CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

With the improvement in life style and economic conditions, consumers today are much more quality conscious than before. They prefer less clothing but of high quality. These aesthetic characteristics of clothing have become the primary consideration in determining serviceability of apparel fabrics. Normally, fabric appearance is determined from several traditional attributes like wrinkle, crease, texture, pilling, color and drape characteristics.(26)

Textile fabrics experience various mechanical effects in the dry and wet state because of their application areas. As result of these effects fibers and yarns of fabrics worn in the course of time, show changes in appearance and touch of fabrics.(40)

The Indian fashion industry has experienced significant expansion in the last decade mainly driven by the growth of domestic designers, some of whom have gained international recognition in recent years. The growth of the indian fashion industry is highlighted by the increase in the number of large fashion events.(42)

With the development of new technology, domestic and overseas market has been developed a variety of new functional fibers. These functional new materials are not only to fill the demand of the traditional textile industry and also improve our quality of life, to meet the requirement of textiles environmental protection, comfort, health and functional.(231)

2.2 The history of textiles

Textiles are made of perishable materials and only survive the millennia when preserved under exceptional circumstances such as the felts discovered buried in the permafrost of Noin Ula in Mongolia which date from around the 4th century BC, or the weavings found in the pre-Columbian tombs preserved by the dry air of the Peruvian coast. However, much has been learned from written sources and even from ancient carvings and artifacts. Egyptian tombs contain paintings of spinning and the weaving of linen while, in the Odyssey, the Greek poet Homer describes how Penelope, the hero’s wife, evaded the
attentions of her unwelcome suitors by weaving a large and delicate shroud for her father-in-law. Laertes, a scene illustrated on a 5th century BC vase. The story of the development of textiles is therefore largely a yarn spun from deduction and conjecture rather than hard evidence. Archeological finds, though, point to a high level of skill and sophistication at an astoundingly early date\textsuperscript{(122)}.

2.3 The first fabric

One of the most basic needs of mankind is protection from the elements. Early hunters utilized the skins of animals they had killed for food. The excavation of Neolithic sites has yielded evidence that tools were used to scrape the hides clean and that needles made from bone slivers were used to sew them together. The first prestigious garments were probably the skins of rare or dangerous animals worn by daring hunters. In many northern regions, such as amongst the Inuit of the Northern Territories of Canada, skins are still the preferred mode of dress since a satisfactory substitute for the insulation they provide against the cold and damp has never been found\textsuperscript{(105)}.

In some tropical regions, such as Fiji, Samoa and Central Africa, an alternative to leather was acquired by stripping the inner bark off certain trees and beating it until it became soft and flexible. A similar material—felt—was developed by pastoral communities who were inspired by the matted coats of sheep and goats\textsuperscript{(31)}.

As the craft of basket making became more and more refined, it became feasible, with twining and interlacing, to employ an enormous variety of animal or plant fibers in the construction of flexible fabrics. Experimentation by succeeding generations also saw the development of techniques to make more flexible fibers and the invention of spinning which was used in different parts of the world to make yarn from wool, linen, cotton and silk\textsuperscript{(76)}.

2.4 Cellulose

Cellulose is the most abundant biopolymer on earth, with an annual production of $10^{11}$ to $10^{12}$ tones\textsuperscript{(31,115)} and is of particular interest in providing renewable, sustainable, biodegradable biopolymers for industrial applications. Cellulose is a linear 1, 4-b-glucan polymer where the units are able to form highly ordered structures, as a result of
extensive interaction through intra- and intermolecular hydrogen bonding of the three hydroxyl groups in each cellulose unit. Currently, the main challenge for industrial applications of cellulose is the development of economical and environmentally friendly chemical processing \(^{(31)}\).

The use of natural cellulose-based fibers for the development of bio-functional materials has recently gained considerable attention, as emphasized by numerous reviews \(^{(181)}\). Cellulose fibres have been applied as an ideal matrix for the design of bioactive, biocompatible, and intelligent materials that can be further expanded or improved for existing applications \(^{(208)}\).

**2.5 Cotton fiber**

**2.5.1 Introduction**

Today cotton is the most used textile fiber in the world. Its current market share is 56 percent for all fibers used for apparel and home furnishings and it is sold in the United States. Another contribution is attributed to nonwoven textiles and personal care items. It is generally recognized that most consumers prefer cotton personal care items to those containing synthetic fibers. World textile fiber consumption in 1998 was approximately 45 million tons. Of this total, cotton represented approximately 20 million tons \(^{(122)}\). The earliest evidence of using cotton is from India and the date assigned to this fabric is 3000 B.C. There were also excavations of cotton fabrics of comparable age in South America. Cotton cultivation first spread from India to Egypt, China and the South Pacific. Cotton plant (plate 2.1) belongs to the natural order of the Malvaceae or the Mallow family \(^{(41)}\).

**Plate 2.1 Cotton plant**
Cotton in its pure form and with blends is the principal textile fiber of the universe and is one of the world’s most socially vital and economically important agricultural cash crops. Millions of people depend on cotton cultivation because it meets the basic necessity of mankind and is known for its diversity, enormous utility, applicability, economic viability and advantageous properties\(^{(105)}\).

### 2.5.2 History of cotton

Cotton was used for clothing in Peru and Mexico perhaps as long as 5,000 years ago. Also, cotton was grown, spun and woven in ancient India, China, Egypt and Pakistan around 3000 B.C. The history of cotton, which is also referred to as “White Gold”.

Cotton belongs to the genus gossypium. It is a native of the tropical and subtropical regions and it has a large number of species found all over the world now. The seeds of the cotton plant have a clump of soft fiber around them that are referred to as bolls. The boll opens about 48 days after the bud forms and it may be picked two days after it has cracked. The separation of hairs from the seed is carried out by a process termed “ginning”\(^{(133)}\). This fiber is spun into yarn that can then be used to spin cotton cloth, very comfortable for warm tropical climates. From its humble beginnings in ancient civilizations, cotton has spawned an industry that occupies an important place in the world economy today.

Cotton is also called as fabric of India since it has played a very important role in the lives of Indians. India holds the largest area of 8 m ha under cotton cultivation and ranked third in world’s cotton production, next to China and USA and second largest consumer of cotton. Majority of cotton grown commercially in the world is white lint but in recent years the color linted cotton has gained popularity\(^{(105)}\).

The cotton industry has always striven to increase productivity and efficiency in order to meet demands and maximize profits. As the job of creating yarn from cotton fibres has progressed to the modern age\(^{(208)}\).

Cotton fiber is distinguished for its comfort properties. Although in the past this fiber was said to be common man’s fiber, today the situation is much different. The cost of this fiber has increased tremendously and also the relative cost of synthetic fibers, mainly
polyester, has gone down. Due to the increasing awareness of environmental damage and requirement of ecofriendly processing, the new trend of producing “Organic Cotton”, is setting in. Such cotton does not make use of synthetic organic fertilizers, fungicides, herbicides and insecticides. Demand for such eco-cotton is increasing in countries like Germany, Switzerland, U.S.A. and European countries\(^{(205)}\).

Besides sustaining the country’s textile industry, it earns precious foreign exchange by way of export both yarn as well as finished goods. Further, more cultivation of naturally color linted cotton on commercial scale not only forms an income generating activity for cotton cultivators, but also a source of livelihood for local spinners and weavers, thus positively supports the socioeconomic status of the handloom weavers, the neglected sector of the weavers community. Generally color linted cotton is short staple, with low fiber strength compared to white cotton. Hence, it may be difficult to spin the color cotton to finer counts to produce quality yarn with absolute uniformity\(^{(105)}\).

2.5.3 Raw cotton components

The over-all contents are broken down into the following components and they are shown in table 2.1.

**Table 2.1 Raw cotton components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>80-90%</td>
</tr>
<tr>
<td>Moisture</td>
<td>6-8%</td>
</tr>
<tr>
<td>Waxes and fats</td>
<td>0.5 – 1%</td>
</tr>
<tr>
<td>Proteins</td>
<td>0 - 1.5%</td>
</tr>
<tr>
<td>Hemicelluloses and pectins</td>
<td>4 - 6%</td>
</tr>
<tr>
<td>Ash</td>
<td>1 - 1.8%</td>
</tr>
</tbody>
</table>

Cellulose, in cotton, is a polymer consisting of anhydroglucose units connected with 1, 4 oxygen bridges in the beta position. The hydroxyl groups on the cellulose units enable hydrogen bonding between two adjacent polymer chains. The degree of polymerization of
cotton is 9,000-15,000. Cellulose shows approximately 66% crystallinity, which can be determined by X-ray diffraction, infrared spectroscopy and density methods.

Each crystal unit consists of five chains of anhydroglucose units, parallel to the fibril axis. One chain is located at each of the corners of the cell and one runs through the center of the cell. The dimensions of the cell area = 0.835nm, b = 1.03 nm and c = 0.79 nm. The angle between ab and bc planes is 84º for normal cellulose I (105).

2.5.4 Repeat unit of cellulose in cotton.

The current consensus regarding cellulose crystallinity (X-ray diffraction) is that fibers are essentially 100% crystalline, and that very small crystalline units imperfectly packed together cause the observed disorder.

The density method used to determine cellulose crystallinity is based on the density gradient column, where two solvents of different densities are partially mixed. Degree of crystallinity is then determined from the density of the sample, while densities of crystalline and amorphous cellulose forms are known 1.505 and 1.556 respectively. Orientation of untreated cotton fiber is poor because the crystallites are contained in the micro fibrils of the secondary wall oriented in the steep spiral (25-30º) to the fiber axis (208).

The basic material of cotton is cellulose, having an empirical formula (C₆H₁₀O₅)ₙ and the chemical structure is shown in figure 2.1 (41).

![Figure 2.1 Structure of cellulose](image)
2.5.5 Structure and properties of cotton fibers

The botanical name of American upland cotton is Gossypium Hirsutum and it was developed from cottons of Central America. Upland varieties represent approximately 97% of U.S. production \(^{(105)}\). The crystalline orientations in cotton fiber have been shown in figure 2.2. Each cotton fiber is composed of concentric layers. The cuticle layer on the fiber itself is separable from the fiber and it consists of wax and pectin materials. The primary wall, the most peripheral layer of the fiber, is composed of cellulosic crystalline fibrils \(^{(61)}\).

The secondary wall of the fiber consists of three distinct layers. All three layers of the secondary wall include closely packed parallel fibrils with spiral winding of 25-35° and they represent the majority of cellulose within the fiber. The innermost part of cotton fiber-the lumen- is composed of the remains of the cell contents. Before boll opening, the lumen is filled with liquid containing the cell nucleus and protoplasm. The twists and convolutions of the dried fiber are due to the removal of this liquid. The cross section of the fiber is bean-shaped, swelling almost round when moisture absorption takes place.

![Figure 2.2 Crystalline orientations in cotton fiber](image)

2.5.6 Common properties of cotton fiber

- Cotton is non-allergic since it does not irritate sensitive skin or cause allergies.
- Cotton’s softness makes it a preferred fabric for underwear and other garments worn close to the skin.

- Cotton’s adaptability allows it to blend easily with most other fibers including synthetics such as polyester and lycra.

- Cotton is one of the easiest fabrics to dye, making it very popular with fashion and home ware designers.

- The three basic cotton weaves are Plain (gingham, percales, chambray, batistes and many other fabrics), Twill (denim, gabardine, herringbone and ticking) and Satin (cotton sateen).

- Cotton can be given a coating or a finish. Cotton used in fire fighting uniforms is coated and finished with Proban®, a flame-retardant chemical treatment.

- Durable press (sometimes called permanent press) is a finishing treatment used in cotton garments to eliminate creasing and this reduces the need to iron. It retains specific contours such as creases and pleats to be resistant to normal usage, washing or dry cleaning.

- Cotton has a high absorbency rate and holds up to 27 times its own weight in water \(^{(151)}\).

- Cotton also becomes stronger when wet.

- Cotton’s strength and absorbency levels make it an ideal fabric for medical and personal hygiene products such as bandages and swabs.

- Terry cloth is a cotton fabric used to make common items such as towels. It can be safely washed in very hot water and with strong bleach and/or detergent.

- Cotton keeps the body cool in summer and warm in winter because it is a good conductor of heat.

- Cotton is often used in the manufacture of curtains, tents and tarpaulins as it is not easily damaged by sunlight.
• Cotton breathes easily as a result of its unique fiber structure. This attribute makes cotton more comfortable to wear than artificial fibers which are unable to provide similar ventilation.

• Unlike synthetic fibers, cotton is a natural product and contains no chemicals

2.5.7 Chemical properties of cotton fiber

Cotton swells in a high humidity environment, in water and in concentrated solutions of certain acids, salts and bases. The swelling effect is usually attributed to the absorption of highly hydrated ions. The moisture regain for cotton is about 7.1~8.5% and the moisture absorption is 7~8% (30).

Cotton is attacked by hot dilute or cold concentrated acid solutions. Acid hydrolysis of cellulose produces hydro-celluloses. Cold weak acids do not affect it. The fibers show excellent resistance to alkalis. There are a few other solvents that will dissolve cotton completely. One of them is a copper complex of cupramonium hydroxide and cupriethylene diamine.

Cotton degradation is usually attributed to oxidation, hydrolysis or both. Oxidation of cellulose can lead to two types of so-called oxy-cellulose, depending on the environment in which the oxidation takes place.

