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AN INTRODUCTION

Yasir Nawab (Ed.)
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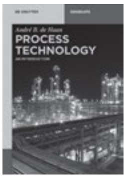

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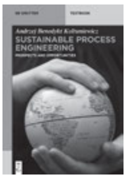

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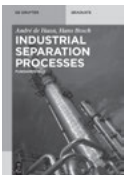

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Textile Engineering

An Introduction

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Foreword

Textile engineering deals with the application of science to reveal the relationships between the raw material, process and the finished product to achieve the desired functional or aesthetic effects in the fabric. The success of fabric engineering depends on reliable objective measurements, prediction and control of fabric quality and performance attributes. Understanding the theoretical relationships between fabric parameters enables the fabric designer to play with different fibres, yarn tex, threads per centimeter and weave to vary texture and other fabric properties. These relationships provide simplified formulae to facilitate calculations which are of value for cloth engineering, problems of structure and mechanical properties.

The authors bring together expertise in textiles – raw materials, yarn manufacturing, fabric manufacturing, textiles processing, clothing, technical textiles, textiles testing, recycling and disposal of textiles, quality control in textiles and computer applications in textiles and basic principles of design engineering – as a tool to support product development. This book is the culmination of teaching, research and methodology in textile industry. It aims to give the readers a good foundation in this area through an in-depth understanding of the principles of physical and mechanical properties of woven textile structures. It is designed as a textbook for undergraduates in textile engineering and also as a reference book for research scholars. The concepts and applications have been demonstrated by the liberal use of examples. The book gives a flavour of the basics and builds up to predictive modeling of some fabric properties. Each chapter gives an abstract of the contents and is concluded, wherever possible, with detailing how these contents can be used and applied in practical situations.

We wish to thank the teachers and researchers in the National Textile University, Faisalabad Pakistan, for their unstinting support in making this endeavor a reality. We also owe our indebtedness to many others who are not mentioned for their indirect contributions in enhancing our knowledge and providing us support. We would like to acknowledge De Gruyter Publishing Limited for their encouragement and assistance. It is hoped that this book will fill the vacuum in the literature on textile engineering. We welcome feedback or suggestions for any errors that may have crept into the book inadvertently.

Yasir Nawab

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Chapter 11

Munir Ashraf

1 Introduction

The word textile originated from Latin word *Textilis* which means woven, fabric, cloth. The textiles can be defined as the products which are formed by the interlacement of fibers or yarn. The broad definition covers any product intermediate or final made in textile industry. Therefore, the term textile includes fibers, filaments, yarns, woven, knitted and braided cloths as well as nonwoven fabrics.

1.1 What is Textile?

A textile product passes through several processes in its manufacturing before it becomes wearable. These processes include spinning, weaving, knitting, processing and garments manufacturing. The flow of these processes is shown in Fig. 1.1.

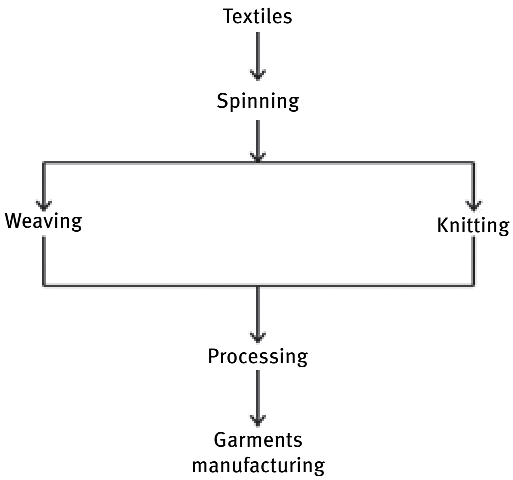

Fig. 1.1: Process flow of textile product manufacturing.

1.2 History of Textiles

The usage of textiles can be traced back to the Neolithic Age (Tab. 1.1). The people around 4000 BC invented hand-operated spindles and looms in Europe and the materials used were wool and flax [1].

Tab. 1.1: Evolution of raw materials and machines to manufacture textile products [1].

Period	Evolution	Raw Material	Spinning	Weaving	Knitting
Stone Age	Animal skins	✓			
4000 BC	Wool, flax (linen)	✓			
	Hand-operated spindle		✓		
	Loom			✓	
1350 AD	Cotton in Central Europe	✓			
	Manual spinning wheel		✓		
	Treadle loom			✓	
	Flyer spinning wheel of Leonardo		✓		
1350	da Vinci				
	narrow fabric loom			✓	
1589	Manual knitting loom of W. Lee				✓
1764	Cotton, wool, flax	✓			
	First spinning machine “Spinning Jenny”		✓		
1785	First use of steam engines		✓		
	Mechanical weaving loom			✓	
1793–1846	Cotton gin	✓			
	Jacquard machine			✓	
	Self-acting mule		✓		
	Ring spinning machine		✓		
	Production of gun cotton	✓			
1863–1900	Flat knitting machine of J. W. Lamb				✓
	Viscose fibre, Cupro fibre, Acetate	✓			
	Weaving loom with automated weft change and electrical drive			✓	
1914	Weft insertion with air jet			✓	
1935–1942	Development of polyamides 6 and 6,6, polyurethane, polyester, polyacrylnitrile	✓			
1950–1955	Loom with shuttles (200 min^{-1})			✓	
	Open-end spinning technology		✓		
	Water jet weaving machine			✓	
1955–1970	Open-end spinning technology		✓		
	Water jet weaving machine			✓	
	Projectile shuttle and rapier loom			✓	
	OE-rotor-spinning machine		✓		
	Wave-shed weaving machine			✓	
1974–1995	OE-friction-spinning machine		✓		
	Air-jet weaving machine (900 min^{-1})			✓	
	Multiphase weaving machine			✓	

The spinning and weaving processes changed considerably at the end of the first millennium AD. In the middle of the 14th century, cotton was introduced in central Europe [1]. Due to the growing world population, the processes developed needed drastic changes to meet the requirements. This led to industrialization. The post-industrialization era witnessed continuous improvement and innovation in textile raw materials, machinery and processes. Around the middle of the 20th century, significant developments in raw materials like manufacturing of polyamides, polyester, polyacronitrile and machinery like water-jet weaving looms and open-end spinning machines took place and this process of innovation and improvement is still in continuation.

The processing of textiles (dyeing and printing) also has its roots in the prehistoric era. The first solid evidence about dyeing of silk and brocades from religious and social records suggests that Indians were aware of the dyeing process in 2500 BC; however, it is also believed that the Chinese in 3500 BC practised dyeing but no solid evidence is available to substantiate it. Safflower was in use for dyeing textiles for red and yellow colours in 2500 BC. Egyptians were able to produce a whole range of colours for textiles by 1450 BC. After the collapse of the Roman Empire, no record is available on the developments of textile dyeing till 1371 when the dyers formed their own independent guild in Florence and made the information public about dyeing. Tab. 1.2 shows the significant developments in dyeing and printing at different times in history [2].

1.3 Status of Textiles in World Exports

According to the statistics of World Trade Organization (WTO), the current world exports of textiles are equal to US$766 billion which has increased from US$455 billion in nine years since the return of normal trading rules in 2005, when the multi-fibre arrangement quota system ended. Even during years of significant economic crisis (2008–2009), the trade data points to the enormous success of exports oriented textiles and clothing [3] as illustrated in Fig. 1.2.

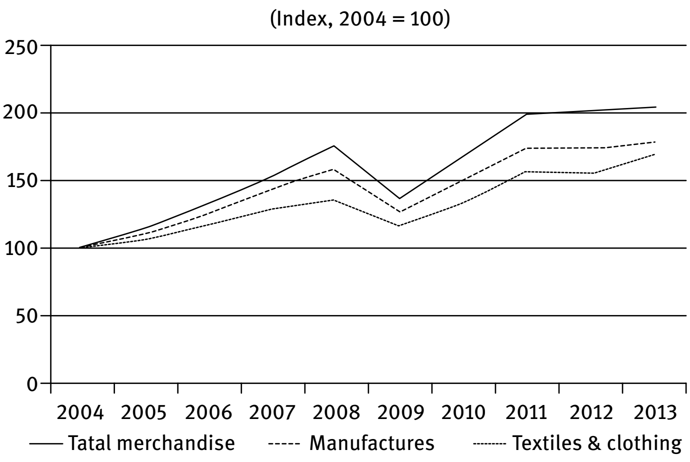

Fig. 1.2: World merchandise exports, 2004–2013.

Tab. 1.2: Evolution of dyeing material and processes [2].

Period	Evolution of dyeing material and processes
3500 BC	Dyeing Practised in China but solid evidence is missing.
2500 BC	Religious and social records suggest that Indians used to dye silk and brocades.
715 BC	Wool dyeing established as craft in Rome.
327 BC	Alexander the Great mentions "beautiful printed cottons" in India.
55 BC	Romans found painted people "picti" in Gaul dyeing themselves with Woad.
2nd and 3rd AD Centuries	Roman graves found with madder- and indigo-dyed textiles, replacing the old Imperial Purple.
273 AD	Emperor Aurelian refused to let his wife buy a purpura-dyed silk garment. It cost its weight in gold.
700s	A Chinese manuscript mentions dyeing with wax resist technique.
925	The Wool Dyers' Guilds first initiated in Germany.
1188	The first mention of Guilds for Dyers in London.
1197	King John (of Magna Carta fame) persuaded Parliament to regulate dyeing of woolens to protect the public from poor quality goods.
1212	The city of Florence had over 200 dyers, fullers and tailors. A directory of weavers and spinners was published as well.
1290	The only blue dye of the period, Woad, began to be raised extensively in Germany.
1321	Brazilwood was first mentioned as a dye, source from East Indies and India.
1472	Edward IV incorporated the Dyers' Company of London.
1507	France, Holland and Germany begin the cultivation of dye plants as an industry.
1614	Dyeing cloth "in the wood" was introduced in England: logwood, fustic, etc.
1689	The first calico printworks was begun in Germany at Augsburg and was later to grow into a large industry.
1745	Indigo begins to be grown in England, after the Revolution when it became cheaper to import from the East Indies.
1774	Swedish chemist, Scheele, discovered chlorine destroyed vegetable colors by observing a cork in a bottle of hydrochloric acid.
1774	Prussian Blue and Sulphuric acid available commercially. Prussian blue formed from prussite of potash and iron salt (copperas). Actually one of the early chemical dyes.
1785	Bell, England, who had invented printing from plates, developed roller printing.
1786	Bertholet, France, recommended chlorine water for commercial bleaching. Other oxidizing agents also came to use: hydrogen peroxide, sodium peroxide and sodium perborate.
1788	Picric acid available (yellow dye and disinfectant), could be dyed from acid dyebath on wool.
1790	Acid discharge of mordant printing developed.
1856	William Henry Perkin discovered the first synthetic dye stuff.
1858	Griess discovered diazotization and coupling on/in the fibre.
1858–1900	Discovery of process to synthesize dyes.
1914	USA importing 90 % of its dye stuffs, a problem during WWI, as many came from Germany.
1922	The AATCC (American Association of Textile Chemists and Colorists) formed its first subcommittee to study the wash-fastness of printed and dyed cottons, formulate testing procedures and standards of fastness.

World exports of textiles and clothing rose by 8 % in 2013 – four times higher than the average growth for world exports (2 %). The top ten exporters all recorded positive growth Fig. 1.3. The highest growth was seen by India, with 23 %, and the lowest was recorded by the Republic of Korea, with 2 %. The top exporters remain in the same positions, with the exception of Viet Nam which overtook the United States in 2013 as the sixth-largest exporter of textiles and clothing. China is the leading exporter of textiles and clothing, with 39 % share in the world exports of clothing and 35 % in textiles in 2013. However, due to the increasing production costs and shifting towards higher value products, China has started importing finished products from countries like Bangladesh.

The breakdown of world textile exports indicates that almost 70 % of textiles are exported from the developing countries and the least developed countries Fig. 1.4 [4].

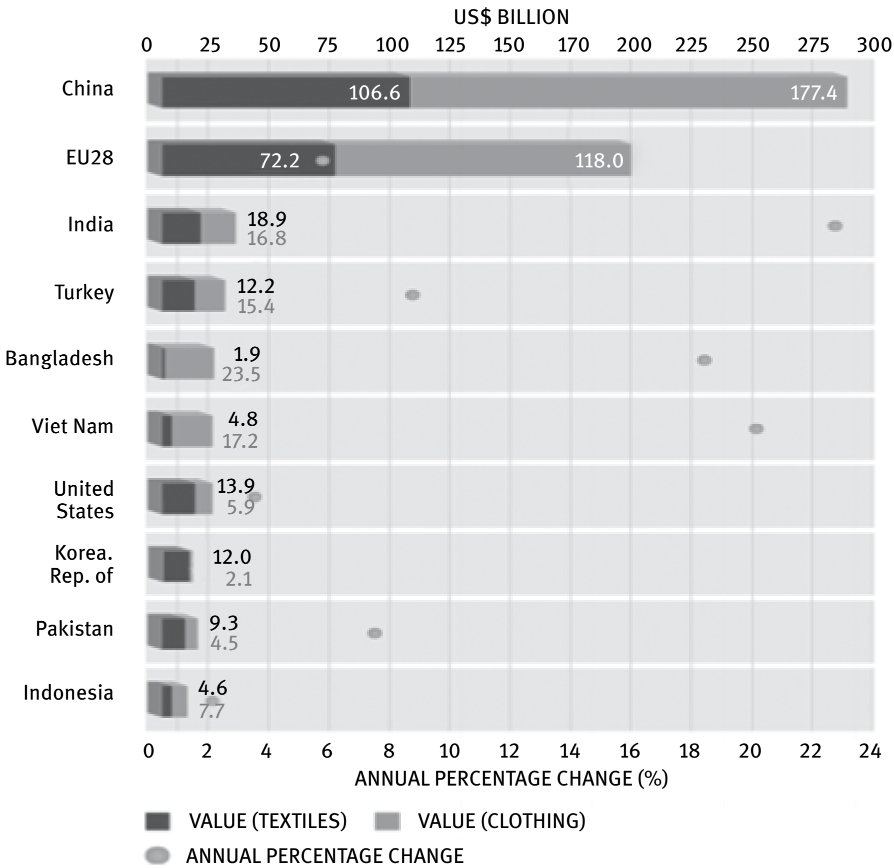

Fig. 1.3: World export of textiles and clothing.

Fig. 1.4: Economies of different countries.

References

[1] T. Gries, D. Veit, and B. Wulfhorst, *Textile Technology: An Introduction*2015: Carl Hanser Verlag GmbH & Company KG.
[2] Druding, S. C. 1982 [cited 2015 November 20]; Available from: http://www.straw.com/sig/dyehist.html.
[3] Yi, X., *World Textiles Trade and the WTO*, in *ITMF 2014 ANNUAL CONFERENCE* 2014: Beijing, China.
[4] Organization, W. T. *International Trade Statistics 2014*. [cited 2015 November 20]; Available from: https://www.wto.org/english/res_e/statis_e/its2014_e/its14_highlights2_e.pdf.

Madeha Jabbar, Khubab Shaker

2 Textile Raw Materials

2.1 Classification

On the basis of origin, the textile raw materials are classified into two main categories as shown in Fig. 2.1.

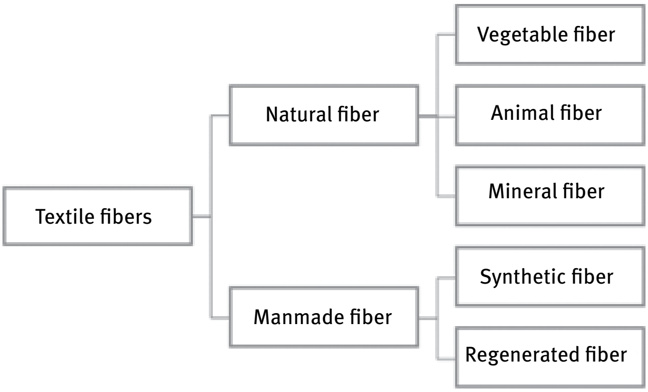

Fig. 2.1: Classification chart of textile fibers.

Natural fibers are those provided by Nature in ready-made form and need only to be extracted On the other hand, man-made fibers are generated by humans from the things which were not in fiber form previously [1].

2.2 Natural Fibers

Natural fibers are divided into three main classes according to the nature of source (origin), i. e. vegetable fibers, animal fibers, and mineral fibers as shown in Fig. 2.2. Natural fibers such as hemp, kenaf, jute, sisal, banana, flax, oil palm, etc. have been in considerable demand in recent years due to their eco-friendly and renewable nature. In addition, the natural fibers have low density, better mechanical and thermal properties and are biodegradable.

Vegetable fibers include the most important of the entire textile fibers “cotton” together with flax, hemp, jute, sisal and other fibers which are produced by plants. They are cellulose based, the material used by nature as structural material in the plant world. They can be collected from different parts of plants and are hence classified on the basis of their source of collection from the plant. Animal fibers include wool and other hair-like fibers and also fibers such as silk, produced by silk worms. These

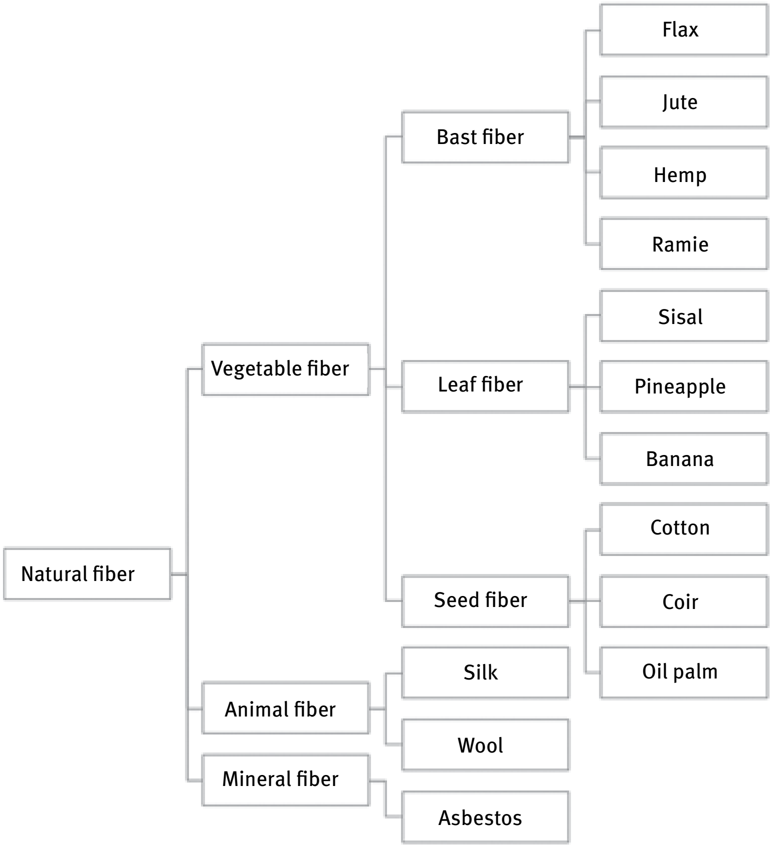

Fig. 2.2: Classification of natural fibers.

animal fibers are protein based, the complex material which most of animal body is made of. Mineral fibers are of less importance in the textile trade. Asbestos is the most useful fiber of this class. The outstanding property of asbestos fiber is its resistance to heat and burning. They are also highly resistant to acids, alkalis, and other chemicals. These fibers are used to make special fire-proof and industrial fabrics.

2.2.1 Cotton Fibers

Cotton is a soft, staple fiber that grows in a protective capsule known as boll around the seeds of cotton plant. The fiber is spun into yarn and used to make a soft, breathable textile, which is the most widely used form of textile for clothing. 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 Southern America. Cotton cultivation first spread from India to Egypt, China, and the South Pacific. Even though cotton fiber had been known already in Southern America, the large-scale cotton cultivation in Northern America began in the 16th century with the arrival of colonists to southern parts of today's United States. The largest rise in cotton production is connected with the invention of saw-tooth cotton gin by Eli Whitney in 1793. With this new technology, it was possible to produce more cotton fiber, resulting in big changes in the spinning and weaving industry.

Cotton picking by hand is still practical in nearly all countries. The common practice in hand picking is to pick the seed cotton and the boll and put it into a sack. An experienced adult can pick 300 lbs. of seed cotton per day under normal conditions. In case of automatic picking, two type of pickers are used, namely stripper and spindle picker. Hand picking is advantageous to machine picking, as fibers are picked only from the completely mature capsules. After picking, the cotton is taken to the ginning factory where fibers are separated from the seeds. The beaters used for ginning are either saw gin or roller gin. Saw gin is more economical due to advanced automation and mechanization. The seeds separated are used to extract oil for edibles or soap / candle manufacture. A pound of seed cotton can be obtained from 50–100 bolls depending on the nature of plant and condition under which it is grown.

The classification of cotton is done on the bases of fineness, staple length, maturity, degree of contamination, and strength. The fineness of fiber is denoted in dtex, i. e. number of grams per 1000 meter. The fineness of cotton fiber is most commonly expressed in terms of micronaire value, i. e. number of microgram per inch. The staple length of fiber determines the fineness of yarn. More the length of cotton fiber, finer is the yarn produced. Immature and weak cotton has a cloudy appearance, while mature cotton appears bright and has a thick cell wall. These parameters describe that fibers should be sufficiently flexible to accommodate the continuous rearrangement in spinning; have a high length to diameter ratio, permit effective consolidation and inter-fiber coherence.

Under a light microscope, cotton fibers are recognized by the presence of the lumen and convolutions, i. e. twists along the length of the fiber. Another unique feature of cotton fibers is the reversal in the direction of the spiral (fibril) structure or helix along the length of the fiber. The important characteristics of cotton fiber are given in Tab. 2.1.

Tab. 2.1: Properties of cotton fiber.

Parameter	Value
Fineness	1–4 dtex / 2.3–6.9 micronaire
Fiber length	10–60 mm
Density	1.5–1.54 g / cm^3
Moisture regain	8.5 %
Breaking strength	25–50 cN / tex
Elongation	5–10 %
Color	Creamy yellow

Cotton fiber turns yellow at temperatures above 110 °C. It is not easily damaged by sunlight; gradual loss of strength occurs on longer exposure to sunlight. Being cellulosic in nature, it dissolves in the concentrated solution of acids, but has excellent resistant to alkalis. A strong caustic solution causes the fibers to swell. Fungus and bacteria attack and degrade cotton. It serves as food for fungus. It contains mineral nutrients (salts of Na, K, Mg, and Ca) and starch which promote growth of fungus and mildew. Mildew grows in high relative humidity. Bacteria and fungus discharge enzymes which attack the cellulose and convert it to sugar. For protection, cotton is treated with materials which either inhibit the growth or kill these microorganisms.

Blending is the process of mixing different fibers into a single yarn, generally to improve the strength of yarn and give it the desired properties. Cotton blends easily with other fibers; mostly with the polyester and viscose. Its strength and absorbency make it an ideal fabric for medical and personal hygiene products such as bandages and swabs. It has low thermal conductivity, and is, therefore, ideal material for both summer and winter clothing. In summer, it prevents the skin from heat, and in winter it preserves the warmth of body. Cotton is often used in the manufacture of curtains, tents, and tarpaulins. It is also preferred widely for apparel including blouses, shirts, dresses, children's wear, active wear, separates, swimwear, suits, jackets, skirts, pants, sweaters, hosiery, and neckwear. Home fashion articles of cotton are curtains, draperies, bedspreads, sheets, towels, table cloths, table mats, and napkins. Some of the industrial applications of this fiber include ropes, bags, shoes, conveyor belts, filter cloth, medical supplies, etc.

2.2.2 Flax

Flax is probably the oldest textile fiber known to mankind. The fiber is obtained from the stem of the plant *Linum usitatissimum* which is 80–120 cm high. The flax woven fabric is also called linen. The first well-documented application of linen fabric was by the Egyptians to wrap their mummies. It was also found in graves in Egypt dating from before 5000 B. C. But even long before that time flax was used for various applications. At excavation sites of Stone Age dwellings in Switzerland, dated at approximately 7000 B. C., flax seeds, twines, and fishing nets were found. The flax plant is thought to have arrived in Europe with the first farmers, and in the Stone Age people were usually dressed in linen clothes [2]. In the Netherlands the cultivation of flax has presumably existed continuously ever since 2500 B. C.

Presently, two types of flax plant are grown, for fibers and for seeds (oil). Fiber flax is optimized for the production of thin strong fibers, while seed flax gives far more linseed and coarser fibers. The cross breeding these two extreme types had resulted in the cultivation of oil–fiber linen named as combination linen. Flax grows in moderate climates and is presently cultivated in large parts of Western and Eastern Europe, Canada, USA, and Russia. The fiber flax grows in humid, moderate areas, while oil flax grows in dry, warm areas. The characteristics of flax differ depending on the sowing and growing conditions; affecting stem length, thickness, and the number of branching.

The harvesting of flax plant is done by pulling the stalk either by hand or using a mechanical puller. Sometimes the plants are cut close to the ground, but pulling is preferred in order to retain the longest fiber length. The flax stalk bundles are then allowed to dry. Rippling is the next process, resulting in the removal of flower heads and leaves from the stem. Next, the plants are spread over the ground for retting. It is the process by which the pectin layer, holding the fiber bundles together in stem, is broken down by the combined action of bacteria and moisture.

The types of retting commonly employed for flax are water retting, enzyme retting, and dew retting. In water retting, the bundles of flax stems are immersed in the running water (rivers) or standing water (ponds or specially prepared pits). The anaerobic bacteria cause fermentation, thus degrading pectin and other binder substances. The enzyme retting employs the use of warm water and enzymes to degrade pectin. This method was developed for the production of very fine fibers. It is a controlled but rather laborious process. In dew retting, the flax stems are spread over the field. The humidity in environment causes the growth of indigenous aerobic fungi which partly degrade the stem. It is an inexpensive process, taking about three to seven weeks depending on the weather conditions.

The flax bundles are then dried, and by now the fibers must have loosened from the stem. The stem is broken by passing the bundles between the fluted rollers. The broken stem parts are then removed from the fiber bundles in the scutching process. The scutching machine consists of two interpenetrating rollers equipped with three or more knives. The knives scrape along the fiber to remove the wooden stem. The scutched fiber bundles are still relatively coarse, thick and ribbon-shaped. After scutching, the fibers are combed (hackling process), producing a thinner fiber with circular fiber structure. The elementary fiber contains about 65–75 % cellulose, 15 % hemicellulose and 10–15 % pectin, along with 2–5 % of waxes. Other properties of flax fiber are given in Tab. 2.2.

Tab. 2.2: Properties of flax fiber.

Parameter	**Value**
Fineness	10–40 dtex
Diameter	10–80 μm
Fiber length	200–800 mm
Density	1.43–1.52 g / cm^3
Moisture regain	12 %
Breaking strength	30–55 cN / tex
Elongation	2–3 %

The flax fiber does not provoke allergies, absorbs humidity, and allows the skin to breathe; therefore, it is preferred in the manufacture of summer articles. It can be washed many times without alteration; rather it becomes softer, something very important for articles of clothing and for daily use which requires frequent washing such as shirts. Linen has very low elasticity and the cloths do not deform. It has vast uses such as tableware, suiting, clothing apparel, surgical thread, sewing thread, decorative fabrics, bed linen, kitchen towels, high quality papers, handkerchief linen, shirting, upholstery, draperies, wall coverings, artist's canvases, luggage fabrics, paneling, insulation, filtration, fabrics for light aviation use, automotive end uses, and reinforced plastics and composite materials, etc. The ability of flax fiber to absorb water rapidly is particularly useful in the towel trade.

2.2.3 Jute

Jute is known as the "golden fiber" due to its golden brown color and its importance. Jute belongs to bast fiber category and is normally spun in the form of coarse threads. Contrary to most vegetable fibers which consist mainly of cellulose, jute fibers are part cellulose and part lignin. Jute fiber offers strength, low cost, high durability, and versatility. It is a cheap natural fiber having variety of end uses, for example to make hessian sacks, garden twine, ropes, and carpets. It is most popular in the agriculture sector to control soil erosion, seed protection, and weed control. It is used for technical applications in the area of geotextiles. Jute is being replaced by synthetic materials for many of these uses, but the biodegradation and sustainability are the main advantages of jute over synthetic fibers.

The jute plant becomes ready for harvesting in 120 days, and is either pulled by hand or cut by sharp edge. These stems are then tied into bundles for retting. The process of retting involves immersion of the stem in water until the bacterial action makes it possible to release the fibers within the stalk. It takes about 12–25 days for completion of retting. Stripping means removal of jute fibers from stem. The most common method is manual stripping, performed by beating the bark gently with a wooden mallet, starting from stem base. The fibers are then separated and dried. The properties of jute fiber are given in Tab. 2.3.

Tab. 2.3: Properties of jute fiber.

Parameter	Value
Fineness	2–3 dtex
Diameter	15–25 μm
Fiber length	650–750 mm
Density	1.44 g / cm^3
Moisture regain	13.75 %
Breaking strength	30–34 cN / tex
Elongation	2–8.2 %

2.2.4 Other Vegetable Fibers

Other commonly used vegetable fibers include coir, oil palm, pineapple, banana, hemp, ramie, sisal, etc. Coir is a coarse, short fiber extracted from the outer shell of coconuts. Its low decomposition rate is a key advantage for making durable geotextiles. Coir fibers measure up to 35 cm in length with a diameter of 12–25 microns. Among vegetable fibers, coir has one of the highest concentrations of lignin, making it a stronger fiber [3]. Brown coir is used in sacking, brushes, doormats, rugs, mattresses, insulation panels, and packaging.

Oil palm is the highest yielding edible oil crop in the world. The trunk, frond and empty fruit bunch (EFB) of the oil palm tree can be used for the extraction of lignocellulosic fibers. The EFB has a potential to yield up to 73 % fibers and hence it is preferable in terms of availability and cost.

Sisal fiber is derived from the leaves of the sisal plant. It is usually obtained by machine decortications in which the leaf is crushed between rollers and then mechanically scraped. The fiber is then washed and dried by mechanical or natural means. The dried fiber represents only 4 % of the total weight of the leaf. Once it is dried the fiber is mechanically double brushed. The lustrous strands, usually creamy white, average from 80 to 120 cm in length and 0.2 to 0.4 mm in diameter. Sisal fiber is fairly coarse and inflexible. It is valued for cordage (ropes, baler, binder twines, etc.) use because of its strength and durability. The higher-grade fiber after treatment is converted into yarns and used by the carpet industry.

Banana plant not only gives the delicious fruit but also provides fiber for textile applications. The fiber is obtained after the fruit is harvested. The small pieces of banana plant trunk are put through a softening process for mechanical extraction of the fibers with subsequent bleaching and drying. The fiber obtained has appearance similar to silk which has become popular as banana silk fiber yarn. In the recent past, banana fiber had a very limited application for making items like ropes, mats, and some composite materials. With the increasing environmental awareness and importance of eco-friendly fabrics, it is finding applications in other fields such as apparels and home furnishings.

The stalk of the hemp plant produces two types of fibers: long (bast) fibers and short (core) fibers. Bast fibers can be cleaned, spun and then woven or knitted into many fabrics suitable for durable and comfortable clothing and housewares. Fabrics with at least 50 % hemp content block the sun's UV rays more effectively than the other fabrics. In comparison with cotton, hemp fibers are longer, stronger, more lustrous, absorbent, and more mildew resistant. Hemp textiles are extremely versatile – they are used in the production of clothing, shoes, apparel, canvas, rugs, and upholstery.

Ramie is one of the oldest vegetable fibers; used for mummy cloths in Egypt during 5000–3000 B. C. It belongs to the category of bast fibers and need chemical treatment to remove the gums and pectin found in the bark. The fiber is very fine like silk, and being naturally white in color does not need bleaching. Ramie is commonly used in clothing, tablecloths, napkins, and handkerchiefs. Outside the clothing industry, ramie is used in fish nets, canvas, upholstery fabrics, straw hats and fire hoses. Ramie is resistant to bacteria, mildew, alkalis, rotting, light, and insect attack. It is extremely absorbent and naturally stain resistant. On the other hand, it is low in elasticity, lacks resiliency, low abrasion resistance and wrinkles easily [4]. A comparison of the properties of common natural fibers is provided in Tab. 2.4.

Tab. 2.4: Properties of other vegetable fibers.

Parameter	Hemp	Ramie	Sisal	Coconut
Fineness	2–6 dtex	5–13 dtex	–	–
Diameter	15–50 µm	40–80 µm	22–80 µm	16 µm
Fiber length	600–750 mm	500 mm	1000–1250 mm	150–300 mm
Density	1.48–1.5 g / cm^3	1.5 g / cm^3	1.16 g / cm^3	1.46 g / cm^3
Moisture regain	12 %	8.5 %	11 %	13 %
Breaking strength	35–70 cN / tex	40–70 cN / tex	30–45 cN / tex	12–18 cN / tex
Elongation	1–6 %	2–3 %	2–3 %	25–27 %

2.2.5 Wool

Wool is an animal fiber obtained by shearing the fibrous covering of sheep and is produced in almost all parts of the world. Sheep are commonly shorn for their fleece once or twice a year and the raw wool obtained is known as fleece. An efficient shearer would remove the fleece from a sheep in 2 minutes. Wool is also removed from the pelts of slaughtered sheep by chemical treatment or bacterial action without damaging the hide. Raw wool is often dirty and contaminated with natural fats, grease and perspiration residues. All these impurities are removed during wool scouring and wool carbonising to get cleaned wool.

The breed of the sheep as well as the environmental conditions strongly affect the quality of wool. The wool also differs in fineness, length and purity depending on the body part of sheep from which it is taken. Wool may be broadly classified into fine wool, medium wool, long wool and carpet wool. Wool is usually spun into two types of yarn i. e. woolen and worsted. Woolen yarns are usually made from short staple fibers which are held loosely and given only a limited twist during spinning. Worsted yarns are much finer, regular, tightly twisted, and smoother than woolen. These are usually spun from longer staple fibers.

Wool fiber has a natural crimp due to its unique chemical and physical structure. This causes the fiber to bend and turn, giving wool an inherent three dimensional crimp [5]. Because it is naturally elastic and resilient, wool imparts to all products that are made from it, many unique properties: rapid wrinkle recovery, durability, bulk, loft, warmth, and resistance to abrasion. Wool can easily absorb up to 30 % of its weight in moisture without feeling damp or clammy. Wool contains moisture in every fiber, it resists flame without chemical treatment. Instead of burning freely when touched by flame, wool chars and stops burning when it is removed from the source of the flame. Wool is self-extinguishing; it will not support combustion.

2.2.6 Silk

Silk is a protein fiber of insect origin, being produced as a fine filament of long length from the body fluid of silkworm (*Bombyx Mori*). The silkworms eat only the leaves of mulberry tree. Silk is a polypeptide, formed from four different amino acids. Silk fibers are relatively stiff and show good to excellent recovery from deformation depending on the temperature and humidity conditions. These fibers exhibit favorable heat-insulating properties but owing to their moderate electrical resistivity, they tend to build up static charge.

The four stages in the life cycle of a silkworm are egg, caterpillar, larva (cocoon), and butterfly. Caterpillars come out of the eggs after hatching for 12 days. During the growth period of the caterpillar, fresh mulberry leaves are its food. After 35 days, the caterpillars are ready for spinning silk. They stop eating and produce their cocoon in a few days. Silkworm makes its cocoon from a twin filament that extrudes from two silk glands in its head. These filaments are coated and glued together by gummy substance called sericin. The worm gradually gets covered and captivated in a strongly structured cocoon made from continuous silk strand (may be up to a mile in length). This filament silk is unwind from the cocoons. The properties of silk fiber are given in Tab. 2.5.

Tab. 2.5: Properties of silk fiber.

Parameter	Value
Fineness	1–3.5 dtex
Diameter	10–13 μm
Fiber length	700–1500 m
Density	1.37 g / cm^3
Moisture regain	9–11 %
Breaking strength	25–50 cN / tex
Elongation	10–25 %
Color	Lustrous white

The fibroin of silk is decomposed by concentrated acids into the constituent amino acids. Silk is more resistant to alkalis and organic solvents, except hydrogen bond-breaking solvents. Continuous exposure of silk fiber to sunlight results in strength loss. It begins to yellow at high temperatures and disintegrates above 165 °C. The moisture absorption results in a temporary 10–25 % strength loss of silk fiber. It is easily attacked by moth and mildew.

2.3 Man-made Fibers

Man-made fibers are classified into synthetic and regenerated fibers as shown in Fig. 2.3. The polymers used for the spinning of synthetic fibers are chemical based, while regenerated fibers are derived from a natural polymer, most commonly cellulose.

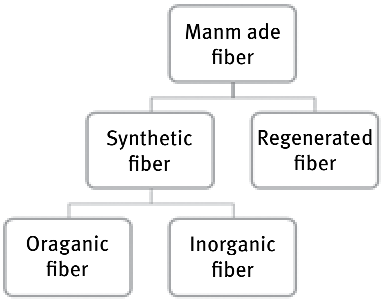

Fig. 2.3: Classification of man-made fibers.

2.3.1 Spinning of Man-made Fibers

There are three most common techniques employed in the production of man-made fibers namely wet spinning, melt spinning, and dry spinning as shown in Fig. 2.4. These techniques vary in the method of liquefying the raw material (powder or pellet). The term spinning here defines the extrusion process of liquefied polymer through spinnerets to solidify in a continuous flow. The melt spinning is a simple transformation of the physical state; however, it can be applied only to polymer having a melting temperature, e. g. PA 6, PA 6.6, PES, PP, etc. In melt spinning, the extruded polymer is transformed directly into a filament owing to its fast cooling, and cross-sectional form remains unchanged [6].

In case of solution spinning, the polymer is dissolved in variable concentrations according to the kind of polymer and of solvent to produce a viscous liquid (dope). It is used for the polymers that degrade thermally at a temperature lower than melting point (cellulosic fibers). The extruded filaments are subject to structural changes due to solvent extraction from the polymer mass. The solution spinning is further divided into type, dry spinning, and wet spinning. In dry spinning, the solvent is removed by flow of warm gas directed to the extruded filaments. The wet spinning method involves introduction of extruded polymeric viscose into a coagulation bath, where water behaves as a solvent for the polymer solvent and as a non-solvent for the polymer mass.

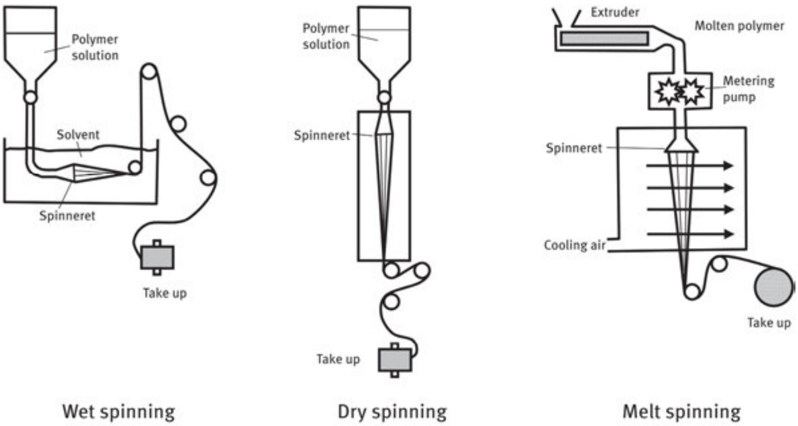

Figure 2.4: Spinning techniques for man-made fibers.

2.4 Regenerated Fibers

The basic element of a cellulose macromolecule is glucose. The empirical formula of cellulose is $(C_6H_{10}O_5)_n$, where n represents the number of glucose molecules constituting the cellulose macromolecule and is called the degree of polymerization (DP). The α-cellulose (insoluble in cold dilute NaOH) has a DP greater than 200, while β-cellulose (hemicelluloses soluble in cold dilute NaOH) has DP less than 200. Wood pulp is used as the raw material for cellulose, and is refined to increase the percentage of α-cellulose. The percentage of up to 99 % can be obtained depending on the cleaning method. The regenerated fibers are produced according to the viscose spinning method.

2.4.1 Viscose Fiber

The production of viscose fiber involves the process of solution spinning. The viscose solution for spinning is prepared by treating cellulose with NaOH producing alkali cellulose. This alkali cellulose reacts with carbon disulphide to give cellulose xanthate, which on dissolution in NaOH gives viscose solution. This solution is extruded from the spinneret into the spinning bath. The composition of spinning bath, its temperature, and spinning speed are adjusted according to the type of fiber to be spun. The solidification into yarn takes place in the spinning bath. These spun fibers are drawn to achieve a regular orientation of the chain molecules.

The spun fibers are further treated to remove impurities, increase brightness, and improve adhesive and frictional properties. These treatments may include washing, bleaching, application of some finish, etc. The spinning process parameters allow the manipulation of properties to a wider level, producing certain fibers like high tenacity viscose, highly crimped viscose, hollow fibers, modal, etc. By the addition of suitable chemicals in viscose solution or spinning bath, spin dyed, flame retardant fibers, etc. can be produced.

2.4.2 Acetate Fiber

The raw material for the production of acetate fibers is also cellulose, but they are composed of cellulose ester. The cellulose is mixed with acetic anhydride and glacial acetic acid under addition of wet splitting chemicals. The spinning is carried out according to the dry spinning technique. The spinning solution is transported to the spinning pump and extruded through spinneret. The filaments exiting the spinneret are passed through stream of warm air in the quench duct which leads to evaporation of solvent acetone and alcohol and freezing of filaments. During the passage, the filaments are drawn, combined, oiled, and wound onto bobbins. The properties of common regenerated fibers are given in Tab. 2.6.

Tab. 2.6: Properties of regenerated fibers.

Parameter	Viscose	Cupro	Acetate
Fiber length	38–200 mm	–	40–120 mm
Tenacity	15–30 cN / tex	16–25 cN / tex	20–40 cN / tex
Elongation	15–30 %	16–25 %	20–40 %
Density	1.52 g / cm^3	1.52 g/ cm^3	1.29–1.33 g/cm^3
Modulus	8–12 cN / tex	40–60 cN/tex	8 cN/tex
Melting point	175–205 °C	175–205 °C	250 °C

2.5 Synthetic Fibers

The synthetic fibers are result of the extensive research to improve the properties of naturally occurring animal and vegetable fibers. These synthetic fibers are produced by the extrusion of a polymeric material having synthetic origin through spinneret into air or water. This fiber forming polymers are obtained generally from petro chemicals. Therefore, these fibers are called synthetic fibers.

2.5.1 Nylon

Nylon 6.6 was the first synthetic fiber produced in 1935 in USA. A parallel development in Germany led to the production of continuous filament (Nylon 6) in 1939 [7]. Nylon fibers are made up of linear macromolecules whose structural units are linked by the amide (–NH–CO–) group. Therefore, these fibers are termed as the polyamides. The most common way for the production of nylon polymers is by the condensation of diamines with diacids. In nylon 6 the molecules are directional with all of the amide links in a particular direction, e. g. –NH–CO–, while in nylon 6.6 there is a reversal in the order of alternate amide linkages.

Nylon 6

$-NH-CH_2-CH_2-CH_2-CH_2-CH_2-CO-$

Nylon 6.6

$-NH-CH_2-CH_2-CH_2-CH_2-CH_2- CH_2-NH -OC- CH_2-CH_2-CH_2-CH_2-CH_2-CO-$

The nylon fibers are produced by the extrusion of molten polymer and no solvents are involved. The polymer chips are melted by a heated grid, or by an extruder where a screw forces the chips along a heated tube. The molten polymer is fed to a controlled metering pump which helps to control the linear density of the fiber. The molten polymer is fed to the spinneret at a temperature of 280–300º C and against a pressure as high as 50–70 MPa. The spinneret is a stainless steel plate, 5 mm or more in thickness, having a number of small holes (100–400 μm in diameter). The number of holes corresponds to the number of filaments required in the final yarn. The polymer emerging from the spinneret holes is drawn down by a take up reel and undergoes a considerable acceleration. The accelerated filaments solidify in the cool air. The properties of nylon fiber are given in Tab. 2.7.

Tab. 2.7: Properties of nylon fiber.

Parameter	Nylon 6.6	Nylon 6
Melting point	255–260 °C	215–220 °C
Softening point	235 °C	170 °C
Modulus	20–35 cN / tex	15–35 cN / tex
Breaking strength	40–60 cN / tex	40–60 cN / tex
Elongation	20–30 %	20–40 %

At a temperature of 21 °C with an R. H. of 65 %, nylon 6.6 or 6 contains 3.5–4.5 % of water by weight as a proportion of the mass of dry fiber. Exposure of nylon 6.6 and 6 to air at temperatures above 100 °C results in a loss of both tenacity and breaking elongation. Exposure to sunlight and other sources of UV radiation also leads to deterioration in the properties of nylons. Nylons are only slowly affected by water at the boiling point. Nylon 6.6 is inert to alkali solution while sensitive to acids. Nylon 6 and 6.6 are inert to most common organic solvents, but they do dissolve in concentrated formic acid and phenols.

2.5.2 Polyester

Polyethylene terephthalate (PET), also called polyester fiber dominates the world synthetic fibers industry. They are inexpensive, easily produced from petrochemical sources, and have a desirable range of physical properties. They are strong, lightweight, and wrinkle-resistant, having good wash–wear properties. Polyester, produced by the condensation polymerization of a dicarboxylic acid with a diol, contains in-chain ester units as their essential polymer-forming chain linkage [8].

Alcohol (R–OH) + Carboxylic acid (R–COOH) → Ester

where R is an alkyl group.

The filament polyester fiber is produced by melt spinning under different conditions. The polymer is melted at a temperature some 15–25 °C above its melting temperature in a screw-extruder. The polymer melt is precisely metered by a positive displacement gear pump which delivers a fixed amount of polymer melt per revolution. The molten polymer is forced through tiny holes (0.180–0.400 mm) in the spinneret plate. The polymer solidifies as it emerges from the spinneret. The cooling process is accelerated by controlled flow of air. The polymer is also drawn down, i. e. stretched in semi-molten state to induce molecular order and orientation in the fiber. The properties of polyester are given in Tab. 2.8.

Tab. 2.8: Properties of polyester fiber.

Parameter	Polyester
Melting point	480 °C
Softening point	460 °C
Modulus	800–1000 cN / tex
Breaking strength	40–60 cN / tex
Elongation	10–20 %
Density	1.22–1.38 g / cm^3
Moisture regain	0.4–0.8 %

2.5.3 Other Synthetic Fibers

The most common among other synthetic fibers are polyolefins, acrylics, and elastane. Olefin fiber is a manufactured fiber. In these fibers, the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 % by weight of ethylene, propylene, or other olefin monomers. Olefin fiber is a generic description that covers thermoplastic fibers derived from olefins. Polypropylene (PP) and polyethylene (PE) are the two most common members of the family. The polypropylene yields greatest volume of fiber for a given weight, because of its low specific gravity i. e. 0.90–0.91 g / cm^3.

