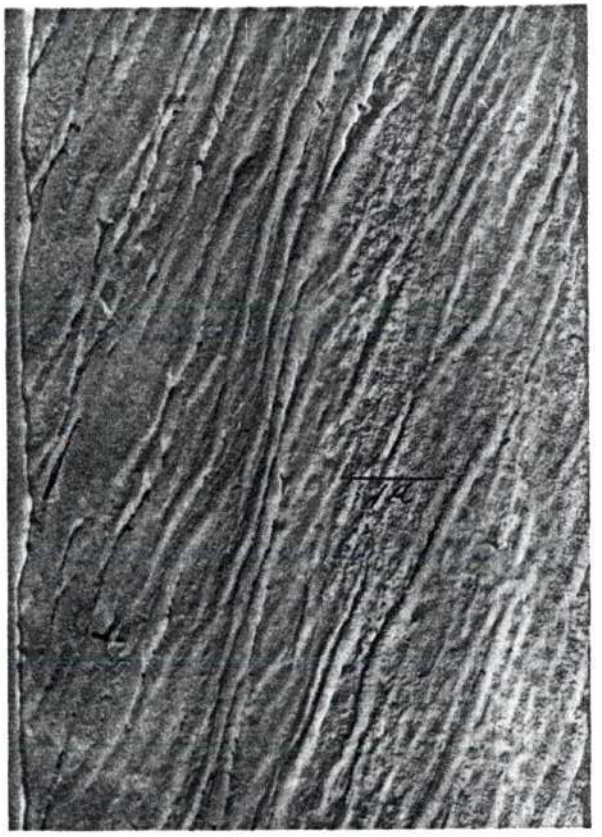
(c) 560X

(d) 560X

Figure 25. Continued, Cotton Rowden, Optical Micrographs of Surface (c) and Cross Sections (d)

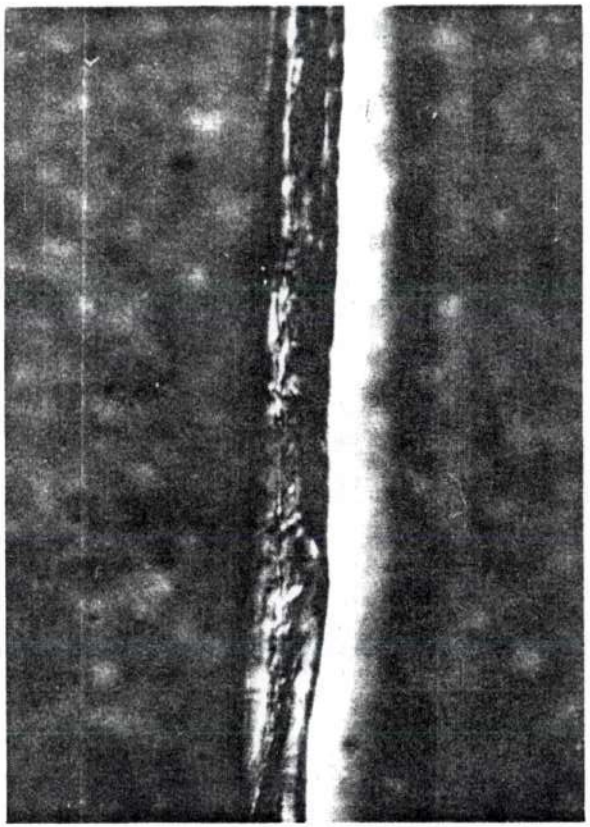


(b) 12,800X

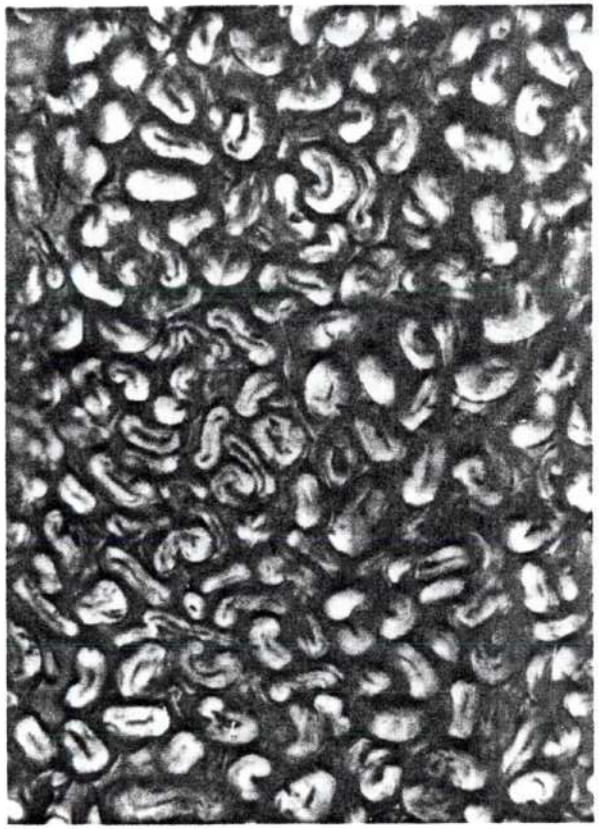


(a) 3,800X

Figure 26. Cotton Pima S-1 (Sliver), Electron Micrographs of Surface (a) and (b)

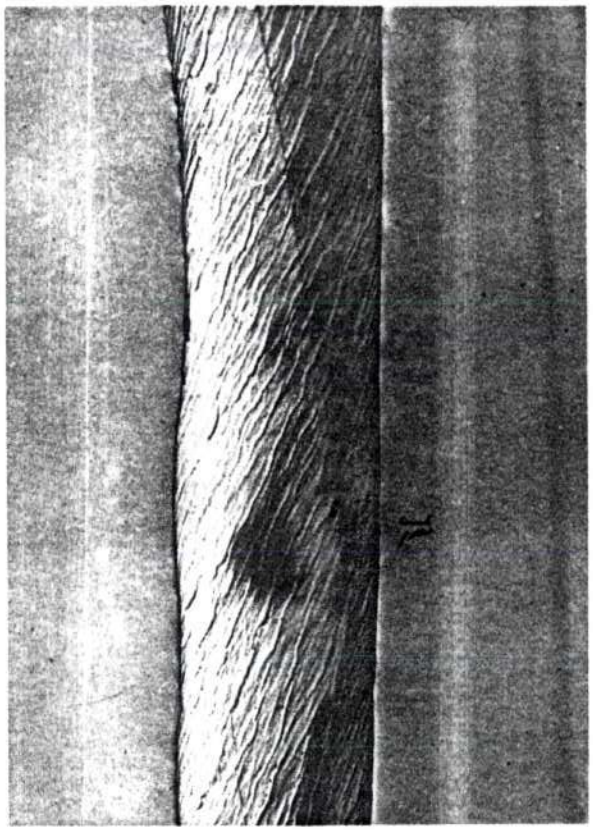


(c) 560X

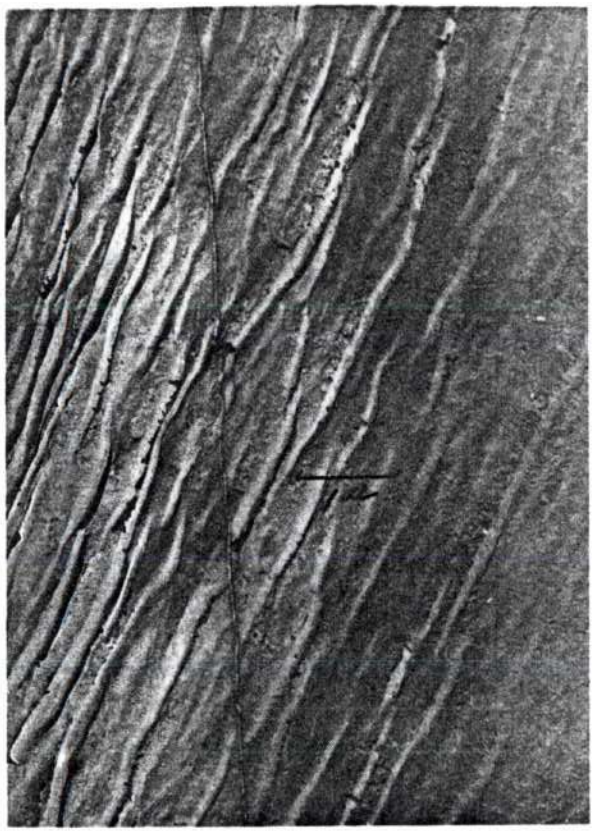


(d) 560X

Figure 26. Continued, Cotton Pima S-1 (Sliver), Optical Micrographs of Surface (c) and Cross Sections (d)

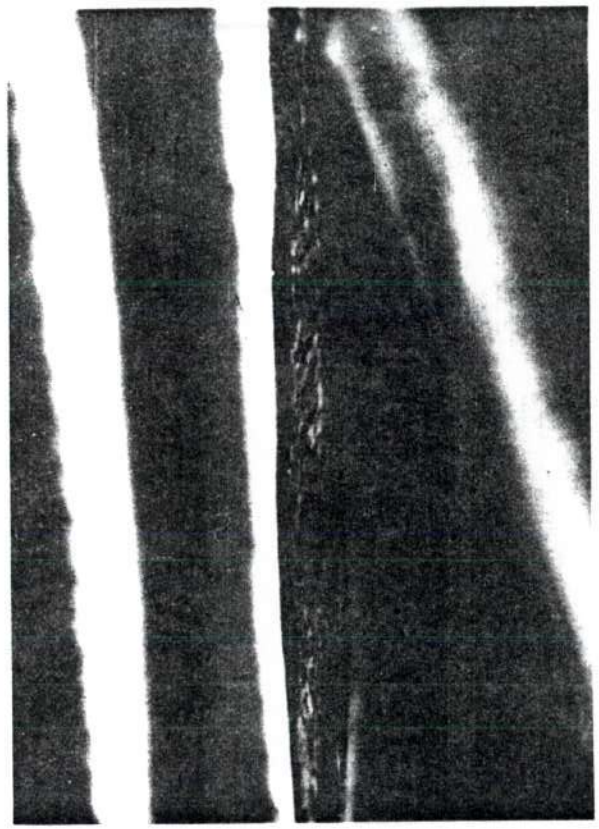


(a) 3,800X



(b) 12,800X

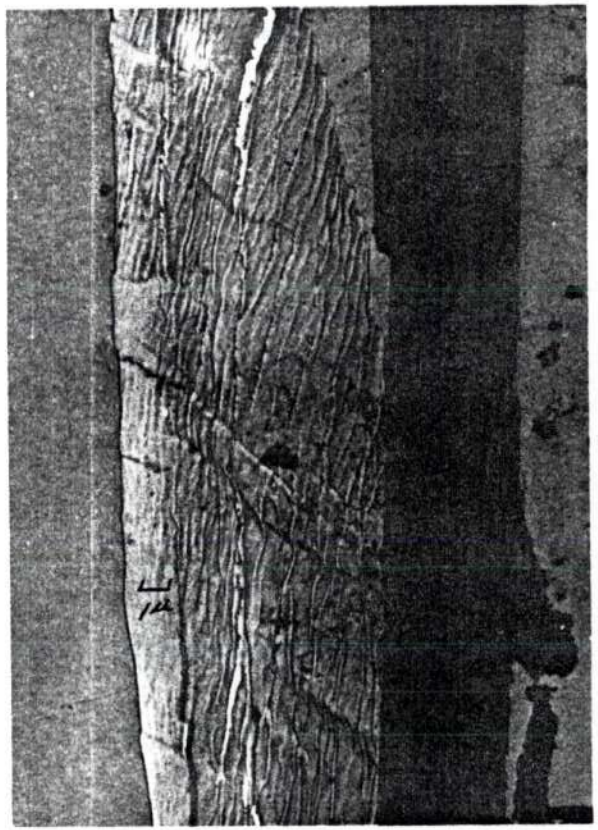
Figure 27. Cotton St. Vincent Sea Island (Sliver), Electron Micrographs of Surface (a) and (b)



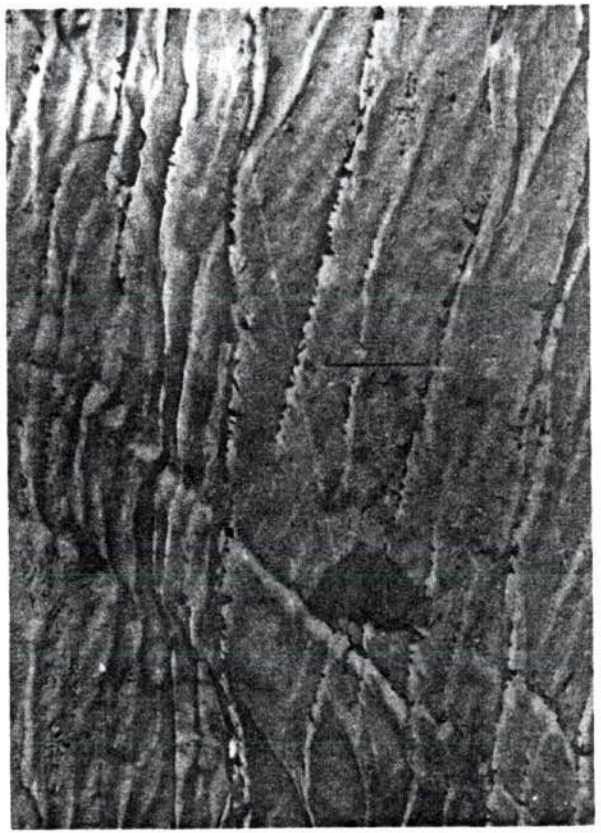
(c) 560X

(d) 560X

Figure 27. Continued, Cotton St. Vincent Sea Island (Sliver), Optical Micrographs of Surface (c) and Cross Sections (d)

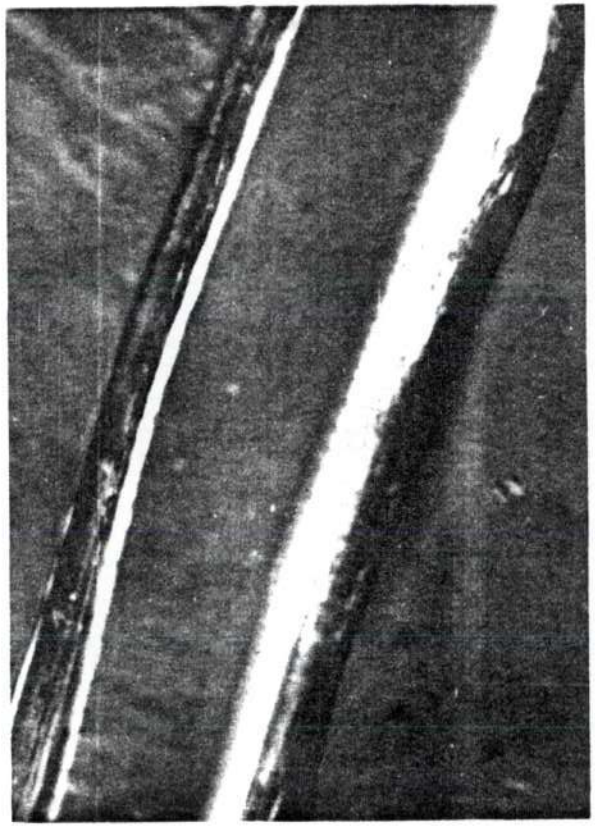


(a) 3,800X

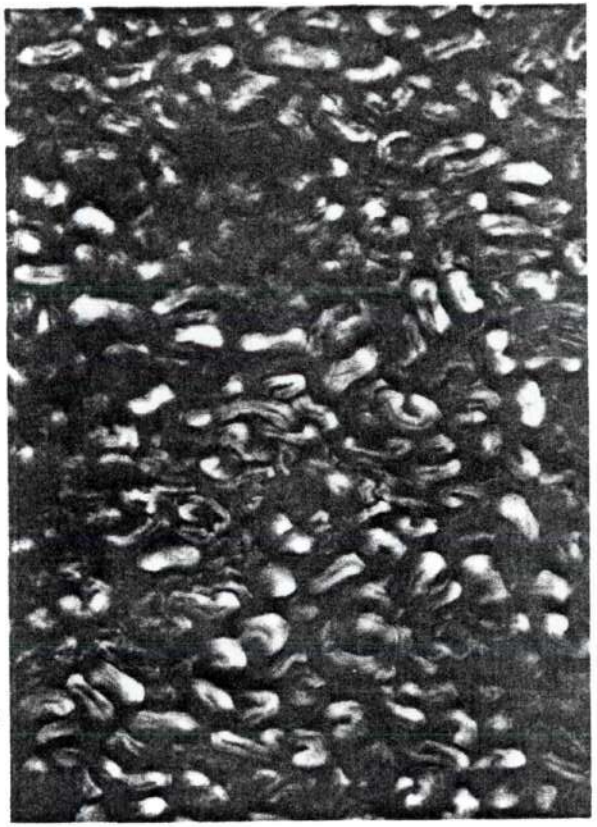


(b) 12,800X

Figure 28. Cotton SXP, Electron Micrographs of Surface (a) and (b)

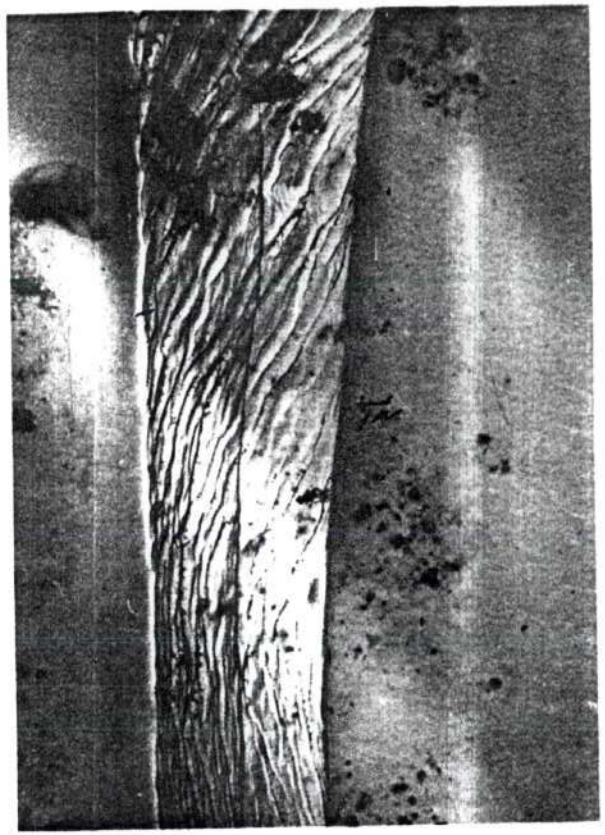


(c) 560X

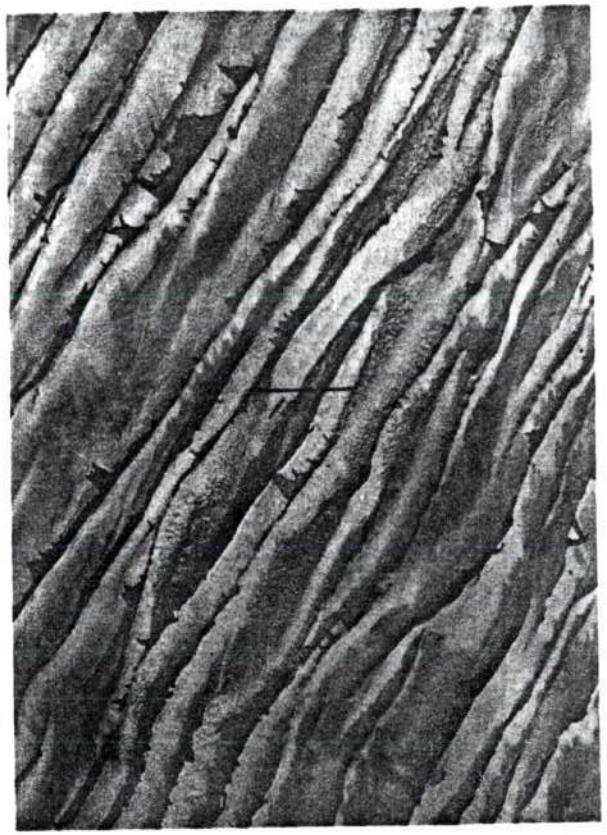


(d) 560X

Figure 28. Continued, Cotton SXP, Optical Micrographs of Surface (c) and Cross Sections (d)