The effects of desizing, scouring, kiering and bleaching on the removal of impurities from cotton fabrics and on fabric properties especially whiteness and hydrophilicity were discussed (137).

An X-ray diffractometer was used to study the crystalline structure of cotton fibers after bleaching, cross linking and a combination of bleaching and cross linking treatments (151). Wet cross linking was accomplished with formaldehyde (Form W) and dry cross linking was carried out with either dimethyloldihydroxyethylenurea (DMDHEU) or citric acid (CA). The results indicated that cross linking of bleached cotton did not change the crystalline nature of cotton (i.e. it was Cellulose I), but it did increase its degree of crystallinity when
cross linked with either DMDHEU or CA; cross linked formaldehyde (Form W) was relatively less crystalline.

Majority of natural dyes need a chemical in the form of metal salt to create an affinity between the fiber and the pigment. These chemicals are known as mordants. Some of the commonly used mordants are alum, potassium dichromate, ferrous sulphate, copper sulphate, stannous chloride and stannic chloride. Treatment of cotton with tannin, either natural or synthetic, introduces additional hydroxyl and carboxyl groups on the fiber matrix. This tannin-metal complex creates affinity on cotton for the natural dye (127).

2.6 Application of dyestuffs in cotton dyeing

Cotton has become one of the versatile textile fibers of the world and now it ranks alongside wool and silk as the three great sources of clothing material to meet the needs of the human race. At the earlier stage, dyeing of cotton was employed with the vegetable dyes. Basic colors and acid colors were adopted only to wool and silk, and they were found less application to cotton. When the benzidine or direct colors were introduced, a new field in cotton dyeing was opened up and the widespread use of dyed materials was much stimulated. Because of the poor fastness property, introduction of aniline black as a specialized feature in cotton dyeing greatly helped to extend the use of dyed cotton materials by providing an extremely fast color. The later introduction of various sulphur dyes also stimulated the use of cotton material by providing a number of fast shades (41). With the advent of the so-called vat dyes, which permitted the production of cotton of a wide range of beautiful shades of the highest possible qualities. Vat dyes are special class of dyes that work with a special chemistry, especially on cellulosic fibers.

Over the decades there have been several papers on the coloration of cotton based textiles. The number of articles dealing with the processing of cotton, including preparation, dyeing and finishing, may be in thousands. An investigation into the possible causes of problems occurring in the coloration of textiles revealed that a comprehensive review of case studies and scientific analysis would be a welcome addition to the already rich pool of knowledge in this area (184).
In the present scenario of environmental consciousness, the new quality requirements not only emphasize on the intrinsic functionality and long service life of the product but also a production process that is environment-friendly. A comprehensive review on natural product based on bioactive agents such as chitosan, natural dyes, neem extract and other herbal products for antimicrobial finishing of textile substrates. The major challenges and future potential of application of natural products on textiles have also been critically reviewed (103).

2.7 Growing demand for blends in apparel market

The accepted definition of a blend, as stated by ASTM, is a single yarn spun from a blend or mixture of different fiber species. Blending is a complicated and expensive process, but it makes it possible to build in a combination of properties that are permanent. Not only are blend used for better serviceability of fabrics but they are also used for improved appearance and hand. In the following chart, some fabric properties are rated. Notice that each fiber is deficient in one or more important property. Blends of synthetic fibers with natural fibers offer the most valuable possibilities for combining desirable physical properties, because the two components are so dissimilar. In blends of polyester or acrylic fibers with cotton or viscose the synthetic component provides crease recovery, dimensional stability, tensile strength and abrasion resistance, whilst the cellulosic fibres contributes moisture absorption, antistatic characteristics and reduced pilling. Different fibers can be blended in textile structures to obtain the desirable properties of each of the fibers in the blend. A blended yarn or fabric generally displays an averaging of the properties of the constituent fibers. A cotton / polyester blend has higher wrinkle recovery than a 100% cotton fabric, but lower recovery than all polyester fabric. The blend level, used to describe textile blends is the percentage by weight of each fiber in the blend (126).

The textile industry in India including the garment industry contributes to over 6% of the Gross Domestic Product (GDP) of India and earns 18% of the total foreign exchange earnings of the country. The garment industry in India is a $23 billion industry and produces over 100 varieties of garments for different end uses. Out of total 3052 million kg production of yarn in the year 2003-04, blended yarn production was 589 million kg. As far as production of fabric in 2003-04 is concerned, blended fabric was 6068 million square meter out of total production of 42383 million square meter (22). The term ‘blending’ is used by the
yarn manufacturer to describe specifically the sequence of processes required to convert two or more kinds of staple fibers into a single yarn composed of an intimate mixture of the component fibers. This is necessary to obtain a uniform yarn from different varieties of the same fibrous polymer.

Native cotton of the Gossypium hirsutum stock still dominates the lion share of the natural fibre for fabric manufacture today, constituting about 89.8% of all fibre production world wide. The processing of this cotton fibre for outer garment, either as standalone or in blend with other fibers\(^{(220)}\).

2.8 Importance of fiber blends in apparels

The reasons for development of blends\(^{(126)}\) are

**Economy:** Economic reasons expensive fibers can be extended by blending them with more plentiful fibers like Cashmere and Wool.

**Durability:** To produce fabrics with a better combination of performance characteristics in the product. This is perhaps the most important reason for blending. In end uses where durability is very important, nylon or polyester blended with cotton or wool provide strength and resistance to abrasion while the wool or cotton look is maintained. In durable press garments, where 100 percent cotton fabrics are not as durable as polyester / cotton.

**Physical properties:** To obtain better hand, or fabric appearance. A small amount of speciality wool may be used to give a buttery or slick hand to wool fabrics, or a small amount of rayon may give luster and softness to a cotton fabric. Fabrics with different shrinkage properties are blended to produce bulky and lofty fabrics or fur-like fabrics.

**Color:** To obtain cross-dyed effects or create new color effects such as heather, when fibers with unlike dye affinity are blended together and then piece dyed.

**Appearance:** To improve spinning, weaving finishing efficiency for uniformity of product as with self-blends of natural fibers to improve uniformity.
2.9 Modal

Modal® is currently called the new "wonder" fabric. Modal is a bio-based fiber made by spinning reconstituted cellulose from Beech trees. It is about 50% more hygroscopic per unit volume than cotton. It has a unique nanofibril structure. It absorbs excess liquid and quickly releases it again into the atmosphere, and so it provides natural hygiene. This fabric combines the benefits of natural fiber and the fantastically soft feel of modern microforms. Modal fiber is commonly blended with cotton as the cross fiber is similar. Modal can be used for toweling, bathrobes, clothing, bed clothes, underwear and furnishings. Textiles made from modal do not fibrillate, or pill, like cotton does, and are resistant to shrinkage and fading. They are smooth and soft, more than even mercerized cotton, to the point where mineral deposits from hard water, such as lime, do not stick to the fabric surface.

Modal is considered a type of rayon. While rayon may be made of the wood pulp of a number of different trees, modal uses only beech wood (plate 2.2 and 2.3). Modal is considered bio-based rather than natural because, though the raw materials used to make it are natural, they are heavily processed using a number of chemicals. Like other types of rayon, originally marketed as “artificial silk”, modal is soft, smooth and breathes well. Its texture is similar to that of cotton or silk. It is cool to the touch and very absorbent. Like cotton, modal dyes easily and becomes colorfast after submersion in warm water.

Plate 2.2 Modal raw material
Both two fibers’s based cellulosic and being natural presents 100% naturalness. Modal fiber’s gentle, comfortable handle, lustrous and high wet and dry tensile strength fastness values formed in yarn features with cotton fiber’s known characteristics. Modal and cotton fibers’ color fastness resembles to provide uniform appearance on produced yarn. Modal/cotton blends produce depend on field of use and required features. Cotton fiber can mix in open end too (244)

2.9.1 Fields of use

Modal is preferred, where comfort and aesthetics, brightness and naturalness are demanded. Some of the fields of use are presented as follows (244)

• T-Shirts
• Socks
• Sports Wear
• Other woven and knitted products
• Bed sheets
• Underwear
• Towels and Bathrobes

Modal® is a fine, smooth fiber made from beech trees. An Austrian company, Lenzing, creates Modal® by turning beech wood into pulp, extracting the fiber, and then reconstituting the fiber so that it can be spun into yarn. Modal® is an all-natural fiber, and the beech wood used in Modal® production is from sustainable forestry plantations growing
native trees. The byproducts of the manufacturing process are used in other industry applications such as leftover wood sugar from processing is used in the manufacture of artificial sweeteners.

The Modal® fibers are extremely smooth and soft, and blending them with cotton helps the yarn to stay soft and vibrantly colored, even after many washes. Shine Sport and Shine Worsted each contain 40% Modal® in their cotton blend, and it’s this fiber that gives them their namesake “shine” and silky texture\textsuperscript{(245)}.

2.9.2 Structure

The “all skin” high tenacity yarns consists of finer and more uniform texture. When coagulation and stretch occur together, before regenerate and crystallization of cellulose, structure has a fibrillar texture (figure 2.3). The cross section is either circular or bean shaped\textsuperscript{(238)}.

![Figure 2.3 Microscopic view of modal fiber](image)

2.9.3 Weaving

2.9.3.1 Introduction

Weaving is probably as old as human civilization, one of the basic necessities of human is to cover their bodies to protect themselves from outside effects hot and cold and look more “Civilized” to the eye, the manner in which the wrap prepared is known as the “Weave”. The three basic weaves are plain weave, stain weave and twill weave and the majority of woven products are created with one of these weaves\textsuperscript{(173)}. 

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A weaving consists of vertical warp fibers and horizontal weft fibers that are interconnected on a loom to form a fabric. Each warp thread is connected to exactly one harness in the loom (227). The harnesses are connected in a pattern to treadles. Pressing a treadle raises a set of harnesses, lifting the associated warp threads. A weft thread is then passed horizontally through the loom. The particular set of harnesses that are raised determines which warp threads are in front of the weft thread and which are behind. For the next weft thread, a different treadle is pressed, raising a different set of harnesses and a different set of warp threads (27).

2.9.3.2 Plain weave

The plain weave is sometimes referred to as the tabby, homespun, or taffeta weave. It is the simplest type of construction and is consequently inexpensive to produce. There is a wide variety of fabrics made of the plain weave constructed from every type of yarn composed of every kind of fiber. Plain weave fabrics range in weight and compactness from thin light weight to compact heavy weights (36).

Plain weave fabrics that are not printed or give a surface finish have no right or wrong side. They do not ravel easily but to wrinkle and have less absorbency than other weaves (236). Each warp yarn goes alternately over and under each weft yarn (69).

Plain weave is characterized by a regular interlocking of warp and weft yarns in a 1/1 order. That is, each weft yarn moves alternately over and under adjustment warp ends, and the sequences is reversed for the alternate weft shots because of the simple respective nature of the plain weave variety comes from the choice and rotations of the colors and features as well as through yarn size and character, beating. All other weave have additional options to provide interest and variety from threading pattern and treading sequences. Two shafts are sufficient to create plain weave (189).

2.9.4 Knitting

2.9.4.1 Introduction

Knitting is a process of manufacturing a fabric by the intermeshing of loops of yarns. When the loop is drawn through the another loop a stitch is formed (176). Knitting is more flexible then weaving. Styles and designs can be changed with unparalleled rapidly (12).
Knitted fabrics are composed of rows of loops with each row caught into the row previously formed. It is due to the ability of these loops to stretch when pulled by a stress (118). Knitting as a method of constructing yarns to fabric that begins with the bending or curving of the yarn into either warp or weft loops (167).

Knitted fabrics are formed by intermeshing loops of single yarn or set of yarn together. Knitted clothing adopts itself to the changing shape of the moving body. It comfort is remarkably superior to the relatively rigid woven fabric structure (228). Knit fabrics are very desirable because do not wrinkle easily, shape to the body without binding are elastic and porous, yet light and warm (90).

Knitting is used to produce garments that covers the human body with a wide range of garment types from socks, caps, gloves, underwear to upper T-shirts and jackets (52). Knits are an important part of every wardrobe because of its comfortness to wear and easy to care for. These fabric consists of a structure formed by interlocking loops of yarn (183).

Knitting is a method of converting yarn into fabric by intermeshing loops, which are formed with the help of needles. Knitted technology is more flexible than weaving technology and hence can give quick response to changes in apparel market. It is the method of creating by fabric by transforming continuous strands of yarn into a series of interlocking loops. There are two basic forms of knitting technology such as warp and weft knitting (240).

Knitted goods are capable of stretching in one or both directions and of recovering form this deformation. The porosity of knit fabric makes them both absorbent and easily washable (53). Knitting is a process in which one or more yarns are form in to a series of interlocking loops. Knitting is the art of constructing fabric by intermeshing the yarn loops by some knitting elements (221).

Popularity of knitted fabrics has grown tremendously in recent years because of the increased versatility of techniques, the adaptability of many new manmade fibres and the growth in consumer demand for wrinkle resistant, stretchable, particularly in the greatly expanding areas of sportswear, other casual wear apparel & even in application like medical or construction textiles (148).
2.9.4.2 Methods of knitting

Knitting is a process of manufacturing a fabric by the intermeshing of loops of yarns. When one loop is drawn through the another loop a stitch is formed. The two main form of knitting technology are weft knitting and warp knitting (228).