Polypropylene does not exhibit a static behavior in normal circumstance. Like other synthetic fibers i. e. nylon, acrylic, and polyester – polypropylene fibers are not attacked by bacteria or micro-organisms; they are also moth-proof and rot-proof and are inherently resistant to the growth of mildew and mold. Polypropylene is hydrophobic and will not absorb water in the fiber. A comparison of the properties is given in the Tab. 2.9.

Tab. 2.9: Properties of synthetic fibers.

Parameter	Polyethylene	Polypropylene	Elastane
Fiber length	38–200 mm	38–200 mm	–
Tenacity	32–65 cN / tex	15–60 cN / tex	4–12 cN / tex
Elongation	10–45 %	15–200 %	400–800 %
Density	0.95–0.96 g / cm³	0.9 g / cm³	1.1–1.3 g / cm³
Modulus	15–30 cN / tex	13–15 cN / tex	0.05–0.1 cN / tex
Melting point	125–135 °C	160–175 °C	230 °C

2.5.4 Glass Fiber

Glass is a non-metallic fiber, widely used as industrial material these days. Generally the glass state is defined as the frozen state of a super cooled and thus solidified liquid. The basic raw materials for glass fiber include a variety of natural minerals and manufactured chemicals. The major ingredients are silica sand, limestone, and soda ash. Silica sand is used as the glass former, while soda ash and limestone help to lower the melting temperature. A low coefficient of thermal expansion combined with low thermal conductivity properties make glass fiber a dimensionally stable material that rapidly dissipates heat as compared to asbestos and organic fibers.

They are produced by direct melting, involving processes of batching, melting, spinning, coating, drying, and packaging. Batching is the initial state of glass manufacture, material quantities are thoroughly mixed at this stage. The mixture is then taken to furnace at a high temperature of 1400 °C for melting. This temperature is high enough to convert the sand and other ingredients into molten state. The molten glass then flows into the refiner, where its temperature is reduced to 1370 °C. Spinning of glass fiber involves a combination of extrusion and attenuation. During this process the molten glass passes out through a bushing with very fine orifices. Bushing plates are heated electronically, and their temperature is controlled to maintain a constant viscosity. Water jets are used to cool the filaments as they exit the bushing at roughly 1204 °C.

Attenuation is the process of mechanically drawing the extruded streams of molten glass into filaments, with a diameter ranging from 4 μm to 34 μm. A high-speed winder is used to provide tension, and draw the molten stream into thin filaments. In the final stage, a chemical coating of lubricants, binders and/or coupling agents is applied to the filaments. The lubrication will help to protect the filaments from abrasion when collected and wound into packages. The packages, still wet from water cooling and sizing, are then dried in an oven. Afterwards, the filaments are ready for further processing into chopped fiber, roving, or yarn.

It is an inorganic material and does not burn or support combustion, retaining approximately 25 % of its initial strength at 540 °C. Most chemicals have little or no effect on glass fiber. The inorganic glass textile fibers will not mildew or deteriorate. Glass fibers are affected by hydrofluoric, hot phosphoric acids and strong alkaline substances. It is an excellent material for electrical insulation. The combination of properties such as low moisture absorption, high strength, heat resistance and low dielectric constant makes fiber glass fabrics ideal as reinforcement for printed circuit boards and insulating varnishes.

The high strength-to-weight ratio of glass fiber makes it a superior material in applications where high strength and minimum weight are required. In textile form, this strength can be unidirectional or bidirectional, allowing flexibility in design and cost. It is extensively used in automotive market, civil construction, sporting goods, aviation and aerospace, boats and marine, electronics, home and wind energy. They are also used in the manufacture of structural composites, printed circuit boards and a wide range of special-purpose products.

2.5.5 Carbon Fiber

A carbon fiber is a long, thin strand about 5–10 µm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the axis of the fiber. This crystal alignment makes the fiber incredibly strong. Several thousand carbon fibers are joined together to form a yarn. Carbon fibers were developed in the 1950s, by heating strands of rayon until they carbonized. This process was inefficient, as the resulting fibers contained only about 20 % carbon and had low strength and stiffness properties. In the early 1960s, a process was developed using PAN as a raw material. This produced a carbon fiber that contained about 55 % carbon and had much better properties.

During the 1970s, experimental work to find alternative raw materials led to the introduction of carbon fibers made from a petroleum pitch derived from oil processing. These fibers contained about 85 % carbon and had excellent flexural strength. But they had limited compression strength and were not widely accepted. About 90 % of the carbon fibers produced are made from PAN. The remaining 10 % are made from rayon or petroleum pitch. All of these materials are organic polymers, characterized by long strings of molecules bound together by carbon atoms. A typical process used to form carbon fibers from PAN includes spinning, stabilization, carbonizing, surface treating, and sizing.

In the spinning process, acrylonitrile powder is mixed with another material like methyl acrylate or methyl methacrylate, and is reacted with a catalyst in a suspension to form PAN plastic. It is then either spun into fibers via coagulation, or heated and pumped through tiny jets into a chamber where the solvents evaporate producing a solid fiber. The fibers are then washed and stretched to the desired fiber diameter. These fibers are stabilized by heating in the presence of air to about 200–300 °C for 30–120 minutes. The fibers pick up oxygen from the air and rearrange the atomic bonding pattern, resulting into a thermally stable ladder bonding.

The stabilized fibers are heated to a temperature of 1000–3000 °C for several minutes in a furnace filled with a gas mixture, other than oxygen. The lack of oxygen prevents the fibers from burning at very high temperature. Heated fibers lose their non-carbon atoms in the form of various gases like water vapor, ammonia, carbon monoxide, carbon dioxide, hydrogen, nitrogen, and others. The remaining carbon atoms form tightly bonded carbon crystals that are aligned parallel to the long axis of the fiber. The surface treatment of these fibers is performed to improve the fiber bonding properties. In sizing process the fibers are coated to protect them from damage during winding or weaving. Typical coating materials include epoxy, polyester, nylon, urethane, and others. The coated fibers are wound onto cylinders called bobbins.

The carbon fibers are an important part of many products, and new applications are being developed every year. Carbon fiber-reinforced composite materials are used in the automotive and aerospace industry, sports and many other components where light weight and high strength are needed. Carbon fibers have high electric conductivity (volumetric impedance) and at the same time have excellent EMI shielding property. This successfully brings CFRP (Carbon fiber reinforced plastics) to the field of EMI shielding. Carbon fibers have low heat expansion ratio and high dimensional stability, and sustains its mechanical performances even under high temperature region. CFRP is superior to steel or glass fiber reinforced plastics (GFRP) in its specific tensile strength and specific elastic modulus (specific rigidity). Fatigue resistance of Carbon fiber surpasses that of other structural material.

References

[1] B. Wulfhorst, O. Maetschke, M. Osterloh, A. Busgen, and K.-P. Weber, *Textile Technology*. Germany: Hanser Publishers, 2006.

[2] H. L. Bos, *The potential of flax fibers as reinforcement for composite materials*. Eindhoven University of Technology, 2004.

[3] B. P. Corbman, *Textiles: Fiber to fabric*, 6th ed. New York: McGraw-Hill, 1983.

[4] B. J. Collier, and P. G. Tortora, *Understanding textiles*, 6th ed. New Jersey: Prentice Hall, 2001.

[5] M. M. Houck, Ed., *Identification of textile fibers*. Cambridge: Woodhead Publishing Limited, 2009.

[6] C. Andreoli, and F. Freti, Eds., *Man-made Fibers*, 2nd ed. ACIMIT, 2006.

[7] J. E. McIntyre, Ed., *Synthetic fibers: nylon, polyester, acrylic, polyolefin*, 1st ed. Cambridge: Woodhead Publishing Limited, 2005.

[8] A. R. Horrocks, and S. C. Anand, Eds., *Handbook of technical textiles*. New york: woodhead publishing Ltd, 2000.

Zulfiqar Ali

3 Yarn Manufacturing

3.1 Introduction

First a brief introduction is given of the terms used in yarn manufacturing.

3.1.1 Yarn

It is an assembly of substantial length and relatively small cross-section of fibres and or / filaments with or without twist. Yarn occurs in the following forms [1]:

a. A number of fibres twisted together;
b. A number of filaments laid together without twist (a zero-twist yarn);
c. A number of filaments laid together with a degree of twist;
d. A single filament with or without twist (a monofilament); or
e. A narrow strip of material, such as paper, plastic film, or metal foil, with or without twist, intended for use in a textile construction.

3.1.2 Spun Yarn

The yarn which consists of staple fibres held together by twist is known as spun yarn. The yarns produced on ring spinning, open end rotor spinning and air jet spinning systems, all are the spun yarns.

3.1.3 Yarn Number

The number which shows the fineness or coarseness of yarn is called yarn number. There are two systems of yarn numbering.

i. Direct system
ii. Indirect system

In direct system, yarn number is called the linear density of yarn with units of tex, denier and dtex, etc. Similarly, in the indirect system yarn number is called the yarn count with units of N_{EC}, Nm and N woollen, etc.

Following is the detailed explanation of these two systems:
– Indirect system

It is used for the measurement of length per unit weight of the yarn. In this system, weight is kept constant while length is variable.

In the indirect system, yarn thickness and yarn number are inversely proportional. This means that as the yarn count increases the yarn weight decreases and hence yarn becomes finer.

The indirect system is also known as English system of counting. The most commonly used indirect numbering systems are

1. English Cotton $Nec = \frac{No.\ of\ hanks}{lbs}$
2. Metric system $Nm = \frac{Km}{Kg}$
3. Worsted $N = \frac{No.\ of\ hanks}{lbs}$

Different hank lengths for different fibres are given in Tab. 3.1

Tab. 3.1: Different hank lengths for different fibers.

Nature of Fiber	Hank Length
Cotton	840 yards
Spun silk	840 yards
Wool	256 yards
Worsted	560 yards
Linen	300 yards
Jute	14400 yards

– Direct system

It is used for the measurement of linear density that is the weight per unit length of yarn. In this system yarn length is kept constant and weight is variable.

$$Linear\ density = \frac{mass}{length}$$

In the direct system, yarn thickness and yarn number are directly proportional. The most widely used direct numbering systems are:

a. Tex (Tex = No. of grams / 1000 m)
b. Grex (Grex = No. of grams / 10,000 m)
c. Denier (Denier = No. of grams / 9000 m)

3.2 Yarn Production

Yarn production is a process of converting fibres into yarn. It consists of different processes. Flow charts of cotton carded ring spun, cotton combed ring spun, open end rotor spun and air jet spun yarns are given in Tab. 3.2–3.5, respectively.

Tab. 3.2: Flow chart of cotton carded ring spun yarn along with input and output.

Input materials	Process machines	Output materials
Raw cotton	Blow room	Lap / Tufts
Lap	Card	Carded Sliver
Carded Sliver	Drawing 1	Breaker Drawn Sliver
Breaker Sliver	Drawing 2	Finisher Drawn Sliver
Finisher Drawn Sliver	Simplex	Roving
Roving	Ring frame	Yarn
Yarn	Auto winding	Yarn Cones

Tab. 3.3: Flow chart of cotton combed ring spun yarn along with input and output.

Input material	Process machines	Output materials
Raw cotton	Blow room	Lap / Tufts
Lap	Card	Carded Sliver
Carded Sliver	Drawing	Drawn Sliver
Drawn Sliver	Lap former	Mini Lap
Mini Lap	Comber	Combed Sliver
Combed Sliver	Drawing	Combed Drawn Sliver
Combed Drawn Sliver	Simplex	Roving
Roving	Ring frame	Yarn
Yarn	Auto winding	Yarn Cones

Tab. 3.4: Flow Chart of cotton carded rotor spun yarn along with input and output.

Input material	Process machines	Output materials
Raw cotton	Blow room	Lap / Tufts
Lap	Card	Carded Sliver
Carded Sliver	Drawing	Drawn Sliver
Drawn Sliver	Open End Rotor Machine	Yarn Cone

Tab. 3.5: Flow chart of air jet spun yarn along with input and output.

Input material	Process machines	Output materials
Raw cotton	Blow room	Lap / Tufts
Lap	Card	Carded Sliver
Carded Sliver	Drawing 1	Drawn Sliver
Drawn Sliver	Drawing 2	Finisher Drawn Sliver
Finisher Drawn Sliver	Air jet machine	Yarn Cone

3.2.1 Lap

A sheet of fibres wrapped around a rod / or roller to facilitate transfer from one process to the other is called lap [2]. Output of Scutcher and Lap former are the examples of lap. Width of lap produced by lap former is about one third of the scutcher lap so it is called mini lap.

3.2.2 Sliver

The assemblage of loose, roughly parallel fibres in continuous form without twist is called sliver [2]. Outputs of card and drawing are the examples of sliver.

3.2.3 Roving

A name given, individually or collectively, to the relatively fine fibrous strands used in the later or final processes of preparation for spinning is roving [2]. Output of roving frame which is used as input for Ring frame is the example of roving.

3.3 Basic Preparatory Processes for Spinning Operations

Fibres in the bale form are not suitable to start the yarn manufacturing. There are number of processes to make them suitable for spinning. Following subsections describe the basic preparatory processes which may be used as per the end products requirements.

3.3.1 Preparation of Cotton to Feed the Blow Room

After opening the strips of selected bale / bales and cleaning the sides, small tufts from the bales are taken and spread on the floor selected area for making the layers of heap, as shown in Figure 3.1. A number of horizontal layer upon layers are made till the end of bales. This heap of cotton is left for 24 hours to release the packing pressure and condition the material so that moisture in the material becomes homogeneous.

Fig. 3.1: Heap of opened cotton.

3.3.2 Blow Room

Blow room line consists of different machines and each manufacturer provides its own line of machines. The sequence of machines in a typical blow room line is shown in the Fig. 3.2.

Objectives of a blow room line are as follows:
- Opening: To open the compressed fibres up to very small tufts
- Cleaning: To remove the impurities like seed fragments, stem pieces, leaf particles, neps, short fibres, dust and sand
- Mixing and blending: To make homogenous mixture of the material
- De-dusting: To extract the dust if present
- Uniform feed for card: To convert the mass of fibres into thick sheet called lap which should be uniform length and width wise or to provide output in the form of tufts of optimum size

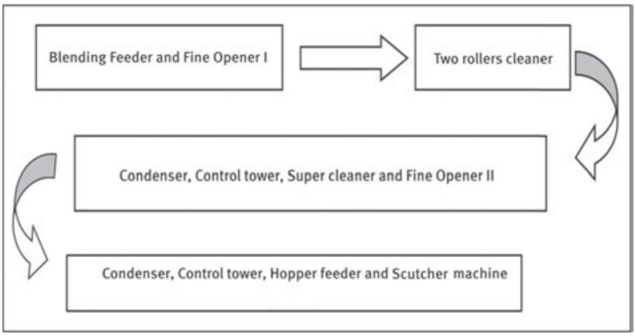

Fig. 3.2: Ohara blow room line.

Following is the blow room operation summary:

Cotton is fed manually on the feed belt of the blending feeder. The opening, cleaning and blending is carried out by the inclined lattice and evener roller. The stripper roller transports this material to the feed lattice of fine opener-I. Fig. 3.3 shows the material flow through the blending feeder machine. The beater of fine opener-I beats it against the grid bars for cleaning. This material is sucked by a condenser transport fan through two rollers cleaner, which performs the opening, cleaning and dust extraction of cotton.

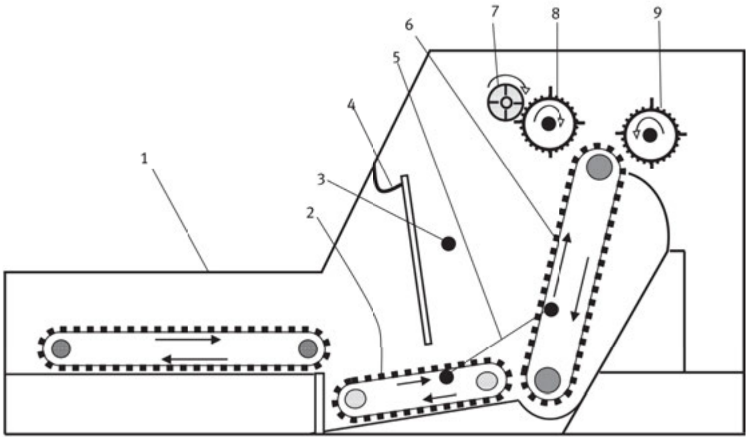

Fig. 3.3: Material flow through blending feeder (1) Feed Table, (2) Internal Feed Lattice, (3) Light Barriers, (4) Baffle Plate, (5) Brush Rolls, (6) Spiked Lattice, (7) Cleaner Roller, (8) Evener Roller, (9) Stripper Roller.

The cage of the condenser separates the dusty air from the material and delivers it on the control tower feed rollers. A beater in the control tower beats the material against the grid bars and transfers to the spiked rollers of super cleaner. The six spiked rollers of super cleaner perform the opening and cleaning of material and deliver it to the feed lattice of fine opener-II. Where a Krishnor beater with steel pins further reduce the tuft size and help in cleaning.

The opened and cleaned material from the fine opener-II is sucked by cage condenser fan and then it is delivered to the control tower. At the bottom of the control tower the material is fed to a beater with the help of a pair of feed rollers. The beater treats the material against the grid bars for cleaning and transfers to the feed lattice of the Hopper feeder. A spiked lattice and an evener roller in the Hopper feeder perform the operation of blending, opening and cleaning. A stripper roller delivers the material to the feed lattice of the scutcher through a condensing box.

The Scutcher consists of a regulating feed unit, pin beater, lap forming cage, calendering unit and lap winding unit. The incoming feeding material in the form of a bulky sheet is checked length-wise and width-wise by a regulating feeding system. Thus a uniform amount of material is fed to the beater. The beater further opens and cleans the material and delivers it to the cage, which makes a lap sheet. The calender rollers compact this lap sheet while shell rollers wind it on a lap rod. Thus a compact roll of lap sheet is delivered by the scutcher, which is transferred manually on a trolley to the next machine called the card.

In the latest blow room lines, the material from fine opners / cleaners is transferred to the card directly by a fan through a chute feed system which is attached at the back of the card. Fig. 3.4 shows the latest blow room line in which the scutcher is excluded and fine cleaner delivery pipes are directly connected to the cards.

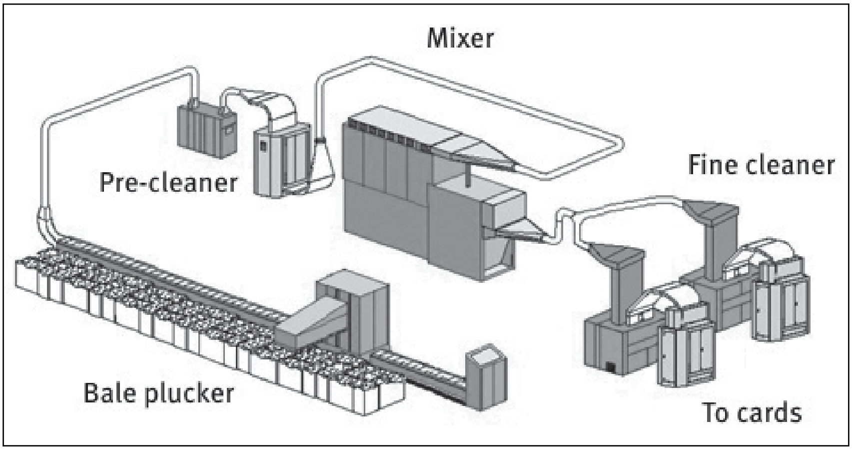

Fig. 3.4: Latest blow room line.

3.3.3 Card

The objectives of carding process are:
- Opening up to individual fibres
- Elimination of impurities
- Disentanglement of neps
- Elimination of dust
- Elimination of short fibres
- Fibre blending
- Fibre orientation or alignment
- Sliver formation

Following is the operation summary to achieve the tasks of card:

Lap prepared from the blow room is placed on the lap roller. Flow of material through the lap feed card is shown in Fig. 3.5 while chute feed card in Fig. 3.6. Feed roller with the help of feed plate delivers it to the taker-in. The taker-in opens and cleans the cotton by dragging it on the mote knives and carding elements. Then this cleaned material in the form of tiny tufts and single fibres is transferred to the cylinder. Cylinder further cleans the cotton and converts it into individual fibre state with the help of stationary and movable flats. At this stage, neps are disentangled and short fibres are separated from cotton. A fan sucks all the waste as well as dirt and dust from the whole machine and collects them in a box.

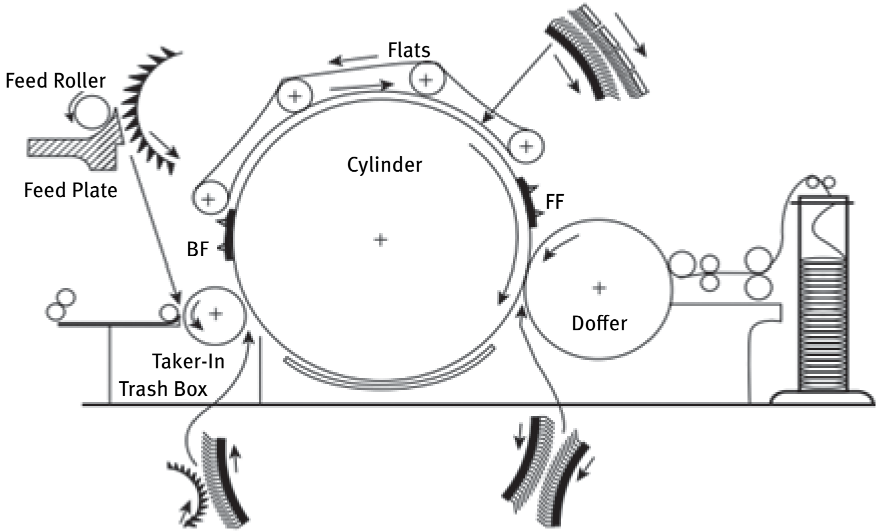

Fig. 3.5: Material flow through revolving flat card.

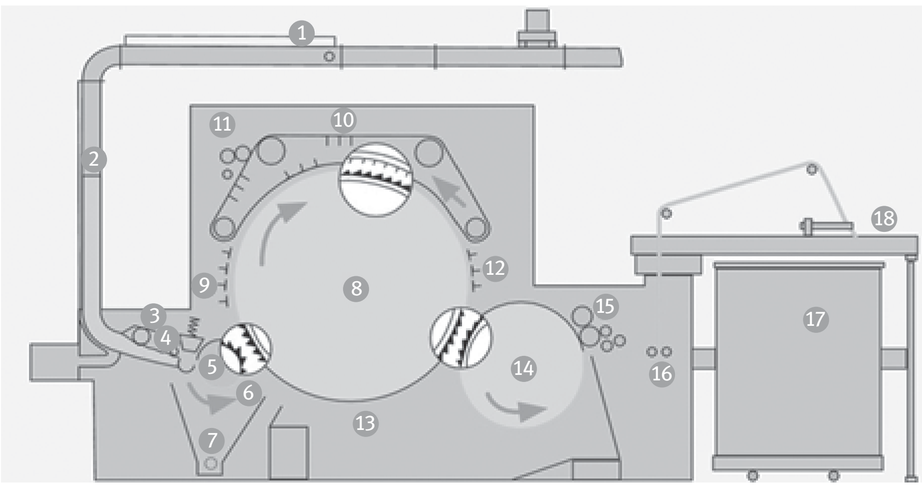

Fig. 3.6: Material flow through chute feed card (1) Conveying duct, (2) Feed chute, (3) Feed Roller, (4) Card Feed, (5) Taker-In, (6) Knife Grid, (7) Suction duct, (8) Cylinder, (9) Front Carding Segment, (10) Flats, (11) Cleaning Unit, (12) Post carding segment, (13) Cylinder Grid, (14) Doffer, (15) Stripping Device, (16) Calender Roller, (17) Can, (18) Coiler.

The doffer takes the fibres from the cylinder in fleece form. From the doffer, the fleece runs through the doffing roller, crush rollers and tongue-groove rollers. These rollers scanned the cross-section / thickness of the carding sliver. The recorded results are compared with the set target value of sliver linear density. Deviations from the set value are corrected by altering the speed of the feed roller. From there, sliver in its final form is coiled into the cans with the help of coiler.

3.3.4 Difference Between Blow Room and Card Cleaning

In the blow room the tightly packed bales are converted into small tufts. These tufts are then transported step by step through a series of machines installed in a sequence. The coarse and gentle opening at the start of blow room line is converted to the intensive and fine opening and cleaning at the end of line. As the larger tufts are further converted into smaller tufts, the degree of cleaning increases gradually due to the generation of new surfaces and decreasing the density of material. In the blow room the opening and cleaning are performed at the same time by a combined action of air currents, opening spikes and cleaning devices. The composition of trash, dust, fibre fragments and fibres removed is called waste. In case of card machine the material is opened to the individual fibre state. So, there are more chances of elimination of impurities, dust and short fibres. In the taker-in zone the coarse trash along with dust is separated from the material. While in carding zone the improved elimination of dirt and dust along with the removal of short fibres is carried out with the help of carding elements, mote knives, guiding elements and suction tubes. The waste of card is categorised into licker-in waste and fly waste.

3.3.5 Drawing

Following are objectives of drawing:

- Equalizing: To improve evenness of the sliver by doubling
- Parallelizing: To create parallel arrangement of fibres in the sliver by drafting
- Blending: To compensate the raw material variations by doubling
- Dust removal: To remove dust within the overall process by suction
- Sliver formation: To make sliver and coil in a can by condensing and calendering

Following is the operation summary to achieve the objectives of drawing:

Four or eight sliver cans prepared on the card are arranged under the creel rollers of the drawing as shown in Figure 3.7. Flow of material through the draw frame is shown in Fig. 3.8. Creel rollers withdraw the slivers from the cans and feed to the drafting system. The slivers running into the drafting arrangement are attenuated by a draft of 4 to 8 and a web having less cohesion is delivered. In order to avoid disintegration of the web, it is condensed into a sliver immediately after the drafting arrangement. This sliver is then guided through a pair of calender roller and a tube which coiled it into a can.

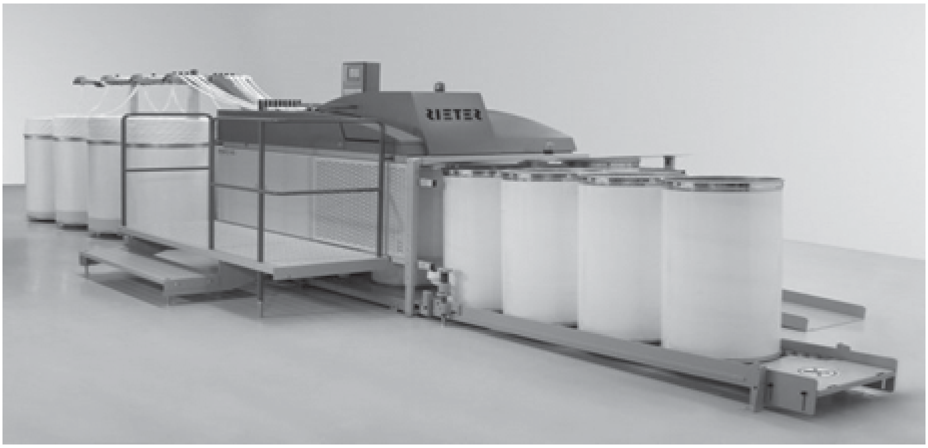

Fig. 3.7: Draw frame.

For cotton, normally two passages of draw frame are given while for blends of cotton with synthetic fibres three passages are used. Drawing frames may be of single delivery or double delivery. Now a days, single delivery draw frames are used for final passage of material which is shown in Fig. 3.9.

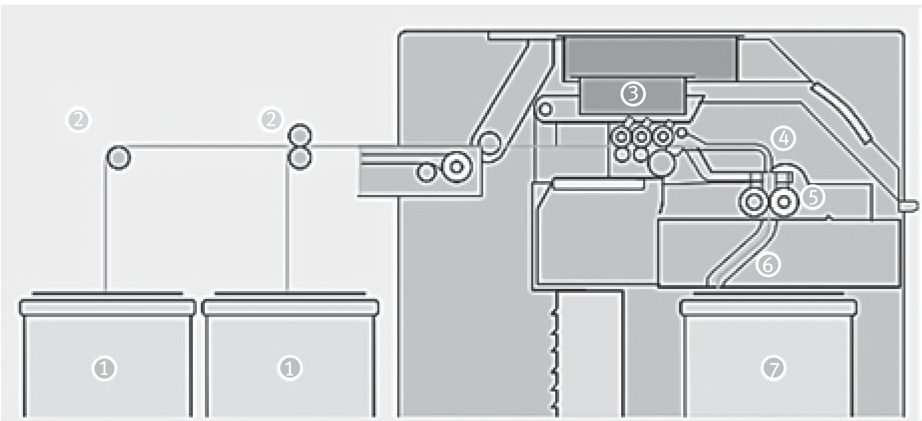

Fig. 3.8: Material flow through draw frame (1) Can, (2) Feed roller pair, (3) Drafting arrangement, (4) Tube (Funnel), (5) Calendering roller, (6) Passage (Coiler tube), (7) Can.

3.3.6 Lap Former

The objectives of lap former are as follow.
- Equalizing: To improve evenness of the lap by doubling of slivers
- Parallelizing: To create parallel arrangement of fibres in the lap by drafting of slivers
- Blending: To compensate the raw material variations by the doubling of slivers
- Dust removal: To remove dust within the overall process by suction
- Lap formation: To make lap by calendering

Following is the operation summary to achieve the objectives of lap former:

Twenty eight cans of drawn sliver from the first draw frame are placed under the two creel rails of the lap former. Flow of material through the lap former is shown in the Fig. 3.9. Creel rollers withdraw the slivers from the cans and feed to the drafting system. The slivers running into the drafting arrangement are attenuated by a draft of 1.3 to 2.5.

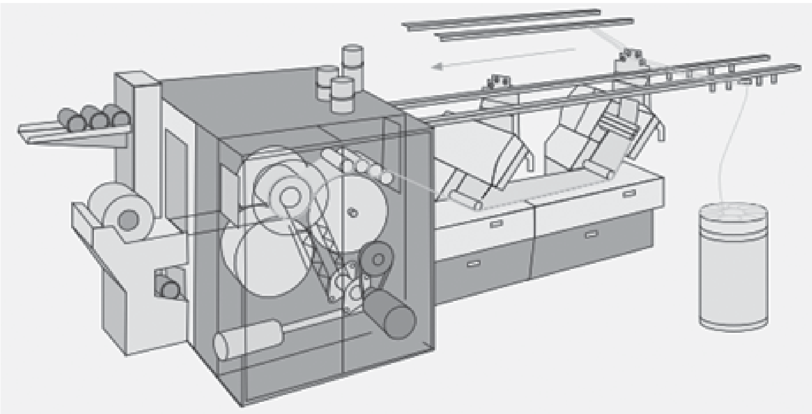

Fig. 3.9: Material flow through Unilap.

The two webs created by the drafting system pass over two deflecting plates onto the web table. These webs are superimposed or placed one above the other. The calender rollers draw these superimposed webs from the table and compact them to make lap and deliver it to the lap winding assembly. Winding assembly winds the lap on an empty tube. Empty tubes are automatically exchanged when length of the lap is completed.

3.3.7 Comber

The objectives of comber are:
- Noil removal: To remove short fibres, neps and impurities by combing
- Equalizing: To improve evenness of the sliver by doubling

- Parallelizing: To create parallel arrangement of fibres in the sliver by drafting
- Blending: To compensate the raw material variations by doubling
- Dust removal: To remove dust within the overall process by suction
- Sliver formation: To make sliver and coil in a can by condensing and calendering

Following is the operation summary to achieve the objectives of comber:

Eight laps made on lap former are placed on the support rolls of the comber which unwind the laps very slowly and deliver to the feed roller as shown in Figure 3.10. Flow of material through the comber is shown in the Fig. 3.11 and 3.13. Assembly of nippers takes the lap from feed roller. Circular combs comb the lap fringe hanging from the nippers and thus remove the short fibres, neps and impurities. Nippers transfer the combed fibres to the detaching rollers which deliver it in the web pan.

This web is condensed in to a sliver with the help of draw-off rollers, trumpet and table calender rollers. Eight slivers coming from each lap are arranged parallel on the table and fed to the drafting system as shown in the Fig. 3.12. The slivers running into the drafting arrangement are attenuated by a draft of 9 to 16. At the delivery end of the drafting arrangement, discharged web is condensed into a sliver. This sliver is then guided through a pair of calender roller and a tube which coiled it into a can. Fig. 3.13 shows a latest comber machine which is being used now a day in the industry.

Fig. 3.10: Comber machine.

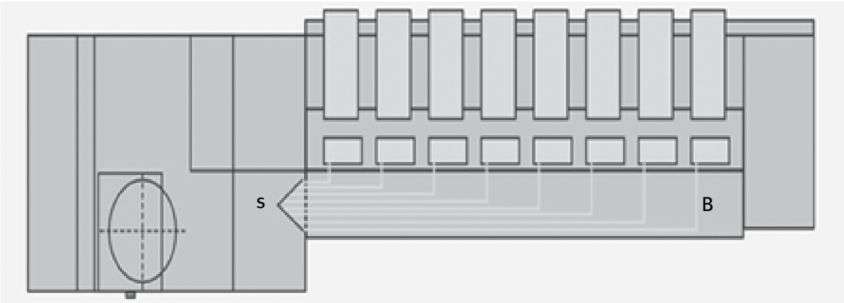

Fig. 3.11: Guiding the sliver from the web table to the drafting arrangement.

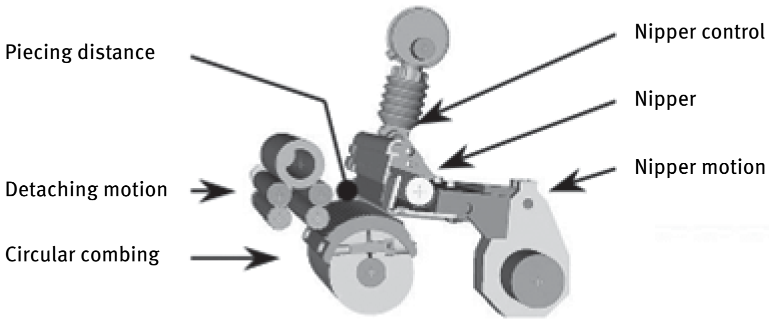

Fig. 3.12: Standard parts of combing head.

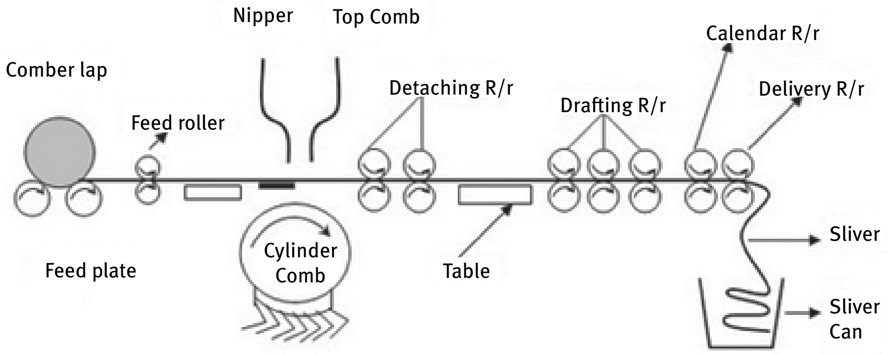

Fig. 3.13: Material flow through comber.

3.3.8 Roving Machine

Following are the objectives of a roving frame:
- Drafting to attenuate the sliver up to required fineness
- Twisting to impart strength
- Winding to make a roving package

Following is the operation summary to achieve the objectives of roving frame:

Sliver cans from the 2nd drawframe or finisher draw frame are placed under the creel of roving frame. Flow of material through roving frame is shown in Fig. 3.14. Creel rollers withdraw the slivers from the cans and forward them to drafting arrangement. The drafting arrangement attenuates the slivers with a draft of about 5 to 20. The material exiting from the drafting system is too thin and it cannot withstand itself. Twist inserting step is necessary immediately at the exit of the drafting arrangement in order to impart strength.

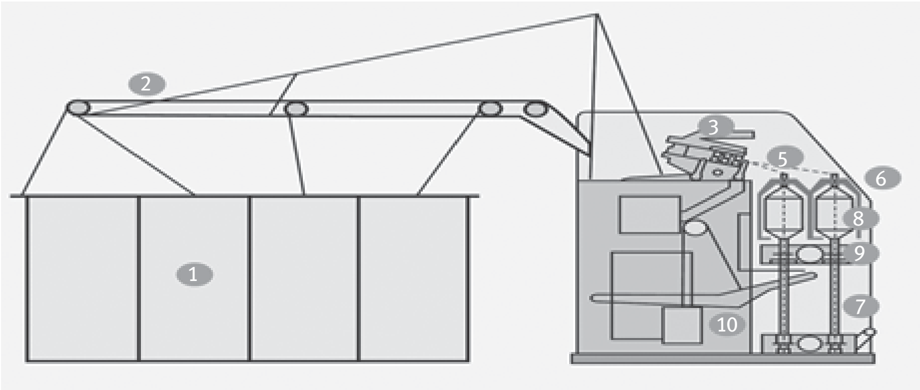

Fig. 3.14: Material flow through roving machine (1) Can, (2) Transport roller, (3) Drafting arrangement, (4) Roving, (5) Flyer, (6) Spindle, (7) Bobbin, (8) Bobbin Rail, (9) Lever.

Twist insertion is done by rotating flyer, usually in the range of 25–70 turns per meter. Roving from the flyer top runs through the hollow flyer leg and reaches to the wind-up point with the help of presser arm. Winding of roving is carried out due to higher speed of bobbin than the flyer. The roving coils are arranged on the bobbin very closely and parallel to one another by bobbin rail which moves up and down continuously. Speed of bobbin is reduced as the bobbin diameter is increased in order to keep its surface speed constant.

Similarly, bobbin rail speed is decreased with the increase in bobbin diameter in order to maintain the coils per inch constant throughout the package building. During package building, length of each next layer of roving is reduced continuously both from bottom and top in order to insert the taper on both ends. Fig. 3.15 shows the latest roving frame which is in use in the industry today.

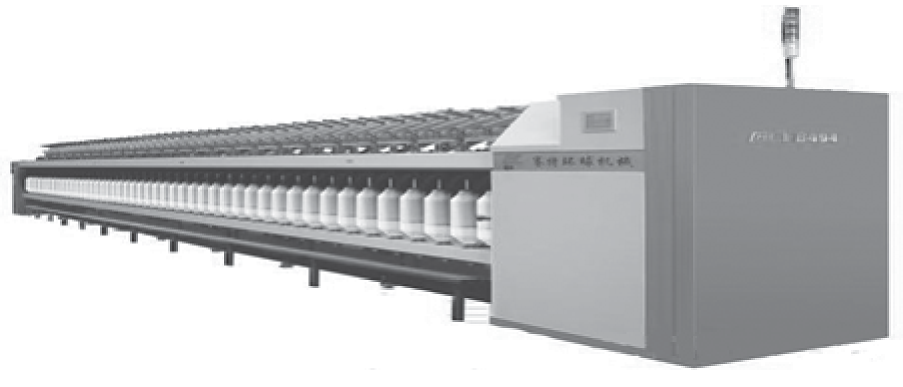

Fig. 3.15: Roving machine.

3.4 Spinning Operations

There are a number of spinning techniques which are being used to produce spun yarns. However, three techniques (Ring spinning, Open end rotor spinning and Air jet spinning) are common in the industry which will be discussed in the following subsections.

3.4.1 Ring Spinning

Following are the tasks which are required to achieve from ring spinning:
- Drafting to attenuate the roving up to the required fineness
- Twisting to impart strength
- Yarn winding to make a suitable package

Following is the operation summary to achieve the tasks of ring frame:

Roving packages made on roving frame are positioned on the hangers of the ring frame creel. Flow of material through ring frame is shown in Fig. 3.16. Roving is fed to drafting system through guiding rods and roving guide. The drafting arrangement attenuates the roving with a draft required to make the final yarn count.

The ribbon exiting from the drafting system is too thin and it cannot withstand itself. So twist inserting step is necessary to impart strength immediately. This step is performed by the ring and traveller with the help of spindle. In this process, each rotation of the traveller on the spinning ring produces a twist in the yarn.

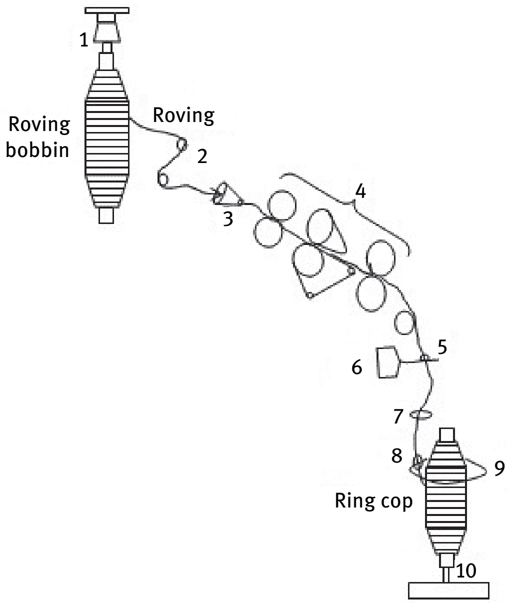

Fig. 3.16: Material flow through ring frame (1) Creel, (2) Guide roller, (3) Roving guide, (4) Drafting rollers, (5) Yarn guide, (6) Lappet, (7) Balloon control ring, (8) Traveller, (9) Ring, (10) Spindle.

The ring traveller has no drive of its own; it is dragged with spindle via the yarn attached to it. Winding of yarn on the bobbin is carried out due to the higher speed of spindle than the traveller. The yarn is wound up into a cop form by raising and lowering of ring rail. Fig. 3.17 shows a latest ring frame which is being used nowadays in the industry.

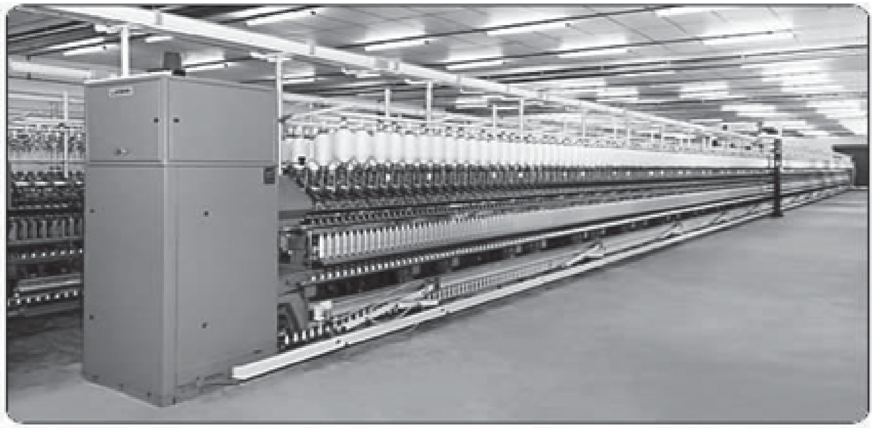

Fig. 3.17: Ring frame.

3.4.2 Winding

Winding is the creation of large yarn packages that can be easily unwound. This makes easier and economical use of yarn on subsequent machines. Thus all yarns made on ring frame are wound in the form of large cones on Autocone winding machine. Yarn faults are also removed on this machine with the help of yarn clearer. Fig. 3.18 shows the latest autowinding machine used in the industry today.

Fig. 3.18: Winding machine.

3.4.3 Open End Rotor Spinning

In open end rotor spinning process the preparatory processes include the operation of the blow room, card and draw frame passage. For the spinning of coarser yarn counts with shorter fibre length, card sliver can directly be fed to the rotor machine. However the need of right quality of sliver determines the requirement of one or two draw frame passage after carding process. Instead of classical roller drafting technique, the dispersion drafting is used in rotor machine. Twist is also inserted due to rotation of rotor.

Usually, the sliver cans from the first draw frame are placed under the Open end rotor machine. The flow of material through open end rotor machine is shown in Fig. 3.19. The sliver from can is fed to the feed roller with the help of sliver guide. Combing roller takes the sliver from feed roller and opens it up to individual fibre and delivers these fibres to the rotor through a fibre transfer tube. The fibres are deposited onto the rotating rotor and slide down into the rotor groove and form a ribbon of fibres. The rotor rotates at very high speed creating a centrifugal force due to which rotor is under a partial vacuum.

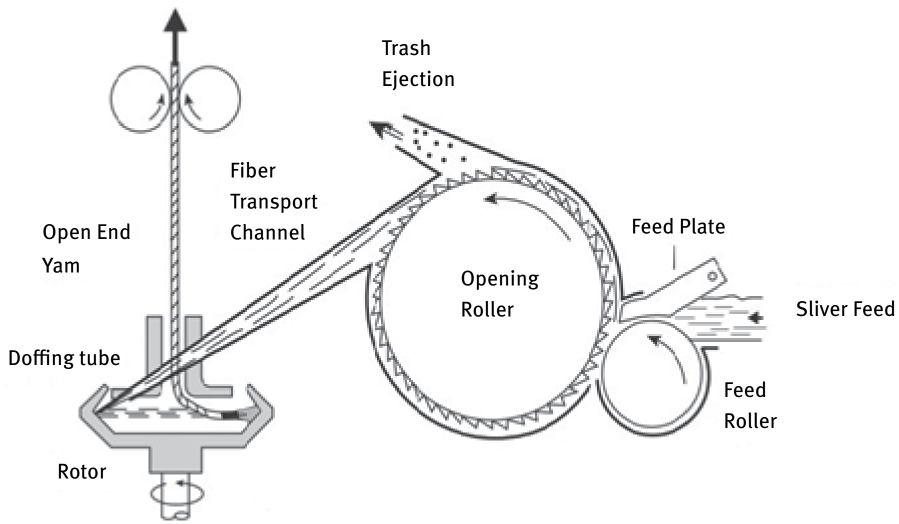

Fig. 3.19: Material flow through open end rotor machine.

To start spinning, a length of yarn already wound onto the package of the take-up mechanism is threaded through the nip line of the delivery rollers and into the draw-off tube. Because of the partial vacuum, the tail end of this yarn is sucked into the rotor due to vacuum. The rotation of the rotor pulls the yarn end onto collected ribbon of fibres and simultaneously inserts twist into the yarn tail. A little of this twist propagates into that part of the ribbon in contact with the yarn tail, binding it to the yarn end. Once the yarn tail enters the rotor, the delivery roller is set in motion to pull the tail out of the rotor. The pulling action on the tail results in a peeling of the fibre ribbon from the rotor groove. The newly formed yarn is wound up on the package by a winding drum.

The production rate of rotor spinning is 6–8 times higher than that of ring spinning. Open end rotor machines are fed directly by sliver and yarn is wound onto packages ready for use in fabric formation so in open end rotor spinning, only one machine is used instead of three machines (Roving frame, Ring frame and Autowinding) in ring spinning. Rotor spun yarns are more even but somewhat weaker and have a harsher feel than ring spun yarns.

