A: NATURAL FIBRES OF VEGETABLE ORIGIN

Introduction

In the complex designs and structures of the higher plants, nature has used fibres as the basis of the strength-providing skeleton. Bundles of fibres, bound together by natural gums and resins, run through the roots and stems and leaves of plants. Some of these fibrous structures act as pillars and girders, for example in the woody cores of the trunks and branches of a tree. Others function as hawsers, like the fibrous bundles that take the strain in the stalks and stems of less robust plants, or in the roots that grip the ground and hold the plant firm against the buffeting of the weather.

Flimsy fibres, delicate and yet supremely flexible and strong, are used by many plants as streamers to catch the wind and carry their seeds for immense distances through the air.

These vegetable fibres are all based upon cellulose,* the substance related to the starch and sugars which the plant builds up from water and from carbon dioxide gas absorbed through its leaves. The resources of cellulose fibre available to us in the plant world are virtually inexhaustible. But only a comparatively small proportion of these resources can be made use of directly as textile fibres. The strands of cellulose fibre in plants are associated with varying amounts of other natural substances such as lignin, pectins, hemicelluloses, waxes and gums. The amount of these associated substances and the ease with which the cellulose fibre can be separated from them determine how useful any vegetable fibre can be as a textile material.

The cellulosic fibres at present in use as textile raw materials can be classified most conveniently by referring to the part of the plant from which they come. There are three main groups:

(1) THE BAST OR STEM FIBRES, which form the fibrous bundles in the inner bark (phloem or bast) of the stems of dicotyledenous plants (i.e. plants which form two seed-leaves).

(2) THE LEAF FIBRES, which run lengthwise through the leaves of monocotyledenous plants (i.e. plants which form one seed leaf).

(3) THE FIBRES OF SEEDS AND FRUITS, including the true seed-hairs and the flosses.

* See page 75.

THE BAST FIBRES

The bast fibres form bundles or strands that act as hawsers in the fibrous layer lying beneath the bark of dicotyledenous plants. They help to hold the plant erect.

These fibres are constructed of long thick-walled cells which overlap one another; they are cemented together by non-cellulosic materials to form continuous strands that may run the entire length of the plant stem.

The strands of bast fibres are normally released from the cellular and woody tissue of the stem by a process of natural decomposition called retting (controlled rotting). Often, the strands are used commercially without separating the individual fibres one from another.

On a tonnage basis jute is the most important of all the bast fibres; the world output (about 4 million tonnes in 1979) is greater than that of all the other bast fibres combined. But most of the world's jute is made into sacking and baggage cloths.

The production of flax is roughly one seventh that of jute (606,000 tonnes in 1979). But flax is the fibre from which we make linen; it is on this basis the most important of the bast textile fibres.

FLAX

Flax was probably the first plant fibre to be used by man for making textiles, at least in the Western hemisphere. Specimens of flax have been found in the prehistoric lake dwellings of Switzerland, and in the tombs of Ancient Egypt. The evidence of biblical writings shows that the spinning and weaving of flax were well advanced thousands of years ago. Linen mummy-cloths have been identified as more than 4,500 years old.

Flax fibre comes from the stem of an annual plant *Linum usitatissimum*, which grows in many temperate and sub-tropical regions of the world. In the inner bark of this plant there are long, slender, thick-walled cells of which the fibre strands are composed.

From the Mediterranean region, flax-growing spread over Europe. Centuries before the beginning of the Christian era, Phoenician traders were bringing Egyptian linen to Britain. Roman legions carried the Mediterranean textile skills, including the crafts of spinning and weaving flax, to every corner of their empire.

During the seventeenth century, linen manufacture became established as a domestic industry in many countries of Western Europe. Flax from Germany was the raw material for a flourishing linen industry that grew in the Low Countries. Linen manufacture spread from Western Europe into England, Scotland and Ireland, stimulated by the flow of French and Flemish weavers who were driven from their homes by religious persecution.

Until the seventeenth century only small amounts of flax were grown in England. Competition from wool had stifled the linen industry. The arrival of linen workers from France and the Low Countries created a demand for flax that was met by importation of the fibre, largely from Russia.

Irish Linen Industry

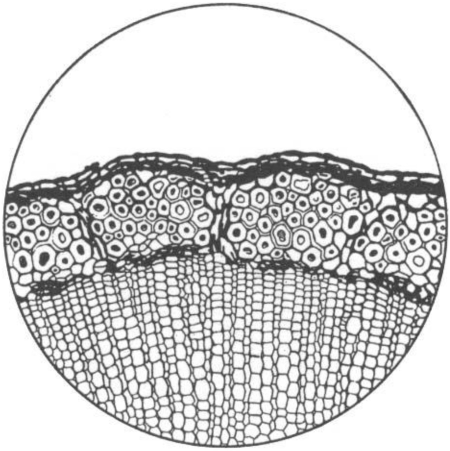
In Ireland, official encouragement by the English Government led to the growth of a flourishing linen industry. But during the eighteenth century, the inventions of Arkwright, Hargreaves and Crompton were developed to the almost exclusive benefit of the cotton industry. And with the rise of cotton, the linen industry was forced into the background. The domestic spinning of flax, and the hand-loom weaving of linen began to diminish. Gradually linen manufacture retired into one or two strongholds, such as Northern Ireland, where it has survived to the present day.

In 1810, Napoleon I offered a reward of a million francs to the man who could devise a machine for spinning flax. A few weeks later, Philippe de Girard patented a machine to do the job, but he did not collect his reward. Five years later, he was invited by the Austrian Government to establish a spinning mill near Vienna; this ran for a number of years but was not a commercial success.

Meanwhile, in Britain, John Kendrew and Thomas Porthouse, of Darlington, patented a flax-spinning machine that was to form a basis for our present spinning machines. But, compared with cotton, progress was slow.

Today, the flax plant is grown for its fibre mainly in Europe, including the U.S.S.R.; elsewhere it has become of only limited importance as a source of fibre. In 1973 Russia grew about three-quarters of the world output of around 600,000 tonnes.

Since the war, accurate figures have not been available from some countries, but it is estimated that flax and tow production in 1977 was some 580,000 tonnes. Of this, France grew 75,000 tonnes, Belgium 14,000 tonnes, the Netherlands ábout 9,000 tonnes.



Flax. This section of the stem of a flax plant shows the bundles of fibre cells lying below the surface layer.

As a source of linseed oil, the flax plant is grown extensively in Canada, U.S.A. and Argentina, but the output of fibre from these countries is relatively insignificant. Soviet Russia grows flax for both fibre and oil.

PRODUCTION AND PROCESSING

Grown for fibre, the flax plant is an annual that reaches 90 – 120cm

(3 – 4 ft). It has a single slender stem that is devoid of side branches other than those which bear the flowers. When the plants have flowered and the seeds are beginning to ripen, the crop is pulled up by the roots (by hand or by mechanical pullers). About one-quarter of the stem consists of fibre.

Retting

The flax fibres are held together in the stems by woody matter and cellular tissue, and 'retting' is a fermentation process that frees the fibres from these materials.

Retting may be carried out in one of several ways:

(1) DAM-RETTING. The flax plants after pulling are tied up in sheaves or 'beets' and immersed for about ten days in water in special dams or ponds dug in the ground. An obsolete method no longer practised except in Egypt.

(2) DEW-RETTING. The crop is spread on the ground after pulling and left for several weeks. Wetting by dew and rain encourages fermentation by moulds to take place.

Dew-retting tends to yield a dark-coloured fibre. It may be used in regions where water is in short supply; it is commonly practised in the U.S.S.R. and France. This is the method by which some 85% of the West European crop is retted. It is far less labour intensive than water-retting and therefore less expensive.

(3) TANK-RETTING. After harvesting, the seed bolls are stripped from the stems by reciprocating metal combs. The de-seeded straw, tied in bundles, is packed into concrete tanks which are filled with water and artificially heated to about 30°C. Retting is completed in about three days. Some of the best and most uniform fibre is produced by this process. Almost all of the flax from the Courtrai district of Belgium is tank-retted. The highest quality of straw may be double-retted, i.e. the partly retted straw is removed from the tank, dried, and then given a further period of retting.

Flax is brought in from a large area to be retted centrally in this way. The advantage of this form of retting lies in the fact that conditions can be controlled and the process can be carried out at any time of the year. In the Belgian method the straw is usually given a preliminary steeping treatment.

Flax used to be retted in the River Lys in Courtrai by immersing the straw in wooden crates, but retting in the Lys is no longer permitted in Belgium.

(4) CHEMICAL RETTING. Retting can also be carried out by treating the flax straw with chemical solutions. Such reagents as caustic soda. sodium carbonate, soaps and dilute mineral acids have been employed with some success. In general, chemical retting of the straw proved to be a more costly process than biological retting and the fibre produced was no better. More recently, attention has been turned towards the chemical treatment of fibre extracted in the green state from unretted straw. With developments in chemical plant for the processing of fibre, this method becomes an economic possibility. A third alternative is to prepare the unretted fibre into rove, and boil or bleach the rove before spinning. During the last war, many thousands of tonnes of green fibre were spun from boiled rove in this way.

'Cottonization' of flax is a form of chemical retting which is carried to the point where the flax is separated into very fine strands. The flax can then be spun on cotton-spinning machinery. This was carried out in Germany and other Continental countries during the war.

Breaking and Scutching

The next stage in fibre-production is 'breaking'. The straw is passed between fluted rollers in a breaking machine, so that the woody core is broken into fragments without damaging the fibres running through the stems. The broken straw is then subjected to the process known as 'scutching', which separates the unwanted woody matter from the fibre. This is done by beating the straw with blunt wooden or metal blades on a scutching machine. The woody matter is removed as *shive*, which is usually burnt as fuel, leaving the flax in the form of long strands formed of bundles of individual fibres adhering to one another.

Hackling

After scutching the fibres are usually combed or 'hackled' by drawing them through sets of pins, each successive set being finer than the previous one. The coarse bundles of fibre are, in this way, separated into finer bundles, and the fibres are also arranged parallel to one another. The long fine fibres are known as *line*: the shorter fibres or *tow* are spun into yarns of lower quality.

The tow is subjected to further combing or 'carding', which aligns the fibres more accurately alongside one another. They are then collected into the loosely-held rope of fibre called a *sliver* or *rove.*

Spinning

Spinning may be carried out dry for the coarse yarns and wet for the finer yarns. In wet spinning the rove is passed through a bath of hot water. This softens the gummy matter holding the strands together, enabling them to be drawn out (drafted) and aligned more perfectly as the rove is elongated and twisted during spinning.

Dyeing

Most linens are dyed in the piece, using techniques similar to those for cotton. Good quality dyestuffs are generally used, as flax is an expensive fibre and linen is a high-quality textile. Vat dyes are used extensively for linen, giving excellent fastness to light and washing.

Azoics and sulphur colours are also used, and selected direct colours with good light fastness are used for furnishing fabrics.

The flax fibre is harder than cotton, and dyestuffs do not penetrate so readily into it. Special techniques are used during linen dyeing to ensure maximum penetration of the dye, such as the pigment padding process (vat dyeing).

STRUCTURE AND PROPERTIES

Flax fibre strands in the scutched state vary in length from a few centimetres (tow fibre) to as much as 1 metre (line). A good fibre averages 45 – 60cm (8 – 24 in). By the time the fibre reaches the spinning stage is has been broken down in length. Even the fibres in line yarn may be shorter than 30 – 38cm (12 – 15 in).

Commercial flax is in the form of bundles of individual fibre cells held together by a natural binding material. Scutching and hackling tend to break up the coarse bundles of fibre as they exist in the bast, but do not separate the fibre strands into their individual fibre cells.

Flax is usually coloured yellowish-white, but the shade of the raw fibre varies considerably depending upon the conditions under which it has been retted. Dew-retted fibre is generally grey.

Flax is usually soft and has a lustrous appearance. The lustre improves as the flax is cleaned, wax and other materials being removed.

The highest quality flaxes come from Belgium, Northern France and the Netherlands. Russian flaxes are generally weaker but are remarkable for their fineness of fibre.

Fine Structure and Appearance

Strands of commercial flax may consist of many individual fibre cells; they vary in length from 6 – 65mm (¼ – 2½ in) with a mean diameter of about 0.02mm (1/1200th in). Seen under the microscope, the fibre cells show up as long transparent, cylindrical tubes which may be smooth or striated lengthwise. They do not have the convolutions which are characteristic of cotton. The width of the fibre may vary several times along its length. There are swellings or 'nodes' at many points, and the fibres show characteristic cross-markings.

The fibre cell has a lumen or canal running through the centre; the lumen is narrow but clearly defined and regular in width. It disappears towards the end of the fibre, which tapers to a point.

The cell walls of the flax fibre are thick and polygonal in cross-section.

Immature flax fibres are more oval in cross-section, and the cell walls are thinner. The lumen is relatively much larger than in the mature fibre.

Tensile Strength

Flax is a stronger fibre than cotton. It has an average tenacity of about 57.4 cN/tex (5.8g/dtex).

Elongation

Flax is a particularly inextensible fibre. It stretches only slightly as tension increases. The elongation at break is approximately 1·8 per cent dry, and 2·2 per cent wet.

Elastic Properties

Within its small degree of stretch, flax is an elastic fibre. It will tend to return to its original length when the tension is relaxed. It has a high degree of rigidity and resists bending.

Linen fabrics tend to crease, but this can be significantly reduced by modern crease-resisting treatments.

Specific Gravity. 1·54.

Effects of Moisture

Flax has a regain figure of about 12 per cent.

Linen is about 20 per cent stronger when wet than dry, which helps it to withstand mechanical treatment in laundering.

Effect of Heat

Highly resistant to decomposition up to about 120°C., when the fibre begins to discolour.

Effect of Sunlight

Gradual loss of strength on exposure.

Chemical Properties

Linen is more difficult to bleach than cotton, but modern methods of bleaching achieve whiteness with the minimum of chemical degradation.

Effect of Acids

Flax will withstand dilute, weak acids, but is attacked by hot dilute acids or cold concentrated acids.

Effect of Alkalis

Flax has a good resistance to alkaline solutions; linen fabrics can be washed repeatedly without deterioration.

Effect of Organic Solvents

Flax is not adversely affected by dry-cleaning solvents in common use.

Insects

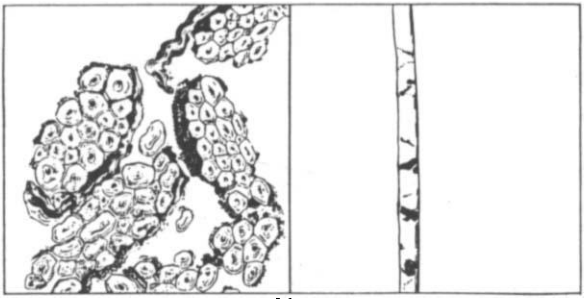
Flax is not attacked by moth grubs or other insects.

Micro-organisms

When boiled and bleached, flax is virtually pure cellulose. Like other pure cellulose fibres, flax in this state has a high resistance to rotting. Under severe conditions of warmth, damp and contamination, however, mildews may attack the cellulose of flax, but resistance is generally high, particularly if the yarn or fabric is dry.

Other Properties

Flax is a good conductor of heat; this is one of the reasons why linen sheets feel so cool.



Flax

FLAX IN USE

In the past flax was in demand where extra strength and resistance to moisture were important. However, such flax products as sail and tent canvas, fishing lines and bookbinders' threads have now been replaced largely by synthetic substitutes. Leather-working thread, sewing thread and suture thread are still produced from flax. The fine household linen trade has declined greatly, but developments in blending with synthetics to give linen 'easy care' properties has ensured a long-term future for flax products. The use of union cloth (cotton and flax blended at the weaving stage) for furnishing fabrics is also established.

Waste flax fibre is made into high-grade banknote, writing and cigarette papers.

The ability of flax to absorb water rapidly is particularly useful in the towel trade. Linen glass-cloths will remove all traces of moisture from a glass without leaving any particles of fluff behind.

The molecular structure of the flax fibre makes linen an excellent conductor of heat; linen sheets are cool and linen garments are comfortable in hot weather.

Linen is often calendered or pounded in the roll by wooden hammers ('beetling') for as long as thirty-six hours. These treatments close up the fabric and bring out the beautiful finish that is characteristic of good linen.

Linen becomes stronger when it is wet, and will withstand repeated washings without deterioration. It is ideal for anything that has to put up with really hard wear.

The long life of linen fabrics was exemplified when Tut-ankhamen's tomb was opened in 1922. Linen curtains, which had been there since about 1250 B.C., were still intact.

JUTE

In common with other bast fibres, jute has been used by man since prehistoric times. It comes from the inner bark of plants of the genus *Corchorus*, which probably originated in the Mediterranean area and was subsequently taken to India where it now grows profusely. Jute fabrics formed the 'sackcloth' of Biblical times.

The jute plant flourishes in hot, damp regions of Asia, and jute has for centuries been grown in enormous quantities for textile purposes. It is now produced in greater quantity than any textile fibre other than cotton. In 1976 – 77 some 3,468,000 tonnes of jute were produced, mainly in India (1,276,000 tonnes), Bangladesh (851,000 tonnes) and Thailand (183,000 tonnes).