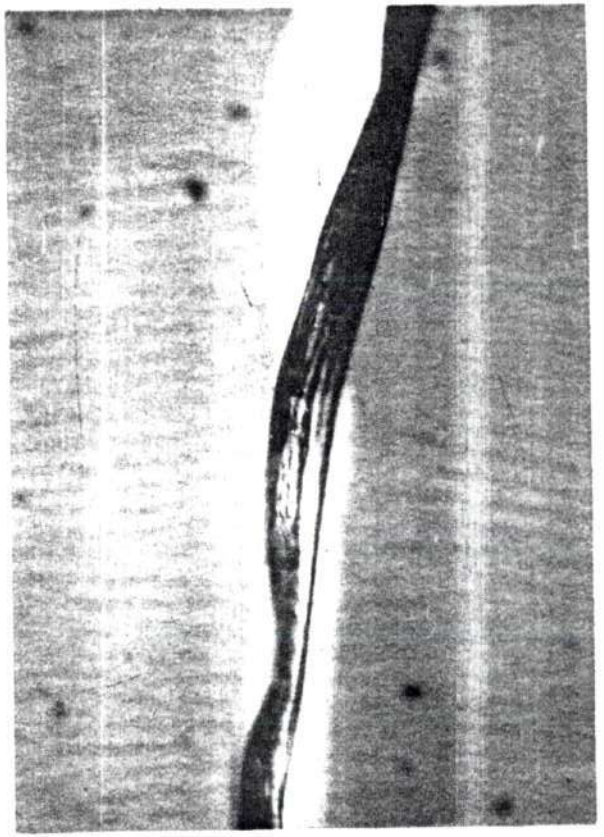


(a) 3,800X



(b) 12,800X

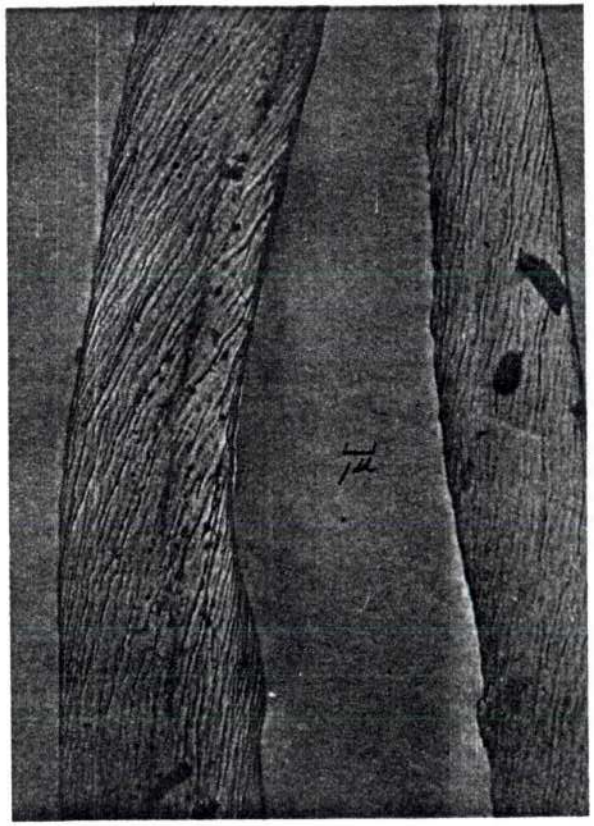
Figure 29. Cotton Bobshaw (1951 Crop), Electron Micrographs of Surface (a) and (b)



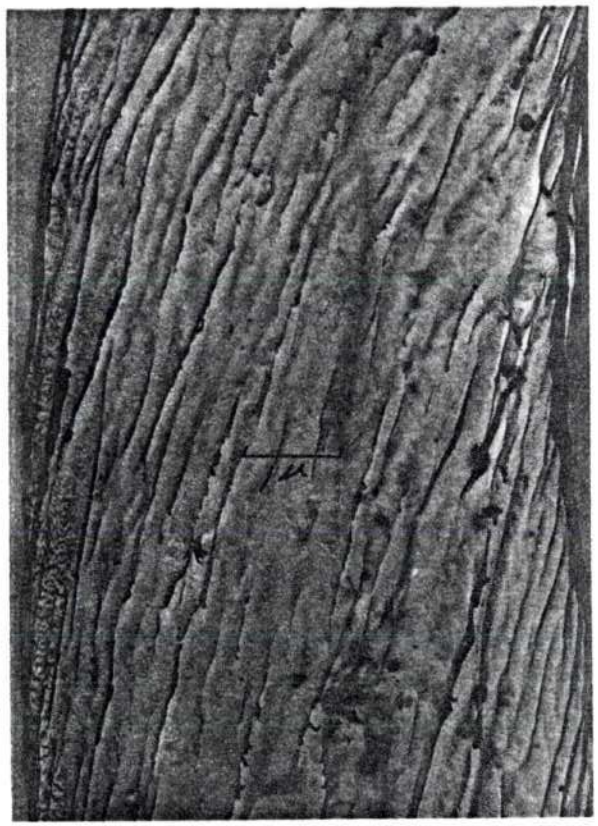
(c) 560X

(d) 560X

Figure 29. Continued, Cotton Bobshaw (1951 Crop), Optical Micrographs of Surface (c) and Cross Sections (d)

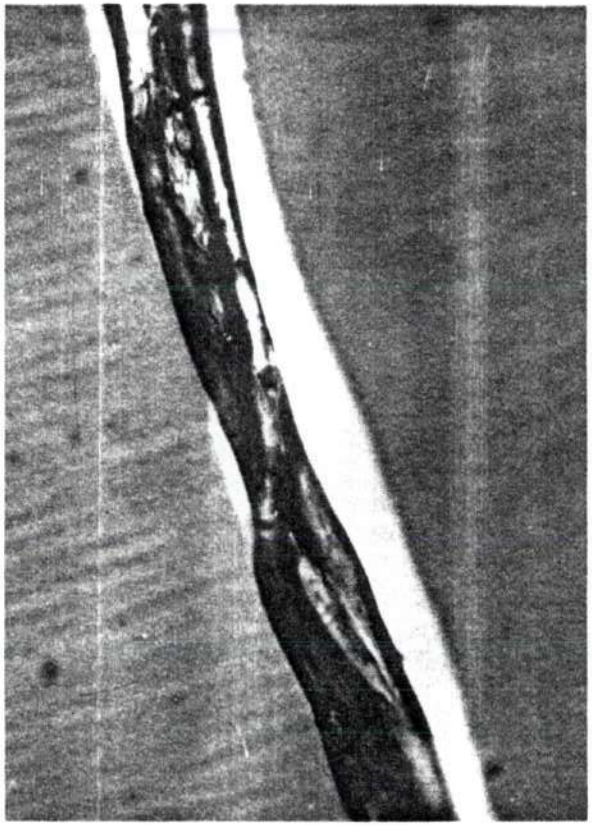


(a) 3,800X

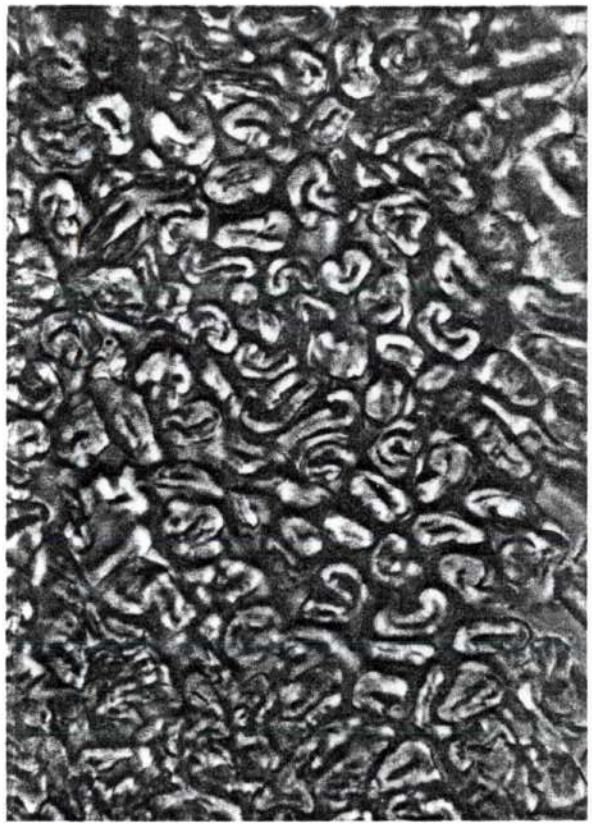


(b) 12,800X

Figure 30. Cotton Hopi Acala 54, Electron Micrographs of Surface (a) and (b)

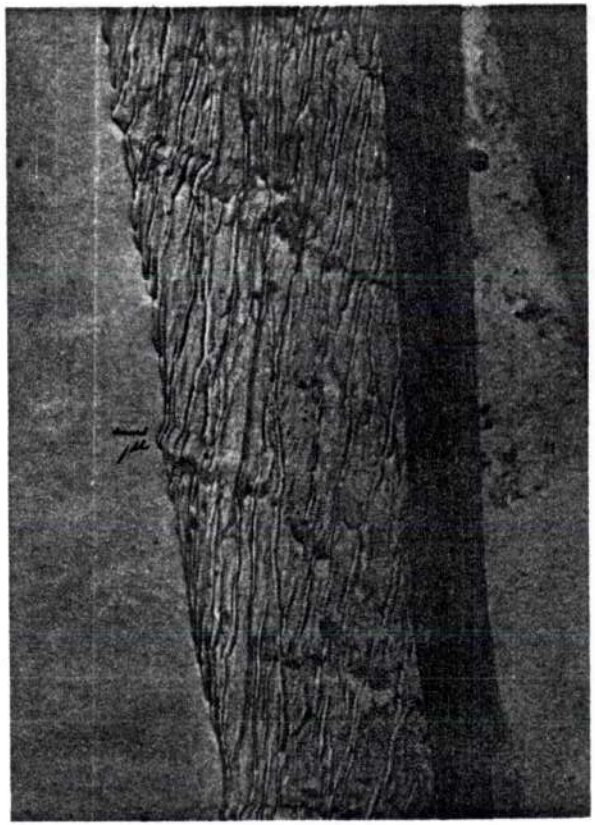


(c) 560X

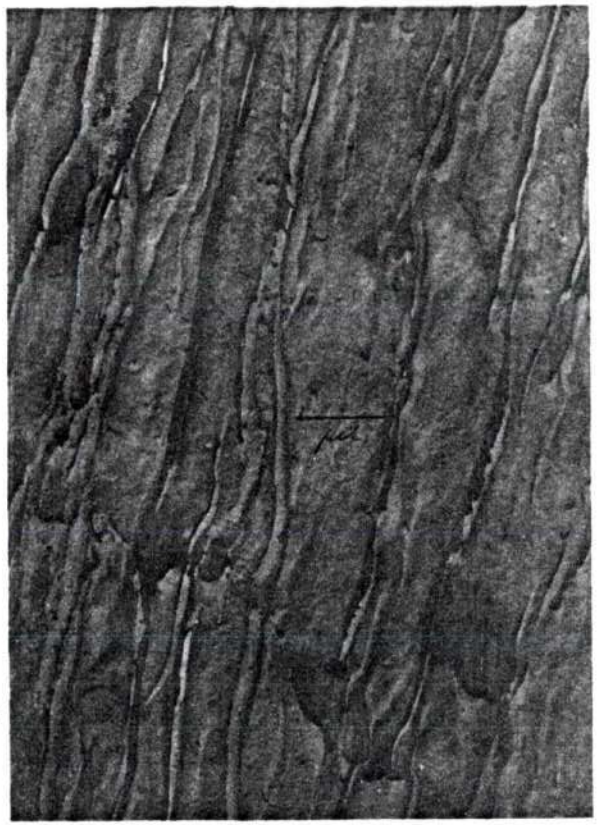


(d) 560X

Figure 30. Continued, Cotton Hopi Acala 54, Optical Micrographs of Surface (c) and Cross Sections (d)

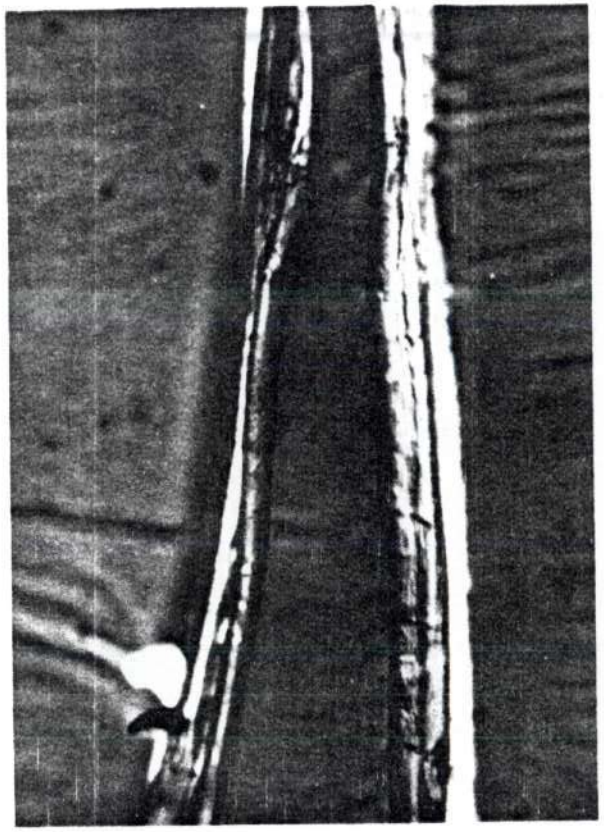


(a) 3,800X



(b) 12,800

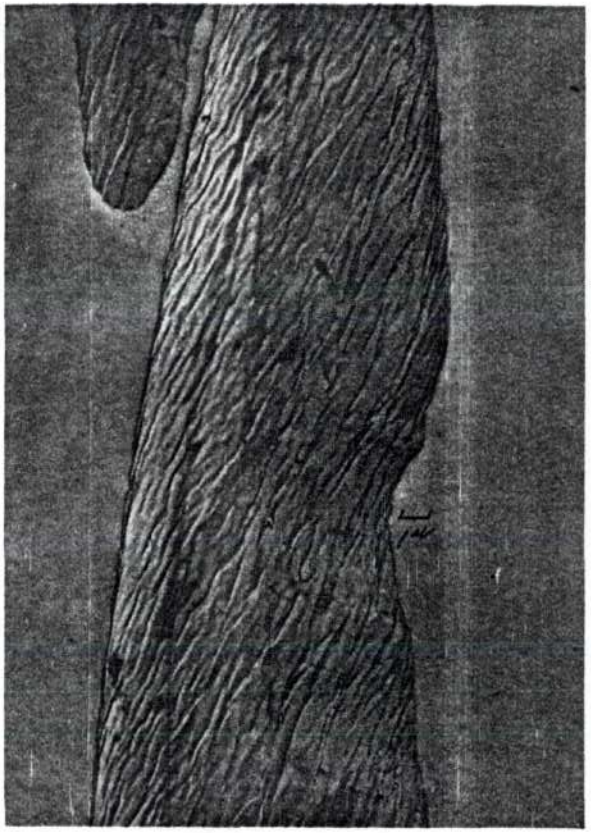
Figure 31. Cotton Pima S-1, Electron Micrographs of Surface (a) and (b)



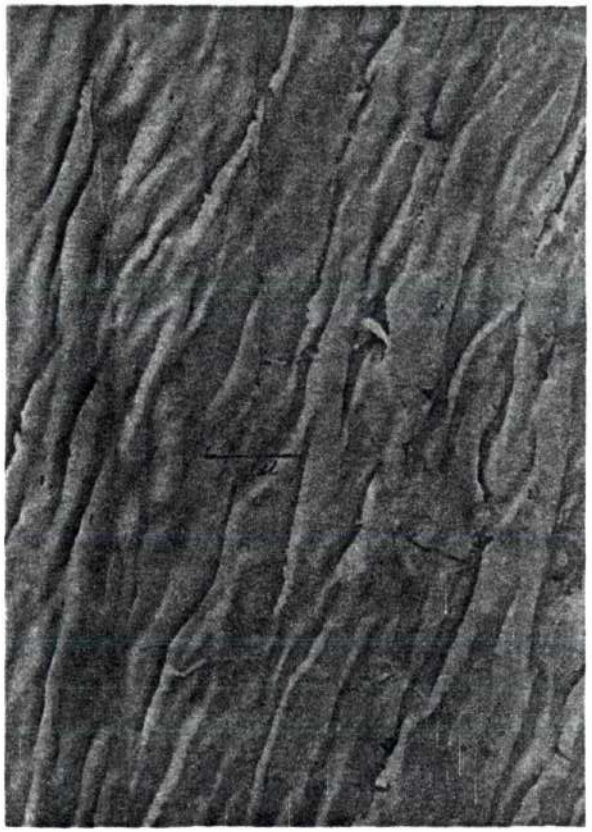
(c) 560X

(d) 560X

Figure 31. Continued, Cotton Pima S-1, Optical Micrographs of Surface (c) and Cross Sections (d)

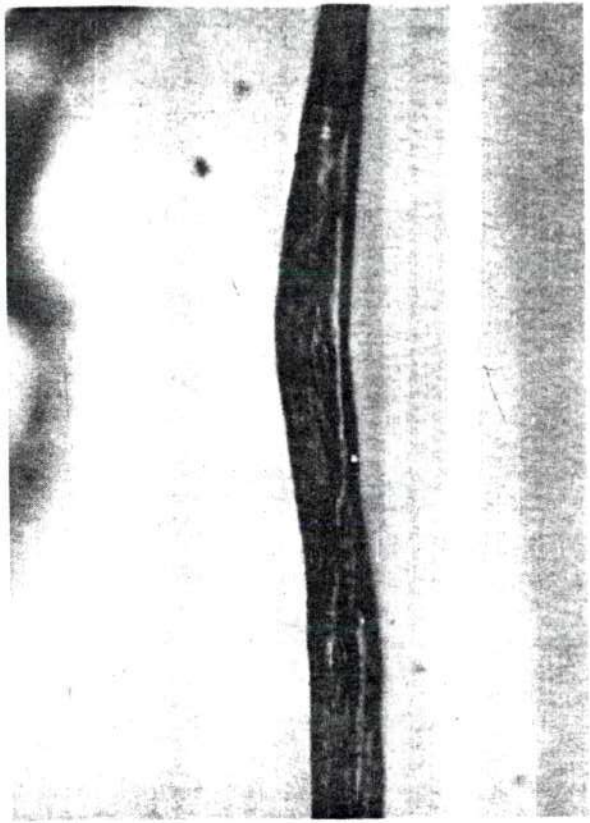


(a) 3,800X



(b) 12,800X

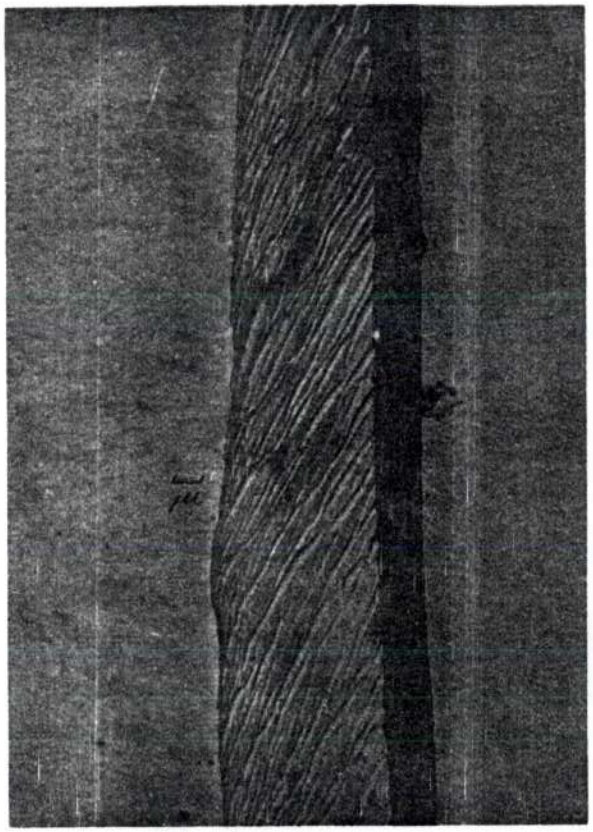
Figure 32. Cotton Deltapine 15, Electron Micrographs of Surface (a) and (b)



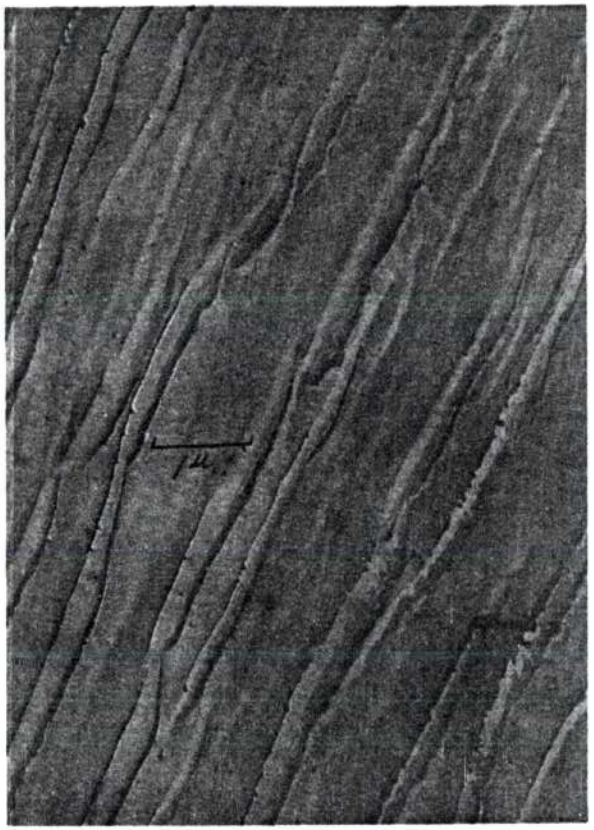
(c) 560X

(d) 560X

Figure 32. Continued, Cotton Deltapine 15, Optical Micrographs of Surface (c) and Cross Sections (d)