Rotor spun yarns are mainly produced in the medium count (40 Ne, 20 tex) to coarse count (05 Ne, 60 tex) range. End uses include denim, towels, blankets socks, t-shirts, shirts and pants. Fig. 3.20 shows a latest open end rotor machine used in the industry today.

Fig. 3.20: Rotor spinning machine.

3.4.4 Air Jet Spinning

Flow of material through Air jet spinning machine is shown in Fig. 3.21. In order to have adequate parallelization of fibres required for air jet spinning, the sliver which has passed through three passages of draw frame is preferred as infeed material. The slivers coming from the creel portion are passed over the stationary creel rods being directed to the drafting arrangement. The drafting arrangement permits draft of 100 to 200 depending upon the required yarn fineness. The highly attenuated fibre strand then passed through the spinning nozzles. The false twist is imparted by the power air vortex generated by the nozzles. The direction of air vortex in these two nozzles is opposite to each other. A typical nozzle arrangement is shown in Fig. 3.22.

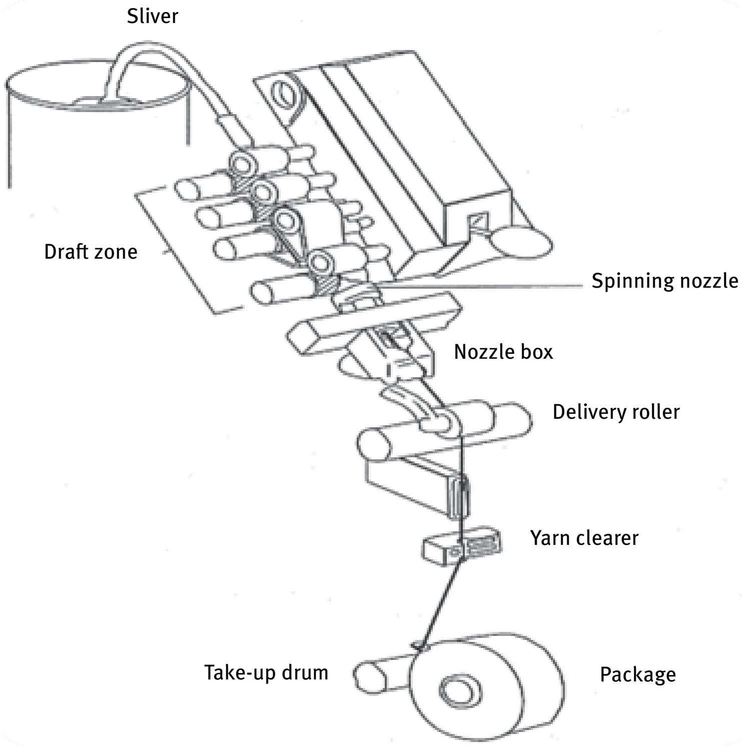

Fig. 3.21: Material flow through air jet spinning machine.

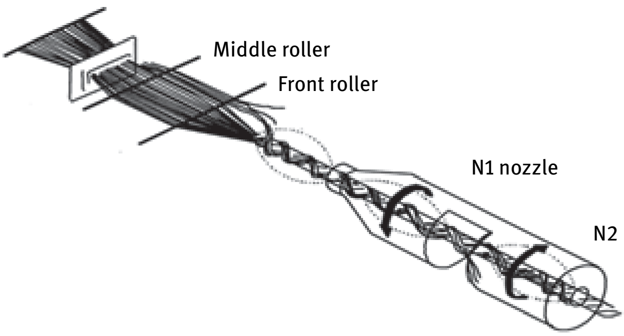

Fig. 3.22: Two-nozzle arrangement.

Due to low intensity of first jet, it only affects the small number of edge fibres. Thus it wraps the edge fibres around the core fibres. The angular velocity of the air vortex inside the second jet is more than 1 million rpm which inserts the twist to all the edge fibres and wound around the parallel fibre strand. They bind the body of fibres together and ensure coherence. The resultant yarn is cleared of any defects and wound onto packages.

The production rate of air jet / vortex spinning is 3–5 times higher than rotor spinning and 10–20 times that of ring spinning machine. Just like rotor spinning; the air-jet spun yarn is very cheaper to produce since it also uses a fewer production stages. As is the case with rotor spun yarns, the air jet spun yarns are more even, but weaker and have a harsher feel than that of ring spun yarns. The air jet spun yarns are mostly produced in the medium count (30 Ne, 20 Tex) range and are mainly polyester / cotton blended yarns. End users of vortex spun yarn include woven sheets and knitted light-weight shirting. Fig. 3.23 shows a latest air jet machine.

Fig. 3.23: Air jet spinning machine.

3.5 Types of Yarns

There are three types of yarns:
- Staple spun yarns
- Monofilament yarns
- Multifilament yarns

3.5.1 Staple Spun Yarn

- Is made from staple fibres – cotton or wool or manufactured fibres cut into short lengths
- Is an uneven, weak yarn with poor lustre and durability?
- Staple spun yarns have good elasticity, resiliency and absorbency
- Are used mainly for apparel and furnishings

3.5.2 Monofilament Yarn

- Monofilaments are simply single filaments of synthetic fibres that are strong enough to be useful without being twisted with other filaments into a yarn.
- They are fine and strong with good lustre and durability, but are inelastic in nature with poor resiliency and absorbency.
- Monofilament yarns are used primarily for hosiery and invisible sewing thread.

3.5.3 Multifilament Yarn

- Is made from two or more filaments of a manufactured fibre
- Is an even, strong yarn with good lustre and durability; has medium elasticity and resiliency and is slightly absorbent
- Is used primarily for evening wear and lingerie

References

[1] Celanese Acetate (2001), *Complete Textile Glossary*, Celanese Acetate LLC, Three Park Avenue New York, USA.
[2] M. J. Denton, P. N. Daniels (2002), *Textile Terms and Definitions*, 11^{th} edition, The Textile Institute, UK.

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4 Fabric Manufacturing

Textile fabric may be defined as the flexible assembly of fibers or yarns, either natural or manmade. It may be produced by a number of techniques, the most common of which are weaving, knitting, bonding, felting or tufting. Conventional fabrics (woven, knitted) are produced in such a way that the fibers are first converted into yarn and subsequently this yarn is converted into fabric. The fabrics can also be produced directly from the fibers. Such fabrics are termed as nonwovens. Each of these methods is capable of producing a large number of fabric structures, depending upon the raw material, machinery and the process involved. These fabrics are used for a wide range of applications from clothing to the technical purposes.

4.1 Weaving

The history of weaving dates back to ancient times, when human beings used woven fabrics to cover themselves. There are evidences that Egyptians made woven fabrics some 6000 years ago and silk became economically important in China 4000 years ago [1]. It is the most commonly used technique of fabric manufacturing. The woven fabrics have a huge number of application areas like apparel, home textiles, filters, geo textiles, composites, medical, packing, seatbelts, industrial products, protection, etc.

The woven fabrics are produced by interlacement of two set of yarns perpendicular to each other [2], i. e. warp and weft as shown in Fig. 4.1. The first set includes the threads running lengthwise in the fabric, while the second is represented by the threads placed in cross or width direction. The fabrics have varying structure, depending on the interlacement pattern of the yarns. This sequence of interlacements is termed as the weave design of the fabric. The properties of fabric are governed by its weave design as well as the fiber content used as the raw material.

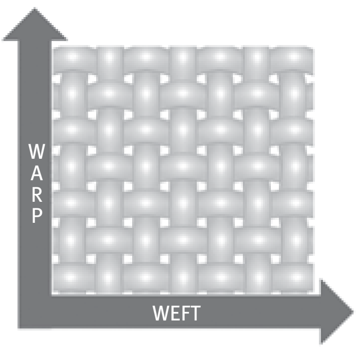


Fig. 4.1: Schematic of warp and weft in woven fabric.

4.2 Warp Preparation Steps

A summary of the process steps from yarn to the final product, i. e. loom-state fabric is shown in Fig. 4.2. Here the warp yarn is subjected to a number of processes, termed as warp preparation before conversion into fabric, while weft yarn does not require any specific preparation. The warp preparatory process consists of the following operations: winding, warping, sizing and drawing-in.

Yarns produced in spinning are used as input of the warp preparation. Winding helps to prepare the yarn for a package which requires shape and size. Weft yarn is then provided to loom, while warp yarns are processed to give a sheet of yarns on warp beam by the process called warping. A coating of size material is applied to the yarn in the subsequent process to impart strength and make the yarn smooth. This warp sheet is then drawn in from the droppers, heald frames and the reed. The actual fabric forming process is carried out at the loom, where this warp sheet and weft are interlaced to give woven fabric.

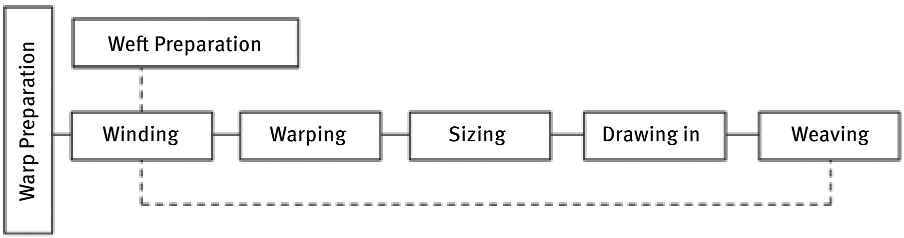


Fig. 4.2: Flow of the weaving process.

4.2.1 Winding

Winding is a process in which yarn from bobbins, which is the end product of ring spinning, are converted into suitable form of package. This transfer of yarn from one type of package to another package, more suitable for the subsequent process is also called winding. Main objectives of winding process are to increase the package size, clear yarn defects and produce a package suitable for subsequent process (size and shape).

The yarn packages are either parallel or tapered, with respect to shape, as shown in Fig. 4.3. The parallel packages may also have flanges, while tapered packages are without flange [1].

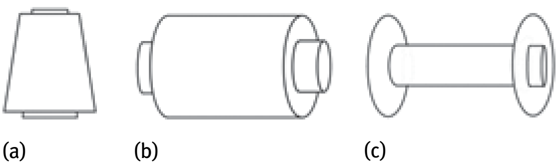
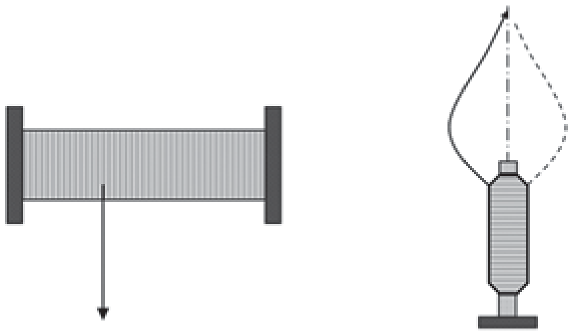


Fig. 4.3: Package types; (a) tapered, (b) parallel without flange and (c) flanged parallel.

The winding process involved unwinding yarn from one package and rewinding it on to another package. The yarn may be unwound in two ways, i. e. over end and side withdrawal as shown in Fig. 4.4. Winding rate is the speed at which the yarn is wound on package surface, while to and fro movement of yarn when it is laid on to package is called traverse. In case of near parallel package, traverse is very slow, but in case of cross wound package traverse is quick. There is no traverse in case of parallel wound packages.



(a) (b)

Fig. 4.4: Package unwinding; (a) side withdrawal, (b) over end withdrawal.

In the winding machine, yarn is taken from the bobbin / cop and is wound on the package after passing through the thread guides, balloon breaker, stop motion and yarn clearer. For cross winding, a grooved drum is also provided on the machine to traverse the yarn.

4.2.2 Warping

In warping process, the yarns are transferred from a number of supply packages (cones) to the warp beam in the form of a parallel sheet. The main objective of warping is to get the required number of ends as per requirement. The three main types of warping are high speed / direct warping, sectional / indirect warping and ball warping. In direct warping, the yarns are withdrawn from the single-end yarn packages (cone) on the creel and directly wound on a beam. A number of beams are warped to get the required number of ends. For example, to produce a fabric with 6040 warp ends, 8 beams will be warped, each with 755 ends. These beams are then combined into a single beam in the sizing process. The process offers only limited pattern possibilities, and is preferred for simple patterns only.

The indirect / sectional warping process completes in two steps, i. e. warping and beaming. In first step, a portion of the required number of threads (called section) is wound onto a conical drum (Fig. 4.5). All the sections are warped on the drum side by side, one after the other. In next step all the sections are unwinded from the drum and wound onto beam to complete the required number of threads. This beam may or may not be taken for the sizing process. The division of warp sheet into small sections provides unlimited patterning possibilities. Therefore this process is suitable for complex warp patterns. Ball warping is the process in which warping is performed in rope form on to wooden ball. The ball is wound on a special wooden core called "log". It is also a two stage process, suitable for denim fabric manufacturing, involving rope dyeing process. Re-beaming is done to convert the rope dyed warp yarn, stored in cans, into beam.

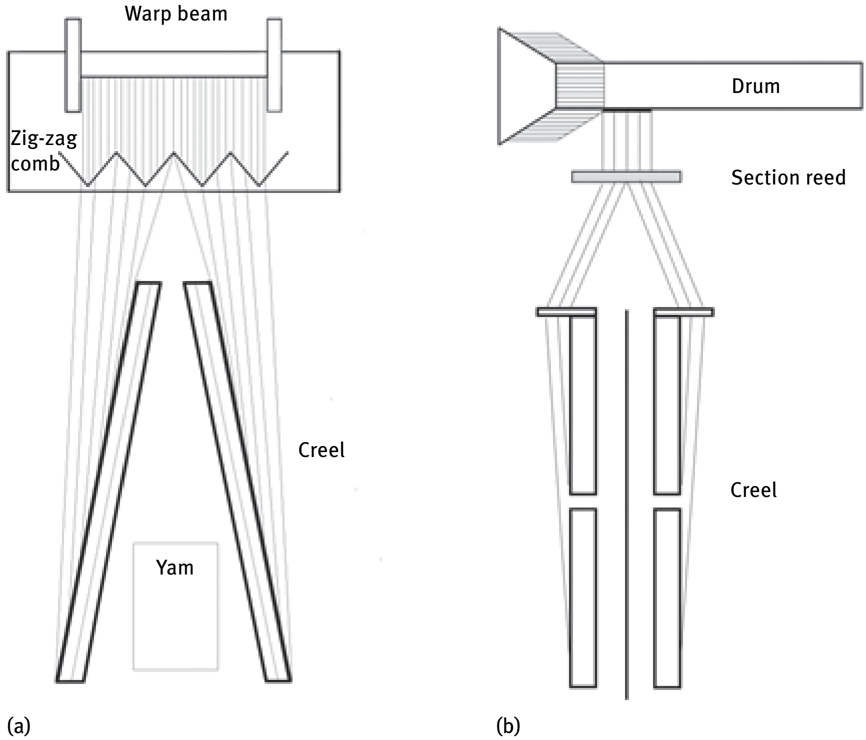


Fig. 4.5: Direct and sectional warping machine schematic diagram (a) Direct warping machine, (b) Sectional warping machine

4.2.3 Sizing

Sizing, also termed as slashing is the coating of warp sheet with size solution. Weaving requires the warp yarn to be strong, smooth and elastic to a certain degree. There is always a friction between metallic parts and yarn during the weaving. So, the warp yarns need to be lubricated to reduce the abrasion. The application of size material helps to improve the mechanical properties of warp, reduce abrasion and the elasticity of yarn. The amount of sizing material relates to the tenacity, hairiness and linear density of yarn, and also to its behaviour during weaving. Another major objective of this process is to get the total ends on a weavers beam, combining the ends of all warp beams. The application of sizing material results in the following properties in yarn.

- High strength
- Low flexibility
- Low abrasion
- Increased smoothness
- Less hairiness

The process of sizing can be classified on the basis of method of application into conventional wet sizing, solvent sizing, cold sizing and hot melt sizing [3]. The main parts of conventional sizing machine include (Fig. 4.6) creel, sizing box, drying section, leasing section, head stock and size cooker.

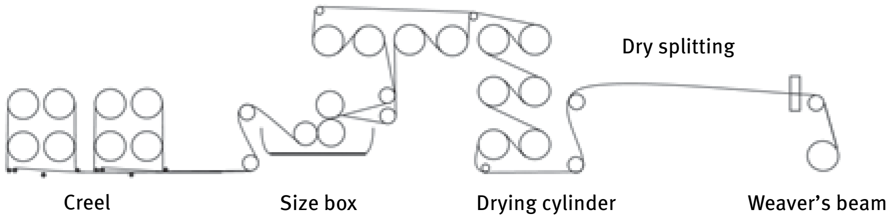


Fig. 4.6: Schematic diagram of conventional wet sizing machine.

In conventional wet sizing, the fundamental constituents of size recipe are the size materials and a solvent usually water. The sizing materials are broadly classified into three groups namely adhesives, softeners and auxiliaries [4].

The adhesives perform two functions; bind the constituent fibers of the yarn together and form a film over the yarn surface, resulting in increased strength, low hairiness and more even yarn. The adhesives are classified on the basis of origin into natural, synthetic and modified adhesives, produced by treating natural adhesives with certain chemicals. The natural adhesives may be obtained from plants or animals, for example maize starch, potato starch, etc. The chemical modification of natural adhesives is performed to induce the desired properties. Some common examples of modified adhesives are modified starches and carboxy methyl cellulose (CMC). The chemically synthesized polymers like poly vinyl alcohol (PVA) and acrylics fall under the category of synthetic adhesives. Starch adhesives are used most commonly because of low cost and environment safety.

The softeners are added in the size recipe to lubricate the yarn and reduce abrasion / friction between adjacent yarns and between yarns and loom accessories. They also give a soft handle to the warp and size film, helping to decrease its brittleness. The softeners may be in solid form (wax group) or liquid form (oil group) and are obtained from animals, vegetables or synthesized chemically. The auxiliaries include antiseptic, antistatic, weighting, swelling agents and / or defoamers. The sized fabric must be subjected to a desizing process prior to the finishing stage. Desizing has a decisive effect on the waste water load in textile production.

4.2.4 Drawing In

The sized warp sheet is wound on to a beam called as the weaver's beam. It has the required number of ends and the yarns have adequate strength to bear the tensions of weaving process on loom. This beam is either used for drawing in or knotting / tying, depending on the requirement (Fig. 4.7).

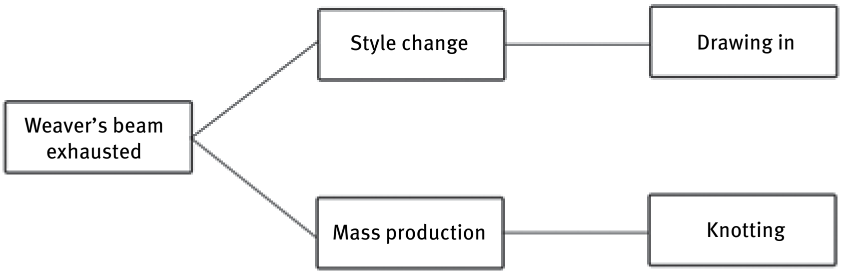


Fig. 4.7: Drawing in / knotting procedure.

Style change involves the production of a new fabric style, while mass production means to continue the weaving of same fabric style just replacing the empty beam with a full beam of same type. Drawing in is the process of entering the individual yarn of warp sheet through dropper, heald eye and the reed dent (Fig. 4.8). The yarns can be threaded wither manually or by using automatic machines.

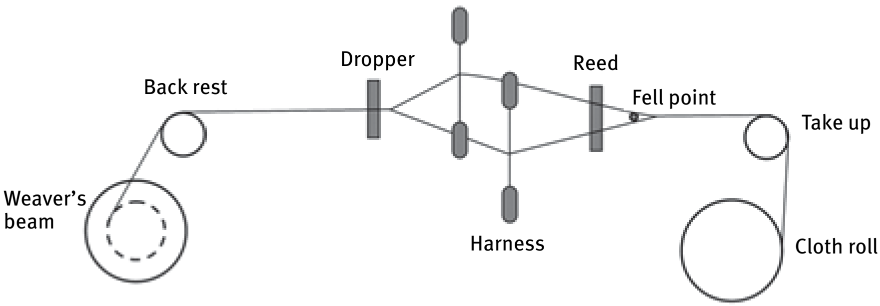


Fig. 4.8: Drawing in schematic and yarn path.

The yarn is now fully prepared for conversion into the fabric, which takes place at the loom. The weaver's beam is gaited on the loom, while weft yarn is provided at right angle either from cone or bobbin depending on the picking media.

4.3 Weaving Mechanisms

The conversion of warp sheet into fabric by interlacing with weft yarn requires the basic operations to be carried out on loom in a specific order. It involves the primary motions, secondary motions and the stop motions [5].

4.3.1 Primary Motions

The primary loom motions include the following three operations:

Shedding: the separation of the warp sheet into two layers to form a tunnel known as the shed

Picking: insertion of weft yarn, across the warp sheet width, through the shed

Beat-up: pushing the newly inserted length of weft (pick) to the fell of cloth.

These operations occur in a given sequence and their precise timing in relation to one another is of extreme importance.

4.3.2 Secondary Motions

The secondary motions facilitate the weaving of fabric in a continuous way [6]. These include:

Let off: this motion provides warp sheet to the weaving area at the required rate and under constant tension by unwinding it from weaver's beam

Take-up: this motion draws fabric from the weaving area at a uniform rate to produce the required pick spacing and wind it onto a roller.

4.3.3 Stop Motions

These motions are used in the interest of quality and productivity; stopping the loom immediately in case of some problem. The warp stop motion will stop the loom in case any warp yarn breaks, avoiding excessive damage to the warp threads. Similarly weft stop motion will come into action in the absence of weft yarn, and stop the loom.

4.4 Types of Shedding Mechanism

There are three most common types of shedding mechanisms, namely Tappet, Dobby and Jacquard shedding [7]. Tappet and dobby systems control heald frames while jacquard provides control of individual warp yarn.

4.4.1 Tappet Shedding

This system is also termed as cam shedding. The cam is an eccentric disc mounted on the bottom shaft, rotating to lower or lift the heald frame. It is relatively simple and inexpensive system handling up to 14 heald frames [8]. But this system has very limited design possibilities and pick repeat, producing simple weaves.

4.4.2 Dobby Shedding

It is a relatively complex shedding system and can control up to 30 heald frames. The pick repeat to dobby system is provided by peg chain, punched papers, plastic pattern cards or computer programming, and is virtually unlimited. This system offers more design possibilities as compared to tappet shedding.

4.4.3 Jacquard Shedding

The jacquard shedding provides unlimited patterning possibilities. The working principle is relatively simple but involves more number of parts that make it a complex machine. Versatility of jacquard shedding is due to control over individual warp yarn. The jacquard shedding system can be either mechanical or electronic.

4.5 Types of Picking Mechanism

Picking involves the insertion of the weft yarn through shed across the width of warp sheet. The picking mechanism is mainly a function of the picking media, used for the insertion of weft (Fig. 4.9). The picking media vary greatly on the basis weft velocity and the insertion rate; and are classified into shuttle and shuttle-less picking.

4.5.1 Shuttle Picking

It is the oldest technique of weft insertion on loom. The picking media is a wooden shuttle that traverses back and forth across the loom width. A pirn or quill having yarn wound on it is placed inside the shuttle. As the shuttle moves across, the yarn is unwound and placed in the shed. A picking stick on each side of loom helps to accelerate the shuttle by striking it. Shuttle travels on the race board, above lower portion of the warp sheet. The shuttle picking takes place from both the sides of loom.

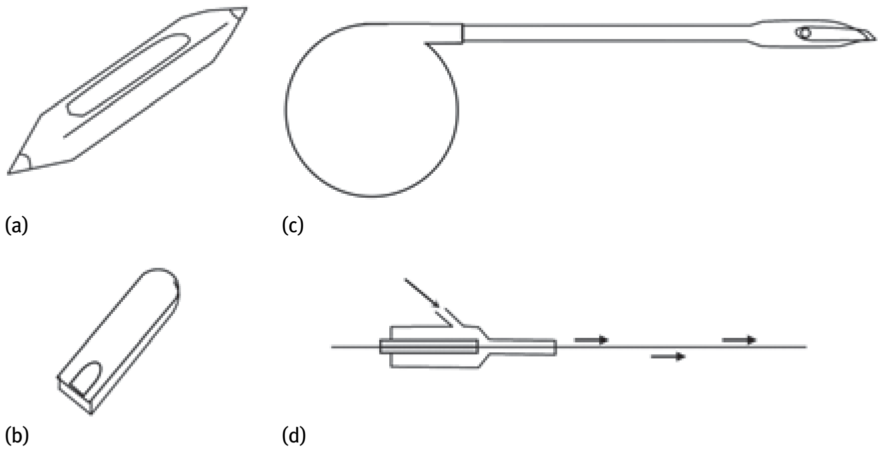


Fig. 4.9: Mechanisms of weft insertion (a) Shuttle, (b) Projectile, (c) Rapier, (d) Air jet.

4.5.2 Projectile Picking

Introduced first time by Sulzer in 1952, this machine uses a small metallic projectile along with gripper to throw the wet yarn across the loom width. The energy required for propulsion of projectile into the shed is provided by twist in the torsion rod. The projectile glides through guide teeth in the shed. It had low power consumption, versatility of yarns and a higher weft insertion rate as compared to the shuttle picking system.

4.5.3 Rapier Picking

This picking system uses a rigid or flexible element called rapier for the insertion of weft yarn across the shed. There are two major variations in the rapier picking; single rapier and double rapier. In case of single rapier picking system, the rapier head grips the weft and carries it across the shed to receiving end. The rapier has to return empty to insert the new weft. The double rapier picking makes use of two rapiers [9]. One rapier (giver) takes yarn to the centre of machine and transfers it to the other rapier (taker), which brings the weft to other side.

4.5.4 Water Jet Picking

The water jet picking involves the insertion of weft yarn by highly pressurized water. This pressurized water takes the form of a coherent jet due to the surface tension viscosity of water. The flow of water has three phases: acceleration inside pump, jet outlet from nozzle and flow into the shed. The amount of water used for the insertion of one pick is less than 2 cm^3. This system is mostly preferred for the synthetic yarns.

4.5.5 Air Jet Picking

In air jet picking system, the weft is inserted into the shed by the use of compressed air. The yarn is taken from the supply package / cone and wound on to the feeder before insertion to avoid tension variations. The weft is then passed through the main nozzle which provides initial acceleration to the yarn. The auxiliary nozzles are present at specific distance along the width to assist in weft insertion. A special type of reed, called profiled reed is used for air jet picking. The channel in the reed guides the yarn across the shed and avoids entanglement with warp. It has an extremely high weft insertion rate.

4.6 Weave Design

The woven fabric is produced by interlacement of warp and weft, and this interlacement pattern is called weave design of the fabric [10]. The three basic weave designs are plain, twill and satin.

4.6.1 Plain

The simplest interlacing pattern for warp and weft threads is over one and under one as shown in Fig. 4.10. The weave design resulting from this interlacement pattern is termed as plain or 1 / 1 weave. The 1 / 1 interlacement of yarns develops more crimp and fabric produced has a tighter structure. The plain weave is produced using only two heald frames. The variations of plain weave include warp rib, weft rib and matt or basket weave.

4.6.2 Twill

This weave is characterized by diagonal ribs (twill line) across the fabric. It is produced in a stepwise progression of the warp yarn interlacing pattern. The interlacement pattern of each warp starts on the next filling yarn progressively. The two sub categories based on the orientation of twill line are Z- and S-twill or right hand and left hand twill, respectively. Some of the variations of twill weave include pointed, skip, and herringbone twill [11].

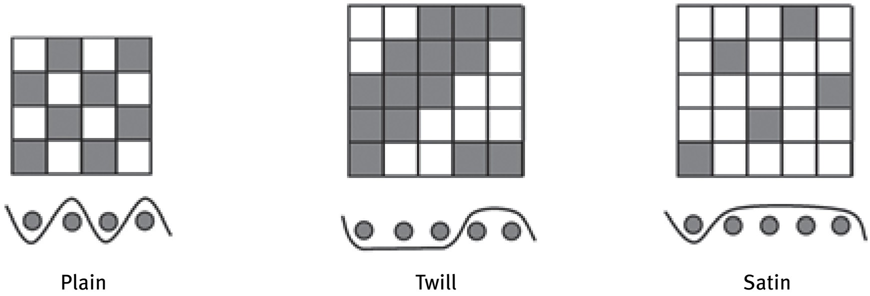


Fig. 4.10: Basic weaves and their cross sectional view.

4.6.3 Satin / Sateen

The satin / sateen weave is characterized by longer floats of one yarn over several others. The satin weave is warp faced while sateen is a weft faced weave. A move number is used to determine the layout in a weave repeat of satin, and number of interlacements is kept to a minimum as shown in Fig. 4.10. The fabrics produced in satin weave are more lustrous as compared to corresponding weaves.

4.7 Specialty Weaving

There are certain specialty weaving techniques used for the production of a specific fabric type, for example circular loom, terry towel loom, denim fabric, narrow loom, multi-phase loom, 3D weaving loom, carpet / rug weaving, etc. The weaving is also used for the production of certain industrial fabrics and technical textiles [2] like conveyor belt fabrics, air bag fabrics, cord fabrics, geotextiles, ballistic protection, tarpaulins, etc. The denim fabrics are woven with a coarse count, high thread density and 3 / 1 twill weave. Dyeing is an additional process involved in the warp preparation for these fabrics [12]. The warp yarn of these fabrics is dyed with indigo dyes in such a way that only surface is dyed and core remains white. The narrow loom usually involves a needle for the weft insertion. It usually draws the warp sheet directly from the creel through tensioning rollers, thus helping to increase efficiency and productivity.

The towels are piled fabrics produced from two different set of warp; one serving as the ground and the other as pile. More length of pile warp is consumed as compared to ground warp. Therefore, two beams are required to produce such fabrics and need additional attachments on loom. In multiphase loom, several weft yarns are inserted simultaneously across the series of sheds. These shed are arranged sequentially in the warp direction. The 3D loom produces a 3 dimensional fabric on the required shape [13]. The carpet weaving involves a loom with two beam arrangement as in case on terry towel fabrics. The ground warp let-off, pile warp let-off and cloth take-up is controlled by servomotors [14]. It allows easy change of pile height and pick density. The tension in the pile warp sheet is controlled by a pneumatic beam brake.

4.8 Knitting

Knitting is the second largest and most growing technique of fabric manufacturing in which yarns are interloped to make thick yet flexible and elastic fabric [15]. Knitting is derived from the Dutch word “Knutten” which means to knot. There are many theories about the history of knitting. According to one theory knitting is linked with knotting fishing nets. This also affirms the historical views that knitting was started by the Arabian seafarers who were sailing and trading in the Middle East back in 200 AD. The earliest example of knitwear we could find is the sock from Victoria and Albert Museum which is knitted in stocking with single needle called Nalbindning. In 600 AD, knitting is believed to have been transferred to Europe with the wool trade. In the13th and 14th centuries some products in circular shape are found which are named as Madonna Knitting. Followed by this was an era of fashionable knits as in 1420s which are also known as knitting guilds. These were the articles which attracted wealthier and more influential clientele and this was Elizabeth I’s period from where history of knitting can be traced. Introduction of fashion items in knitting attracted attention of many from the adjoining areas of Europe and it was 17th century where knitting socks got popularity. After Industrial Revolution in 18th century knitting was found primarily performed with knitting machines and the first knitting machine was thought to be invented by William Lee in 1589 and his wife was a hand knitter. Elizabeth I was reluctant to patent the machine because of its likelihood of unemployment among the masses but it thrived in France. This art remained in the hands of the underdeveloped and poor section of the society till the first half of the 20th century [16].

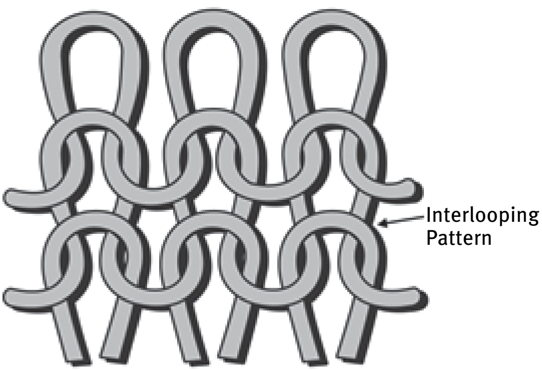


Fig. 4.11: Interloping pattern of knitted fabric.

Knitting is fabric formation technique in which the yarn is bent into loops and those loops are interconnected to form fabric [17]. Knitting can be defined in simple words as the interloping of yarn as shown in Fig. 4.11. The bending of yarn provides better stretchability, extensibility, comfort and shape retention properties. However they tend to be less durable than the woven fabric.

4.9 Comparison of Woven and Knitted Fabrics

The woven fabrics produced by interlacement of two sets of yarn and knitted fabrics formed by the interloping of yarn, have unique characteristics and have their own end-user applications [15]. In most of the cases, both fabrics can be a substitute for each other and selection of the right fabric can possibly meet the requirement of the wearer in a better way. Tab. 4.1 presents a comparison between woven and knitted fabrics.

Tab. 4.1: Comparison between woven and knitted fabrics, machine and process.

Sr. #	Parameter	Woven Fabric	Knitted Fabric
1	Process requirement	Fabric requires two sets of yarn for interlacement, one is warp and other is weft yarn.	Fabric can be produced from a single end or a cone of a yarn in case of weft knitting.
2	Dimensional stability	More stable	Less stable. Careful handling is required for knitted fabric during wet processing and stitching.
3	Comfort	Less comfort due to tight structure	More open spaces that give better air permeability and moisture management
4	Shape retention properties	Woven garments retain their own shape	Knitted garments get the shape of the wearer's body, hence, best for undergarments
5	Crease resistant	Poor crease resistance	High crease resistance
6	Development route	Yarn preparation requires like warping, sizing drawing, etc.	Fabric can be produced from yarn package. So process route is very short
7	Conversion cost	Conversion from yarn to fabric involves various processes. The conversion cost is higher.	Conversion requires no preparation, so conversion cost is low
8	Environmental effect	Preparation includes a sizing of warp yarn that has to remove before color application, that may cause environmental pollution	The yarn is just waxed. No need to size the yarn, so development cause less environmental hazards

4.10 Types of Knitting

The knitted fabric can be categorized into two major classes i. e. warp and weft knitting on the basis of yarn feeding and direction of movement of yarn in fabric with respect to the fabric formation direction.

The weft knitting technique is more common as the fabric can be produced from single end and there is no need of yarn preparation like warping. In weft knitting, the direction of movement of yarn is in the weft direction of the fabric [15]. The loops are formed horizontally with the same yarn, as shown in Fig. 4.12.

The warp knitting technique is a more advanced technique and the fabric is much closer to the woven fabric in terms of dimensional stability. The loops that are formed are connected in the warp direction and movement of yarn is also in the warp direction as shown in Fig. 4.12.

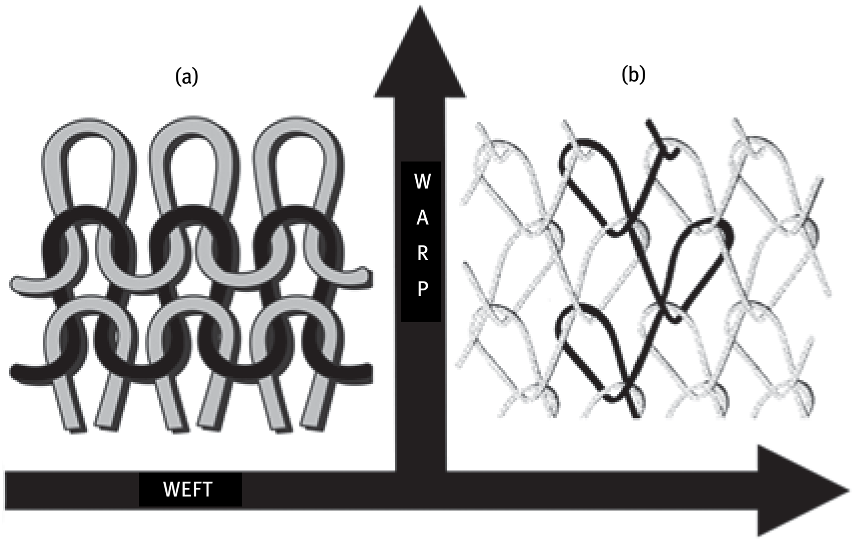


Fig. 4.12: Yarn direction: (a) Weft knitting, (b) Warp knitting.

4.10.1 Weft Knitting

Weft-knit fabric is familiar for their comfort and shape retention properties. The fabric can be produced from a single end. The movement of yarn in the weft direction provides the stretch ability in both directions that could be engineered to achieve the required properties. The apparels, either inner or outerwear, are the most demanding area of weft-knit fabric. This technique is further classified into different machine type and structure that is given in Fig. 4.13. Circular knitting machines are particularly used to produce tubular fabric. Circular machines are classified into three major categories on the basis of cylinder and Dial. The first category in which machine has only one cylinder, needles are placed inside the cylinder trick that moves up and down for loop formation. Popular structures are single jersey and their derivatives. The second type of machine has both dial and cylinder. The needles are placed in both dial and cylinder. The cylinder needles move up and down while dial needle moves in to and fro manner. The major machine types are Rib and Interlock. The difference in their construction is the placement of tricks or grooves. The grooves on Rib machine of both dial and cylinder are alternative to each other whereas on interlock the grooves are exactly opposite to each other. The third class is Purl, in which the machine has two cylinders. These cylinders are superimposed. The purl fabric is also known as link-link fabric. The needle is hocked on both sides. The same needle is placed in opposite tricks of these cylinders [19]. The flat machines can produce both single and double-knit fabrics.

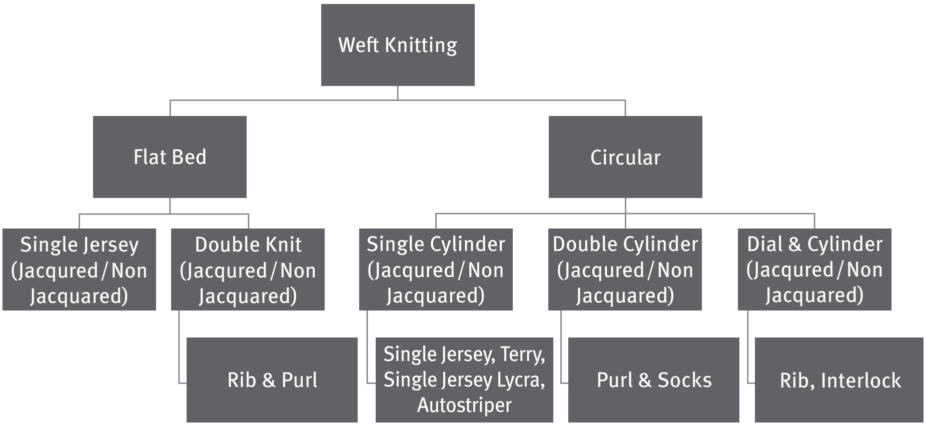


Fig. 4.13: Classification of weft knitting machines and their structures.

4.10.2 Weft Knitting Machine Elements

The needle is the most important and essential part of loop formation. The needles are placed in tricks or cut of bed (flat or circular) at regular intervals so that they can move freely during the loop formation cycle. Generally, machine manufacturers prefer to use the latch needle for their machines. The latch needle is self-actuating and no auxiliary part is required. Different needle types and their parts are shown in Fig. 4.14.

There are three main types of needle

1. Latch needle
2. Spring Bearded needle
3. Compound needle

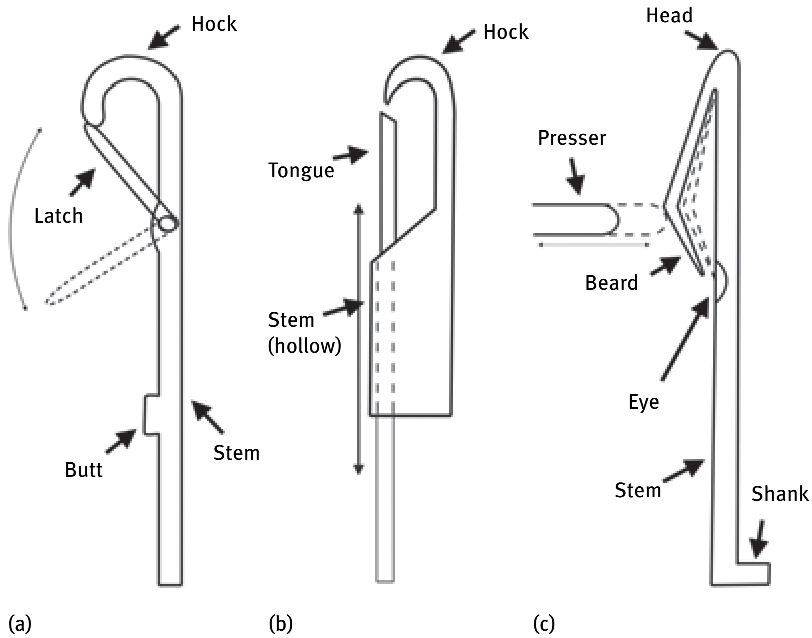


Fig. 4.14: Needle types and their parts: (a) Latch needle, (b) Compound, (c) Bearded needle.

Another important part of the machine is sinker. The sinker is a thin metal plate placed on the horizontal surface at perpendicular to the needle. They move to and fro in between the needle. The sinkers get their movement from the sinker cams. The purpose of the sinker is to hold the old loop when it is cleared from the needle. The sinker is used both in weft and warp knitting [19]. Different types of sinkers are used in different machines to produce the required variety of results. The machine that has double bed construction does not need to use sinker as either bed needle hold the old loop while other bed needle is in working position. The sinker and their parts are given in Fig. 4.15.

The sinker performs one or more of these functions:

1. Loop formation
2. Holding down
3. Knocking over

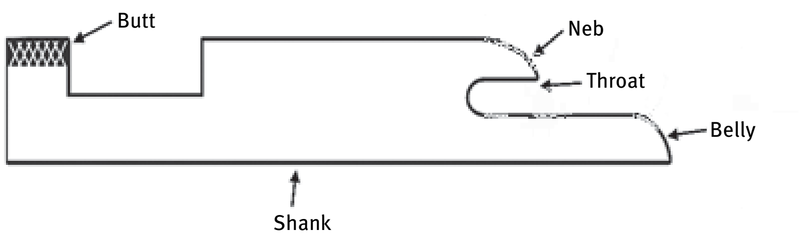


Fig. 4.15: Sinker and its parts.

4.11 Loop Formation Cycle with Latch Needle

The loop formation cycle of the latch needle explains the working of needle during loop formation process in weft knitting. The loop formation cycle is explained in Fig. 4.16.

1. The needle starts moving upward as the direction given by cam. The latch opens and old loop slips on the latch.
2. Now the needle clears the old loop. In this step the needle goes to its maximum height.
3. From this step the descending of needle starts, the needle engages the new yarn in the hook. This is a feeding of new yarn.
4. The needle moves down. The latch is now closed. This is a knock over position, the old loop is totally disengaged from the needle.
5. The final step is the loop pulling process. The needle goes to lower-most position and pulls the new loop from the previously formed old loop.

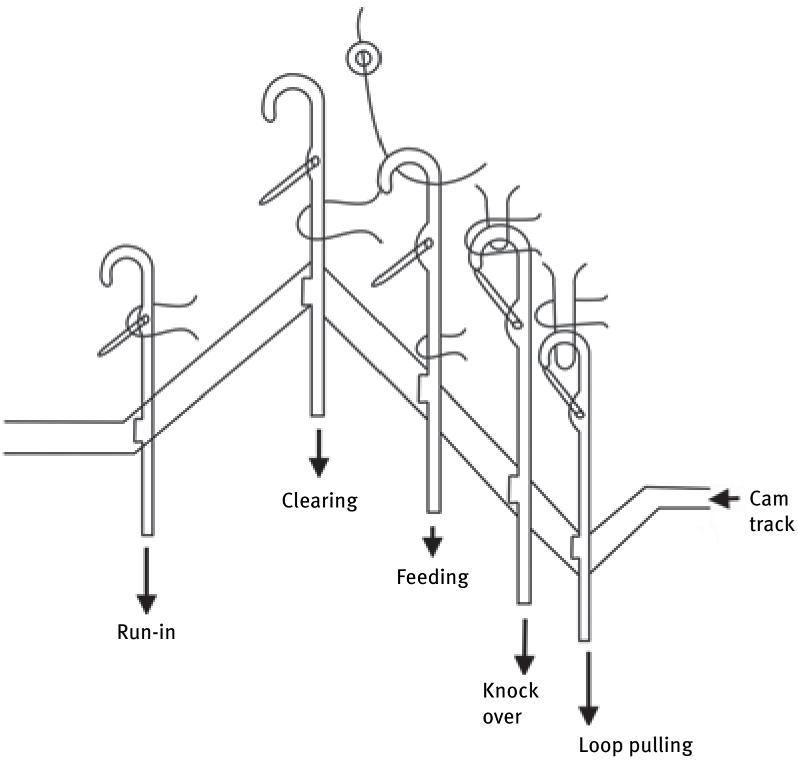


Fig. 4.16: Loop formation cycle of latch needle.

4.12 Principle Stitches in Weft Knitting

There are mainly four basic types of stitches in weft knitting, namely knit, tuck, purl and miss or float. Most of the weft-knitted fabrics and their derivatives are based on the combination of these stitches.

Knit Stitch
Knit stitch is formed when the needle is raised enough to engage the new yarn in the hook by the camming action and old loop is cleared. The technical back side of the knit stitch is called a purl stitch [18]. The clearing position of knit stitch is illustrated in Fig. 4.17.

Tuck Stitch
Tuck stitch is formed when the needle is raised to get the new yarn but not enough to clear the previous formed old loop. The needle then holds two loops when it descends as shown in Fig. 4.17. The needle can hold up to four loops only, and so it has to clear the previous held old loops quickly. The fabric gets thicker with tuck stitch as compared to knit stitche due to the accumulation of yarn when needle clears all the old loops. The structure becomes more open and permeable to air than knit stitches. It can also be used to get different color effect in the fabric [19].

Miss or Float Stitch
When the needle does not move upward to clear the old loop and also does not take the new yarn that presented to it then the miss or float stitch is formed. Needle is not activated in miss stitch. Moreover, it holds the old loop as shown in Fig. 4.17. Float stitch on the successive needles produce longer float of yarn that may cause the problem of snagging. The float is preferably used where we need to hide some color from the technical face of the fabric. The hide yarn floats at the back of the fabric. The yarn gets straighter in float stitch construction so the extensibility decreases as compared to tuck and knit stitches [19].