During the latter half of the eighteenth century, the first shipments of jute reached Western Europe from India. In 1820, jute was spun experimentally at Abingdon near Oxford. The new fibre was of immediate interest to the flax and hemp spinners located at Dundee in Scotland. The Napoleonic Wars had cut off supplies of hemp and flax from Russia, and the Dundee mills began spinning jute in 1822. After ten years of experiment, the Dundee manufacturers were able to spin jute satisfactorily, and by 1850 the jute industry was well established. It was given further encouragement by the Crimean War which cut off hemp and flax supplies in 1853, and by the American Civil War of 1861–65 which interrupted the flow of cheap cotton.

Although other European countries took up the spinning and weaving of jute, Dundee has remained a centre of the industry. Meanwhile, India and Bangladesh have been steadily increasing the number of jute spinning and weaving mills, and both countries are now processing much of their own fibre.

PRODUCTION AND PROCESSING

The jute plant, *Corchorus*, is a herbaceous annual. It may grow to 5m (15 ft), with a stalk diameter of 20mm (¾ in). In India and Bangladesh, the plants are commonly harvested with a hand sickle.

Retting is carried out in a manner similar to that used for flax, the stalks being steeped in a sluggish stream of water. They are examined daily until the stage is reached at which the fibre can be separated easily from the stem. The strands of fibre, often as much as 2m (7 ft) long, are washed and hung up in the sun to dry. They are compressed into bales and sent off to the mills for spinning.

It is necessary to incorporate small amounts of mineral spindle oils into the fibre during conversion into yarn. Normal jute goods may contain up to 5 per cent oil, but so-called 'stainless' yarns containing 1 per cent of oil or less are commonly available when the jute is to be used for special purposes, e.g. cables, fuses, carpet backings, wall-coverings, etc.

Bleaching and Dyeing

Jute is used very largely for cheap commodities such as sacks, bags and wrappings. Where necessary, and the extra cost is warranted, it is possible to bleach jute goods through various shades of pale cream up to pure white, and also to incorporate 'optical bleaches' (i.e. colourless dyestuffs which fluoresce a vivid white in daylight).

Dyestuffs of various types, as used for cotton, may also be applied to jute. The fibre has a special affinity for basic dyes, which provide brilliant effects even on unbleached base. Unfortunately, these effects are not very fast either to light or to water. Acid, direct and sulphur dyes are increasingly fast in this order, but also give increasing dullness of shade – all at reasonable cost. The increased demand for rugs, mats and carpets (especially cheaper tufted carpetings) has stimulated a corresponding demand for dyed jute yarns and fabrics suitable for these applications. Very bright and fast results are obtained with azoic and vat dyes, but their high cost limits their use with jute. The tendency for jute to turn brown in sunlight is a permanent disadvantage in better quality applications.

STRUCTURE AND PROPERTIES

Fine Structure and Appearance

Commercial jute varies from yellow to brown to dirty grey in colour, and it has a natural silky lustre. It consists of bundles of individual fibres held together by gummy materials, including the natural plastic lignin which plays an important role in the structure of all woody plants.

Jute usually feels coarse and rough to the touch, although the best qualities are smooth and soft. Retting destroys the cellular tissue that holds the bast bundles together, but does not normally separate the individual cells one from another. Some of the fibre-ends become detached from the strands, giving the jute its hairy, rough feel.

The individual cells of jute are about 2·6mm (1/10th in) long, on average. The cell-surface is smooth, but disfigured here and there by nodes and cross-markings. The fibres are coated with a layer of woody material.

Seen in cross-section, the cell is polygonal, usually with five or six sides. It has thick walls and a broad lumen of oval cross-section. By contrast with the regular lumen of flax, that of jute is irregular; it becomes narrow in places quite suddenly. Towards the ends of the cell, which are tapered, the lumen widens; the cell walls become correspondingly thin.

Jute contains about 20 per cent of lignin.

Tensile Strength

Jute is not so strong as flax or hemp, nor is it so durable. Individual fibres vary greatly in strength, owing to the irregularities in the thickness of cell walls.

Elongation

Jute fibres do not stretch to any appreciable extent. Jute has an elongation at break of about 1·7 per cent.

Elastic Properties

Jute tends to be a stiff fibre, owing to the part played by the material which cements the cells together.

Specific Gravity. 1·5.

Effects of Moisture

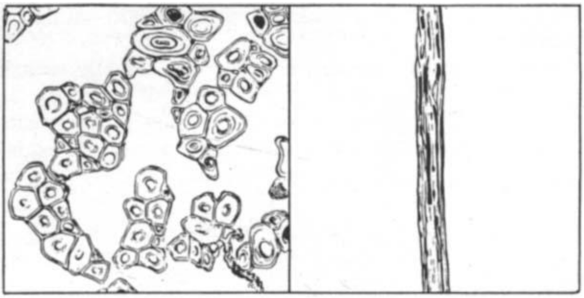
Jute is an unusually hygroscopic fibre. Its regain figure is 13·75 per cent. It can absorb as much as 23 per cent of water under humid conditions.

Effect of Age

If kept dry, jute will last indefinitely although the high content of non-cellulosic matter tends to make it sensitive to chemical and photochemical attack. Moisture encourages deterioration of jute, which loses strength with age.

Micro-organisms

Jute is more resistant to rot than either grey cotton or flax (i.e. uncleaned or unscoured). If lightly scoured it can have an excellent resistance owing to the protective effect of the lignin.



Jute

JUTE IN USE

Jute is cheap and reasonably strong, and is available in large quantities. These characteristics have enabled it to become an important fibre for sacks and packing cloths. These are used extensively for the storage and transport of agricultural products.

The resistance of jute fibres to stretching forces has proved a valuable property when jute is used for storage and transport purposes. Sacks and bales remain firmly in place after stacking; they do not distort and shift position as they would if made from a fibre more elastic than jute.

The hairiness of jute can be a disadvantage when jute sacks are used for food storage. The fibre-ends may break away and contaminate the food.

The finer qualities of jute are made into curtains and furnishing fabrics; mixed with wool, after treatment with caustic soda, jute is spun and woven into cheap clothing fabrics.

Familiar uses for jute include the following: Sacks, bags, baling and bundle cloths, wrappings (e.g. for bacon), bedding foundations, bonded fabrics, boot and shoe linings, mine brattice cloths and vent tubings, starched and glued buckrams and tailor's black packings, camp beds, cargo and other separation cloths (e.g. in rubber technology), cattle beddings, concrete cleavage fabrics, tarpaulins, damp courses, cables, plastics reinforcement, filter cloths, fire curtains, fuse yarns, furnishings, handbag and all types of stiff bag and case linings, hop pockets, horse covers, aprons of all heavy types, iron and steel tube and rod wrappings, canal linings (heavily bituminized), mail bags, motor car body linings, needlefelts, oakum, oven cloths, plasterers' scrim, prefabricated road and runways, roofing felt, rope soled sandals, trunk covering fabrics, tyre wrappings, upholstery foundations, strings for all purposes, certain ropings, wall coverings, wool packs, etc.

HEMP

In many parts of Asia, the fibre hemp has been in use since prehistoric times. Ancient records describe the use of hemp in China in 2800 B.C. During the early Christian era, production of hemp spread to the countries of Mediterranean Europe, and since then the fibre has come into widespread use throughout the world.

Like flax, hemp is a bast fibre. It comes from the plant *Cannabis sativa*, an annual of the family Moraceae, which grows to a height of 3m (10ft) or more.

The hemp plant is now cultivated in almost every European country, and in many parts of Asia.

Important producing countries include the Soviet Union, Yugoslavia, Roumania and Hungary.

PRODUCTION AND PROCESSING

The hemp plant is harvested and processed in a manner similar to that used for flax. Fibre is freed from woody matter by dew-retting or water-retting, followed by breaking and scutching. The fibre is softened by pounding it mechanically or by hand.

Hemp can be separated from the straw by a mechanical process more easily than in the case of flax. 'Green' hemp is now produced commercially in this way.

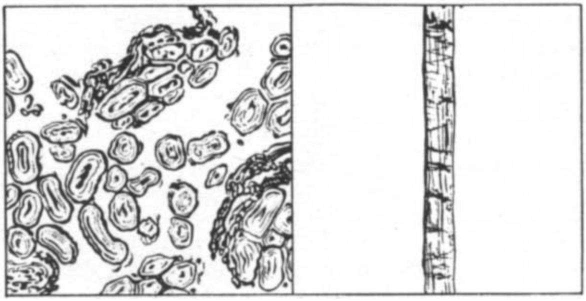
Dyeing

Hemp is used very largely in its natural state. When dyeing is necessary, direct colours are often used. Basic dyestuffs provide bright shades, the fibre being mordanted with antimony and tannin.

STRUCTURE AND PROPERTIES

Hemp is a coarser fibre than flax; it is dark in colour and difficult to bleach. The fibre is strong and durable, and is used very largely for making string, cord and rope.

Some Italian hemps are produced with great care; they are light in colour and have an attractive lustre similar to that of flax.



Hemp

Strands of hemp fibre may be 2m (6 ft) in length. The individual cells are, on average, 13 – 26mm (½ – 1 in) long. They are cylindrical in shape, with joints, cracks, swellings and other irregularities on the surface.

Like flax, the cells of hemp fibre are thick-walled; they are polygonal in cross-section. The central canal or lumen is broader than that of flax, however, and the ends of the cells are blunt.

The hemp fibre is more lignified than flax, and is consequently stiffer.

HEMP IN USE

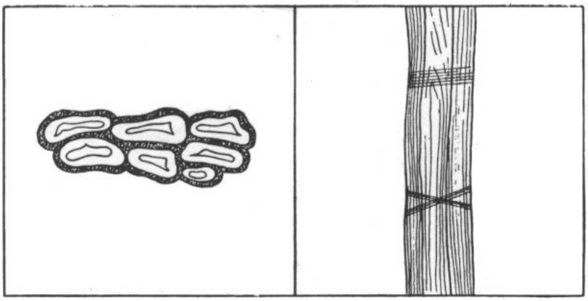
During its long history, hemp has been used for almost every form of textile material. It has been made into fine fabrics by skilful spinning and weaving of carefully produced fibre, notably in Italy where a hemp fabric similar to linen is made. Nowadays, hemp is used mainly for coarse fabrics such as sacking and canvas, and for making ropes and twines.

Hemp can be 'cottonized' by a process similar to that used for flax, so that the individual fibres are freed. Cottonized hemp does not spin easily alone, but it gives useful yarns when mixed with cotton (up to 50 per cent hemp).

SUNN (Indian Hemp; Sann Hemp; Bombay Hemp)

The plant *Crotalaria juncea* has been grown in India and Pakistan since prehistoric times. It is a source of the bast fibre known as sunn; it was first brought to Europe during the early nineteenth century.

C. juncea grows to a height of 3m (10 ft), with stalks nearly 2.5cm (1 in) thick. It is cultivated and harvested in India and Bangladesh in a manner similar to jute. In 1976, the world production of sunn amounted to about 6,000 tonnes.



Sunn

Retting is carried out by steeping the stalks in water, and the fibre is peeled away from the rotted stalks by hand. It is dried in the sun and hackled (combed) by hand to remove any woody matter that may be adhering to it.

STRUCTURE AND PROPERTIES

Sunn is a light-coloured fibre when carefully prepared. It has a fine lustre.

Sunn fibre is almost as strong as hemp, and its strength is greater when wet.

Strands of commercial sunn are some 150cm (5 ft) long, and consist – like other bast fibres — of many individual fibres held together by natural gums.

The cells of sunn fibre are cylindrical, and are marked here and there by joints. The lumen is not so regular as it is in flax, and it is often filled with a yellow substance. Towards the ends of the fibre cells, the lumen disappears. The ends of the cell are blunt and rounded.

Seen in cross-section, the cells of sunn fibre are oval. There is a comparatively thick coating of lignin surrounding each cell.

Individual cells are about 8.5mm (⅓ in) long.

SUNN IN USE

Sunn fibre is used for cordage and paper manufacture. It is made into sacking and into carpet and rug materials.

The fibre has a good resistance to the effects of moisture, and is not readily attacked by micro-organisms present in sea water. These characteristics, allied to the increasing strength of sunn as it gets wet, have made the fibre particularly useful for fishing nets.

KENAF (Guinea Hemp; Mesta)

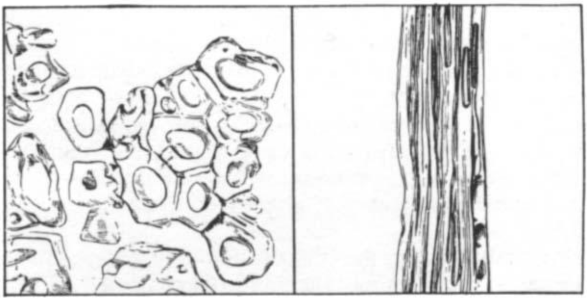
In Africa, there is a plant *Hibiscus cannabinus* which has long been used as a source of fibre for making cordage and coarse fabrics. The fibre is known as kenaf, Guinea hemp, or Mesta.

Kenaf has been grown in India for thousands of years, but the fibre was unknown in Western Europe until about two hundred years ago. It has been used since then as a sacking fibre, but did not really arouse any great interest until World War II. The shortage of jute during and after the war stimulated production of kenaf in the U.S., Cuba, Mexico and other countries.

Most of the world's kenaf is grown in India, Bangladesh and Thailand.

PRODUCTION AND PROCESSING

The kenaf plant is an annual, with 12mm (½ in) diameter stalks that reach 3m (10 ft) in height. It grows well in the hot damp climate of tropical countries.



Kenaf

The methods used for harvesting and processing kenaf are similar to those used for jute. The stalks are retted and then beaten to free the fibre from unwanted material.

STRUCTURE AND PROPERTIES

Kenaf is a pale-coloured fibre which contains less non-cellulosic material than jute. It has the lustre which is characteristic of many bast fibres.

Kenaf has a breaking strength similar to that of low-grade jute, and it is weakened only slightly when wet.

The cells of kenaf are short, reaching only 6mm (¼ in) in length. They are cylindrical and the surface is striated and irregular. The lumen varies greatly in thickness at different points in the cell, sometimes disappearing altogether.

Seen in cross-section, the cell of kenaf fibre is polygonal and has a thick wall. It is coated with a layer of lignin. The fibre ends are thick and blunt.

KENAF IN USE

Most of the kenaf produced at present is used for making ropes and twines, and for coarse fabrics such as canvas and sacking. Some of the better quality fibre is made into carpet materials.

URENA

During World War II, the shortage of jute stimulated interest in another fibre, urena. This is a bast fibre that comes from the plant *Urena lobata*. It has been used from prehistoric times in Brazil.

The urena plant grows wild in many of the tropical regions of the world. It is cultivated as a fibre plant in the Congo and in Equatorial Africa. Brazil and Malagasy produce a considerable amount of urena, but most of it comes from plants growing wild.

Although urena has been used for centuries in those countries where the plant grows wild, it has been slow to develop as a commercially important fibre. The first attempts to cultivate urena were made in the Belgian Congo in 1926 and in 1929. During the 1930s, the crop became of increasing importance and cultivation was started in French Equatorial Africa. Since then other tropical countries have followed suit and many are now growing urena on a small scale. Most of it comes from the Congo Republic.

PRODUCTION AND PROCESSING

The urena plant is a perennial, with stalks that grow to a height of 3m (10 ft). After harvesting, the stalks are retted like jute in ponds or slow streams for 1 – 2 weeks. The fibres are stripped from the retted stalks by hand and washed to remove unwanted material.

STRUCTURE AND PROPERTIES

Urena has an attractive handle and appearance. It is near-white when carefully retted, and is soft to the touch. It has a natural lustre.

Strands of commercial urena are often 1.2m (4 ft) long. The fibre has a strength similar to that of jute.

Individual cells of urena are generally less than 2.6mm (1/10th) long. The lumen, as in the kenaf cell, is usually irregular.

URENA IN USE

Urena is made into yarns and fabrics similar to those that are made from jute. Much of it is used for sacking.

RAMIE (China Grass, Rhea)

Egyptian mummies of the pre-dynastic period (5000–3300 B.C.) were wrapped in fabric that has been identified as the bast fibre we now call ramie or China grass. This fibre comes from plants *Boehmeria nivea* or *Boehmeria tenacissema* which belong to a family of stingless nettles. The former is cultivated mainly in China and Formosa, and the latter in more tropical countries. *B. nivea* was grown as a source of fibre by the early Mediterranean civilizations, and during the Middle Ages came into widespread use in Europe. Ramie fibre was used by the early inhabitants of the American continent; it was made into twine for attaching the blades of knives and spears to handles and shafts used by American Indians.

During the eighteenth and nineteenth centuries, ramie cultivation became established in many areas of the Western world. Spinning mills were operated in England, France and Germany towards the end of the nineteenth century. But it is only in comparatively modern times that the production of ramie fabric has become established on a commercial scale.

In 1975 the world production of ramie was estimated at about 130,000 tonnes. The fibre is produced mainly in China (around 80% of total), South America, The Philippines, Korea, Japan and Indonesia.

PRODUCTION AND PROCESSING

The ramie plant is a perennial, sending up many stalks to a height of 1.2 – 2m (4 — 6 ft). The plants are hardy and grow well in warm climates. They are harvested when the lower stalks turn yellow and the new stalks are beginning to make their appearance.