Weft knitting: Weft knitting is a method of forming a fabric. Knitting means in which the loops are made in horizontal way from a single yarn. Intermeshing of loops take place in a circular or flat form on a crosswise basis. In this method one or more yarns are being fed one at a time to a multiplicity of knitting needles placed in either lateral or circular fashion. Most of the weft knitted structures comes out in a tubular form (196).

Weft knitting is the process of making a fabric by forming a set of connected loops from weft yarn inserted into successive rows across the width of the fabric (69). The essential features is that the yarn is introduced in a weft wise direction, at right angles to the direction of growth of the fabric. Weft knitted fabrics can be produced in either flat or tubular form. It is generally highly elastic and highly drapable, these two attributes, make it suitable for a wide range of apparel application (159).

Weft knitting the loop course is formed either consecutively loop after loop or by alternation of one or several yarn system in the direction of the yarn course (117). Weft knitting is produced by yarn fed to a series of needles in a crosswise or weft direction (198).

Weft knitted fabrics offer plenty of movements and flexibility. It needs less preparatory process and thus cheaper to produce (50). Weft knitted fabric is porous and comfortable both for outer garments and under garments. The yarn may be fed as to traverse back and forth across the fabric or it may be fed continually in the same direction, giving rise to a tubular fabric (29).

2.9.4.3 Weft knitting techniques

Weft knitting is a method of creating a fabric by interlocking of loops in a filling wise of weft direction, weft knits accounts for approximately eighty to eighty five percentage of all the knitted fabrics produced.
Three primary structures of weft knitting techniques are single jersey, rib and interlock. These are the base structures from which all weft knitted fabrics are derived. Each is composed of a different combination of face reverse meshed stitches knitted on a particular arrangement of needle beds (183).

2.9.4.4 RIB knit structure

Rib is a reversible structure, face and back side has the same appearance. This appearance shows vertical cords and thin ridges in between. Rib fabrics are balanced structures because of alternative number of face and reverse wales on each side (116).

Rib is balanced by alternative wales of face loops in each side. It is therefore lies flat without curl when cut. It is more expensive to produce than plain and is heavier structure (193). A fabric in which both front and back loops occur along the course, but all the loops contained with in any wales are of the same types (10).

A rib structure implies a weft knitted fabric with face and back loops occurring in the course but not in the same wale. These fabrics can be produced on V-bed flat machines and circular machines, where one set of needles draw new loops on the face of the fabric and other at the back side of the structure (183).

The opposition of the face and back loops cancels the unbalanced forces that produce edge curling, and this property together with high widthwise extension and recover, accounts for the use of this type of structure in ribs and cuffs, where good fit to the body is required. Apart from 1x1 rib, the most commonly used rib structures are 2x2 or Swiss rib in body blanks, and 6x3 rib in socks. Rib construction is costlier because of the greater amount of yarns needed (204).

Rib is a double face or reversible fabric which is similar cord appearance on each side. It is thicker and heavier fabric. It unravels at the end knitted last (147).

2.10 Bioprocessing of cellulosic textiles

Enzymes used on cellulose are (39) as follows

- Amylases: to decompose starches in sizing preparations.
• Catalases: act on hydrogen peroxide to decompose it into water and oxygen.
• Protease, lipases and pectinases: combined act on proteins and natural waxes.
• Laccases: decompose indigo molecules for wash down effect on denim.
• Cellulases: breakdown cellulosic chains to remove protruding fibers by degradation and create wash-down effect by surface etching on denims, there are different processing phases in cellulose in which enzymes are used.

2.10.1 Bio-scouring and bleaching

The enzyme system for bio scouring consists of an optimized mixture of pectinases, protease and lipase, that act on pectins, proteins and waxy matters, to effect scouring of cotton fibers. Cotton fibers, on an average, contain up to 1% waxes, 5-6% pectins, proteins and 1% mineral matter, as primary impurities. Pectins can be broken down by pectinases, while lipase enzymes degrade waxy materials. The uniqueness of bio-scouring process lies in the fact that the conditions involved are so mild that it would perhaps be the most preferred option for processing of alkali sensitive cotton blends containing wool, silk \(^{(85)}\) or various regenerated cellulosic fibers.

The advantages of bio scouring
• Milder conditions of processing
• Less energy and water consumption
• No oxy-cellulose formation
• Less strength loss
• Uniform removal of waxes
• Uniform levelness in dyeing due to better dye uptake
• Highly suitable for scouring of blends of silk, wool, viscose, lyocell and lycra.
• Lower COD and BOD effluent loading
• Softer and fluffier fabric, ideal for terry towel/knitted goods.

2.10.2 Single stage bio-desizing and bio-scouring

The unified bio-desizing and bio-scouring process is based on amylase, protease, pectinases and lipase enzymes. This combination or enzyme formulation acts on starch, proteins, pectins and natural waxes to affect desizing and scouring simultaneously under mild conditions \(^{(63)}\).
2.10.3 Enzymatic scouring

Cotton fiber is made up of 86-94% cellulose and 6-14% non-cellulosic impurities. The amount of natural impurities present in it greatly depends on variety, territory, conditions of cultivation and ripeness at the time of harvest. These impurities cause water repellency, harsh unacceptable hand and yellowish appearance. Waxy materials are mainly responsible for the non-absorbent characteristics of raw cotton. Pectic substances present on the outer layer act as glue in binding of wax on the cotton fiber. Common industrial practices use sodium hydroxide to remove non-cellulosic materials. In this process, the individual non-cellulosic components are loosened from the fiber surface by hydrolysis in the alkaline condition. This traditional scouring process consumes large quantities of energy, water and also not ecofriendly. High level of pH and temperature used in the process damages the cellulose due to non-specific attack of alkali especially when performed in presence of oxygen. The outer layer of cellulose experience auto oxidation, which causes strength loss. Hence a scouring process carried out at a mild condition was required. It has led to a development of substrate specific, low water consuming and environmental friendly process, namely 'Enzymatic Scouring'. In this process, the non cellulotic impurities are removed by pectinolytic enzymes (pectinases) either with or without the support of other enzymes, namely, cellulases, xylanases and proteases \(^{(211)}\).

2.10.4 Bio-singeing

This method has been specifically developed to achieve a cleaner pile on terry towels. A treatment with Ultrazyme LF concentration, which is a powerful cellulase composition, gives a clear look to the pile, improved absorbency and softness. Fabrics containing regenerated cellulotic fibers often show fuzzy surface due to chafing during wet processing. A smooth and clear finish can be achieved by bio singeing \(^{(147)}\).

2.10.5 Bio-carbonizing

Dyed or printed polyester-cellulosic blends are often treated with a strong solution of sulphuric acid to dissolve the cellulosic component. The treated goods have a soft and fluffy feel. The process is risky due to use of highly corrosive acid. In bio-carbonizing process, the goods are treated with a cellulase enzyme based formulation Chemizyme UZ to achieve dissolution of cellulosic component. The goods are padded in a warm solution of this
formulation and batched on a roll under normal conditions and are washed off after 12-16 hours. This process offers an eco-friendly option to the obnoxious use of strong acids (37).

2.10.6 Bio-desizing

Sizing is done using polymeric materials to improve weavability of warp yarn. One of the most widely used sizing agents is starch. It can be removed by acid hydrolysis but this process has following disadvantages.

- Detrimental effect on strength of the cotton fabric
- Release of high amount of effluent.

Therefore, today, enzymatic hydrolysis is preferred over acid hydrolysis for ease of control and ecofriendliness. Earlier, the endogenous enzymes present in malt were used for desizing. More recently, fungal or bacterial amylases are employed. Bacterial amylases are particularly useful, since they can operate at fairly high temperature, are reasonably stable in the presence of alkali, and act at moderate pH optimum 5-7.5. A typical commercial preparation DemiPrime L (Novo Nordisk), used for desizing denim and other cotton fabrics, contains both that are active throughout the temperature range of 50-58 °C (47).

Desizing with enzyme treatment (α-amylase and lipase) is found to:

- Improve the removal of starch and triglycerol
- Give less risk of dye defects, a higher whiteness after scouring and bleaching
- Give a higher uptake of dye
- Give softening effect to the fabric.

2.10.7 Mercerization

Enzymatic mercerization processes are not widely studied. A comparative study of the effect of mercerizing with and without tension on the action of the acid and enzymatic hydrolysis has been undertaken. It was reported that the greater accessibility and lower crystallinity of cellulose mercerized without tension is a decisive factor in the enzymatic hydrolysis process. The effect and action of enzymes seems to be very limited because of the stronger conditions of alkali in mercerization process (24).
2.10.8 Bio-finishing / bio-polishing

The most widely used enzyme in finishing process involving cellulosic fiber is cellulase. This enzyme is used extensively in bio polishing of cellulosic fabrics to remove surface fibers and to promote softness of the consumer item. Cellulase acts on 1, 4 – β glucoside linkage. The effects obtained on fabric by cellulase treatments are:

- Smooth and soft feel
- Reduced pilling tendency
- Clear fabric surface with less fuzz
- High drapability
- Slight improvement in absorbency
- Fashionable effects on fabric like distressed look
- Increased flexibility, so improved sewability

Enzymatic bio-polishing can be carried out prior to or as subsequent process to dyeing. When carried out prior to dyeing, enzyme biopolishing boots dyeability. Enzymatic degradation of cellulose affects technological properties of fabric and requires precise interruption within the reaction. Enzymatic degradation of cellulose is also possible in the course of reactive dyeing. Here, the dyeing process is affected at the same time as the biofinish resulting in saving of time, energy and cost with the advantage of nap-free, smooth fabric surface.

Perhaps one of the most intriguing new uses for enzymes in finishing processes is that of enzymatically catalyzed cross-linking of cotton fiber. It is well known that lipases are used to catalyze the hydrolysis of lipids or fats, but it is not so well known that these enzymes can be made to work in reverse manner when no water is present. It is possible that suitable lipases or other enzymes can be found that will catalyze cross linking reactions between polybasic organic acids or other cross linking agents and cellulose to produce durable press fabrics having improved properties (143).

2.11 Technical textiles in environmental protection

Environmental threats loom large on almost every nation in the world today. With this threat gaining its status day by day, textiles gain utmost importance as one of the most useful resources that help promote new innovations, in an ecofriendly manner. The use of textiles in environment protection and safety is booming. Technical textiles plays very important role in the global issue like environment protection (45).
2.12  Dyes

A dye can generally be described as a colored substance that has an affinity to the substrate to which it is being applied. The dye is usually used as an aqueous solution and may require a mordant to improve the fastness of the dye on the fiber. Dyes are used for coloring the fabrics. Dyes are molecules which absorb and reflect light at specific wavelengths to give human eyes the sense of color\(^{(64)}\).

2.12.1 Classification of dyes

Natural dyes are again gaining interest due to increase in awareness about environmental protection and problems associated with synthetic dyes. This natural dyes have been an integral part of human life since time immemorial. This comprise of those colourants that are obtained from animal or vegetable matter without chemical processing\(^{(207)}\).

There are two major types of dyes - natural and synthetic dyes. The natural dyes are extracted from natural substances such as plants, animals, or minerals. Synthetic dyes are made in a laboratory. Chemicals are synthesized for making synthetic dyes. Some of the synthetic dyes contain metals too\(^{(16)}\).

2.12.1(I) Natural dyes

The natural dyes are obtained from animal, vegetable or mineral origin with no or very little processing. The greatest source of dyes has been the plant kingdom, notably roots, berries, barks, leaves and wood, but only a few have ever been used on a commercial scale.

i) Sources of natural dyes

The sources of natural dyes are broadly classified based on cultivation and collection. The natural sources cultivated are marigold, annatto and indigo. The collection of natural dyes are from cooperative stores and wholesale ayurvedic shops\(^{(206)}\).

Use of natural dyes on textile material has become very much popular throughout the world due to its eco-friendliness, ancient heritage and aesthetic approach. Since 1990, many researchers have been making enormous efforts to search new sources and different methods of applications with natural dyes\(^{(18)}\).
The importance of vegetable dyes has increased presently, with increased awareness about harmful effects of chemical dyes both in production and in its usage by human beings. In the light of these factors there is a very huge potential for vegetable dye and food colors, since all of them are extracted from natural sources and are having no harmful effects \(^{(96)}\). Different parts of plants, animal residues and some of the minerals are the sources of natural dyes. Vegetable source of natural dyes are renewable \(^{(101)}\). Pigments extracted from the roots of vegetable sources are mostly used for red dyes.

The organic cultivation of dye plants for the certified natural textile industry is as emerging and promising sector of organic farming \(^{(16)}\). Henna or Egyptian privet is the source of an ancient and very important yellow dye \(^{(64)}\). This dye has the rare distinction of being a dye whose use can be traced back to antiquity and which continues to be as commonly used all over the world today as it is in the ancient times \(^{(46)}\).

Turmeric is the most commonly used yellow dye (plate 2.4, 2.5 and 2.6) followed by harshingar (nyctanthes arbor-tristis) and palash (butea frondosa). Weld has been the most commonly used natural yellow color in europian countries \(^{(206)}\).