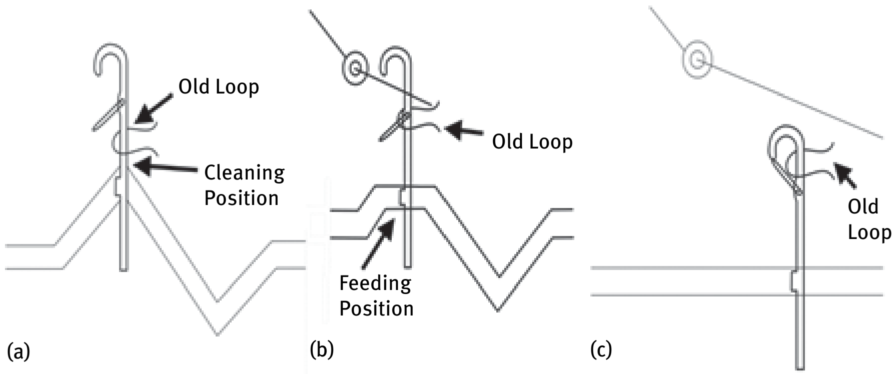


Fig. 4.17: Stitch types:(a) Knit, (b) Tuck, (c) float or miss stitch.

4.13 Knitting Terms and Definition

4.13.1 Loop Parts

The needle loop has different parts. The loop parts are important to understand the technical face and back side of the loop. The loop parts are given in Fig. 4.18.

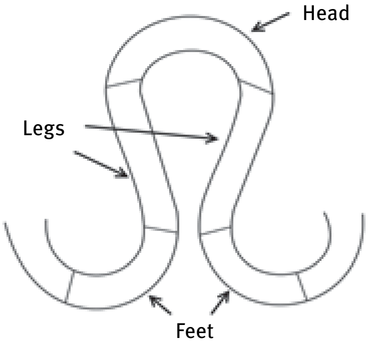


Fig. 4.18: Parts of a knitting loop.

4.13.2 Technical Face and Back

If the feet of the new loop cross under the legs of the old loop and legs cross over the head of the old loop, then this side is technical face or it may be defined as the side having all the face of the knit loop. Fig. 4.19 illustrates the interloping of the old and new loops, forming technical face side. If the feet of the new loop cross over the legs of the old loop and new loop legs pass under the head of old loop then it is said to be a technical back side. The interloping pattern of technical back is given in Fig. 4.19.

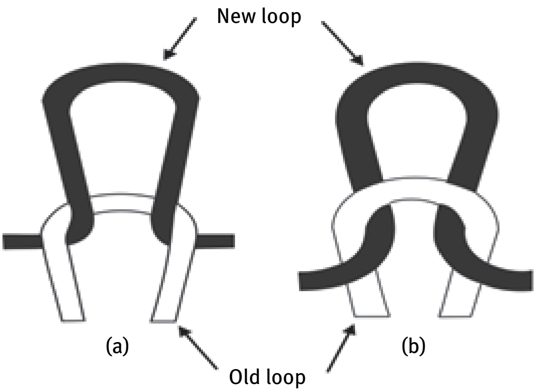


Fig. 4.19: Fabric sides: (a) Technical face, (b) Technical back.

4.13.3 Wales and Courses

The series of loops that are immersed vertically are known as wales. The consecutive loops that are connected horizontally are called courses. The rows and columns of loops connected are shown in Fig. 4.20.

4.13.4 Stitch Density

The number of loops or stitch per unit area is called stitch density. This can be calculated by the product of course and wales density. In one inch square area of fabric, there are 6 loops or stitches as displayed in Fig. 4.20.

Stitch density of a knitted fabric is expressed as wales density and courses density. The number of wales per unit length is called the wales density, normally measured in wale / inch or wale / cm. In Fig. 4.20, there are three wales in one inch of fabric.

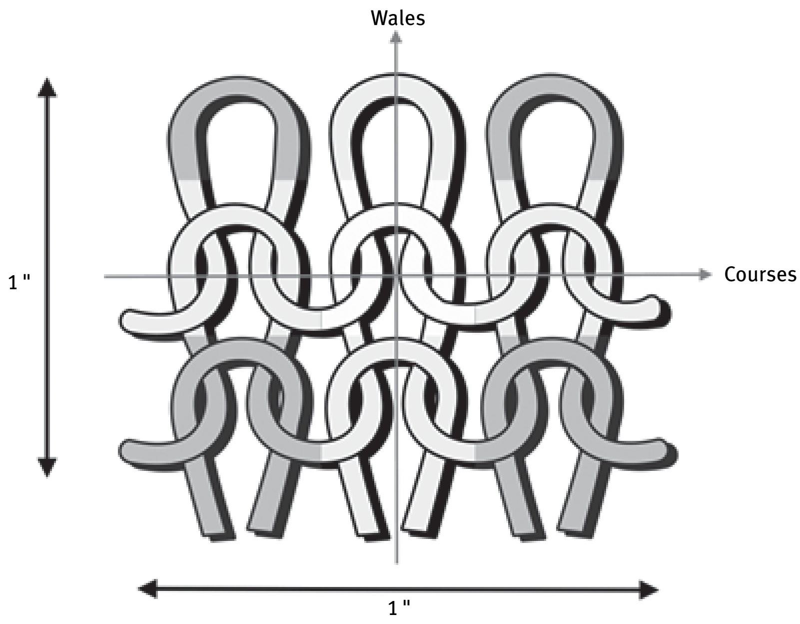


Fig. 4.20: Schematic pattern of a knitted fabric.

The number of courses per unit length is called the course density, normally measured in wale / inch or wale / cm. There are two complete courses in one inch of the fabric as shown in Fig. 4.20.

4.13.5 Stitch Length

The stitch length is the most important part of knitting. It is basically the length of yarn consumed to make one complete loop [16]. The knitted fabric dimensional, physical and mechanical properties are truly based on the stitch length that can be engineered to meet the requirement of the fabric. The individual loop is shown in Fig. 4.18.

4.14 Warp Knitting

Warp knitting may be defined as the loop formation process along the warp direction of the fabric [18]. The simultaneous sheet of the yarn is provided to the machine along the warp direction for the loop formation process. The sheets of yarn are supplied from warp beam as in weaving. Each warp end is provided to each individual needle. The same yarn runs along the warp direction and the needle draws the new loop yarn through the old loop that was formed by another yarn in the previous knitting cycle. Each yarn also passes through the guide mounted on guide bar that provides the movement of the same yarn between the needles.

The warp knitting machines are flat and fabric formation technique is more complex as compared to weft knitting. The flow process is given in Fig. 4.21. The comparison of warp and weft knitting is given in Tab. 4.2.

Fig. 4.21: Flow process of warp knitting.

Tab. 4.2: Comparison of warp and weft knitting [19].

Sr. #	Weft Knitting	Warp Knitting
1	Individual yarn is provided to feeder. If a machine has 90 feeders and all are active, then 90 courses are inserted in a complete revolution.	Simultaneous sheets of yarns are fed to the machine. Number of ends required will be equal to the number of needles on the machine.
2	Loop formation along the weft or course direction of the fabric.	Loop formation along the wale or warp direction of fabric.
3	The yarn is supplied in the form of cones or cheese. The number of cones required will be equal to the number of feeder available on machine.	Yarn supplied to machine from warp beam, so additional warping process is required to prepare warp beam.

Tab. 4.2: (Continued)

Sr. #	Weft Knitting	Warp Knitting
4	The spun yarns are mostly the raw materials for weft knitting so only waxing may require to avoid abrasion between the yarn and the machine parts.	The filament yarn is used in warp-knitted fabric according the end application. Antistatic oiling is required to avoid static charge.
5	The weft-knitted fabric has less dimensional stability so careful handling is required.	The warp-knitted fabric is dimensionally very stable due to overlapping and underlapping of yarn.
6	The weft-knitted fabric is more stretch-able in both directions (warp and weft)	The warp-knitted fabric are less stretchable and mostly they stretch in the weft direction.
7	Latch needle is preferably used in weft-knitting machine.	Latch as well as bearded and compound needles are used in warp-knitting machine.
8	The application of weft-knitted fabric is mostly apparel including both outer and inner garments.	The application area of warp-knitted fabric is not only apparel but also have huge demand for domestic, industrial and technical applications.

4.14.1 Classification of Warp Knitting Machine

Warp knitting machines are categorized on the basis of construction of different machine parts and their operations. Tricot and Raschel are two main categories of machine. Further classification of warp knitting is given in Fig. 4.22, while comparison of Tricot and Raschel warp knitting is given in Tab. 4.3.

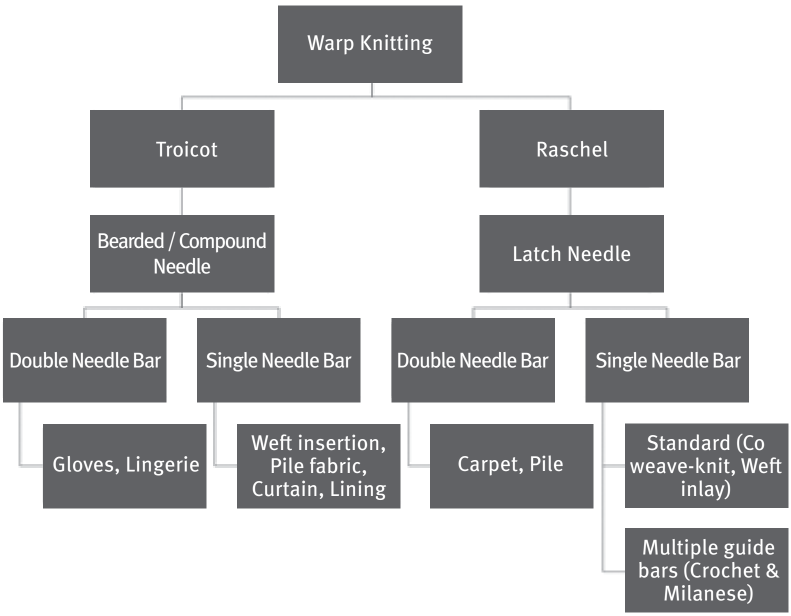


Fig. 4.22: Classification of warp-knitting machines and their structures.

Tab. 4.3: Comparison of Tricot and Raschel machines [18].

Sr. #	Machine Parts and their Operations	Tricot	Racshel
1	Needle Type	Bearded and compound needle is mostly used	Latch needle is preferably used
2	Sinkers	Sinkers work through out the knitting cycle	Sinkers active only when the needle rises
3	Machine Speed	Machine can run at a speed of 3500 courses / min	Raschel machine works at a bit lower speed of up to 2000 courses / min
4	Gauge	Tricot machine gauge is expressed by the number of needles per unit inch	Gauge defined by the number of needles per two inch
5	Warp Beams / Guide bars	Option to use less number of guide bars that can be up to 8	Minimum 2 and maximum 78 guide bars can be used
6	Structure type	Comparatively less complex or simple structure can be developed	Advance and complex structure can be produced on raschel
7	Take down angle	The take down angle is 90°	The angle is 160°
8	Fabric Width	More wider fabric can be achieved up to 170 inches	Width of fabric is limited to 100 inches

4.15 Applications of Knitted Fabrics

The application area of knitted fabric is mainly classified into three major categories such as clothing which includes weft-knitted vests, sweaters, pullovers, stockings, sportswear, underwears, etc. The home and furnishing textile is the second major class comprises of warp-knitted curtains, terry towel and weft-knitted blankets, upholstery, etc. The knitted fabrics also have a huge applications range in technical textile. Both warp- and weft-knitted fabrics are used in medical textiles such as compression bandages. The automobile industry also has the consumption of warp-knitted fabric in the form of seat covers, roofing and filtration. Packaging materials and mosquitoe nets are also made with knitted fabric [20].

4.16 Nonwoven

During the nonwoven fabric production, the yarn manufacturing as well as yarn preparation processes (required in woven fabric) are eliminated. Due to this reason nonwoven fabrics are cheaper as compared to the conventional fabrics. The great advantage of nonwoven fabrics is the speed with which the final fabric is produced.

All yarn preparation steps are eliminated, and the fabric production itself is faster than conventional methods. Not only the production rate is higher for nonwovens as shown in Tab. 4.4 [21], but the process is more automated, requiring less labor than even most modern knitting or weaving systems. The nonwoven process is also efficient in its use of energy.

Tab. 4.4: Production comparison of woven, knitted and nonwoven fabrics (INDA).

Method	System	Production (m^2 / hour)
Weaving	Shuttle	15
Overall average 0.583 m^2 / min	Rapier	30
	Water jet	35
	Projectile	40
	Air jet	55
Knitting	Double knit	125
Overall average 8.5 m^2 / min	Rib	175
	Single jersey	250
	Raschel	800
	Tricot	1200
Nonwoven	Stitch bonded	450
Overall average 335.5 m^2 / min	Needle punched	7200
	Card bond	15000
	Wet laid	30000
	Spun laid	48000

In the 19th century, realizing that a large amount of fiber is wasted as trim, a textile engineer named Garnett developed a special carding device to shred this waste material back to fibrous form. This fiber was used as filling material for pillows. The Garnett machine, though greatly modified, today still retains his name and is a major component in the nonwoven industry. Later on, manufacturers in Northern England began binding these fibers mechanically (using needles) and chemically (using glue) into batts. These were the precursors of today’s nonwovens [22].

The term ‘nonwoven’ rises from more than sixty years ago when nonwovens were considered as cheaper alternative of conventional textiles and were generally made from carded webs using textile processing machinery [22]. The nonwovens industry is very sophisticated and profitable, with healthy annual growth rates. It is perhaps one of the most intensive industries in terms of its investment in new technology, and also in research and development. Therefore, the nonwoven industry as we know it today has grown from developments in the textile, paper and polymer processing industries. Today, there are also inputs from other industries including most branches of engineering as well as the natural sciences.

4.16.1 Definitions

Different definitions of nonwovens are available by different organizations. According to the ASTM D 1117–01, nonwovens can be defined as:

> "A textile structure produced by the bonding or interlocking of fibers, or both, accomplished by mechanical, chemical, thermal or solvent means and combinations thereof"

According to the standard ISO-9092:1988, the nonwovens are:

> "Manufactured sheet, web or batt of directionally or randomly orientated fibers, bonded by friction, and / or cohesion and / or adhesion, excluding paper and products which are woven, knitted, tufted, stitch-bonded incorporating binding yarns or filaments, or felted by wet-milling, whether or not additionally needled. The fibers may be of natural or man-made origin".

The Association of Nonwoven Fabrics Industry, USA (INDA) defines nonwovens as:

> "A sheet, web or batt of natural and/or man-made fibers or filaments, excluding paper, that have not been converted into yarn, and that are bonded to each other by any of several means.
>
> To distinguish wet-laid nonwovens from wet-laid paper materials the following differentiation is made. (a) More than 50 % by mass of its fibrous content is made-up of fibers with a length to diameter ratio greater than 300. Other types of fabrics can be classified as nonwoven if, (b) More that 30 % by mass of its fibrous content is made up of fibers with a length to diameter ratio greater than 600 and / or the density of the fabric is less than 0.4 g / cm^3.

The European Disposables and Nonwovens Association (EDANA) describes the nonwovens as:

> "A manufactured sheet, web or batt of directionally or randomly oriented fibers, bonded by friction, and / or cohesion and / or adhesion, excluding paper and products, which are woven, knitted, tufted or stitch-bonded, or felted by wet-milling, whether or not additionally needled. The fibers may be of material or man-made origin. They may be staple or continuous filaments or be formed in situ". To distinguish wet-laid nonwovens from wet-laid papers, a material shall be regarded as a nonwoven if, (a) More than 50 % by mass of its fibrous content is made-up of fibers with a length to diameter ratio greater than 300; or (b) More than 30 % by mass of its fibrous content is made up of fibers with a length to diameter ratio greater than 300 and its density is less than 0.40 g / cm^3."

4.16.2 Nonwoven Products

Nonwoven fabrics have wide area of applications depending upon the properties required in the end product. EDANA has given the nonwoven fabric applications according to the end use as shown in Fig. 4.23.

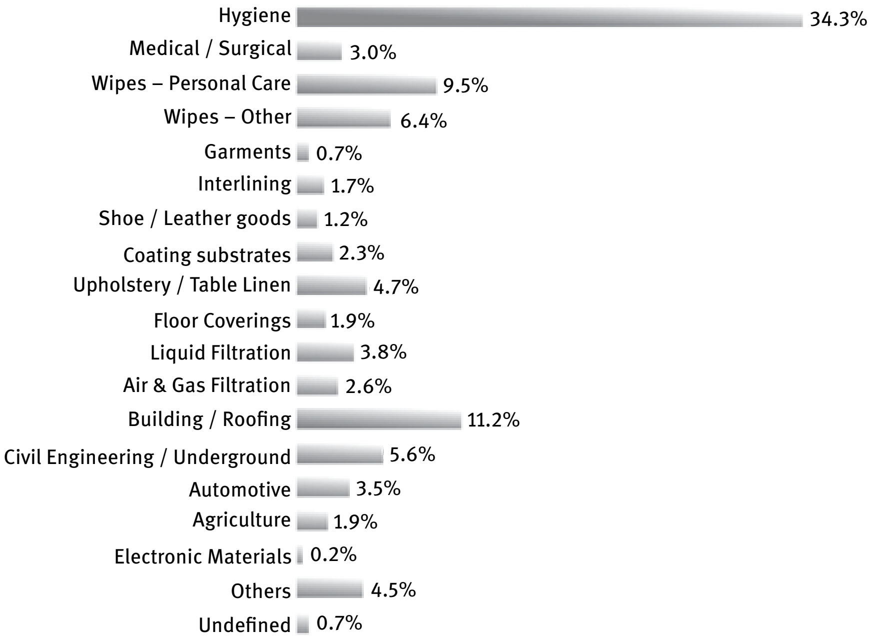


Fig. 4.23: Application areas of nonwovens [23].

Nonwoven fabrics have wide range of products like disposable gowns, face masks, gloves, shoe covers, dressings, sponges, wipes, diapers, sanitary napkins, lens tissues, vacuum cleaner bags, tea and coffee bags, hand warmers, interlinings, incontinence products, floor covers, air filters, paddings, blankets, pillows, pillow cases, aprons, table cloths, hand bags, book covers, posters, banners, disk liner, sleeping bags, tarpaulins, tents, crop covers, green house shadings, weed control fabrics, golf and tennis courts, road beds, drainage, sedimentation and erosion control, soil stabilization, dam embankments, etc. [24, 25].

4.16.3 Raw Materials for Nonwovens

Different types of man-made and natural fibers are used in the nonwoven fabric production. Man-made fibers have 90 % share of the total fiber consumption [22].

Polymers, fibers and binders are the basic raw materials for nonwovens. Most of the fibers and binders are made of polymers. A polymer is a large molecule built up by the repetition of small single chemical units. Large molecules are called macromolecules consisting of hundreds to millions of atoms linked together by chemical bonds (typically covalent bonds) which are called primary bonds. The special properties of polymers result particularly from secondary bonds acting between the macromolecules which are known as van der Waals forces. Virtually all types of fibrous material can be used to make nonwoven fabrics depending on:

– The required profile of fabric
– The cost effectiveness
– The demands of further processing

Most common fiber types used in nonwoven fabric production are: polypropylene, polyester, viscose rayon, polyamide 6 and 6.6, bicomponent fibers, surface modified fibers, superabsorbent fibers, Novoloid fibers, wool is used in felts production, cotton in hygienic goods and another quantitatively important group of fiber raw material for nonwovens is waste fiber materials.

Production of nonwovens is carried out after considering the following points:
– Process ability in a particular technology
– Impact on the product properties
– Price

Thus, it is very essential to study different fiber properties for the development and production of nonwoven fabrics. According to a study carried out by Tecnon Ltd. the world consumptions of different types of fibers are as: polypropylene 63 %, polyester 23 %, viscose rayon 8 %, Acrylic 2 %, polyamide 1.5 %, others 3 %. Polypropylene fibers consumption is highest in nonwoven fabric production due to certain properties like: low density, hydrophobicity, low melting and glass transition temperature, biological degradation resistance, chemical stability, good mechanical strength [22].

4.17 Manufacturing of Nonwoven

Production of nonwoven fabric is comparatively easier as compared to the conventional fabric production method like weaving. First of all, fiber type is selected from natural or manmade origin and then selected fibers are converted in the form of a regular sheet or web. In the third step fibrous sheet or web is bonded together for consolidation and strength of sheet and in last step finishes are applied over the consolidated web according to the end use. The production sequence of nonwoven fabric is shown in Fig. 4.24.

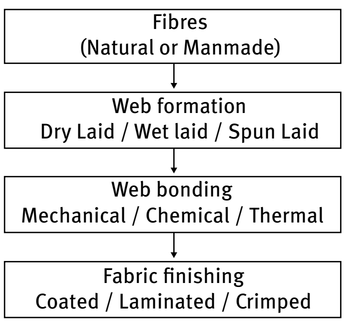


Fig. 4.24: Nonwoven production steps.

Nonwoven fabrics can be classified on the basis of fibers orientation during web formation and bonding of the web. Structure based classification of nonwoven fabric is shown in Fig. 4.25.

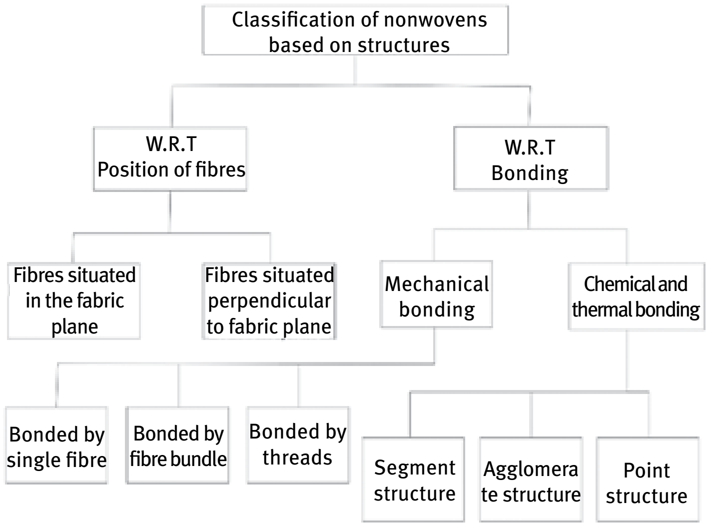


Fig. 4.25: Structure based classification of nonwoven fabrics.

4.17.1 Web Formation

After the fiber selection web formation is the major step of nonwoven fabric formation. During web formation fibrous sheet, web or batt is formed having two dimensional or three dimensional assemblies. Orientation, dimension and structural arrangement of fibers in the web greatly influence the final product properties. Fibrous sheet or web formation is classified in three areas: dry laid, wet laid and polymer laid (Spun bonded). Dry laid technique is directly related to the conventional spinning process while wet laid technique is related to the paper making industry and polymer laid technique is directly related to the polymer extrusion through spinneret.

4.17.2 Dry Laid Web

Dry laid web formation is concerned with carding process of spinning. Carding produces one or more webs, in which fibers are preferentially oriented in the machine direction (MD). A multilayer web is produced by using more than one card machines in a single line. The major objective of carding is to disentangle and mix the fibers to form a homogeneous web of uniform mass per unit area. This purpose is achieved by the interaction of fibers with toothed rollers situated throughout the carding machine. The first and the most basic principle of carding is “working” and the second is “stripping”. The whole carding process is essentially a succession of “working” and “stripping” actions linked by incidental actions. Every card has a central cylinder or swift that is normally the largest roller and small rollers (called worker and strippers). Generally small rollers operate in pairs and situated around cylinder and carry out the basic function of working and stripping. Many cards have more than one cylinder with their own small rollers. Arrangement of rollers in a basic carding machine is shown in Fig. 4.26.

Worker and stripper pairs around the cylinder perform both opening and mixing functions. Doffer cylinders condense and remove the fibers from the cylinder surface in the form of a continuous web. The points of teeth on a worker roller directly oppose the points of cylinder teeth in a point-to-point relationship. The worker revolves in the opposite direction to that of the cylinder. The teeth on worker and cylinder travel in the same lateral direction at their point of interaction, causing a “working” action between the worker and cylinder. Then a stripping action between the stripper and the worker, followed by a further stripping action between the cylinder and the stripper. After removal of the web from the first card machine, it is allowed to pass under the second card machine through a conveyor, to achieve the required thickness of web. Batt drafting is done to increase the fibers orientation in the machine direction.

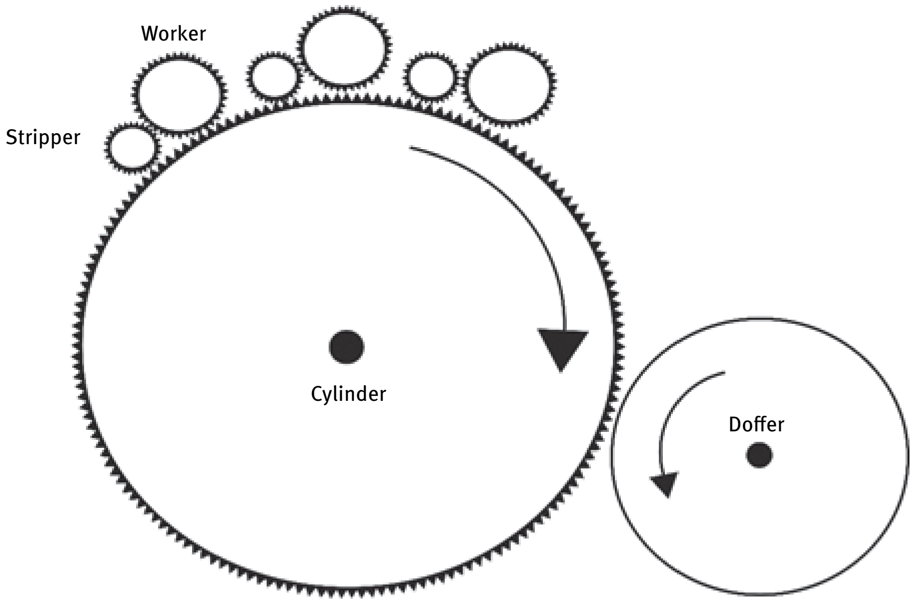


Fig. 4.26: Working and stripping actions.

4.17.3 Wet Laid Web

The technology of wet-laid nonwovens is closely related to that of paper and paper-making which itself goes back some 2000 years, developed in China. But wet-laid nonwovens are differentiated from paper manufacturing and regarded as nonwoven: if more than 50 % by mass of its fibrous content is made up of fibers (excluding chemically digested vegetable fibers) with a length to diameter ratio of greater than 300; or more than 30 % by mass of its fibrous content is made up of fibers (excluding chemically digested vegetable fibers) with a length to diameter ratio greater than 300 and its density is less than 0.40 g / cm^3.

A dilute slurry of water and fibers is deposited on a moving wire screen and drained to form a web as shown in Fig. 4.27. The web is further dewatered, consolidated, by pressing between rollers, and dried. Impregnation with binders is often included in a later stage of the process. Wet laid web-forming allows a wide range of fiber orientations ranging from near random to near parallel. The strength of the random oriented web is rather similar in all directions in the plane of the fabric. A wide range of natural, mineral, synthetic and man-made fibers of varying lengths can be used.

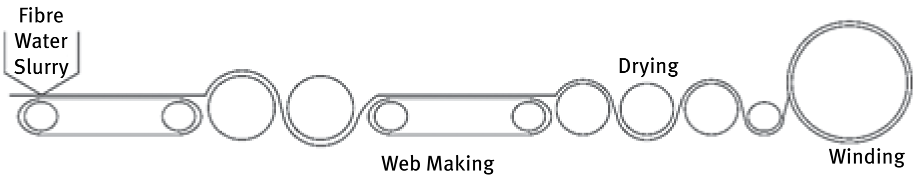


Fig. 4.27: Schematic of wet laid web formation.

4.17.4 Polymer Laid Web

Polymer-laid, spun laid or “Spun melt” nonwoven fabrics are produced by extrusion spinning processes, in which filaments are directly collected to form a web instead of being formed into tows or yarns as in conventional spinning. As these processes eliminate intermediate steps, they provide opportunities for increasing production and cost reductions. In fact, melt spinning is one of the most cost efficient methods of producing fabrics. Commercially, the two main polymer-laid processes are spun bonding (spun bond) and melt blowing (melt blown). A primary factor in the production of spun bonded fabrics is the control of four simultaneous, integrated operations: filament extrusion, drawing, lay down, and bonding. The basic stages of spun bonded nonwoven fabric include [22]**:**

Polymer melting → Filtering and extrusion → Drawing → Laydown on forming screen → Bonding → Roll up

The first three operations are directly adapted from conventional man-made filament extrusion and constitute the spun or web formation phase of the process, while the last operation is the web consolidation or bond phase of the process, hence the generic term spun bond. All spun bond manufacturing processes have two aspects in common:
- They all begin with a polymer resin and end with a finished fabric.
- All spun bond fabrics are made on an integrated and continuous production line.

Melt blowing is a process in which, usually, a thermoplastic fiber forming polymer is extruded through a linear die containing several hundred small orifices. Convergent streams of hot air (exiting from the top and bottom sides of the die nosepiece) rapidly attenuate the extruded polymer streams to form extremely fine diameter fibers (1–5 μm). The attenuated fibers are subsequently blown by high-velocity air onto a collector conveyor, thus forming a fine fibered self-bonded nonwoven melt blown web as shown in Fig. 4.28.

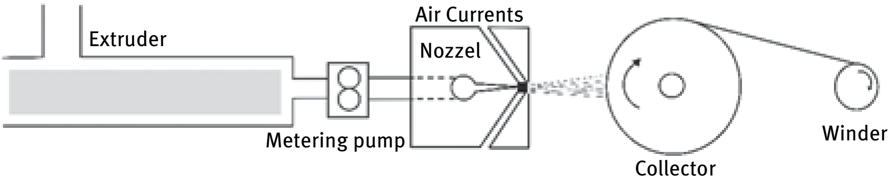


Fig. 4.28: Schematic of melt blown web formation [22].

In general, high molecular weight and broad molecular weight distribution polymers such as polypropylene, polyester and polyamide can be processed by spun bonding to produce uniform webs. Medium melt viscosity polymers, commonly used for production of fibers by melt spinning, are also used. In contrast, low molecular weight and relatively narrow molecular weight distribution polymers are preferred for melt blowing. In the past decade, the use of polyolefin, especially polypropylene, has dominated the production of melt blown and spun bonded nonwovens. One of the main reasons for the growing use of polyolefin in polymer-laid nonwovens is that the raw materials are relatively inexpensive and available throughout the world.

4.18 Web Bonding

After the web preparation, next major step in the nonwoven production is web bonding. Different web bonding techniques are available depending upon the end product properties and cost. Nonwoven web bonding mainly has three categories:
- Thermal bonding
- Chemical bonding
- Mechanical bonding

4.18.1 Thermal Bonding

Thermal bonding requires a thermoplastic component to be present in the form of a fiber, powder or as a sheath as part of a bicomponent fiber. The heat is applied until the thermoplastic component becomes viscous or melts. The polymer flows by surface tension and capillary action to fiber-to-fiber crossover points where bonding regions are formed. These bonding regions are fixed by subsequent cooling. No chemical reaction takes place between the binder and the base fiber at the bonding sites. Binder melt and flow into and around fiber crossover points, and into the surface crevices of fibers in the vicinity, and adhesive or mechanical bond is formed by subsequent cooling. Thermal bonded products are relatively soft and bulky depending upon the fibers composition. Thermal bonding process is economical, environment friendly and 100 % recycling of fibers components can be achieved. In thermal bonding technique generally hot calendar rollers are used to bind the fibrous sheet. Thermal bonding has further sub categories: point, area, infra-red, ultra-sonic and through air bonding.

4.18.2 Chemical Bonding

In chemical bonding, different types of chemicals or binders – rubber (latex), synthetic rubber, copolymers, acrylics, vinyl esters, styrene and different natural resins are sprayed on the nonwoven web for bonding purpose. Latex binder is most commonly used for nonwoven web bonding. During chemical bonding process chemicals are sprayed on the nonwoven web or web is allowed to pass through the chemical box. In chemical bonding different techniques are used for the web bonding. Most frequently used chemical bonding processes are spray adhesives, print bonding, saturation adhesives, discontinuous bonding and application of powders.

4.18.3 Mechanical Bonding

In mechanical bonding process, fibrous sheet or web is bonded together through the application of liquid or air jets, punching needles and by stitching. Depending upon the selection of any type of mechanical media, nonwovens are classified as hydro entanglement, needle punching and stitch-bonded fabrics. In hydro entanglement techniques, fibrous sheet is allowed to pass under the liquid jets provided by multiple nozzles. Through the jet pressure web is fused, consolidated and provide strength to the sheet as shown in Fig. 4.29. The major disadvantage of this technique is the drying of sheet after consolidation. Hydro entangled nonwoven fabrics are used in wipes and medical nonwoven industry because of their additive free, lint free, soft, strong, and cost effective characteristics.

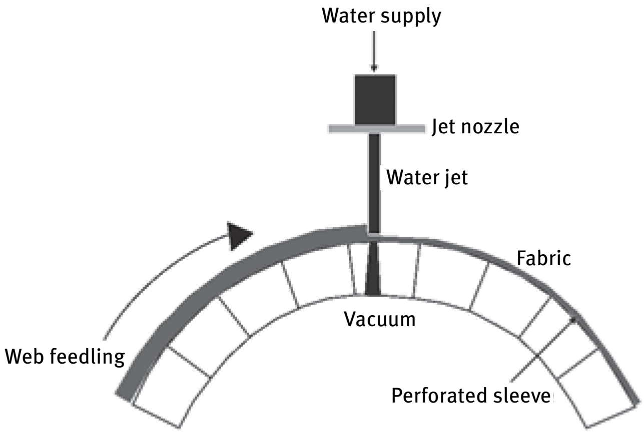


Fig. 4.29: Hydro-entanglement bonding assembly [22].

In needle punching method, fibrous web is allowed to pass under a bar containing multiple needles. These needles pass in through the thickness direction of web and entangle the fibers to give strength to the fibrous sheet. Schematic representation of a needle punching is shown if Fig. 4.30. Needle punched nonwovens are used in automotive, construction, home furnishing industries, geotextiles, shoe felts, blankets, filters and insulators.

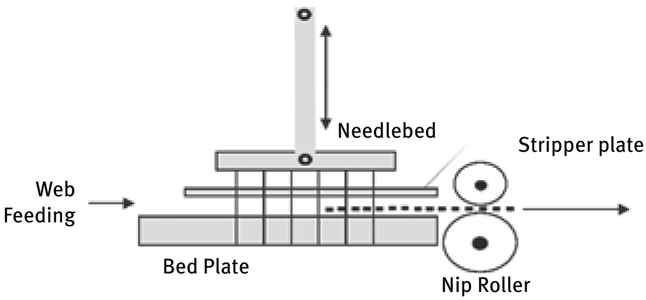


Fig. 4.30: Schematic representation of needle punching technique [22].

Stitch bonded nonwoven fabrics are produced by stitching the fibrous web or sheet with other fibers or yarns. The performance properties of stitch bonded nonwoven fabric depends upon the stitching yarn type, stitch density, stitch length, stitching yarn tension and machine gauge. Stitched bonded fabrics may be of one side stitched, two sides stitched or one side stitched with the projection of pile on the other side of the fabric. In order to get flexibility in the fabric Lycra yarn is used and for higher strength fabric, high performance yarns are used for stitching purpose. Commercially, two stitch bonding systems: Maliwatt and Malivlies are available. Stitch bonded fabrics are used to produce vacuum bags, geotextiles, filters, and interlining, the biggest market is shaped by home furnishing industry.

4.19 Finishing

Keeping in view the end use of nonwoven fabric, different types of finishes are applied over the fabric. The variety of both chemical and mechanical finishes provided new horizon for the application of nonwoven fabric. Different types of wet finishes, dyeing, coating as well as calendaring, embossing, emerising and micro creping were used. These days, many types of chemical finishes like the antistatic finish, antimicrobial finish, water repellent finish, UV absorbers, flame retardant finish, soil release agent, optical brightener and super absorbent finishes are applied on the end product keeping in view the performance application of the product. Plasma treatment, microencapsulation, laser etching, biomimetic and electrochemical finishes are under developing stages for nonwoven finishing.

4.20 Characterization of Nonwoven

Nonwoven fabric is different from other textile structures, because it is produced from fibers or fibrous sheet rather than yarn. In addition to the fiber and binder type, structural properties of nonwoven fabric are influenced by the web formation process, bonding technique and finishing process. The structure and dimensions of nonwoven fabrics are frequently characterized in terms of fabric weight / mass per unit area, thickness, density, fabric uniformity, fabric porosity, pore size and pore size distribution, fiber dimensions, fiber orientation distribution, bonding segment structure. Majority of nonwoven fabrics have porosities >50 % and usually above 80 %. The fabric weight uniformity in a nonwoven is normally anisotropic, i. e. the uniformity is different in different directions (machine and cross direction) in the fabric structure. Certain mechanical properties like tensile strength, tear strength, compression recovery, bending and shear rigidity, abrasion and crease resistance frictional properties are tested according to the end use.

References

[1] P. R. Lord, and M. H. Mohamed, *Weaving: Conversion of Yarn to Fabric*. Elsevier, 1982.
[2] S. Adanur, *Handbook of Weaving*. Washington, USA: CRC Press, 2001.
[3] B. Wulfhorst, O. Maetschke, M. Osterloh, A. Busgen, and K. -P. Weber, *Textile Technology*. Weinheim: Wiley Online Library, 2006.
[4] B. C. Goswami, R. D. Anandjiwala, and D. Hall, *Textile Sizing*. 2004.

[5] R. Marks, ATC. Robinson, *Principles of Weaving*. Manchester: The Textile Institute, 1976.
[6] A. Talukdar, Sriramulu, *Weaving Machines Mechanism Management*, 2nd ed. Ahmedabad: Mahajan Publishers, 1998.
[7] J. Arora, *Modern Weaving Technology*. India: Abhishek Publications, 2002.
[8] A. Ormerod, *Modern preparation and weaving machinery*. England: Woodhead Publishing, 2004.
[9] S. Maity, K. Singha, and M. Singha, “Recent Developments in Rapier Weaving Machines in Textiles,” *Am. J. Syst. Sci.*, vol. 1, no. 1, pp. 7–16, 2012.
[10] R. Marks, ATC. Robinson, *Woven cloth construction*. Manchester: The Textile Institute, 1973.
[11] E. B. Berry, *Textile Designing: Pure and Applied*. North Carolina State College, 1967.
[12] S. Adanur, “Property Analysis of Denim Fabrics Made on Air-jet Weaving Machical Part II: Effects of Tension on Fabric Properties,” *Text. Res. J.*, vol. 78, no. 1, pp. 10–20, Jan. 2008.
[13] N. Gokarneshan, and R. Alagirusamy, “Weaving of 3D fabrics: A critical appreciation of the developments,” *Text. Prog.*, vol. 41, no. 1, pp. 1–58, Apr. 2009.
[14] A. M. Seyam, “Advances in Weaving and Weaving Preparation,” *Text. Prog.*, vol. 30, no. 1–2, pp. 22–40, 2000.
[15] D. J. Spencer, *Knitting Technology A comprehensive handbook and practical guide*. 2001.
[16] T. Gries, D. Veit, and B. Wulfhorst, *Textile Technology*. Henser Publications, 2006.
[17] T. Hussain, “State of Textile and Clothing Exports from Pakistan,” *TEXtalks*, vol. July / Augus, pp. 62–65, 2013.
[18] Sadhan Chandra Ray, *Fundamentals and Advances in Knitting Technology*. 2011.
[19] Dr. Anbunami, *Knitting Fundamentals, Machine Structure and Development*. New Delhi: New Age International (P) Limited, 2005.
[20] K. F. Au, Ed., *Advances in Knitting Technology*. Woodhead Publishing, 2011.
[21] “www.INDA.org”.
[22] S. J. Russell, *Handbook of Nonwovens*. Cambridge, England: Woodhead Publishing Limited, 2007.
[23] “www.EDANA.org”.
[24] R. A. Chapman, *Applications of Nonwovens in Technical Textiles*. Cambridge, England: Woodhead Publishing Limited, 2010.
[25] W. Albrecht, H. Fuchs, and W. Kittelmann, *Nonwoven fabrics: Raw materials, Manufacture, Applications, Testing process*. Weinheim, Germany: WILEY-VCH, 2003.

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5 Textile Processing

5.1 Introduction

Textile materials in different forms, such as fiber, yarn, woven fabric, knitted fabric or garment may be subjected to different textile processing operations. A general textile processing flowchart is given in Fig. 5.1. An additional heat-setting process may be required for fabrics containing synthetic fibers. Some processes may be combined, for example scouring or bleaching may be combined in one operation; similarly dyeing may be combined with some chemical finishes or finishing may be done directly after bleaching. These processes are briefly described in the following sections, with the example of woven fabrics.

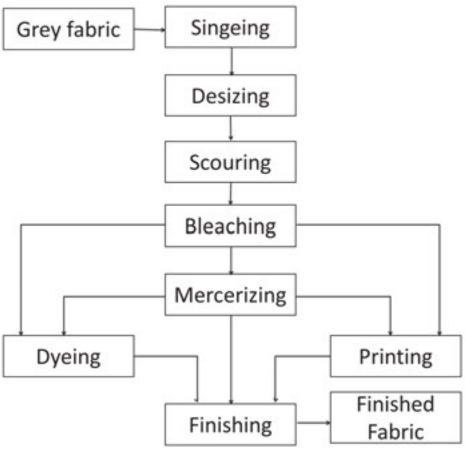

Fig. 5.1: General steps in textile processing.

5.2 Textile Pre-treatments

The main objective of fabric preparation or pre-treatments is to remove any impurities or contaminants from the fabric and make it ready for the subsequent operations such as optical brightening, dyeing, printing or finishing. The overall objectives of fabric preparation include removal of fabric impurities such as protruding fibers, sizing agents, cotton seed husks, fats, oils, waxes, dirt, dust, lubricants, etc.; improved absorbency and / or whiteness of the fabric; minimum fiber damage; uniform residual size, pH, alkalinity, whiteness, absorbency and moisture content. The commonly used fabric pre-treatment processes are briefly described in the following sections.

5.3 Singeing

Singeing is a process of passing an open-width fabric over a gas flame at such a distance and speed that it burns only the protruding fibers but does not damage the main fabric. The main objective of the singeing process is to produce a clean fabric surface and reduce fabric pilling tendency by removing the protruding fibers from the fabric surface.

There are three different methods of singeing such as hot plate singeing, hot rotary cylinder singeing and gas flame singeing. However, gas flame singeing is the most commonly used singeing methods because of better singeing efficiency. Different singing positions may be used for different fabrics in order to attain different intensity of singeing. Main singeing positions are: singeing onto free guided rollers; singeing onto water-cooled rollers and tangential singeing [2].

The main parameters of gas flame singeing include gas flame intensity, fabric speed over the flame, singeing position (or angle between the fabric and the flame), distance between the fabric and the flame, and width of the flame.

The commonly used methods to assess the singeing efficiency include observation of fabric surface with magnifying glass or stereo microscope, and fabric pilling test. A harsher fabric hand-feel may also be an indication of over-singeing. Commonly encountered problems in singeing operations include incomplete singeing, uneven singeing along the fabric length, uneven singeing along the fabric width, horizontal / width-way singeing stripes, vertical / length-way singeing stripes, over-singeing or thermal damage to fabric, and formation of molten fiber beads in synthetic or blended fabrics.

5.4 Desizing

Desizing is a process of removing sizing agents from the fabrics, which are usually applied on the warp yarns before weaving. Sizing agents mostly comprise macromolecular film-forming and fiber-bonding substances such as starch, PVA and polyacrylates, which are applied on warp yarns to increase their strength and reduce yarn breakages during weaving. Some auxiliaries such as wetting agents, softening agents, lubricating agents or hygroscopic agents may also be included in the sizing recipe.

Removal of sizing agents after weaving is necessary in order to make the fabric more absorbent for dyes and other chemical processing agents. The choice of method for desizing depends on the type of sizing agents used during sizing. Different desizing methods include enzymatic desizing, oxidative desizing, acid desizing, desizing with hot alkali treatment and desizing with hot detergent solutions. Starch-based sizing materials are usually not water-soluble and require use of amylases enzymes for their removal. Enzymatic method is most commonly used for desizing fabrics which contains starch-based sizing materials. Advantages of enzymatic desizing in comparison to oxidative and acid desizing include no damage to the fiber, no use of aggressive chemicals, high biodegradability and wide variety of application methods.

Water-soluble sizing materials such as polyvinyl alcohol (PVA) or carboxymethyl cellulose (CMC) may be removed by simple washing with hot water, without the use of any enzymes. Important parameters for enzymatic desizing method include liquor pH, temperature, time, type and amount of any wetting agent or detergent. The effectiveness of desizing process can be checked by putting a drop of iodine solution on the desized fabric, which turns into blue colour if there is still some unremoved starch present in the fabric [3].

5.5 Scouring

Scouring is a process for removing natural and acquired impurities from fabrics to make them more absorbent and suitable for subsequent processes such as bleaching, dyeing, printing or finishing. Natural cotton contains very small amount of oils, fats and waxes, in addition to acquiring dirt or dust, etc. during transportation and storage, which make is dirty and less absorbent. Cotton fabrics are usually scoured by using liquors containing strong alkali such as caustic soda and detergents at boiling temperature. Impurities such as calcium or magnesium may also be present not only in the cotton fiber but also in the process water. Sequestering agents may also be used during scouring to counter the negative effect of calcium and magnesium on scouring. Bioscouring is an alternative method to conventional scouring with caustic soda and detergents, in which enzymes such as pectinases are used for cotton scouring.

Fabrics made from wool are also subjected to scouring. However, since wool is sensitive to alkalis, milder scouring conditions are used for wool. Since fabrics made from regenerated and synthetic fibers do not contain any natural impurities but only small amounts of processing lubricants and dirt, their souring also requires milder conditions as compared to those required for cotton fabrics. Since, scouring is a process for removing natural and acquired impurities from fabrics, the severity of the scouring treatment depends upon the nature and amount of the impurities present as well as the sensitivity of the fiber to different scouring agents. The aim is to remove the impurities without damaging the fiber.

Main parameters of the scouring process include type and amount of alkali, type and amount of detergent, type and amount of sequestering agent, temperature and time of the treatment. In case of enzymatic scouring, the main parameters include type and amount of enzymes, pH, temperature and time of the treatment. The efficiency of scouring treatment can be evaluated by testing fabric absorbency and determining fabric weight loss after the treatment. A cotton fabric which can absorb a drop of water within a few seconds is considered to be well scoured [1, 3].

5.6 Bleaching

The purpose of bleaching is to remove any coloring matter from the fabric and confer it a whiter appearance. In addition to increase in fabric whiteness, the bleaching process may also result in improved fabric absorbency and removal of cotton seed husks and trash from the fabric. Although there are different bleaching agents which may be used for bleaching textile fabrics, such as sodium hypochlorite or calcium hypochlorite, hydrogen peroxide is the most commonly used bleaching agent for cotton and its blended fabrics, because of its advantages in comparison with other bleaching agents.

The main parameters for bleaching with hydrogen peroxide include concentration of hydrogen peroxide, concentration of alkali (e. g. NaOH), type and concentration of bleaching stabilizer (e. g. sodium silicate), type and concentration of sequestering agent, pH, temperature and treatment time. A pH in the range of 10.2–10.7 is considered optimum for bleaching cotton fabrics with hydrogen peroxide. Quality of the bleached fabric may be evaluated by testing its whiteness with the help of a spectrophotometer, fabric absorbency, and checking for any fabric damage [1, 3].