Decortication

The ramie fibres are removed from the stalks by the process of decortication. This is usually carried out by hand; the process consists in peeling or beating the bark and bast material from the stalk soon after harvesting. The fibres are freed by soaking the bark in water and scraping with knives made from shells, bamboo, bronze or iron.

The long strands of ramie fibre are then dried and bleached in the sun.

The decortication process varies in detail in different regions. Sometimes the stalks are beaten against rocks before being peeled; the bark is battered with wooden mallets to free the fibre from adhering woody matter. In Indonesia the stalks are scraped in such a way as to leave the bast fibres clinging to the woody cores. These are then washed and the fibres are peeled away in the form of long ribbon-like strands.

During the 1930s great interest was aroused in the large-scale commercial possibilities of ramie as a textile fibre. But development of ramie production was held up by the primitive methods used in decortication, and attempts were made to devise machinery that could strip the fibres from the stalk.

Several machines are now in commercial use, and decortication has been mechanized.

Degumming

Before the ramie fibres can be spun, they must be released from the ribbons or strands in which they are held together by natural gums.

There are many degumming processes in use in different parts of the world. Where fibre production is carried out simply and by hand, the gums are removed by repeated soaking and scraping. Soda or lime may be used if these are available.

Commercial degumming is usually carried out by treating the fibres with caustic soda solution for as long as four hours. The fibres are then treated with bleaching powder, followed by immersion in a bath of dilute acid. The bleaching and acid-steeping are repeated until all the gum has been removed. Then the fibre is washed, oiled and dried.

Dyeing

Ramie can be dyed with all the classes of dyestuffs used for cotton, including direct, sulphur, basic, azoic and vat dyes. The techniques used are similar and the results are good. Dyeing is level and the fastness to light and washing is comparable with that of the same dyestuffs on cotton.

STRUCTURE AND PROPERTIES

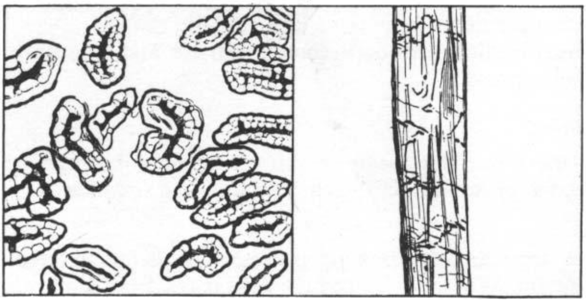
Ramie fibre is white and lustrous. Ramie yarns may be as strong as flax line yarns. The fibre is durable but lacks elasticity.

Ramie absorbs water readily. Fabrics made from it will launder easily and dry quickly. They can be dyed readily.

Ramie yarn tends to have a hairy feel, due to the stiffness and coarseness of the fibres, which reduces their cohesion.

The cells of ramie fibre often reach 45cm (18 in) long. They are smooth and cylindrical, with thick walls. The surface of the cell is marked by little ridges.

The lumen narrows and disappears towards the ends of the ramie cell, which tapers to a rounded point.



Ramie

RAMIE IN USE

Ramie is made into many types of heavy industrial fabric, such as canvas and packing materials. It is finding an increasing use in upholstery and furnishing fabrics and in clothes. Ramie yarns are used for fishing nets and sewing threads.

The lack of cohesion between ramie fibres and the consequent hairiness of ramie yarn makes it difficult to weave ramie into a smooth fabric. Much of the attractive natural lustre of ramie is lost when it is made into cloth.

This drawback can be overcome by a mercerizing process similar to that used for cotton. Ramie yarns are maintained under tension and treated with caustic soda. This brings about chemical and physical changes similar to those that take place in cotton.

NETTLE

Nettles have been cultivated for centuries in Scandinavia as a source of fibre for making sails. In other European countries, nettle fibres have long been used in small amounts for spinning and weaving into textiles. Certain species of stinging nettle are still grown in France and Germany for their fibre. The total output, however, is quite small.

PRODUCTION AND PROCESSING

Nettles are plants of the family *Urticaceae*. Of the thirty-odd species found in temperate climates, three are commonly used as sources of fibre: *Urtica dioica*, the Common or Great Nettle; *Urtica urens*, the small nettle; *Urtica pilulifera*, the Roman nettle.

U. dioica is a perennial; the other two are annuals.

After harvesting, the nettles are retted to free the bark from the woody core of the stalk. The bark is then boiled to release the fibres, which are hackled (combed) and oiled.

STRUCTURE AND PROPERTIES

Nettle fibres are creamy white to grey in colour, depending on the care taken in retting. They feel soft and pleasant to the touch. The strands are often about 1m (3 ft) in length.

The thickest fibres come from *U. dioica* which gives the highest yield. Fibres from *U. urens* and *U. pilulifera* are narrower, with thicker walls.

Individual fibre cells (*U. dioica*) may be 5cm (2 in). The surface of the cell is usually marked and distorted in many places. The lumen is narrow and contains a yellow material. The ends of the fibre cells are rounded; they are often broken into thin filaments.

Seen in cross-section the cell is oval, with thick walls.

Nettle

NETTLE FIBRES IN USE

Nettle fibres are made into twine and rope, and are woven into canvas and sailcloth. In some parts of Europe they are used for clothing and furnishing fabrics.

MISCELLANEOUS BAST FIBRES

There are many other bast fibres in use locally in different parts of the world. They come mostly from plants growing wild, and are used in the main because they are cheap and ready to hand.

THE LEAF FIBRES

The leaves of monocotyledenous plants are held in shape and strengthened by fibres which run in hawser-like strands through the length of the leaf. These leaf fibres are often of great commercial value, and are used in large quantities for making ropes and cordage, and for the production of textile fabrics.

In general, leaf fibres are coarser than the fibres which come from the bast of dicotyledenous plants. Bast fibres are commonly described as 'soft' fibres and the leaf fibres as 'hard' fibres. This classification is not, however, a rigid one; some leaf fibres are softer than some bast fibres.

SISAL

The ancient Mexicans and Aztecs clothed themselves in fabric woven from the fibre known as sisal. This is a leaf-fibre that comes from the plant *Agave sisalana*, which is indigenous to Central America. It derives its name from the Yucatan port of Sisal on the Gulf of Mexico.

The sisal plant is now cultivated widely in East Africa, Mexico, Haiti, Brazil and in other regions of South America. The world output (1978) is in the region of 550,000 tonnes.

PRODUCTION AND PROCESSING

Sisal plants send up huge leaves almost from ground level. The leaves are firm and fleshy, and form a rosette on a short trunk.

After six or seven years of growth, the sisal plant sends out a flower stalk that rises to some 6m (20 ft). When it has flowered, the plant produces tiny buds which develop into small plants. These fall to the ground and take root, and the parent plant dies.

Leaves are harvested when the plants are 2½ to 4 years old and at intervals until the plant eventually dies. A good plant may yield 400 leaves during its lifetime, and each leaf may contain up to 1,000 fibres. The outer mature leaves are cut away and treated in machines which scrape the pulpy material from the fibres. After washing, the fibre is dried and bleached in the sun, or oven-dried.

Dyeing

Sisal has a good affinity for direct cotton and acid dyestuffs, which provide attractive shades of good light fastness.

Direct dyestuffs are used in the same way as in the dyeing of cotton. Acid dyes are applied from a neutral or acid dyebath.

Basic dyes are commonly used for dyeing sisal which is used in ropes. They have poor light fastness and are less satisfactory than direct or acid dyes when the sisal is used for matting.

STRUCTURE AND PROPERTIES

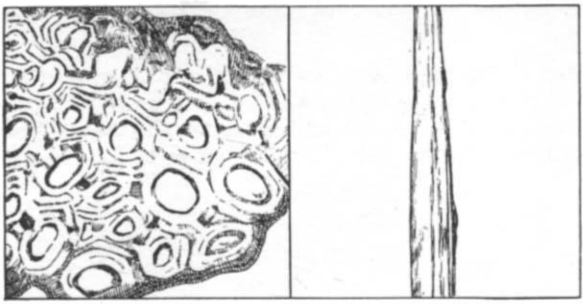
Strands of commercial sisal are 60 – 120cm (2 – 4 ft) in length. They are strong and consist of many individual fibres held together by natural gums. If processing has been carried out carefully, the sisal is creamy-white in colour.

Sisal fibre tends to be stiff and rather inflexible. It absorbs moisture readily and is weakened by being steeped for long periods in salt water.

There are a number of different types of cell in a typical specimen of sisal. The 'normal' fibre cells are straight and stiff; they are cylindrical and often striated. The average length is about 2.5mm (1/10th in). These fibres sometimes appear saw-edged and have tapering ends. The lumen varies in thickness and definition; the cell walls are thick where the lumen is thin and vice versa. The lumen is often packed with tiny granules.

Sisal also contains broader fibres with a characteristic lattice pattern and with small pore-markings. Some cells are cushion-shaped and others are short and rectangular. Here and there, small spiral-shaped bodies can be seen, like little springs.

Sisal contains about 6 per cent of lignin (based on dry material).



Sisal

SISAL IN USE

Sisal is one of the most valuable of all cordage fibres. It is too stiff to be used satisfactorily for certain purposes, such as power transmission, in which it has to run through pulleys or over wheels. Prior to World War II, sisal ropes were also regarded as being of limited use in marine cordage; it was believed that sisal deteriorated too rapidly in salt water. Experience during the war showed, however, that this is not the case, and sisal is now widely used for marine ropes and hawsers particularly in under-developed areas.

Sisal is used extensively for making baler and binder twine, and for sacks, paper filters and other industrial uses.

The high strength, lustre and good colour of sisal have made it into an attractive fibre for certain textile uses. It is made into matting and rugs. Its ability to take up direct cotton and acid dyestuffs has made it a popular fibre for ladies' hats.

HENEQUEN

In Yucatan, the fibre henequen is produced from a plant *Agave fourcroydes*, which is closely related to the *A. sisalana* which yields sisal. Henequen fibre is also a valuable export from Cuba. It is often known as 'Yucatan sisal' or 'Cuban sisal'.

Henequen is an important leaf-fibre; the total output is in the region of 150,000 tons a year. Mexico produces about four-fifths of the world's henequen, most of which comes from the State of Yucatan. The remaining fifth comes almost entirely from Cuba.

PRODUCTION AND PROCESSING

The henequen plant is very similar to that from which sisal is obtained. The leaves are prickly and grey-green in colour. They are first cut, one or two at a time, from plants about six or seven years old. Then, for fifteen to eighteen years, a few leaves are removed twice yearly until the plant flowers and dies.

The leaves are processed in the same way as sisal and the strands of washed fibre are dried in the sun.

STRUCTURE AND PROPERTIES

Henequen is very similar to sisal. The strands of fibre, 150cm (5 ft) long, are of good colour and have an attractive lustre. They are usually finer than strands of sisal fibre.

The individual cells of henequen are almost identical with those of sisal.

HENEQUEN IN USE

Henequen is used in much the same way as sisal. It provides much of the world's agricultural twine.

Coarse fabrics such as canvas have been made from henequen in Mexico since prehistoric times.

ABACA (MANILA)

The *Musaceae* family of plants is one of the most useful in the world. It provides us with all manner of foods and industrial raw materials. *Musa sapientum*, for example, gives us the banana; *Musa textilis* is a source of the paper-making and cordage fibre abaca, or Manila hemp.

The abaca plant is indigenous to the Philippine Islands; native islanders were making textiles from its fibres when Magellan visited the islands in 1521 during his circumnavigation of the globe.

During the early nineteenth century, supplies of abaca began to reach the Western world, and its value as a cordage fibre was quickly appreciated. It was better than hemp for many purposes, particularly in marine ropes and hawsers.

Despite the many attempts that have been made to establish abaca production in other parts of the world, the Philippine Islands remain the chief source of the fibre. Total production in 1977 was 75,000 tonnes, of whch some 85 per cent came from the Philippines. The remainder came from Ecuador.

PRODUCTION AND PROCESSING

M. textilis grows easily in the Philippines and needs little cultivation. The plant comprises a cluster of sheath-like leaf stalks. The stalk is composed of a fibreless pulpy centre core surrounded by overlapping leaf-sheaths. Each sheath contains a thin layer of fibre.

These stalks often reach a height of 7.5m (25 ft). After one and a half to two and a half years' growth the blossom appears on some of these stalks, normally on two to four. This is the most satisfactory stage for fibre production, and these stalks are then cut down near the ground level. By this time the plant consists of from ten to thirty stalks in various stages of growth, and two to four of these reach maturity in four to six months after the previous cutting. The diameter of mature stalks is usually 13 – 30cm (5 – 12 in). The average useful life of the plant is about fifteen years, although some varieties continue producing for up to thirty years.

Fibre Extraction

The fibre is extracted by separating the ribbons of fibre from the layers of pulp. These ribbons, which are known as tuxies, are then drawn under a knife, usually made of metal, and the residual pulp is removed from the fibre, which is then hung up to dry.

Grades

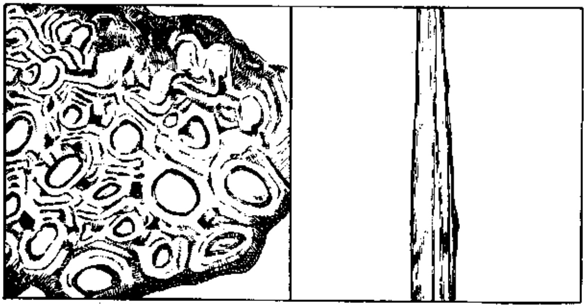
The leaf sheaths vary in colour and texture according to their position on the stalk. The sheaths comprising the stalk normally fall into four groups. The outside sheaths (baba) are of dark brown or light purple and green strips. (This discoloration is due to exposure to the sun.) The sheaths next to the outside (segunda baba) are striped very light green and purple. The middle sheaths are a very light green or light yellow. The inner sheaths (ubud) are almost white. The outer sheaths produce the strongest and the inner sheaths the weakest fibre. The tuxies from these four groups of sheaths produce basically four qualities of fibre. In practice many qualities are produced by varying the type and pressure of the knife used for removing the residual pulp.

Other factors affecting the quality of the fibre are the condition of the stalks; immature or over-mature stalks reduce the quality as also does delay in removing the tuxies from a stalk after it has been cut, and delay in drying the fibre after extraction.

STRUCTURE AND PROPERTIES

Commercial abaca fibre is in the form of strands containing many individual fibres held together by natural gums. The strand-length varies greatly depending on the precise source and treatment of the fibre during processing. Good quality abaca is often in the form of strands up to 4.5m (15 ft) long.

Abaca has good natural lustre. Its colour depends upon the conditions under which it has been processed; good quality abaca is off-white, whereas some poor quality fibre is nearly black.



Abaca

Abaca is strong and sufficiently flexible to provide a degree of 'give' when used in rope. The fibre is not readily affected by salt water. It has a slight natural acidity which can cause corrosion when abaca is used as a core in wire ropes.

Individual fibre cells are cylindrical and smooth-surfaced. They are as much as 6mm (¼ in) long, are are regular in width. The ends taper gradually to a point.

In cross-section, the fibres are polygonal and the cell walls thin. The lumen is large and distinct; it is round and uniform in diameter although both fibre and lumen show occasional constrictions. In places, the lumen contains granular bodies.

Abaca fibres are largely cellulose (about 77 per cent of moisture-free fibre), but are coated with considerable amounts of lignin (about 9 per cent). The individual fibres can be freed by boiling the strands in alkali.

Abaca which has been treated in this way contains epidermal cells which are almost rectangular. They cling together forming little rafts among the fibrous cells.

ABACA IN USE

Most of the abaca produced today is used in the manufacture of strong high-grade paper, such as tea-bags, stencil tissue, meat casing and disposables. Some is still used for ropes and cordage. The fibre's resistance to the effects of sea-water, and its natural buoyancy, have created a ready market for it in the manufacture of hawsers and ships' cables.

Abaca fibre is also used for making hoisting and power-transmission ropes, well-drilling cables, fishing nets and lines, and other types of cordage where strength, durability and flexibility are essential.

Some of the fine inner fibres from the abaca leaf-stalk are used directly, without spinning, for making delicate, lightweight, yet strong fabrics. These fabrics are used in the Philippines for clothing, and for hats and shoes. Some abaca is used for carpets, table mats, etc.

OTHER LEAF FIBRES

1. Canton

SOURCE: Philippines, from plant of *Musa* species similar to *M. textilis* (abaca).
CHARACTERISTICS: Similar to abaca.
USES: Cordage.

2. Pacol

SOURCE: Philippines, from plant of *Musa* species.
CHARACTERISTICS: Weaker and softer than abaca.
USES: Cordage.

3. Cantala (Maguey)

SOURCE: *Agave cantala*. Native of Mexico; grown in Philippines, India, Indonesia.
CHARACTERISTICS: Similar to henequen. Softer than henequen and more supple. Fibre strands are of round cross-section (c.f. sisal – horseshoe shape). Individual fibres long and fine. Thicker cell walls and narrower lumens than sisal.
USES: Same as sisal and henequen. Native fabrics.

4. Letona

SOURCE: *Agave letonae*. Grown commercially in El Salvador.
CHARACTERISTICS: Similar to henequen. Lustrous strands.
USES: Coffee bags, canvas, hammock cloth.