**Plate 2.4 Turmeric plant**  **Plate 2.5 Lime powder**  **Plate 2.6 Kum kum**

Natural kum kum powder, is traditionally made by mixing turmeric and lime. Coreopsis, goldenrod, onion skins give yellow color. Lilies, queen anne’s lace, rhododendrum give green color. For purples or lavenders the sources are blackberries and grapes \(^{(55)}\). Acrons, marigold, pomegranate give brown color. Lac is a unique dye material of animal origin being the secretion of tiny insect kema lacca \(^{(107)}\).
Most of the plant materials used for the extraction of dyes are also credited with medicinal properties, and are rich in napthoquinones (106). Black walnut (juglans nigra), pecan (carya illinocnsis), shagbark hickory (carya ovata mill). Nut hulls can be used to make a dye to color the textiles to a brown color, pecan and a red/orange (137).

Indigo is the most important blue component (Plate 2.7) in the class of natural dyes for cellulosic and protein fibers (100). Brown from tengar, bakau, obah, durina. Reddish brown from engkerbai psychutria viridiflora reinu, megkudu angsana. Yellow from the wood of asepong, bebaru, engkala burong, pedalai. Blue from tarum, indigofera. Purple from the pods of jering (62).

Teak plants are abundantly available in the forest of orissa, west Bengal and in many other states (134). Teak leaves are left as waste which can be utilized to get dye for textile industry. It is reported that the teak leaves contain 6% of tannin and also brownish red dye pigment in large quantity (11, 43).

Plate 2.7 Indigo plant, Indigo block and Indigo powder

Plate 2.8 Barberry tree
ii) Classification of natural dyes

Natural dyes are obtained either from animal, vegetable or mineral origin. Tyrine, kermes, cochineal are from animal sources. Roots, stems, barks, leaves, berries, flowers are from vegetable sources (199). Iron buffs, rust, copper belong to mineral sources, one other class which describes the role of natural dyes, rather than their mode of use is the categorization of mordant dyes and vat dyes which are basically anthroquinone and triphenyimethane constituents.

Natural dyes can be broadly classified as natural organic dyestuff or vegetable, animal origin and mineral dyestuff or inorganic pigments. The organic dyestuffs are obtained from roots, stems, leaves, berries and flowers by various plants and from certain insects and shellfish, with a very elaborate series of processes. The inorganic pigments are insoluble salts precipitated on fiber by suitable double decomposition (8).

Natural dyes are aesthetically appealing and to make the work less strenuous it has been traditionally divided into diverse groups and they are named accordingly to their specific function. These categories were known as rangraj the dyers, chipper the printer, khatri tand bandhej for tie and die work, majithia or guldraj for merchants dealing with madder and vermilion. All these dyes Concentrate on natural sourced dyes (104). Flavonoids which yield yellow dyes can be classified under flavones, flavonoils, iso-flavones, aurones and chalcones (217).

Based on the chemical nature it can be classified as

<table>
<thead>
<tr>
<th>Groups</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diarylomethane dyes</td>
<td>turmeric</td>
</tr>
<tr>
<td>Carotenoid dyes</td>
<td>saffron, annatto</td>
</tr>
<tr>
<td>Alkaloid dyes</td>
<td>barberry</td>
</tr>
<tr>
<td>Quinonoid dyes</td>
<td>dolu, henna</td>
</tr>
<tr>
<td>Flavonoid dyes</td>
<td>French, marigold</td>
</tr>
<tr>
<td>Flame of forest dyes</td>
<td>kamala, kaiphal</td>
</tr>
<tr>
<td>Benzoquinone dyes</td>
<td>kamala, kaiphal</td>
</tr>
<tr>
<td>Anthroquinone dyes</td>
<td>manjit, chay root.</td>
</tr>
</tbody>
</table>
Natural dyes are classified into two groups namely substantive and adjective dyes. The substantive dyes require no pretreatment to the fabric (Indigo, orchil and turmeric) the adjective dyes can only dye the material mordanted with metallic salts or with the addition of a metallic salt to the dye bath (Logwood, madder and cochineal), the substantive dye can be further classified as direct, acid and basic dyes \(^{(48, 146)}\).

The direct class of dyes can be directly applied on cotton which they get absorbed without any pretreatment to the dye or the fiber. Many natural dyes belong to this categorization (turmeric, safflower). The mordant dyes require application of some mordant for fixing onto the fiber. It can be applied before dyeing, during dyeing and after dyeing \(^{(66)}\). Now-a-days all those dyes which form a complex with mordants and have been included under this category (Indian barberry, onion). Then indigo (neel) - indigo tinctoria which is a vat dye that produces all shades of blue \(^{(99)}\).

Some investigators classify natural dyeing tanning materials into two categories - hydrolysable and condensed tannins. The hydrolysable tanning extracts yield water soluble products upon hydrolysis with acid or enzymes while condensed tanning extracts from precipitates known as tanners red or phlobaphene under these conditions. This classification corresponds mainly to groups based on flavone related components. Condensed tannins do not have much textile use.

a) Flavonol dyes

Flavonols are the hydroxylated flavones, which contain hydroxyl group at position – 3 and are widely distributed in the plant kingdom usually in the form of glycosides. The pigments of this group give yellow colors which are deeper than those obtained from flavones but they are not so fast to light, undoubtedly due to their great sensitivity to oxidation \(^{(214)}\). Some common botanicals that comes under flavonol group are weld, quercitron, fustic, osage, chamomile, tesu, dolu, marigold and cutch \(^{(9)}\).

b) Iso-quinoline dyes

Isoquinoline is a heterocyclic aromatic organic compound. It is a structural isomer of quinoline. Isoquinoline and quinoline are benzopyridines, which are composed of a benzene ring fused to a pyridine ring. Common botanical that comes under isoquinoline group is barberry \(^{(82, 111, 150)}\).
c) Chromene dyes

A dye group that gives yellow dye that independently represents hydrogen, halogen or an alkoxy group of 6 carbon atoms that independently represents cyano, esterified carboxy, amide, a substituted or unsubstituted benzoazole, or alkylsulfonfyl or may be taken together to form a pyrazolone, barbituric acid or meldrum's acid residue \(^{(17)}\). Common botanical that comes under chromene group is Kamala \(^{(9)}\).

d) Napthoquinone dyes

The majority of naphthalene derivatives found in nature are quinones and most of these are plant products. Naphthaquinones can exist in three isomeric forms and a group of closely related polyhydroxyl derivatives is found in certain species of sea urchin and a few others are elaborated by micro-organisms also. Some common botanicals that comes under naphthaquinone group are henna, walnut, alkanet and pitti \(^{(9)}\).

e) Anthroquinone dyes

Anthroquinone as such is not found in nature, although it had been prepared by laurent as early in 1835 by oxidation of anthracene with nitric acid. The term ‘anthra’ refers to the greek word for coal from which anthracene was originally obtained. Anthraquinone is one of the most valuable intermediates in the manufacture of dyestuffs. It comprises of a greater number of dyes having outstanding fastness properties than any other group of dyes \(^{(32)}\). Some common botanicals that come under napthaquinone group are lac, cochineal, madder \(^{(9)}\).

f) Benzoquinone dyes

The benzoquinone dye-carathamin is a red dye extracted from flowers of safflower (carathamus tinctorius). This group is isolated from the flowers that contain principally two matters, carathamin, which is sarlet red and insoluable in water and safflower yellow which is soluable in water. It gives cherry red color to cotton, silk and wool \(^{(109)}\).

g) Indigoid dyes

Chemically indican is indoxyl D-glucoside having molecular formula C\(_{14}\)H\(_{17}\)NO\(_6\). It occurs in the leaves of indigofera tinctoria and isatis tinctoria. Indican hydrolyses easily to
glucose and indoxyl when the leaves are macerated with water. The indoxyl oxidizes by atmospheric oxygen to give insoluble indigotin, which is also known as indigo blue (55). Natural indigo is a mixture of indigotin (indigo blue) and indirubin (indigo brown). The color of indigo is due to extended chromophore present in the indigotin structure. This dye has remarkable permanancy and strength for its deep blue color.

iii) Colors derived from natural dyes

The Color Index lists only three natural blue dyes, that is Natural Indigo, sulphonated Natural Indigo and the flowers of Japanese used mainly for making awobana paper.

The prominent red dyes are madder (rubia tinctorum), manjeet (rubia cordifolia.L), brazil wood / sappan wood (caesalpina sappa), morinda (Morinda Citrifolia), cochineal (coccus aacti), lac dye (caccus / accae).

Yellow is the most common color in the natural dyes. However most of the yellow colorants are fugitive(228). Some of the important yellow dyes are obtained from barberry (plate 2.8) (berberis aristata), tesu flowers (butea frondosa, monoperma) and kamala (mallotus philippensis).

Tannins are the most important ingredients in dyeing with Natural dyes producing yellow, brown, grey and black colors (78).

Eupatorium odoratum is a plant herb and the colors obtained are bright yellow with alum, greenish yellow with blue vitriol, dark green with iron, brown with chrome. Ageratum Condyzoides is a plant herb and the colors obtained are bright yellow with alum, bierge with blue vitriol, grey with iron, brown with chrome (58).

The strength and the colors of each Plant differs. The color also changes according to the dyeing process and ingredients used (185). Starting from light shades to deep shades all could be dyed with varieties of mordants. India also yielded pink, purple, turquoise, green, olive and yellow shades from Indigo (13).

Composite color or mixed color can be obtained by mixing dyestuff in the same bath, or different dyestuff or can be boiled separately and mixed in various proportions. The color can again be altered by the addition of small amount of mordant after dyeing. Some examples of composite colors are (i) khaki, grey, bronze, maroon, choklate, brown, dark,
plum and shades of red. (ii) green color can be obtained by adding red yellow colors. (iii) blue-black colors can be prepared by combining blue and black grey. (iv) purple, violet, crimson, lilac, lavender can be prepared by red and blue (182). The sources of natural dyes and its colors are given in table 2.2.

The wood from trees contain the colorless haematozylon which oxidize in air to red dye haematin and on using with iron mordant black color has got different colors. Madders are purplish red while combining alum, madder and logwood, brown from iron, madder and fustic. Reddish brown from chrome, madder, fustic and logwood. Also colors such as dull black from chrome, logwood, fustic chips. Green black from alum, logwood, fustic in large extent. Lavender from chrome, logwood and madder (67).

**Table 2.2 Sources of natural dyes and its colors**

<table>
<thead>
<tr>
<th>Red</th>
<th>Yellow</th>
<th>Black</th>
<th>Brown</th>
<th>Green</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safflower</td>
<td>English oak</td>
<td>Alder</td>
<td>Marigold</td>
<td>Lily</td>
</tr>
<tr>
<td>Caesalpinia</td>
<td>Parijatha</td>
<td>Robiamala</td>
<td>Sumach</td>
<td></td>
</tr>
<tr>
<td>Moninab</td>
<td>Marigold</td>
<td>Custard</td>
<td>Balsam</td>
<td></td>
</tr>
<tr>
<td>Citrifolia</td>
<td>teak</td>
<td>Apple</td>
<td>Cutch</td>
<td></td>
</tr>
<tr>
<td>Beet root</td>
<td>Agrimony</td>
<td>babia</td>
<td>Anin bark</td>
<td></td>
</tr>
<tr>
<td>Anchusa</td>
<td>Chir</td>
<td>harda</td>
<td>Auch</td>
<td></td>
</tr>
<tr>
<td>Ladiesbed</td>
<td>Pomegranate</td>
<td>Lodh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cochineal</td>
<td>Weld</td>
<td></td>
<td>Blackberry</td>
<td></td>
</tr>
</tbody>
</table>

**iv) Types of natural dyes**

There are three major types of natural dyes which are i) substantive dyes, that require no mordants, ii) vat dyes, iii) mordant dyes, that require auxiliary substances to become attached to the fiber. Less common forms of natural dyeing include rust dyeing, dye painting with earth oxides, and mud dyeing (87).
a) Substantive dyes

Substantive dyes are used by simply combining the dyestuff, usually in a quantity equal to or twice that of the weight of the fiber, with the fiber (or fabric) and simmering for an extended period of time. An example is turmeric, the spice, which works on cotton as well as on wool, others include onion skins, walnut husks, and tea (98).

Substantive dyes, if made from edible materials, have the advantage of allowing the use of a regular cooking pot for dyeing in, most dyes, even natural dyes, and most mordants, require that a dye pot be devoted to their use, never to be used for cooking again. Another word for a substantive dye is direct dye (88).

b) Vat dyes

The vat dyes work the same way on protein and cellulose, by being introduced into the surface of the fiber while in soluble form and then converted into an insoluble form (109).

The vat dyes include many synthetic dyes, but also the natural dye indigo, and the ancient tyrian purple dye extracted from shellfish. They are complex to use, requiring the establishment of an anaerobic (oxygen-free) fermentation.

c) Mordant dyes

Most natural dyeing is done with the use of mordants, most commonly heavy metal ions, but sometimes tannins. (Tannins are particularly important in dyeing cotton and other cellulose fibers.) The mordant allows many natural dyes which would otherwise just wash out to attain acceptable wash fastness. A mordant remains in the fiber permanently, holding the dye. Each different metal used as a mordant produces a different range of colors for each dye (157).

V) Natural mordants and mordanting techniques

Natural dyes have been used as a means to color textiles for centuries. Most natural dyes are substantive dyes. They have little coloring power within themselves and require the aid of mordant to improve their characteristics (78). The word mordant has been derived from
the latin word “Mod-ere” which means ‘to bite’. The mordant bites the surface of a fiber so that a dye can sink in.