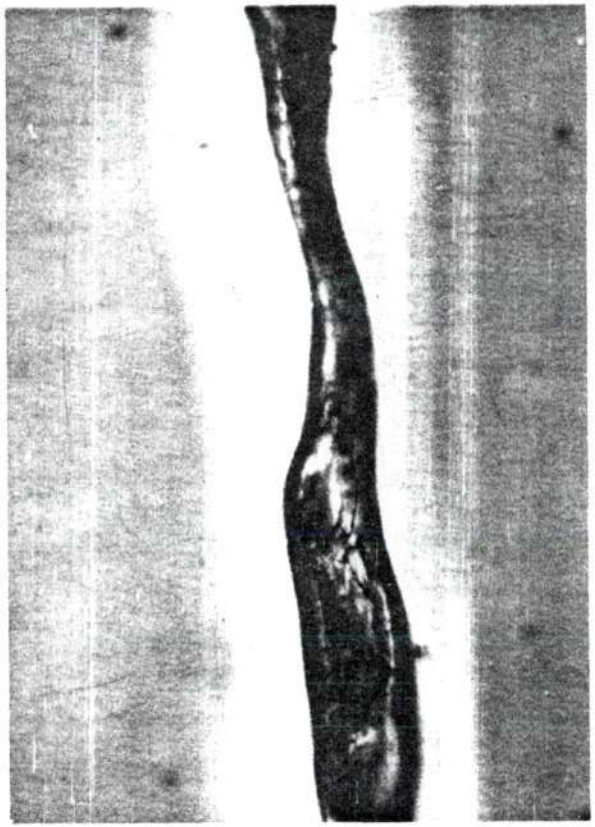


(a) 3,800X

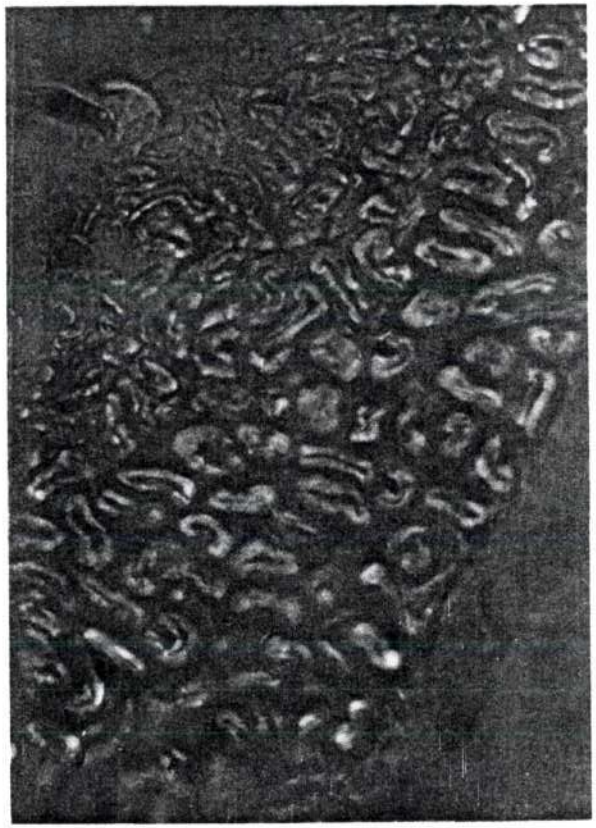


(b) 12,800X

Figure 33. Cotton Bobshaw (1955 Crop), Electron Micrographs of Surface (a) and (b)

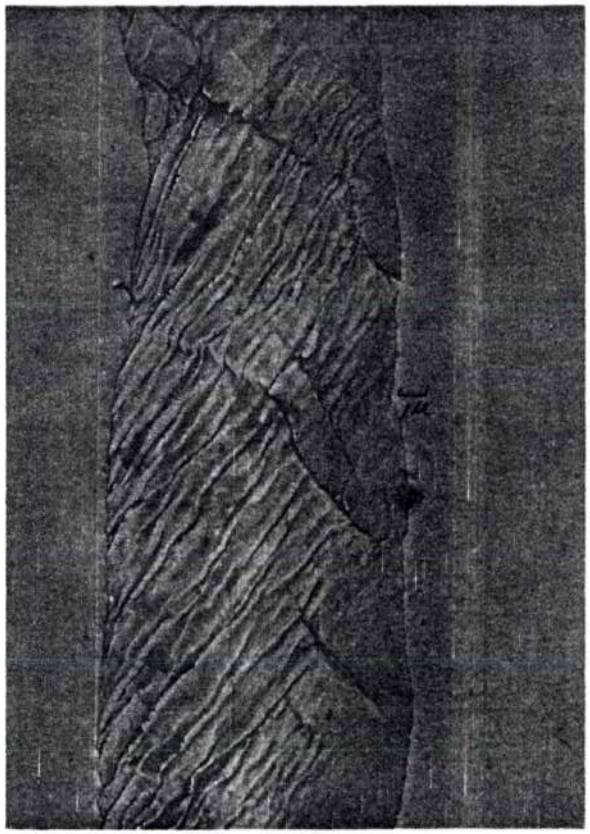


(c) 560X



(d) 560X

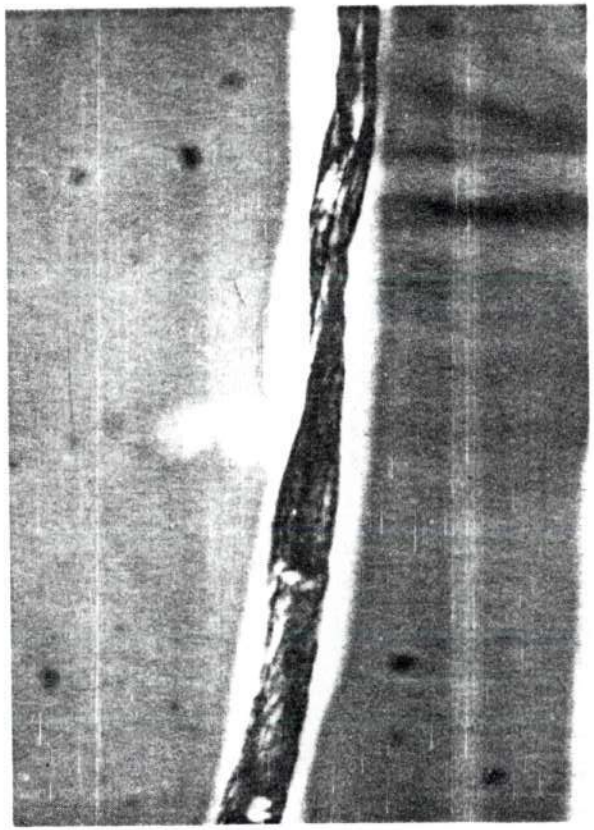
Figure 33. Continued, Cotton Bobshaw (1955 Crop), Optical Micrographs of Surface (c) and Cross Sections (d)



(a) 3,800X

(b) 12,800X

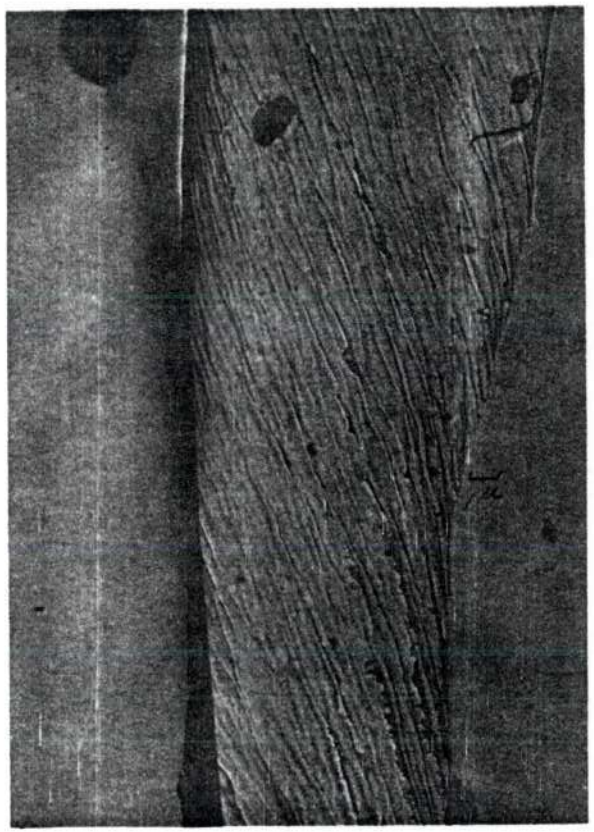
Figure 34. Cotton Stoneville, Electron Micrographs of Surface (a) and (b)



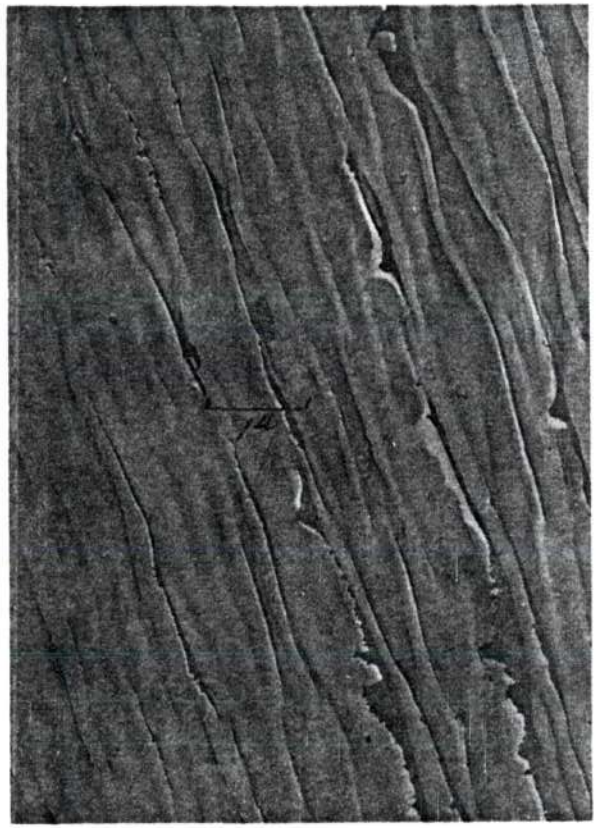
(c) 560X

(d) 560X

Figure 34. Continued, Cotton Stoneville, Optical Micrographs of Surface (c) and Cross Sections (d)

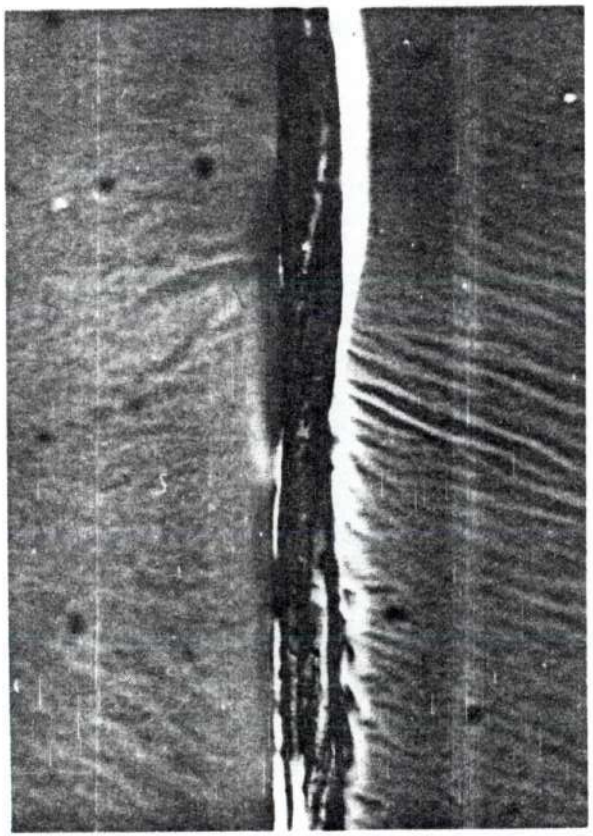


(a) 3,800X



(b) 12,800X

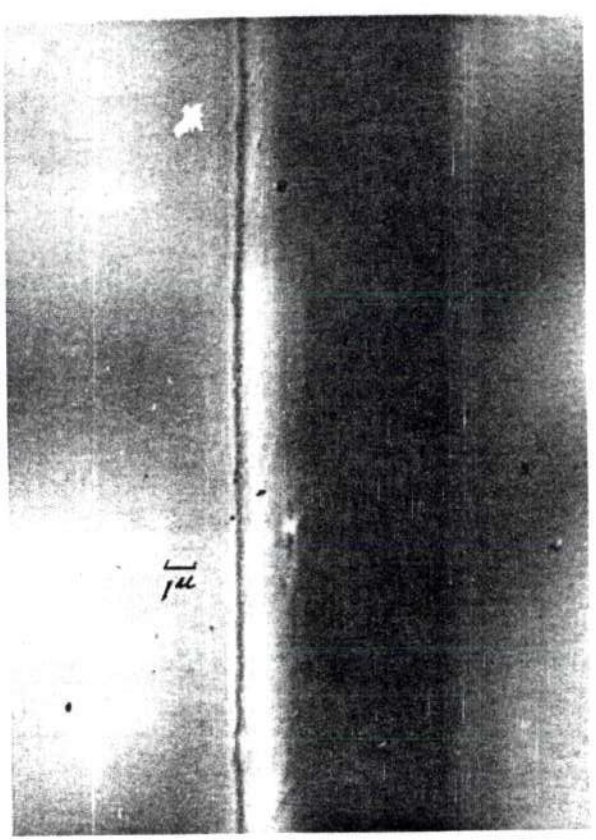
Figure 35. Cotton Deltapine (1955 Crop), Electron Micrographs of Surface (a) and (b)



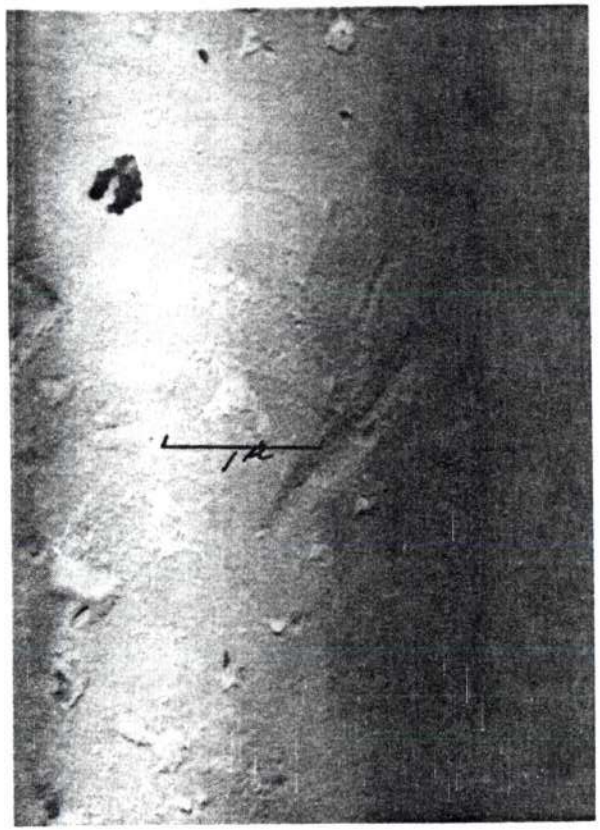
(c) 560X

(d) 560X

Figure 35. Continued, Cotton Deltapine (1955 Crop), Optical Micrographs of Surface (c) and Cross Sections (d)

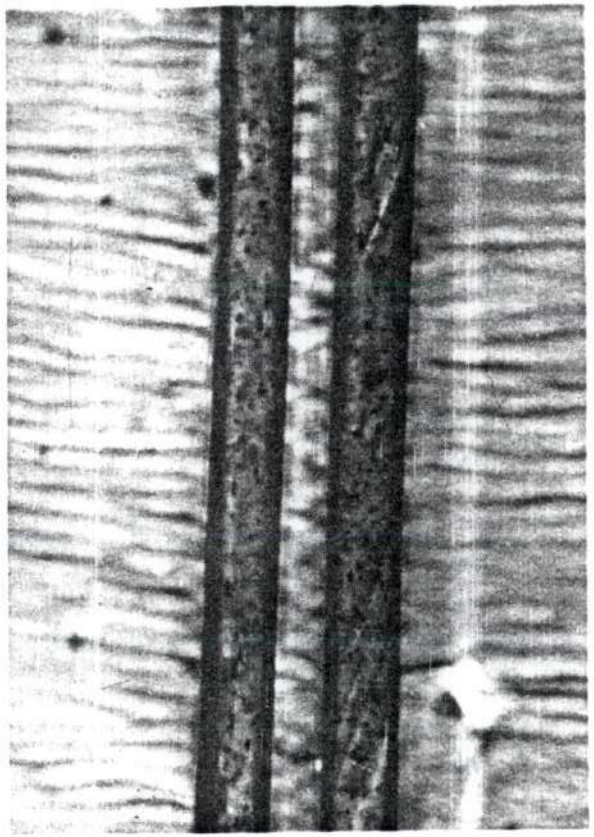


(a) 3,800X

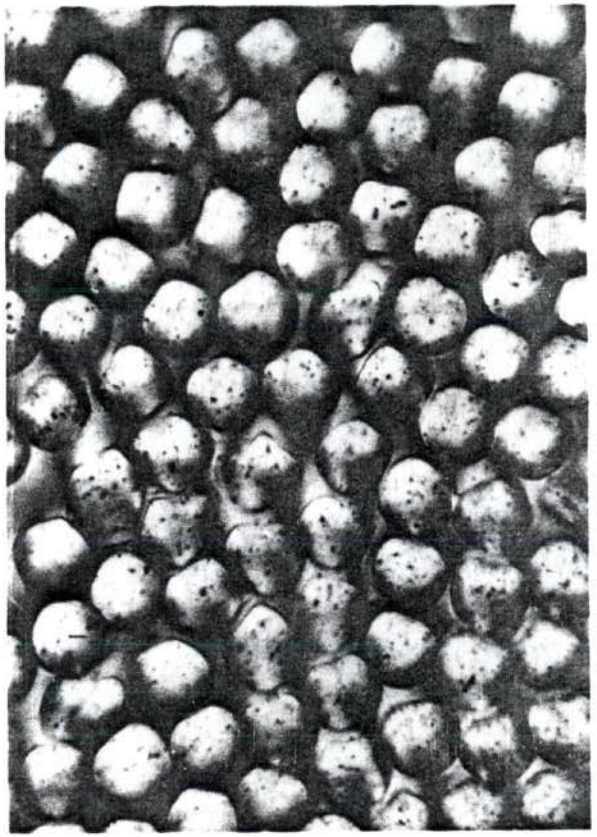


(b) 20,500X

Figure 36. Dacron Polyester, Electron Micrographs of Surface (a) and (b)

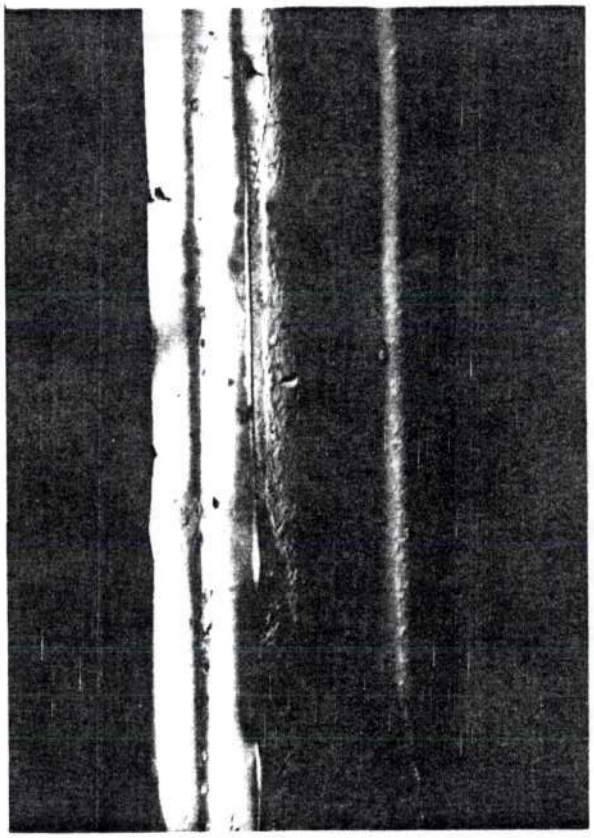


(c) 560X

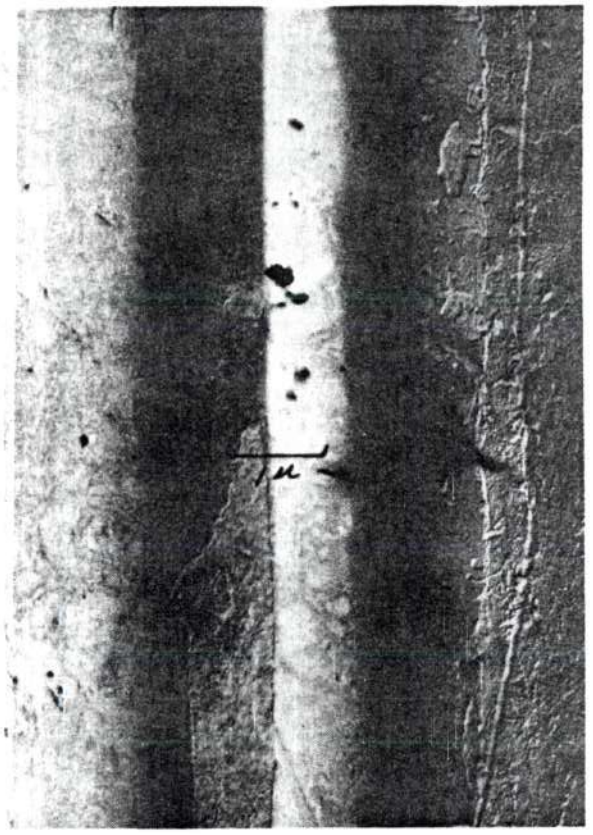


(d) 560X

Figure 36. Continued, Dacron Polyester, Optical Micrographs of Surface (c) and Cross Sections (d)