5. Mauritius fibre

SOURCE: *Furcraea gigantea*. Resembles Agaves in growth and habits. Island of Mauritius.
CHARACTERISTICS: Long white, lustrous strands. Similar to sisal and henequen, but weaker, finer and softer.
USES: Bagging and coarse fabrics.

6. Phormium (New Zealand 'flax' or 'hemp')

SOURCE: *Phormium tenax*. Indigenous to New Zealand. Leaves about 3m (10 ft). Fine native fabrics noted by Captain Cook. Also grown commercially in St Helena, the Azores, South Africa and in some South American countries.
CHARACTERISTICS: Fairly strong; flexible, good lustre, good resistance to sea-water. Softer and weaker than Manila hemp. Individual fibres smooth with pointed ends, average length about 6 mm. Cross-section round with thick cell walls. Narrow circular lumen tapering and disappearing towards ends.
USES: Ropes, twines, coarse bagging materials.

7. Sansevieria

SOURCE: Various species of genus *Sansevieria*. Indigenous to Africa and India. Cultivated in Yucatan, Mexico.

CHARACTERISTICS: White and soft to touch. Good lustre. Fairly strong and resilient. Good resistance to sea water.

USES: Ropes and twines. Bagging fabrics.

8. Caroa

SOURCE: *Neoglazovia variegata*, indigenous to Central and South America. Grows wild in Brazil in large quantities.

CHARACTERISTICS: Creamy white. Strong, flexible and fairly soft to touch. High proportion of lignin.

USES: Ropes and twines. Clothing fabrics, e.g. for lightweight suits.

9. Pineapple fibre

SOURCE: *Ananas comosus*, the pineapple plant. Cultivated in many parts of world, principally Hawaii, Philippines, Indonesia, India, West Indies.

CHARACTERISTICS: Soft, white and good lustre. Strong and hard wearing. Smooth-surfaced cells, tapering to pointed ends. Narrow lumen. Oval cross-section.

USES: Cordage and threads. Woven into fine cloth of great beauty.

10. Pita floja

SOURCE: *Aechme magdalenae*. Central and South America. Grows wild in Brazil.

CHARACTERISTICS: Creamy white. Good lustre. Strong, Good sea-water resistance.

USES: Ropes, twines, coarse fabrics.

11. Bromelia

SOURCE: Species of *Bromelia*. Indigenous to Central and South America. Cultivated in Mexico for fibre.

CHARACTERISTICS: Fine, soft, lustrous fibre. Creamy white.

USES: Canvas-type fabrics, ropes and twines.

12. Palma

SOURCE: *Samuela carnerosana*. Native to Mexico.

CHARACTERISTICS: Strong.

USES: Ropes and twines, bagging fabrics, brushes.

13. Fique (Cabuya)

SOURCE: *Furcraea macrophylla*. Colombia. Wild and cultivated.

CHARACTERISTICS: Coarse fibre.

USES: Bagging fabrics, coffee bags, canvas for hammocks, etc.

14. Piassava

SOURCE: Leaf stalks of palms.
Bahia piassava (*Attalia funifera*).
Para piassava (*Leopoldinia piassaba*) exported from Brazil.
Stalks retted.

CHARACTERISTICS: Stiff fibres.

USES: Brooms and brushes.

15. Raffia

SOURCE: Madagascar. Strips of fibrous material from surface of leaflets of certain palms.

CHARACTERISTICS: 1.2 – 1.5m (4 – 5ft) strands. Pale creamy colour.

USES: Horticulture, hats, etc.

THE SEED AND FRUIT FIBRES

The seeds and fruits of plants are often attached to hairs or fibres which, like other plant fibres, are constructed in the main from cellulose. Many of these fibres are used in the textile industry; one of them – cotton – has become the most important textile fibre in the world.

COTTON

Though the bast and leaf fibres are of very great value to the world, they cannot begin to compare in importance as textile fibres with the seed fibre, cotton.

Cotton is the backbone of the world's textile trade. Many of our everyday textile fabrics are made from cotton; fabrics that are hard-wearing and capable of infinite variety of weave and colouring.

Like the other plant fibres, cotton is essentially cellulose. But it is not produced by the plant as part of its skeleton structure, as are the bast and leaf fibres. Cotton is attached to the seeds of plants of the *Mallow* family; the fibre serves probably to accumulate moisture for germination of the seed.

Early History

The idea of using these fine seed-hairs as textile fibres came at an early stage in textile manufacture. Cotton fabrics were made by the Ancient Egyptians and by the earliest of Chinese civilizations. Samples of cotton materials have been found in Indian tombs dating back to the year 3000 B.C. There is some evidence that cotton may have been in use in Egypt in 12,000 B.C., before the use of flax was known. Specimens of woven cotton fabric have been found in the desert tombs discovered in Peru. These pre-Inca textiles were designed and woven with immense skill. They include brocades and tapestries, crocheting and lace.

No matter where the spinning and weaving of cotton may have been developed first, there is no doubt that India was the true cradle of the cotton industry. Cotton fabrics of remarkable quality were being produced as early as 1500 B.C., using only the most primitive of spinning and weaving techniques.

As textile skills developed in India, many different types of fabric were produced. Brocades and heavy fabrics, embroidered materials and muslins were made in great variety and of incredibly high quality. By the seventeenth century, Indian textile craftsmen were spinning and weaving cotton into the fabulous Dacca muslin; this beautiful fabric was so light that 66m (73 yd), 90cm (1 yd) wide, weighed only 454g (1 lb) – less than one-quarter of the weight of a modern fine-quality muslin. These Dacca muslins were used for royal and ceremonial occasions. They were woven from yarn spun entirely by hand, using only a simple spinning stick.

At the time of the Roman Empire, cotton growing and manufacture became established around the shores of the Mediterranean. Trade with India developed, and lasted until the Roman Empire collapsed, bringing with it a breakdown in trading activities between the Mediterranean and the East.

During the seventh century A.D. the Saracens built up their Mediterranean empire and reached to the borders of India itself. Once again trade grew between India and the Levant. New caravan routes were established and commerce thrived as it had never done before. The foundation of much of this intercontinental trade was cotton.

Cotton was being grown on the Greek mainland from the eighth century A.D., and its cultivation became established in other European countries. As the Moors penetrated into Spain, they carried their technical and artistic knowledge with them. Some of the finest fabrics were made in Spain during the tenth century; Cordova, Seville and Granada were centres of the cotton weaving and dyeing trades, and their products compared favourably with those of Eastern cities.

Europe, however, was too involved in religious struggles to allow of any volume of trade with Spain. When the Moors were eventually driven out their skills in cotton cultivation and manufacture went with them.

During the twelfth and thirteenth centuries, the Crusades brought Europe into contact with the arts and crafts of Eastern countries. Once again, cotton became one of the most important of the articles that flowed through these great trade routes, and the textile industries of southern France and northern Italy began to flourish. The trading centres of Genoa and Venice became the gateways of the European continent.

Cotton in Europe

One of the earliest mentions of cotton in European history records the weighing of cotton in the public scales at Genoa in 1140. This cotton came from Antioch, Alexandria and Sicily. Venice, however, is believed to have been the first European city (outside Spain) to manufacture cotton fabrics. Here, cotton from the Mediterranean was spun and woven into cloth for Europe, and during the next three hundred years the textile trade flourished along the eastern Mediterranean shores. Cotton became an established article of commerce between Venice and cities of Central Europe. During the Middle Ages, Germany became an important centre of European cotton manufacture.

Despite this steady development of cotton spinning and weaving in parts of Europe, the finest calicos and prints were still brought by caravan from India. Europe had not yet been able to match the skill of Asian craftsmen.

In 1368, the great Mogul Empire in Central Asia, which had favoured commerce with the West, was succeeded by the Ming Dynasty. The overland routes were closed and as the Turks conquered Syria and Egypt the trade with India virtually ceased. This was responsible more than anything else for the great voyages of exploration that made the fifteenth century live in history. The search for a water route to the East led Columbus to America and took Vasco da Gama on his voyage to Calcutta via the Cape of Good Hope.

For the next hundred years, Portugal monopolized the sea-borne cotton trade that grew between Europe and the East. From Lisbon, cotton was shipped by the Dutch to Antwerp, Bruges and Haarlem, which became the textile centres of eastern Europe.

As Spain's sea power grew, trade between British and Dutch ports and the East was diminished, but the defeat of the Armada in 1588 opened up once and for all the trade routes from Europe to India. This was the time of the great trading companies that were built up largely on the cotton trade. The British East India Company formed in 1600 was followed within a few years by those of the Dutch and French; the first steps had been taken towards the creation of the European empires. And cotton was a commodity with which these trading companies were very much concerned.

Meanwhile, the manufacture of textiles was growing into an industry in Britain. Thousands of Protestant artisans had fled from religious persecution on the Continent, bringing with them their skill in the textile crafts. By the end of the seventeenth century, Britain had become an exporter of cotton fabrics – a trade in which she was ultimately to establish the leadership of the world.

The Industrial Revolution

The eighteenth century saw textiles developing as a national industry in place of the local guilds that had served during mediaeval times. In 1736, the Manchester Act wiped out the law of 1700 which had been engineered by the wool merchants to prohibit the sale of cotton goods in England. Lancashire then set out to become the cotton centre of the world.

During the latter half of the eighteenth century, the Industrial Revolution in Britain transformed production methods in the textile industry. This was the age of invention that was to make Britain the workshop of the world.

At this time, most British cotton was being imported from the West Indies, with a certain amount from India, the Levant and Brazil. Cotton has been planted and grown for commercial use in Virginia since 1607, but the production of American cotton was held up owing to difficulty in removing the cotton from the seeds to which the fibres clung tenaciously. In 1793, Eli Whitney invented the cotton gin, a machine for removing the fibres from cotton seeds, and America entered the world market as a cotton producer. By 1800, she was exporting 8 million kg (18 million lb) a year to England; eleven years later this had reached 28 million kg (62 million lb).

From this time on, Lancashire was to reign unchallenged as the cotton manufacturing centre of the world – a position she held until the First World War.

Since then, the great consumer countries of the East have developed their own manufacturing industries, and Lancashire no longer holds her former position in the textile world. Many factors have combined to intensify the changing conditions in the cotton trade; better home heating and changing fashions have reduced the clothing worn by women to a quarter of the yardage carried by their Victorian grandparents. And man-made fibres like nylon and rayon are encroaching steadily in the fields where cotton was previously employed.

In 1964 – 65 the world production of cotton amounted to 11,300 million kg The most important producing countries are shown in the table.

The Cotton Boll

PRODUCTION AND PROCESSING

Formation of the Fibre

Cotton grows inside the seed pods of a wide variety of plant species included in the *Gossypium* family. The early primitive cottons grew naturally as perennials, and for many years cultivated cotton was also grown as a perennial. In the tropics, perennial cotton plants may grow 6m (20 ft) high. Nowadays, with only one or two major exceptions, the world's cotton is grown by raising annual crops, the plants reaching a height of between 1.2 and 1.8m (4 – 6 ft).

Cotton seed is usually sown in the spring and the young plants are thinned out later into rows. In due course, many creamy-white flowers appear, which turn pink towards the end of the first day. On the third day, the flower withers and dies to leave a small green seed pod, or 'boll'.

The cotton fibres form on the plant as long hairs attached to the seeds inside the boll. As the plant grows, the fibres are packed tightly into the boll. When it reaches maturity, the boll bursts and the cotton appears as a soft wad of fine fibres.

The individual cotton fibre is a seed-hair consisting of a single cell. It grows from the epidermis or outer skin of the cotton seed.

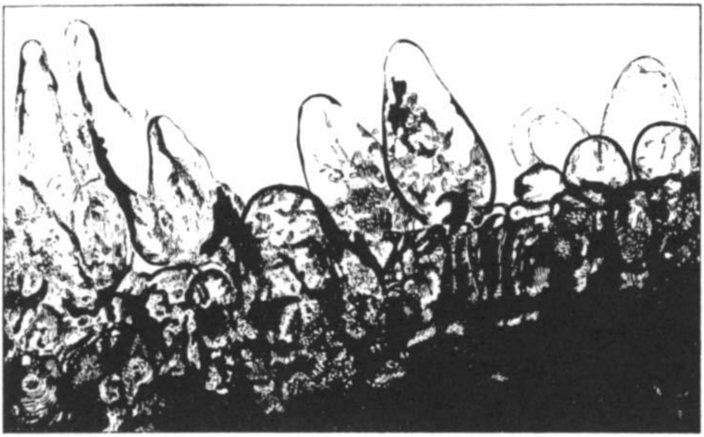
Each cotton seed may produce as many as 20,000 fibres on its surface, and a single boll will contain 150,000 fibres or more. The boll itself is a fruit which forms when the flowers drop from the

Production of Cotton during Season
1979 *thousand tonnes)*

U.S.A.	3,163
U.S.S.R.	2,821
China	2,207
India	1,220
Egypt	482
Mexico	336
Brazil	575
Pakistan	650
Turkey	505
Peru	72
Argentina	140
Sudan	131
Syria	132
Iran	110
Spain	40
Uganda	13
Colombia	108
Greece	100
Nigeria	43
Salvador	72
Mozambique	15
Nicaragua	109
Tanzania	60
Eastern Europe	9
Guatemala	146
Afghanistan	38
Burma	17
Paraguay	71
Korea	6
Angola	13
South Africa	47
Zimbabwe, Malawi, Zambia	45
Kenya	11
Australia	53
West Indies	1
Israel	75
TOTAL	14,050

cotton plant. The young fruit that remains increases in size for perhaps seven weeks, forming the ripe boll; this then opens to expose the mass of cotton fibres which expand and dry into a light fluffy mass.

The growth of these cotton fibres takes place throughout the boll-ripening period. In some varieties of cotton, tiny fibres can be detected on the embryo seed one or two days before flowering. Other varieties begin their fibre-production a day or two after flowering.



Cotton. The surface of a very young seed, showing infant cotton fibres forming – *After Mary L. Rollins, U.S. Dept. of Agriculture.*

Fibre Growth

During the first week after the cotton plant has flowered, hundreds of fibres appear from the seed coat. For several days, more and more young fibres continue to thrust their way out of the seed until each seed is carrying a 'crop' of thousands of individual fibres.

For six days, the growth of the young cotton fibre is comparatively slow. Then for the next fifteen days it is much more rapid; the fibre may reach a length equal to 2,000 times its diameter during this three-week growing period. Then for three days it grows more slowly again until the lengthwise growth comes to a sudden stop.*

During its period of rapid elongation, the cotton fibre is in the

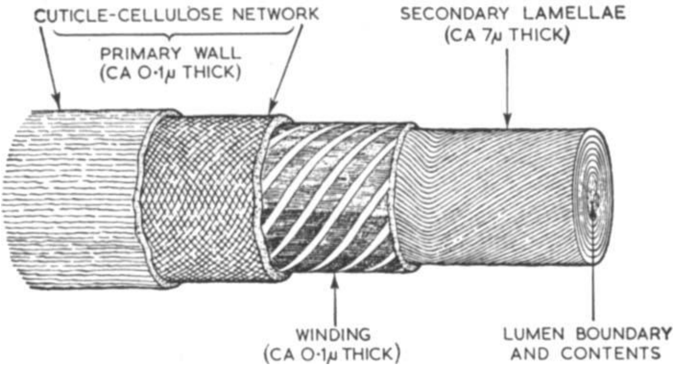
* The time-scale given in this section represents that of a typical cotton plant; it varies considerably according to variety and conditions of growth.

form of a thin-walled tube of cellulose with one end closed and the other attached to the seed. It is filled with protoplasm and liquid nutrients which have been drawn from the main supply vessels of the plant. It resembles a long thin balloon distended with water from a tap. Magnified to the thickness of a finger a typical fibre would be about 15m (50 ft) long.

Growth Rings

When it stops its lengthwise growth, the cotton fibre begins to strengthen its internal structure. Layers of cellulose are added one after another to the thin cellulose membrane from inside the cell. Each day sees a new layer deposited, creating a structure similar in cross-section to the growth rings in a tree. The cotton fibre, however, adds its layers by depositing cellulose from the liquid inside the fibre; the innermost layers are the youngest ones, whereas the outermost layers are the youngest in a tree.

Each growth-ring in the cotton fibre corresponds to a day of growth and cellulose-deposition. Every ring consists, in fact, of two layers, one solid and compact and the other porous.



Cotton. A diagram showing the layered components of a cotton fibre cell wall – *After Mary L. Rollins, U.S. Dept. of Agriculture.*

Experiments have shown that cotton grown under constant artificial illumination and constant temperature has no growth-rings. On the other hand, cotton grown in artificial light switched off and on develops rings like the natural fibre. The cellulose is laid down in the form of spiral fibrils or tiny threads, some 1,000 or more to each ring. The deposition of cellulose continues for about twenty-four days, so that each mature cotton fibre can be regarded as being constructed from thousands of fibrils of cellulose arranged in spiral form.

When the boll opens, the moisture evaporates from the fibres. Until this happens, the fibres maintain their tube-like appearance, with a circular cross-section. But as the fibres dry out, the cell walls collapse, forming a ribbon-like structure that resembles a bicycle inner-tube from which the air has been removed.