Nearly all natural dyes with few exceptions, require the use of mordants to fix the dyestuff on to the fabric\textsuperscript{(206)}. There are several different mordants, out of which the most effective ones are alum, copper, iron and tin. Mordants give wash –fastness, prevent color bleeding, brighten or change colors. Over the centuries many substances were used including organic and other inorganic chemicals\textsuperscript{(241)}.

A mordant is a chemical which forms unison between the dye and the substance to be dyed. It is a color fixative. Mordanting of natural dyes improves its affinity for the dye and the fabric. The same dye gives different shades on fabric when applied with mordants.

Nearly all natural dyes require mordants to give substantivity. A natural dye is attached to the textile fiber by a mordant, which can be an organic or inorganic substance\textsuperscript{(186)}.

Several metal salts are used as mordants but the most effective ones are alum, copper sulphate, chrome, ferrous sulphate and stannous chloride. While dyeing with natural dyes, a substantial proportion of mordant remains unexhausted in the residual dyebath, which may pose serious effluent problems.

vi) Types of mordants

a) Metal salts or metallic mordants

Some of the metallic salts like alum, potassium dichromate, ferrous sulphate, copper sulphate, stannous chloride and stannic chloride fall under the category.

b) Tannins and tannic acid

Tannins such as harda, tannic acid are considered as natural mordants. Myrobalans (Harada) and sumac are the substance containing tannin.
c) Oils and oil mordants

Oil mordants are used mainly in dyeing of turkey red color from madder. Synthetic mordants may have a deteriorating effect on the fibers. Iron and tin mordant have negative impact on the fiber. Iron damages the fiber and tin tends to make the yarn brittle.

The mordant is usually applied in a separate process before dyeing, but with an increasing number of dyes, the mordanting comes last, and in some case the mordant and dye are used together\(^{(156)}\).

d) Alum

The word “alumen” which we translate “alum”, occurs in natural history. Alum as imported into England mainly from the Middle East, from the last 15th century onwards. It is used as a dye fixer(mordant) the value of which increased significantly if dyed.

Alum is commonly used in baking powder, include juice antiperspirants, and to treat water supplies to “clarify”, by combining with dissolved tannins and precipitating them\(^{(250)}\).

Alum (Aluminium Sulphate) is the most widely used mordants for dyeing with natural dyes. It adds brightness and fixes the color which use of too much will leave the fiber feeling “sticky” and harsh. The use of cream of tarter with alum is recommended as it softens the effects and helps with evenness.

Natural dye is an eco friendly dye. Different mordant combination was carried out with different mandating methods. Various fastness tests were determined such as colour fastness to washing, perspiration, sunlight and crocking\(^{(129)}\).

2.12.1(II) Synthetic dyes

The first man-made organic dye, mauveine, was discovered by William Henry Perkin in 1856. Many thousands of dyes have since been prepared and because of vastly improved properties imparted upon the dyed materials quickly replaced the traditional natural dyes\(^{(35)}\).
A dye, whether it is from a natural or synthetic origin, is used, not only to just color the surface of fibers, but it must also become a part of the fiber. After dyeing, the fabric should not be affected during the washing process, dry cleaning with organic solvents and also the dye should give fastness to light, heat and bleaching.

The global consumption of textiles is estimated at around 30 million tonnes, which is expected to grow at the rate of 3% per annum. Moreover, such a huge amount of required textile materials cannot be dyed with natural dyes alone. Hence, the use of eco-safe synthetic dyes is also essential (80).

The global market for textile dye stuffs is dominated by the disperse (35%), and reactive (28%) dyestuff ranges, together with acid (12%), direct (7%), Vat and indigo (8%), Sulphur (6%) and azoic and other dyestuffs (4%) (119).


a) Basic and modified basic dyes

Mauveine, the first to be discovered by Perkin, was a basic dye and most of the dyes which followed, including magenta, malachite green and crystal violet, were of the same type. Basic dyes, dye wool and silk from a dye bath containing acid, but they dye cotton fibers only in the presence of a mordant usually a metallic salt that increases affinity of the fabric for the dye. Basic dyes include the most brilliant of all the synthetic dyes known, but unfortunately they have very poor light and wash fastness (156).

b) Direct dyes

These are soluble in water and have direct affinity for all cellulose fibers. Some will also dye silk and wool. As these dyes, when dyed without additives, do not exhaust well, an addition of salt is required to improve the yield of the dye and to obtain deeper shades. Generally, the wash fastness of these dyes is inferior, but there are a number of after
treatments available to improve the wash fastness of the dyeing. Direct dyes, dye all cellulosic fibers, including viscose rayon, and most of them also dye wool and silk.\textsuperscript{35}

c) Vat dyes

Indigo, probably the oldest dye known to man is one of the most important members of this group.\textsuperscript{22} These dyes, which are insoluble in water, can be converted into alkali soluble leuco compounds (colorless), when reduced with sodium hydrosulphite. After introducing into the fabrics, the dye will be oxidized on exposure to air and will become insoluble in water again.\textsuperscript{186} Previously, the reduction process of the dye was carried out in wooden vats, hence the name vat dyes. These dyes are used to color cotton fibers. Indigo (plant source: Indigofera tinctoria) is a good example for vat dye which is water insoluble and blue in color when reduced, convert into indigo white which is colorless and water soluble.

d) Reactive dyes

This is a new class of dye introduced in the market in 1956. They react chemically with the fiber being dyed, and if correctly applied, it cannot be removed by washing or boiling. The main feature of the dyestuff is its low affinity to cellulose. Therefore, large amount of salt is required to force its deposition on the fabric. After this has been achieved, addition of alkali causes the deposited dyes to react with the fiber. Only a successfully concluded reaction guarantees a fast dyeing. Basically there are two types of reactive dyes (plate 2.9 and 2.10) the cold dyeing and hot dyeing types.\textsuperscript{187}

Reactive dyes for cellulosic materials were invented in 1954 and ICI in England introduced the first range of reactive dye popularly known as Procion dye in the year 1956. Invention of these dyes in textile industry has brought sea changes in the history of dyes. Reactive dyes are the most predominant class of dyes for cellulosics today and 50% of cellulosics are dyed with these dyes. They are also increasingly gaining importance for wool and polyamide fibers. Share of reactive dyes among all textile dyes in 29%, which is next to disperse dyes consumption (32.5%).\textsuperscript{154}
Easy application and choice of different kinds of application techniques like exhaust, semi continuous and continuous, suitability to dye on any conventional or modern machines, presence of wide range of gamut of shades from dull to bright and pastel to dark, compatibility, possibility of getting acceptable all round fastness properties and cost effectiveness are the major key factors which are responsible for the growth of reactive dyes. It is estimated that reactive dyes represent the only range of cellulosic dyes that is expected to increase in sales volume in the early part of the next century. Reactive dyes are expected to take share from other cellulosic dyes like sulphurs and azoics on environmental ground, vats on cost and application, directs on fastness. On the other hand, these dyes are also facing criticism on the ground of being highly polluting either during their manufacturing or their application on textile substrate\(^{(35)}\).

Reactive dyes in general require high usage of salt (especially in exhaust method of application), alkali for fixation and high usage of urea (CDR and printing), which adds more load during treatment of effluent. Besides these, reactive dyes are facing issues like presence of AOX within the dye molecule, more water consumption, presence of heavy metal ion in dye molecules (Cu, Br, Cr, co), relatively low fixation levels, difficulty in removing hydrolyzed reactive dyes and removal of color from effluent streams to meet legal limits\(^{(59)}\).

**Plate 2.9 Reactive hot dye**  **Plate 2.10 Reactive cold dye**

\[\text{Plate 2.9 Reactive hot dye} \quad \text{Plate 2.10 Reactive cold dye}\]

e) **Eco-friendly dyeing using sulphur dyes**

Sulphur dyes are water insoluble compounds. They are first converted into water-soluble substantive form by reduction using sodium sulphide and applied to textile material in this form. After application, the dye is absorbed on the fiber is reconverted into original water insoluble form by oxidation. Conventional dyeing process will contribute sulphides into the effluent. This sulphides give foul smell, toxic, contaminates the environment and human.
Therefore alternative environment friendly agents were investigated for sodium sulphide. Glucose is found to be safe alternative out of hydrol, hydroxyl acetone and glucose. Hydrol is found to be best alternative for Na₂S. Hydrol is available in plenty from maize starch industry and sugar manufacturing industry at less cost. Application method of hydrol in sulphur dyeing is same as that of Na₂S. Due to sulphur dyeing using hydrol the sulphide concentration in the effluent is reduced. It eliminates foul smell at working place and reduces corrosion of equipments used for effluent treatment. The wastewater can be treated effectively. It eliminates bronziness during normal dyeing. Hydrol is available in plenty at cheap rate and also eco-friendly and biodegradable product. The fastness properties are comparable with conventional dyeing (154).

f) Black dyeing

Black is one of the highest volume shades dyed on cotton and synthetic textile material having all time great demand especially for casual wear (denims and garments). Amongst all the classes of dyestuffs, sulphur black is an important class of dye for the coloration of cellulosics, being into existence for nearly a hundred years. The good fastness properties, cost effectiveness and ease of applicability under different processing conditions – exhaust, semi-continuous and continuous make it one of the most popular dyestuffs. Further, a wide choice of selection of various forms – conventional, leuco and solubilized form is the major factor contributing to the continuous existence and ever-increasing demand for this class of dyestuff (194).

g) Sulphur black dyeing

Sulphur dyeing is used for dyeing of cotton. Sulphur dyes are available in the market both in powder (plate 2.11) as well as in liquid form. In exhaust dyeing, mainly powder form is used in dyeing of cotton material. Sulphur black dyeing helps in covering immature cotton present in the fabric and a number of fashion shades are available in the sulphur dyes range. It is a general practice to cover up most of the faulty dyeing by dyeing the fabric with sulphur black.
Basically, sulphur dyes belong to reduction-oxidation-dyeing system. Though sulphur black is a leading member, demand for other colors like greens, navy blue, browns, Bordeaux, khakhi and olives is also increasing (195).

h) Azoic dyes

The word 'Azoic' is the distinguishing name given to insoluble azo dyes that are not applied directly as dyes, but are actually produced within the fiber itself. This is done with impregnating the fiber with one component of the dye, followed by treatment in another component, thus forming the dye within the fiber (187). The formation of this insoluble dye within the fabric makes it very fast to washing. The deposition of the free pigment on the surface of the dyed fabric produces poor rub fastness, but once the loose pigment is removed by boiling the fabric in soap, the dyeing becomes one of the fastest available.

i) Sulphur dyes

The first sulphur dye was discovered in France in 1873, and further work done by Raymond videl enabled the manufacture of ‘Videl black’. Its outstanding fastness to light, washing and boiling far surpassed any cotton black known at that time. The general disadvantage of the sulphur dyes is that they produce dull shades and lack red color. The main advantage lays in their cheapness, ease of application and good wash-fastness (187). In their normal state sulphur dyes are insoluble in water, but they are readily soluble in the solution of sodium sulphide. In this form they have high affinity to all the cellulose fibers.
j) **Mordant dyes**

As the name suggests, these dyes require a mordant. This improves the fastness of the dye on the fiber such as water, light and perspiration fastness \(^{22}\). The choice of mordant is very important as different mordants can change the final color significantly. Most natural dyes are mordant dyes and there is, therefore, a large literature base describing dyeing techniques \(^{187}\). The most important mordant dyes are the synthetic mordant dyes (chrome dyes) used for wool. These comprise some 30% of dyes used for wool and they are especially useful for black and navy shades. The mordant potassium dichromate is applied as an after-treatment.

k) **Acid dyes**

Water soluble anionic dyes are applied to fibers such as silk, wool, nylon and modified acrylic fibers from neutral to acid dye baths. Attachment to the fiber is attributed, at least partly, to salt formation between anionic groups in the dyes and cationic groups in the fiber. Acid dyes are not substantive to cellulosic fibers \(^{22}\).

l) **Disperse dyes**

The introduction of a new regenerated cellulose acetate fiber in 1920 led to the necessity of developing an entirely new range of dyes. It was found that cellulose acetate (or Celanese fiber had hardly any affinity for water-soluble dyes. So a new dyeing principle was introduced. Dyeing with water dispersed colored organic substances. These finely colored particles are applied in aqueous dispersion to the acetate material and actually dissolved in the fibers \(^{35}\).

m) **Oxidation dyes**

These are not dyestuffs in the same sense as other soluble or disperse dyes, but because of their exceptional fastness to light and washing they are of great importance. The most important member of this group is produced by oxidation of aniline and it is used much in the dyeing of fur and leather goods \(^{35}\).
n) Mineral and pigment dyes

Although it is preferable to use water soluble dyes in textile dyeing for two reasons, ease of application and greater softness of the fabric, there are two processes where pigment coloration is used\(^{(187)}\). Cotton army equipment, where it is used because of its cheapness and because it also renders fabric resistant to rotting and attack by insects in damp conditions.

2.13 Dyeing

Archaeological evidence shows that, particularly in India and the Middle East, dyeing has been carried out for over 5000 years. Dyeing is a method which imparts beauty to the textile by applying various colors and their shades on to a fabric. Dyeing can be done at any stage of the manufacturing of textile fiber, yarn, fabric or a finished textile product including garments and apparels. The property of color fastness depends upon two factors namely selection of proper dye according to the textile material to be dyed and selection of the method for dyeing the fiber, yarn or fabric\(^{(187)}\).