5.7 Mercerizing

Cotton and its blended fabrics are sometimes subjected to a mercerization process to enhance various properties such as increase in dye affinity, chemical reactivity, dimensional stability, tensile strength, luster and fabric smoothness. Mercerization process is performed using caustic soda. Although caustic soda is also used in scouring cotton fabrics but the concentration of caustic soda is very low in scouring (e. g. 5–10 %) while the concentration in mercerization may be up to 22–25 %. The main mercerization parameters include concentration of caustic soda, type and concentration of wetting agent, temperature, fabric liquor pick-up, time duration, and tension on fabric during the process. Fabric pick-up in mercerization is usually kept as near to 100 % as possible and the dwell / contact time with caustic liquor 40–60 seconds. After mercerization, the fabric is rinsed for removal of alkali and its pH is neutralized to make it suitable for subsequent processing. The mercerization process in only done for those fabrics which are made from 100 % cotton or contain substantial amount of cotton in case of a blend. Mercerization is not done for purely synthetic fabrics such as those made from polyester or nylon [1, 3].

5.8 Heat-setting

Heat-setting process is only used for synthetic fabrics such as those made from polyester or their blends to make them dimensionally stable against subsequent hot processes. Other benefits of heat-setting include less fabric wrinkling, low fabric shrinkage and reduced pilling tendency. Heat-setting process involves subjecting the fabric to dry hot air or steam heating for a few minutes followed by cooling. The temperature of heat-setting is usually set above the glass transition temperature and below the melting temperature of the material comprising the fabric [4].

5.9 Textile Dyeing

Two major processes used for coloration of textiles are dyeing and printing. Dyeing can be defined as a process during which a textile substrate is brought in contact with the solution or dispersion of a colorant, and the substrate takes up the said colorant with reasonable resistance to its release form the substrate. Dyeing comprises the application of colorant to the entire body of a textile substrate with a reasonable degree of fastness. Textile materials can be dyed in fiber, yarn, fabric or garment form. Dyeing of fibers is known as 'stock dyeing'. Addition of colorant to the polymer melt o solution prior to their extrusion is called 'dope dyeing' or 'solution dyeing'. Dyeing of yarns in the form of wound packages, skeins or beams is known as 'package dyeing', 'skein dyeing' or 'beam dyeing' respectively. Fabric dyeing is also known as 'piece dyeing' [5].

Different requirement that a dyer has to meet include matching the required shade on the dyed material; achieving level / uniform dyeing; obtaining required degree of colour fastness (i. e. resistance to washing, rubbing, light, perspiration, etc.); avoiding any deterioration of textile properties during dyeing (e. g. loss in strength, softness, etc.); keeping the dyeing cost as low as possible; and minimizing harmful impact on the environment.

5.10 Dyes and Pigments

There are two main types of colorants: pigments and dyes. Dyes are either soluble in the dyeing medium (e. g. water) or can dissolve into the textile substrate. Pigments are neither soluble in the dyeing medium nor can dissolve into the substrate. Both pigments and dyes can be natural or synthetic. Colorants from natural sources such as plants have been obtained since pre-historic times. The first synthetic dye was accidently discovered by an English chemist named William Henry Perkin in 1856.

From the application point of view, dyes have been classified into different groups, each group being suitable for certain types of textile substrates. Some commonly used dyes and their suitability for different fibers is given in Tab. 5.1. For example, the most commonly used type of dye for cotton, polyester and acrylic are reactive dyes, disperse dyes and basic dyes, respectively.

Tab. 5.1: Main dye classes and their suitability for different fibers.

Fibres	Class of Dyes							
	Acid	Basic	Direct	Disperse	Azoic	Reactive	Sulphur	Vat
Cotton			☑		☑	☑	☑	☑
Viscose			☑		☑	☑	☑	☑
Tencel®			☑		☑	☑	☑	☑
Modal®			☑		☑	☑	☑	☑
Bamboo			☑		☑	☑	☑	☑
Flax			☑		☑	☑	☑	☑
Ramie			☑		☑	☑	☑	☑
Wool	☑					☑		
Silk	☑					☑		
Acrylic		☑		☑				
Nylon	☑			☑				
Polyester				☑				
Triacetate				☑				

5.10.1 Acid Dyes

The acid dyes are usually applied under acidic conditions. They are commonly used for dyeing protein fibers (e. g. wool and silk) and nylon fibers. Acid dyes are anionic in nature, and their negatively charged anions are attracted by positively charged amino groups in wool under acidic conditions. The application of acid dyes on wool or nylon results in ionic bond or salt links between the anionic dye and the positively charged groups in the fiber under acidic conditions. In addition to ionic bonds, hydrogen bonds as well as Van der Waal's forces may also be formed between the fiber polymer system and the acid dye molecules.

Because of the high dye-fiber affinity due to opposite charges, there is risk of rushing of dye molecules towards the fibers at high rate with possibility of unlevel dyeing. To avoid unlevel dyeing, some retardation in the dyeing rate is obtained by making use of sodium sulphate.

The acid dyes are further classified into three main groups:
– Levelling dyes
– Milling dyes
– Super-milling dyes

The main differences in the above three types of dyes include: their molecular weight, affinity for fiber, levelling properties, amount of levelling agent required, dyeing pH and fastness properties. Levelling dyes have the lowest affinity and the best levelling properties but poor wash fastness. Super-milling dyes have the highest affinity, the worst levelling properties but good wash fastness. The levelling properties of dyes can be improved with careful control of dyeing parameters.

5.10.2 Azoic Dyes

The azoic dyes are named so because of the presence of azo group in their molecule. They are also known as naphthol dyes. Azoic dyes may be used for dyeing cellulosic materials and some man-made fibers. However, these dyes are not popular these days due to difficulties in their application and shade matching.

5.10.3 Basic Dyes

The basic dyes are most commonly used for dyeing polyacryonitrile or acrylic materials. They are also known as cationic dyes because of the presence of positive charge in the dye molecules under dyeing conditions. During dye application, the negatively charged acrylic fiber attracts the positively charged dye cations for ionic bonding. Due to high attraction between the oppositely charged fiber and dye molecules, there is risk of unlevel dyeing because of high rate of dyeing. This risk may be reduced by careful control of dyeing temperature and used of suitable retarding agents.

The basic dyes are well known for their intense hues and brilliant shades, unrivalled by any other class of dyes. Basic dyes have excellent light fastness because of their resistance to destructive effect of ultraviolet radiations in sunlight. Their washing fastness is also quite good, which may be attributed to hydrophobic nature of the acrylic fiber and good substantivity of the dye for the fiber.

5.10.4 Direct Dyes

The direct dyes are one of the cheapest groups of dyes used for dyeing cotton and other cellulosic materials. They are water soluble and can be applied relatively easily using a variety of methods. These dyes are anionic in nature and have negative charge in aqueous solution, as do the cellulosic fibers. The addition of common salt (sodium chloride) or Glauber's salt (sodium sulphate) is usually necessary during dyeing to overcome repulsion between the negatively charged dye and the substrate. After absorption into the fiber, these dyes are held to the fiber by hydrogen bonding and / or Van der Waals forces.

Based on their leveling properties, direct dyes are grouped into three main classes:

- Class A: self-leveling dyes
- Class B: dyes with average leveling properties (controlled salt addition improves leveling)

- Class C: dyes with poor leveling properties (controlled salt addition and careful temperature control improves leveling)

Direct dyes usually do not have very good wash fastness properties and tend to fade away from the fabric on repeated washings. However, their fastness properties can be improved by various after-treatments, including:
- Treatment with cationic agents
- Treatment with copper sulphate
- Treatment with chrome compounds, such as potassium dichromate
- Treatment with combined potassium dichromate and copper sulphate
- Treatment with formaldehyde

5.10.5 Disperse Dyes

The disperse dyes are mainly used for dyeing polyester. Disperse dyes have extremely low water solubility and usually used in the form of aqueous dispersions. From application point of view, disperse dyes can be classified as follows:
- Low energy disperse dyes: have high rate of diffusion; can be dyed easily with a carrier at atmospheric pressure; have poor sublimation fastness
- Medium energy disperse dyes: have moderate diffusion rate; usually require high temperature exhaust dyeing method; have moderate sublimation fastness
- High energy disperse dyes: have low rate of diffusion; require very high dyeing temperature; have very good sublimation, wet and light fastness properties

The disperse dyes are usually applied in acidic pH, in the presence of a dispersing agent. Other dyeing auxiliaries may include wetting agent, levelling agent and dyeing carrier.

5.10.6 Reactive Dyes

The reactive dyes constitute the most commonly used class of dyes for dyeing cellulosic textiles, because of their good all-round properties, such as water solubility, ease of application, variety of application methods, availability of different shades, brightness of colour shades, good to excellent wash and light fastness and moderate price. Reactive dyes may have poor fastness to chlorine bleach.

The reactive dyes are further classified according to the type of their reactive groups, giving them different degrees of reactivity. For example, dichlorotriazine-based dyes are highly reactive and give good dyeing results at low dyeing temperature, whereas dyes based on trichloropyrimidine have poor reactivity and give good colour yield only at high dyeing temperatures. Vinyl-sulphone-based dyes have moderate reactivity.

The important process variables for dyeing with reactive dyes by exhaust method, include: dyeing temperature, type and amount of electrolyte (e. g. common salt or Glauber's salt), dyeing pH (controlled by type and amount of alkali used), liquor to material ratio and dyeing time. The fixation of reactive dyes on cellulosic fibers takes place through formation of covalent bonds under alkaline conditions (pH 9–11).

The typical exhaust dyeing procedure involves the exhaustion of the dye onto the substrate with salt addition and temperature control, followed by the addition of alkali for dye fixation through covalent bonding. After the dyeing process, any unfixed dye or hydrolyzed dye (i. e. the dye which has reacted with water in the dyebath instead of the cellulose) is removed by washing off using a suitable detergent.

5.10.7 Sulphur Dyes

The sulphur dyes are named so because of the presence of sulphur atoms in their molecules. Like direct dyes, sulphur dyes are also quite cheap for dyeing cellulosic textiles with limited colour fastness properties. Different types of sulphur dyes include:
- CI sulphur dyes
- CI leuco sulphur dyes
- CI solublized sulphur dyes
- CI condensed sulphur dyes

The commonly used sulphur dyes are not soluble in water and need to be converted into soluble form by reduction with the help of a reducing agent and an alkali. Sulphur dyes are usually easier to reduce and more difficult to re-oxidize as compared to vat dyes. General phases in the dyeing of cellulosic materials with sulphur dyes include:
- Reduction: conversion of the water-insoluble dye into soluble form, in the presence of a reducing agent and alkali
- Application: absorption of solubilized sulphur dye by the textile substrate
- Rinsing: removal of any loose colour from the substrate before oxidation
- Oxidation: conversion of the dye absorbed by the textile substrate back into the insoluble form
- Soaping: for increased colour brightness and fastness of the final shade.

Sulphur dyes have fair degree of light fastness due to poor stability of the dye molecule to ultraviolet radiations present in sunlight which degrade the dye chromophore. Washing fastness of sulphur dyes is poor because of the inherent limitations of the sulphur dye chromophores. However, like direct dyes, the fastness properties of sulphur dyes can be improved with suitable after-treatment of the dyed textile materials. Unlike direct dyes, the colour range of sulphur dyes is quite limited to black, brown, olive and blue shades. Moreover, sulphur dyes are not available in as bright colours as are available in other class of dyes. However, sulphur dyes are quite cheap and may be economical in dyeing deep black and navy shades.

5.10.8 Vat Dyes

The name 'vat' comes from the wooden vessel which was first used for the reduction and application of vat dyes. Vat dyes are among the most expensive dyes used for dyeing cellulosic materials with best overall fastness properties, including washing fastness, light fastness and chlorine fastness. They are preferred for dyeing workwear or uniforms, or where the textiles and apparels are expected to undergo repeated industrial launderings.

The vat dyes are generally not soluble in water. However, solubilized vat dyes are also available but are usually more expensive as compared to generally available insoluble vat dyes. Based on their chemistry, vat dyes can be classified into two main groups: indigo derivatives and anthraquinone derivatives. In general, fastness properties of anthraquinone-based vat dyes are usually better as compared to those of indigo-based dyes. Indigo blue vat dyes are commonly used for producing indigo denim, with different wash-down and worn-out looks. Based on application properties, vat dyes are classified into four main types: IN vat dyes; IW vat dyes; IK vat dyes; IN special dyes. Major differences in the above four groups of vat dyes include: their leveling properties, dyeing temperature, and amount of alkali, salt and leveling agent required during dyeing. General phases in dyeing with vat dyes are as follows:
- Reduction: conversion of insoluble vat dye into soluble sodium leuco vat anions, with the help of a reducing agent (sodium dithionite) and alkali (sodium hydroxide)
- Diffusion: penetration of the reduced / solubilized sodium leuco-vat anions into fibers
- Rinsing: removal of excess alkali and reducing agent from the dyed material
- Oxidation: conversion of vat dye absorbed in the fibers back into insoluble form
- Soaping: during which the vat dye molecules absorbed by the textile material are re-orientated and associate into a more crystalline form.

The vat dyes have excellent light fastness due to stable electron arrangement in the chromophore (colour-bearing group) of the dye molecule and presence of numerous benzene rings. Vat dyes have excellent wash fastness owing to the aqueous insolubility of the oxidized dye absorbed in the fiber and due to large vat dye molecules trapped within the polymer system. However, vat dyes are usually very expensive and need more expertise for their application because of greater number of steps involved in dyeing.

5.10.9 Pigments

The pigment colorants usually have no affinity for any type of fiber. They also do not have any ability to form chemical bonds with the fibers. They are commonly applied with the help of chemical binders which keep them adhered or bound with the textile materials. With the help of binders, pigments can be used for dyeing or printing of all type of fibers and their blends. Dyeing with pigments usually comprises padding the textile in the pigment and binder dispersion (along with other suitable auxiliaries), followed by drying and curing at a suitable temperature. The pigment dyed fabrics are usually stiffer (because of use of binders) and have poor rubbing fastness properties as compared to the fabrics dyed with dyes. However, pigment dyeing process can be more conveniently combined with finishing process resulting in more economical and ecological processing.

5.11 Dyeing Methods

Dyeing methods can be classified into two main types: exhaust dyeing and pad dyeing [6].

5.11.1 Exhaust Dyeing

In exhaust dyeing, a finite amount of textile materials (in the form of fibers, yarn or fabric) is placed in the dye liquor and remains in its contact throughout the dyeing time, during which the dye molecules gradually move (or exhaust) from the liquor toward the fabric, for absorption and fixation in the textile material. The rate of dye exhaustion, absorption and fixation are controlled with the help of dyeing temperature, liquor agitation, pH or auxiliaries such as electrolytes, alkalis, leveling agents or retarding agents, etc. the liquor to material ratio (L:R) is also an important factor in exhaust dyeing i. e. the ratio between the amount of liquor and the weight of textile material dyed in that liquor in a batch. Total dyeing time required in exhaust dyeing depends on several factors including: depth of shade, type of dyestuff, nature of textile material and type of dyeing machine. The general phases in exhaust dyeing include the following:

- Disaggregation of dye particles in aqueous solution or dispersion
- Exhaustion or movement of the dye molecules from the solution / dispersion towards the textile substrate
- Adsorption of the dye molecules on the surface of the textile substrate
- Absorption, penetration or diffusion of the dye molecules into the fibers of the textile substrate
- Fixation of the diffused dye in the fibers through chemical bonding or by some other mechanism

5.11.2 Pad Dyeing

In pad dyeing method, a continuous batch of fabric in open width, passes through an impregnator (or padding trough) containing dye liquor, followed by a passage between a pair of squeeze rollers. The pressure of the squeeze rollers can be adjusted to obtain a desired wet pick-up. For example, a wet pick-up of 100 % would result in fabric twice its original dry weight, after the impregnation and squeezing. The concentration of the dye in the padding tough and the wet pick influence the final depth of colour obtained on the fabric. After passing through the squeeze rollers, the fixation of the dye on the fabric may be accomplished by variety of means including: making a batch of fabric and keep rolling the batch for a specific period (pad-batch dyeing method); passing the fabric through a drying and fixation unit (pad-dry-fix dyeing method); passing the fabric through a drying and steaming unit (pad-dry-steam dyeing method); passing the fabric through a steaming unit (pad-steam dyeing method). After both the exhaust and pad dyeing methods, the dyed fabric is usually subjected to a washing / rinsing step to remove any unfixed dye from the fabric. Selection of a particular dyeing method depends on several factors including the form of textile material (fiber, yarn, knitted or woven fabric), availability of suitable equipment in the mill and batch size of the textile material.

5.12 Dyeing Machinery

Commonly used dyeing machines are as follows:

5.12.1 Exhaust Dyeing Machines

- *Package dyeing machine*: mainly used for dyeing yarn in package form
- *Winch or beck dyeing machine*: mainly used for dyeing knitted fabrics (in rope form) at atmospheric pressure but may also be used for woven fabrics
- *Jet dyeing machine*: mainly used for dyeing knitted fabrics (in rope form) at atmospheric or higher pressure but may also be used for woven fabrics
- *Jigger dyeing machine*: mainly used for dyeing woven fabrics (in open-width form)

5.12.2 Pad Dyeing Machines

- *Pad-batch dyeing machine*: used for dyeing fabrics in open-width form in semi-continuous manner
- *Pad-steam dyeing range*: mainly used for dyeing cotton fabrics in open-width form in full-continuous manner

- *Pad-thermosol dyeing range*: mainly used for dyeing polyester and polyester / cotton blended fabrics in open-width form in full-continuous manner
- *Stenter*: mainly used for simultaneous finishing and dyeing of fabrics with pigments

5.13 Blends Dyeing

Textile fabrics comprising blend of more than one type of fibers can be dyed with suitable dyes to achieve different dyeing effect. In “union dyeing” both the fibers in a two-fiber blend (e. g. polyester / cotton) are dyed to have the same shade. In “cross dyeing”, each fiber component in a blend is dyed in different shade. In “tone-on-tone dyeing” two fibers in a blend (e. g. cotton / viscose rayon) are dyed with the same class of dye but the two types of fibers have different depth of shade.

5.14 Textile Printing

The word “printing” is derived from the Latin word meaning “pressing” and implies the application of “pressure”. Printing can be considered as “localized dyeing” and comprises the application of one or more dyes or pigments on textile materials in the form of a design or pattern [7]. Unlike dyeing, printing designs or patterns are usually printed on only one side of the fabric.

5.15 Common Styles of Textile Printing

5.15.1 Direct Printing

In direct printing, a colour pattern is printed directly from a dye or pigment paste onto a textile substrate without any prior mordanting step or a follow-up step of dyeing, etc.

5.15.2 Transfer Printing

In transfer printing, a design is printed first on a flexible non-textile substrate (e. g. paper) and later transferred from the paper to a textile substrate.

5.15.3 Discharge Printing

In discharge printing, a textile fabric is first dyed with a suitable dye and then the dye is selectively destroyed from certain areas of the fabric to give the look of a printed pattern.

5.15.4 Resist Printing

In resist printing, the fabric is first printed with a resist agent and then dyed. On dyeing, the fabric attains colour only on areas where resist agent is not present. After dyeing, the resist agent is removed and the fabric gives the look of a printed pattern.

5.16 Common Methods of Textile Printing

5.16.1 Block Printing

The block printing is an old method of printing which involves the use of wooden blocks with raised printing surface, which are inked and then pressed on to the fabric. This printing method is used only at small scale or in cottage industry and is not used at industrial scale because of less flexibility and productivity.

5.16.2 Screen Printing

The screen printing is the most commonly used printing method at industrial scale. There are two main types of screen printing: flat-bed screen printing and rotary screen printing. Flat-bed screen printing can be manual or automatic. Rotary screen printing is usually automatic and gives the highest printing productivity. Screen printing involves passing the print paste onto a fabric through a mesh or screen which has some open and some blocked areas according to the desired print pattern. The print design obtained on the fabric depends on the pattern of the open areas of the screen.

5.16.3 Roller Printing

The roller printing is done by making use of heavy copper rollers engraved with a pattern. A separate roller is used for printing each colour in the pattern. Due to low productivity, roller printing method has been almost completely replaced by rotary screen printing.

5.16.4 Digital Printing

Digital ink-jet printing is one of the most modern ways of printing textile fabrics. This method can be used for most of the commercially available fabrics. In this method, a printing pattern can be directly printed from the computer onto the fabric with an ink-jet printer, without any need for making printing screens or engraved rollers. The design-to-print lead time is minimum in digital ink-jet printing and complex designs of photographic quality can be promptly printed. However, as compared to rotary screen printing, the productivity of ink-jet printing is very low. Hence, the method is mostly used for very short production runs or for printing smaller articles such as flags, banners, etc. [8–9].

5.17 Main Steps in Direct Printing

5.17.1 Fabric Preparation

Good fabric preparation is necessary for obtaining good quality printing results. Before printing, the fabric should be free from any impurities and protruding fibers. This is accomplished with appropriate singeing, desizing, scouring and bleaching. Fabrics, especially containing thermoplastic fibers such as polyester are made dimensionally stable by heat-setting before printing, so that the print designs do not get changed by any subsequent shrinkage in the fabric.

5.17.2 Print-paste Preparation

The print paste consists of a thickened solution or dispersion of dyes or pigments. The type of dye used depends on the fiber composition of the fabric to be printed. However, pigments can be used for printing fabrics made from all types of fibers. The use of binder is essential in case of pigment printing, which is not required in case of printing with dyes. For making a printing paste of suitable viscosity, thickening agents or thickeners are used. The type of thickener used usually depends on the type of colorant used in printing. Viscosity is a very important parameter of the print paste because it determines the amount as well as the spread of the print paste applied during printing, ultimately affecting the penetration and sharpness of the prints. Stability of the print paste is also very important, which depends on the compatibility of the thickener with the colorant and auxiliaries and other factors such as pH of the paste. Apart from the thickener, the use of any other auxiliary depends on the type of colorant used. Some examples of thickening agents include starch and its derivatives; British gum; locust bean gum; guar gum; gum tragacanth; gum Arabic; sodium alginate and acrylate copolymers.

5.17.3 Printing

The application of the print paste can be accomplished by any suitable equipment and method that is available in a mill or lab, e. g. flat-bed screen printing, rotary printing or roller printing. The exact printing parameters depend on the type of process and equipment used.

5.17.4 Drying

After printing, the fabric is dried (usually by hot air) to prevent any accidental distortion or smearing of the print.

5.17.5 Fixation

For fixation of the colorants, the printed and dried fabric is passed through a steamer or high-temperature hot-air curing / fixation / ageing machine. The temperature and time of fixation depends on the type of colorant / auxiliary system used for printing.

5.17.6 Washing-off

After fixation, the fabric is usually subjected to a washing-off treatment to remove any unfixed dye, thickener or any other left-over auxiliaries from the fabric. Washing-off process is sometimes not necessary for fabrics printed with pigment / binder systems.

5.18 Textile Finishing

Finishing comprises final processes in the textile processing sequence to improve the appearance, hand-feel or other aesthetics of the textiles or to add any extra functionality such as water repellency or flame retardancy, etc.

There are two broad categories of finishing:

- Chemical finishing
- Mechanical finishing

Commonly used chemical finishes include softening, stiffening / hand-building, easy-care / wrinkle-recovery / durable-press, water / oil repellent, soil repellent, soil release, flame retardant, anti-slip, anti-static, anti-pilling, anti-microbial, elastomeric, UV protection, insect resistant / moth protection, bio-polishing, fragrance, moisture management, temperature adaptability, and finishes to improve colour fastness of the dyed or printed fabrics [10]. Commonly used mechanical finishes include calendaring, compressive shrinkage / Sanforizing, raising, emerizing / sueding / peaching, shearing / cropping [11].

Although both of the above categories of finishing are accomplished with the help of some machine, in chemical finishing the final effect obtained on the textiles is primarily due to the chemicals used in finishing. In mechanical finishing, the final effect obtained on the textiles is primarily due to some mechanical action on the fabric by the machine. Chemical finishing results in change of chemical composition of the fabric. Most of the chemical finishes do not result in change in the fabric appearance but may result in change in some other physical and mechanical properties of the fabric. Mechanical finishing does not result in any change in the elemental composition of the fabric. However, most mechanical finishes alter the fabric appearance.

In chemical finishing relatively minor amounts of chemicals (often $< 5\,g/m^2$ of the fabric) are applied on both sides of the fabric through padding or impregnation. In coating, relatively high levels of chemicals (15–50 g/m^2 of the fabric or even more) are applied on usually one side of the fabrics (although sometimes fabrics may be coated on both sides).

From the durability perspective, there are three categories of finishes:

- Durable finishes undergo repeated laundering or dry cleaning without losing effectiveness. Durable finishes are usually expected to last more than 50 laundering cycles on the fabric.
- Non-durable finishes do not withstand washing or dry cleaning, and these are applied to textiles which are disposable or not supposed to be washed, or when the finishing effect is temporarily required.
- Semi-durable finishes have their life in-between that of the durable and non-durable finishes.

More than one type of finishes can be combined together in one process if they are compatible. Compatibility of finishes in a single formulation means that the finishes do not result in formation of precipitates or instability of the formulation. For example, anionic finishes may not be compatible with cationic finishes. Combined finishes should also be compatible in terms of their final effect on the fabric. Some finishes may be obviously contradictory. For example, hydrophobic finishes and hydrophilic finishes; stiffening finishes and softening finishes. Some finishes may result in more than one effect. For example, some fabric softening finishes may also make the fabric hydrophobic. Some softeners may also have anti-static effect on the fabric. Some finishes may also have undesirable side-effect. For example, the application of crease recovery finish may result in loss of fabric strength.

There are two primary requirements that chemical finishes should meet:

- Optimum desired effect in fabric properties at lowest possible cost of the chemicals and the process
- Possible adaptation of the finishing effects, according to the customers' requirements

Some secondary requirements of chemical finishes include:

- Suitability of the finish for all fibers in all forms
- Desired durability of the finishing effect
- No loss of desirable fabric properties, e. g. appearance, hand-feel, strength, comfort, abrasion resistance
- No yellowing of the white finished fabric
- No change in colour of the dyed or printed fabric
- Safe to use and simple to apply on the fabric

- Good storage stability and shelf life
- Good compatibility with other ingredients of the finishing formulation
- Easy correction in case of faulty finish application
- Sustainability and no harmful impact on the environment

Factors that are commonly considered for proper formulation of the chemical finishes include:
- The type of textile being treated (fiber type, yarn type, fabric construction)
- The performance requirement of the finishes (the extent of desired effect and its durability)
- The cost to benefit ratio
- Limitations imposed by the available machinery or environmental issues
- Compatibility of various components of the formulation

5.19 Chemical Finishing

5.19.1 Softening

Softening is one of the most commonly used textile finishes. Fabric softness usually depends upon four measurable fabric characteristics, i. e. coefficient of friction, flexibility / bendability, compressibility and elasticity. Objectives for the application of chemical softeners include improvement in hand-feel, drape, tear resistance or sewability of the fabric. Softeners lubricate the fibers, decrease coefficient of friction, improve fabric smoothness and may also lower the glass transition temperature of the polymer. The lubricating effect of the softeners improves fabric sewability by reducing friction between the sewing needle and the yarns in the fabric. Higher friction between the sewing needle and the fabric may cause rise in the needle temperature, leading to possible needle breakage and yarn damage. Softeners increase fabric softness by reducing fabric coefficient of friction or by internal lubrication or plasticization of the fibers and yarns or by reducing glass transition temperature of the polymer.

Based on their ionic nature, softeners may be classified as non-ionic, anionic, cationic or amphoteric. Non-ionic softeners do not have any electrical charge and may be based on hydrocarbons, ethylene oxides or silicones. Because of having no electrical charge, they have good compatibility with other finishes. Some non-ionic softeners may also be effective in improving fabric wrinkle resistance, abrasion resistance, tear strength and sewability. They have low tendency to make yellow the white fabric or change colour of the dyed fabrics. Some silicone-based softeners may be expensive and may also be hydrophobic, thus being unsuitable for softening of towel fabrics.

Anionic softeners have negative charge and may be based on fatty esters, waxes or sulphonated oils. They often retain good rewetting properties for the treated fabric. However, due to no inherent attraction for the cellulosic materials, may not exhaust from the aqueous bath onto the textiles. Moreover, they have limited durability to washing and dry cleaning.

Cationic softeners are positively charged and may be based on quaternary ammonium salts, fatty amines, imidazolines or aminoamides. Due to their affinity for cellulosic materials, they can easily exhaust from aqueous bath onto the textile material. Cationic softeners often give good softness with low add-on, improve fabric abrasion and tear resistance of the fabric. However, they may be incompatible with anionic finishes and auxiliaries and may make the fabric hydrophobic. They also have the potential to yellow the white fabrics and result in shade change of the dyed fabrics.

Amphoteric softeners may have positive or negative charge depending on the pH of the application bath. However, these softeners are less commonly used as compared to other classes of the softeners.

In addition to subjective assessment with hand, the softness of the fabric treated with softeners can be assessed using fabric touch tester, softometer, handl-o-meter, Kawabata evaluation system, fabric stiffness tester, bending length tester or FAST (Fabric Assurance by Simple Testing) system.

5.19.2 Stiffening / Hand-building

Hand-building finishes are applied to the fabric to increase fabric stiffness, stability, bulkiness or weight. Objectives of improving fabric stiffness include improving fabric handling during cutting and sewing, stabilizing a limp fabric or improving fabric appearance.

Hand-building finishes may be non-durable or durable. Non-durable finishes include starch, polyvinyl alcohol (PVA) and carboxymethylcellulose (CMC). Durable hand-building finishes may be thermoplastic or thermosetting. Thermoplastic hand-builders include vinyl polymers and examples of thermosetting hand-builders include melamine formaldehyde and urea formaldehyde. The choice of hand-building finishes depends on cost, ease of application, degree of stiffness, bulkiness, stability and durability required. The assessment of the fabrics treated with hand-building finishes may be done by determining increase in fabric weight per unit area, bending length, stiffness or flexural rigidity, etc.

5.19.3 Easy-care, Wrinkle Recovery and Durable Press Finishing

The cellulose anti-swelling or cellulose crosslinking finishes may be applied on cellulosic fabrics (e. g. cotton) to achieve different effects such as a smooth wrinkle-free appearance after washing without ironing (easy-care and wrinkle resistance); retention of intentional creases after washing (durable-press); shrink resistance after washing (dimensional stability). Such finishes may also be used to increase fabric's pilling resistance and pile resilience, or to enhance the durability of dyes, pigments or other finishes. These finishes may result in the reduction in fabric elasticity, flexibility, abrasion resistance and tear strength.

The woven fabrics with tighter fabric density containing yarns with higher twist levels and coarser fibers and higher hydrophilic character, are more prone to wrinkling and vice versa. Woven fabrics made from cotton tend to wrinkle more as compared to polyester or blended fabrics. Cotton fibers can absorb moisture, which can disrupt hydrogen bonding between hydroxyl groups of the cellulose polymer chains, facilitating the chain movement and formation of new hydrogen bonds in a new wrinkle configuration. The process can be reversed by steam ironing the fabric. The application of cellulosic crosslinking finishes results in more permanent cross-links between the cellulose chains, restricting their free movement on moisture absorption, thus limiting their tendency to wrinkling.

Different types of easy-care / wrinkle recovery finishes include: urea / formaldehyde; melamine formaldehyde; dimethylol dihydroxy ethylene urea (DMDHEU); methylated / modified DMDHEU; polycarboxylic acids such as butane tetracarboxylic acid (BTCA). The most commonly used easy-care / wrinkle recovery finish is DMDHEU, which is usually applied in the presence of a catalyst such as magnesium chloride.

In pre-cure finishing, the fabric is cured immediately after drying followed by the impregnation in the finishing liquor, i. e. prior to garment manufacturing. The process results in improved wrinkle recovery of the fabric. In post-cure finishing, the fabric is impregnated in the finishing liquor, dried and then converted into garment form before the curing step. The post-cure process is usually used for durable press effect such as crease retention in trousers or pleated skirts. In addition to pre-cure and post-cure methods, the crosslinking finish may also be applied after garment manufacturing, for example spraying a denim garment with the finishing liquor for obtaining creases at specific places on the garment.

Different methods are used for fabric assessment after wrinkle recovery or durable press finishing. These methods include:

- AATCC Test Method 88C: Retention of creases in fabrics after repeated home laundering
- AATCC Test Method 124: Smoothness appearance of fabrics after repeated home laundering
- ISO 2313: Determination of the recovery from creasing of a horizontally folded specimen of fabric by measuring the angle of recovery

5.19.4 Water Repellent Finishing

The water repellent fabrics have the ability to resist wetting whereas water-proof fabrics are impermeable to water even at high hydrostatic pressure and also usually impervious to air. Water repellency of a fabric depends on several factors including nature of the fibers, yarn structure, fabric porosity, finish applied and water impact force. Some fabrics such as those made from cotton easily wet out as compared to those made from hydrophobic fibers such as polypropylene. Generally, fabrics or other surfaces which have high surface free energy have better wetting as compared to those of lower surface free energy.

Different chemicals may be applied on the fabric to lower surface free energy of fabrics than water surface tension to decrease their wetting ability and increase their water repellency. Three main types of water-repellent chemicals are: wax-based repellents, silicone-base repellents and fluorocarbon-based repellents. Wax-based repellents are usually the cheapest while the fluorocarbon-based repellents are usually the most expensive and the most durable. While wax and silicone-based chemicals may result in water repellency only, fluorocarbons result in water as well as oil repellency in the fabric.

The water contact angle is a good indication of water repellency of a fabric. The higher the contact angle, the higher will be the water repellency of the fabric. Fabrics with water contact angle of greater than 90 may be considered as water repellent while fabric with contact angle greater than 130–150 may be considered as super-repellent fabrics. Different standard test methods can be used to evaluate the water repellency of fabrics. One such method is AATCC Test Method 22–2001: water repellency – spray test. This method involves spraying of water against the taut fabric surface under controlled conditions. Degree of wetting is rated from 0–5 scale, where 0 refers to complete wetting and 5 to no wetting.

5.19.5 Stain Resistance Finishing

Staining refers to localized soiling of a textile material by oil, grease, dry particulate matter, oil-borne stains or water-borne stains whereas soiling is the overall contamination or discoloration of a textile material. An example of staining may be a drop of tea, oil or ketch-up on a shirt. Stain repellency is the ability of a fabric to resist penetration by liquid soils under static conditions, i. e. conditions under which the liquid is not forced into the fabric by external influence other than the weight of the liquid drop and capillary forces. Stain resistance is the degree to which a fabric, stained under dynamic conditions, can be returned to its unstained state by wiping or blotting of the fabric surface.

Stain resistance finishing is usually obtained by application of silicones or fluorocarbons which lower the surface free energy of fabrics and make them water and oil repellent. Silicones may result in resistance to only water-borne stains but fluorocarbons give resistance to both water-borne as well as oily stains.

5.19.6 Stain or Soil Release Finishing

Stain or soil release is the ability of a fabric to be cleaned easily by laundering. Stain release properties are important for those textiles that can be washed whereas stain resistant properties are important for upholstery, carpets or such other fabrics that cannot be conveniently laundered. Soil release, particularly of oily stains, is usually difficult in textiles made from hydrophobic fibers such as polyester. Soil release properties may be imparted by applying hydrophilic treatments to hydrophobic textiles. For example, low molecular weight block copolymers of hydrophilic segments like polyoxyethylene can be used to improve soil release properties of polyester fabrics. Conventional soil resistance finishes deteriorate soil release properties of fabrics but dual action fluorocarbons comprising a block copolymer of fluorocarbon component and a hydrophilic polyoxyethylene component have good soil resistance as well as good soil release properties.

5.19.7 Flame Retardant Finishing

Flammability of textiles pertains to their relative ease of ignition and relative ability to sustain combustion. A fabric can be considered flame resistant if it does not burn or does not continue to burn when subjected to a flame or heat source, with or without removal of the source. A chemical applied to a fabric to impart flame resistance is called a flame retardant. Different factors affecting flammability of textiles include type of fiber, yarn structure, fabric structure, and any chemicals / coatings applied on the fabric. Three necessary components for a fire are fuel, heat and oxygen. Flame retardant finishes improve flame resistance by masking or removing any one or more components that are required for burning. Some flame retardants promote char formation of cellulosic textiles, thus removing the fuel in the form of fiber which is required to sustain fire. Some flame retardants form an insulating layer on the fibers, thus restricting their access to air which is required to sustain burning.

Some chemical flame retardants may be durable even after more than 50 laundering cycles while others may be non-durable and washed away after single laundering. Some examples of non-durable flame retardants for cellulosic textiles include ammonium phosphate, di-ammonium phosphate, ammonium chloride, ammonium bromide and borax-boric acid mixtures. Examples of durable flame retardants for cellulosic textiles include tetrakishydroxyphosphonium chloride (THPC) / ammonia and N-methylol dimethylphosphonopropionamide (Pyrovatex). Most of the flame retardants are applied by pad-dry-cure method, although some may be applied using exhaust method.

Two commonly used methods for assessing the flammability of textiles are vertical flame test and 45 degree test, where the fabric test specimens are held vertically or at 45 degrees respectively. Determination of limiting oxygen index (LOI) is also another useful method for characterizing fabrics treated with flame retardants. LOI measures the amount of oxygen required to sustain burning. LOI of untreated cotton is around 18.5. The higher the LOI, the lower is the flammability of the textile material.

5.19.8 Anti-microbial Finishing

The anti-microbial finishes are those which work against the microbes (e. g. bacteria, fungi, mildew, virus, etc.) by inhibiting their growth or by killing them altogether. Biostatic finishes inhibit the growth of microbes whereas biocidal finishes kill the microbes. Microbes may not only result in loss of some functional properties of textiles such as loss in strength but may also result in bad odour, staining and discoloration. Their undesirable effects on humans may include perspiration smell, eczema, irritation, allergy or even infection or disease.

The two main types of anti-microbial finishes are leaching-type and chemically-bound type. Leaching-type antimicrobial finishes leave the textile and chemically enter or react with the microorganism through controlled release mechanism. They are effective on the fabric surface and in small surrounding environment but eventually the reservoir is depleted and the finish may be no longer effective. Chemically bound type antimicrobials may be more durable, and they do not leave the textiles and control only those microbes which come into contact with the textile. Mechanism of various antimicrobial finishes include preventing microbial cell reproduction, blocking of enzymes, reaction with cell membrane, destruction of cell walls or poisoning the cells from within.

Some examples of anti-microbial finishes include triclosan, quaternary ammonium compounds (e. g. octadecylaminodimethyltrimethoxysilylpropylammonium chloride), polyhexamethylene biguanide (PHMB), chitosan, and silver nanoparticles. Textiles treated with antimicrobial finishes may be characterized by using qualitative as well as quantitative methods. In quantitative methods, the number of bacteria or bacterial colonies are counted, after an opportune contact time. The qualitative tests indicate the presence or absence of antibacterial activity (e. g. through a zone of inhibition).

5.19.9 Bio-polishing

Bio-polishing is a process of treatment of cotton and other cellulosic textiles with cellulases enzymes to remove protruding fibers from textile fabrics and produce a softer and smoother hand-feel. Bio-polishing also reduces fabric pilling tendency and improves fabric luster, brightness and drape. Bio-polishing can also be used as a replacement or as a supplementary process for denim stone-washing. In bio-polishing, the celluases enzymes are used to break down the cellulose polymer chains of the surface fibers by hydrolysis, which are then easily removed during washing due to increased water solubility. Important parameters of cellulases bio-polishing process include concentration of the enzyme, pH, temperature, any surfactant used, process time and agitation / mechanical action during the process.

5.19.10 Moisture Management Finishing

Moisture management refers to the engineered movement of perspiration from a garment's near-to-skin side, through the fabric to the outer side for evaporative cooling effect for the wearer. Garments made from hydrophilic fibers such as cotton are good in perspiration absorption but poor in wicking and drying because of hydrogen bond formation with water. On the other hand, garments made from hydrophobic fibers such as polyester are poor in sweat absorption but good in wicking and drying due to lack of hydrogen bonding sites. The controlled application of some hydrophilic finishes on fabrics made from hydrophobic fibers has been reported to improve the moisture management properties of such fabrics.

5.19.11 Anti-static Finishing

The garments made purely from hydrophobic fibers such as polyester, have tendency to develop static charge, resulting in clinging of garments to the wearer's body and / or annoying crackling sound while wearing on or taking off a garment. The tendency to accumulate static charge can be decreased by increasing the fabric conductivity and / or reducing the frictional forces by applying suitable lubricating agents. The hygroscopic finishes can be used to increase the fabric conductivity. Some examples of non-durable antistatic finishes include polyethylene glycol and polyethylene oxide compounds. Some polyamines may be reacted with polyglycols for durable hydrophilic finishing of textiles. Deposition of carbon or metallic (e. g. nano-silver) coatings may also result in increased fabric conductivity and reduced static charge accumulation.

5.19.12 Optical Brightening

Fabrics which are to be finished white, may be treated with optical brightening agents (OBAs) or fluorescent brightening agents (FBAs) to increase their brightness. Such agents may be considered as colourless dyes, which when present on the fabric have ability to absorb the wavelengths of light in the UV region and reflect them back in the visible region, thus making the fabric appear brighter as compared to the untreated fabric.

5.20 Mechanical Finishing

5.20.1 Napping

Napping is a process of raising protruding fibers from the surface yarns of a fabric to form a raised pile. The objective of raising protruding fibers at the fabric surface is to improve fabric's hand-feel and ability to give warmth. The warmth of the fabric is increased due to its increased ability to entrap air because of the raised fibers. Air, being a good heat insulator improves the fabric heat retention ability. Examples of napped fabrics include fleece and flannel.

Napping or raising of fibers at the fabric surface is achieved by passing the fabric across rapidly rotating wire-covered rollers. The wire-covered rollers of a napping machine usually rotate against the fabric's direction of passage. The extremely sharp wires on the rollers pluck and raise fabric surface fibers. Main parameters of the napping machine include: machine type, speed of the rollers, condition of roller wires, yarn and fabric construction, fabric speed and tension, and presence of any finishing agent (e. g. softener) on the fabric.

5.20.2 Shearing

Shearing is a process of removing fuzz or fibers protruding on a fabric surface, to produce an even surface with uniform height of the pile of raised fibers on the fabric. Shearing is usually done after the napping process to cut the raised fibers for producing even pile height on the fabric surface. Shearing may also be done for fabrics which are not napped, and the process may be used as an alternative to singeing and bio-polishing for removing the protruding fibers from a fabric surface. The shearing process results in smoother fabric surface and improvement in the pilling resistance of the fabric. Shearing is achieved by passing the fabric in close proximity to a revolving spiral blade in contact with a ledger plate. The spiral place and the ledge plate together resemble the action of blades of a pair of scissors, cutting the fibers on the fabric surface.

5.20.3 Sueding / Emerising

Sueding or emerizing is a process of raising very short fibers on the fabric surface by passing the fabric over sandpaper-covered / emery rolls. The purpose of sueding or emersing is to produce special hand-feel on the fabric that is similar to suede leather or skin of peach fruit. The length of raised fibers after sueding / emerising is usually shorter as compared to that obtained after napping. Important parameters of the sueding process include speed of the sand rolls, coarseness of the sandpaper, yarn and fabric construction, fabric speed, pressure between the fabric and the sandpaper, direction of rotation of rolls with respect to direction of fabric passage through the machine and the type of sueding machine. Two main types of sueding machines are single cylinder and multi-cylinder.

5.20.4 Calendering

Calendering is a process of imparting luster and smoothness to a fabric by passing it between pressurized rollers. If the moist fabric is passed through the pressurized rollers, the calendered fabric will be quite similar to steam ironed fabric. Main effects produced by calendering include reduction in fabric thickness, compaction of weave structure, change in fabric handle, change in fabric luster. Variation in any of the following parameters results in different effects produced by calendering: fiber content, fabric construction, moisture in the fabric before calendering, any chemical finish applied before calendering, temperature of calender roll(s), relative speeds of fabric and rolls, roll composition and configuration, pressure applied and number of times the fabric is passed through the calender rolls. One of the calender roll is usually made of stainless steel (which may be heated to the required temperature) while the other may be covered with highly compressed cotton, paper or synthetic material. Common types of calenders used in the industry include: 3-roll friction calenders, Schreiner calenders and embossing calenders.

5.20.5 Compacting

Compacting is a process of mechanical compression of fabrics in lengthwise direction, in order to minimize its tendency to shrink during consumer use. The compacting process has little effect on the widthwise shrinkage of the fabric. The compacting process also results in increase in fabric areal density and thickness, and reduction in the overall fabric length yardage. Different types of machines can be used for compacting including the trademark Sanforizer (also known as blanket compacter), the heated roll and shoe compactor, and the blade compactor. The compacting process was originally devised for woven fabrics but the process of also later on adapted for knitted fabrics.

5.20.6 Relaxation Drying

Relaxation drying is a process of drying knitted fabrics by passing it through a dryer with overfeed and minimum tension, so that the fabric may be able to shrink during fabric processing rather than later in garment form during consumer use. Conveyer-belt type relaxation dryers are the most popular, although a number of other designs also exist. Important factors in relaxation drying include the amount of overfeed, the spreading of tubular knits before entering the dryer, moisture content in the incoming fabric, the mechanical action of the dryer, the temperature of the dryer, and the presence of any finish on the fabric before the process.

5.20.7 Decatising

Decatizing is a process for improving luster and smoothness of wool fabrics by layering the wool fabric between heavy cotton fabrics on a roller and exposing to steam.

The pressure and steam of the process flatten the wool fabric, improving its luster and smoothness.

References

[1] R. Shamey, T. Hussein, Critical solutions in the dyeing of cotton textile materials. *Text. Prog.*, 2005, 37(1–2), 1–84.

[2] Osthoff Singeing Technology (accessed February 17, 2015 at http://www.osthoff-senge.com/en/technologie.html).

[3] C. Tomasino, Chemistry and technology of fabric preparation and finishing, NCSU, North Carolina, (accessed February 10, 2015 at http://infohouse.p2ric.org/ref/06/05815.pdf)

[4] V. B. Gupta, Heat setting. *J. Appl. Polym. Sci.*, 2002, 83, 586–609.

[5] M. Clark, *Handbook of industrial dyeing – volume 1: principles, processes and types of dyes*, Cambridge, UK, Woodhead Publishing, 2011.

[6] M. Clark, *Handbook of industrial dyeing – volume 2: application of dyes*, Cambridge, UK, Woodhead Publishing, 2011.

[7] W. C. Miles, *Textile printing*. 2nd ed. Bradford, UK, Society of Dyers and Colorists, 2003.

[8] H. UJIIE, *Digital printing of textiles*, Cambridge, UK, Woodhead Publishing, 2006.

[9] C. CIE, *Ink jet textile printing*, Cambridge, UK, Woodhead Publishing, 2015.

[10] W. D. Schindler, and P. J. Hauser, *Chemical finishing of textiles*, Cambridge, UK, Woodhead Publishing, 2004.