During its period of growth, cotton is compressed tightly into the limited accommodation available inside the boll. As the cell walls thicken, the fibres are fixed in their distorted positions. Then when the boll bursts and the fibres dry out in the air, they twist lengthwise, forming convolutions which are characteristic of the fibre. These twists take place in both directions in the fibre; some are left-handed and others right-handed, with an almost equal number of each in any individual fibre.

The number of convolutions varies greatly; on average, a fibre will have some 50 twists per cm (125 twists per in).

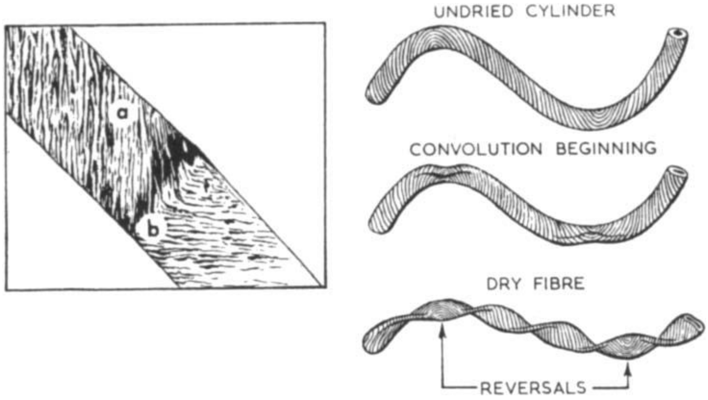
Effect of Growth Conditions

The basic characteristics of the cotton fibre, such as its diameter, are determined by hereditary factors. But the nature of the fibre is also affected greatly by the conditions under which the plant is grown.

In a typical plant, the cotton will be developing for perhaps seven weeks inside the boll. But all the bolls do not mature at the same time; bolls may go on opening on a cotton plant for a period of eight or nine weeks. The total time between flowering and the opening of late bolls may thus amount to about four months.

The ultimate yield of cotton is affected by the conditions under which the plant has grown before it flowered. The quality of the fibre is influenced by the conditions it experiences during the time that the fibres are developing inside the boll.

A setback in the growth of the plant during the period of fibre development may slow up the deposition of cellulose. When conditions are restored to normal, the fibre-growth will continue, but the effects of the interruption will be shown in the quality of the fibre. Short fibres result from poor growth in the initial phase of development; thin-walled fibres arise from interrupted or slowed-down development of the wall in the second phase.



Cotton Fibre: Convolutions. As the cotton fibre grows, layers of cellulose are laid down inside the thin primary wall. Each layer corresponds to a day's growth, and the cellulose is laid down as fibrils which form a spiral pattern round the long axis of the fibre (a). The layers of cellulose laid down in this way form the secondary wall which makes up the major part of the fibre.

The growing fibre is a tiny tube of near circular cross section. The lumen acts as a channel through which materials are carried along the fibre.

When the boll opens, the fibres dry and collapse into flattened tubes. Convolutions appear, the bends in the fibre corresponding to places in the fibre where the spiral pattern of fibrils reverses its direction (b) – *After U.S. Dept. of Agriculture.*

No matter how the cotton is grown, it is inevitable that many of the fibres in every boll will be in an immature state. The proportion of immature fibre to mature fibre is an important factor in determining the quality of the cotton.

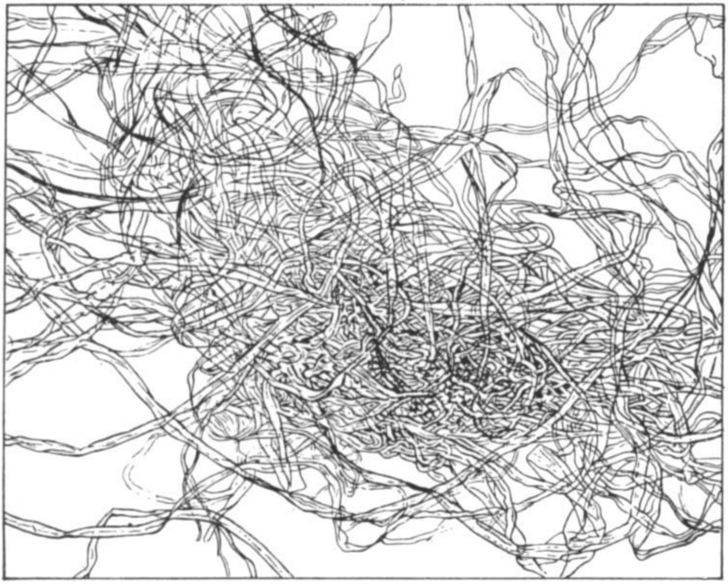
In ordinary commercial cotton, about one-quarter of the fibres will be immature. Sometimes, the proportion of mature cotton reaches 90 per cent, but such high 'maturity counts' are rare. In commercial upland cotton, maturity counts of more than 84 per cent are described as 'hard-bodied'. Average maturities lie between 68 and 76 per cent and cottons with maturity counts below about 67 per cent are regarded as immature ('soft-bodied' or 'weak').

Neps

The immature, thin walled fibres can cause trouble in several ways. They do not dye to as dark a shade as the thick walled fibres; they break easily, causing greater losses of waste fibre during processing. They are more flexible than the thick-walled fibres, so that they bend and tangle more easily, forming 'neps'. If these 'neps' appear in the dyed cloth they show up as specks of lighter shade.

Production of Cotton

Cotton is usually picked by hand or by machine in the autumn. As the bolls on a plant do not all mature at the same time, a field has to be picked over several times before the crop is in. Mechanical pickers have been developed during recent years, and are in almost universal use. The cotton they pick includes a high proportion of leaves and bolls, which increase the amount of cleaning needed and also tend to stain the fibres. In the U.S., more than 99 per cent of the crop is now mechanically harvested. Mill machinery has been devised to improve the cleaning of mechanically picked cotton.



Cotton. A single nep seen through the microscope, showing a mass of tangled, immature fibres – *After Mary L. Rollins, U.S. Dept. of Agriculture.*

Boll Weevil

Cotton growing is now one of the major agricultural industries of the world. Yet cotton is subject to attack from a wider range of insects and diseases than almost any other plant. In particular, a small beetle called the cotton boll weevil (*Anthonomus grandis*) is responsible for tremendous losses in the cotton crop every year. This beetle is a native of Mexico that first appeared in the cotton fields of Texas towards the end of the last century.

Crossing the Rio Grande river in 1892 it spread rapidly eastwards and northwards. By 1903, the boll weevil had reached Louisiana; four years later it was in Mississippi. In 1909 the insect was in Alabama and by 1915 it was attacking cotton in Georgia. By 1921, the boll weevil had spread over the entire cotton-growing area of the United States, causing damage to the crop amounting in bad years to as much as 200 million dollars.

The boll weevil is a tiny beetle that feeds on the buds and bolls of the cotton plant. It has a long snout with which it is able to bite into the plant; it then feeds on the interior of the plant and lays its eggs inside the puncture. Three days later the eggs hatch into fat white maggots which begin feeding on the boll. After a week to twelve days they are fully grown and turn into pupae from which the weevils emerge after three to five days. Then in another week's time the weevil is ready to start rearing a family on its own account. The whole life cycle takes only three to four weeks; barring losses the offspring from a single pair of weevils could amount to several millions during a season.

Cotton growers today have achieved a high degree of control over the boll weevil. Quick-maturing varieties of cotton are grown when possible to avoid the worst season for attack; cultivation methods have been improved and modern synthetic insecticides have carried the war to the insect itself.

Other Pests and Diseases

The pink boll worm (*Pectinophora gossypiella*) is another insect pest that causes great economic loss in all cotton growing countries, especially in India, Egypt and Brazil. This insect has damaged the Egyptian cotton crop to the extent of £8 million or more in a single season.

The adult insect is a small brown moth which leaves its eggs on the cotton plant. Larvae hatch from the eggs and tunnel into the bolls. They eat the seeds of the cotton, preventing proper development of the fibre. Cotton attacked by the boll worm is often stained pink.

Carbon disulphide is used to destroy the pink bollworm; in Egypt, cotton seed is heat treated to prevent infestation.

Other insect pests, such as the cotton leaf worm, cotton boll worm, cotton stainer and cotton red spider, attack the cotton crop in different countries, causing great damage if adequate precautions are not taken.

The cotton plant, like all other living things, is subject to attack by disease-producing micro-organisms. Cotton wilt and cotton anthracnose are fungus diseases; Angular leaf-spot or Blackarm is caused by bacteria; root knot is caused by a tiny worm that enters the roots of the cotton plant from the soil. Black rust is a deficiency disease that is common in regions where the soil is lacking supplies of essential nutrients.

A World Crop

Cotton cultivation has now become a major industry in sixty countries and the plant has adapted itself to a range of climatic conditions. Its essential needs are a growing period of up to six months with plenty of moisture and sunshine, and a dry period that enables the plant to mature. Such conditions are found in general between the north and south latitudes of 40 degrees.

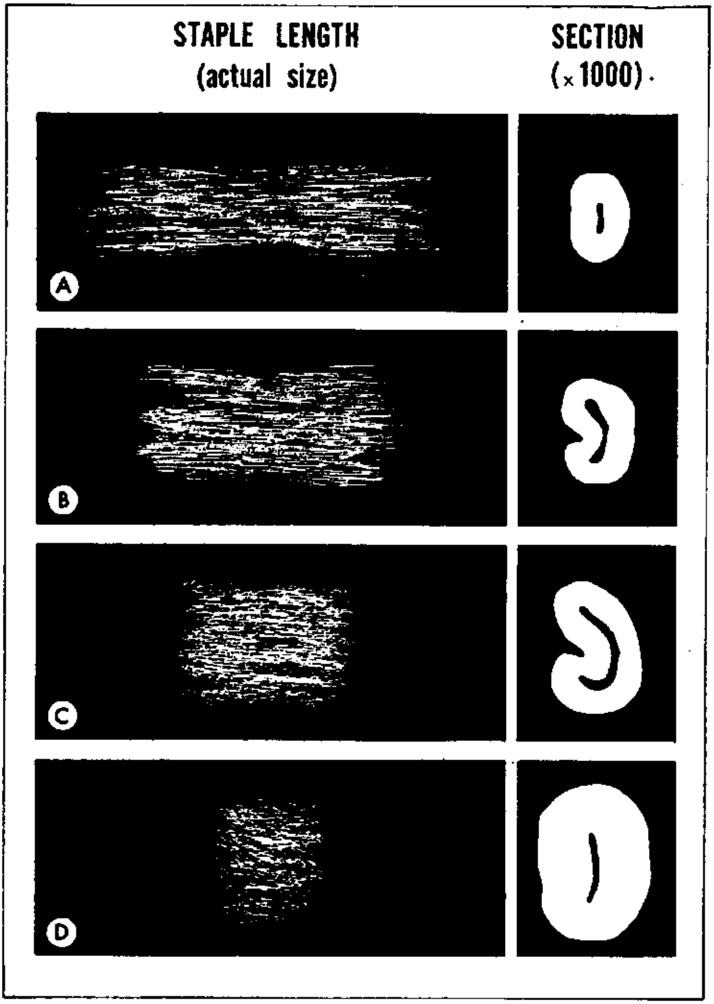
The U.S., U.S.S.R., India, China, Mexico, Brazil, Egypt, Pakistan, Turkey, Argentina and Peru are main centres of cotton cultivation; the U.S. produces almost one fifth the total crop

Altogether, over 10 million tons of cotton are grown every year. The United States cotton belt alone has more than a million farms with cotton as the main crop; the average yield per acre rose from 47.7kg (105 lb) in 1925 to 197.5kg (435 lb) in 1957.

Types of Cotton

Many varieties of cotton plant are grown commercially in different parts of the world, under a wide range of growing conditions. As a result, there are a great many different grades and qualities of cotton, which vary widely in their properties and characteristics.

The assessment of cotton is inevitably a difficult job, requiring great experience and skill. In general, quality is linked directly with staple length, and this is the characteristic that is commonly quoted in referring to any cotton. Staple length is an assessment of a fibre with respect to its technically most important length. In the case of cotton, staple length corresponds very closely with the most frequent length of the fibres when measured in a straightened condition.



Cotton. Comparison of staple lengths and mature sections of different types of cotton. (A) Sea Island (St. Vincent); (B) Sudan (Gezira); (C) American (Texas); (D) India (Bengals) – *After Cotton Board.*

Commercial cottons may be classified broadly into three categories with reference to the staple length:

(1) STAPLE LENGTH 1–2½ IN. (26–65mm). Includes the fine, lustrous fibres which form the top quality cottons. The fibres are generallly of 10–15 microns diameter 1.1–1.8 dtex (0.99–1.62 den).

Sea Island, Egyptian and American Pima (American-Egyptian) cottons are in this category. These high quality cottons are often the most difficult to grow, and are in comparatively short supply.

(2) STAPLE LENGTH ½–1$^5/_{16}$ IN. (12–33mm). Includes the medium strength, medium lustre cottons which form the bulk of the world crop. The fibres are generally of 12–17 microns diameter, and are of 1.4 — 2.2 dtex (1.26–1.98 den).

American upland and some Peruvian types come into this category.

(3) STAPLE LENGTH ⅜–1 IN. (9–26mm). Includes the coarse, low-grade fibres which are often low in strength and have little or no lustre. The fibres are generally of 13–22 microns diameter, and are of 1.5–2.9 dtex (1.35–2.61 den).

Many of the Asiatic, Indian and some Peruvian cottons come into this category.

Ginning the Seed Cotton

After picking, the cotton fibre has to be separated from the seeds, a process carried out mechanically by the cotton gin. There are two forms of this machine in general use, the saw gin and the roller gin. The saw gin is used mainly for short and medium length cotton, and the roller gin is often preferred for longer fibres, although the short Asiatic types of India and Pakistan are roller ginned. Roller ginning is a slower and more costly process.

The Saw Gin

This consists of a steel grating in which are narrow slits. Through these come toothed saws that revolve, catching the fibres in their teeth and pulling them through the slits. The seeds are too big to go through, and remain behind. The ginned cotton is called 'lint'.

Ginning does not remove all the cotton; short fibres are left adhering to the seeds. These fibres are removed by passing the seed through another gin, and the mass of short fibre produced ('linters') is used for stuffing upholstery and as a source of pure cellulose for industry.

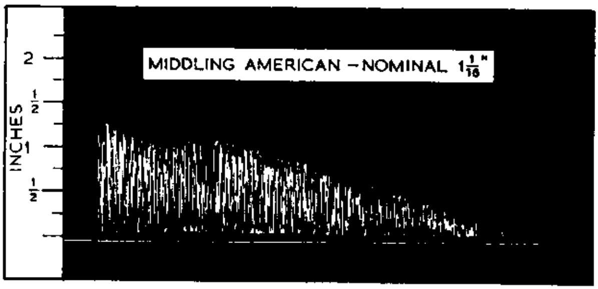
The Roller Gin

This consists of leather discs attached to a wooden roller. The leather surface of the revolving roller passes close to a 'doctor' knife leaving a space through which fibres can pass but seeds cannot. As the roller revolves, the fibres cling to the leather surface and are carried through the gap between the leather and the knife. The seeds are caught by the knife and removed.

Ginned cotton is pressed and packed into bales weighing 200 – 720 lb (91 – 327kg) and sent off for spinning into yarns. 1 oz (28.4g) of cotton contains about 100 million fibres, so that a 500 lb (227kg) bale will contain some 800,000 million fibres. Placed end to end, these fibres would reach 20 million km (12½ million miles).

Grading

Hundreds of varieties of cotton are grown in different climatic conditions and in all manner of soils and environments. The grading and classification of all these cottons, with special reference to the yarns and fabrics they will produce, is obviously no simple task.



Cotton. This drawing shows a typical staple array of Middling American cotton (nominal $1\frac{1}{16}$ in.) – *After Cotton Board.*

The assessment of cotton is carried out traditionally by the cotton 'classer', who depends upon personal skill and long experience in judging cotton quality by inspection and feel. In arriving at his assessment, the classer takes note of (1) the staple length, (2) the colour and (3) the amount of impurity in the cotton, and the quality of its preparation.

In the U.S.A. and other cotton producing countries, standards have been established, using these factors as the basis of cotton classification, and it is the classer's job to assess a batch of cotton with reference to these standards.

The classer works very largely by a hand-examination of the cotton. Staple length is judged by taking a sample and pulling it to display a filmy web of fibre.

In addition to these basic qualities, a skilled classer will take many other factors into consideration in arriving at his judgment of the value of the cotton to the spinner and the weaver. Nowadays, he can support his personal judgment by laboratory tests which give precise, numerical values to the various properties of the cotton.

Cotton Spinning

Cotton arriving at the mill is normally dirty and contaminated by bits of leaf, dust and twigs. Impurities will commonly amount to about 2–3 per cent of the total weight. The cotton has also been compressed tightly in the bale in order to minimize transport costs.

Before the actual spinning of the cotton can be carried out, the fibres are subjected to several preliminary processes. First, cotton from the bale is put into a machine called an opening hopper, in which several spiked rollers are revolving at high speed. The spikes tear the tightly-packed cotton apart, loosening the fibres and allowing many of the impurities to sift out.

Next, the cotton passes to similar machines in which it is beaten to free it from impurities that remain. Another machine continues the cleaning process, delivering the cotton eventually in the form of 'laps', which are continuous sheets of fibre about 102cm (40 in) wide and 2.5cm (1 in) thick. At this stage, the cotton is like an enormous roll of 'cotton wool'.