Introduction of reactive dyes gave dyers a wide range of shades with brightness, required fastness characteristics, flexibility in application, consistency in shade and cost effectiveness. Dyeing of knit fabrics in the traditional process house is carried out in winch machines with varying capacities. Although the cost of dyeing in winch machine at MLR 1:15 much higher than that is possible with soft flow dyeing machine, people continue to resort to winch process because of lower initial investment. The modern soft flow dyeing machines operate at MLR between 1:4 to 1:8 depends upon type of machine. Many knit processing units in the organized sector have machines from some of the reputed manufacturers like Sclavos (Greece), Fongs (Hongkong) and Thies (Germany)\(^{(75)}\). The dyeing process of polyester / cellulose blend fabric is made up of four basic steps as dyeing of polyester, reductive washing, dyeing of cellulose, reactive washing, respectively. This is called two-bath dyeing method. Except for this method, there are two common methods called one-bath and two-step dyeing\(^{(22)}\).

In the conventional two-bath dyeing, polyester component is dyed in the first bath using general polyester high temperature dyeing method. After dyeing, alkali reductive
washing is carried out. In the second bath, cellulose component is dyed by the general reactive dyeing method. In the last step, the unfixed reactive dye is removed by washing.

In this standard process, washing treatments are applied to remove the unfixed dyes and improve fastness of fabric. As disperse dyes have limited dissolving in water, some particular disperse dye molecules may still be occluded onto fiber surface after the dyeing is completed. If not removed, this surface contamination can determine the brightness of shade as well as the washing, sublimation, rubbing and light fastness results. The usual treatment is reductive clearing, where the dyed fabric is treated in a strong reduction bath, usually made up of sodium hydrosulphite and caustic soda. It is well known that all commercial ranges of reactive dyes suffer the problem during their exhaustive application to cellulosic fibers, the dyes undergo hydrolysis, which severely reduces the efficiency of the dye-fiber reaction fixation\textsuperscript{(59)}.

However, to achieve the characteristically high level of wet fastness during dyeing, it is necessary, in most cases, to employ a series of rinsing and soaping stages which are collectively known as reactive washing in order to remove unfixed dye.

Especially, the washing of blend fabrics such as polyester/viscose or polyester/cotton has always been a problem because of their dyeing processes. Some kind of washing agents or other chemicals can cause damage to fiber. For instance, reductive clearing is used successfully on polyester at temperatures below Tg where the dye inside the fiber is unaffected\textsuperscript{(194)}.

However, caustic used in reductive clearing of polyester decreases the brightness of viscose. Moreover, the reductive washing agents reduce the reactive dyes and cause the hydrolysis because of high reduction potential. Therefore, in the dyeing process of polyester/cellulose blend, dyeing and washing of polyester is applied as the first stage of two-bath dyeing method before cellulosic component is dyed\textsuperscript{(187)}.

If the fastness of dyeing is poor after completion of dyeing process of polyester/cellulosic blend, the extra washing process should be applied to improve fastness as reproduction \textsuperscript{(149)}. 

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2.14 Functional textiles

Functional textiles such as anti-microbial, anti-UV, self-cleaning, anti-radiation, insect resistance, and fragrance-finished products have attracted much attention in recent years. In order to impart the demanded properties, proper finishing formulations should be selected taking into consideration type of textile, performance requirements, functional chemical agents, compatibility with other ingredients, available machinery as well as economical and ecological aspects, and innovative technologies such as nanotechnology could be used for developing innovative products with high value added functional properties. Very recent studies have discussed the application of nano-sized TiO₂ in textile finishing, using the sol–gel technique, to impart effective protection against UV radiation and bacteria as well as self-cleaning due to its photo catalytic activity.

2.15 Healthcare textiles

Healthcare textiles have a well-established market in the developed countries where people are conscious of the risks posed to the healthcare workers, especially from blood-borne diseases. Massive growth in the population in developing countries and rising standard of living has helped in creating a vast potential for healthcare textiles. Hospital textiles such as bedding, clothing, surgical gowns, and hospital cloths are expected to fulfill comfort and hygienic properties such as moisture management, thermal conductivity, breathability, antimicrobial activity, and odor resistance.

Nosocomial infections are a constant cause of concern in hospital environments. Generally, hospital workers do their utmost to reduce as much as possible, the accumulation of bacteria on various plane surfaces (floors, walls and tables), especially through the use of biocides. Linen is a potential reservoir of bacteria and can even be a source of cross-contamination. The addition of biocides to textiles used for making hospital garments aids in slowing down the spread of bacteria, which would provide an additional approach to the control of nosocomial infections. The purpose of this study was to monitor the antibacterial activity of an active textile and to measure its efficiency in real-life healthcare conditions.
2.16 Textile finishing

Textile finishing is the final process in converting greige fabricated textile materials into a condition that allows formation of garments, home furnishings and other consumer goods. Chemical finishing, that is, applying chemicals to textiles to achieve specific performance results, is a major part of the finishing process. Desirable physical and chemical properties of the textile can be enhanced and undesirable properties minimized. In order properly to control, evaluate and optimize the chemical finishing process, analysis of the finished fabric and performance evaluation are necessary\(^{(91)}\).

The identification of chemical finishes on fabrics can serve several purposes. Often a fabric with an unknown finish needs to be analyzed for forensic or competitive reasons. Fabrics that do not perform as expected need to be determined if the particular finish were applied in proper concentration. Regular analysis of production fabrics forms a basis for process improvement through application of statistical process control methods\(^{(230)}\).

The special character of textile finishes can make chemical analysis less than straightforward. A typical chemical finish for textiles has numerous components including the active agent, surfactants, softeners and miscellaneous processing aids. In addition, many finishes undergo chemical changes during the finishing process, that is, the cross-linking reactions that occur in durable press finishing. If the fabric has been washed after finish application either as part of the finishing process or by a consumer after purchase, the water-soluble components may have been partially or completely removed. The most useful approach is often to prepare fabrics with known finishes and use these as internal standards when analyzing unknown or questionable fabrics\(^{(83)}\).

2.16.1 Garment finishing

Garment finishing though is synonymous word for the process in denim industry called “Washing Effects”, has now extended to the processing of whole range of ready garments from shirt, T-shirt, trouser, jacket to all types of clothing. In apparels, chemicals are widely used to add value to garments through effects varying from various feels such as soft, supple, dry feel, bouncy feel and to add the functionality, durability of the garment such as water-oil repellant finish, wrinkle free finish, moisture management and stain protection\(^{(56)}\).
a) **Wrinkle free treatment**

By applying resins it is possible to improve specific properties of cellulosic fibers. Examples of this kind are the improvement in crease recovery, dimensional stability, non-iron, reduced pilling and particularly with knit goods an improved appearance after several washes. For successful resin finishing, it is absolutely essential that the goods are well prepared and the recipes and processes are adhered to and monitored exactly.

Wrinkle free technology for cotton fabrics application formula results in increased productivity, improved energy usage as well as improved abrasion resistance and fabric strength, and reduced chemical usage without compromising durable press ratings\(^{(209)}\).

The wrinkle free treatment package comprises of a low formaldehyde resin, silicones and polyethylene emulsion. This treatment involves chemical application of the elements comprising of this package through a cross linking effect that prevents the formation of creases and wrinkles which result in easy to iron fabrics. Resins do however also have several effects on the fibers. Resins reduce the (tear) strength of cotton\(^{(139)}\).

**2.16.2 UV protection finishing**

a) **UV Protection**

Fabric treated with UV absorbers ensures that the clothes deflect the harmful ultraviolet rays of the sun, reducing a person’s UVR exposure and protecting the skin from potential damage. The extent of skin protection required by different types of human skin depends on UV radiation intensity and distribution with reference to geographical location, time of day, and season. This protection is expressed as SPF (Sun Protection Factor), higher the SPF value better is the protection against UV radiation. The SPF value of the textile depends on fiber type, the fabric construction (porosity and thickness), and the finish. It means that transmission, absorption and reflectance nature of textile influences SPF value. It provides vital information about the fabric’s sun protection ability\(^{(164)}\).

In order to achieve the required UV-protection level using right choice of UV-absorbers and applying it properly, the use of UV absorbers is a must for cellulosic minimizing the risk to loose UV-protection of garments while in use. By using UV absorbers,
exposure of the textile to UV lights is reduced on the one hand as well as the intensity of the transmitted UV light on the other. Good skin protection is achieved by the textile itself with a sufficient weight of fabric. But the desired protective function is achieved by means of an additional finish. An UV absorber can be applied either during fiber manufacture or in the final finish which also offers the same degree of protection\(^{(23)}\).

The dyes used to colour textiles can have a considerable influence on their permeability to ultraviolet radiation. Depending on their chemical structure, the absorption band of many dyes extends into the U.V. spectral region. U.V. protective textiles are developed in regard to the geometric properties, specific type of fibre and through various finishing techniques using U.V. absorbing chemicals\(^{(222)}\).

Ultraviolet (UV) radiation is harmful to human health. This radiation is composed of three types: UV-A, UV-B and UV-C, ranging between 320 nm and 400 nm, 290nm and 320 nm, 100 nm and 290 nm, respectively. UV-A may cause premature ageing and wrinkling of skin also is recently implicated as a cause of skin cancer. UV-B is more dangerous than UV-A and has been implicated as a major cause of cancers and sunburns. UV-C is extremely dangerous. But fortunately, UV-C radiation is completely absorbed by the ozone layer. However, UV-A and UV-B reach the earth’s surface and can cause serious health problems.

b) UV – Protective finishes

One important function performed by garments is to protect the wearer from the harmful rays of the sun. The rays in the wavelength region of 150-400 nm are known as ultraviolet (UV) radiation. The most important UV radiation source is the sun – almost every living organism is exposed to radiation from the sun. The biological reactions resulting from UV exposure are very diverse. The sunburn reaction on human skin is probably the best known. Sunburn is associated with inflammatory signs and symptoms: erythema, excessive warmth, swelling, and pain. Another type of dermatological response to sun exposure is immediate or delayed pigmentation. UV radiation is also responsible for photoaging and photocarcinogenesis\(^{(197)}\).

During the past decades, awareness of the effect and consequences of exposure to U.V. radiation and skin cancer has led to an increased effort in R & D focused on protection
against U.V. rays. Protective textiles, with regards to U.V. protection, offer lot of opportunities to carry out modifications of existing material process and to innovate new materials\(^{(70)}\).

Several types of UV stabilizers are available, the most common being benzophenones and phenylbenzotriazoles. These molecules are able to absorb the damaging UV rays of sunlight. Factors to be considered in selecting a UV stabilizer includes the substrate to be protected, method and conditions of fabrication, degree and type of protection desired, size and shape of the finished product, end use and the presence of other additives such as antioxidants, antistatic agents, colorants, filters and accelerators. UV-protective finishes can be applied during dyeing, under a reductive process. They may be applied by exhaust or padding method\(^{(188)}\).

The UV absorbers commonly used in the photo stabilization of wool are monomeric and are used without chemical fixation. Some of the factors that decrease the effectiveness of such UV absorbers are their low resistance to washing and low intermolecular interactions between the absorber molecule and the fibers. Photo stabilization on wool can also be achieved along with anti-soil and water-repellent properties using polymeric UV stabilizers with a polymethacrylate backbone. It has been found that the light fastness of wool and silk dyed with natural dyes incorporating a mordant is enhanced by UV absorber after treatment \((201, 140)\).

c) UV Protection on cotton fabric

Ultraviolet (UV) transmittance of a fabric depends mainly on the amount of UV radiation passing through the voids formed between interlaced warp and weft yarns, and on its potential to pass through the fibers. It is well known that UV light can be prevented from passing through the fibers in different ways, by incorporating TiO\(_2\) delusterant into fibers or by applying dyestuffs, finishes (titanium hydrosol), optical brighteners, or UV absorbers. The TiO\(_2\) pigment particles, whether applied on the surface of fibers or added into the polymer mass before fiber formation, increase the reflectance and absorption of UV rays. Experiments on lightweight viscose fabrics show that UV protection could be improved with close weaving and by using TiO\(_2\)-pigmented fibers. Viscose materials have the capacity to swell when wet, increasing their UV protection factor (UPF). Dyes with absorption spectra shifted
into the UV region provide additional UV protection. Deeper dyeing of these hues provides proportionally higher protection against UV rays\(^{(197)}\).

Cotton transmits large amounts of UV radiation even when closely woven, providing little protection. Synthetic materials, especially polyester with a large number of aromatic rings in its structure, provide very good UV protection when closely woven. Accordingly, lightweight cotton materials, which are not finished with optical whitening agents or dyed a deep shade with UV-absorbing dyes, fully transmit UV rays. Such fabrics are usually washed with detergents containing optical brighteners and it has been found that after 10-20 washes, these brighteners gradually increase the UPF of cotton through their capacity to absorb UV rays. However, the UV absorbency of optical brighteners is much lower than that of UV absorbers that could be applied during the manufacturing process to decrease the transmission of UV rays through fibers. UV absorbers are capable of absorbing UV radiation and transforming it into thermal energy\(^{(225)}\).