[11] D. Heywood, Textile Finishing, Bradford, UK, Society of Dyers and Colorists, 2003.

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6 Clothing

6.1 Introduction

Before going in to the details of the clothing manufacturing process, the readers need to know a few basic definitions:

6.2 What is Garment / Apparel / Clothing?

"Any object which can be used to wear is termed as garment / apparel / clothing" (e. g. pants, shirt and sweater, etc.). Another definition is "The 3-dimensional shape of cloth which is used to cover the body". They can also be used to achieve a specific function, for example fire resistance or cut resistance, etc. Garments are a part of apparel, whereas apparel is a broad terminology. For instance, shoes and hats are also included in apparel.

6.3 Types of Garments

Garments can be classified on the basis of wearing, shape or fashion.

On the basis of wearing, garments are classified into three types:

- Tops
- Bottoms
- Undergarments

Tops: The garments which cover the trunk portion of the body are known as tops (e. g. shirt, jacket, coat, etc.).

Bottoms: The garments which cover the lower part of body are called bottoms (e. g. trousers, pants, shorts, etc.).

Undergarments: Any garment worn under the visible outer clothes, usually next to the skin are called undergarments. Vest, underwear, briefs and brassieres are examples of undergarments. These garments are used for different parts of body for different purposes. Underwear and brassieres are worn to provide support to particular body parts. Vests are used in warm seasons to absorb perspiration so as to prevent the sweat reaching the outer clothes.

Garments are classified into two types on the basis of silhouette / shape:

- Fitted garment
- Loose garment

Fitted garment: The garments which fit closely to the body and depict the shape of body are called fitted garments.

Loose garment: These garments are manufactured with enough allowance and garment doesn't stick to the body tightly.

On the basis of fashion, garments are classified into four types:

- Staple products
- Semi-styled products
- Styled products
- Fashioned products

Staple products: These garments are manufactured without any change for a long time. With slight alterations these garments are manufactured as such for many years. Sometimes fabric is slightly altered. These products have more lead time but very low profit margins (Fig. 6.1). Examples: vests, under wears and dungarees (work cloths).

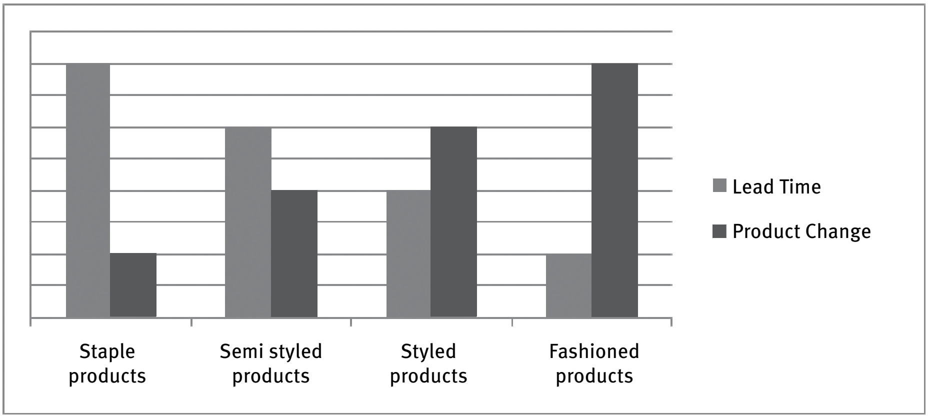


Fig. 6.1: Comparison of garment types on the basis of lead time and product change.

Semi-styled products: These are basic type of garments which bear slight changes in style. These types of garments have more alterations than staple products and these are also manufactured as such for long time. The alterations include color change, change in shape and patterns of pockets, cuffs and collars, etc. Example: men's formal shirts and trousers.

Styled products: The garments which are altered quite often are known as styled products. These garments have more and quick alterations than semi-styled products. For instance, change in length of garment, change in shape of garment, change in cuffs and collars, etc. are some alterations. Examples: jackets and ladies' dresses.

Fashioned products: These garments are manufactured in different styles at a time. These garments are quickly altered and have many alterations. It is quite difficult to manufacture such products. It requires highly skilled labour and management. These products have minimum lead time and maximum profit [1]. Examples: fashioned articles.

6.4 Global Apparel Industry

During the last decade, the apparel industry is shifting towards Asia. Earlier this industry was flourished in USA, UK and Europe. The reason for shifting this industry to Asia is the availability of cheap labour. The other reason is that the developed countries are stepping forward in technologies and are working on machinery, weapons, mechatronics and telecommunications, etc.

According to World Trade Organization [2], China, Hong Kong, Bangladesh, India and Turkey are the biggest clothing exporters in the world. Pakistan is the 11th biggest clothing exporter in the world.

Clothing exports of Bangladesh are four times higher than the clothing exports of Pakistan. Despite the fact that Bangladesh has to import all of its raw material while Pakistan is the fourth biggest cotton producer in the world. Pakistan has a very well structured spinning and weaving industry. Pakistan can increase its clothing exports by using raw material as its strength. In addition to that, improvement in quality may also impact positively the exports of Pakistan. Global apparel industry can be divided into four parts as shown in Fig. 6.2.

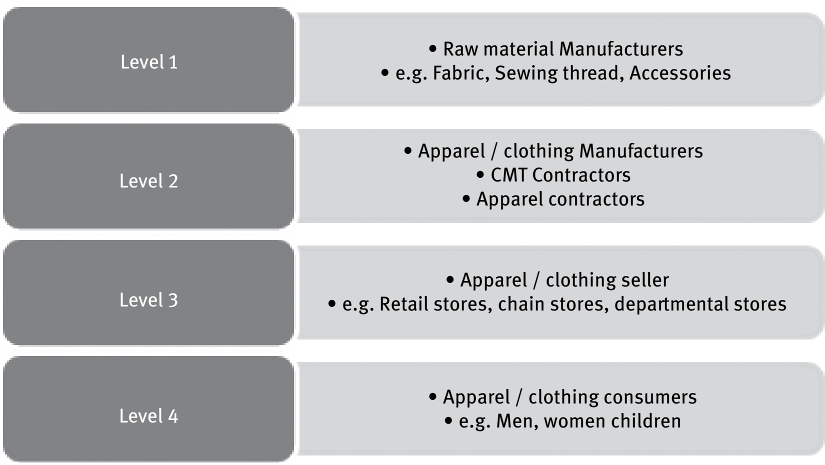


Fig. 6.2: Levels of global apparel industry.

According to Fig. 6.2, apparel industry is divided into four parts. We will discuss each level one by one.

Raw material manufacturer come at **level 1**. Raw material means the material required for apparel / clothing, such as fabric, sewing thread, labels, packing material, etc. In this respect spinning, weaving and textile processing are working on level 1. Garment industry is acquiring its raw materials from these manufacturers.

Apparel manufacturers are at **level 2**. Apparel manufacturers are those people who are making finished products. Such companies normally have an organizational structure which has merchandizing / marketing, finance, operations and production department. Most of the apparel manufacturers in Pakistan are working with contractors while a few hire their own labour. Particular operations like sewing / stitching, cutting and finishing which require more labour are assigned to the contractors. Contractor is responsible for providing operators for each task and completing each consignment in time.

Sometimes apparel manufacturers have more orders than their operational capacity. In such cases, CMT is an option which can be used. CMT stands for (Cut, Manufacture and Trim). CMT is also a type of contract. In this contract, a manufacturer who has more orders than his capacity gives a contract to another manufacturer who is known as CMT contractor. CMT contractor is responsible for all operations including cutting, stitching and trimming. Some small-sized manufacturers who do not have their marketing / merchandizing setup only work as CMT contractors. Therefore apparel manufacturers, CMT contractors and labour contractors are working at level 2.

Apparel sellers are at **level 3**. Once the finished products are manufactured, they are sent to the sellers. Different types of sellers are as follows:
- Retail stores
- Chain stores
- Discount stores
- Departmental stores
- Mass merchandisers

Consumers are the part of this system at **level 4**. It includes all men, women and children in the world.

6.5 Structure of an Apparel Firm

There is a lot of variation in the structure of an apparel firm worldwide. Each firm creates its own structure keeping in view its resources and constraints. Fig. 6.3 depicts the basic structure of an apparel industry.

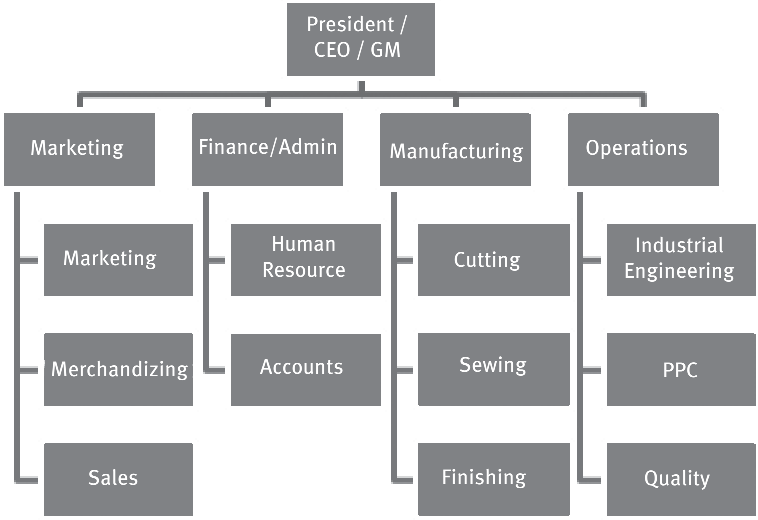


Fig. 6.3: Structure of an apparel firm.

6.6 Marketing Division

The basic responsibility of marketing is to satisfy the customers. They are also responsible to find out the new customers. They contact different potential customers in the world and try to convince them to do business with their company. There are three basic functions of marketing:

Marketing section is responsible for scheduling the marketing calendar, product pricing, product planning and customer relationships. In majority of the organizations in Pakistan's apparel industry either there is no marketing department or it is not efficiently functioning. The reason is that they do not design the products. Normally, the production takes place according to customer's requirements and instructions.

The basic objective of *merchandizing* is to provide the right product, at the right place, at the right time and at the right price. Therefore there are four basic functions of merchandizing. Merchandizing department performs these functions by acting as a bridge between the customer and manufacturing. They continuously monitor the production of a certain order and in case of any problem they correspond with the customer.

A merchandizer should be technically very strong because he / she has to deal with the whole manufacturing process. Unfortunately, in Pakistan merchandizing is full of people without much technical background. That is why, industry here loses many orders. For example, the majority of the merchandizers do not know the capacity of their units. Therefore, they accept the orders which cannot be manufactured in their unit. In such case new machinery has to be purchased and the manufacturing cost is increased. In addition to that machine layouts have to be changed again and again to make different types of products. Further, the operators have to be trained each time which causes fall in production and increase in cost. Another example is that the quality is not given the prime focus while buying the raw materials, in particular fabrics. Price is considered the most important factor. As a result, low quality fabrics are purchased due to which our consumption per unit is increased which results in overall high cost of the product. It should be kept in mind that the fabric contributes 40–60 % in the total cost of an apparel product.

Sales is the third function of the marketing department. Sales teams are responsible for market research, sales forecast, promotions and selling. It should be kept in mind that the sales teams are only functional in the firms where new products are made.

6.7 Finance / Admin Division

The basic responsibility of a *Finance department* is to manage the finances. In the apparel industry, the payment of an order is made after the goods are received by the buyer. Therefore, the manufacturer has to arrange the finances for the complete order. For example, total cost of an order, of 10000 pieces of an article whose cost per unit is PKR. 1000, will be PKR. 10,000,000 (PKR. 10 million).

Human resource is considered the most important resource nowadays. Companies having better human resource may create a competitive advantage over other companies. The basic responsibility of *Admin/Human resource* department is to manage the human resource. The responsibilities of the Human resource department are as follows:

– to find out and hire the appropriate human resource for the company
– to train the human resource according to the needs of the company
– to keep the human resource motivated
– to retain the human resource.

6.8 Manufacturing Division

Manufacturing department is the heart of an organization. The manufacturing department of an apparel company is subdivided into three parts, i. e. cutting, sewing and finishing.

The basic objective of a cutting department is to provide the sufficient and quality cutting to the sewing department. Cutting department receives the fabric from store. Further, they receive technical package from the marketing. By using the information given in technical package, they plan how to spread and cut for a particular order. Once they have planned an order, they spread and cut. Finally, they number all the bundles and send them to the sewing department.

The basic objective of sewing department is to stitch. There are multiple operations involved in the manufacturing of an article. The stitching department receives cutting from the cutting department. In addition to that they receive technical package from the marketing department. Then they prepare the operation breakdown. After that they arrange the appropriate sewing machines according to the requirements. After stitching, the stitched garments are sent to the finishing department.

Finishing department is a very important department because this department is responsible for finished look of the garment. Basic functions of finishing department are threading, repairing, stain removing, pressing and packing. Finishing department receives the stitched garments and extra threads (hanging) are cut. Some of the garments get stained during stitching. Stains are removed from such garments. Repairing is the next step which is conducted on those garments which have got some stitching faults. After that garments are pressed and packed according to buyer's instructions.

More details about the functioning of this department are given in the next section of this chapter.

6.9 Operations Division

Operations division is considered as the brain of the company. The functions of the division are as follows:
- Material planning and sourcing
- Production planning
- Sampling
- Method study
- Time study
- Process improvement
- Quality control and assurance

This division is considered as the supporting department. This division is normally subdivided into several departments, i. e. Production Planning and Control (PPC), Product Development (PD), Industrial Engineering (IE) and Quality.

PPC department is responsible for material planning, material procurement and production planning. Product Development is responsible for sampling and new product development.

Industrial Engineering department is one of the very important assets of a company. The key functions of IE department are as follows:
- to suggest process improvements
- to simplify the production process

- to suggest the steps to increase the efficiency
- to suggest the steps to reduce the overall cost of the process
- to conduct time study and to calculate the Standard Minute Value (SMV) and Standard Allowed Minutes (SAM) for a product
- To decide the piece rate for the operators

The ultimate goal of the IE department is to simplify the process and to reduce the cost. Nowadays people are more conscious about the quality of the product they buy. Therefore, an excellent quality department is a necessity to be a good company. Quality department consists of two parts:
- Quality assurance
- Quality control

It is very important to understand the basic concept of quality assurance. In this industry, most of the people have a misconception about quality assurance. Quality assurance is, in fact, everything that one performs to make things right at the very first time. For example, training and machine maintenance are the examples of quality assurance. Each employee performs to make sure that the product made is according to the requirements. As a matter of fact, everyone wants to avoid the rework and rejection of products. Both rework and rejection cause different types of losses – material loss and / or time loss. We can also say that the steps for quality assurance are taken before the production starts. In this industry, once an order is ready to be shipped, the cartons are opened and checked. This activity is considered as quality assurance which is a misconception. In fact, it is a part of quality control.

Quality control, is different from quality assurance. The objective of quality control is to check if the products being produced are according to the given specifications. Their entire job is during the production process. Quality control department has quality inspectors / auditors who check the product specifications at different stages of production. In most of the industries, the quality control teams are divided into two parts. First team is responsible for inline quality inspection. Inline quality inspection means that the quality inspectors check the products at different machines randomly. The second team is responsible for final inspection. Final inspection means that the inspection of goods at the end of production line. The amount of inspection varies from industry to industry. We can reduce the inspection cost by reducing the number of samples to be checked. But it increases the risk of bad products being passed.

The costs incurred on quality control and quality assurance are a part of Cost of Quality (CoQ). Most of these costs are the costs of non value-added activities. It is necessary to spend on quality but the cost of quality must stay at a minimum level. Further, we can reasonably reduce the cost of quality control by increasing a small amount of cost of quality assurance. As a result, the total cost of quality may be reduced.

6.10 Clothing Production

Clothing production involves multiple steps which are shown in Fig. 6.4. These steps are further explained as follows:

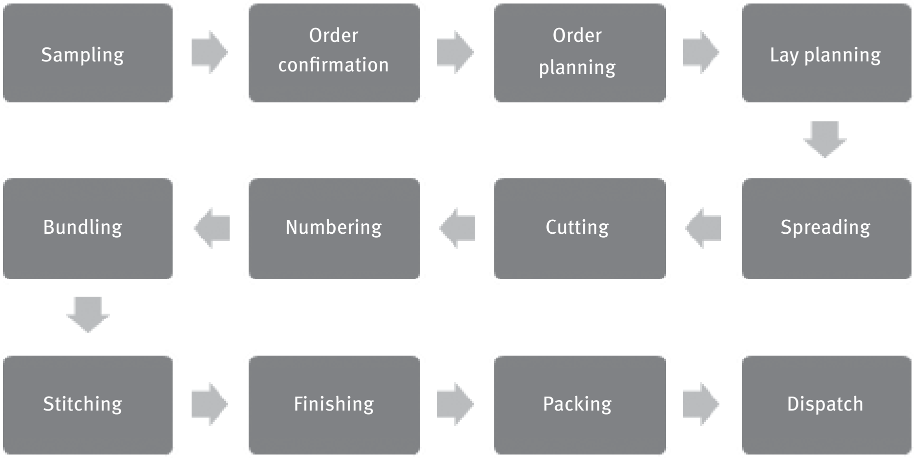


Fig. 6.4: Flowchart of clothing productions.

6.11 Sampling

Sampling is the first step in clothing production. Sampling is normally the responsibility of sampling department. In some industries, the same department is known as product development department or research and development department. Product development means to develop a new product. Unfortunately, most of the garment-making organizations in Pakistan do not produce new products. Instead, they reproduce the samples given by the customers. Several types of samples are produced and sent to the customers at different times.

The first sample for a product is known as *Prototype*. The customers want to judge the capability of a manufacturer from these samples. These samples are very important because customers make up their mind to work with the manufacturer after inspecting these samples. Prototype samples are normally made by sampling department. The approval process of a prototype sample is given in Fig. 6.5.

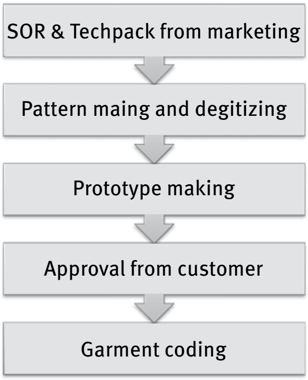


Fig. 6.5: Approval process of a prototype sample.

First of all sample order request (SOR) along with technical package is received from the marketing division. Sampling department makes the patterns and digitizes them (if they have CAD system). After that the sample is stitched by using the available fabrics and sewing thread. Then, the sample is sent to the customer through marketing division. Customer may accept the sample as it is or suggest some changes. If the customer suggests the changes, the same process is repeated again. Once the sample is approved from the customer, garment is given a unique code so that it may be used in future as a reference.

Salesman sample is the next type of sample after the approval of prototype sample. The customers display these samples on their stores so that the consumers may know about the upcoming products. In this sample, all the raw materials and accessories used are exactly according to the requirement of the customer. The first step is the fabric development and approval. The details of this process are given in Fig. 6.6.

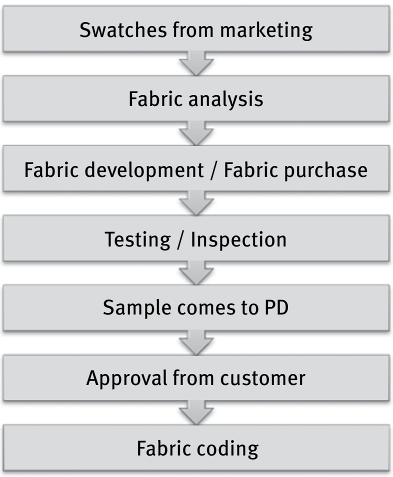


Fig. 6.6: Fabric development and approval process.

First, fabric swatches are received from marketing division. Sampling department analyses the fabric and the fabric characteristics are noted. After that, either the fabric is developed in-house or it is purchased from outside the firm. After that the fabric is tested and inspected to make sure that the fabric meets the customer's requirements. Now the developed / purchased fabric sample is sent to the customer through marketing. Customer may accept the sample as it is or suggest some changes. If the customer suggests the changes, the process is repeated again. Once the sample is approved by the customer, the fabric is given a unique code so that it may be used in future as a reference. Accessories and sewing thread are purchased during the course of fabric approval. Now the salesman samples are prepared and sent to the customer.

Next, the samples are prepared in all sizes provided by the customer. These types of samples are known as a *size set*. The objective of these samples is to check the measurements and shape of the garment before the production starts. These samples may be accepted in its form or with minor changes. These samples are made in the sampling room.

Another type of samples is the *pre-production samples*. These samples are normally produced in the production line before the start of production. The customer checks the samples and sends his / her comments. Any changes suggested are made before the start of the bulk production.

Finally, samples are taken during production and are sent to the customer. These types of samples are known as *during production samples*. The customer compares these samples with the samples already sent to him.

6.12 Order Planning

Orders are confirmed as a result of sampling. Once an order is confirmed, order planning is started. Planning is considered as the responsibility of PPC department. There are two basic functions of PPC department:
- Material planning
- Production planning

In some firms, there is a separate department for material procurement. First of all they prepare Bill of Materials (BoM). BoM is a document which contains details and quantity of the materials required to manufacture an order. Different formats are used in different firms. A sample BOM is depicted in Fig. 6.7.

It should be kept in mind that the BoM contains the details and quantities of materials required to make an order but it does not contain the cost / price of the materials. The next step is the purchase / development of the raw materials. It is better to work with multiple suppliers for a certain material because each supplier has limitations.

Bill of Material					
Purchase Order #:________ Customer ID:________			Order quantity:________ Style #:________		
Sr.#	Ref.#	Description	Quantity / unit	Total	Grand Total (5% access)
1	Fab-001	Body fabric (meters), 1x1 plain, Blue (180 gsm)	1.5	1500	1575
2	Fab-002	Pocketing (meters), 1x1 plain, white (90 gsm)	0.1	100	105
3	Acc-120	Buttons (#)	5	5000	5250
4	Acc-121	Sewing thread (meters)	150	150000 (50 cones)	53 cones
Prepared by: ________ Approved by: ________			Verified By: ________		

Fig. 6.7: Bill of materials.

Vendor assessment is a part of PPC's job. They have to see which vendors are better than the others. PPC department keeps in mind three things when buying from a vendor:

– Price
– Quality
– In-time delivery

As a rule of thumb, price is considered the most important but this is not a good approach. Quality of the material should be given more importance. Only a good quality raw material can make good quality products which can then be sold in good price. PPC department should judge the importance of these three factors according to the situation.

Second part of order planning is production planning. At some places it is also called scheduling. PPC department must know the capacity of each of their department. PPC department assigns the work keeping in view the capacity of a department and availability of raw material for an order. Unfortunately, our suppliers are not able to provide the raw material within the time period committed, most of the times. That is the reason why PPC department has to make frequent changes in their plans / schedules. Sometimes firms receive orders above their capacity. In such situations, some of the orders are outsourced.

The contract is known as CMT. CMT stands for Cut, Manufacture and Trim. According to the contract, we hire a small manufacturer who has the capability of cutting, stitching and finishing. We place the order to the manufacturer and pay him for his services. In such contracts, quality control is the responsibility of the parent firm.

6.13 Lay Planning

Once the fabric for an order is received, it is inspected by the quality department. If the fabric is rejected due to poor quality, it is sent back to the supplier. In case the fabric is accepted by the quality department, it is issued to cutting department. Cutting department starts cut order planning and lay planning. Cutting department, first prepares shade sequence. They arrange, all the fabric rolls in a sequence (from lightest to darkest shade). Then lay planning is done keeping in view the total order quantity, sizes and their ratios.

First of all the base patterns are received from sampling department. These patterns are **digitized** with the help of digitizing table. Next step is **grading**. Grading is the process of making patterns of all sizes from base size. For grading, we have to make a rule table. Let us try to understand it with a simple example. Fig. 6.8 depicts a pattern piece and Tab. 6.1 describes its measurements in four different sizes.

Tab. 6.1: Size chart.

Size	Length(")	Width(")
S	4	2
M	6	3
L	8	4
XL	10	5

For the pattern piece given in Fig. 6.8, the rule table is given in Tab. 6.2.

Fig. 6.8: Pattern piece.

Tab. 6.2: Rule table.

	P1		P2		P3		P4	
	X	Y	X	Y	X	Y	X	Y
S-M	0	0	0	1	2	1	2	0
M-L	0	0	0	1	2	1	2	0
L-XL	0	0	0	1	2	1	2	0

We can make the patterns of all sizes by applying the rule table given in Tab. 6.2. Now that we have patterns in all sizes, model making is the next step. A model contains information about the garment parts and their quantity. Model of a basic trousers is given in Tab. 6.3.

Tab. 6.3: Model of a basic trousers.

Sr. #	Garment Part	Quantity
1	Front panel	2
2	Back panel	2
3	Yoke	2
4	Back pocket	2
5	Facing	2
6	Watch pocket	1
7	Waist band	1
8	Right fly	1
9	Left fly	1

For one type of fabric in a garment, one model is made. For example, in trousers pocketing fabric is not added in the model as the pocketing fabric is normally different than the base fabric. Order making is the next step. An order guides us about how many pieces of each size has to be placed on the marker. Tab. 6.4 describes an order.

Tab. 6.4: An order.

Size	S	M	L	XL
Quantity	1	2	2	1

Here we can see that we will have to place 1 piece of size S, 2 pieces of size M, 2 pieces of size L and 1 piece of size XL. Now we have to make marker breakup which is shown in Fig. 6.9.

Marker Breakup					
Order #	ABC123				
Customer	Levis				
Fabric reference	Fab-001				
Total quantity	1000				
Size name	S	M	L	XL	Total
Size ratio	1	2	2	1	6
Quantity	167	333	333	167	
Marker 1	60	120	120	60	
Marker 1 Repeat 1	60	120	120	60	
Marker 1 Repeat 2	48	96	96	48	
Total quantity	168	336	336	168	

Fig. 6.9: Marker breakup.

Marker making is the next step. Process of placing patterns on the fabric in a way that the fabric utilization is maximum is known as marker making. Marker making is very important because raw material cost is from 50–60 % of the total cost in apparel industry. It means that if we can save 2 % of the fabric, we can increase 1 % profit margin.

Markers may be of different types which are as follows

- Half garment marker
- Whole garment marker
- Single size marker
- Multi size marker
- Sectional marker
- Interlocking marker
- Mixed multi-size lay

Details of marker types are out of the scope of this book.

6.14 Spreading

Once the marker is ready, information about the marker length is sent to the spreading team. Spreading is the process of superimposing fabric layers to get the required

number of garment pieces. One layer of the fabric is known as ply or layer whereas multiple number of layers ready to be cut are known as lay or spread. There are two types of spreading:
- Manual spreading
- Automatic spreading

Manual spreading is widely used. Particularly, in home textiles there is no concept of using automatic spreading. Very few industries use automatic spreading. In manual spreading, it is a two-man team: one on each side of the spreading table. The fabric roll is placed along the width of the table. A spreading table is shown in Fig. 6.10.

Fig. 6.10: Spreading / cutting table.

There are two modes of fabric spreading, that is, face to face and face one way. Fig. 6.11 explains the fabric spreading modes.

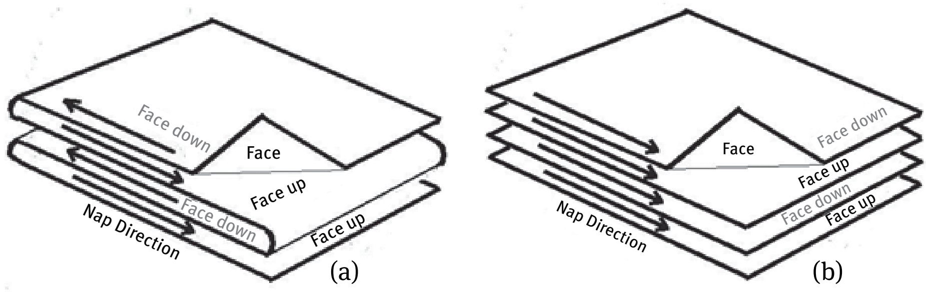


Fig. 6.11: (a) Face to face (b) Face one way.

Face to face spreading is easier and less time consuming. It may be used for the products which have mirror pieces. In denim industry, face to face spreading is used to make denim trousers. One the other hand face one way is more time consuming. But this is the only technique which can be used for directional fabrics. Directional fabric means the fabrics having any directional effect or print on its surface. During spreading, shade sequence is kept in mind to avoid the shade variations at later stages.

6.15 Cutting

When a lay is ready, cutting is the next process. There are two types of cutting:
- Manual cutting
- Automatic cutting

Manual cutting is the widely used method in the industry. A reciprocating knife hand cutter is used for this purpose. Fig. 6.12 depicts a fabric hand cutter (Eastman company). The cutter has a base plate which is inserted beneath the lay for cutting. There is a straight knife which reciprocates vertically to cut the fabric. The knife is driven by a motor. Furthermore, there is a handle as well. The operator holds the cutter with this handle and push the cutter to cut through the fabric lay.

Fig. 6.12: Reciprocating knife hand cutter.

The other type is automatic cutting in which a computer operated cutting machine is used. The process is also known as Computer Aided Manufacturing (CAM). An automatic cutting machine consists of a cutting table, and a moving head. Under the cutting table there is a suction mechanism. After spreading, the lay is dragged on to the cutting table and a polythene bag is placed on the upper side of the lay. Now the suction fans are switched on. The air entrapped between the fabric layers is sucked. Now the lay is squeezed and adhered to the cutting table. The process is necessary so that the fabric cannot move from its place during the action of very high speed cutting. After that the cutting head is given command to cut and it starts cutting. An automatic cutting machine (Gerber company) is shown in Fig. 6.13.

Fig. 6.13: Gerber automatic cutter.

Automatic cutting is faster and accurate than the manual cutting. But a huge investment is required to buy automatic cutting machine. Particularly, in home textile there is no concept of automatic cutting. Popular view is that home textile articles are very simple and straight; therefore, automatic cutting is not required.

6.16 Numbering and Bundling

Numbering and bundling is the next process after cutting. Each bundle is labeled. The label contains the information i. e. pattern, size, number of pieces, etc. The objective of this labeling is to avoid mixing of different sizes during stitching. Now each piece in a bundle is numbered. For example, the top most ply is given number 1 and the lowest ply is given number 30 in a 30 pieces bundle. The objective of this numbering is to avoid shade variation during stitching. The basic idea is to attach all the pieces in a garment from the same ply. Let us try to understand it with an example. Imagine we have spread a lay with two fabric rolls having slight shade variation. Now one sleeve comes from one fabric roll and the other comes from the 2nd roll in the same garment. The shade of both the sleeves will be different which is considered a fault. Such garment will be rejected by the quality department.

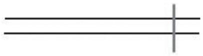
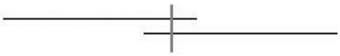
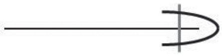
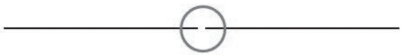
Now the cutting is transported to the sewing department and bundles of all garment parts of a size are placed on a trolley. The bundles are placed on trolleys in a sequence that each trolley contains one bundle of one size. Therefore, we will have the same number of trolleys as we have the number of bundles in a cut. This can be seen from marker breakup (Fig. 6.9).

6.17 Stitching

The process of joining of fabric to make a garment is known as stitching. There are two things involved in stitching process, i. e. stitches and seams.

The line where two or more fabrics are joined together is known as a **seam**. There are six basic seam classes which are explained in Tab. 6.5.

Tab. 6.5: Seam classes.

Sr. #	Seam Class	Designation	Figure
1	Superimposed seam	SS	
2	Lapped seam	LS	
3	Bound seam	BS	
4	Flat seam	FS	
5	Edge finishing	EF	
6	Ornamental stitching	OS	

Each seam is further divided into subclasses. Superimposed seam is the simplest and most commonly used seam type. Lapped seam is used to make double-sided garments. Bound seam is used in collars and cuffs. Flat seam is rarely used. Bottom hemming is an example of edge finishing. Embroidery is an example of ornamental stitching. A **stitch** is the specific configuration of a sewing thread. There are three methods to make a stitch.

6.17.1 Interlacing

When a thread or a loop of thread passes over or around another thread or loop of another thread, it is called interlacing.

6.17.2 Intralooping

Passing of a loop of thread from another loop of the same thread is called intralooping.

6.17.3 Interlooping

Passing of a loop of thread from a loop of another thread is called interlooping.

There are six stitch classes which are described in Tab. 6.6. All the stitch classes are based on interlacing, intralooping and interlooping.

Tab. 6.6: Stitch classes.

Sr. #	Stitch Class	Description	Examples
1	Class 100	Single thread chain stitch	Blind stitch machine
2	Class 200	Hand stitch	All hand stitches
3	Class 300	Lockstitch	Single needle Lockstitch, Double needle Lockstitch, Bartack
4	Class 400	Multi-thread chain stitch	Feedo, 2 thread chain stitch
5	Class 500	Over-edging	Overlock, safety and mock safety
6	Class 600	Cover stitch	Flat lock, inter lock

All of the sewing machines are designed keeping in view the stitch classes. Each stitch class has subclasses as well. Stitching is done by combining different types of seams and stitches.

Trolleys with fabric bundles are received in stitching department. Each product has to go through different sewing operations during stitching. It is necessary to perform these sewing operations in a sequence. There are sewing operations which cannot be performed after the other operations. Therefore, sewing department makes a list of operations and their sequence first of all. It is sometimes called operation breakdown / operation sequence. Then the sewing machines are arranged according to the operation sequence. Each machine is run by an operator. One operator performs only one operation on all the pieces of a bundle and then he moves the bundle to next operation. One by one operations are performed and finally all the parts are stitched together to make the final product. Operation sequence for a t-shirt is given in Fig. 6.14.

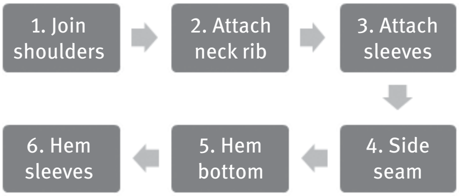


Fig. 6.14: Operation sequence of a t-shirt.

6.18 Finishing

Sewn products are sent to the finishing department. Finishing department takes care of the following functions:
- Trimming
- Stain removing
- Repairing
- Pressing

After stitching, there will be some hanging sewing threads on the finished product. Trimming is the operation of removing these extra hanging threads. Sometimes, finished products get stained during the production process. Finishing department is responsible to remove those stains by using different wetting agents. Some of the sewn products may also have some open seams or other stitching faults. The finishing department repairs such products before packing. The last objective of finishing department is pressing. The sewn products are pressed to remove the wrinkles and to enhance the look of the garment. An industrial pressing machine is shown in Fig. 6.15.

6.19 Packing

Packing is the last step in manufacturing. This section receives the finished products from the finishing department. Here, the products are packed according to the customer's requirements. Technical package is consulted to get the information about the packing size of the product, carton size, number of pieces in a carton and their distribution. The size of the carton is a very important factor. The carton is designed in a way that it takes minimum space in the container. After packing, the products are ready to be shipped.

References

[1] R. E. Glock, G. I. Kunz, *Apparel manufacturing: Sewn product analysis*. Prentice Hall, 2000.
[2] World Trade Organization, "International trade statistics," 2012.

Abdul Basit

7 Technical Textiles

7.1 Introduction

When one hears the word textiles, the first word that flashes in one's mind is the "clothing" for human beings. Certain properties, for example drape, fine look, texture, colour, lustre, design, etc. are required to be for good clothing that is called aesthetics. Currently, the term textiles is also used to refer to technical textiles.

In other words, technical textiles can be defined as "the textiles in which the performance properties are of greater importance than the aesthetics," says author Michael Litton [1].

The use of fibres, yarns and fabrics for applications other than clothing and furnishing is not a new phenomenon. Different natural fibres such as cotton, linen, flax, etc. were used for tents, roping and sacking, etc. Silk was used in surgical sutures. During the Roman Empire period, some meshed fabrics were used in road construction for its better stabilization [2].

7.2 Functions of Technical Textile

Different functions can be achieved through technical textiles. These can be categorized into four groups.

- Mechanical functions:
  It includes mechanical resistance, reinforcement of the materials, tenacity, elasticity, etc.
- Exchange functions:
  It includes filtration, insulation and conductivity, drainage, permeability, absorption, etc.
- Functionalities for living beings:
  It includes antimicrobial, anti-dust mites, biocompatibility, biodegradability, etc.
- Protective functions:
  It includes protection from fire, chemicals, infrared and ultraviolet rays, electromagnetic fields, environment, etc. [3].

7.3 Categories of Technical Textiles

Currently, technical textiles can be categorized into 12 groups depending on their applications:

- Agrotech: Textiles used in agriculture, horticulture and forestry
- Buildtech: Textiles used in building and construction

– Clothtech: Textiles used in technical components of footwear and clothing
– Geotech: Textiles used in geotextiles and civil engineering
– Hometech: Textiles used in furniture, household textiles and floorcoverings
– Indutech: Textiles used in filtration, conveying, cleaning and other industrial uses
– Medtech: Textiles used in hygiene and medical field
– Mobiltech: Textiles used in automobiles, shipping, railways and aerospace
– Oekotech: Textiles used in environmental protection
– Packtech: Textiles used in packaging
– Protech: Textiles used in general protection
– Sporttech: Textiles used in sport and leisure.

7.3.1 Agrotech

The textiles used in agriculture are called as agro-textiles as shown in Fig. 7.1. The properties of the textiles which are required in agro textiles include strength, elongation, stiffness, porosity, bio-degradation, resistance to sunlight and resistance to toxic environment. There are many applications which include the growth and harvesting of live products and foodstuffs, such as gardening and landscaping, agriculture, forestry, animal husbandry, in fences, etc.

The fishing segment is a large consumer of textile materials. However, growth is limited due to the declining of fish stocks and contraction of fishing fleets. Fishing

Fig. 7.1: An example of an Agrotech.

methods have become more industrialized that has replaced older, small net- and line-fishing techniques. In many developed countries, due to the decline in the area of land for agriculture and horticulture, the search for higher and more frequent yields is increasing. Agrotech textiles can be a choice to achieve this goal, for example by artificially controlling the climate for plants and animals. However, agro-textiles are costly which limits their use. The agro-textiles can be beneficial in terms of increase in yield, water saving, lesser crop diseases, weed control, soil-borne pathogens control, etc. It can improve the quality of the crops as well [4].

7.3.2 Buildtech

The textiles that are used in the construction and architectural application are termed as buildtech. Buildtech segment consists of textiles or composite materials that are used in the construction of permanent and temporary buildings as well as structures. There are so many applications of the textiles which are being used in construction such as in the interior design and construction, air conditioning, heat insulation, proofing materials such as from water, reinforcement of the concrete, environmental protection, noise proof, etc. The buildtech textiles offer the mechanical properties which are often superior to traditional materials. This is the reason that the share of such textiles is increasing in the market.

Fibres and textiles have a major role to play in building and equipment insulation. Glass, polypropylene and acrylic fibres are used to prevent cracking of the concrete, plastic and other building materials. Glass fibres are almost universally used in place of asbestos now. Adhesives like epoxy resins are also used in the textile reinforcement. Textiles in buildtech are used in temporary and in permanent way. In dams, bridges, tunnels and roads, these are used permanently however, temporary structures such as tents, marquees and awnings are some of the most noticeable and evident applications of textiles. High strength, high modulus textile fabrics are increasingly being used in the buildings and construction industry as a replacement for traditional materials (wood, concrete, steel, etc.) The mechanical properties of fabrics made with aramid, carbon and glass fibers with the combination of resin systems form a composite and provide high strength to weight, high stiffness to weight, etc. [5].

7.3.3 Clothtech

Clothtech includes fibres, yarns and textiles used as technical components in the manufacturing of clothing such as sewing threads, interlinings, waddings and insulation. Most of these components are hidden, for example interlinings in shirts, labels, sewing threads, hook, loop fasteners, etc. Clothtech also includes the fabrics which are used in umbrella cloth. The sophistication level of these components is increasing due to the use of new, “high performance” garment fabrics [5].

7.3.4 Geotech

All the fabrics (woven, nonwoven and knitted textile materials) which can provide a range of primary functions such as support, drainage and separation at or below ground level, lie in the category of geotextiles as shown in Fig. 7.2. Geotextiles are used in the construction of buildings, bridges, dams, roads, railways and paths as well as embankments and sub-sea coastal engineering projects. It is forecasted that geotextiles will have the highest growth rate out of the twelve technical textile application areas [5].

Fig. 7.2: An example of geotech.

Fig. 7.3: An example of a home-tech.

7.3.5 Hometech

Hometech segment of technical textiles comprises of the textile components used in the domestic environment – interior decoration and furniture, carpeting, protection against the sun, cushion materials, fireproofing, floor and wall coverings, textile reinforced structures / fittings, filter products for vacuum cleaners as shown in Fig. 7.3. They are made of both natural and synthetic fibres.

The most modern and most refined development is the addition of temperature phase change materials into such insulation products to provide an additional degree of control and resistance to sudden extremes of temperature, hot or cold [6].

7.3.6 Indutech

Indutech includes technical textile products used in the manufacturing sector. The applications are diverse such as separating and purifying industrial products, cleaning gases and effluents, transporting materials between processes and acting as substrates for abrasive sheets and other coated products. In addition, it is a tremendously diverse application sector in terms of products, functions and end-uses ranging from lightweight non-woven filters, knitted nets and brushes to heavyweight coated conveyor belting [4].

7.3.7 Medtech

Medtech products comprise textile materials used in hygiene, health and personal care as well as surgical applications as shown in Fig. 7.4. The Medtech products are available in all forms such as woven, knitted and non-woven based on the area of application. Medtech needs the basic textile properties like softness and lightness, flexibility, absorption, filtering, etc. Synthetic fibre is being used largely in manufacturing these products.

Medical textiles can be considered as a part of the wider group of technical textiles. It links with other applications as in the use of similar materials for different purposes; for example in the operating theatre, protective textiles are used which are similar to other kinds of protective clothing including chemical, bio-hazard or foul-weather protection. Therefore, new developments intended for foul-weather protective clothing, like densely woven micro-fibre fabrics or breathable laminated textiles, were established as gowns, too. As a result, the surgeon and the other operating room staff achieved a higher level of protection and also a good wear comfort.

Medical textile is not only an interesting research area, but is also tremendously important from the economic point of view. Medical textiles have been developed widely in recent times. Medical textiles are today an inevitable constituent of modern

Fig. 7.4: An example of Medtech.

disease management. Starting from common cotton fabrics, medical textiles have shown speedy development over the last few decades. This progress affects nearly all textile sectors such as the new bio-degradable fibre constituents enabled novel types of implants, development of the three-dimensional spacer fabrics; and silver-ion based finishes effectively reduce bacteria growth. In this fashion, the field of medical textiles has grown expansively over the years [7].

7.3.8 Mobiltech

Mobiltech segment of technical textiles is used in the construction of automobiles, railways, ships, aircraft and space craft as shown in Fig. 7.5. The Mobiltech products can be broadly classified into two categories – visible components and invisible components. The visible components include seat upholstery, carpets, seat belts, headliners, airbags, etc. The invisible components include noise vibration and harness (NVH) components, tyre cords, liners, etc.

Fig. 7.5: An example of Mobiltech.

7.3.9 Oekotech

Any textile product which is produced in eco-friendly way and also processed under eco-friendly limits come under oekotech. The fabrics made up of organic cotton, hemp, bamboo, recycled polyester or tencel or PLA (poly-lactic acid) fibres are more eco-friendly as these do not or less affect the environment. The PLA fibers are the form of polyester which are biodegradable hence it is an ideal example of oekotech. Currently, research is being carried out in textiles to replace non-biodegradable polyester with biodegradable polyester, i. e. PLA. Also, cotton is being tried to be replaced with tencel so as to avoid the loss of water and use of insecticides and pesticides in growing cotton. Such efforts are made so as to make the environment safe [4].

7.3.10 Packtech

The several flexible packaging materials used for industrial, agricultural, consumer and other goods come under the term Packtech as shown in Fig. 7.6. It consists of synthetic bags used for industrial packaging and jute sacks used for packing food grains. Packaging is a long established application for textiles. Packtech is the largest end-use. Bags, sacks, flexible and wrappings for textile bales and carpets are used in one hand; however, on the other hand, it includes lightweight nonwovens used as durable papers, tea bags and other food and industrial product wrappings.

Strong, lightweight spun-bonded and nonwoven paper-like materials are particularly useful for courier envelopes. Also, the adhesive tapes, often reinforced with fibres, yarns and fabrics, are increasingly used in place of traditional twine. Woven strappings are less dangerous to cut than the metal bands and wires traditionally used with densely packed bales.

Fig. 7.6: Examples of packtech.

7.3.11 Protech

The textiles that provide protection against different functions are called protective textiles as shown in Fig. 7.7. Textiles for protection is an important area that has drawn a great attention towards it. Protech consists of all those textile materials and products used in the production of protective clothing of various types. The different functions that need to be protected by textiles are diverse. It includes protection against ballistic, cuts, abrasion and other types of wounds of explosion or fire, extreme heat, hazardous dust and particles, high voltages, electricity, extreme cold, etc.

Some fabrics have also been developed which provide protection against UV light with alterations in the construction parameters of fabrics with appropriate light absorbers and suitable finishing methods [7].

7.3.12 Sporttech

The textiles that are used in sports in any form are called as sporttech as shown in Fig. 7.8. The applications are diverse and range from artificial turf (e. g. in hockey) used in sports surfaces through to advanced carbon fibre composites for racquet frames, fishing rods, golf clubs and cycle frames. Other uses are balloon fabrics, parachute and paraglider fabrics and sailcloth. The demand for sportech is increasing day by day due to the increase of leisure time, people showing interest in health-related activities, increased women participation in sports, increased accessibility and availability of sports such as skiing, golf and sailing and the growth of sports facilities.

Fig. 7.7: An example of protech.

Fig. 7.8: An example of sporttech.

Recently the fabrics equipped with sensors have been developed which give complete physiological monitoring of the body during the exercise. The fabrics have also been developed with phase change materials which give cooling effect during sports in summer. The New Zealand cricket team wears black kit during sports which provides discomfort as the black color absorbs light and becomes heated. To avoid the heating and to achieve cooling effect, the phase change materials have been incorporated in the fabric for making the sporting kits [6].

References

[1] Handbook of Technical Textile Design 23rd January 2012, Scotland.
[2] *Textile Terms and Definitions*, published by the Textile Institute by Woodhead Publishing Ltd UK.
[3] C. Byrne, Technical textiles market – an overview, in *Handbook of Technical Textiles* A. R. Horrocks, Anand, S. C. (Eds.), 2000, Woodhead Publishing Ltd., Cambridge, UK.
[4] Technical Textile Messe Frankfurt in Germany http://techtextil.messefrankfurt.com/frankfurt/en/aussteller/willkommen.html.
[5] Business Model and Project Viability for a Technical Textile Project.
[6] Kevlar chemical structure. png http://www.chm.bris.ac.uk/webprojects2002/edwards/chemistry.htm.
[7] http://www.performancefibers.com/.

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8 Textile Testing

8.1 Introduction

Quality could be termed as customers' satisfaction; a good quality product means that it will fulfil all the purposes for which it has been produced [1].