Carding

The next process is 'carding', which is carried out by a 'carding engine'. This process separates the cotton fibres, takes out most of the remaining impurities and removes short and immature fibres.

From the carding engine, the cotton is delivered as a filmy web which is collected together to form a loose rope of fibres which are just able to cling together and support their own weight. This loose, soft rope is called a sliver.

Drawing

Slivers from the carding engine are stretched or drawn in stages by passing them through a drawing frame. This consists of a series of rollers, like a succession of tiny 'wringers', in which each set of rollers is revolving slightly faster than the previous set. Slivers are fed into the drawing frame in groups of from four to eight; as they pass between the rollers they are drawn out into narrower slivers in which the fibres have been blended and aligned more closely. They are collected together as they leave the drawing frame, forming a single draw frame sliver.

Combing

If the cotton is to be made into fine or high-quality yarns it is combed to align the fibres more accurately and to remove more of the shorter fibres. This operation is carried out in a comber. The sliver from the draw frame is passed through a machine which converts it into small laps; the laps are fed into combers in which the cotton is combed by a revolving cylinder equipped with many needle-like spikes. The cotton comes from the comber as a fine web which is again collected into a loose rope or sliver. Several of the individual slivers are brought together and combined into a single sliver.

The stretching or drawing process is repeated on other machines, such as the slubber and roving frame, until eventually the cotton is in the form of a much narrower sliver in which the fibres are lying sufficiently parallel and uniform to be ready for spinning. At this stage, the sliver acquires a new name; it is a roving if it comes from the roving frame, or slubbing if it comes from the slubber.

As the roving is wound up on leaving the frame it is given a slight twist. This enables the fibres to hold onto one another sufficiently to prevent the roving from breaking.

The number of 'drawing' processes through which the cotton sliver or roving passes depends upon the nature of the yarn that is to be made. The more the cotton is attenuated, the finer and more uniform will the yarn be.

Spinning

All these stages in the processing of cotton have developed with the mechanization of textile manufacture. When spinning was carried out with simple hand equipment, such as the spindle or the spinning wheel, it was not possible to ensure that the yarn would be absolutely uniform. Nor was it necessary when yarn was to be woven on simple hand-operated looms. But mechanization, in textiles as in other industries, demands a degree of uniformity; the processes leading up to the production of the roving are designed to provide a yarn that is consistent and is suitable to act as a raw material for the mechanized weaving processes.

The roving corresponds, in effect, with the strand of fibre that was drawn out from the mass by the hand-spinner. The simple operation of pulling out a strand of fibres in this way provided some degree of alignment to the fibres, and by stretching his strand of fibres during the twisting operation the spinner was able to exercise his skill in order to obtain a reasonably uniform yarn.

Mechanization

The mechanization of this simple spinning process was accomplished only with difficulty, and many inventors, mostly Lancashire men, contributed to the success which was achieved.

In 1738, Lewis Paul of Birmingham invented the method of drawing out cotton slivers until they were fine enough for spinning into yarn. Between 1764 and 1767, James Hargreaves of Standhill developed the spinning jenny on which many threads or yarns could be spun at a time. Then came Richard Arkwright, who perfected the method of using rollers for drawing out the fibres during spinning; Arkwright's inventions enabled the spinner to produce a finer and firmer yarn than had been possible with Hargreaves' jenny.

Between the years 1774 and 1779, Samuel Crompton of Bolton followed up these inventions and combined the principles of Hargreaves' jenny and Arkwright's water-driven frame in a machine called the mule. Cotton could be spun on the mule into a yarn much finer than any that had previously been manufactured.

In mule spinning, which still survives in a few places, rovings are drawn out and mounted as spindles on a moving carriage. As this runs outwards, the spindles revolve, twisting the roving into a yarn or thread which is wound up as the carriage returns in the opposite direction.

The modern spinning process is called ring spinning, which is carried out on a more compact machine without a movable carriage. The operation of the ring spinner is continuous, by contrast with the to-and-fro intermittent movement of the mule. The basic operations of stretching and twisting the roving are, however, the same.

Count

The fineness of the yarn produced by spinning is denoted by a number called the 'count'. This is a measure of the length of a certain weight of the yarn; the finer the yarn, the higher is the count.

The count of a cotton yarn is the number of hanks, each 840 yards (756m) long, in 1 lb (454g). Fine-spun yarns have counts of 50 or more with an upper limit for cotton of about 300. This type of ultra-fine yarn is spun from high-quality Sea Island cotton of the longest and finest staple. A 240 count cotton may be spun from high-quality Sea Island fibre of staple length 1¾ in (44mm).

Most of the world's fine cotton spinning is done in the 50 – 150 count region. Counts of less than 50 are regarded as medium or coarse yarns. A good quality Bengal cotton of only ½ in (12mm) staple, for example, will spin to a count of 12.

To produce a yarn of a desired fineness, the spinner buys cotton of a staple-length and quality that is capable of providing the count he wants. By adjustment of the machines, he can then spin the cotton to this count.

When the spinner has done his job, the cotton fibres have been drawn out and aligned, and then twisted together so that they grip one another and can combine to resist a 'pull'. The finished product provided in this way by the spinner is a yarn.

Yarns may be processed further in many ways. Several yarns are, for example, twisted together or 'doubled' to form threads.

Scouring and Bleaching

Cotton is normally spun into yarns and threads without undergoing any treatment other than the mechanical processes already described. A small amount of mineral oil may be added during spinning, and yarns may be treated later with size. The non-cellulosic materials remain in the cotton, however, and the untreated yarns, threads or fabrics are known as grey goods.

Before these grey goods can be dyed and finished for sale, they are cleaned and purified by processes that are described fairly generally as bleaching. There are many modifications of cotton bleaching techniques in use today; they are carried out largely after the grey yarns have been woven into cloth.

Before bleaching, the cloth is often singed by passing it quickly across open gas flames, or between red-hot rollers or plates. The cloth is then quenched in water or dilute sulphuric acid.

During weaving, the cotton yarns are normally sized with starch. This size is removed after singeing by steeping the cloth in dilute sulphuric acid or with the help of enzymes. The cloth is washed thoroughly after desizing.

Alkali Treatment

Impurities are removed from the cotton cellulose by the process known as kier boiling. The cotton is placed in a pressure vessel and heated in a solution of caustic soda at about 118°C (250°F).

Kier boiling removes some of the wax from the surface of the cotton fibres, and increases the 'wettability' of the cotton. The cotton is washed thoroughly and is then ready for the bleaching proper which destroys remaining coloured non-cellulosic impurities and whitens the cotton.

Bleaching

From the earliest days of the cotton industry, chlorine compounds have been used in bleaching cotton. Bleaching powder or sodium hypochlorite release active oxygen which combines with the impurities without doing appreciable damage to the cotton cellulose.

After bleaching, the cotton is treated with dilute sulphuric acid, washed and then treated with sodium bisulphate to remove residual chlorine. It is then washed thoroughly.

In recent times, hydrogen peroxide has been used increasingly as a cotton bleach in place of the traditional chlorine compounds. Much of the U.S. cotton is now bleached with peroxide; the process saves time and the cloth is subjected to less handling. In addition, the finished cloth has a softer handle.

Chemical Modification of Cotton

The cellulose of cotton is an active chemical, and its character and behaviour can be altered by chemical treatment. Research in recent years has been extremely active in this field, and chemically modified cottons are now appearing on the market in a number of different forms. These cottons retain the essential fibre structure of the original cotton, but the cellulose from which they were originally formed has been subjected to chemical modification. It is no longer cellulose, but a chemical derivative of cellulose.

These changes brought about in the essential chemical structure of the cotton are accompanied by permanent changes in the properties of the cotton. In effect, they provide us with entirely new types of fibre.

Cotton is a particularly useful fibre to serve as the raw material for chemically modified fibres of this sort. It is produced in great abundance, and it can therefore carry the added cost of chemical treatment without becoming too expensive to be of real commercial value.

PA COTTON. Treatment of cotton with acetic anhydride in acetic acid converts it to partially acetylated cotton (PA cotton). This material looks like the original cotton; it has no smell and is non-toxic. But in many of its properties, PA cotton differs from the normal fibre. Most important of all, it has a greater resistance to heat than cotton. At 250°C., for example, cotton loses one-third of its strength in three minutes, whereas PA cotton in similar yarns loses one-third of its strength only after twenty-five minutes at the same temperature. That is to say, PA cotton lasts for eight times as long before losing one-third of its strength. This extra heat-resistance is borne out in practice in the added life of cotton fabrics that are constantly being subjected to heat. Laundry press covers, for example, will last five times as long when made from PA cotton as they do when made from ordinary cotton.

Added to this heat-resistance, PA cotton withstands the attacks of micro-organisms such as those responsible for mildew and rotting. In a test carried out at the Southern Regional Research Laboratory of the U.S. Department of Agriculture, ordinary cotton lost most of its strength after burial in active soil for a week; ordinary cotton treated with copper rot-proofing agents had lost two-thirds of its strength in eight to twelve weeks. PA cotton, on the other hand, retained more than four-fifths of its original strength after being buried for almost a year.

PA cotton is also more resistant to attack by certain chemicals. In 20 per cent hydrochloric acid, for example, it loses only one-third of its strength after eight hours, whereas ordinary cotton loses about two-thirds.

Under certain circumstances, PA cotton shows better weathering resistance than ordinary cotton. It is also a better electrical insulator.

The increasing interest shown in chemically modified cotton has stimulated development of PA cotton. But it is not a 'new' material; PA cottons have been produced in Europe on a small scale since the 1930s.

PA cotton is being used for a number of diverse applications. Sandbags made from PA cotton will last two years under conditions where rot-proofed cotton bags disintegrated in 2–5 months.

PA cotton has been made into fishing nets and lines which were doing useful service after eight months' use; cotton equipment lasted only for a month under similar conditions, and tar-coated cotton was unserviceable after four months.

AM COTTON. When cotton is treated with 2-aminoethylsulphuric acid in sodium hydroxide, another form of chemical modification takes place. Once again, the fibre retains its essential structure, but its properties have changed. The new fibre is known as AM cotton.

AM cotton accepts certain types of dyes more readily than does ordinary cotton; the dyed materials have better resistance to light and washing. The chemical groups in AM cotton are able to react readily with other chemicals, and many new properties can be given to the fibre by subsequent treatment. Rot-resistance can be 'built into' AM cotton in this way.

CM COTTON. Cotton treated with monochloroacetic acid and then sodium hydroxide is converted into CM cotton. Two distinct types can be made in this way.

One type of CM cotton has a 'starched' appearance and handle. It absorbs water more readily than cotton and can accept crease-resisting treatments with greater effect.

The second form of CM cotton disintegrates readily in water. It can be used as a temporary yarn for making fabrics from which the unwanted yarn can easily be removed.

The insoluble CM cotton can be produced easily in mercerizing equipment, at very low cost. The product can be crease-proofed with particularly good effect.

CN COTTON. Treatment of cotton with acrylonitrile yields a chemically modified cotton described as cyanoethylated (CN) cotton. This fibre looks and feels like ordinary cotton, and many of its physical properties are similar to those of cotton. CN cotton, however, has extremely good resistance to rotting influences.

Buried in soil, samples of CN cotton retained their full tensile strength after seventy days; ordinary cotton had rotted completely in five days.

CN cotton has a much better resistance to the effects of heat tnan has ordinary cotton; this resistance is retained under conditions of high humidity.

CN cotton dyes more readily than cotton with certain types of dye.

PL COTTON. Treatment with propiolactone converts cotton into a modified cotton described as PL cotton.

MISCELLANEOUS. The reactive hydroxyl groups of cellulose can be oxidized to aldehyde with periodic acid, hypohalites or nitrogen dioxide; the latter has yielded a fibre used as a soluble surgical dressing.

Cotton treated with phosphoric acid and urea is converted into a phosphorylated cotton containing up to 4 per cent of phosphorus. This fibre, though weaker than normal cotton, is flame resistant. It has cation-exchange properties similar to the ion-exchange resins that are widely used in water-softening.

Ethylene oxide dissolved in carbon tetrachloride will modify the structure of cotton in such a way as to give cotton fabric an organdie-like finish.

The treatment of cotton with formaldehyde confers crease-resistance and affects the dyeing behaviour of the fibre.

Cotton can be made water-repellent by treatment with stearamido-methyl pyridinium chloride. This is the basis of the Zelan and Velan processes used commercially.

Dyeing

Cotton is used for an immense variety of textile applications and dyestuffs are available which will give satisfactory results under almost any conditions encountered in practice.

Vat and azoic dyes are used when the colours must be fast to washing and chlorine. Sulphur colours, developed direct colours and Hydron Blues provide good light and washing fastness. Direct colours are used when the fabrics are not to be subjected to exposure or to repeated washing; they are also used in dyeing union fabrics containing cotton. Basic dyes provide attractive, brilliant shades when fastness is not a primary consideration.

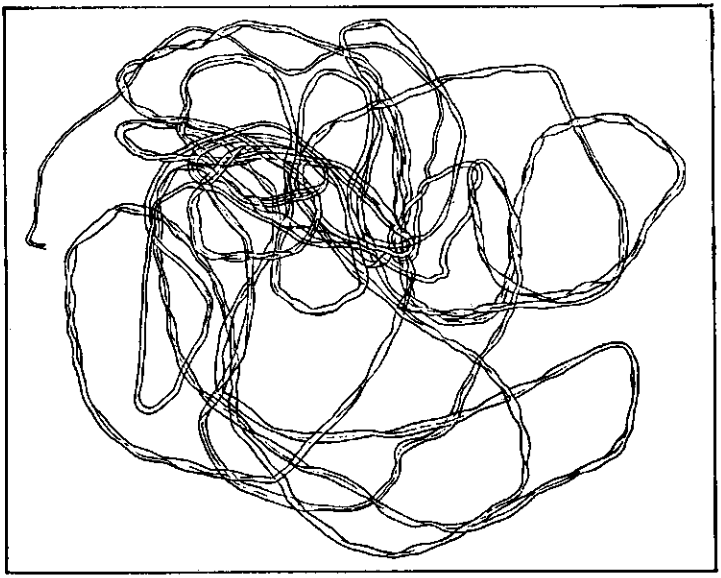
STRUCTURE AND PROPERTIES

Fine Structure and Appearance

One of the characteristics of cotton is the great variety of shape and form that its fibres show. Any sample of raw cotton will contain fibres in different stages of development, and the microscopic features of these fibres will differ widely one from another. Moreover, samples of cotton from different varieties of plant and from plants grown under different conditions will differ too.

Convolutions

The cotton fibre is a single cell which has collapsed into a flattened tube of cellulose as it dried. The mature fibre can be recognized by the twists or convolutions which are a characteristic of cotton. A typical Sea Island cotton will have some 300 half-convolutions to the inch (25mm); Egyptian 230; Brazilian about 210; American about 190, and Indian 150. The direction of twist reverses after every two or three convolutions.



Cotton. A single cotton fibre seen through the microscope, showing the variations in size and shape of the dried, shrivelled tube – *After Mary L. Rollins, U.S. Dept. of Agriculture,*

Length

The length of the individual cotton fibre varies greatly, depending upon the variety of the plant, the conditions under which it has been grown, and the state of maturity of the fibre at the time of picking. A good Sea Island fibre may be 2½ in (65mm) long, whereas a linters fibre will be less than ¼ in (6mm) in length.

Fineness

In general, the cotton fibre is of fairly uniform width. At one end, it tapers to a tip. The other end of the fibre is open and irregular; this is the point at which the fibre was torn from the seed during ginning.

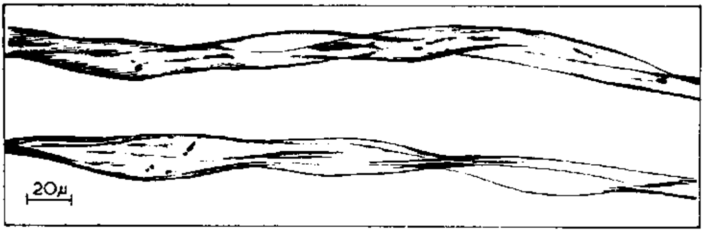
The actual width of a typical cotton fibre 'ribbon' may vary between about twelve and twenty microns.* The central section of the fibre is thicker than the ends.

Seen in cross-section, the normal mature fibre is oval or kidney-bean shaped. The thick cellulose wall encloses a well-defined lumen.

Immature Fibres

Immature cotton fibres can be recognized by the thinner cell walls. The dry, immature fibre does not show the oval or kidney-bean shape cross-section; instead, the fibre tube collapses into a thin ribbon that curls into a variety of distorted shapes. Often the immature fibre is U-shaped in cross-section.

These thin-walled, immature fibres may not twist as they collapse on drying. They seldom have the pronounced convolutions that are so typical a feature of the mature fibre.



Cotton. Longitudinal view of mature (above) and immature (below) cotton fibres, showing typical convolutions – *After U.S. Dept. of Agriculture*

Micro-structure

In recent years, studies have been made of the fine structure of the cotton fibre. New techniques and instruments such as the electron microscope have enabled us to examine the internal make-up of the fibre in a way that has not been possible before.