The understanding of the detrimental effects of UV radiation on the cutaneous and subcutaneous cells has been quickly advancing. In the past, UVA radiation was thought to be less important than UVB radiation in generation of sun damage and skin cancer, but it is now known that UVA does indeed induce mutations in DNA, leading to skin cancers in both animal and human skin. It is important that clothing used as protection against the sun is optimally protective in both these regions of the spectrum\(^{(72)}\).

d) UV Protective textiles

Immediate UV-induced damage to the skin is indicated by the release of free radicals in the cells of the epidermis. At the Hohenstein Institute, these are identified using a specific tracing reaction for oxygen radicals. Skin cells which have not been exposed to radiation are virtually free of oxidative damage. By contrast, the control test, in which the oxidative damage was caused chemically, leads to over 90% oxidative stress in the form of released free radicals. In another test, the skin cells were exposed to a total UV radiation dose of 5 J/cm\(^2\). Cells receiving this dose subsequently suffered over 50% oxidative damage. In a parallel test, with the same UV exposure, the skin cells protected by textiles (covered with a T-shirt with a UPF factor of 80 according to UV standard 801) showed that the oxidative damage could be significantly reduced to about 18%, virtually its initial level\(^{(89)}\).
e) UV Protective testing

The harmful effects of exposure to ultraviolet radiation from sunlight on human skin were recognized by the medical community in the early 1990s. Long-term exposure to ultraviolet light can result in accelerated skin ageing, acne, phototoxic reactions with drugs, sunburn, skin cancer, cornea damage and DNA mutations. The textile industry has responded to this recognized need by providing chemical treatments that absorb ultraviolet light. Government agencies around the world have also responded by providing standards for clothing designed to protect the wearer from ultraviolet rays. The standards define an ultraviolet protection factor (UPF) to be included on clothing sold as ultraviolet protective. The higher the UPF, the greater the ultraviolet protection provided\(^{(23)}\).

The early test methods for determining the ultraviolet protective effects of clothing involved exposing volunteers to ultraviolet radiation until their skin reddened (erythema) to a specific degree. Fortunately, instrumental methods of evaluation have been developed that eliminate the need for sunburned assistants. AATCC test method 183-2000 determines the transmittance of ultraviolet light through fabric samples. Through the use of established tables and formulas, the UPF is calculated \(^{(89)}\).

2.16.3 Soil release finish

Soil release finish facilitate removal of waterborne and oil stains from fabrics such as polyester and cotton blends and fabrics treated for durable press, which usually show some resistance to stain removal by normal cleaning processes. This finish is especially suitable for sportswear, underwear, uniforms and work wear\(^{(81)}\).

a) Finishing with softeners

The softeners can be roughly classified into two groups:

- Non – permanent softeners which can be removed fairly easily by washing,
- Permanent softeners, which still exhibit a distinctly soft handle even after several washes.

Typical representatives of the non-permanent softeners are products based on fatty acid derivatives. They mainly consist of relatively small molecules with a molecular weight of less than 1000. Through this composition, these products provide a more or less hydrophobic effect. They import an outstanding soft handle to virtually all types of fiber.
There is a certain connection between the ionic character and type of handle of most softeners like,

- Cationic softeners generally provide the best soft handle which is distinguished by a flowing, bulky character.
- Anionic and nonionic softeners usually exhibit slightly less soft effects with a smooth, often filling handle character.
- Amphoteric products provide an effect, which lies approximately between those of these two groups.
- Their hydrophobic or hydrophilic properties also have an effect on the handle character of the finished textiles:
  - Softeners with a hydrophobic effect impart a pleasant, voluminous, often slightly fatty handle,
  - Softeners with hydrophilic properties usually provide much drier handle which is often felt to be less soft\(^{56}\).

The influence of the ionic character and hydrophilic or hydrophobic behavior on the handle effect of a softener is generally also observed with the permanent softeners. This group consists usually of polymers with a molecular weight larger than 1000. As a rule they have reactive groups and they deposit themselves like a film on the textile fibers. The most commonly used permanent softeners are polysiloxane. Interesting effect variations have been achieved through modification of the basic model of the polysiloxane. By introducing amino groups in the siloxane molecule, a significant increase in the soft handle effect has been achieved. At present amino-functional silicon elastomers are the most efficient softeners in the field of textile finishing\(^{91}\).

Polyurethane softeners also provide interesting, permanent handle variations. They are based on special reactive polyurethanes. Polyurethane softeners provide an elastic handle on virtually all types of fiber. On microfibers they produce a characteristic rubbery handle. The handle effects obtainable with softeners depend not only on the chemical character, but also on their position in the textile. If the softener is attached mainly on the outside of the yarns, then it is the primary effect of the chemical character which is felt moist, dry, fatty, oily, smooth and rubbery, however, if the softener is able to penetrate into the yarn between...
the individual fibers, a secondary handle effect is obtained: so-called “inner softness” produced by the reduction in friction between the individual fibers (161).

b) Silicones and their versatile applications

Silicones are synthetic polymers and are therefore not found naturally. They have a linear, repeating silicon-oxygen backbone akin to silica. However, organic groups attached directly to the silicon atoms by carbon-silicon bonds prevent formation of the three-dimensional network found in silica. These types of compound are also known as polyorganosiloxanes. Silicon is in the same group of the periodic table as carbon and is structurally similar to carbon. Silicon is also significantly different than carbon as it is more electropositive than carbon, does not form stable double bonds and is capable of unique chemical reactions. Technically known as ‘polyorganosiloxanes’, silicones are polymeric compounds in which silicon atoms join together with oxygen as chains or networks. The remaining valences of silicon link with organic groups mainly methyl groups. It is essentially organically modified quartz like, two oxygen atoms attached to every silicon atom have been replaced by methyl groups. This changes the structure from the three-dimensional backbone of quartz to linear polymer molecules. Silicones therefore are composed of the elements Si, O, C and H. Silicone molecules are usually tangled up in each other. However, the methyl groups are free to rotate about the –Si-O-Si- chain. In this way silicones unite the durability of quartz and the many qualities of modern plastics (229).

Innovation in chemical finishing has capitalized on a host of new developments in the world of science and engineering, including biotechnology, plasma technology, and softening technology (210).

Other groups can be attached to the silicon-oxygen backbone instead of methyl groups. The linear silicone polymers can be cross-linked to each other to different extents covalently via groups of atoms. This explains the various different properties of the corresponding silicones. Silicone materials exhibit unique properties based on their chemical structure. The bond enthalpies, (the measure of bond strength) of silicon-oxygen and silicon-carbon bonds are quite high so the organic silicones tend to be stable. The configuration of the silicones has the water-resistant hydrocarbon groups arrayed along the outside of the chain of Si-O atoms (168).
The bending length and crease recovery angle, which are measures of softness, were found better in case of dyed samples treated with silicone nano emulsion softener than silicone conventional emulsion softener and untreated\(^{44}\).

2.16.4 Stain removal

Out of the various causes of fabric rejection both at the grey stage and also at the finishes stage, incidence of stains is most rampant. Although, the grey fabric itself carries with it the stains of various types introduced during each stage of manufacturing from fiber to grey fabric, the stains are also introduced in the cloth during processing. Processing of fabric is the final stage of manufacturing which involves a large number of steps with different routings with different machines and the conditions of process vary depending on the type of fabrics processed. A processor is expected to ensure that the stains observed and reported in the grey fabrics are eliminated completely and no additional stains are introduced in the fabrics during processing \(^{168}\). In actual practice, the condition of a process house is far from satisfaction to fulfill the above task due to several factors.

a) Sources of stains in grey fabrics

The oily black and colored stains of varying intensity \(^{74}\) normally appearing in the grey fabric are due to the following reasons

- Mixing of coloring matters with cotton fibers.
- Excessive oiling of machines.
- Soiled hands of operatives.
- Piecing of broken ends with dirty hands.
- Lack of proper scheduled maintenance of machinery and lubrication system.
- Improper material handling system.
- Poorhouse keeping.

b) Mechanism of stain removal

The removal of oil stain from the grey fabric is physical action. The oil stain is first either dissolved in the solvent present in the stain-removing agent or dispersed or emulsified and then separated from the fabric surface. If there is any other contaminants like metal particles or dirt in the oil, the removal of the same may pose a problem. In that case, it is necessary to subject the fabric to scouring treatment to make it free from any yellow tinge.
The hydrophobic nature of oil or grease is similar to that of synthetic fibers. The removal of stain is easier when the stain is fresh\(^{(74)}\).

### 2.16.5 Wrinkle free finish on garments

The wrinkle-free finish (also known as ‘Easy care’, ‘Durable Press’, ‘Wrinkle-Resistant’, ‘Wash and Wear’, ‘No-Iron’) is obtained by cross-linking cotton. Permanent press finishes function by forming cross-links between adjacent cellulose polymer chains, these give cotton some elastic and resiliency properties. Such cross-linked cotton can recover from deformation stresses and thus wrinkles will not form. Cotton has two regions, crystalline and amorphous. During wear, hydrogen bonds break at the junctions between these regions, leading to the formation of hydroxide ions (-OH groups). More of these groups mean more creases. Resins react with the -OH groups of successive cellulose chains, resulting in fewer free -OH group in the amorphous region. This means less hydrogen bonding and fewer creases, but increased brittleness. A wrinkle-free finish should be compatible with all finishing chemicals (cationic, anionic and non-ionic) and fiber blends. Such finishes can be applied by padding as well as exhaust methods \(^{(89)}\).

**a) Wrinkle resistant finish**

Cotton is still the ‘king’ of fibers because most of the world’s apparel is made of cotton. It has fairly good strength, and is considered to provide comfortable textile fabrics due to the fiber’s good moisture absorption and wicking properties. Cotton fabrics, however, have a tendency to wrinkle badly and have smooth drying properties after laundering. Under distortion and moist conditions, the hydrogen bonds that hold the cellulose chains together are ruptured, and then the chains slide to minimize the stress within the fibers. This phenomenon causes the hydrogen bonds to reform in a new position after removal of distorting force. The rupture and reformation of hydrogen bonds causes wrinkle problems on cotton or cotton blend fabrics \(^{(130)}\).

**b) Crease recovery**

Fabric appearance is a major criterion for its consumer acceptance. Fabric tailorability depends largely on its formability. Thus, the formability is a major determiner of the final garment appearance. Pressing performance is yet another important aspect for good aesthetic appeal of a suit. Crease recovery angle can be treated as an index to predict the pressing
performance of fabrics. Apart from crease retention property, drapability of a cloth significantly contributes to graceful appearance of a suiting cloth. This is strongly related to the low-stress mechanical properties of the fabric, like bending rigidity. Thus, the measurement of drape and its correlation to the total appearance value of the fabric would make the understanding of the inter-dependence of these parameters more relevant and object oriented (25).

2.16.6 Improving the finish of a garment

Both in regard to appearance and functional performance, it is more important than ever to improve the finish of a garment in order to appeal to the modern consumer. Improvement in functional performance of a garment through speciality finishing has led to the development of up-market and niche products in recent times. Developments have taken place in easy care, softening, water repellent, soil-release, stain-release, flame retardant, antimicrobial and breathable finishes. Most of these finishes are given at the fabric’s processing stage itself. Technology for vapour-phase treatment, which allows finishing to be carried out at the garment stage, is still under development. The only functional finish which has reached some level of satisfactory application and performance is the ‘wrinkle-free’ finish (185).

a) Fragrance finish

Fragrances range from fine perfume, florals, and fruits to products designed to counteract body odor and aromatherapy. Fabric strips with extra fragrance loadings are sewn in critical garment spots such as armpits and crotches. Inorganic fragrant powders may now also be added as active ingredients. Fragrance finishing technology is a multi-sensory marketing tool. There are several niche markets for microencapsulated fragrances and cosmetics in textiles. Children’s apparel is one possible application, hosiery is another. Thirty percent of women are unable to wear hosiery because it dries the skin. Applying microencapsulated Aloe vera to hosiery during the wet processing step of manufacture overcomes this problem (185, 15). In microencapsulation, the active ingredients of a finish are enclosed in 5- to 10- µm diameter capsules made of polyurethane or urea-formaldehyde resin formulated to withstand printing, padding, jet spraying, and heat setting, yet weak enough to rupture by friction during wear.
Humid and warm environment still aggravate the problem. Infestation by microbes causes cross infection by pathogens and development of odour where the fabric is worn next to skin. With the increasing demand for fresh and hygienic textiles, the demand for antimicrobial and odour control finishing is increasing rapidly\textsuperscript{(152)}.

b) Insect repellant finish

Menthoglycol is a natural insect repellent derived from lemon eucalyptus, which is a natural and renewable source. Testing of menthoglycol with a moderately aggressive cage population of Aedes aegypti mosquitoes resulted in no bites for up to four hours. Fabrics treated three months earlier with microencapsulated menthoglycol also repelled foraging mosquitoes over a four-hour period. This finding was consistent with those obtained with the same fabric about one week after its treatment with the test material. The result indicated that menthoglycol persisted on the fabric during the three-month storage period and rubbing of the fabric released the menthoglycol. This findings suggests that microencapsulation may greatly extend the effective lifespan of menthoglycol insect repellent\textsuperscript{(21)}.

c) Anti yellowing finish

Many garments are produced in countries far from the markets where they are eventually sold, but long periods of transportation and storage packed in film can cause areas of yellowish discoloration on light-colored clothing known as “storage yellowing”. Such areas occur especially at points where the film and fabric are in permanent contact. Colorless butyl hydroxyl-toluene (BHT), an additive in the packaging material, migrates into the garment and reacts with nitrogen oxides from vehicle exhausts, producing a yellow nitro dye. The phenomenon is promoted by moisture and high temperatures. Anti-yellowing finishes prevent nitrogen oxides from combining with the BHT molecule, so that yellowing cannot occur and textiles retain their light shade\textsuperscript{(139)}.

d) Antimicrobial finish

Microbes are minute organisms but, can cause allergic responses, disease, infection, objectionable odors, and unsightly stains. Microbes require certain conditions to grow, including dirt, fiber of perspiration, a warm environment moisture (such as humidity or spills) and a receptive surface (like skin or fabric). To control microbe growth, which in turn controls the above effects, one can treat fabrics or garments with specialty chemicals.
Antimicrobial finishing is used when the chances of bacterial growth are high and safety is paramount. This type of finishing often improves the life span of the articles to which it is applied. It is effective on any substrate, including cellulose, synthetics, blends, and non-textile surfaces and can improve the hand of most fabrics (230).