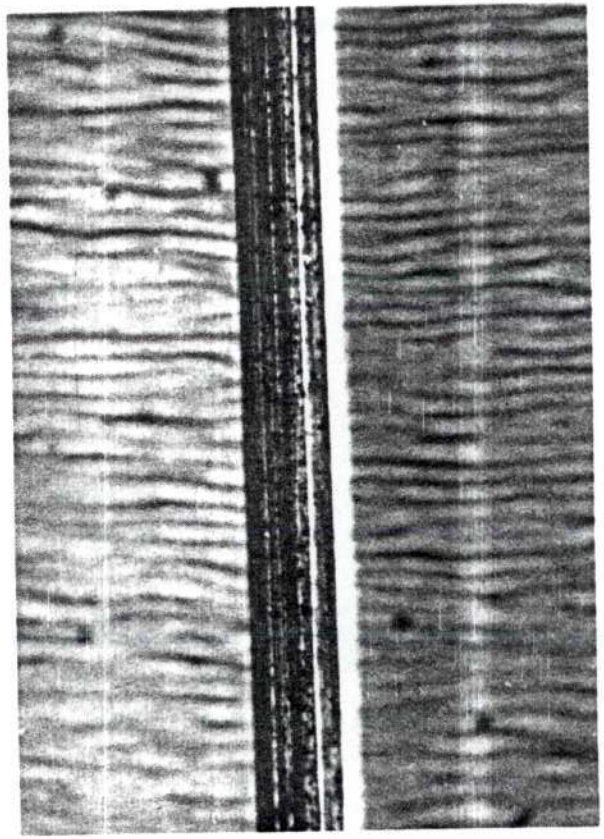


(a) 2,900X

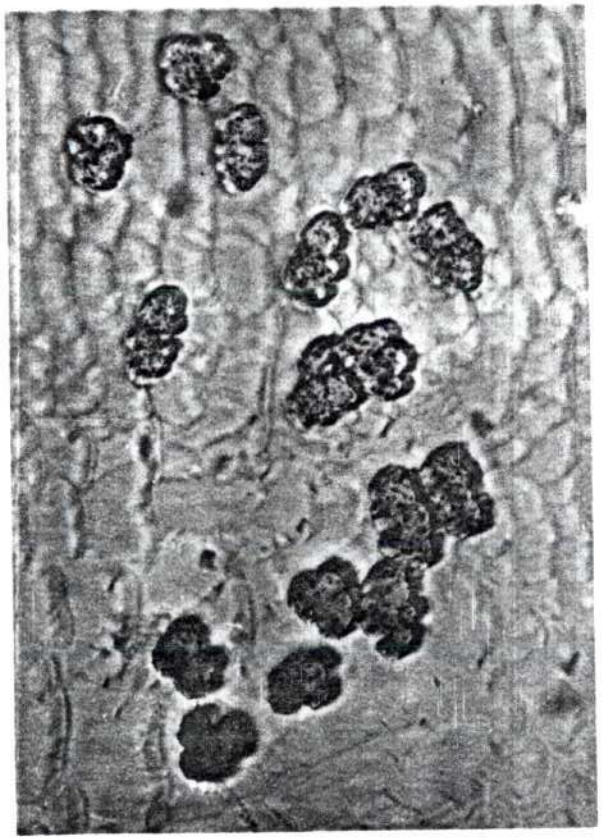


(b) 12,800X

Figure 37. Celanese Dull Triacetate, Electron Micrographs of Surface (a) and (b)

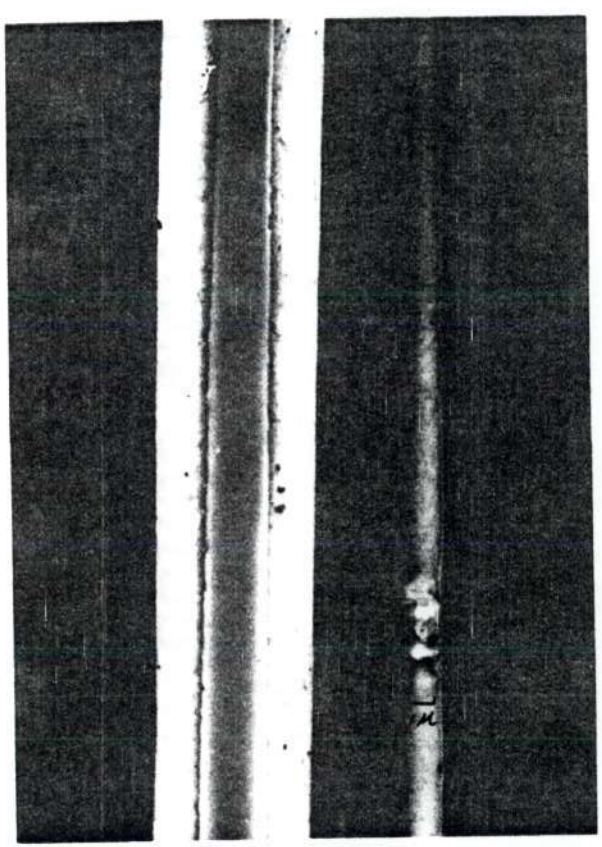


(c) 560X

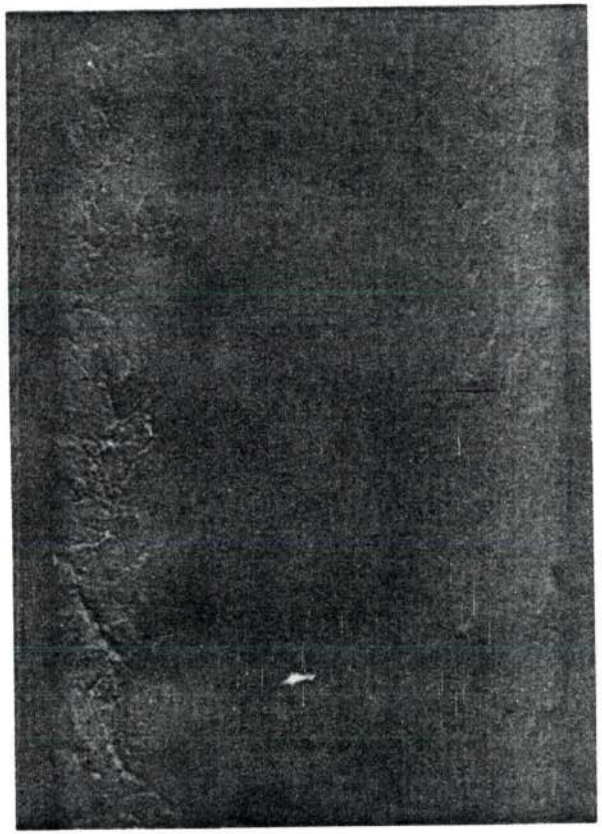


(d) 560X

Figure 37. Continued, Celanese Dull Triacetate, Optical Micrographs of Surface (c) and Cross Sections (d)

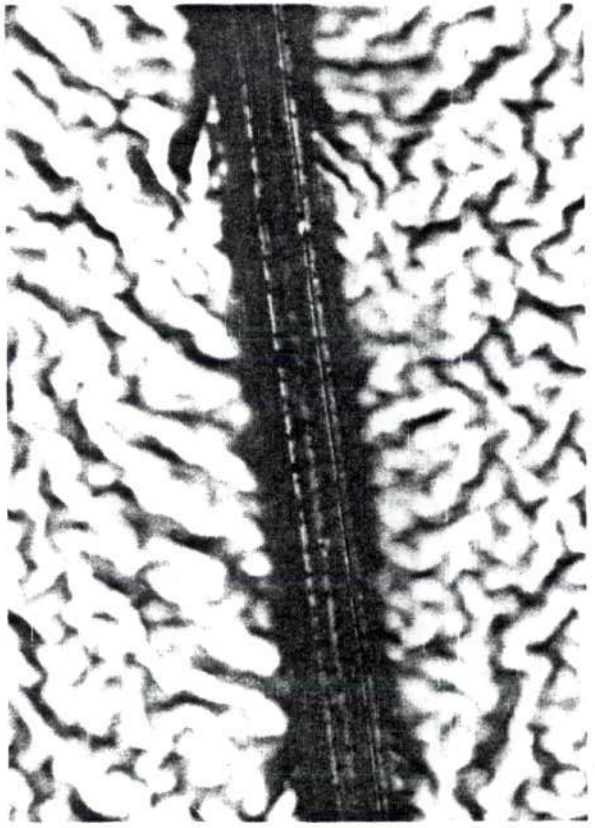


(a) 3,800X

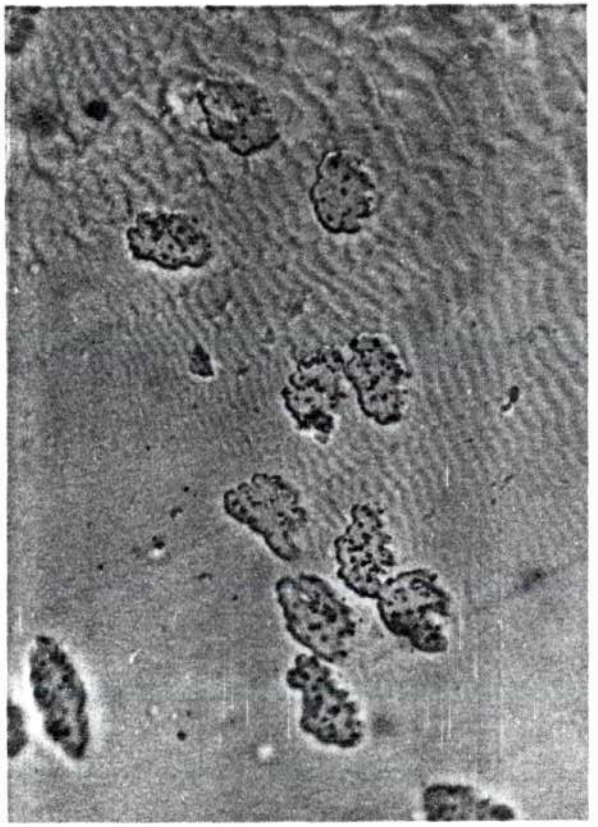


(b) 12,800X

Figure 38. Avisco Rayon, Electron Micrographs of Surface (a) and (b)

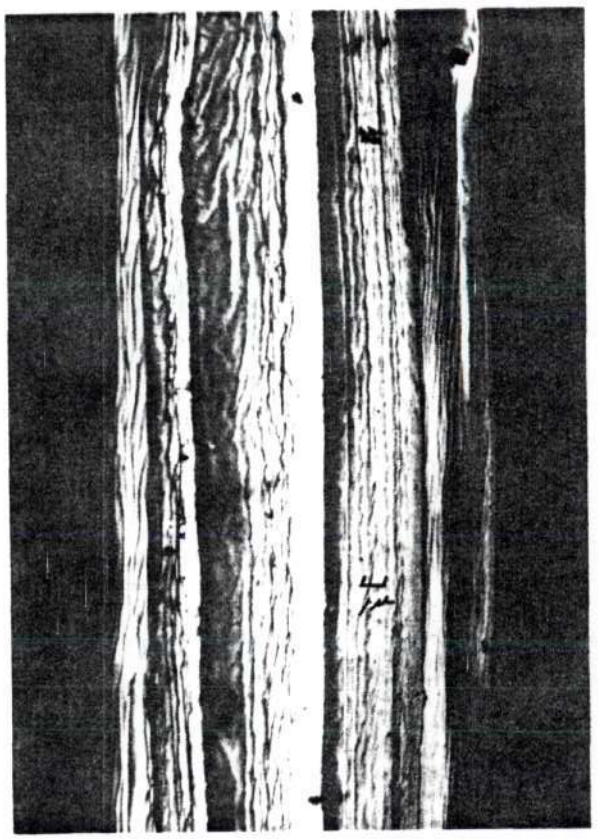


(c) 560X

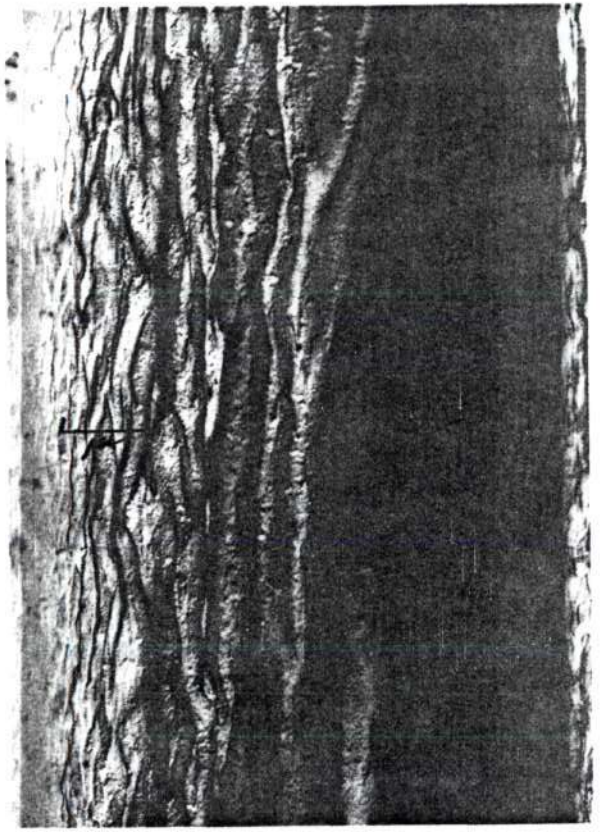


(d) 560X

Figure 38. Continued, Avisco Rayon, Optical Micrographs of Surface (c) and Cross Sections (d)

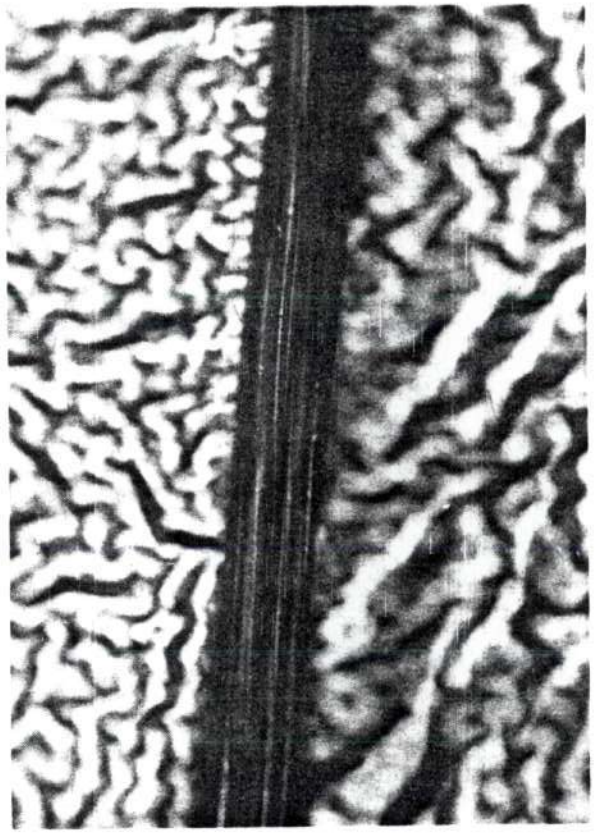


(a) 2,900X

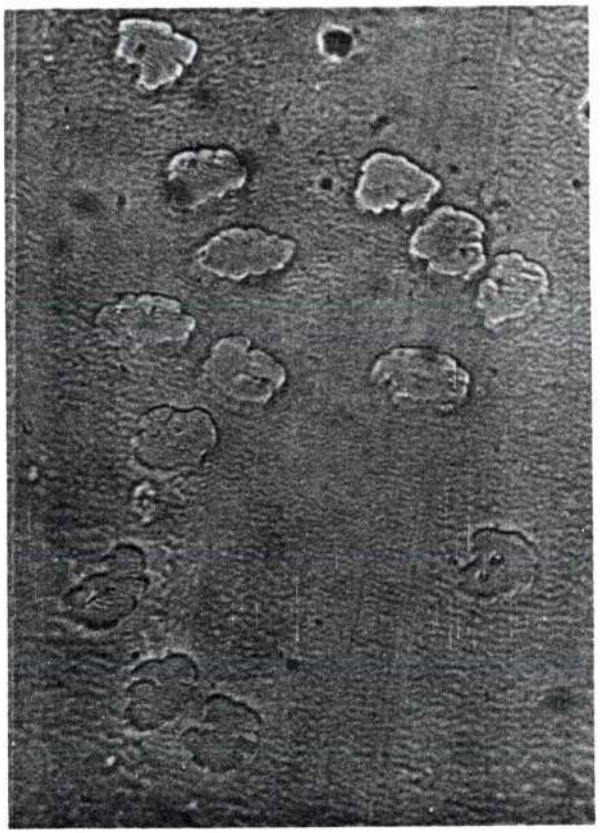


(b) 12,800X

Figure 39. Avisco Bright Rayon, Electron Micrographs of Surface (a) and (b)

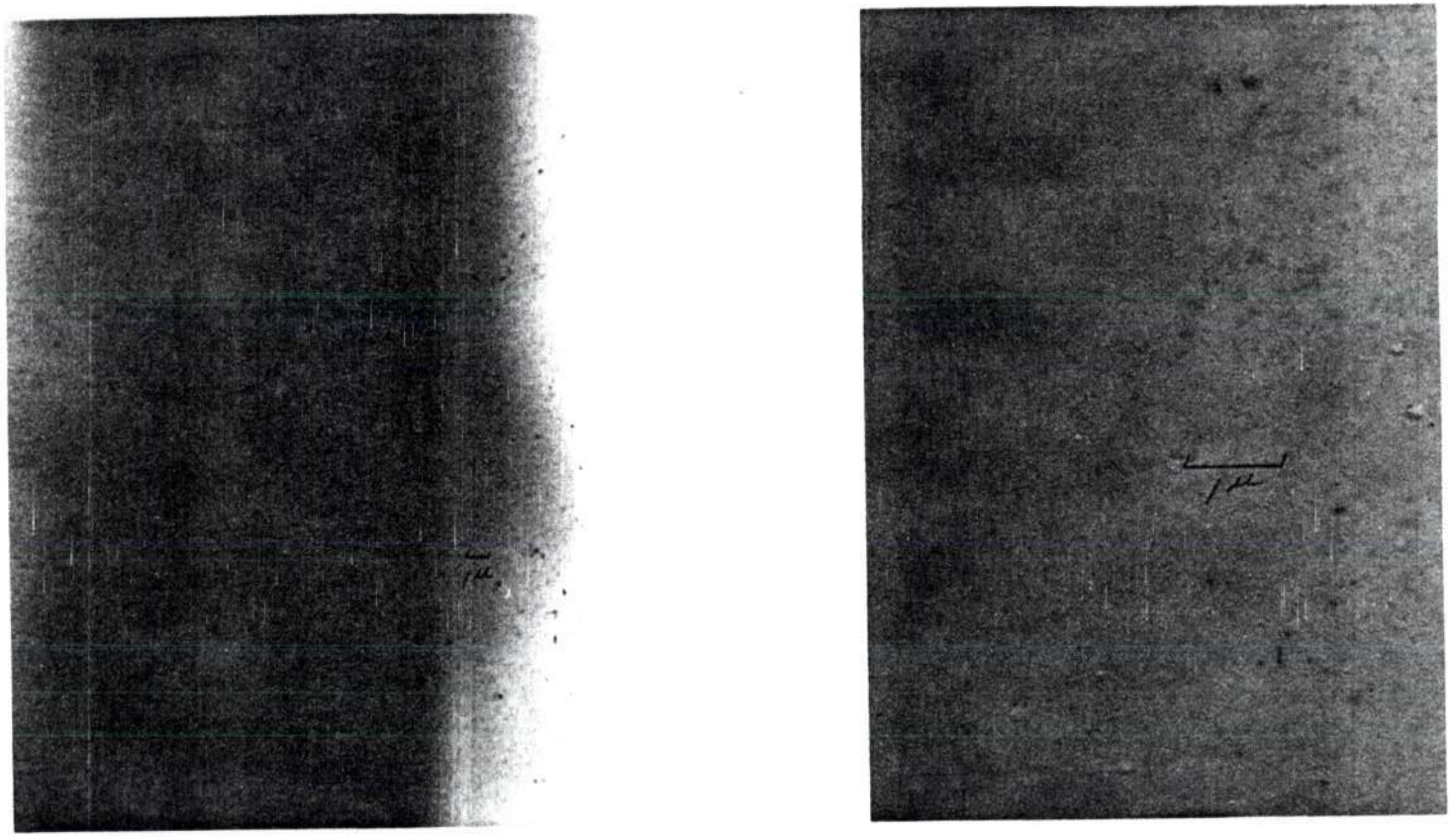


(c) 560X



(d) 560X

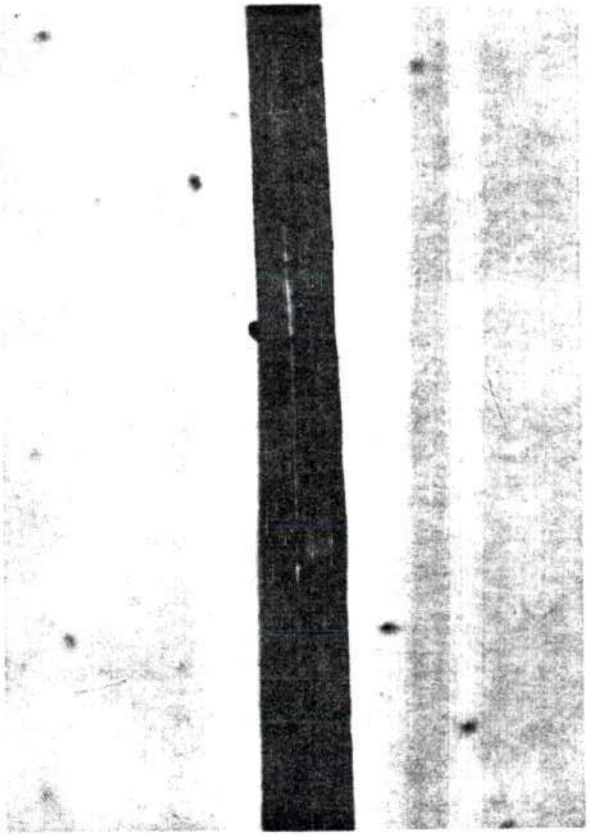
Figure 39. Continued, Avisco Bright Rayon, Optical Micrographs of Surface (c) and Cross Sections (d)