8.2 Quality Control

Quality control is a continuous and regular control of the parameters which affect the quality of the final product. It comprises of planning, raw data compilation, its investigation and implementation. Following are the objectives of quality control:
- to produce required quality product
- to fulfil the customer's required standards
- to reduce the production process cost
- to minimize the process wastage
- to get maximum profit at minimum possible cost

8.3 Standardization of Testing

When a textile material or product is tested, its results must fulfil both explicit and implicit requirements. The explicit requirements from the tests are either that how the product will perform during its life cycle or how it will meet the required specifications. The core purpose of testing is that it must be reproducible; it means that if the same material tested under similar conditions in different laboratories, or at another time, and by another operator but it should yield the same results. However, testing results of textile materials are not expected to be similar every time. The factors affecting the reproducibility of results are as follows:
- *Variation in the material*: It could be minimized by proper selection of representative sample from the material being tested by using some statistical tools.
- *Variations imparted by test method*: These variations are caused by conditions under which the testing is being held like speed, pressure, gauge length, temperature, relative humidity, etc. These variations could be minimized by specifying the standard written test methods for testing. For this purpose, organizations like ISO (International Organization for Standardization) are working to build internationally accepted standard test methods.

8.4 Repeatability and Reproducibility

The precision of a testing method can be evaluated by redundant testing of the same material between various testing laboratories and within the same laboratory by using the identical testing instruments. These testing results are then compared and the reproducibility / repeatability of various laboratories computed. The variations between laboratories are always higher than the variations observed within a single laboratory.

The repeatability could be defined as follows:

a. Qualitatively: It is the accuracy between consecutive test results collected with the identical method on same material, under the same conditions.
b. Quantitatively: It could be described as the value below which the difference between two test results collected under the above-mentioned conditions may be expected to fall with a discrete value of probability [1].

8.5 Sampling

It is not necessary to perform the testing of complete material and it is practically impossible as well, due to time and cost factor. Also some tests are of destructive type, in which no material remains after testing. Due to this we use model / symbolic samples from the bulk material for testing. Major objective of sampling is to make an unbiased sample representing the whole.

Following terms are being used in sampling:

8.5.1 Consignment

It can be described as the quantity of material which is transported at the same time. Each consignment may consist of single or many lots.

8.5.2 Test Lot

All the containers of a material having one specific type and quality which are delivered to the customer are considered as test lot. It is presumed that the whole material is uniform and all the parameters of the material are checked.

8.5.3 Laboratory Sample

Samples of the material which are used to perform testing in the laboratory are considered as laboratory samples. Random sampling procedures are adopted to derive laboratory samples from the test lot.

8.5.4 Test Specimen

Test specimen is the portion of the material that will actually be utilized for testing, which is taken from laboratory sample. Several test specimens are tested to get reliable test results.

8.5.5 Package

Elementary units within each container in the consignment is known package. Package might be bobbins, cones, fabric rolls, etc. [1].

8.6 Moisture Content & Moisture Regain

The quantity of moisture in a textile material can be indicated in terms of its moisture content or moisture regain. In textile industry, the most used term is moisture regain.

"*Moisture Regain*" could be defined as the weight of water in a textile material described as the percentage of its oven dry weight:

Moisture Regain = (100 × W) / D {expressed in %}

"*Moisture content*" could be defined as the weight of water in a textile material described as the percentage of its total weight:

Moisture Content = (100 × W) / (D + W) {expressed in %}

where,

D = Dry weight and W = Weight of the absorbed water [1].

8.7 Standard Atmospheric Conditions for Testing

Properties of textile materials are significantly changed as the moisture content changes, so it is the basic requirement to standardize the temperature and relative humidity in which any testing procedure is executed. For this purpose, standard conditions of temperature and relative humidity has been agreed for testing environment; that is, a relative humidity of 65 % ± 4 and a temperature of 20°C ± 2. By maintaining these conditions, repeatability and reproducibility of testing are more likely to be enhanced [2].

8.8 Testing of Fibers

Testing of raw material is very important and in case of spinning raw material could be fibers, so it is necessary to find out the complete parameters of fiber that will help in the process of spinning. The properties of the yarn and fabric are directly influenced by the properties of fiber from which yarn and fabric are made. For testing of fibers, mostly used instruments are USTER HVI and USTER AFIS.

Tab. 8.1: Comparison of parameters measured by USTER HVI and USTER AFIS [3].

A comprehensive explanation of parameters evaluated by USTER HVI (High Volume Investigation)	**A comprehensive explanation of parameters evaluated by USTER AFIS (Advanced Fiber Investigation System)**
1) Upper Half Mean Length (UHML): UHML could be defined as average length of the longer (upper) half fibers in the sample checked. Its unit will be inches or millimeter.	1) Nep (Count per gram): It is the number of entanglements of fibers in the cotton sample.
2) Mean Length: Average length of all the fibers in the sample being tested. Its unit will be inches or millimeter.	2) Nep Size: It is the size of the total neps in the cotton sample and expressed in μm.
3) Uniformity Index (UI): It is also defined as Length uniformity, and it is the ratio between the average length and the upper half mean length (UHML) of the fibers. It is described in percent.	3) Seed Coat Neps (Count per gram): It is the number of the fragments of cotton seeds in the sample that still have some fibers attached.
4) Short Fiber Index (SFI): Amount of Fibers in percent that are less than 0.5 inch (12.7 mm) in length.	4) Seed Coat Nep: It is the size of the total seed coat neps in the cotton sample and expressed in μm.
5) Strength: It is defined as the force in grams required for breaking a bundle of fibers having one Tex unit size. It is expressed in Gram / Tex.	5) Mean length by weight: It is the average fiber length of all the cotton fibers in a cotton sample computed on a weight basis and expressed in inches or millimeter.
6) Elongation: The average length of distance to which the fibers extends before breaking. It is expressed in percent.	6) Upper Quartile Length by weight: It is the length of the longer 25 % of all fibers in a cotton sample on weight basis and expressed in inches or millimeter.
7) Moisture: Amount in percent of water (H_2O) which is present in the sample being tested.	7) Short Fiber Content by weight: The percent of all fibers in a cotton sample that are shorter than 0.5 inch or 12.7 mm on weight basis.
8) Reflectance (Rd): This value expresses the whiteness of the light reflected by the cotton fibers. It corresponds to the reflectance (Rd) in the Nickerson-Hunter color chart.	8) Mean length by number: It is the average fiber length of all the cotton fibers in a cotton sample computed on a number basis and expressed in inches or millimeter.
9) Yellowness (+b): It is a measure of the yellowness of the fiber and is based on the Nickerson-Hunter scale. Cotton ranges from 4 to 18.	9) Upper Quartile Length by number: UQL is defined as the length of the longer 25 % of all fibers in a cotton sample on number basis and expressed in inches or millimeter.

Tab. 8.1: (Continued).

A comprehensive explanation of parameters evaluated by USTER HVI (High Volume Investigation)	A comprehensive explanation of parameters evaluated by USTER AFIS (Advanced Fiber Investigation System)
10) Color Grade (C Grade): Reflectance (Rd) is used in conjunction with the yellowness (+b) to determine the instrument-measured color grade of cotton.	10) Short Fiber Content by number: The percent of all fibers in a cotton sample that are shorter than 0.5 inch or 12.7 mm on number basis.
11) Trash Count: It is a measure for the trash of cotton. It is the number of trash particles measured on the surface of the sample.	11) 5 % length by number: It is the length of the longer 5 % of all fibers in a cotton sample and expressed in inches or millimeter.
12) Trash Area: The value is also a measure for the contamination of cotton. It indicates the contaminated area in comparison to the total area of the sample measured.	12) Fineness: It is mean fiber fineness (weight per unit length) in millitex. One thousand meters of fibers having a mass of 1 milligram equals 1 millitex.
13) Trash Grade: Classer's leaf grade, it depends upon Trash area (%) and ranges from 1 to 8.	13) Maturity Ratio: It is the ratio of fibers having 0.5 (or more) circularity ratio divided by the amount of fibers having 0.25 (or less) circularity.
14) Micronaire (Mic.): It is the fiber fineness. A sample of fibers having constant weight is tested by passing air through it and the drop in pressure is recorded then. It is expressed in µg / inch.	14) Immature Fiber Content: It is defined as the percentage of fibers in a sample having a cell-wall thickness covering less than 25 % of the full area.
15) Maturity Index: is a relative value calculated from other HVI measurements, such as micronaire, strength and elongation. It indicates the degree of cell-wall thickness in a sample.	15) Dust Count per gram: It describes the smaller particles from the plant and simply dirt from the cotton field that sticks with the plant. (Particle size <500 µm).
	16) Trash Count per gram: It is the general term for larger impurities containing particles from the cotton plant itself and other plants contaminating the cotton fields. (Particle size >500 µm).
	17) Total Trash Count per gram: All particles removed by AFIS fiber individualizer, regardless of size, are counted and reported under this heading.
	18) Visible Foreign Matter: It takes both dust and trash particles as well as their size into account and expressed as percent.

8.9 Testing of Yarn

8.9.1 Linear Density

Among the other parameters of a yarn, its diameter is a significant factor. But determining the diameter of a yarn is impossible by any means. It is due to the fact that diameter of a yarn varies significantly as it is squeezed. Besides the optical technique, all other methods involve compressing of yarn during testing. Due to this compressive behaviour of yarn, the measured diameter varies with the pressure applied. Optical techniques of determining a yarn's diameter have the problem of specifying where the peripheral edge of the yarn lies as the surface can be unclear or rough due to hairiness on it. This is the reason why the positioning of the yarn edges is subject to operator interpretation. Due to these troubles a system must be designed to find out the delicacy of yarn by weighing its predefined length. This quantity is called linear density which can be determined with accuracy if tested length of yarn is sufficient. There are two systems to find out the linear density of yarn, direct and the indirect.

8.9.2 Direct System

In the direct system of linear density we determine weight per unit length of a yarn. The widely known direct systems in use are as follow:
- Tex = It is the number of grams in 1000 meters length of yarn.
- Decitex = It is the number of grams in 10,000 meters length of yarn.
- Denier = It is the number of grams in 9000 meters length of yarn.

8.9.3 Indirect System

In the indirect system of the linear density, length per unit weighed of a yarn is determined. This linear density is also called count, due the fact that it is based on determining the number of hanks of a specified length which are required to equal a fixed weight. It is the most widely used system of measuring the yarn's linear density [1].

The widely known direct systems in use are as follow:
- Yorkshire Skeins Woollen Ny
  Count = No. of hanks per pound (where one hank = 256 yards)
- Worsted Count New
  Count = It is no. of hanks per pound (where one hank = 560 yards)
- Cotton Count Nec
  Count = It is No of hanks per pound (where one hank = 840 yards)

– Metric count Nm
  Count = number of kilometre per kilogram

* In the indirect systems the fineness and count yarn count are directly proportional to each other.

Tab. 8.2: Conversion table [4].

Wanted \ Known	Tex	dtex (Decitex)	den (Denier)	Nm (Number metric)	Nec (Number english cotton)	Worsted
Tex		$\frac{\text{dtex}}{10}$	$\frac{\text{den}}{9}$	$\frac{1000}{\text{Nm}}$	$\frac{591}{\text{Nec}}$	$\frac{885.8}{\text{Worsted}}$
dtex (Decitex)	Tex × 10		$\frac{\text{den}}{0.9}$	$\frac{10'000}{\text{Nm}}$	$\frac{5910}{\text{Nec}}$	$\frac{8858}{\text{Worsted}}$
den (Denier)	Tex × 9	dtex × 0.9		$\frac{9000}{\text{Nm}}$	$\frac{5310}{\text{Nec}}$	$\frac{7972}{\text{Worsted}}$
Nm (Number metric)	$\frac{1000}{\text{Tex}}$	$\frac{10'000}{\text{dtex}}$	$\frac{9000}{\text{den}}$		Nec × 1.693	$\frac{\text{Worsted}}{0.886}$
Nec (Number english cotton)	$\frac{591}{\text{Tex}}$	$\frac{591}{\text{dtex}}$	$\frac{5319}{\text{den}}$	Nm × 0.59		$\frac{\text{Worsted}}{1.5}$
Worsted	$\frac{885.8}{\text{Tex}}$	$\frac{8858}{\text{dtex}}$	$\frac{7972}{\text{den}}$	$\frac{\text{Nm}}{1.129}$	$\frac{\text{Nec}}{0.666}$	

8.9.4 Evenness of Yarn

It could be defined as the variation in its thickness or in weight per unit length of the yarn. Evenness of yarn is measured by the following methods:

8.9.4.1 Visual Examination

In this method yarn evenness is checked by wrapping it on a black board in uniformly spaced turns to reduce the effect of optical illusions caused by irregularity. These boards are then checked under proper lighting using a uniform and unidirectional light. Normally visual examination is done without any comparison with standard but comparison could also be made with ASTM standard if IT is available. Today, more uniformly spaced yarn boards are prepared by the help of motorized wrapping machines. With these wrapping reels, the yarn moves steadily along the tapered black-board as it is rotated. Tapered black boards are preferred to evaluate or determine the periodic faults. It there are periodic faults in the yarn they produce a woody pattern which is clearly visible. This visibility of the yarn faults on the tapered boards is due to the equal spacing of the yarns on the board [1].

8.9.4.2 Cut and Weigh Method

It is the simplest method of measuring variation in mass per unit length of a yarn. It consists of cutting consecutive lengths of the yarn and weighing them all. For this testing, we need an accurate way of cutting the yarn as all the lengths should be same. Because the small error in cutting the lengths of yarn will cause an equal error in the measured weight leading to wrong results. For this purpose yarn is wrapped around a grooved rod which has a circumference of exactly 2.5 cm and then a razor blade is run along the groove, leaving the yarn in equal 2.5 cm lengths. The lengths so produced can then be weighed on a suitable sensitive balance. If the mass of each cut length of yarn is plotted on a graph as in Fig. 8.1.

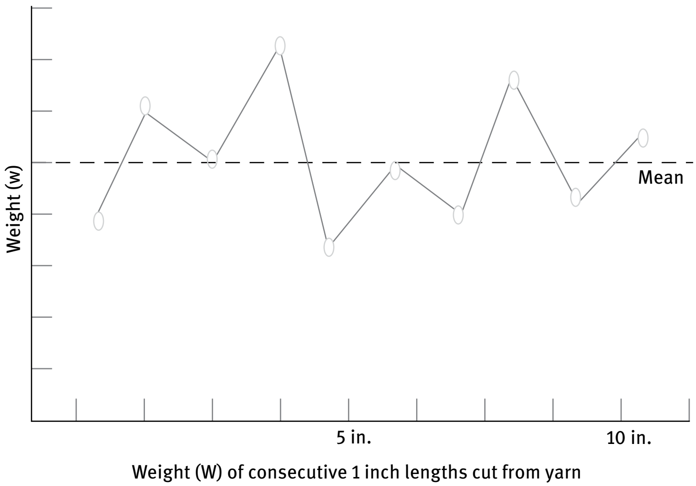

Fig. 8.1: Variation in mass per unit length of a yarn.

A line showing the mean value can then be drawn on the plot. The scatter of the individual values about this line will then give a visual indication of the unevenness of the yarn. A mathematical measure of the unevenness is required which will take account of the distance of the individual points from the mean line and the number of them. There are two main ways of expressing this in use:

The average value for all the deviations from the mean is calculated and then expressed as a percentage of the overall mean which is known as percentage mean deviation (PMD). This term is used by USTER Technologies to indicate U %.

The value of SD (standard deviation) is calculated by squaring the deviations from the mean and this is then expressed as a percentage of the overall mean.

The deviations having a normal distribution about the mean are correlated as follows [1]:

CV = 1.25 PMD

8.9.4.3 USTER Evenness Tester

The USTER evenness tester finds the variations in thickness of a yarn by using capacitive techniques. The yarn to be examined is passed through a pair of parallel capacitor's plates whose capacitance is continuously measured electronically. The capacitance of system changes continuously due to the presence of the yarn between the capacitor's plates. The capacitance depends on the mass of material (yarn) between the plates and its dielectric constant (type of raw material used). For the same dielectric constant, the signals are directly related to the mass of the yarn between the capacitor plates. To get the same relative permittivity for yarn, it should be made up of the same type of fiber and it must have uniform moisture content throughout its length. The varying moisture content or an uneven blend of two or more fibers will vary the dielectric constant in different parts of the yarn and this variation will be signaled as unevenness. The readings made by the USTER tester are equivalent to weighing successive 1 cm lengths of the yarn [5].

The following can be the possible reasons for yarn unevenness:

- The number of fibers in the yarn cross-section is not constant; it varies widely depending upon the fiber parameters. This is the most significant reason of yarn unevenness.
- The staple spun yarn made up of natural fibers having the variable fineness, this variation leads to a difference in yarn thickness even when the number of fibers in the cross-section remains the same.

8.9.5 Yarn Hairiness

It is the ratio of length of all protruding fiber in 1 cm and the yarn actual length (1 cm). It is a unit less parameters. It is an undesirable parameter which directly influences the fabric production. Therefore it is very important to measure it so that it can be controlled. Hairiness value of the coarser yarns is normally lower than the finer yarn due to good cohesive / frictional forces between the constituent fibers in the coarser yarns. Shirley yarn hairiness tester, Zweigle G565 and Uster tester 5 hairiness meter attachment are used for testing the hairiness of the yarns [1].

8.9.6 Tensile Strength

It can be defined as maximum force / load which is required to break the material [6]. Tensile strength of the yarn is an important parameter regarding the fabrication of the yarn because it directly influences the strength of the developed fabrics. Two different approaches are used to measure the yarn strength. In first approach single yarn strength is determined. Normally Newton (N) and cN units are used for the yarn strength [7]. The amount of force which is applied on the material to produce an acceleration of meter / second square per second is one Newton [1]. Single yarn strength provides information about the warping machine and loom efficiency. In order to calculate the combined strength effect of the yarn count lea strength product (CLSP) of the yarn is calculated. Lea of 120 yards is made by the help of wrapping Reel and weight of the lea is determined in order to calculate the yarn count by using the formula no of hanks / pound [8]. Lea strength is determined by using the lea strength machine which has two jaws, one is fixed and the other is attached with the load. Using the constant rate of loading principle, tensile strength of the lea in determined [9].

8.10 Types of Tensile Strength Testing Machines

On the basis of working principle, tensile strength testing machine can be categories into 3 major categories;

1. Constant rate of extension (CRE): the machines in which rate of elongation of the specimen is constant and with increasing load there is negligible movement of the load measuring mechanism. The working principle of the Tensorapid-4, which is used to evaluate the tensile strength of the single yarn strength, is constant rate of elongation [1].
2. Constant rate of loading (CRL): the machines in which the applied load on the test sample is increased constantly with time. In this the specimen is free to elongate and extension of the specimen depends upon its properties at any applied load [1]. Working principle of the lea strength machine is CRL.
3. Constant rate of traverse (CRT): in such types of machine two pulling clamps are used to evaluate the tensile strength of the sample. One clamp moves with uniform rate and the load is applied by the other clamp which moves to activate a load measuring mechanism. In such machines rate of increasing load / elongation usually are not constant, and so, the rate of increase of load or elongation is usually not constant and is dependent on the extension characteristics of the specimen [1]. Normally old machines use this mechanism such as old fabric tensile strength testing machine.

8.11 Fabric Tests

After the development of the fabric different tests are performed on it to evaluate different parameters. Different strength tests are performed to evaluate the fabric strength.

8.11.1 Strip Test

In this test five different samples are prepared which are expanded in the direction parallel to ends (warps) and five other samples which are parallel to weft yarn. Sample

60 mm × 300 mm is cut from the fabric. After cutting, the sample is frayed down from both sides in the width equally to produce a fabric sample of 50 mm thickness for the final test. The fraying of the sample is done in order to minimize the human error which we have to face in case of improper cutting of the sample. Gauge length is 200 mm and 50 mm / min is the speed of the extension. The mean breaking force and mean extension as a percentage of initial length are reported.

8.11.2 Grab Test

There are three different approaches to produce the fabric samples for tensile strength test. These methods are given below:
- In this approach a fabric sample of 25 mm × 50 mm is prepared as prepared in strip method.
- Cut strip in 1 in (25 mm) and 2 in (50 mm) width which is intended to be used with fabrics which cannot easily be frayed such as heavily milled fabrics.
- Grab method is relatively simpler and quicker. Jaw faces are used in this method which is considerably narrower than the fabric so fray the fabric to width is not required. In this test only the 25 mm sample is tested in the jaws.

8.11.3 Tear Tests

Tear strength is an important parameter which is required during the exposure of the cloths in the severe environmental conditions. It is usually the most common kind of strength failure of fabrics in use. Tear strength is an important parameter regarding the industrial fabrics which are exposed to rough handling in use such as tents. In case of outdoor clothing, overall and casual dresses tearing strength is an important characteristics.

Tearing strength can be defined as the force required to propagate an existing tear in the fabric. Different tear tests are performed in order to measure the tear tests; basic principle of testing is the same, only the geometry of the specimen is different. Rip tear test is the simplest test. A cut is introduced in the centre of a strip of specimen and by the help of jaws of tensile strength tester two tails are pulled apart and the tear strength is evaluated [10].

8.11.4 Elmendorf Tear Tester

Pendulum type ballistic tester is used to tear the fabric sample and energy loss during the tearing is measured (Fig. 8.2). Following formulas are used to determine the energy loss during tearing.

Energy loss = force required to tear × distance travelled

In this case loss in potential energy will be equal to work done. The apparatus used in this test is shown below; at starting position the potential energy of the pendulum is maximum due to its height. The sample is fixed between the clamps of the tester and the tear is started by a slit cut in the fabric sample which is fixed between the tester clamps. The pendulum is then released to determine the tear strength and the specimen is torn as the moving jaw moves away from the fixed one. The potential energy of the pendulum is due to its straight height. As a result of tearing, the energy of pendulum is lost and it does not get the same height from which it was released. The energy lost during the specimen is directly proportional to the difference between the initial height and the final height after energy loss. By this tester tear strength or percentage of the original energy is determined [11].

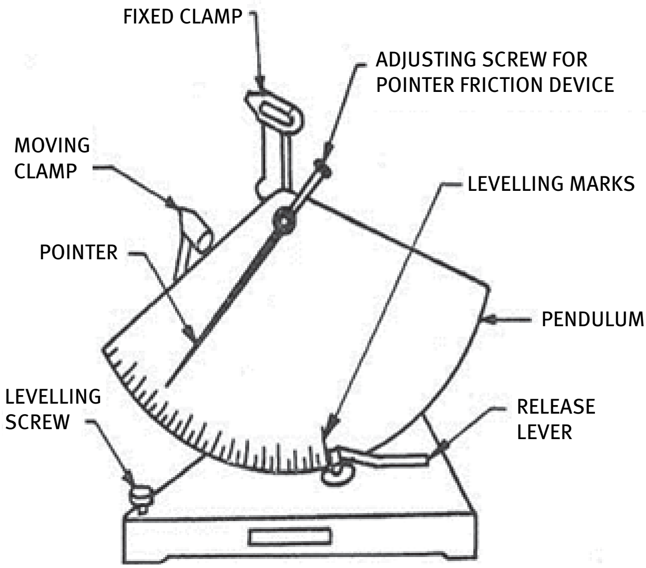

Fig. 8.2: Elmendorf tear strength tester.

8.11.5 Bursting Strength of Fabric

It can be defined as the force required to rupture a woven / knitted fabric by dilating it with a force which is applied perpendicular to the plane of the sample, under slandered conditions.

The working principle of the machine which is used for this test method is Constant Rate of Elongation (CRE). The sample is securely clamped to the machine without any kind of tension on the ball burst attachment. A force is applied against fabric sample by the help of a polished, hardened steel ball until rupture occurs [12].

8.11.6 Weight per Square Yard (GSM)

Mass per unit area (weight) of the fabric sample is determined by using the GSM cutter. In order to determine the weight per unit area of the fabric samples of 113 mm diameter are prepared from different places by the help of GSM cutter. Five random samples are prepared and the weight is determined by the help of weighing balance. Sample weight is determined in grams; it is divided by the constant (0.01) in order to determine the gram per square meter. Gram / square yard can also be determined by this method [13].

8.11.7 Color Fastness to Perspiration

Color fastness can be defined as the resistance of the fabric sample to change of its color properties to the adjacent materials or both on the exposure of sample to any environment that may take place during the processing, testing, storage, etc. [14].

Perspiration is saline fluid which is produced by the sweat glands. In order to test the colorfastness of the fabric sample, two textile specimens are used. Both samples are wetted in the simulated acid perspiration solution. The test samples are wetted under controlled specific mechanical pressure. After wetting the specimens are dried at slowly elevated temperature. After the conditioning process the color change of the specimen is checked and other specimen or fiber materials are checked for color transfer [14].

8.11.8 Abrasion Resistance of Fabrics (Accelerator Method)

Abrasion Resistance: when mechanical action takes places between the two fabric surfaces then distortion of the samples takes place. Resistance against this wearing action is called abrasion resistance.

Unfettered fabric specimen is used for this test, which is driven in a zigzag course by the help of rotor generally in circular orbit in a cylindrical orbit. The specimen is subject to high velocity and rapid impacts. During movement in the cylindrical orbit sample undergoes different mechanical actions such as compression, shock, stretching, etc. Rubbing action of yarn against yarn, surface against abradant and surface against surface produces abrasion in the test sample. Weight loss of the specimen or strength loss of the woven specimen determines its abrasion resistance. Change in other fabric characteristics also used to evaluated the abrasion resistance of the specimen [15].

8.11.9 Water Repellency (Spray Test)

Tendency of any material to resist wetting is called its water repellency. In this test water is sprayed on the stretched fabric sample from 150 ±2 mm height under controlled conditions. A wetted pattern is produced whose size is dependent on the water repellency of the specimen. The wetted sample is compared by the standard spray ratings to evaluate the water repellency of it [7].

Fig. 8.3: Spray tester [16].

8.11.10 Water Resistance / Impact Penetration Test

In this test water is sprayed on stretched fabric sample backed by a weighted blotter under controlled conditions. After the spraying the blotted paper is reweighted in order to determine the water penetration. If the weight difference of the blotted paper is more, then the water repellency of the fabric will be less and vice versa. Diagram of impact penetration is given in Fig. 8.4 [17].

Fig. 8.4: Impact penetration.

8.11.11 Air Permeability

Air permeability of any material can be defined as the air passing at right angle through a known area of the specimen in a unit time under a prescribed air pressure differential between the two surfaces of a specimen.

In order to evaluate the air permeability of the specimen, air passing perpendicularly through the specific area of the fabric in a unit time is adjusted in order to obtain the predetermined air pressure difference between the two surfaces of the samples. This rate of air flow helps determine the air permeability of the fabric sample. This parameter directly influences the comfort parameter of the fabric [18].

8.11.12 Moisture Management Test

This test is performed to determine the dynamic liquid moisture transport behavior if the sample in multiple directions. Moisture management test is performed by placing the samples between the two horizontal sensors. Each horizontal sensor has seven concentric pins. In order to measure the electrical conductivity changes, specific volume of test solution are dropped onto the center of the specimen facing upward. The test solution is free to move in multi-directions. Changes in electrical resistance of sample during the test are determined and recorded [19].

8.11.13 Colour Fastness

It is the resistance of the material to its change in its color properties, to transfer its colorants to the other material.

Crocking is the transfer of the colorants from the surface of the colored fabric or yarn to adjacent area of the same fabric or the other fabric principally by rubbing. Under controlled conditions colored specimen is rubbed with the white test cloth. Color transfer to the white cloth is evaluated by comparison with the standard Gray Scale [20].

8.11.14 Thermal Transmittance of Textile Materials

It can be defined as the time rate of unidirectional heat transfer per unit area, in the steady-state, between parallel planes, per unit difference of temperature of the planes.

For this test, dry fabric sample is used. In this test the overall thermal transmission coefficient of the specimen is determined as a result of the combined action of the convection, conduction and radiation for the dry specimen and other materials within the limits. The unit of the thermal transmittance of the textile materials is W / m2·K. Permeability of air, breathability and thermal conductivity of the fabric directly influence the comfort parameters of the fabric samples [21].

8.11.15 Effect of Repeated Home Laundering on Textiles

Laundering of the textile materials is a process, which is performed to remove the soils, stains, etc. from the fabric by treating with an aqueous detergent solution. Rinsing, extracting and drying processes are performed for laundering. Repeated home laundering effect on the appearance of the specimen is evaluated by this test method [22].

8.11.16 Colour Fastness to Perspiration

This test method is used to evaluate the resistance against the color change of the colored textiles as a result of perspiration. Alkaline and saline solutions which contain histidine are used to treat the composite specimens, drained and placed in a Perspirometer for 30 minutes at room temperature. The colored fabric sample and the undyed cloths are removed from the solutions and dried separately. The staining of the undyed cloths and change in color of the specimens are evaluated by comparing with standard grey scales [1].

8.11.17 Seam Strength

Joining line of the two or more fabrics is called seam. Seam failure of the garment can be defined as, the point at which sewing threads or the fabric is ruptured or causes excessive yarn slippage adjacent to the stitches. Seam strength is an important parameter which should be considered during garment making. There are different possible causes of seam failure:
- Wear out or fail of the sewing thread before the fabric.
- Damaging of the sewing thread during sewing process by needle.
- Slippage of the seam takes place.

In order to evaluate the seam slippage of the fabric, two samples, one with seam and one without seam are prepared from the fabric having the same warp and weft density. The sample without a seam is stretched first by the help of the tensile tester, and the applied load limit is up to a load of 200N and a force elongation curve drawn. By using the same method, the fabric sample having seam is tested. Both curves are now compared. Horizontal separation of the curves will be due to the seam slippage.

References

[1] B. P. Saville, *Physical testing of textiles*. Cambridge, England: WoodHead Publishing Limited, 1999.
[2] BS EN ISO 139:2005, "Textiles-Standard atmosphers for conditioning and testing," 2005.
[3] https://www.uster.com/fileadmin/customer/Knowledge/Textile_Know_How/Yarn_testing/U_LabSystems_Description_of_al_quality.pdf.
[4] http://www.warptek.net/calculations.html.
[5] Standard Test Method D 1425-96, "Standard Test Method for Unevenness of Textile Strands Using Capacitance Testing," 1996.
[6] Desingnation: D 123-01, "Standard Terminology Relating to Textiles," 2002.
[7] ASTM D 2256-97, "Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method," 1997.
[8] Desingnation: D 1907-01, "Standard Test Method for Linear Density of Yarn (Yarn Number) by the Skein Method," 1997.
[9] Desingnation: D 1578-93, "Standard Test Method for Breaking Strength of Yarn in Skein Form," 2000.
[10] Desingnation: D 2256-96, "Standard Test Method for Tearing Strength of Fabrics by the Tongue (Single Rip) Procedure (Constant-Rate-of-Extension Tensile Testing Machine)," 1996.
[11] Desingnation: D 1424-96, "Standard Test Method for Tearing Strength of Fabrics by Fallingyoe-Pendulum Type (Elmendotrf) Apparatus," 1996.
[12] Desingnation: D 6797-02, "Standard Test Method for Bursting Strength of Fabrics Constant-Rate-of-Extension (CRE) Ball Burst Test 1," 2002.
[13] ASTM 3512, "Standard Test Method for Pilling Resistance and Other Related Surface Changes of Textile Fabrics: Random Tumble Pilling Tester," 2014.
[14] AATCC Test Method 15-2002, "Colorfastness to Perspiration," 2002.
[15] AATCC Test Method 93-1999, "Abrasion Resistance of Fabrics: Accelerotor Method," 1999.
[16] http://dir.indiamart.com/ahmedabad/textile-testing-machine.html.
[17] AATCC Test Method 42-2000, "Water Resistance: Impact Penetration Test," 2000.
[18] Desingnation: D 737-96, "Standard Test Method for Air Permeability of Textile Fabrics," vol. 14, pp. 1–5, 1996.
[19] AATCC Test Method 195-2011, "Liquid Moisture Management Properties of Textile Fabrics," 2011.
[20] AATCC Test Method 8-2001, "Colorfastness to Crocking : AATCC Crockmeter Method," 2001.
[21] ASTM D 1518-85, "Standard Test Method for Thermal Transmittance of Textile Materials," 1998.
[22] AATCC Test Method 124-2001, "Appearance of fabric after repeated home laundering," 2001.

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9 Disposal and Recycling of Textiles

9.1 Introduction

In the United Kingdom, approximately 1.9 million metric tons of textiles and footwear were consumed in 2003; 1.2 million metric tons of used clothing and soft furnishings were disposed of as waste; and a further 303,000 metric tons of textiles were reprocessed by the secondary textile industry for reuse or recycling [1]. In its Waste Strategy 2007, the UK government has identified textile waste as the fastest growing domestic waste-stream next to aluminium. An increasing textile waste-stream testifies to UK's failure to push waste higher up the five levels of the waste disposal hierarchy (with prevention at the top, followed by reduction, reuse, recycling, and disposal at the bottom) as more and more cast-off clothing in the country fall to the lowest level of rubbish.

The pressing questions in the West are now perceived to be "how to reduce textile disposal through the encouraging of extended use in the first place", "how to reuse clothing through redesign or simply resale", and "how to increase recycling through disassembling used garments and bringing them back together again in a new form". What values can be called upon to maximize a textile's potential after it has ceased to be worn as clothing? This is a conspicuously difficult problem in the West simply because clothing is so closely associated with fashion. The very term "fashion" implies that clothing is redundant when it is no longer stylish rather than when it is no longer usable [2].

The focus on problems of pollution indirectly carries a concept of sustainable growth, which combines environmental aspects with human needs. According to this viewpoint, in urban areas, environmental problems are considered in combination with quality of life improvements which is influenced by the variations in the institutional arrangement. Studies carried out within this structure usually deal with the means in which various actors play their part to improve environmental issues as well as to effectively improve the strategies of urban livelihood. According to urban solid-waste management, another environmentally concerned view consists of recycling, reuse, and recovery activities, and safe waste disposal (through incineration or in sanitary landfills), the pretended waste hierarchy, as shown in Fig. 9.1. This study uses the last structure for analysis, focusing special consideration on the reuse, recovery, and recycling processes already following in the private sector in many developing countries [3].

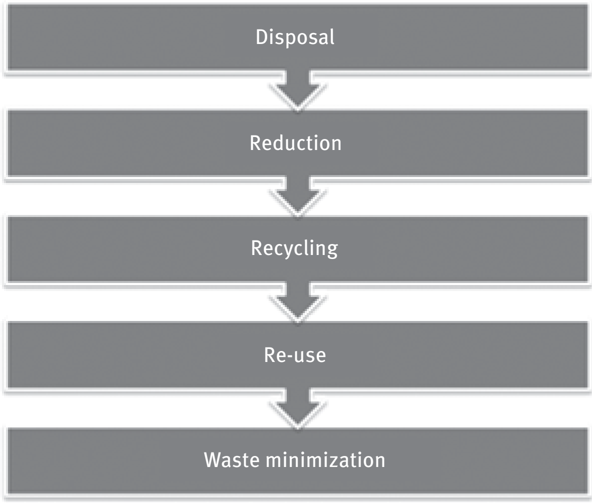

Fig. 9.1: Hierarchy of waste management.

Recycling of waste from textile processes and products have many convincing reasons. They include reduction of the landfills need, resources conservation, and paying the related tipping fee, and facility of low-cost raw materials for making products. Even then, in actual, the textiles recycling rate is not very high. Moreover, the often endorsed reason of inadequate public will to participate in recycling, economics is frequently the reason of acceptance of other waste disposal modes.

For the past few decades, world fiber production has been continuously increasing. The increase in fiber consumption and demand is a result of the overall upgrading in living standards and population growth globally. Generally, fiber applications belong to the following three wide categories: home furnishing, apparel, and industrial. Most fiber products are for short term (e. g. disposables) to medium term (e. g. carpet, apparel, automobile interior) use, lasting up to limited years in their service life. In 2003 alone in the United States of America, about 10 million tons of textile waste was generated accounting for 4.5 wt. % of the total municipal solid waste at 236 million tons / year [4]. According to the source of the same data, landfilled municipal solid waste is 55 %, incinerated in waste-to-energy facilities is 14 %, and 31 % is recovered.

Most fibrous waste consists of synthetic and natural polymeric materials such as polyester, cotton, polypropylene, and nylon. For synthetic polymers, the primary raw material source is petroleum. Even for renewable natural polymers like cotton, the production requires chemicals and energy which are based on non-renewable resources. Although the global petroleum resources may be present at least another hundred years at current consumption rate, practically, petroleum and other natural resources are non-renewable. So for the benefit of future generations, it is our responsibility to conserve such resources.

Waste stream recovery comprises of re-use of a product in its original form, a common practice for clothes, and to recycle them to convert the waste into another product. Typically, recycling techniques are divided into primary, secondary, tertiary, and quaternary methods. Primary methods involve recycling the product into its original form; secondary recycling includes preparation of a new product by melt processing a plastic product that has a lower level of mechanical, physical, and / or chemical properties. Tertiary recycling includes processes such as hydrolysis and pyrolysis, which convert the plastic wastes into basic fuels or chemicals. Quaternary recycling includes burning of fibrous solid waste and consuming the heat produced. All of these four methods are used for fiber recycling [5].

In the USA, landfilling is a major method of solid waste disposal. There are numerous disadvantages related with this practice regarding fibrous waste. First, a tipping fee is required. Second, there is increasing demand to prohibit polymers from landfills due to environmental issues. Third, landfilling of polymers is a waste of material and energy. So, while dealing with fibrous waste, recycling becomes a better choice. But, recycling itself faces many challenges. Other than direct re-use, some processing like chemical, mechanical, or biological is involved in the recycling of waste into products, demanding additional raw materials, use of certain amount of energy, and causing the waste emission into water, air, and soil. Once a recycled product is prepared, it must be marketed. Is there a sound demand? Is it cost-competitive? The next challenge is concerned with the waste availability to be processed. Is there a constant supply at sensible price, especially for the full capacity production?

Therefore, it is concluded that more petroleum could be consumed by recycled operation than it saves, cause more environment harm due to emissions, producing too expensive a product for a quickly saturated market, and have inadequate supply to run the production plant effectively. Such a situation is obviously avoided. While on the other end, one hopes to find an ideal recycling scheme, a practical process will possibly be somewhere in the middle in terms of cost and environmental benefits [6]. Therefore, the following questions must be asked to evaluate the feasibility of a recycling process:

- Do the pollutions and energy savings from the recycling process balance the alternatives such as virgin materials, other recycling methods, Waste-to-Energy?
- Are the products cost-competitive and do they have viable markets?

Due to the involvement of uncertainties, it is not an easy task to answer the above questions. There are some environmentally concerned tools that could be added in the evaluation process, such as cost / benefit analysis, life-cycle analysis, and contingent valuation method. Currently, the overall recovery rate for fibrous waste is somewhat low; it is about 15 % in the USA. Many enterprises have been fairly successful in recycling fiber, while others, including some with US$100 million-plus facilities, are no longer operational due to low profit. Clearly, recycling is not always the desired approach, considering product competitiveness and environmental impact;

but preference is always changing and relative. For example, oil price hike might favor the market, demand for products might change, the plastics recovery and legislation might put a control on other options like landfilling. Even without these external factors that are unpredictable, recycling may still overtake the alternatives and gain acceptance. Here, the key is the availability of better technologies that are more energy efficient, cleaner, and less expensive. Developing better technologies requires resources, talent, and time. It requires a handy public–private–academia co-operation [7].

9.2 Environmental Impacts of Textiles

Once the manufacturing of textile fabric has been done, its potential for the environment damage has no limits. A fabric is of little or no use unless it is changed into something, no matter how well it is finished, and how high its quality or, colors are generally enhanced. The possible products of this additional processing comprise such widespread objects as upholstery, clothing, bedding, drapery, and industrial goods. We normally consider the primary (i. e. fabric production) and secondary (i. e. products manufactured from fabrics) textile industries separately, but the environment makes no such difference; pollution is pollution irrespective of its source. One of the key problems facing the whole industry today is the lack of communication between these two different areas, since mostly, there is a misunderstanding of the secondary sector needs by members of the first one, as well as a misinterpretation of the primary industry capabilities by the secondary one. Nature may benefit considerably by developing a closer connection between the two, decreasing the number of discarded materials, that is, the outcome of these failures to match the abilities, needs, and production.

9.2.1 Impact of Laundering

The fashion requirement replenishment per se does not only cause environmental issues in the debate concerning recycling versus disposal. As a result of our modern technology and lifestyle, dirt and dust, and soiling demands emergency measures in the form of dry cleaning or laundering. Both of these can result in environmental difficulties. Laundering includes exposing the textile item to the combined effects of heat, water, detergent and agitation. Frequently, a fabric softener or optical bleach is added to the mix, and machine drying is often used. Both of these measures give a much more comfortable feel than an untreated wash and outdoor drying on a clothing line. The energy needed for water heating and operating the machinery, together with the chemicals thrown away into the drain, are a harmful source, as also are the operating heat and the polluted drain discharged from the dryer. The thermal load from both drying and washing can also upset the surrounding water or air making it risky for other species existing in the neighborhood of the rejection point unless precautions are taken to minimize the temperature rise occurring on discharge [8].

9.2.2 Impact of Dry Cleaning

Dry cleaning also has ecological concerns. The machinery is needed to be built and operated, while the solvents used for the dirt extraction are often carcinogenic or toxic. Even though active efforts are made to hold and recycle them for later use, there is still a certain loss because of entrapment into fibers or escape in the air via the path through garment transport. Jipp refers to the removal of nontoxic stain using solvents without chlorocarbons, so that the chemicals can be considered as being generous to both environment and the fiber. Yet, all of the reagents used in maintenance, even non harmful ones, have to be prepared, with expensive environment loading [8].

9.2.3 Maintenance Chemicals

The chemical substances used in the maintenance can be tested in more detail to find out their potential for environmental harm. Due to our current attraction for cleanliness, garments are cleaned or washed a number of times than necessary for our proper health or even hygiene. As a result, the quantities of softeners, detergents, dry cleaning solvents, bleaching agents, or other chemicals ejected are enormous. Detergents comprise of organic chemicals and alkalis that act as pollutants. They also frequently contain phosphates, used as builders to improve the efficiency of the washing action, which are recognized to support the algae growth in large bodies of water. These can capture the oxygen present in the water, avoiding other species (both vegetable and animal) from having its access, Consequently, fish die and serious disturbance in the balance of the local aquatic plants occur, carrying about main changes in the locality and ultimately resulting in a dead body of water where fish no longer exist and weeds block the entire surface. Usually, quaternary ammonium compounds as fabric softeners are becoming more and more common. These cause water pollution. These compounds are formed by relatively complex chemical reactions, with the usual environmental concerns and discarding them into the environment causes dangerous changes in the local water supply [9].

9.2.4 Emissions

During textile production, fluids emissions are the most obvious example of dangerous substances released into the environment. Importance of this particular subject can be best judged by the amount of work focused on it. A report confirms that effluents from textile mills that are discharges of waste water from wet processing such as neutralizing, scouring, desizing, mercerizing, carbonizing, fulling, printing, bleaching, and dyeing are definitely toxic and are likely to have instant or long-term damaging effects on the environment. As a result of publication of this report, mills will face stringent control regulations of emission in Canada. Bradbury *et al.* suggest that "smart rinsing" with careful consideration to the location of inlet and outlet water in kier (a type of vat) dyeing can decrease rinsing times and can provide more use of waste effectively. Care in the selection of flow rates, volume, and temperature is also needed. Reife and Freeman summarize the possibilities of prevention from pollution by reducing waste and source reduction in producing pigments or dyes. They comprise substitution of toxic metals by less dangerous ones, process optimization, and the replacement of toxic inorganic pigments comprising nickel, copper, calcium, or lead by other substances, then recommend the pollutants reuse (such as phenols or aniline).

Other research papers lean towards one of two categories, the main one deals with purification before release into rivers or streams and others in which for reuse in processing operations, the water is purified. Frangi comprises both areas from the economic and environmental health perspectives, marking four separate factors (cleanliness quality for textile use, reserves management, industrial treatment techniques, and waste purification) in the context of European Union regulations and the specific requirements of particular processes. Peralta-Zamora *et al.* feel that the wide use of organic dyes is the main cause of environmental problems in textile industry because they are recalcitrant carcinogenic materials. They included three methods in their study – degradation of an anthraquinone dye, enzyme and photocatalytic degradation with titanium or zinc oxide, and ozonation. Ozone use quickly creates complete decolorization, but no mineralization; enzyme treatment results quick decolorization, but is restricted to about 30 % mineralization. Photocatalysis yields complete mineralization and decolorization in about 60 minutes. Alho40 gives seven steps that can improve dyeing color control, thus escaping from premature discarding of goods or unnecessary retreatment. Holme proposes emissions decreasing at source by purification process optimization [10].

Purification before discharge is tried (partial success) by using chemical, mechanical, or biological treatments, alone or in combination. Bischefberger *et al.* describe an overview of the waste treatment possibilities, utilization, and avoidance. Perhaps the simplest techniques for purifying effluents are the works of Bonono and Canziani who simply use a sand filter for filtering, decolorization, and denitrification of a dye effluent and by Ibrahim *et al.* who use a composite prepared from cross-linked wood sawdust for the same purpose. Papic *et al.* use a flocculation / coagulation process to treat waste water of reactive dye with ferric chloride as coagulant. They notice more than 99.5 % color removal and find that there is an optimum pH, in each case, that depends on the coagulant amount added and the dye type, but pH is in the range 2.55–2.70 for the conditions used in their tests. Gonçalves *et al.* remove color from waste by using an up flow anaerobic sludge blanket reactor, observing that some azo dyes are readily decreased (with an average removal efficiency of 80–90 %) but that the technique is ineffectual for disperse dyes. Baughman finds that by sorption on a suitable sludge, during 4 hours, 91 % of the copper ions from 12 direct dyes are removed from solution.

Air emissions should also be mentioned briefly. These can arise from many segments of the industry and are dealt with to some extent, but their removal is often attempted before the discharge in to the air or water takes place. An exhaust clearing system is a system that provides recovery of waste process heat, reducing the need for fuel and hence lowering the production costs. Another anonymous author reviews the needs for a satisfactory air cleaning installation for use in filtration, waste handling, and air conditioning requirements. Freiberg notes that, until recently, it was impossible to operate air cleaning systems efficiently because they suffered either from external high energy consumption, or from high water consumption, or from considerable maintenance needs. He claims that it is now possible to operate modern cleaners efficiently and at lower costs, because they include an option to omit exhaust air cleaning where it is not needed. He then describes three types of successful cleaners.

9.3 Ecologically Beneficial Practices

In the textile context, there are many published references in the environmental protection area, including some general ones dealing with the industry need to attack problems of pollution. Germany forms regulations to eliminate or limit health and environmental hazards for industries of textile and leather processing. Japanese textile firms stress coordination with the environment, mentioning, for example, the possibility (in the West, well known for many years) of recycling used clothing. They also present industrial consumers to the ideas of making environmentally friendly products, reducing water pollution and saving energy [11].