Antimicrobial agents can be applied to textile materials by padding, exhaust, or spraying methods. To apply the finish by padding, fabric is run through a pad-bath for approximately 1% pick up on the weight of cotton. Other finishes may be applied simultaneously through slight modification of the processing conditions. In the exhaustion method, the chemical treatment exhausts rapidly from a dilute aqueous solution onto the cotton. The spraying method is generally suitable for nonwoven fabrics. Antimicrobials can also be added to the spinning dope creating a fiber with antimicrobial properties (65). The durability of antimicrobial finishes is important.

i) What are microbes or microorganisms?

Microbes are the tiniest creatures not seen by the naked eye. They include a variety of microorganisms like bacteria, fungi, algae and viruses. Bacteria are unicellular organisms, which grow very rapidly under warmth and moisture. Further, sub divisions in the bacteria family are Gram positive (Staphylococcus aureus), Gram negative (Escherichia coli), spore bearing or non-spore bearing type. Some specific types of bacteria are pathogenic and cause cross infection. Fungi, molds or mildew are complex organisms with slow growth rate. They stain the fabric and deteriorate the performance properties of the fabrics. Fungi are active at a pH level of 6.5. Algae are typical microorganisms, which are either fungal or bacterial. Algae require continues sources of water and sunlight to grow and develop darker stains on the fabrics. Algae are active in the pH range of 7.0 - 8.0. Dust mites are eight legged creatures and occupy the household textiles such as blankets, bed linen, pillows, mattresses and carpets (162). The dust mites feed on human skin cells and liberated waste products can cause allergic reactions and respiratory disorders.

ii) Requirements for antimicrobial finish

Textile materials in particular, the garments are more susceptible to wear and tear. It is important to take into account the impact of stress strain, thermal and mechanical effects on
the finished substrates \(^{(175)}\). The following requirements need to be satisfied to obtain maximum benefits out of the finish:

1. Durability to washing, dry cleaning and hot pressing.
2. Selective activity to undesirable microorganisms.
3. Should not produce harmful effects to the manufacturer, user and the environment.
4. Should comply with the statutory requirements of regulating agencies.
5. Compatibility with the chemical processes.
8. Resistant to body fluids.
9. Resistant to disinfections / sterilization.

iii) Antimicrobial finishing methodologies

The antimicrobial agents can be applied to the textile substrates by exhaust, pad-dry-cure, coating, spray and foam techniques. The substances can also be applied by directly adding into the fiber spinning dope. It is claimed that the commercial agents can be applied online during the dyeing and finishing operations. Various methods for improving the durability of the finish include:

1. Insolubilisation of the active substances in/on the fiber.
2. Treating the fiber with resin, condensates or cross-linking agents.
3. Microencapsulation of the antimicrobial agents with the fiber matrix.
4. Coating the fiber surface.
5. Chemical modification of the fiber by covalent bond formation.
6. Use of graft polymers, homo polymers and/or co polymerization on to the fiber \(^{(71, 218)}\).

Apart from textiles for daily wear, these fibers are used in products for places such as hospitals, hotels, airports, spacecraft and industry. Hence it is necessary to develop commercially available fibers to withstand various environmental conditions. This is highly important for high-performance applications such as medical garments, sanitary napkins, socks, underwear, disposable wipes, shoe insoles and carpets\(^{(225)}\).
Among all the effects of microbes on polymers, odor development is one of the most noticeable for end-users. The use of an antimicrobial prevents odor development induced by microbial activity. This efficient protection can have a positive effect on the attractiveness of finished goods. Odor is a result of microbial metabolism, and microbial breakdown of organic residues into volatile components. Reducing odors is an attractive benefit for many applications, such as clothing and waste containers.

Plastic materials are expected to keep their initial aesthetic property. It is therefore necessary to protect the material against microorganism growth to avoid staining without over-maintenance. The introduction of antimicrobial in the polymer matrix is more efficient that surface treatment to inhibit staining.

Two main mechanisms are responsible for staining issues - intra and extra - cellular pigments produced by fungi and bacteria and staining by green chlorophyll from algae and moss.

iv) Antimicrobial properties

There has been an increasing interest in fabrics with antimicrobial properties in general and in particular those used for wound dressings. Since textile-based structures are potentially good substrates for the growth of microorganisms, there exists a large volume of literature discussing the survival and growth of microorganisms in textiles and their possible health-related risks. The common bacteria found on the skin of humans are capable of producing foul odors, especially on the foot and in the auxiliary regions. These types of bacteria also play a part in injuries at a certain regions of the skin. For several decades, alkoxysilanes have been widely used by a number of industries as coupling agents for binding and reinforcing substrates. In the earliest applications have described the bacteriostatic action of quaternary ammonium compounds on textiles. There has since been growing demand for the production of antimicrobial fabrics that could kill microorganisms upon contact, a technology that reacts with the substrate making the surface antimicrobial. This type of antimicrobial technology is used in textiles that are likely to have human contact or where their durability is of much value.
Chitosan, the deacetylated form of chitin is naturally antimicrobial, hemostatic, and biocompatible, and is widely believed to have good healing properties due to its vulnerability to break down by the enzymes present in the exudates and their subsequent role in regeneration and proliferation of new tissues\(^{(113)}\). Chitosan, unlike many other materials, is highly reactive due to its amino and hydroxyl groups carrying a positive charge at pHs below 6.5. Most natural materials including fibers, human skin, bone, hair, and microbes bear negative charges and are therefore potentially capable of interacting with chitosan. One such possible interaction is the combination of sodium alginate and hydrolyzed chitosan in a single fiber with the intention of achieving combined properties.

2.16.7 Finish performance tests

Chemical finishing is an important area in textile processing and requires a diligent fabric-testing program to maximize the benefits of the chemical treatments. Many chemical finishes have an optimum level of application, too much chemical can be wasteful, too little can compromise the desired fabric properties\(^{(132)}\). The development of the appropriate performance test methods is just as important to the commercial success of a chemical finish as the development of the finish itself. A test method is appropriate if it provides useful, reproducible results that correlate with actual ‘real world’ performance. The best test methods utilize simple, inexpensive equipment with easy to follow procedures and yield precise, accurate data.

Organizations such as the Association of American Textile Chemists and Colorists (AATCC) and the American Society for Testing and Materials (ASTM) in the USA, the British Standards Institute (BSI) in the United Kingdom, the Deutsches Institute for Normung (DIN) in Germany and the International Organization for Standardization (ISO) headquartered in Switzerland publish test methods that can be used to evaluate the performance of chemical finishes\(^{(120)}\).

a) Soil release testing

Most consumers would like to be able to clean their garments effectively during laundering. The ability of textiles to release soil during laundering is a function of many factors including the nature of the soil, the mechanical action imparted by the washing
machine, the composition of the detergent, the structure of the textile, the washing temperature and the surface characteristics of the textile fiber. In order to release oily soil easily, the most difficult soil to remove from synthetic fibers, the fiber surface should be both hydrophilic and oleophobic\(^{(114)}\). A variety of chemical materials have been used commercially to achieve this goal. Evaluating soil release finishes is best done by subjecting the fabrics to simulated home launderings under carefully controlled conditions.

AATCC test method 130-2000 has been developed to measure the ability of the fabrics to release an oily stain when laundered. Fabric samples (15 X 15 inches – 38 X 38 cm) are stained with corn oil, then a specified weight is used to force some of the oil into the fabric interior. After laundering with a specified detergent under a choice of laundering conditions, the samples are dried in a tumble dryer and compared to photographic standards (stain release replica with the usual AATCC 1-5 scale).

b) Repellency testing

Repellent finishes are important components of many protective textiles. Applications for repellent textiles range from medical textiles to raincoats. The low surface energies provided by repellent finishes can keep solid and liquid soils from adhering to treated fiber surfaces. Finishes based on hydrocarbon and silicone chemistries can yield water repellent textiles, while fluorochemicals are necessary to achieve the low surface energies\(^{(112, 108)}\) needed for dry soil and oil repellency.

AATCC test method 22-2001 is a simple test for rapid screening of water repellency. The fabric sample (7 X 7 inches – 18 X 18 cm) is stretched tight in an embroidery hoop, held at a 45° angle in the test apparatus and sprayed with 250 ml of water through a specified spray head from a height of 150 mm. Photographic standards are used to evaluate any wetting pattern that is formed. A completely non-wetting fabric is given a 100 rating, while a fabric that wets completely is given a 0 rating.

AATCC test method 35-2000 is designed to simulate a rain event. A special apparatus is used to hold the 20 X 20 cm fabric sample in a vertical position backed by a weighed piece of blotter paper. The fabric face is sprayed with water under constant hydrostatic pressure for
5 mins and the blotter paper reweighted. The increase in weight of the backing paper is a measure of the resistance of the fabric to penetration by the simulated rain.

c) Antimicrobial testing

The growth of microorganisms on textiles can cause functional, hygienic and aesthetic problems. Fungi and bacteria are the most troublesome organisms. Fungi can cause discoloration and fiber damage, while bacteria can produce unpleasant odors and a slimy feel to fabrics. The growth of pathogenic bacteria on textiles presents health hazards to the wearer and to the general public. A successful antimicrobial textile finish must be effective against the target organisms, yet not harm the wearer or the environment. Textiles marketed as biocidal that is, capable of killing organisms, are mandated by law to meet strict efficacy requirements, whereas biostatic (growth inhibiting) textile finishes are held to much more lenient standards. In the USA, biocidal products must be registered with the Environmental Protection Agency (EPA) before they can be sold(160).

d) Antibacterial tests

Qualitative and quantitative test methods have been developed for evaluating the antibacterial properties of textiles. AATCC test method 147-1998 provides a qualitative measure of a textile’s antibacterial effects (5). A small sample of the textile (25 X 50 mm) is placed in a sterile agar – containing plate that has been streaked with either a gram positive – or gram-negative bacteria-containing solution. After incubation for 18 – 24 hours at 37 °C, the plate is examined for bacterial growth. If the bacteria did not grow on the textile, an antibacterial effect can be claimed. Although this method is suitable for a rapid assessment, a more quantitative test is needed to determine if the effect is biocidal or biostatic.

AATCC test method 100-1999 was developed to provide a quantitative evaluation of a textile’s antibacterial properties. A swatch of the antimicrobial treated textile (1.9 inch (4.8 cm) diameter disc) is inoculated with a bacteria-containing solution (either gram positive or gram negative) and incubated for 18 – 24 hours at 37 °C. The swatches are then extracted and the number of bacteria in the extract determined by serial dilutions placed on sterile agar containing plates and incubated for 48 hours at 37 °C. Calculations are made to find the percentage reduction of bacteria found on the antimicrobial treated textile compared to the number of bacteria found on an untreated textile of similar construction. Care must be taken
to ensure that bacteria actually grow on the untreated textile sample. This can be accomplished by incorporating a small amount of growth medium in the initial inoculating solution\(^{136}\).

e) Antifungal tests

AATCC test method 30-1999 provides four methods for determining the antifungal properties of a textile. The first method involves covering the textile samples (1.5 X 6 inches) (4 X 15 cm) with fungi-containing soil and incubating the mix for 2-16 weeks at 28 °C. In the second method, cellulosic fabric (1.5 inch (4 cm) diameter disc or 1.5 X 6 inch (4 X 15 cm) strip) is inoculated with a standard fungus (Chaetomium globosum) solution and incubated on a sterile agar-containing plate. The third method is similar to the second except that the fungus Aspergillus niger is used as the inoculum. The fourth method exposes 1 X 3 inch (2.5 X 7.6 cm) textile samples to a high humidity environment for 14 – 28 days in a sealed jar after inoculation with a mixture of three fungi. In all methods, the extent of fungal growth is determined visually and reported as ‘no growth’, ‘microscopic growth’ or ‘macroscopic growth’. In all the methods except the third, fabric strength losses can also be measured\(^{83}\).

In the world wide of textiles and garments, multi functional finishes on cotton fabric plays a vital role for quality and value. In the abundance of various finishes, microencapsulated finished fabrics are among the latest generation of intelligent textiles\(^{224}\).

2.16.8 Quality of water

The water used in the laboratory and in the process house should be from the same source with pH neutral or slightly acidic. Water should be free of iron and copper\(^{184, 191}\). The hardness should be less than 300 ppm after addition of salt. Water should not contain any residue of chlorine and hydrogen peroxide. Whenever recycling of water is carried by RO, care should be taken to ensure that quality of water with respect to all the parameters\(^{131, 153}\) is consistent. The bicarbonate content in water should be nil.