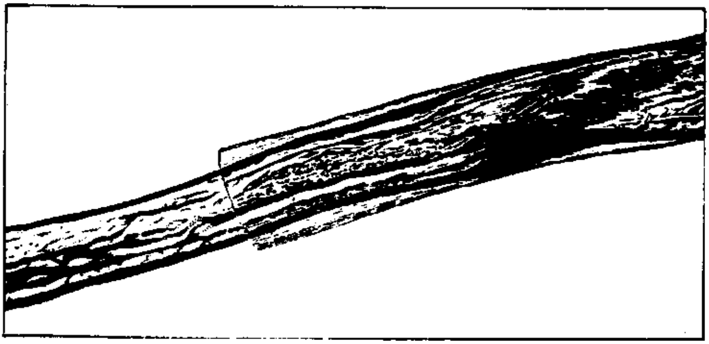
The wall of the fibre varies in thickness. It consists of two main sections, the primary wall or cuticle forming the outer layer, and the secondary wall forming the inner layer.

* 1 micron = 1/1,000 mm. = 1/25,000 in. approx.

Primary Wall

The primary wall is a tough, protective layer that formed the shell of the fibre during its early days of growth inside the boll. Seen under the microscope at high magnification, the surface of the cotton fibre is wrinkled like a prune. These surface wrinkles are caused by shrinkage as the fibre has dried.

At the Southern Regional Research Laboratory of the U.S. Department of Agriculture, methods have been devised for removing the primary wall from the fibre. Cotton is beaten in water under special conditions and short fragments of the primary wall slip off like sleeves. Chemical analysis of primary wall material isolated in this way has shown that it contains wax, protein and pectinaceous substances as well as cellulose. When these non-cellulosic materials are removed chemically, the cellulose fibrils can be seen with the help of the electron microscope as a felt-like mat of tiny threads. These cellulose fibrils are between 1/40th and 1/100th of a micron in diameter, and consist of many long cellulose molecules held tightly alongside one another by natural forces of attraction that are exerted between close-packed molecules.



Cotton. In this photomicrograph, the outer membrane of the cotton fibre is seen peeling from the fibre surface – *After Mary L. Rollins, U.S. Dept. of Agriculture.*

These tiny fibrils of cellulose are, like the fibre itself, strongest in a longitudinal direction. The criss-cross network of fibrils forming the primary wall of the cotton fibre is an arrangement that confers great peripheral strength. The outer wall of the fibre is able to resist forces from any lateral direction, although it does not have the immense longitudinal strength that would be available if all the cellulose fibrils were arranged side by side along the longitudinal axis of the fibre.

This tough-skin effect of the primary wall is noticeable when cotton is immersed in solutions which are able to swell and dissolve cellulose. In cuprammonium hydroxide, for example, the cotton fibre swells up into a distended tube which is tied at intervals like a string of sausages. This is probably due to the resistance of the primary wall to the effects of the solvent. As the cuprammonium hydroxide penetrates and swells the secondary cellulose inside the fibre, the primary wall ruptures and is rolled back into tight ligatures that resist the swelling effects of the solvent. This resistance on the part of the primary wall is largely due to the matted arrangement of the cellulose fibrils forming the network of the wall. In this respect, it is interesting to find that immature fibres, which have little secondary cellulose, are swelled only slightly by solvents.

Secondary Wall

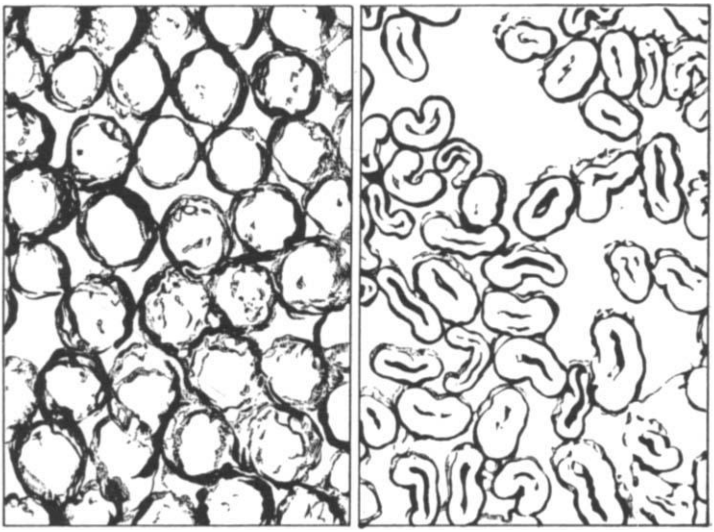
The inner or secondary layer of cellulose forms the bulk of the cotton fibre. This is the cellulose that is laid down during the second stage of fibre growth, after the fibre has attained its full length, when consolidation of the cellulose wall takes place.

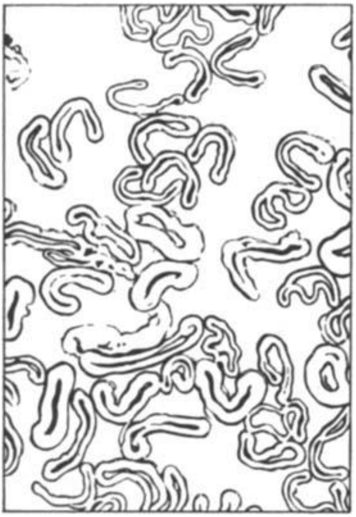
The growth-ring arrangement of the cellulose in the secondary wall can be seen when swollen fibres are examined microscopically. With the help of the electron microscope, the organization of the fibrils can be followed. The fibrils of the secondary wall are packed together in a near-parallel arrangement. The layers of fibrils lie in spiral formation along the fibre, the direction of the spirals often reversing in the same layer.

The secondary wall is almost pure cellulose, and represents about 90 per cent of the total fibre weight. The bulk of the cellulose in the cotton fibre is therefore arranged in the form of fibrils that are packed alongside each other; they are aligned as spirals running lengthwise through the fibre. The fibrils are therefore able to exert high strength in a longitudinal direction in the fibre bestowing immense longitudinal strength on the fibre itself.

Lumen

When the cotton fibre is alive and growing, it is distended by the pressure of the liquid nutrients and protoplasm inside it. As the fibre dies and collapses, the liquid disappears leaving an almost





Cotton. Cross sections of cotton fibres.

Top Left: Growing fibres filled with plant juices are round in cross section.

Top Right: Thick-walled, mature fibres collapse into oval shapes on drying.

Bottom Left: Thin-walled, immature fibres collapse into distorted shapes on drying – *After Mary L. Rollins, U.S. Dept. of Agriculture.*

empty channel running lengthwise through the centre of the fibre. This central canal is the lumen.

In a mature cotton fibre, the deposition of cellulose in the secondary wall may have been so heavy as to leave very little lumen at all. The dry fibre looks like a solid rod rather than a tube. An immature fibre, on the other hand, may have so little secondary cellulose that the lumen is wide and distinct.

When the cellulose of the primary and secondary walls is dissolved by powerful solvents, a thin membrane of protoplasm is left behind. This is the dried-up residue of the materials that were dissolved in the watery liquid inside the living fibre. It contains a coloured substance, the endochrome, which gives the cotton its natural colour. Cottons have been grown experimentally in which the lumen contains brown or green pigments which act as natural 'dyes'.

In a normal cotton fibre, the lumen although almost completely collapsed represents a considerable volume of unoccupied space. It enables the cotton fibre to absorb water by capillary attraction and so has an important influence on the properties of cotton as a textile.

The lumen, however, forms only a part of the unoccupied space in a cotton fibre. The cellulose walls are porous and can absorb considerable quantities of water on their own account.

Although the fibrils of cellulose forming the fibre walls are compact and relatively impervious to water penetration, the submicroscopic spaces between them form capillaries that make the cellulose network porous. Large surfaces are exposed by the fibril network, and water is able to penetrate by capillary attraction.

It has been estimated that as much as 20–41 per cent of the volume of a cotton fibre consists of unoccupied space. One-third of this is accounted for by the lumen; the rest is provided by the spaces between the fibrils in the fibre walls. In general, the coarser varieties of cotton are more porous than the compact, finer cottons.

Fibre Surface and Colour

The surface of the cotton fibre, seen at high magnification, is wrinkled and striated. But for most practical purposes, cotton can be regarded as having a smooth surface.

When cotton is spun to form a yarn, the fibres are able to hold together, despite this smoothness, by virtue of their convolutions. The natural twists enable the fibres to grip one another and prevent the slippage that would otherwise take place. A maximum grip is exerted by fibres with 150–175 half-convolutions to the inch (25.4mm).

Cotton fibres have a natural lustre which is due, in part, to the natural polish on the surface. The smooth, hard primary coat of cellulose contains waxes which no doubt contribute to the lustre of the fibre. This surface-smoothness, however, is not the only factor that controls the lustre of cotton. The shape of the fibre is important as well; a high lustre is provided by fibres of nearly circular cross-section and with fewer convolutions such as those produced when cotton is mercerized.

The colour of cotton, normally creamy-white, is affected greatly by the conditions under which it is produced. If the fibre is left too long in the boll before being picked, it may turn grey or bluish-white. A sharp frost will sometimes open the bolls prematurely: this cotton is often darkened to a buff colour. Its fibres are immature and weak.

Tensile Strength

Cotton is a moderately strong fibre; tenacity is 26.5–44.1 cN/tex (3.0–5.0g/den) and tensile strength 2800–8400kg/cm^2 (40,000–120,000 lb/in^2). The strength is affected greatly by moisture (see below) and by the test conditions such as rate of loading, and length of fibre section tested.

The long, fine cottons, such as Sea Island and Egyptian, yield the strongest yarns and materials. Yarn strength is a complex property that involves many factors. The long cotton fibres, for example, are able to grip one another more effectively than the shorter ones, so that there is less tendency for slippage to take place. Long fine fibres of good strength can thus be spun into finer yarns.

Elongation

Cotton does not stretch easily. It has an elongation at break of 5–10 per cent.

Elastic Properties

Cotton is a relatively inelastic, rigid fibre. At 2 per cent extension it has an elastic recovery of 74 per cent; at 5 per cent extension, the elastic recovery is 45 per cent.

Specific Gravity. 1·54.

Effects of Moisture

The tensile properties of cotton fibres and yarns are affected appreciably by the amount of moisture absorbed by the fibres.

Under average humidity conditions, cotton takes up about 6–8 per cent of moisture; it has a regain of 8·5 per cent. At 100 per cent humidity, cotton has an absorbency of 25–27 per cent.

Up to a relative humidity of 100 per cent, absorption of water by the cotton cellulose results in an increase in fibre strength. Fibres saturated with water are about 20 per cent stronger than dry fibres. Cotton yarns will continue to become stronger at high relative humidities.

The humid atmosphere of Lancashire was peculiarly favourable to the spinning and weaving of cotton during the early years of the industry. The damp yarns and threads were not so inclined to break during manufacture. Today, humidity in a factory can be controlled artificially as easily as temperature, and the climate of Lancashire is no longer a critical factor in the cotton trade.

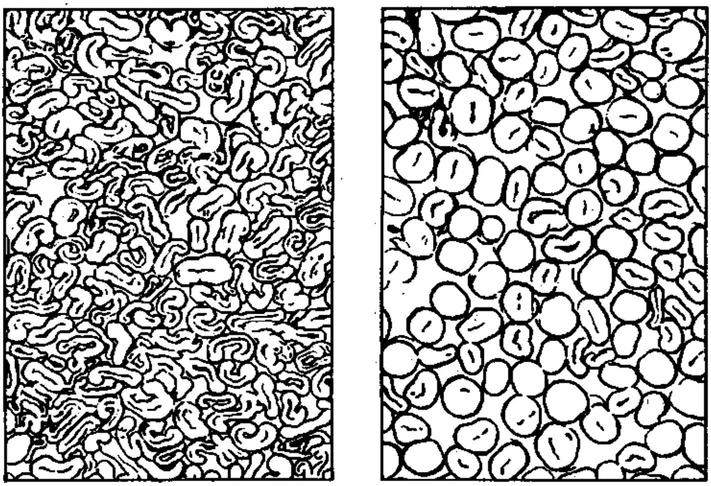
Action of Water on Cotton

The dry cotton fibre, constructed from its fibrils of cellulose, is a fairly stiff, rigid entity. The cellulose molecules are held tightly together inside the fibrils, bound by bonds established between molecules lying close alongside one another.

Water, however, is able to penetrate into the cellulose network of the cotton fibre. It makes its way into the capillaries and spaces between the fibrils and into less tightly bound areas of the fibrils themselves and attaches itself also by chemical links to groups in the cellulose molecules. In this way, water molecules tend to force the molecules of cellulose apart, lessening the forces that hold the cellulose molecules together and destroying some of the rigidity of the entire cellulose structure.

Water acts, in this way, as a 'plasticizer' for cotton. By penetrating into the mass of tightly-bound cellulose molecules it permits the molecules to move more freely relative to one another. The mass of cellulose is softened, and can change its shape more easily under the effects of an applied force.

This action of water on the cotton fibre is responsible for a number of important features in the processing of cotton fabrics. The cellulose molecules in wet cotton are so well lubricated by the water molecules that the fibres become quite plastic and easily deformed. And the effect of pressure upon the cotton is identical with its effect upon any other plastic – it changes its shape. When cotton fabrics in this state are passed through a pair of pressure



(A) (B)

Mercerization. During mercerization, the cellulose of the cotton fibre is swollen rapidly, and the fibre becomes almost a solid cylinder of cellulose. The effect remains even after the cotton has been washed and neutralized. The drawing shows cross sections of cotton yarns; (A) untreated; (B) mercerized – *U.S. Dept. of Agriculture.*

rolls, therefore, the fibres accommodate themselves to the force applied to them; a smooth, flat finish is given to the cloth.

The ability of cotton fibres to take up water has been used in a number of other ways. Tightly woven cloths, for example, can be made in such a way that as soon as the fibres become wet they absorb water and swell. As they swell, the cotton threads close up the interstices of the cloth, thus preventing water from getting through.

The swelling of cotton yarns and fabrics in water is accompanied by some shrinkage.

Mercerization

A most valuable application of this swelling of cotton is in the process known as mercerization. Here, a strong solution of caustic soda is used to bring about intensive swelling of the fibres so that the cotton can be deformed.

Mercerization was discovered in 1844 by one of Britain's great textile scientists – John Mercer of Accrington – who found that by treating cotton with caustic soda the fibres could be made to swell. This caused an overall shrinkage in the fabric as the strains between the threads released themselves. At the same time, the fabric became much stronger and was much more easily dyed.

The mercerization process was taken a stage further in 1890, when H. A. Lowe found that by holding the cotton so as to prevent its shrinking during mercerization it developed the beautiful lustre that we now associate with the process.

During mercerization under these conditions the cotton fibres regain their original circular cross-section due to the swelling of the cellulose, and they tend to lose their convolutions. As they are held fast the whole time, they cannot take up the strains by shrinking; the plastic cellulose deforms and the cloth develops a smoother surface than it had before.

After washing and drying, the mercerized cotton fibre retains this smooth cylindrical form.

Nowadays, cotton yarn is mercerized usually to improve its lustrous appearance and its dyeing qualities. Cloth is mercerized to obtain similar effects and to stabilize its dimensions. When the cotton contains a high proportion of thin-walled immature fibres, mercerizing will swell these fibres and make them dye more like maturer fibres.

Mercerized cotton is chemically little different from ordinary cotton. It remains almost pure cellulose, but in a different physical form. It is more reactive, and will take up about 12 per cent of water from the air, compared with its usual 6–8 per cent.

Sulphuric and other acids are being used to swell cotton and yield effects that resemble those of mercerization. Cotton is passed rapidly through strong sulphuric acid, so that the material is in contact with the acid for only a few seconds. Acid finishing of this sort is adapted to provide a number of different effects. Cotton fabric is made more transparent or more wool-like in this way. It is given an organdie finish which is permanent; the fabric regains its characteristic stiffness after washing and ironing.

Many other acids and salts are used for treating cotton, and the details of such processes are often undisclosed. The effect produced depend on the conditions used and on the nature of the fabric itself. In most cases, however, it is the swelling of the cotton fibre that is the most important factor.

Effect of Heat

Cotton has an excellent resistance to degradation by heat. It begins to turn yellow after several hours at 120°C., and decomposes markedly at 150°C., as a result of oxidation. Cotton is severely damaged after a few minutes at 240°C.

Cotton burns readily in air.

Effect of Age

Cotton shows only a small loss of strength when stored carefully. It can be kept in the warehouse for long periods without showing any significant deterioration. After fifty years of storage, cotton may differ only slightly from fibre a year or two old. Ancient samples of cotton fabric taken from tombs more than 500 years old had four-fifths of the strength of new material.

Effect of Sunlight

There is a gradual loss of strength when cotton is exposed to sunlight, and the fibre turns yellow.

The degradation of cotton by oxidation when heated is promoted and encouraged by sunlight. It is particularly severe at high temperatures and in the presence of moisture. Much of the damage is caused by ultra-violet light and by the shorter waves of visible light. Under certain conditions, the effects of weathering in direct sunlight can be serious. The cotton can be protected to some degree by using suitable dyes.

Chemical Properties

Cotton fibre, as it is picked from the plant, is about 94 per cent cellulose. The remaining 6 per cent is made up of protein (1–1·5 per cent), pectic materials (1 per cent), mineral substances (about 1 per cent), wax (about 0·5 per cent) and small amounts of organic acids, sugars and pigments.