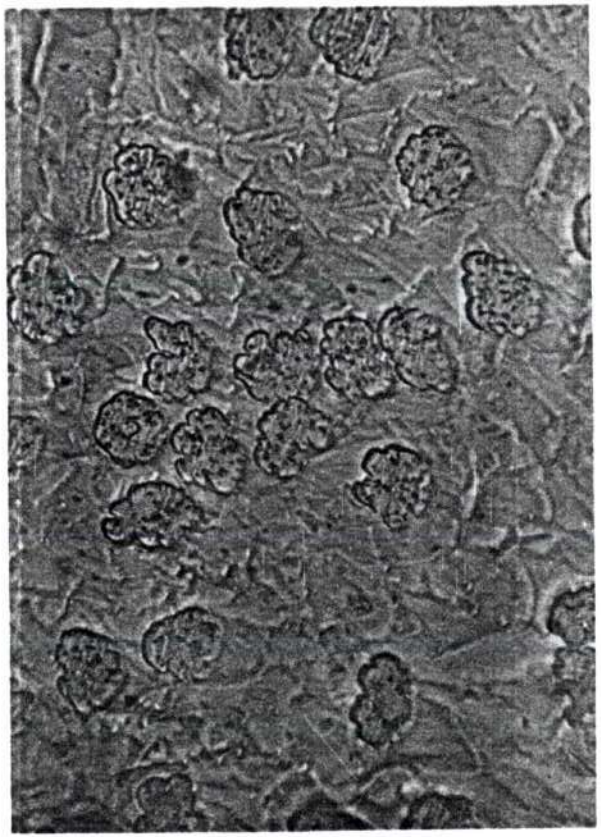
(a) 2,900X

(b) 12,800X

Figure 40. Avisco Dull Rayon, Electron Micrographs of Surface (a) and (b)

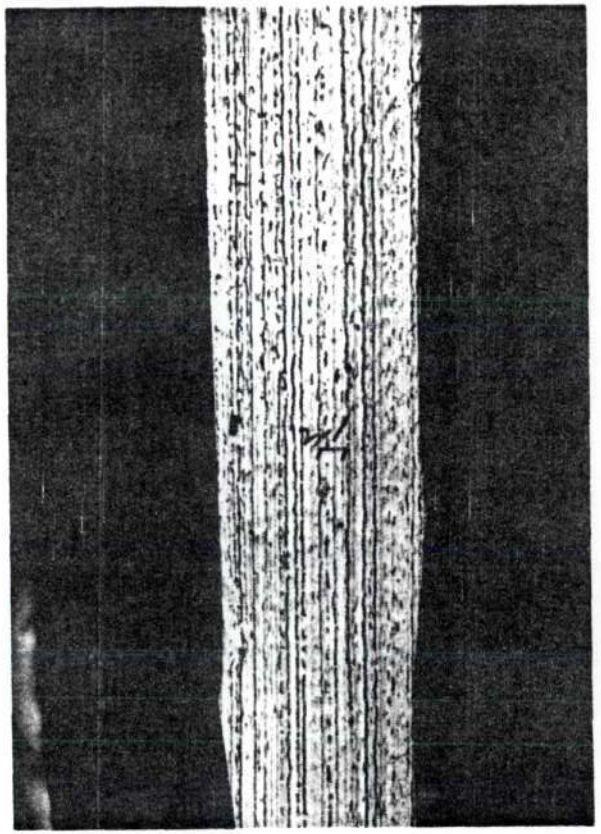


(c) 560X

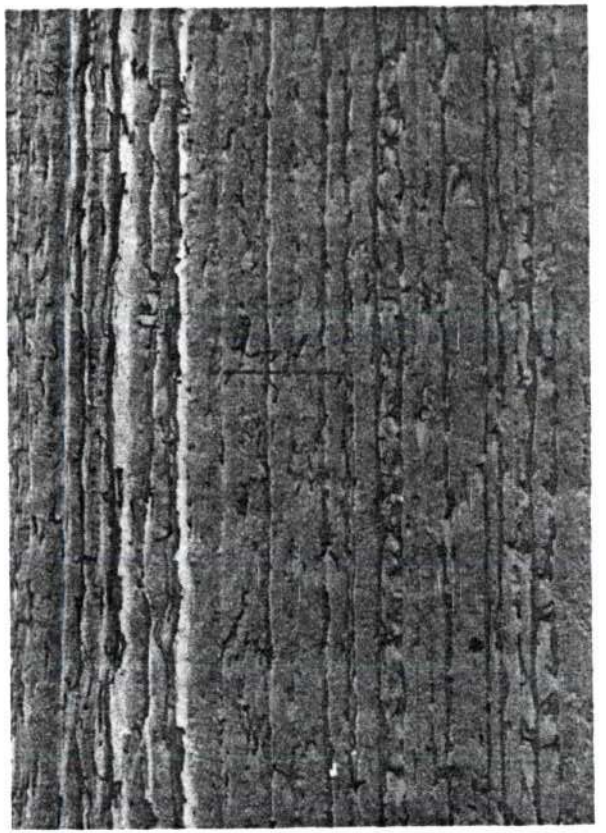


(d) 560X

Figure 40. Continued, Avisco Dull Rayon, Optical Micrographs of Surface (c) and Cross Sections (d)

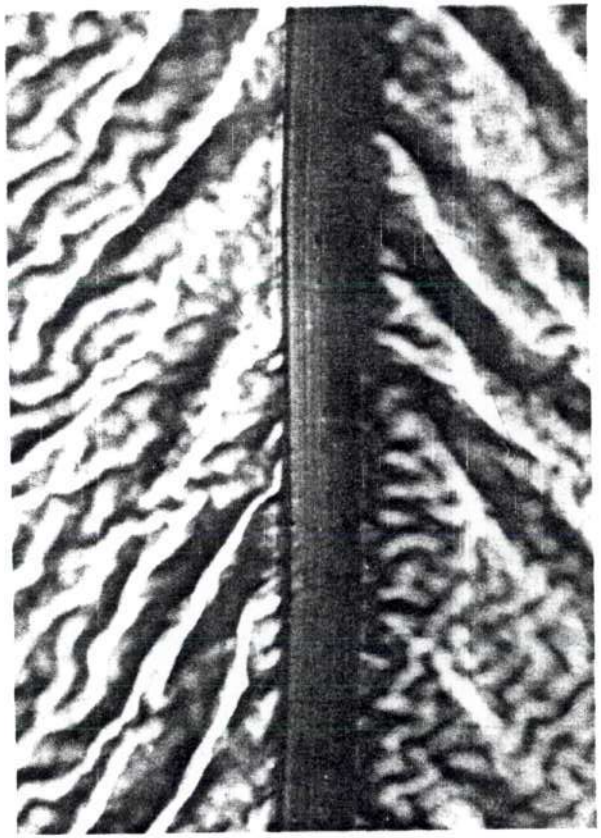


(a) 3,800X

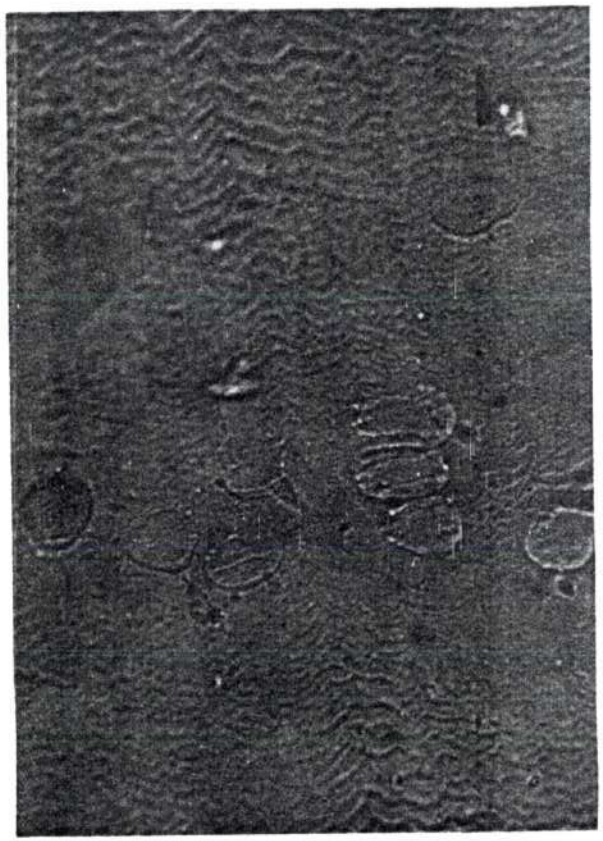


(b) 12,800X

Figure 41. Avisco Bright Fiber 40 Rayon, Electron Micrographs of Surface (a) and (b)

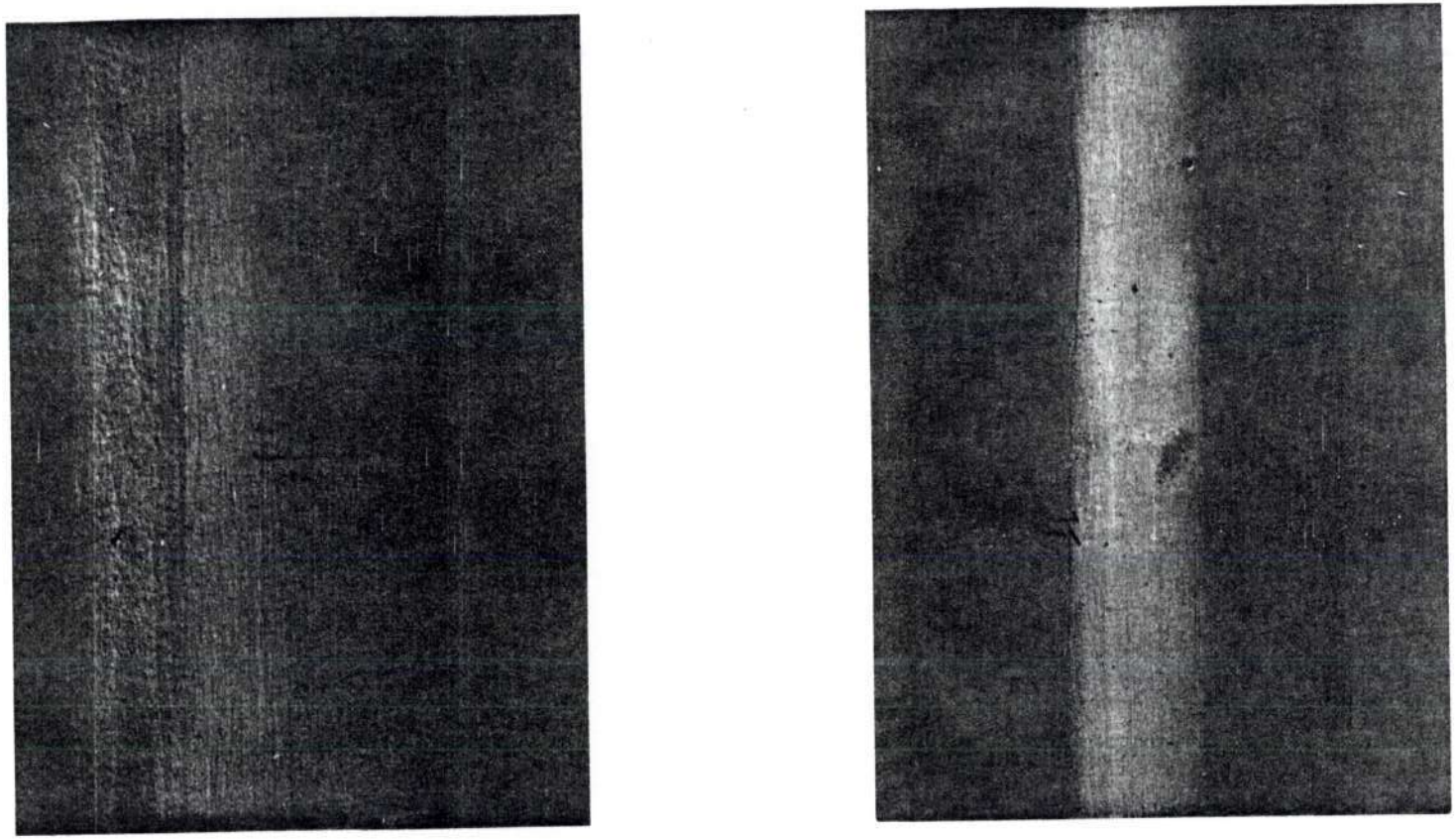


(c) 560X



(d) 560X

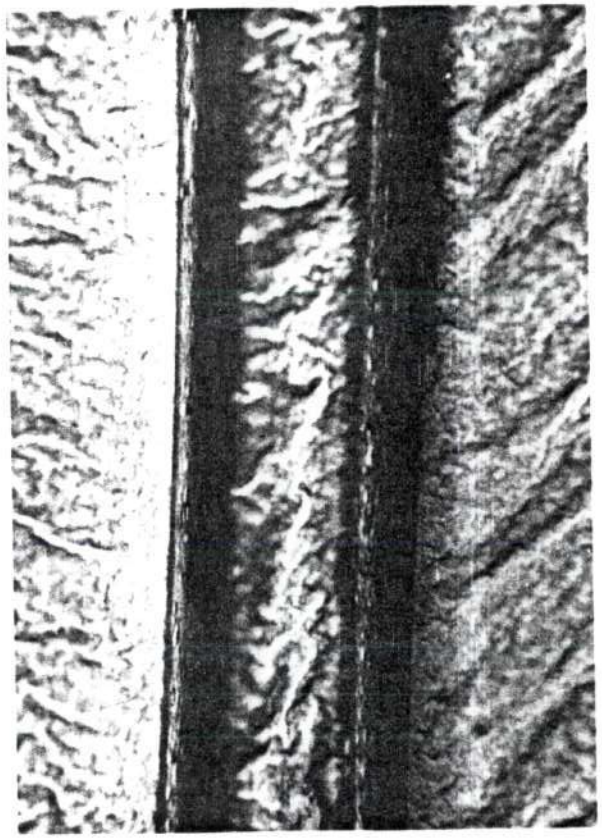
Figure 41. Continued, Avisco Bright Fiber 40 Rayon, Optical Micrographs of Surface (c) and Cross Sections (d)



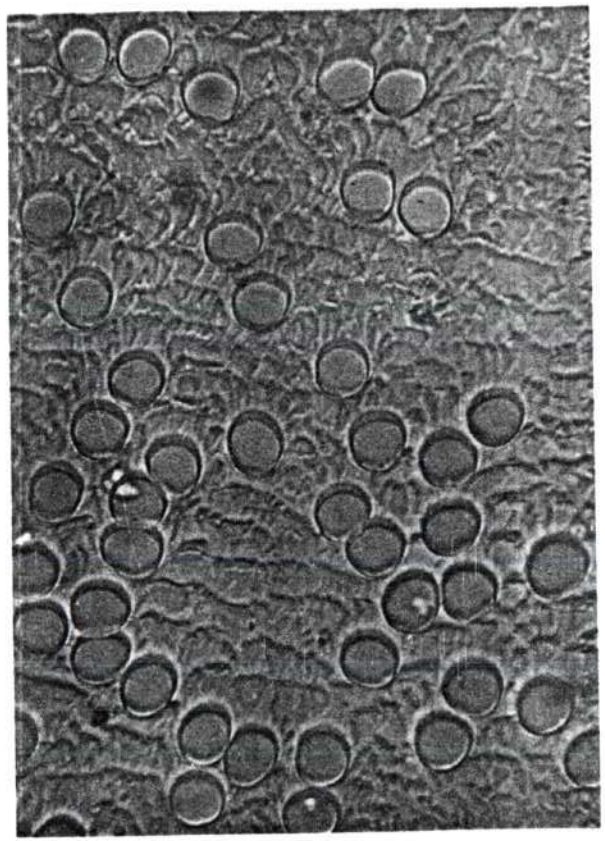
(a) 3,800X

(b) 12,800X

Figure 42. Enka Rayon, Electron Micrographs of Surface (a) and (b)

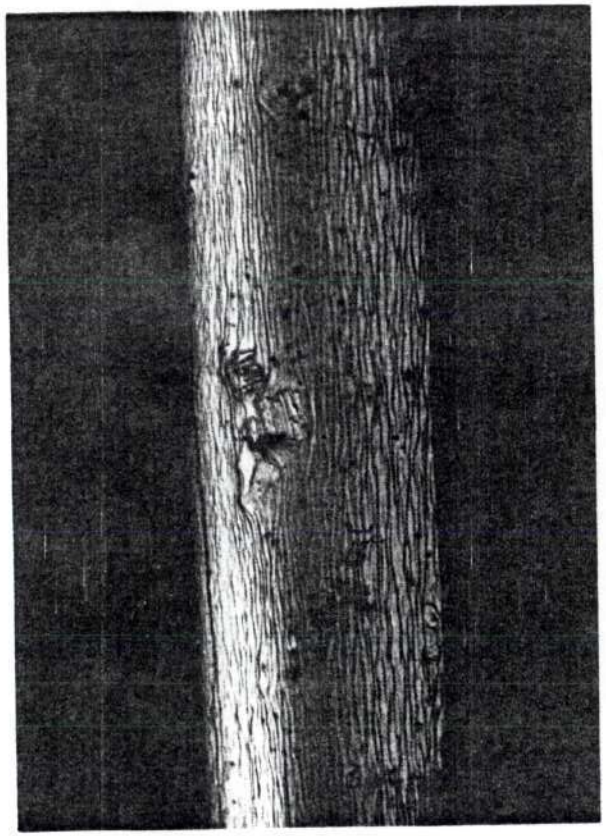


(c) 560X

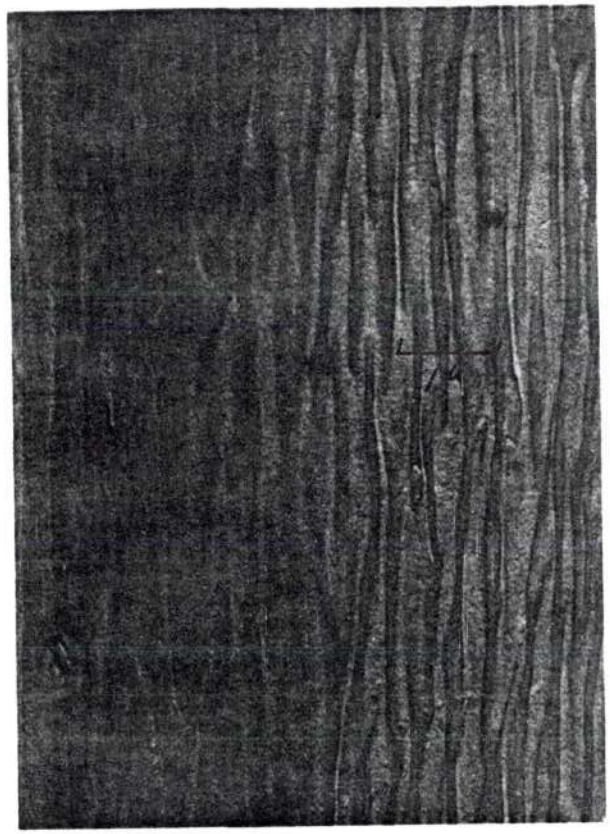


(d) 560X

Figure 42. Continued, Enka Rayon, Optical Micrographs of Surface (c) and Cross Sections (d)