Much of this non-cellulosic material is removed from cotton by scouring and bleaching processes, leaving a fibre that consists of about 99 per cent cellulose.

The purification of cotton cellulose provides a stronger and whiter fibre which absorbs moisture more readily. The natural wax has a useful lubricating effect during spinning, however, and most cotton is spun with its wax still present in the fibre.

Analyses of fibres from different sources have shown that the amount of wax, pectin and protein increases with increasing immaturity of the fibre.

Cotton is highly resistant to the chemicals encountered in normal use. Dyestuffs, mild bleaching agents and similar materials have no significant deleterious effects on cotton fabrics if used with reasonable care. Cotton is attacked by strong oxidizing agents, including hydrogen peroxide and chlorine bleaching compounds.

The purity of scoured and cleaned cotton, and the chemical stability of cellulose, together make cotton into a remarkably durable material.

Effect of Acids

Cotton is attacked by hot dilute acids or cold concentrated acids, in which it disintegrates. It is not affected by cold weak acids.

Effect of Alkalis

Cotton has an excellent resistance to alkalis. It swells in caustic alkali (cf. mercerization) but is not damaged. It can be washed repeatedly in soap solutions without taking harm.

Effect of Organic Solvents

There are very few solvents that will dissolve cotton completely. It has a high resistance to normal solvents but is dispersed by the copper complexes cuprammonium hydroxide and cupriethylene diamine, and by concentrated (70 per cent) H_2SO_4.

Insects

Cotton is not attacked by moth grubs or beetles.

Micro-organisms

Cotton is attacked by fungi and bacteria. Mildews, for example, will feed on cotton fabric, rotting and weakening the material. They have a characteristic musty smell, and stain the fabric with naturally produced pigments.

Mildews are particularly troublesome on cotton that has been treated with starchy finishes, and much of the damage can be avoided by thorough scouring. The pure cellulose is a less attractive food for mildew than the starch.

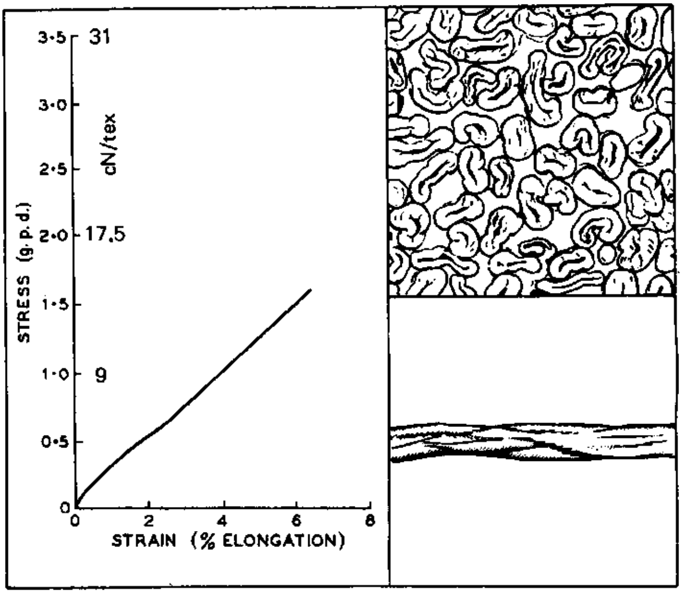
Mildews and bacteria will flourish on cotton under hot, moist conditions. When cotton fabrics are to be used under conditions favourable to attack by micro-organisms, they can be protected by impregnation with certain types of chemical. Copper compounds, such as copper naphthenate, will destroy organisms that would otherwise attack the cotton cellulose.

COTTON IN USE

In cotton, nature has given us an all-round utility fibre that is second to none. Cotton fabrics combine remarkable durability with attractive wearing qualities. Cotton fabrics have a pleasant feel or 'handle'. They are cool in hot weather.

Cotton is inherently strong, and it is stronger when wet than it is when dry. This property, allied with cotton's stability in water and alkaline solutions, endows cotton garments with a long useful life. Cotton can withstand repeated washings, and is therefore ideal for household goods and garments that can be laundered time and time again. Heavily soiled garments can be rubbed vigorously without being damaged.

The cotton fibre itself is dimensionally stable. A made-up cotton garment may shrink to some extent due to the tensions introduced by spinning and weaving, but the fibre itself does not contribute significantly to any shrinkage.



Cotton

This so-called 'relaxation shrinkage', caused by the easing of strains set up during spinning and weaving, can be overcome by a treatment called compression shrinkage. 'Rigmel'- and 'Sanforized'-shrunk cotton fabrics are compression-shrunk in this way; they are dimensionally stable and will neither stretch nor shrink more than 1 per cent in either direction.

The resistance of cotton to washing and wear is matched by the permanence of many cotton dyes. Cotton can be dyed easily, and the colours will often remain fast to repeated washings and to prolonged wear. Vat dyes, in particular, are used for cotton goods where first-rate fastness is essential.

Cotton cellulose is not affected unduly by moderate heat, so that cotton fabrics can be ironed with a hot iron without damage. Cotton fabrics come up crisp and fresh on ironing.

The strength of cotton fibre is one of the main factors in cotton's hard-wearing qualities. But fibre-strength alone does not confer hard wear on a fabric. Other factors come into play, such as the ability of fibres to grip one another during spinning. The twists and convolutions in cotton fibres enable cotton yarns to resist being pulled apart.

The cotton fibre is fairly rigid and stiff, and cotton yarns and fabrics are not as flexible, in general, as fabrics woven from wool, nylon or some rayons. They are, however, more flexible than linen.

To achieve flexibility, cotton can be spun into fine yarns and made into a tight-woven fabric. Poplins, voiles and flannelettes are made in this way; they are extremely flexible and yet have the crispness associated with cotton. Heavier fabrics, such as drills and denims, are much less flexible.

Although cotton is used in great quantity as a fabric for hot-weather wear, it is able to provide warmth as well. The warmth of a garment depends very largely on the pockets of air that are entrapped between the fibres in the fabric. Woollen garments excel in this respect, as the wool fibres are crinkly and rough-surfaced; they can be spun and woven or knitted into full fabrics that hold innumerable air-cells which act as insulators.

Cotton fibres are smoother, stiffer and straighter than wool and they do not make up so readily into air-entrapping fabrics. But special cellular weaves can be used to create the air-cells that provide warmth, and the surface of cotton fabrics can be raised to form an air-filled pile. Molletons, winceyettes and flannelettes are cotton fabrics of this sort.

Much of the comfort of a textile material depends upon its ability to absorb and desorb moisture. A garment that does not absorb any moisture at all will tend to feel clammy as perspiration condenses on it from the skin. Cotton fibres, however, are able to absorb appreciable amounts of moisture, and having done so they will get rid of it just as readily to the air. Cotton garments are therefore comfortable and cool, passing on the perspiration from the body into the surrounding air. No matter how tightly woven a cotton fabric may be, it will permit the body to breathe in this way.

This absorbency of cotton makes it an excellent material for household fabrics such as sheets and towels too.

Cotton is widely used in making rainwear fabrics. It can be woven tightly to keep out the driving wind and rain, yet the fabric will allow perspiration to escape. Special rainwear materials are woven in such a way that water swells the cotton fibres and closes up the interstices in the cloth. Ventile fabrics, for example, are close-woven cotton materials of this sort which are given additional water resistance by a chemical proofing with Velan.

The versatility of cotton has made it into the most widely used of all textile fibres. Cotton is made into every type of garment and household fabric. It goes into boots and shoes, carpets and curtains, clothing and hats. Heavy cotton yarns and materials are used for tyre cords and marquees, tarpaulins and industrial fabrics of all descriptions.

MISCELLANEOUS SEED AND FRUIT FIBRES

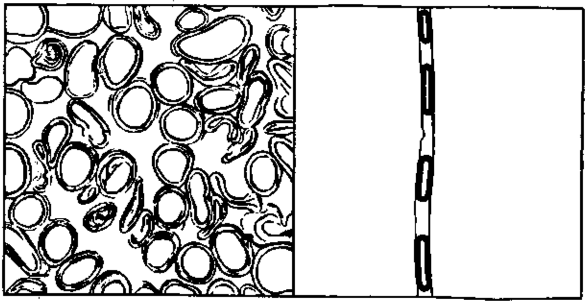
1. **Coir** (*Cocos nucifera*)
   SOURCE: Coir is a coarse fibre which comes from the husks of coconuts.
   CHARACTERISTICS: Coarse. Dark brown colour. Individual fibres short; 0.5mm (1/50th inch) long. Thick walled with irregular lumen. Surface covered with pores.
   USES: Cordage, matting, brushes.
2. **Tree Cotton** (Malvaceae, *Bombax*). (Vegetable Down or Bombax Cotton).
   SOURCE: Seed fibre of cotton-tree plant belonging to *Bombaceae* family. Grows in tropical countries. Cultivated in West Indies and Brazil.
   CHARACTERISTICS: Soft near-white fibre. Weaker than ordinary cotton. Poor resilience. Individual fibres 25mm (1 in). Cell walls thin and irregular. Circular cross-section. Contains some lignin.
   USES: Wadding and upholstery material.

3. Java Kapok (*Ceiba pentandra*)

SOURCE: Seed fibres similar to bombax cotton. Grows in Malaya, Indonesia. Fibre removed by hand from bolls. Dried and shaken up to remove seeds.

CHARACTERISTICS: Extremely buoyant. Soft but inflexible fibre. Too brittle to spin. Fawn colour. Good lustre. Very light weight. Individual fibres up to 32mm (1¼ in). Smooth surface. Transparent. Oval or circular cross-section. Thin walled and wide lumen. Contains lignin.

USES: Padding and stuffing of upholstery. Lifebelts and other safety equipment at sea. (Kapok will support more than thirty times its own weight and does not waterlog.)



Kapok

4. Balsa Fibre

SOURCE: *Ochroma pyramidale.* Grown in West Indies.

CHARACTERISTICS: Dark brown fibre. Individual fibres up to 12mm (½ in). Folded. Striated surface. Cell wall thick, particularly towards ends. Lumen contains granules. More lignin than bombax cotton.

USES: Stuffing of mattresses and cushions.

5. Kumbi (galgal)

SOURCE: *Cochlospermum gossypium.* Grown in India.

USES: Upholstery and cushion stuffing.

6. Chorisia speciosa

SOURCE: Brazil.

CHARACTERISTICS: Fine silky fibre.

USES: Mattress and pillow stuffing. Spun and woven into fine quality fabrics.

7. Beaumontia grandiflora

CHARACTERISTICS: Pure white fibres with good lustre. Very strong. Individual fibres up to 50mm (2 in) long. Thin cell walls contain fine pores.

USES: Stuffing upholstery.

8. Strophanthus spp.

Similar to *B. grandiflora*, but yellow colour.

9. Milkweeds (*Asclepias*)

SOURCE: Plants of genus *Asclepias, A. syriaca* (common milkweed) and *A. incarnata* (butterfly-weed) give excellent seed floss. Indigenous to America. Perennials which grow well in many types of soil in U.S. Pods harvested in late autumn, ginned to remove seeds (see cotton).

CHARACTERISTICS: 'Vegetable silk' or 'Milkweed floss' has a high lustre and is soft and pleasant to the touch. Yellowish white colour. good buoyancy. Too brittle to spin easily. Individual fibre has thick ridges running lengthwise, sometimes five in each fibre, which distinguish it from bombax cotton. Fibres are single cells, often 26mm (1 in) in length. Small amount of lignin and much oily material.

USES: Substitute for kapok in lifebuoys, etc. Upholstery padding.

10. Calotropis Floss ('Akund')

SOURCE: *Calotropis gigantea* and *C. procera*. Indigenous to Southern Asia and Africa. Cultivated in South America and West Indies. Seed floss harvested by hand.

CHARACTERISTICS: Yellowish floss. Individual fibres are thin-walled cells. Up to 32mm (1¼in) long.

USES: Upholstery stuffing.

11. Cattail Fibre (Typhaceae)

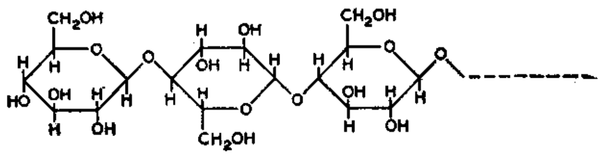
SOURCE: *Typha latifolia* and *T. angustifolia* (Cattails). Indigenous to many regions of America. Fibres separated mechanically from gathered spikes.

CHARACTERISTICS: Delicate, soft fibre. Greyish colour. Good sound and heat insulation. Buoyant and very light. Individual fibres up to 26mm (1 in). Attached to one another like parachute strings. Fibres round in cross-section. High lignin content makes them brittle.

USES: Substitute for kapok in life jackets, etc. Heat and sound insulation.

TECHNICAL NOTE

Cellulose, the basis of all plant fibres, is a substance of empirical formula $(C_6H_{10}O_5)_n$. It is a polymeric material formed by condensation of glucose molecules in the following way:—



The molecular weight of cellulose appears to vary widely, depending on its source. Cellulose from cotton has been quoted as M.W. 200,000 to 400,000, and cellulose from ramie at 240,000 to 320,000. There are probably between 2,000 and 3,000 glucose residues in the molecule. Some estimates put the figure even higher; cotton cellulose may contain as many as 10,000 glucose residues per molecule.

Micelles; Fibrils

The long, thread-like cellulose molecule is the basic unit from which natural plant fibres are constructed. The association of cellulose molecules takes place in stepwise groupings, fibre-like bodies of increasing size building up into the comparatively massive structure of the fibre itself.

The cellulose molecule is able to align itself alongside neighbouring molecules in such a way that molecular bundles are held together by natural cohesive forces. This alignment or orientation of the cellulose molecules in a regularized fashion confers crystalline properties on the tiny groups of molecules, or micelles.

In a plant fibre, the micelles align themselves together to form micro-fibrils. These sub-microscopic filaments, formed from chains of micelles, are in turn constructional units which align and orientate themselves to form fibrils. The electron microscope enables us to 'see' how these fibrils of cellulose are built up to form the fibre itself. In cotton, for example, the fibrils are laid down in a spiral fashion inside the massive secondary wall of the fibre.

Crystalline-Amorphous Structure

According to modern theories of cellulose fibre structure, the long cellulose molecules can individually form part of two or more crystalline regions. These ordered regions are thus held together by cellulose molecules which run from one crystalline region to another. Between the crystalline regions the cellulose molecules are arranged in random fashion, forming regions of amorphous cellulose.

The relative amounts of crystalline and amorphous cellulose have an important influence on the properties of the cellulose fibre. Water is able to penetrate easily between the molecules in the amorphous region, for example, whereas it finds difficulty in entering the close-packed crystalline micelles. Dyestuffs and other substances will tend to favour the regions of amorphous cellulose, leaving the interior of the micelle untouched. Reactions such as acetylation take place more rapidly in cotton than in the more highly orientated flax or ramie. The reagents cannot penetrate so easily into the latter.

Estimates of the proportion of crystalline cellulose in different fibres are difficult to make with accuracy. It is believed that ramie fibre has only a small proportion of random amorphous cellulose, possibly about 5 per cent. Cotton has 5–15 per cent. Other estimates put the proportions of amorphous cellulose very much higher.

Orientation Pattern

The arrangement of the micelles, microfibrils and fibrils with respect to the fibre itself are complicated. In flax and ramie, the micelles are probably orientated almost parallel to the long fibre axis. In cotton, they take up their spiral form.

The pattern of orientation of the molecular bundles has an important bearing on the strength and extensibility of the fibre. The more perfect the orientation, the less extensibility the fibre will show. The micelles are able to hold tightly together, and there will be little 'give' before the fibre ruptures. The mutual grip of the micelles will, however, confer great tensile strength.

If the degree of orientation of the micelles or fibrils is low, a pull on the fibre will tend to align the micelles more accurately. The movement of the micelles as they swing into line confers a high degree of extensibility on the fibre. The tensile strength, on the other hand will be lower than that of a fibre in which orientation is high.

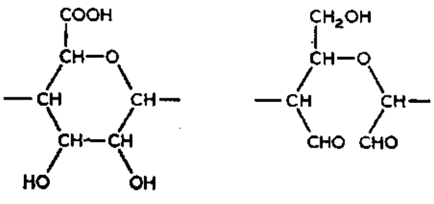
Chemical Reactions of Cellulose

Cellulose is an active chemical, with three hydroxyl groups attached to each glucose residue. Those in the 2 and 3 positions behave as secondary alcohols; the hydroxyl in the 6 position acts as a primary alcohol.

These hydroxyl groups take part in normal chemical reactions, and a great number of cellulose esters and ethers have been made. Some, like cellulose nitrate, are of immense commercial importance.

The chain of atoms forming the cellulose molecule can be broken by chemical attack. Acid hydrolysis produces hydro-celluloses.

Oxidation of cellulose gives rise to oxycelluloses. These are of two types.



(a) (b)

(*a*) The acidic type of oxycellulose is formed by alkaline oxidizing agents which attack the carbon atoms in the 6 position on the glucose residues. The alcohol group is oxidized first to aldehyde and then to acid.

(*b*) The reducing type of oxycellulose, in which cleavage of the ring takes place between the carbon atoms in the 2 and 3 positions.