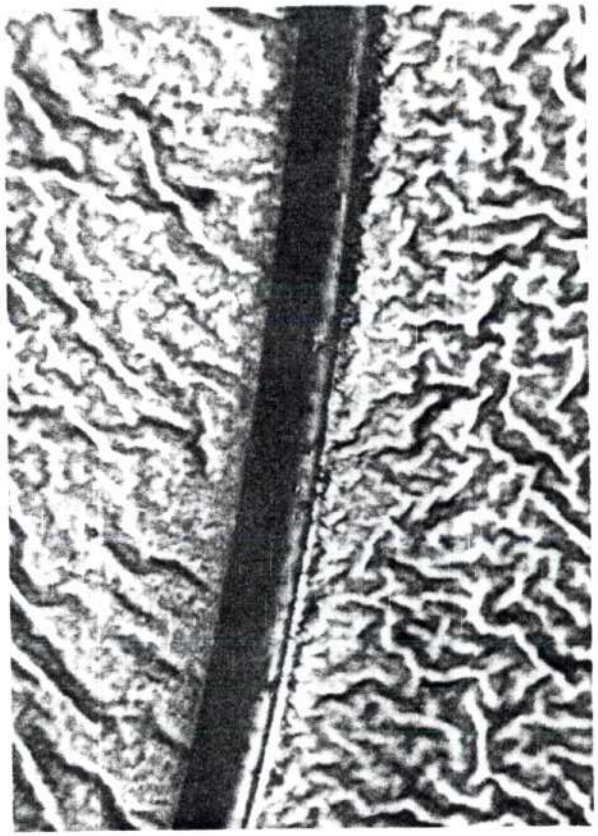


(a) 2,900X

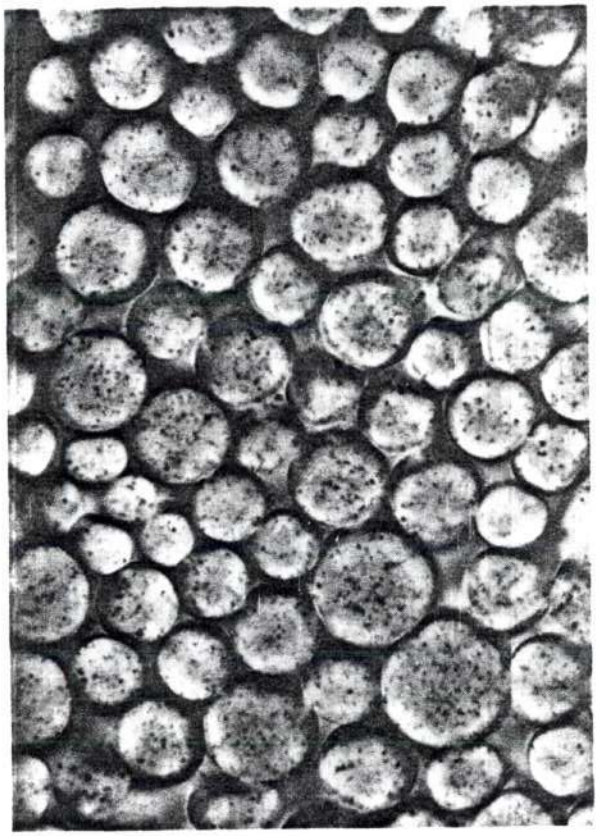


(b) 12,800X

Figure 43. Dupont Nylon Polyamide Semi-dull, Electron Micrographs of Surface (a) and (b)

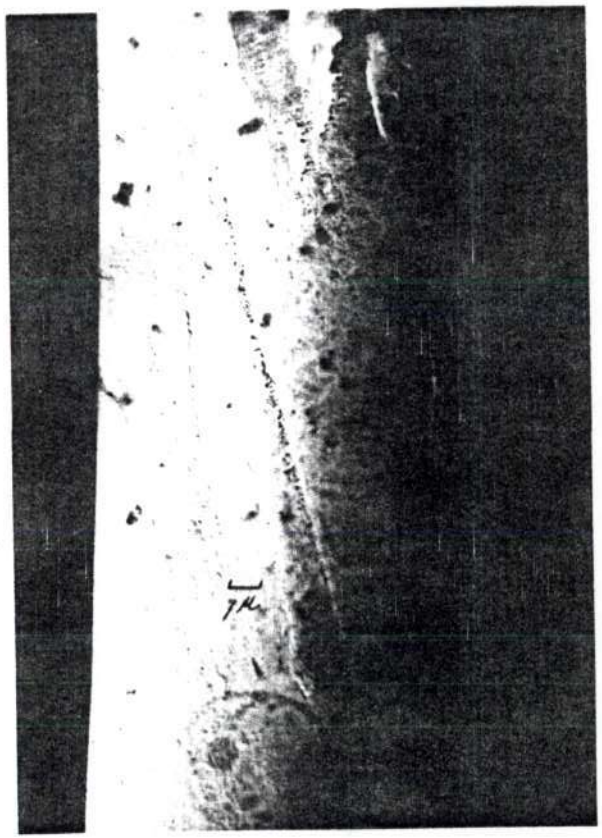


(c) 560X



(d) 560X

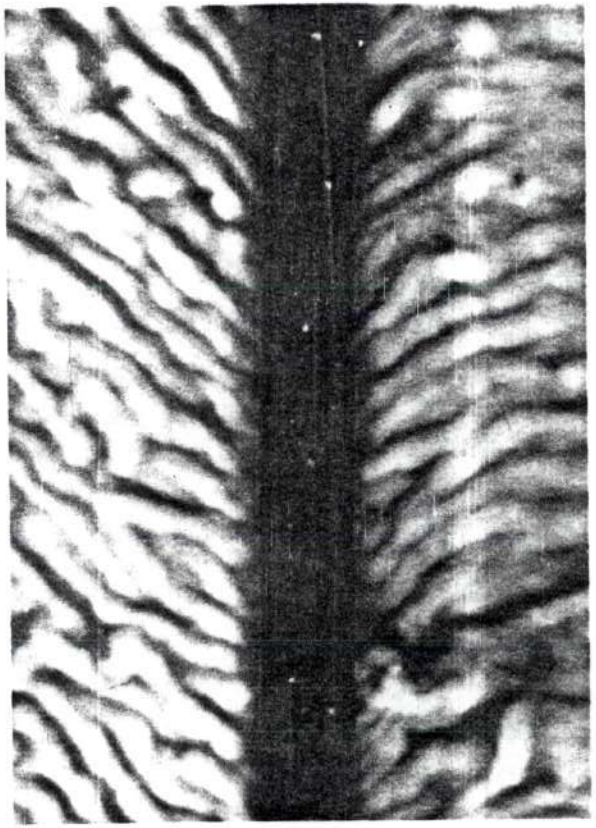
Figure 43. Continued, Dupont Nylon Polyamide Semi-dull, Optical Micrographs of Surface (c) and Cross Sections (d)



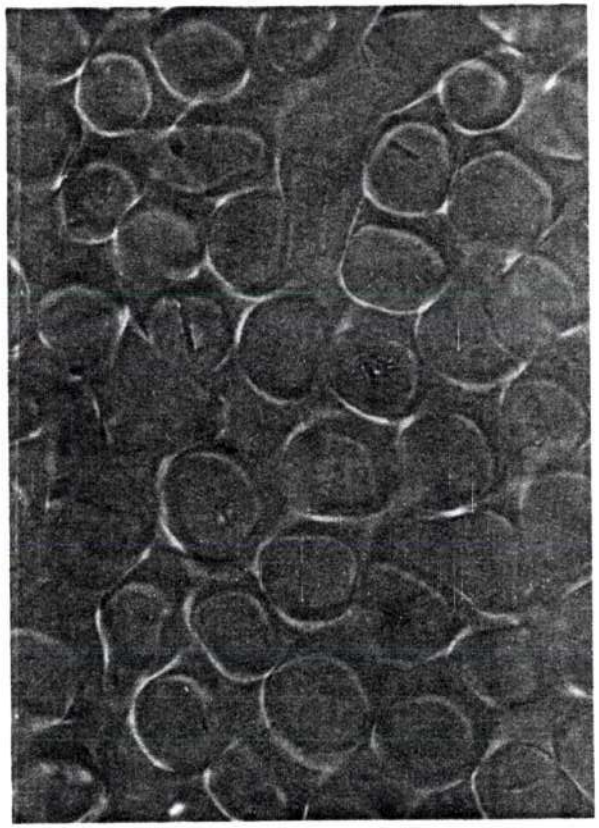
(a) 3,800X

(b) 12,800X

Figure 44. Herculon Polypropylene, Electron Micrographs of Surface (a) and (b)

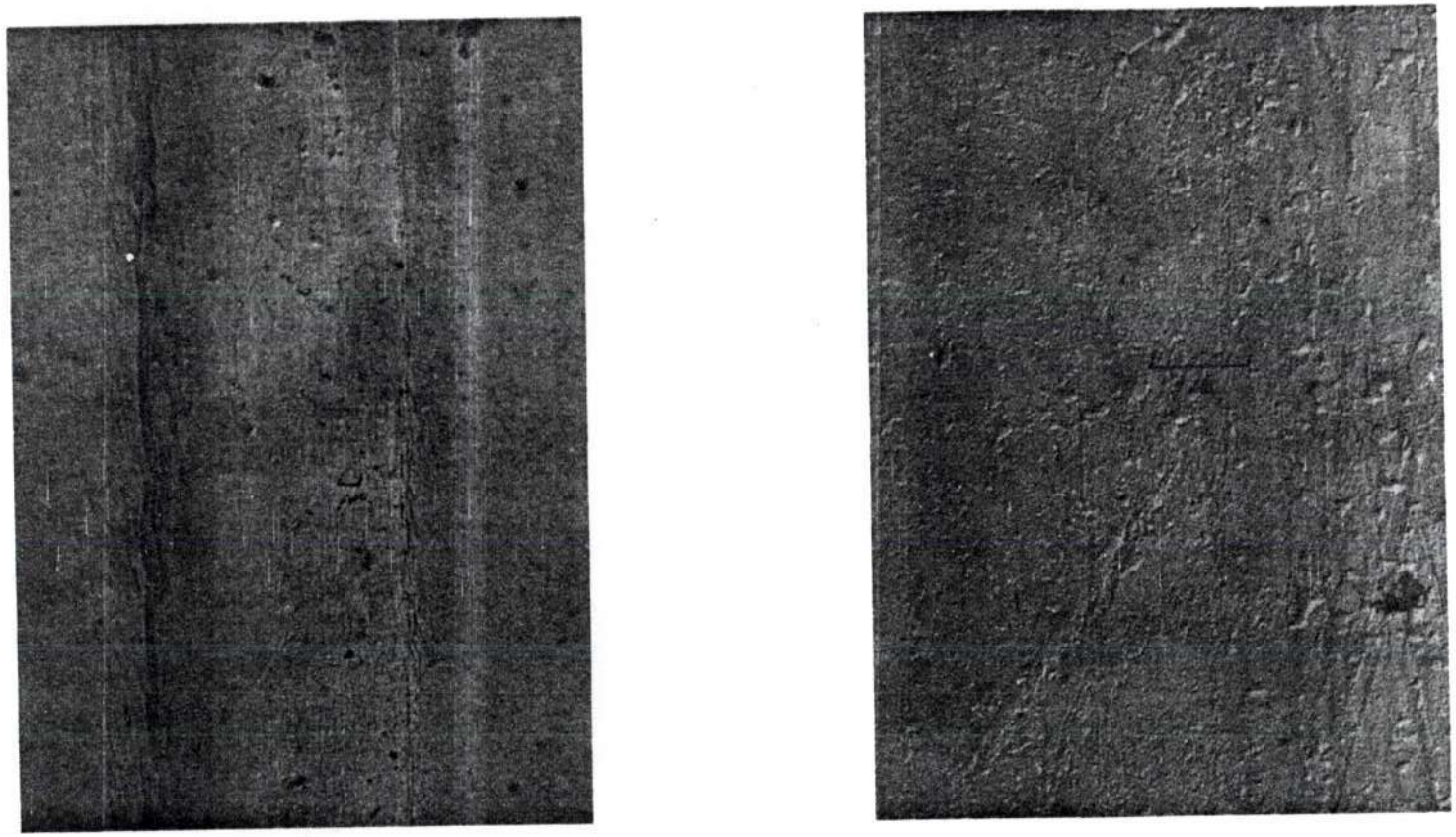


(c) 560X



(d) 560X

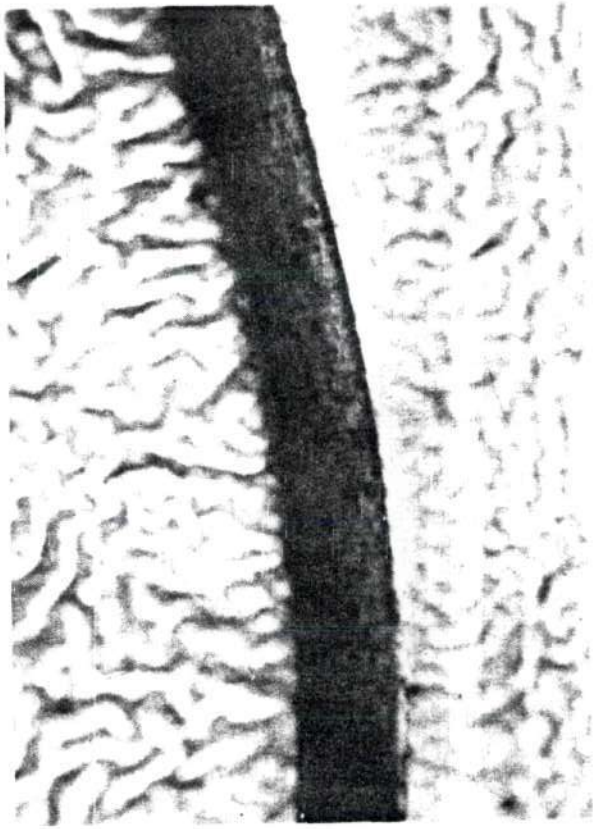
Figure 44. Continued, Herculon Polypropylene, Optical Micrographs of Surface (c) and Cross Sections (d)



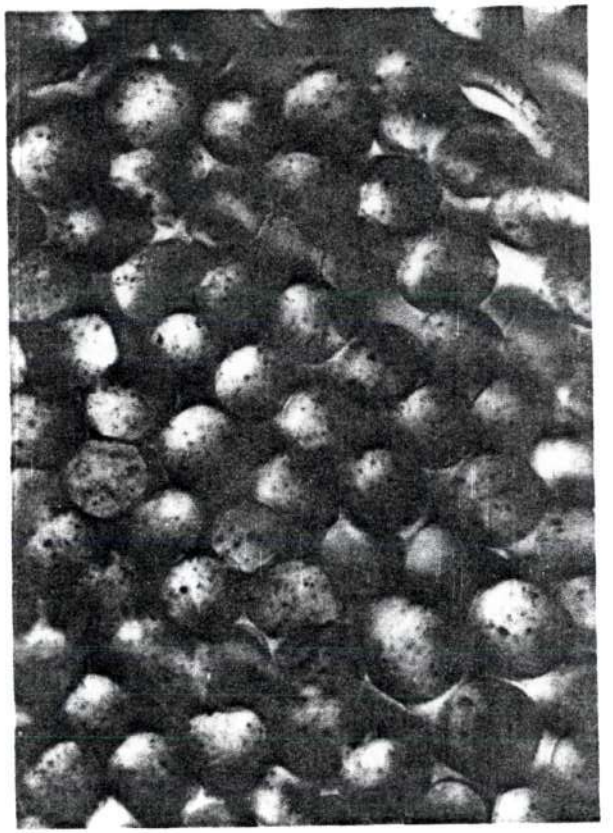
(a) 2,900X

(b) 12,800X

Figure 45. Kodel Polyester II Semi-dull, Electron Micrographs of Surface (a) and (b)

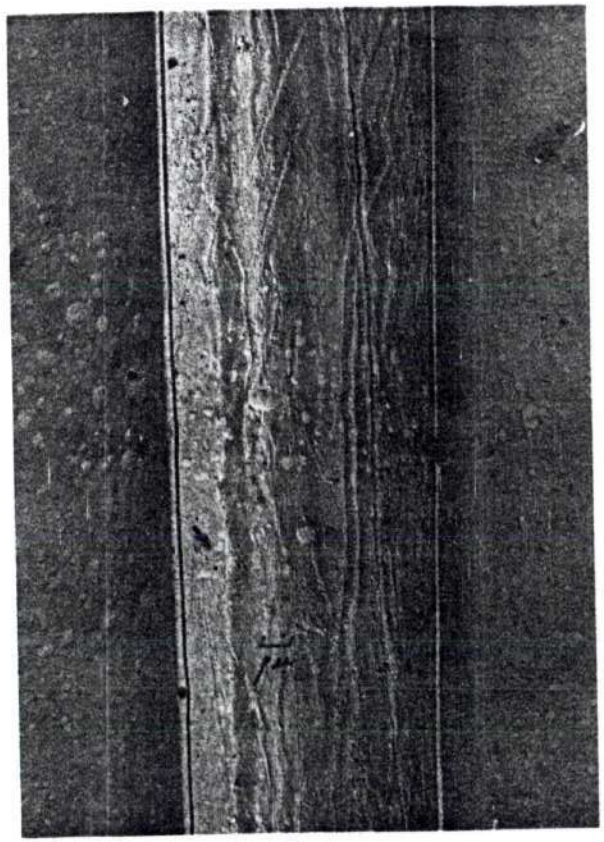


(c) 560X

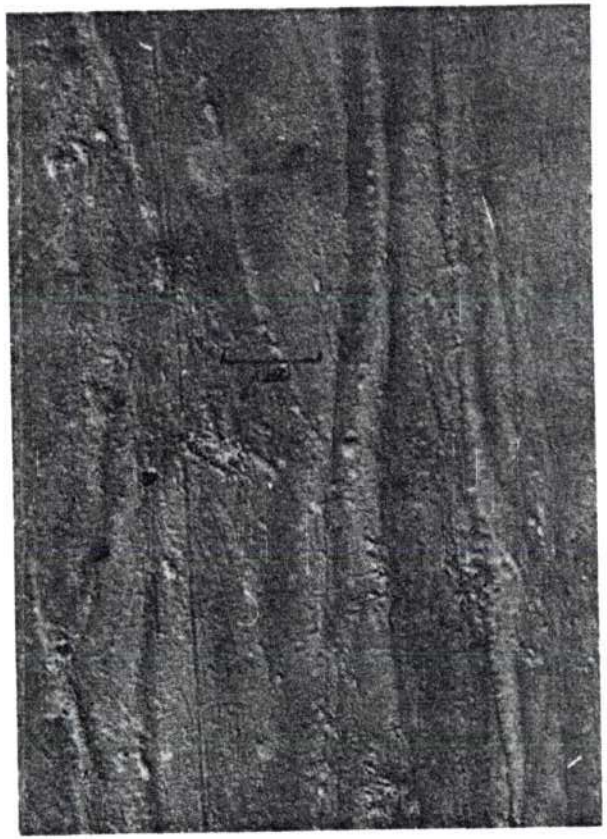


(d) 560X

Figure 45. Continued, Kodel Polyester II Semi-dull, Optical Micrographs of Surface (c) and Cross Sections (d)

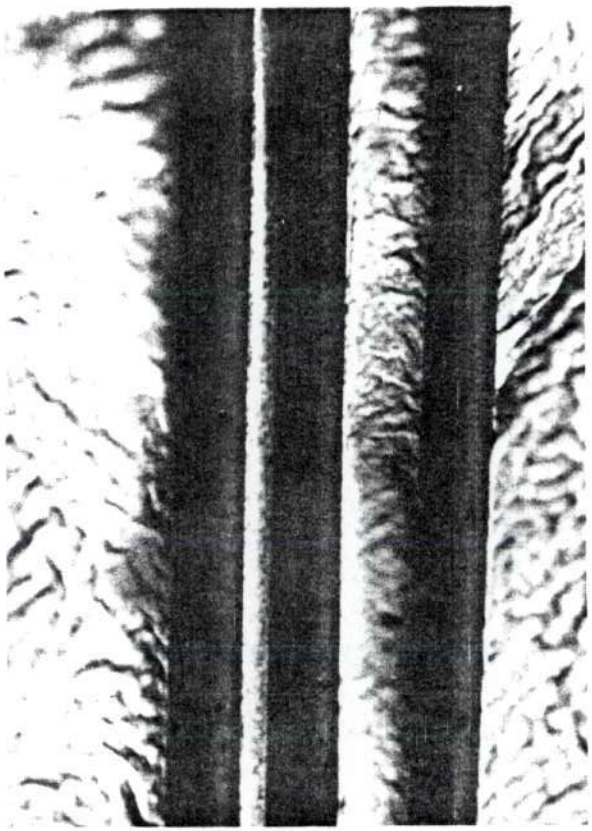


(a) 3,800X

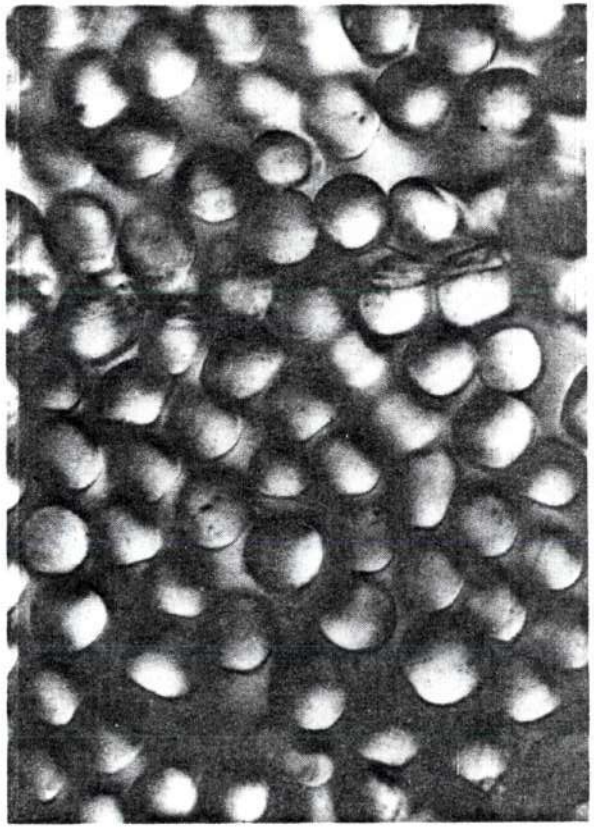


(b) 12,800X

Figure 46. Kodel Polyester IV Semi-dull, Electron Micrographs of Surface (a) and (b)

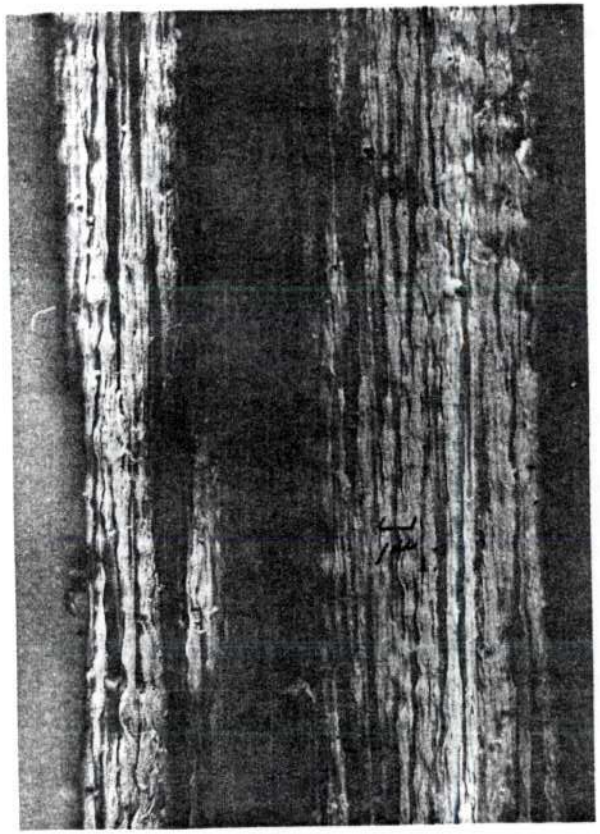


(c) 560X

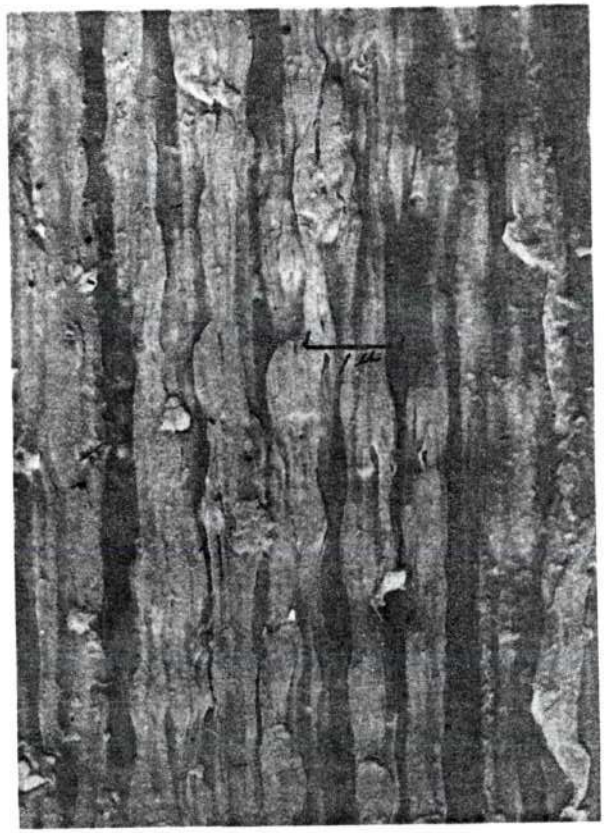


(d) 560X

Figure 46. Continued, Kodel Polyester IV Semi-dull, Optical Micrographs of Surface (c) and Cross Sections (d)

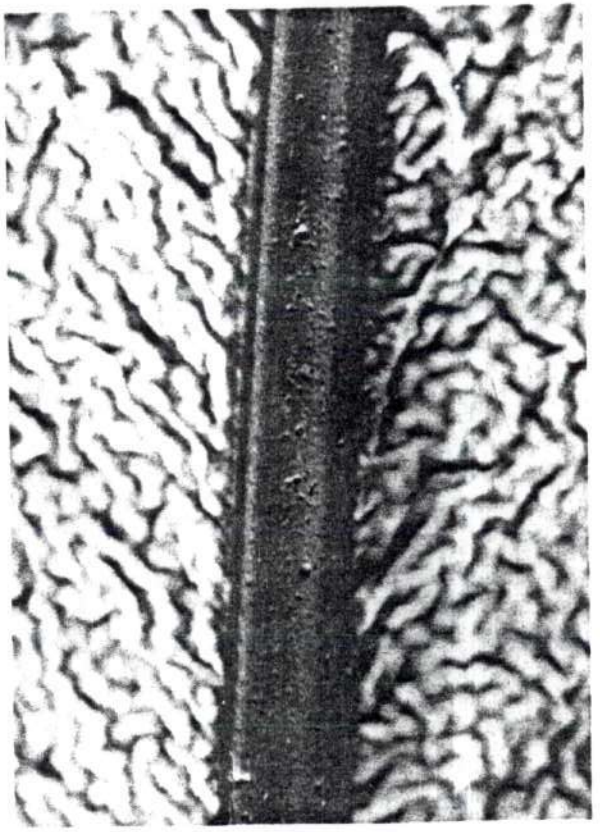


(a) 3,800X

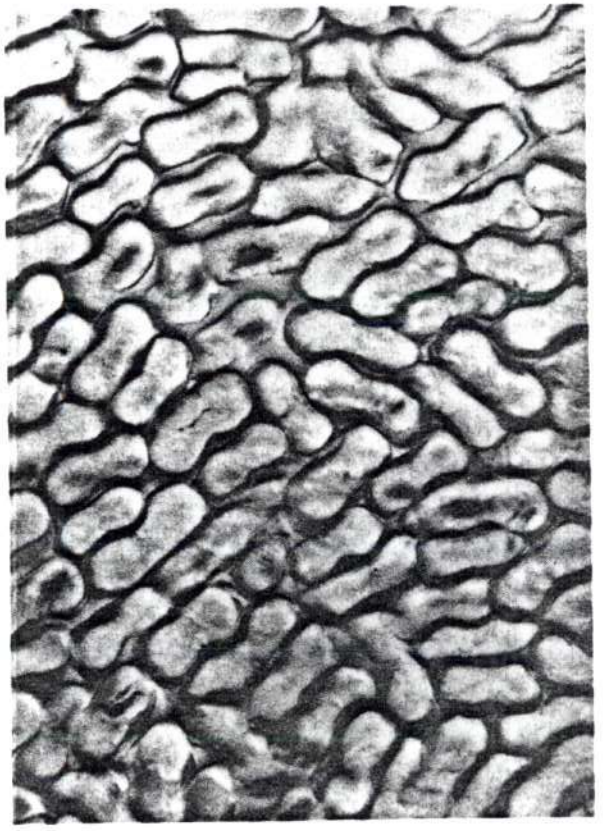


(b) 12,800X

Figure 47. Verel Modacrylic Bright, Electron Micrographs of Surface (a) and (b)

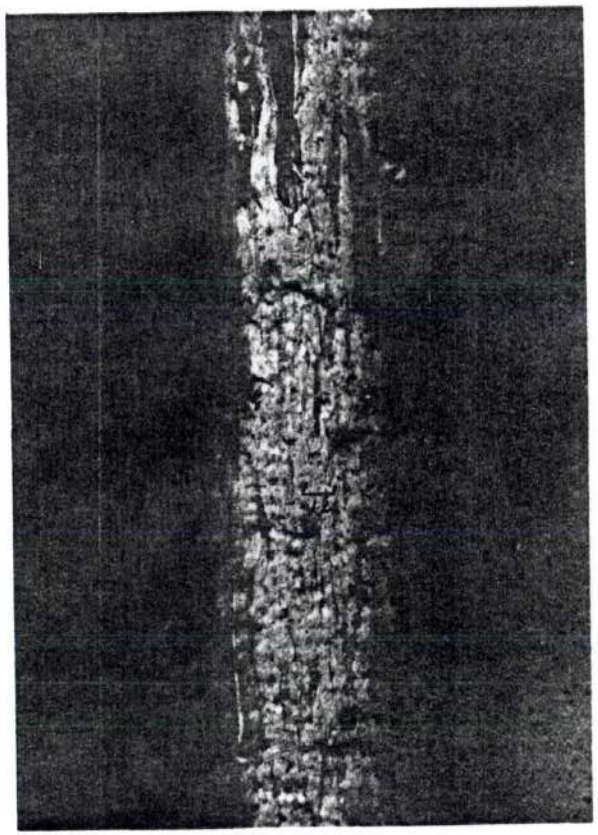


(c) 560X

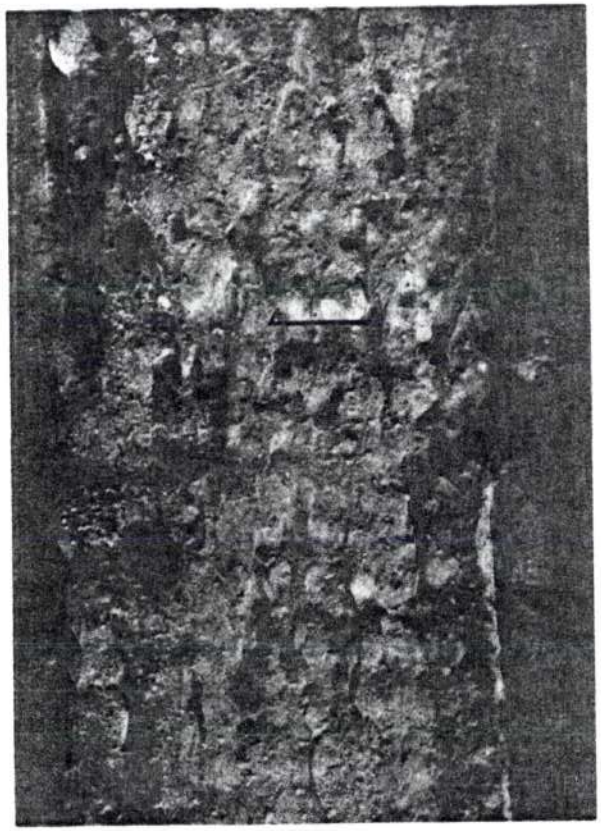


(d) 560X

Figure 47. Continued, Verel Modacrylic Bright, Optical Micrographs of Surface (c) and Cross Sections (d)

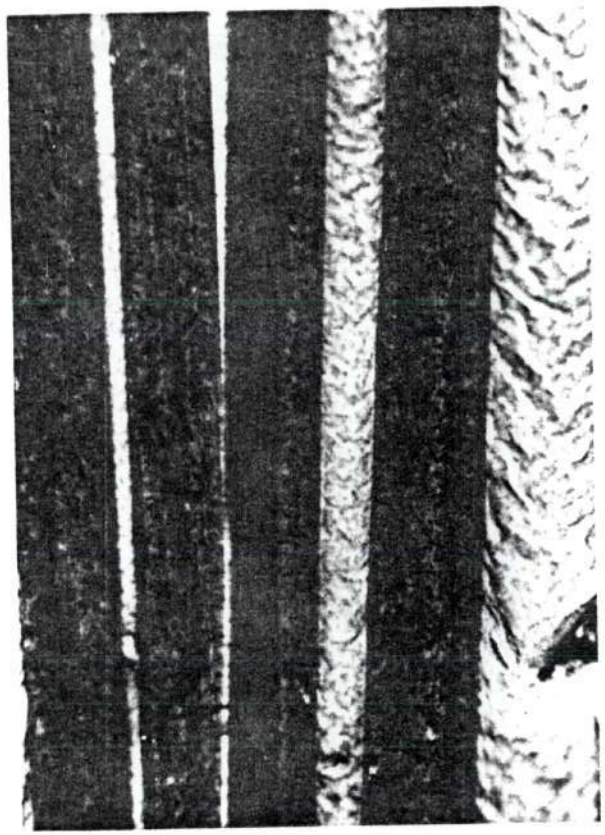


(a) 3,800X



(b) 12,800X

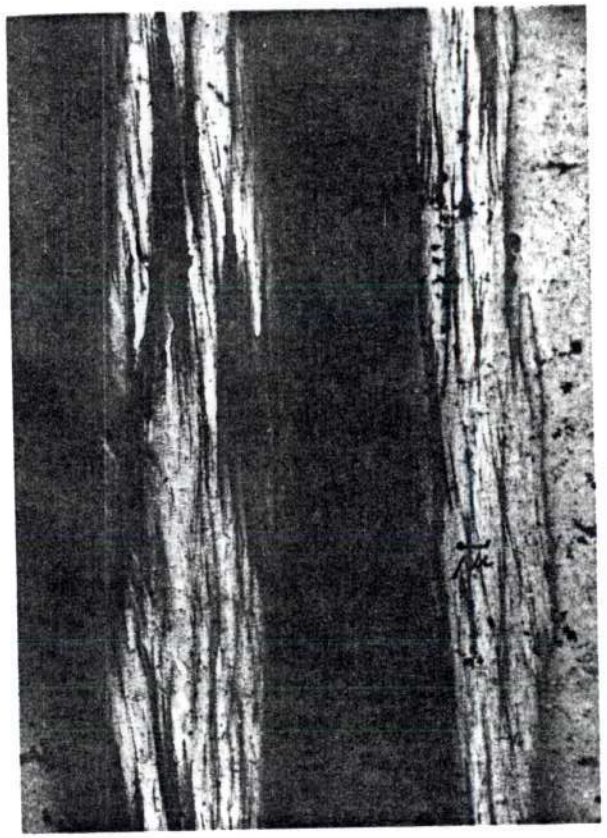
Figure 48. Verel Modacrylic Dull, Electron Micrographs of Surface (a) and (b)



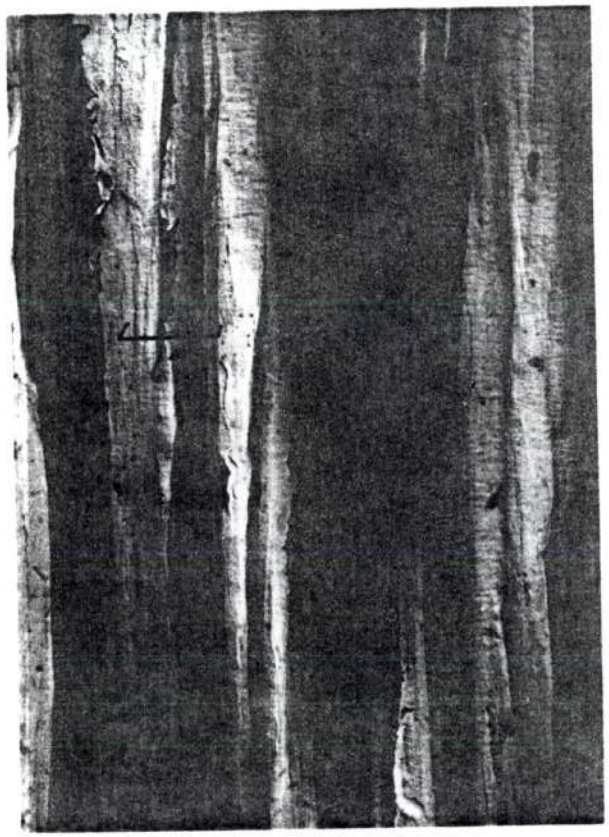
(c) 560X

(d) 560X

Figure 48. Continued, Verel Modacrylic Dull, Optical Micrographs of Surface (c) and Cross Sections (d)

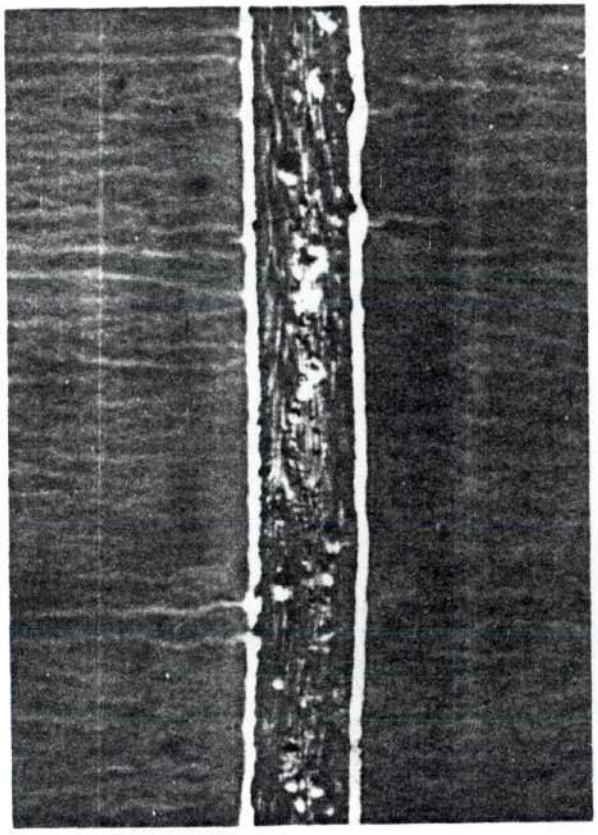


(a) 3,800X

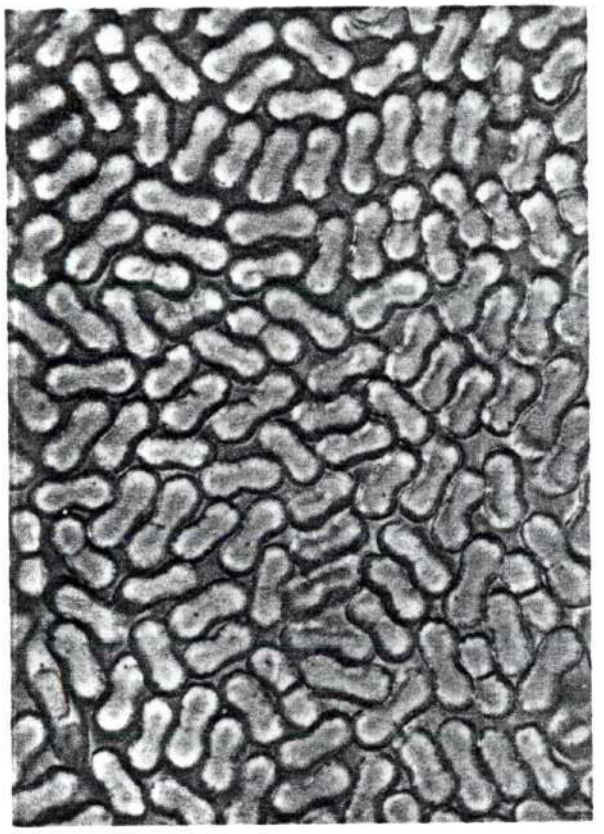


(b) 12,800X

Figure 49. Orlon 72 Acrylic, Electron Micrographs of Surface (a) and (b)

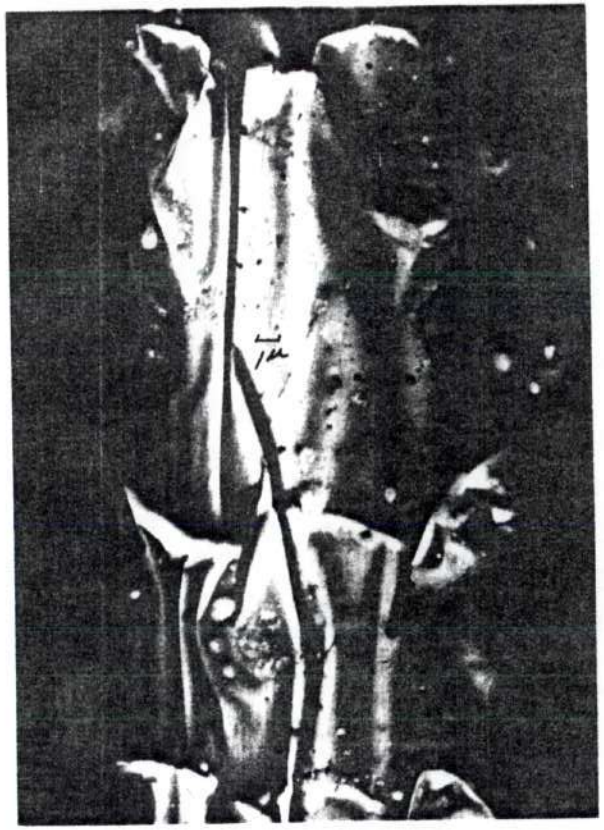


(c) 560X

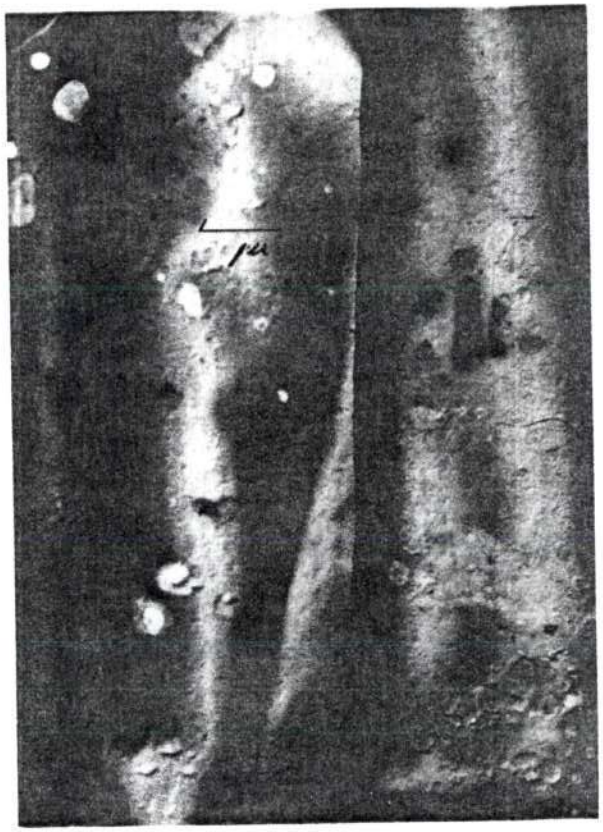


(d) 560X

Figure 49. Continued, Orlon 72 Acrylic, Optical Micrographs of Surface (c) and Cross Sections (d)

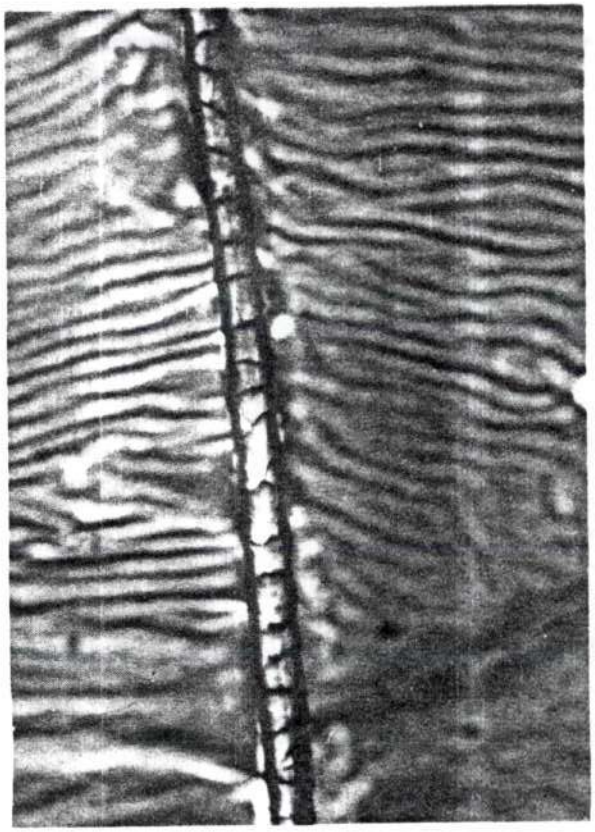


(a) 2,900X

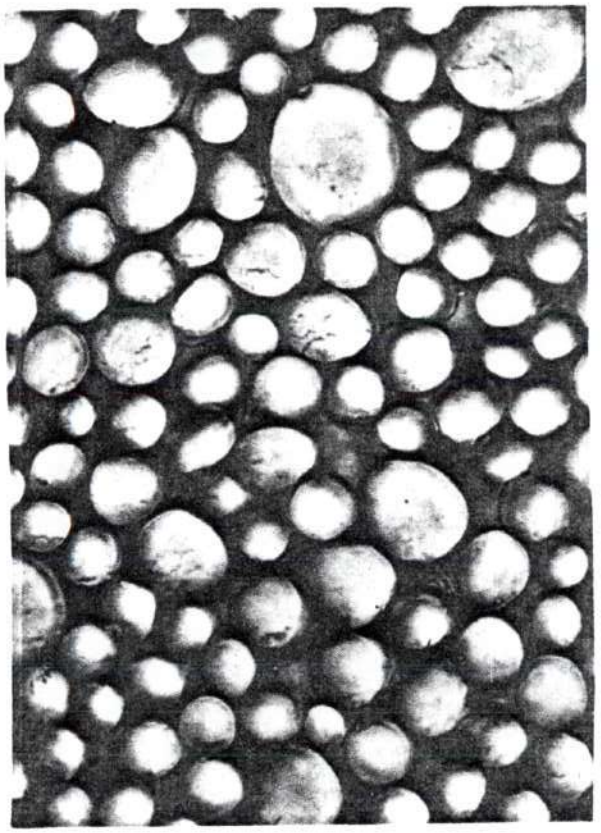


(b) 12,800X

Figure 50. Wool Unscoured, Electron Micrographs of Surface (a) and (b)

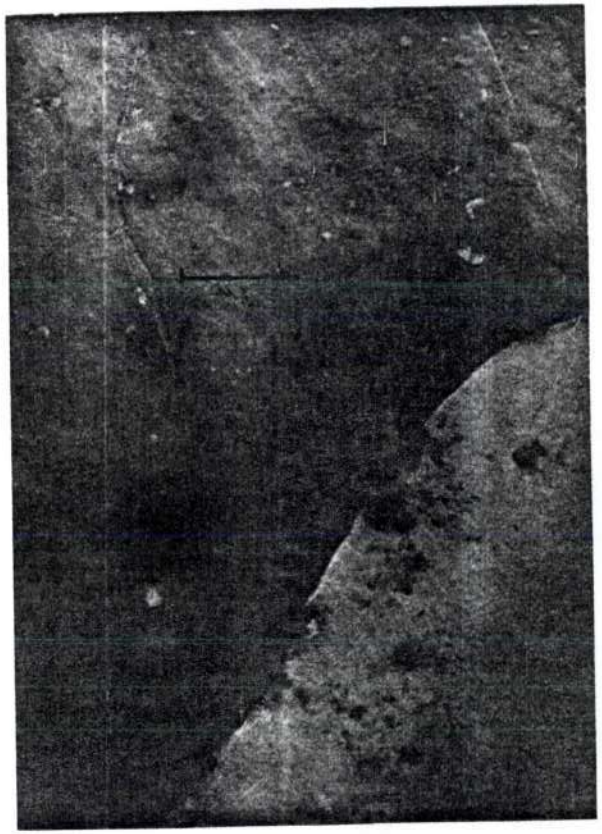


(c) 560X

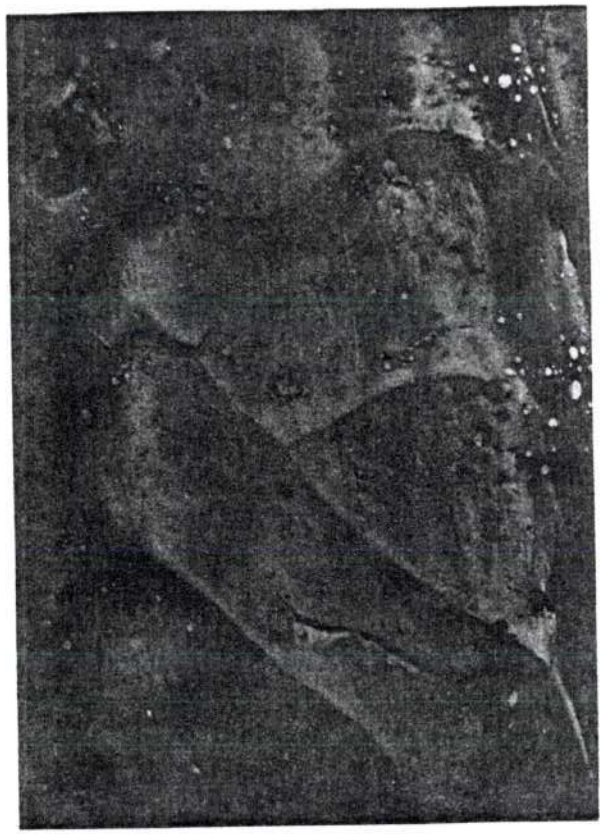


(d) 560X

Figure 50. Continued, Wool Unscoured, Optical Micrographs of Surface (c) and Cross Sections (d)

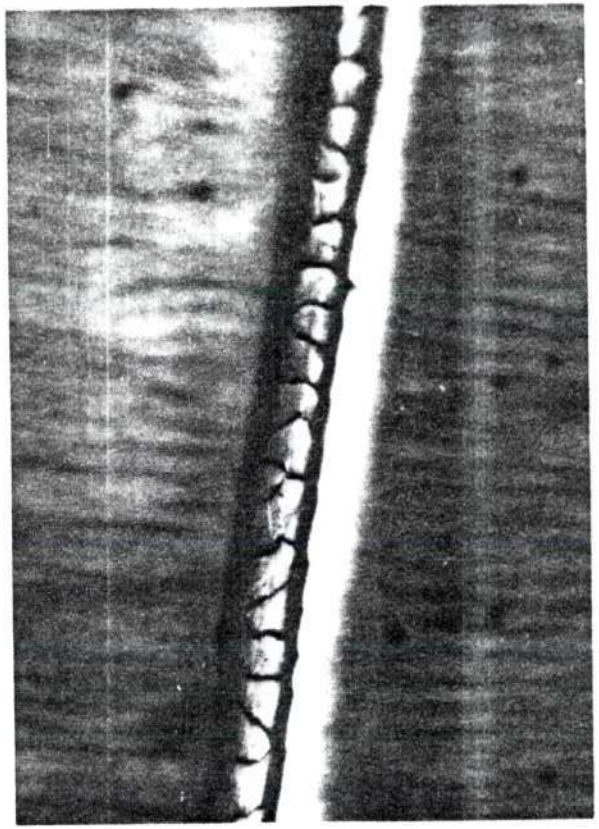


(a) 2,900X

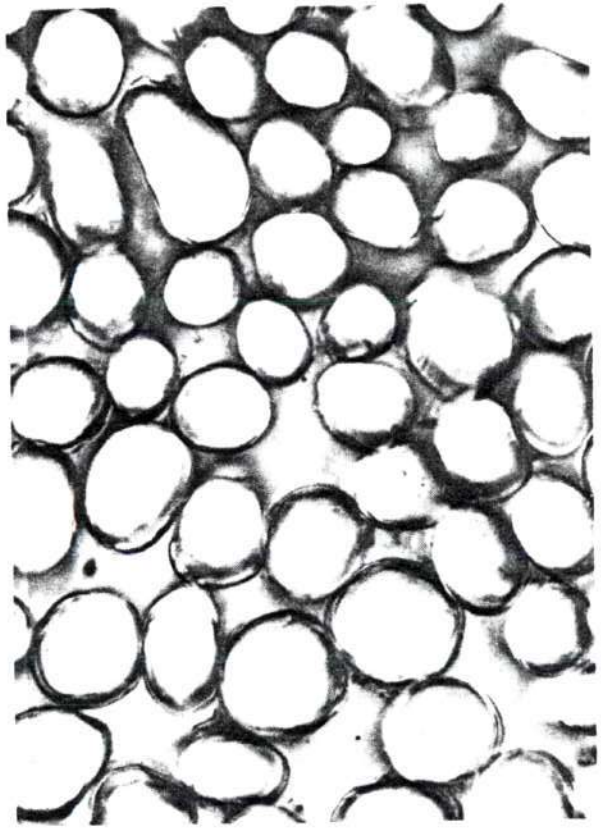


(b) 12,800X

Figure 51. Wool Scoured, Electron Micrographs of Surface (a) and (b)



(c) 560X



(d) 560X

Figure 51. Continued, Wool Scoured, Optical Micrographs of Surface (c) and Cross Sections (d)

COMMENTS ON FIGURES 12-51

General Comment

Most of the cottons shown are members of the American Upland type which is a member of the Gossypium Hirsutum species. The cottons that are members of other species are indicated as such in the comments on each figure. Over 99 percent of the cotton produced in the United States is American Upland cotton (70). The exception is a small quantity of Egyptian type cotton grown in the West. Other important sources of American Upland cottons are Mexico, Brazil, Pakistan, Turkey, and Uganda.

Comments on locations of growth and possible uses of the specimens are taken from references 70, 71, and 72. Comments on chemical composition and properties of specimens for the man-made fibers are taken from reference 73.

Comments

Figures 12, 13, 14, and 15

These fiber specimens are all Empire WR, a cotton that is grown in the southeast and the Gulf southwest. A popular use for this fiber is in carded broadcloth. These particular specimens were collected at the locations indicated. Examination of the electron micrographs shows the striated ridged appearance that is characteristic of the surface topography of cotton. These are caused by the fibrillar structure of the cotton. These striations appear to be not greater than one micron apart and generally appear to be about 0.25 micron apart. Cross sections show the characteristic kidney or bean shape. Optical surface studies in each of the figures show the convoluted shape of the fiber. Particular attention is directed to the fiber on the left of Figure 12 (c) which exhibits one full convolution as defined in this study.

Figures 16 and 17

Dixie King is a typical southeastern United States cotton. These specimens were grown in Georgia. As indicated, these micrographs compare seed cotton and ginned lint. The surface studies present some interesting comparisons. Figure 16 (a) shows a left hand spiral while Figure 17 (a) shows a right hand spiral. Figure 16 (b) exhibits an interesting portion of the surface. The ridges representing fibrils in this portion are greater than one micron apart and there are striations running perpendicular to as well as along the normal axial striated direction. Cross sections are very uniform in both cases and optical surfaces studies are typical.

Figures 18, 19, 20, and 21

Carolina Queen is another typical southeastern cotton that was grown in Georgia. These specimens are differentiated as to seed cotton or ginned lint as well as method of harvest. Optical studies of cross sections and surface show regularity and typical topographic features. Electron micrographs of Figure 18 indicate that the ridges appear to be about 0.25 micron wide and 0.25 to one micron apart. Figure 19 exhibits a smoother surface with few striations. Figure 20 shows very narrow ridges (about 0.1 micron), while distance between ridges varies from 0.5 to two microns. Those in Figure 21 are typical views of a cotton fiber.

Figure 22

Wilds Five cotton fiber is grown primarily in the Mississippi Valley. The electron micrographs of this specimen exhibit a highly striated appearance. The ridges appear to average about 0.2 micron in width and about 0.2 micron to 0.4 micron between ridges. The cross sections appear to be quite irregular. The optical surface study is typical of a cotton fiber.

Figure 23

Delfos is usually grown in the Gulf southwest. A familiar use of Delfos is in carded broadcloth. The micrographs of this specimen exhibit a very smooth surface for a cotton. The striations appear as smooth waves or undulations. The cross sections are fairly regular. The optical surface study shows a good example of a sharp reversal at the top of the micrograph.

Figure 24

Mexican Big Boll is a cotton grown primarily in the southwest. The

electron micrographs show the usual striation. One feature to note is the ridges that run down the center of the fiber area pictured. The cross sections and optical surface study are regular and typical.

Figure 25

Rowden cotton is grown primarily in the Gulf southwest and is a very popular fiber. Rowden is versatile in that it is often used in narrow sheetings and duck. The cross sections are somewhat regular. The striations on the surface present a smooth hill and valley contour effect.

Figure 26

This specimen of Pima S-1 cotton was in sliver form. It had already been processed up through the opening, picking, and carding processes. Pima is an American Egyptian cotton which is the Vitifolium form of the Gossypium Barbadense species. Pima is generally grown in the far west and in Peru. Pima is used in such fabrics as combed lawns, organdies, and fine shirtings. The fineness of this fiber is exhibited by the cross section of the fiber in that the fibers are smaller than average. The optical micrograph exhibits smoothness which, after examination of the electron micrographs, proves to be narrow striations that are close together (less than 0.5 micron apart).

Figure 27

St. Vincent Sea Island is a member of the Gossypium Barbadense species. It is a very long, fine fiber grown primarily in the West Indies and Puerto Rico. Sea Island cottons are used primarily in the most luxurious cotton fabrics. The cross section of this fiber shows its fineness as does the optical surface study. The electron micrographs exhibit a

relatively smooth surface. The area between ridges ranges from about 0.25 to 0.5 micron.

Figure 28

SXP is a long staple cotton grown in the Gulf southwest and west. Its fineness is exhibited by the optical studies. The electron micrographs show some irregularity in striations. The striations appear to vary from less than 0.2 to greater than one micron between ridges.

Figure 29

Bobshaw is an Upland cotton grown in the Mississippi Valley and Gulf southwest. It is often used in such fabrics as combed broadcloth. The cross sections of this fiber are somewhat irregular in shape. The surface studies indicate ridge widths and distance between ridges to be about equal for the most part (0.2 to 0.5 micron).

Figure 30

Hopi Acala 54 is one of the Acala group of Upland cottons. Acala is generally grown in the far west and Mexico. Acala fibers are often used in fabrics such as print cloth and carded broadcloth. The cross sections appear to be fairly regular. The portions of the fiber shown in the electron micrographs exhibit a rough appearance with narrow ridges and distances of 0.2 micron or less between ridges.

Figure 31

Pima S-1, which is in this case, ginned cotton, is similar in all respects to the specimen exhibited in Figure 26. The surface studies show the same narrow ridges but greater distances (over one micron) between most of the ridges.

Figure 32

Deltapine 15 is usually grown in the southeast, Mississippi Valley, Gulf southwest, Mexico and Argentina. It is used in the production of such fabrics as wide sheetings and combed broadcloth. The cross sections are somewhat irregular in shape. The surface studies show a rough appearance with some deep striations apparent.

Figure 33

Bobshaw, in this case from the 1955 crop, is similar in most respects to the specimen exhibited in Figure 29 except the electron micrographs show a greater distance between ridges (up to 1.5 microns) than is shown in Figure 29 (b).

Figure 34

Stoneville is grown in the Mississippi Valley and Argentina. It is used in print cloths and other fabrics. The cross sections exhibit a great deal of irregularity. The electron micrographs show a surface that has striations both lengthwise and crosswise the fiber.

Figure 35

Deltapine from the 1955 crop is similar to that shown in Figure 32. One interesting point to notice on the surface study is the torn appearance of the surface near the lower right corner of the (b) portion of the Figure.

Figure 36

Dacron is a member of the polyester family. A polyester is a manufactured fiber in which the fiber forming substances are any long chain synthetic polymer composed of at least 85 percent by weight of an ester of a dihydric alcohol and terephtalic acid. Polyester fibers possess high strength, low stretch, and low moisture absorption. The cross section of

the fibers shown are circular. Surface studies show a relatively smooth surface. The particular fibers shown are 3.0 denier, 1-1/2 inch cut staple.

Figure 37

Triacetate, a member of the acetate family, is made from cellulose acetate, where not less than 92 percent of the hydroxyl groups are acetylated. Triacetate has high resistance to shrinking, stretching, and wrinkling. This fiber is 2.5 denier, 2 inch staple, and is classified as dull because of a high percentage of titanium dioxide present. The cross section of this fiber shows a crenulated configuration. The surface studies show striations.

Figure 38

Avisco Rayon is a member of the rayon family, a generic term describing fibers formed from regenerated cellulose. Rayon fibers are flexible and easy to dye and finish. This fiber is 3.0 denier, 2 inch staple. The cross section shows the crenulated effect and all the surface studies show striations.

Figure 39

Avisco Bright Rayon is lighter in appearance than dull or semi-dull fibers. Cross sections exhibit the crenulated effect. An interesting point about the electron micrographs is that the surface of this fiber looks very much like the surface of a cotton fiber. This fiber is 3.0 denier, 1-9/16 inch staple.

Figure 40

Avisco Dull Rayon has a very smooth surface. The dullness is caused by the titanium dioxide which is loaded into the fibers as a delusterant.

The fiber is 3.0 denier, 1-9/16 inch staple.

Figure 41

Avisco Bright Fiber 40 Rayon is a high wet modulus fiber. The cross section of this fiber is oblong. Brightness is evident in all studies. The surface of the fiber is striated. This fiber is 3.0 denier, 1-9/16 inch staple.

Figure 42

Enka Rayon exhibits a near circular cross section. Surface studies indicate a high degree of uniformity in the striations. The striations are very close together, thus giving a very smooth effect. This fiber is 1.5 denier, 1-1/2 inch staple.

Figure 43

Nylon is a member of the polyamide family, where the fiber forming substance is any long chain synthetic having recurring amide groups as a part of the chain. Nylon has great strength, high durability, and water repellence. The cross section of this fiber shows high irregularity. Surface also exhibits a pocked appearance. This nylon is 3.0 denier, 1-1/2 inch staple.

Figure 44

Polypropylene is a member of the olefin family where the fiber forming substance is any long chain polymer compound of at least 85 percent by weight of propylene. Olefin fibers give excellent strength, abrasion resistance, and chemical resistance. The cross section of this fiber is fairly circular. Surface studies show the fiber is generally quite smooth. This specimen is 3.0 denier, 1-1/2 inch staple.

Figures 45 and 46

Kodel II and Kodel IV, members of the polyester family, are similar in most respects. Cross sections are circular; the Kodel II appears to have a greater amount of added delusterant although both fibers are classified as semi-dull. Surfaces are fairly smooth but Kodel IV appears to be more striated than Kodel II. This Kodel II fiber is 3.0 denier, 1-1/2 inch staple and the Kodel IV is 3.0 denier, 2 inch staple.

Figures 47 and 48

Verel A Bright and Dull, shown in Figures 47 and 48 respectively, are members of the modacrylic family. Modacrylics are formed by a long chain polymer compound of less than 85 percent but greater than 35 percent of acrylonitrile units. Verel fibers are easy to dye and give warmth and resilience. Cross sections exhibit the characteristic dogbone or dumbbell shape. Though optical surface studies (c) appear smooth, examination of the electron micrographs shows a great deal of striation. It is also evident that the dull Verel contains a great deal of added delusterant. Both fibers are 3.0 denier, 2 inch staple.

Figure 49

Orlon 72 is a member of the acrylic family. An acrylic is formed by a substance containing a long chain synthetic polymer compound of at least 85 percent by weight of acrylonitrile units. Acrylic fibers give warmth and resist shrinking, sagging, stretching, and wrinkling. Cross sections of the fiber are dogbone or dumbbell shape. The optical surface study shows a rough character while close examination by electron microscopy reveals a highly striated surface. This fiber is 1.5 denier, 1-1/2 inch staple.

Figures 50 and 51

The history of the wool fiber specimens is unknown. Wool fibers are characterized by the scales that form the epidermis of the hair. These scales are readily visible in the optical study and the lower power electron micrograph (a). The scales give wool its well known felting characteristic. Cross sections are round to oblong. The specimen in Figure 50 is unscoured as differentiated from that of Figure 51, which is scoured. Observation of the two groups of photomicrographs shows the main difference is that the fibers in Figure 51 are lighter.

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