Benisek states that ecologically valuable practices are one of the major focus areas and on a later one with a strong stress on the "green" future of textiles, comprising replacement of dangerous catalysts or other reagents and improved finishing or dyeing conditions. Smith describes the greening of the textile supply chain, noticing that better waste management and cleaner products are essential. Gale *et al.* produce a regular column concerning the environmental issues and include suggestions or reports such as (a) pollution of water should be restricted by water quality, not individual discharges, (b) some new pigments and dyes may change in classification concerning toxicity, and (c) benign chemicals (in a wet processing stage, with special procedures to avoid dimensional changes in fabrics) are being wanted as a substitute for perchloroethylene in dry cleaning. In another general review article of environmental issues, Gale and Bide give a recommendation to minimize the ammonia content in effluent regarding early life stages of fish.

Gale and Bide also mention concerns about tributylin as an antibacterial agent that, even though it is not supposed to be used because of its hazardous nature, has nevertheless been found on certain football jerseys that have now been withdrawn from the market; it is entirely possible that other examples of this kind of irresponsible manufacturing may exist. In the same article, the authors also summarize work dealing with dye decolorization with oxides of zinc or titanium, or with hydrogen peroxide in conjunction with ultraviolet radiation, then discuss the aerobic treatment of dye waste water. In another article, they record the move towards replacing regulatory control of pollution with voluntary responsibility based on incentive, an apparently dangerous precedent in view of the tendency of many manufacturers to ignore environmental concerns totally until forced to take them into account. They also note a revived interest in low-wet-pick up techniques in dyeing (such as the use of foams) to reduce the amount of water removed in drying, thereby decreasing costs. The recycling of water, they feel, is becoming more attractive as disposal costs rise and they mention water-saving techniques such as filtration and the use of membrane, biological or ozonation procedures, as well as a new method to allow recycling of solvents by low-pressure steam [12].

9.4 Textile Recycling

As we consider the case of textile and apparel recycling it becomes apparent that the process impacts many entities and contributes significantly, in a broader sense, to the social responsibility of contemporary culture. By recycling, companies can realize larger profits because they avoid charges associated with dumping in landfills, while at the same time contributing to goodwill associated with environmentalism, employment for marginally employable laborers, donations to charities and disaster relief, and the movement of used clothing to areas of the world where clothing is needed.

As consumers buy new apparels regularly, unused clothes will be continuously discarded as waste further compounding to the problem of discarding the packaging, old apparels and home textile products. Clothes today are different from those of several decades ago, not only in design but also in the texture andcontent of the fiber. After the arrival of synthetic fibers to the market in the 20th century, textile recycling became more complex for two distinct reasons: (i) fiber strength increased making it more difficult to shred or ‘open’ the fibers, and (ii) fiber blends made it more difficult to purify the sorting process. Nonetheless, the recycling industry must cope with everything that the fashion industry has generated.

It is well established that recycling is economically beneficial, yet much of the discarded clothing and textile waste in the USA fails to reach the recycling pipeline. The US textile recycling industry annually diverts approximately 10 pounds *per capita* or 2.5 billion pounds of post-consumer waste from the waste stream. This represents only about 30 % of the total post-consumer annual textile waste. For example, although there are several well-established uses for denim waste, the denim industry still deposits more than 70 million pounds of scrap denim in US landfills annually. Furthermore, analysis of municipal solid waste indicates that unrecovered textile waste contributes to approximately 4.5 % of the US landfills [12].

According to the US Environmental Protection Agency (2003), this equates to 4 million tons of textiles going to the landfills each year. While this may not seem like a large amount, it is when one considers that nearly 100 % of the postconsumer waste is recyclable.

Textile recycling material can be classified as either pre-consumer or postconsumer waste; textile recycling removes this waste from the waste stream and recycles it back into the market (both industrial and end-consumer). *Pre-consumer waste* consists of by-product materials from the textile, fiber, and cotton industries that are re-manufactured for the automotive, aeronautic, home building, furniture, mattress, coarse yarn, home furnishings, paper, apparel, and other industries. *Post-consumer* waste is defined as any type of garment or household article made from manufactured textiles that the owner no longer needs and decides to discard. These articles are discarded either because they are worn out, damaged, outgrown, or have gone out of fashion. These are sometimes given to charities or passed on to friends and family, but ultimately deposited into the trash and end up in the municipal landfills [12].

9.4.1 Conversion to New Products

Two categories of conversion to new products will be used here. Shoddy (from knits) and mungo (from woven garments) are terms for the breakdown of fabric to fiber through cutting, shredding, carding, and other mechanical processes. The fiber is then re-engineered into value-added products. These value-added products include stuffing, automotive components, carpet underlays, building materials such as insulation and roofing felt, and low-end blankets. The majority of this category consists of unusable garments – garments that are stained, torn, or otherwise unusable. One informant, however, was sorting for 100 % cotton sweaters because he was selling shredded cotton fiber to mix with sand for use in ‘Punch-n-Kick’ bags, made by one of the world’s largest sporting manufacture companies. A vast number of products are made from reprocessed fiber because much of this fiber is re-spun into new yarns or manufactured into woven, knitted, or non-woven fabrications, including garment linings, household items, furniture upholstery, insulation materials, automobile sound absorption materials, automobile carpeting, and toys. New yarn producers include, for example, those in Prato, Italy who reduce cashmere sweaters to fiber, spin new yarns and produce cashmere blankets for the luxury market [13].

This process represents an economic and environmental saving of valuable fiber that would otherwise be lost to the landfill. Ironically, the most unusable and damaged of post-consumer textiles often have the highest level of specifications forced upon them by the end-use industries (e. g. building, auto, aeronautics, and defence). Another informant reports that used fibers are being utilized in the production of US currency.

9.4.2 Wiping and Polishing Cloths

Clothing that has seen the end of its useful life as such may be turned into wiping or polishing cloths for industrial use. T-shirts are a primary source for this category because the cotton fiber makes an absorbent rag and polishing cloth. Bags of rags can be purchased at retail stores such as in Wal-Mart's automotive department. One informant said that he sells wiper rags that he has reclaimed from the sorting process to a washing machine manufacturer for use-testing of the machines. But because of its excellent wicking and oleophilic properties, some synthetic fiber waste (particularly olefin) is cut into wipers to serve in industries where oil spills need to be cleaned up or wiped. An informant sells oleophilic wipers to the oil refining industry. Another informant reported that oil spills are being cleaned up with large 'snakes' made with a combination of oleophilic and hydrophilic used fibers [14].

9.4.3 Landfill and Incineration for Energy

This category has two components. For some reclaimed fiber no viable value added market has been established, so the used goods must be sent to the landfill. Rag-sorters work hard to avoid this for both environmental and economic reasons because there is a charge per pound for goods that must be taken to the landfill. In the USA, testing has just begun for the process of incinerating reclaimed fiber for energy production. Although emission tests of incinerated used fibers are above satisfactory, the process of feeding the boiler systems in many North American power plants is not feasible (Weide, 2004). The incineration of used textiles as an alternative fuel source is more commonly done in Europe than in the USA [14].

9.5 Methods of Recycling

The simplest method of recycling scrap is by granulating but this produces a product which in most cases is impossible to reuse directly into the primary manufacturing process of fiber or film. It is noisy and dirty with much dust; the scrap cannot be filtered to remove impurities. The standard method of extrusion is by melting, filtering and pelletizing. Scrap cannot be fed directly into the extruder and needs to be put through a granulator first. This gives problems because the often light fluffy material is difficult to feed, output is low, different materials sometimes require different screws and dies, material is degraded due to high shear and heat, the process is dusty and noisy and energy usage is high. Semi- or fully automatic aggregators, also termed disc mills, can be used but they have to be fed with granulated material and the final pellet is not uniform in size; it has a lower bulk density, contains fines and has not been filtered. Consequently, it is difficult to feed material back into prime production process [15].

Fig. 9.2: Erema recycling plant concept.

In 1982, three Austrian engineers designed and patented a system which utilized the advantages of all the above and overcame the disadvantages to produce THE EREMA PROCESS which is an in-line extrusion process that is dust free, has a low noise level, occupies a small space, has low energy usage and generates low maintenance costs. It can produce clean, full bulk density, filtered pellets with little or no degradation directly from PP, PE, PET film, fiber or scrap bottles at a high output and low operating cost. This high performance, which is independent of the shape and bulk density of material to be processed, results from the EREMA concept of using a shredder drum attached to an extruder (see Fig. 9.2). The shredder drum is continuously fed, with the rate being automatically controlled by the load on the shredder motor which drives high speed rotary knives that not only cut the material but also heat it to just below its melting point. This hot material is then fed into an extruder which melts the material and passes it through a filter to remove contaminants, and then into water cooled die head to produce pellets which are dried, stored or bagged. Since the material is fed hot into a short extruder, the screw is designed with deep flight which produces little or no shear. This provides a minimum heat history which results in little or no change in the melt index. The quality of material is such that it can be used in higher value-added products. In the conventional extrusion, material is heated primarily by shear from the extrusion screw, which causes considerable degradation of polymer, and a high energy usage [15].

9.5.1 Easily Recyclable Textile Products

It is observed that the growth of eco-friendly products is facing a great challenge in the products design that are easily recyclable. Wastage should be evaded both in the products' disposing stage and during the production process. Furthermore, at the end of the product's life cycle, material substance should be recycled for reuse. This is also applicable for the manufacture of textile fabrics and, particularly, technical textiles.

In general, it is the designer who chooses the product structure and the top materials to use. He / she will definitely consider budget and functionality. Functionality is attained by combining or selecting the correct materials. Those appropriate for manufacturing technical textiles may be both textile fibers and non-textile materials such as films, foams, and plastics. Depending on the process of manufacturing used, textile materials may partly or even totally fail to show their textile characteristics. The selected materials have an effect on the manufacturing processes as well as on the processes of product disposing and recycling at the end of its life. In fact, they pre-find all these processes [16].

Products comprising of only one material in a single system (non-composite) are pure and easy to re-use. Generally, with these, it is not essential to separate the structure of the product before processing. Single material systems are hence considered for easily recyclable product designs. Still, such systems, might get their limitations in cases where

– large amounts of special materials are used,
– used material is expensive,
– product functionality needs the use of several material layers (single material composites).

Blends of different textile kinds prepared from the same polymer (e. g. PP fiber and PP coating or film) are single-material composite systems, which are also easily recyclable. If the required product characteristics are not attainable by using one material then multi-material composite systems are essential. Systems comprising separable composites need to be disassembled before recycling, which can be achieved by machine or manually. This is what occurs, for instance, to non-textile functional components used within garments, and with technical textiles. Processes such as laminating, gluing, or stitching may give composites that cannot be separated. With respect to complete re-use, the selected materials should drive well for processing together.

One example of how composite systems of multi-material may be used is when "reclaimed fibers" are mixed together. Compacting as in the plastic materials recycling is another example. Nevertheless, the agglomerate attained by this way faces problems with respect to marketing. In a composite system of multi-material, the materials are used as raw material or as fuel if they do not get together and if they cannot be separated from one another.

All these methods yield textile products that are planned to be easily recyclable and categorized by the ability to be disassembled and the ability to be disposed of or re-used. Both these conditions also concern economical processes.

Possible path selection can be grasped in the examples below. They characterize the spirit of the current state of the art with respect to the technical textiles re-use.

Designs having concentration on products that are easily recyclable are helpful in both, that is, with the recycling procedures at the end of the product life cycle and with the waste recycling created during the production process. These examples necessitate the association of those dynamic in both product chains, that is, horizontal as well as vertical. They also mean the starting up of new initiatives to control waste and end-of-life textiles and their processing [16].

9.5.2 Single Polymer Design

From synthetic polymers, many products such as polyester, polyamide, or polypropylene can be recycled by thermo-chemical method so as to maintain their polymeric characteristics or the polymer is re-formed in some way. With this good way for the raw material recycling, the polymers of all components confined within the composite in question must be the similar. One famous example of a single polymer system recycling is the manufacturing of polyester fibers from polyester soft drinks bottles. It generates an open material cycle. Excluding spun-bonded nonwovens, single-polymer systems are mostly needle-punched geo-nonwovens. Here, functionality of product is exclusively achieved by the parametric variation like punching intensity and fiber diameter [17].

9.6 Easily Separable Components

Many products for daily use such as upholstered furniture and the interior lining of vehicles comprise both textile and non-textile constituents. Mostly, such multimaterial composite systems can be easily separated and therefore can be re-used economically. Components, yet, should be existed in a well-sorted order.

Usually, upholstered furniture comprises wood, plastic materials, PU foam, textiles, and metal. Separately, each of such materials is re-usable. By the process of injection molding, the constituents of plastic materials are cut and compressed and again prepared into plastic products. This process is also useful with flock fiber coated materials, whose specific design does not agree to reclaim as they do not offer any fibers sufficiently long for re-use. On the other hand, one may get benefit of these flocked materials largely or wholly comprising of synthetic fibers.

Wood is a worldwide material in making furniture. The waste wood recycling may get importance by the help of breaking up the fibers and, then compressing them into boards. Though wood can be maintainable, it is a beneficial material which permits a wide range of applications so it must be used with care. Except the conventional wooden elements type, wood particles boards attached by synthetic resins are also used. They show a range of densities and work as extensive features of the furniture frame. Burning is the most economical method for their disposal. The PU foam used

as the core of upholstery furniture can be torn into foam particles. These particles may be used in a number of ways:
- filling cushions or bags for upholstery purposes or for packing;
- manufacturing another core by means of foaming with primary polyurethane;
- blending the foam particles with recycled and thermo-sensitive bonding fibers, manufacturing mats and, in a following process, creating acoustically effective stamped parts (thermal fixation) for use in the automotive industry.

Upholstered furniture comprises of non-woven textile with a number of bonding degrees. They are also set up as textile cover material. Non-wovens used in areas well below the surface are made from reclaimed fibers. They are of low interest with respect to recycling. Yet, the voluminous cover non-wovens used directly between the foam core and the surface cover material are definitely of concern. Usually, these are prepared from white primary fibers. Made into reclaimed fibers, such materials can well be re-used to make non-wovens. The main requirement to allow recycling is an economical method to disassemble and positive separation of the components [17].

9.7 Solid Waste Management

Waste minimization actually offers the best possibilities for environmental aspects of sustainable development, by reducing resource use and avoiding production of waste. Yet, this leads to a focus on changes in production systems. Reduction of the waste flow through source separation, reuse, and recycling (material and energy recovery) systems was introduced by governments in developed countries such as the Netherlands. These systems were established on households separating materials voluntarily with little or no compensation, and subsidies by governments to reuse and recycle materials (from domestic waste). Indirectly, this system was based on households' agreement with the goals of waste reduction, and their active co-operation. This situation is in stark difference to that in developing countries. Waste reduction is, to our knowledge, not normally applied as a matter of public policy.

Recovery, trade, and recycling activities cover the next step in the waste management hierarchy, and involve a larger and variable chain of actors. Maximizing waste diversion toward recovery and recycling is the primary environmental goal at this point in the waste management hierarchy. In developing countries, however, the environmental perspective at this point is not well developed among the local authorities and citizens. Rather, these activities take place mainly in a private market context. Therefore, evaluating their economic value is currently the only method we can use to expect to what extent recovery of waste materials is likely to increase when the incentives are changed.

An important difference in evaluating the value of such waste flows is that made between unmixed sources of waste, which retain a higher economic value, and mixed waste, which presents a much less attractive source of raw materials for trade and recycling enterprises. Therefore, some authors suggest that more emphasis should be put on increasing source separation in order to maximize clean, homogenous waste materials, whereas mixed wastes should be phased out of an integrated system. This might enhance the size of both organic as well as inorganic waste flows and their economic value, if other factors remain constant. It also has implications, for which actors remain involved [18].

References

[1] A. Kumar, *Environmental Engineering*. New Delhi: New Age International (P) Limited, Publishers, 2009, pp. 63–68.
[2] M. Aller and I. Liu, *Environmental Engineer's Handbook*, no. 0. New Jersey: CRC Press, 2000, pp. 103–113.
[3] N. Nemerow, *Environmental Engineering*. New Jersey: John Wiley & Sons, 2009, pp. 133–145.
[4] R. Weiner, *Environmental Engineering*. Burlington: Butterworth-Heinemann, 2003, pp. 233–245.
[5] A. Maczulak, *Environmental Engineering – Designing a Sustainable Future*. New York: Facts on File, 2010, pp. 95–103.
[6] L. Pawlowski, *Environmental Engineering*. Leiden: CRC Press, 2010, pp. 478–497.
[7] I. Baud, *Soild Waste Management and Recycling*. New York: Kluwer Academic Publishers, 2004, pp. 134–156.
[8] L. Norris, *Recycling Indian Clothing*. Bloomington: Indiana University Press, 2010, pp. 221–234.
[9] F. Ackerman, *Why Do We Recycle*. Washington: Island Press, 1997, pp. 189–200.
[10] K. Slater, "Textiles and the environment," in *Handbook of Technical Textiles*, London: Woodhead Publishing Limited, 2009, pp. 530–540.
[11] R. Horrocks, *Recycling Textile and Plastic Waste*. Cambridge: Woodhead Publishing Limited, 1996, pp. 167–180.
[12] Y. Wang, *Recycling in textiles*. Cambridge: Woodhead Publishing Limited, 2006, pp. 73–80.
[13] R. Gaur, *Basic Environmental Engineering*. New Delhi: New Age International (P) Limited, Publishers, 2008, pp. 33–45.
[14] B. Addis, *Building With Reclaimed Components and Materials*. London: James and James Science Publishers, 2006, pp. 13–25.
[15] R. Porter, *Energy Savings by Wastes Recycling*. London: Elsevier Applied Science Publishers, 2005, pp. 237–245.
[16] K. Slater, *Environmental impact of textiles*. Cambridge: Woodhead Publishing Limited, 2003, pp. 123–167.
[17] J. Peirce, *Environmental Pollution and Control*. London: Woodhead Publishing Limited, 1997, pp. 305–323.
[18] L. Wang, *Environmental Bioengineering*. London: Humana Press, 2010, pp. 687–712.

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10 Quality Control and Quality Assurance

10.1 Introduction

Everyone identifies the term “quality” and expects the services and products he is buying to be of the best quality. The concept and vocabulary of quality is indefinable. For different people the concept of the quality is different. A small number of persons can explain quality in quantifiable standings that can be operationalized. When we asked quality distinguish their product / service to their competitor. The teller will answer “service of their bank,” A medical doctor will answer “quality health care,” the inn eatery worker will reply “consumer loyalty” and the producer will essentially reply “quality item with acceptable cost.” Today’s firms, particularly those having a place with the international trade area, are mindful that to stay focused and dedicate to fulfill the requirements of clients and customers’ needs. The usage of value administration frameworks and Quality Management system.

Harvard professor David Garvin, in his book *Managing Quality* summarized five principal approaches to defining quality: transcendent, product based, user based, manufacturing based, and value based. Let us discuss each one of them in the following sections.

10.1.1 Transcendental View of Quality (Innate excellence)

Persons who hold transcendental view would say, “I can’t explain it, but I distinguish when I use it.” Most of Advertising companies are endorsing and promoting their items in this way. “Where shopping is a delight” (grocery store), and “It implies lovely eyes” (beauty care products) are some examples.

10.1.2 Product-based View

Product based quality dimensions are distinctive. Quality is seen as measureable and quantifiable attributes or traits. For instance durability (life of product) or reliability of an item can be measured (e. g. mean time between failure, fit and complete), and the specialist can outline to that benchmark. Quality is resolved dispassionately. In spite of the fact that this methodology has numerous advantages, it has confinements too. Where quality depends on individual taste or inclination, the benchmark for estimation may be misdirecting.

10.1.3 User-based View

User-based definitions are based on the idea that quality is an individual matter, and products that best satisfy their preferences (i. e. perceived quality) are those with the highest quality. This is a rational approach but leads to two problems. First, consumer preferences vary widely, and it is difficult to aggregate these preferences into products with wide appeal. This leads to the choice between a niche strategy and a market aggregation approach which tries to identify those product attributes that meet the needs of the largest number of consumers.

10.1.4 Manufacturing-based View

Manufacturing-based definitions are concerned primarily with engineering and manufacturing practices and use the universal definition of "conformance to requirements." Requirements, or specifications are established design, and any deviation implies a reduction in quality. The concept applies to services as well as products. Excellence in quality is not necessarily in the eye of the beholder but rather in the standards set by the organization.

This approach has serious weaknesses. The consumer's perception of quality is equated with conformance and hence is internally focused. Emphasis on reliability in design and manufacturing tends to address cost reduction as the objective, and cost reduction is perceived in a limited way – invest in design and manufacturing improvement until these incremental costs equal the costs of non-quality such as rework or scrap.

10.1.5 Value-based View

Value-based quality is defined in terms of costs and prices as well as a number of other attributes. Thus, the consumer's purchase decision is based on quality (however it is defined) at the acceptable price. Mainly, industries are categorized into two types: product manufacturing and service providing. Textile industry comes under the product manufacturing category today; a lot of resources are being utilized yearly throughout the world to develop and introduce a system to produce reliable quality products and services (**Fig. 10.1**). International competitions among producers are diverting manufacturers from quantity production to highly reliable and quality products and services. Now, the big question is "what makes the quality?" When the same technology is adopted at different textile mills, do they get the same quality all the time? Why is there a difference in the quality of the products of both the mills? Even after spending billions in buying the latest machinery and the best raw material and hiring the best skilled workers, manufacturing companies don't achieve the best quality. The correct answer to these questions is the difference in work quality of both the mills. The highly motivated human resource of

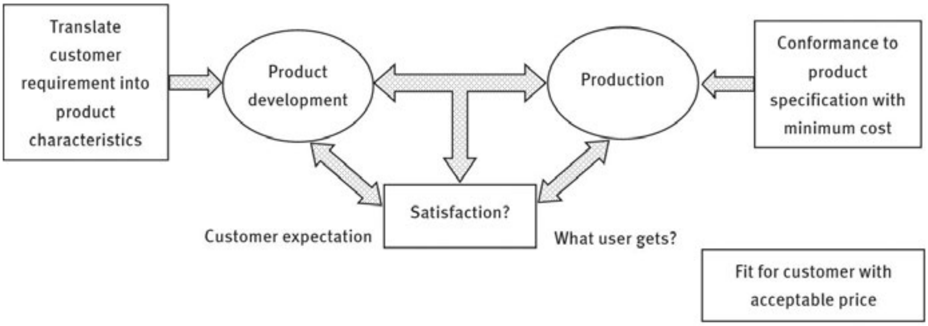

Fig. 10.1: Value-based view.

the company is more important to get the best quality. To drive the workers to achieve the quality should be emphasized more than anything else. When the management succeeds in involving the people at work, the quality can be achieved even with old machines; of course, the productivity may be less. Do they adopt any different settings or speeds? No, it is the same machinery and the same setting, but when the work is done devotedly, there is no room for mistakes. Only the best quality products are manufactured. According to the Gurus of Total Quality Management, quality is a firm's strongest weapon that can take an organization higher and higher even among competitors. In simple words, quality means customer wants to be completely satisfied. Failure to sustain a sufficient and suitable quality standard can be unsuccessful and a challenging thing for that firm, but maintaining an adequate standard of quality also costs effort. Right from the first investigation to discover what the potential client for latest manufacturing item truly needs, and keep up it continually through the procedures of outline, detail, controlled manufacturing, and sale.

Being the oldest among industries, the textile and garment industry has embraced development in a number of statutory, legal, and regulatory requirements; development of new management techniques; and development of norms for industrial relations and so on. In spite of the industry being the oldest and has undergone various ups and downs, even today it is not in a position to stabilize itself and be a role model for other industries. The problems faced by the industry and the employees are getting increased though getting solved. Advancement of technology, automations, computer-aided techniques, etc. has helped the industry in getting high productivity and quality, but the same is not getting sustained. Customers are able to clearly precise the quality they require, and in the fashion world all the earlier so-called mistakes or poor quality are getting accepted with a different name "highly fashionable". The people do not prefer to work in textile or garment industry due to various reasons, and the managements are not trying to retain the people interested in working in the industry. The administration and top management are accusing staff and specialists and the workers are blaming administration. The administrations demands the laborers to give more productivity yet are over-burdening them with persistent working and most of time organization are not respecting them as an important part of their industry. All new and innovative installing is an attempt to accomplish quality and efficiency and paying tremendous pay rates to the top persons in the association, however are not tending to the fundamental necessities of clean and quality organization, enhancing the nature of work, creating amicability among the staff and specialists, and bringing a sentiment unity among all. The general population with force are diverted by the fleeting arrangements as it looks lucrative and are not attempting any endeavors to make the base more grounded.

There are basically two quality systems – "Quality control" and "Quality Assurance." Manager of a firm and also the culture of the firm used to decide that which one they have to adopt. Quality control is a reactive approach and at the other end Quality assurance is a proactive approach. There is an integration of Product Development to Production. Everybody can check the quality after production, but if it is so, then what was your role in making quality product.

With that approach an organization assures you that all the goods have been checked and all the defective ones are removed. But it will not take the organization higher in quality manufacturing. For that, they have to control and take care of the production by improving the process. When the system has been improved to avoid and stop defects, it is a Quality Assurance approach; but if we just remove defects after production then it will be a Quality Control approach.

10.2 Quality Control

QC (Quality Control) is certainly the most established framework and its roots sink into the introductory measurable statistically examination completed by Shewart (1939). These standards were further created in Japan after the end of the Second World War. Feigenbaum created TQC, characterizing it as (1961) ''a network of the management / control and procedure that is required to produce and deliver a product with a specific quality standard'' (1961). Quality control is responsive style. At whatever point, product, services or administrations don't fulfill needs set by clients or by the association itself, a non-congruity is created, with its related poor quality costs. Quality control is seen as the agent of Quality Assurance or total quality control. It is a set of activities that ensure quality in products. It focuses on identifying defects in the actual products produced. Quality control aims to identify and correct the defects in the finished product. The goal of quality control is to identify the defects after a product is developed and before it's released. However, in the current times (i. e., by 1907) the Western Electric Company was the first to utilize essential quality control standards in configuration, assembling, and establishment. In 1916, C. N. Frazee of Telephone Laboratories effectively connected measurable ways to deal with examination related issues, and in 1917, G. S. Radford begat the expression "quality control" (4Chae, et al., 200. 6o, Dhillon 2007) In 1924, Walter A. Shewhart of Western Electric Company created quality control graphs. All the more particularly, he composed a notice on May 16, 1924, that contained a representation of current quality control diagram. After seven years, in 1931, he wrote a book entitled Economic Control of Quality of Manufactured Product (7).

So technology is in the continuous process of development to produce the best-quality products There are a large number of factors on which quality fitness of textile industry is based such as – Durability aesthetics performance, coloring feeling reliability, visual and Transcendental quality of the yarn, apparel, gray fabrics garment, finishing, designing and clothing. Quality needs to be defined in terms of a particular framework of cost. Quality control offices assume an essential part in delivering great quality material items in a material authoritative / plant / manufacturing plant. QC department have to perform multiple jobs / functions such as shown in Fig. 10.2. The historical backdrop of quality control in the clothing material business may be followed back to Zhou Dynasty (11^{th} to 8^{th} centuries B. C) in China. For example, one empire declaration expressed that "Cottons and silks of which the quality and size are not up to the norms are not permitted to be sold in market [9, 10]. In the present day connection, the first use of factual quality control ideas had all the earmarks of being in yarn fabricating items amid the late 1940s and 1950s [2]. In 1981, one of the biggest organizations of textile of eighties, Milliken and Company, propelled its aggregate quality administration endeavors particularly coordinated to make a promise to consumer loyalty plaguing all organization. By 1989, it was in ahead of its competition regarding all measures / dimension of consumer loyalty in the USA and won the Malcolm Baldridge National Quality Award. According to Dhillon], there were around 30,000 textile related organizations in the United States, and a number of them have actualized quality administration activities for Reducing cost of quality and enhancing both items and consumer loyalty [9].

Allocating control obligations is concerned with characterizing and allotting control obligations regarding things, for example, checking, control estimations, and weighing of waste all through the production line / factory. Assigning control responsibilities is concerned with defining and assigning control. Developing and maintaining the textile testing material laboratory is concerned with setting up and maintaining the testing laboratory with appropriate maintained equipment and qualified manpower.

Confirming brief rescue of restorative measures are based on planning of remedial activities in such a way, to the point that set aside least time between the identification of defective product / operation and their restorative. Evaluating the plan viability is worried with routinely checking on the plan and rolling out improvements as considered suitable. Setting up a satisfactory reporting / documenting framework is concerned with planning structures for purposes, for example, recording estimations, calculation of estimation changes with time, and Quality control chart.

For example, in the textile industry, quality control is practiced right from the initial stage of sourcing raw materials to the stage of the final finished garment and clothing. For textile and apparel industry product quality is calculated in terms of quality and standard of fibers, yarns, fabric construction, color fastness, surface designs and the final finished garment products. However, quality expectations for export are related to the type of customer segments and the retail outlets.

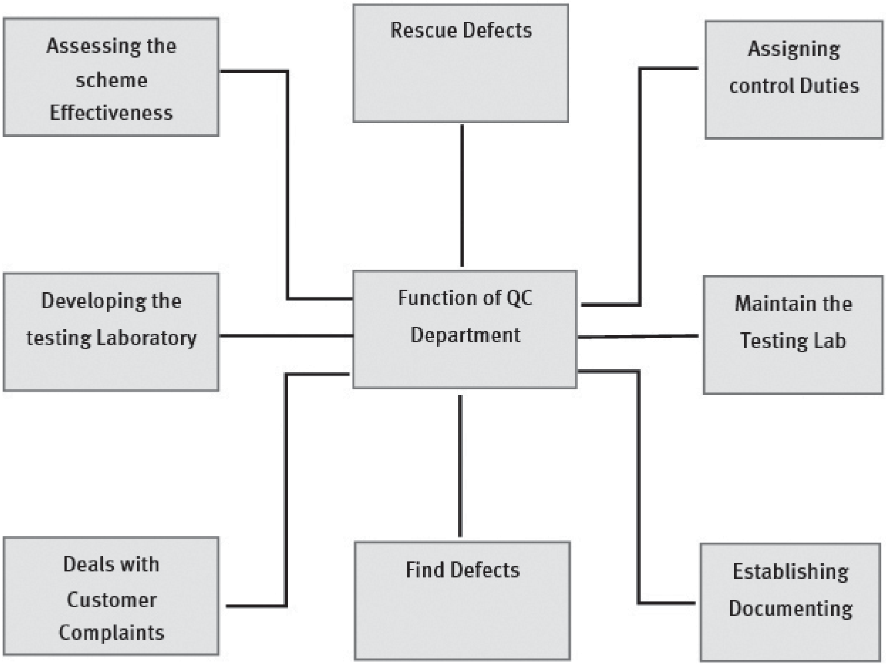

Fig. 10.2: Quality control department functions. (Adapted from Dhillon, B. S. (2007). Applied reliability and quality: fundamentals, methods).

There are two types of quality control:

- On-line quality control system
- Off-line quality control system

10.2.1 On-line Quality Control System

This type of quality control work without any discontinuing the running of procedure. With the purpose of continuing of all procedure is performs robotically and check the error in materials, furthermore sometime automatically takes remedial action. On-line quality control contains the raw material quality control and the process control and all other precautions related to manufacturing and when the product is in line for assembling it also needs to be taken care of all the processes to make a fine finished product.

10.2.2 Off-line Quality Control System

Off-line quality control system performs in the laboratory and other production areas by stopping the production process and it includes fabric inspection and laboratory and other tests. Corrective steps are taken according to the test results. Both the physical tests and chemical tests are carried out to ensure that the product is fine.

All the statistical, scientific, and all other checking methods are used to verify the quality of the produced goods. A famous saying is “quality is made in the BOD (Board of Directors) or top management’s offices, not only at employees’ end”. There is a need to justify all the working efforts of the employees rather than using their efforts only for the output. Make employees an important part of the management, that is, lower level or front line staff should be well aware of all the procedures in the organization and there should be a proper and fast communication between the top and lower level management. If this is done, production staff will become more dedicated and they will show their loyalty towards the organization by manufacturing the best products. They will give you more than you expect from them. By all means, no matter how much you work or struggle for quality control system it will never satisfy you for a long time. Every time you have to repeat all the steps of on-line and off-line quality control system, but if you adopt the total quality management (TQM) approach regarding quality assurance you will get the benefit permanently.

10.3 Quality Assurance

Quality assurance is a proactive approach. It is an uplifting process for the fine production and the quality of production. In quality assurance we do not have any need to do the inspection of the workers because our main focus is on the process and not on the people. For example, Dr Deming (1986) emphasized, “Productivity increases with improvement of quality control and quality assurance. Low quality means high cost and loss of competitive position. Companies having better quality management practice possessed better business results, including higher market share growth and higher profitability” [6]. Quality Assurance procedures incorporate Jidoka, 5S, Kiazen, Quality circle, Poka-Yoke and Lean Six Sigma. Poka-yoke, as presented by Shingo [12], is executing basic minimal effort that detect abnormal situations before they happen or once they happen stop the production to prevent further defects. The Lean Six Sigma approach, as Taghizadegan (13) clarifies, is an data driven way to deal with discover critical issues for producing a lots of defects and uses the define, measure, analyses, improve, maintain and control (DMAIC) method to resolve the problems.

Quality costs are depend on top management decision in quest for development in quality culture, consumer loyalty, expanded market share and benefit improvement. The primary reason for quality cost contemplations is to warn against approaching unbearable monetary losses to the organizations. Juran, in his famous quality control handbook used the analogy of “Gold in the Mine” which means that losses due to avoidable mistakes / defects equal the cost of quality [3].

The cost of quality is generally classified into four categories [13].

1. External Failure Cost
2. Internal Failure Cost
3. Inspection (Appraisal) Cost
4. Prevention Cost

1. External Failure Cost: Cost associated with defects found after the customer receives the product or service. For example, Processing customer complaints, customer returns, warranty claims, product recalls.

2. Internal Failure Cost: Cost associated with defects found before the customer receives the product or service. For example, Scrap, rework, re-inspection, re-testing, material review, material downgrades.

3. Inspection (Appraisal) Cost: Cost incurred to determine the degree of conformance to quality requirements (measuring, evaluating, or auditing). For example, Inspection, testing, process or service audits, calibration of measuring and test equipment.

4. Prevention Cost: Cost incurred to prevent (keep failure and appraisal cost to a minimum) poor quality. For example, New product review, quality planning, supplier surveys, process reviews, quality improvement teams, education, and training.

The first three categories of cost of quality deal with cost of not creating a quality product or service. (Quality Control) while preventive cost deals with quality assurance. For industry as a whole, the costs of quality have been estimated at between 4 and 15 % of turnover and in some cases as high as 30 %. It has been shown by Crosby and others that good quality management practices can lead to a substantial reduction in these costs and in the long term enhance competitiveness and market share.

Proponents of TQM and quality assurance approach like Deming, Crosby, and Juran advocated that implementation of quality management philosophy helps the companies to achieve higher levels of quality and performance. For example, Deming (1986) asserts, “Productivity increases with improvement of quality. Low quality means high cost and loss of competitive position” [6]. We need to take necessary actions and corrective measures to make that process fit for the required quality of a thing or product. It starts from the purchasing of raw material or required material for production. At the beginning, the purchaser of a firm needs to be very careful. Instead of saving the cost, firm should consider quality first. If the manager can manage the cost without sacrificing quality then it is an advantage and the most important thing to that firm to attain efficiency of resources. Later, when moving towards production, ensure that the required standards are achieved by investigating and taking actions on substandard performance.

Quality Assurance (QA) is a way of preventing mistakes or defects in manufactured products and avoiding problems when delivering solutions or services to customers. ISO 9000 defines quality assurance as “a part of quality management focused on providing confidence that quality requirements will be fulfilled”. It thus differs subtly from quality control.

Quality Assurance refers to administrative and procedural activities implemented in a quality system so that the requirements and goals for a product, service, or activity will be fulfilled. It is the systematic measurement, comparison with a standard, monitoring of processes, and an associated feedback loop that confers error prevention. This can be appeared differently in relation to quality assurance (QA), which is centered on procedure. Two standards ideologies incorporated into Quality Assurance are: "Fit for intended use", the product ought to be suitable for the proposed use; and "Right first time", all the potential defects ought to be eliminated. QA includes management of the quality of raw materials, assemblies, products and components, services related to production, and management, production and inspection processes.

Successful quality management requires an orientation toward quality that permeates the entire organization. Many physical and emotional, as well as physical and mechanical, factors contribute to the production for high-quality consumer goods. Top executive must establish quality management as an ongoing part of the organization and provide the equipment, supplies, personnel, and budget to support its existence. Continual improvement in quality comes only with the commitment of managers and employees to consistency and high-quality performance in all aspects of the business.

Firms that have adopted this total concept of quality often use the terms QA and Total Quality Management (TQM). The acronym QA is used throughout this discussion. Under a QA system, evaluation of conformance to standards involves performance of all the company's divisions as well as the products and services that are produced by the firm. It is recognized that production of quality products depends on the quality consciousness of the entire organization, including merchandising, marketing, finance, operations, and production (Abend. *2002*).

Employee involvement throughout the firm is normally a part of a QA strategy. Employees receive training on how to identify causes of product defects and how to resolve the problem so defects do not continue to occur. Driving individuals to executing particular arrangements for continuous improvement for example, Balancing assembly line, Six Sigma, lean production, TQM, Kanban, and so on make a textile organization versatile and persistently moving forward. Most important tool is how individuals can sense and comprehend a future situation, and respond to it in a way that moves the organization forward. The technicians assume a significant part in quality administration / Quality assurance of any Type of textile unit. Establishment of textile unit is not a special case. The technicians are the involved in the design development and foundation of the procedure, planning and coordinating with the all stakeholders and making them get it, executing the procedure, checking and rectifying them and accomplishing the desired results as far as quality and efficiency. In this manner, the credit for achievement or disappointment of a procedure goes to the lower management in the organization. A few studies have demonstrated that less than 20 % of rejected pieces of clothing have imperfections subject to the sewing administrator, which is normally the center of more restricted quality control program.

Quality control (QC), a more limited form of quality management is the process of assuring that products are made according to specifications. QC activate tend to focus directly on the production process rather than on quality as a responsibility of the entire firm.

10.3.1 Quality Assurance Policies and Records

A necessary tool for understanding and communicating a quality program is through the development of a written quality policy and a quality manual. The quality policy establishes priorities relative to materials, processes, training, product development, and customer service. The quality manual provides documentation of the quality policy and all related standards and procedures.

Fig. 10.3 shows the range of function that may be performed by quality assurance department. The quality policy and manual are essential for all types of organizations.

Although it is often the responsibility of a QA team to develop and implement quality policy, all employees must have total understanding of and commitment to the quality program and its objectives. Writing a quality policy requires a great deal of thought and synthesis of ideas from a wide range of employees, all of which contribute to the development of an effective system. The quality policy provides a means of communication both within and outside the firm. All of the firm's employees and business partners should be made aware of priorities and implications, should be supplied with the copy of the policy, and should have the policy explained and discussed. The quality policy is also essential when negotiating with the firm's suppliers and customers. A summary statement of the quality policy may be made available to the customers so they understand the firm's priorities better.

One of the essential parts of a quality policy is a list of the objectives of the QA program. Quality objectives should be stated in measurable terms, and "what and when" the aspects of issues should be specified. Clearly stated objectives help to unify the quality effort, motivate action, and promote harmony among the managers and workers because they all understand that they are working toward the same goals. The objectives also provide a basis for the evaluation of the firm's quality program.

Clearly communicated objectives contribute to the development of quality consciousness among suppliers, customers, managers, contractors, supervisors, and sewing operators. Quality consciousness helps in developing better workmanship.

Deducting irregularities early, preventing 'seconds' and rejects, and minimizing repairs also eliminate the need for 100 % inspection. Objectives should reflect a determination to minimize the production of non-conforming goods. This can be accomplished through identifying and correcting primary sources of quality variation so that inspecting and testing can be avoided.

Fig. 10.3: Quality Assurance department functions.

Another essential part of the quality policy is a statement of quality standards. As defined in ISO 9001:2008, "standards are a set of characteristics or procedures that provide a basis for resource and production decisions. Standards reflect the overall quality and performance levels the firm seeks to achieve. They constitute the basis of product development decisions and specifications. The statement of quality standards should cover minimum standards and tolerances for materials, production processes, and finished goods. This includes definitions of critical, major, and minor defects, and forms for recording the results of the various tests and inspections. A statement of a firm's quality standards often constitutes a major portion of the quality manual. In addition to a written quality policy and standards, documentation of quality procedures, inspection systems, and quality analysis reporting is required. Without documentation, it is difficult to trace quality problems to the source. A QA system reduces the focus on finished goods inspection and increases the focus on quality commitment within the entire organization.

10.3.2 Need of Quality Assurance in Textile Industry

The evolution and checking of the product like design, styles, colors, rightness and correctness of components, of the product is the foundation of quality assurance system. The products are inspected in a organized method to find potential defects and errors. If defects are recognized then the product is said to have failed the quality assurance, but after examination, if yarn, fabric, finish, color, and fineness meet the requirement then it is considered to be good. Ultimately it improves quality and standard of the product. Now let us discuss some functions of quality management and assurance department.

10.3.2.1 Improves efficiency and productivity of products

The primary purpose of quality assurance is to have feedback on the product like whether color, texture, finishing, designing and style of the fabric is good and according to requirement or not. Also make sure that there is continuous development and efficiency and effectiveness in production.

10.3.2.2 Stimulate research effort

Research efforts are usually made to learn more about relationship between inventories and expected outcome. This is very important to improve product. Other than improvement there are new products that can be made with innovative research, like any changing needs of designing, color schemes etc. This can only possible by research in assurance.

10.3.2.3 Identify and Address the various problems

The different issues in item are all distinguished and enhanced and different methodology and result are finished. This is another essential motivation behind quality certification. The issue may be in working of the item or structure of the item itself. As though there is imperfection in completing system, all is controlled effectively by confirmation. Also all different imperfections in making of fabric and so forth can be distinguished and tended to through consistent quality affirmation check.

10.3.2.4 Understanding the requirement of a customer

Understanding the customer prerequisite exactly and requirements is the important duty of quality assurance department. Unless we are clear in this we can't give the desired characteristics of products and administrations. The customer gives his prerequisite and desires through purchase order however should express his genuine concerns just when there is an issue. The buy requests don't contain the worries of a customer. It is in this way the experts ought to take interest. It is constantly better that a specialist visits the customer to comprehend the specialized prerequisites, instead of relying upon the depictions given by business persons.

10.4 Quality Assurance and H. R. Development

An autonomous division should be established to develop Quality Based Human Resources department at organization level. This department is directly reporting to the top management. The HR department of textile is responsible to bring quality cultural in the textile organization.

10.4.1 Other Responsibilities of QA Department

Conduct the trainer training and also training of workers are also duties of QA department. QAQ department also develop the Laborites for testing. It is also duty of QA department to calibrate the equipment's which are present in laborites. It is also duty of QA department to implementation of different quality standards in the organization. Identify quality problems and potential problems and investigate root cause, as well as initiate effective corrective actions in a resourceful and timely manner. Communicate effectively with others on QA activities and decisions. QA department also make sure that there is continuous development and efficiency and effectiveness in product, processes and production.

References

[1] J. Abend. modern definition of quality and quality assurance and meeting retail requirements. Bobbin, 43(10) 2002.
[2] P. B. Crosby, *Quality is Free*, New York, McGraw-Hill, 1979.
[3] J. JURAN, *Quality Control Handbook*, London, McGraw-Hill, 1974.
[4] Y. M. Chae, H. S. Kim, K. C. Tark, H. J. Park, and S. H. Ho, Analysis of healthcare quality indicator using data mining and decision support system. *Expert Systems with Applications*, 24(2), 2003, 167–172.
[5] T. G. Clapp, A. B. Godfrey, D. Greeson, R. H. Jonson, C. Rich, and C. Seastrunk, Weaving a Quality Industry *Quality Initiatives Re-shape the Textile Industry*, 2001, 21(10):52–8.
[6] Deming, W. Edwards. "Out of the crisis, Massachusetts Institute of Technology." Center for advanced engineering study, Cambridge, MA 510 (1986). Available Online at http://www.qualitydigest.com/oct01/html/textile.html.
[7] E. Chaplin, "Customer Driven Healthcare Comprehensive Quality Function Deployment," *Proceedings of the 56th Annual Quality Congress*, 2002, 767–781.
[8] B. S. Dhillon, *Applied Reliability and Quality: Fundamentals, Methods and Procedures*. Springer Science & Business Media, 2007.
[9] P. Siekman, The Big Myth About U. S. Manufacturing, *Fortune Magazine*, 2000. vol. 142, no. 7
[10] S. Shingo, *Zero Quality Control: Source Inspection and the Poka-Yoke System*. Cambridge, MA: Productivity Press, 1985.
[11] S. Taghizadegan, *Essentials of Lean Six Sigma*. Oxford, UK: Elsevier Inc., 2006.
[12] J. E. Ross, and S. Perry, *Total Quality Management: Text, Cases, and Readings*. CRC Press, 1999.
[13] United Nations Industrial Development Organization. *Quality Control in the Textile Industry*. New York: United Nations, 1972.

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11 Computer Applications in Textiles

11.1 Introduction

As scientific research progresses, man is equipped with more sophisticated technology. Textiles has a major contribution in bringing the naked human being to the current state of civilization. The textile research is not only focused on clothing, but also plays a vital role in other areas of research such as electrical and electronic engineering, geo-engineering, structural engineering and many more. The invention of computers has accelerated this research. MATLAB, Minitab, Microsoft Office, etc. are frequently used for statistical analysis, mathematical modelling, algorithm and report writing. Abaqus and COMSOL are used for finite element analysis, mechanical and electrical properties analysis and product development. Current era is the age of computerization. Each industry is getting benefit from automation and ease provided by computer science. Textile sector, a major industry in terms of revenue generation for a country, has badly neglected all this ease. Information Technology is the industry which has its impact on each and every other field of life, bringing a lot of innovations. Converting the old, time consuming, manual approaches to very efficient and novel methods.

Textile industry is mainly dealing with the design and production of yarn, cloth and garments. A general textile production process flow is shown in Fig. 11.1. With the advent of human civilization, textile products (yarn and fabric) have made their significance. Use of cloths is as old as mankind on earth. One of the main reasons for its early emergence is the adverse need of human's body to protect it from dynamic and severe climatic conditions. As civilization evolved, they felt the need to cover themselves to look civilized. Later on, social status and religious requirements also added up. [1]

Textile industry is a well-established industry all over the world, being developed to modern standards in 21st century with the invention of automated machines. Textiles make a global export of $ 400 billion, with 8 % of the world trade in manufacturing goods, in 2002, which shows the importance of this sector for the development of a country. Pakistan being major shareholder in global textile exports also demands to be equipped with the modernized techniques. Like other industries, textile sector is also adding in the huge dataset generation, which needs to be analysed for the useful knowledge. It will ultimately lead to the betterment and progress of this sector with improved and enhanced technology. Inclusion of data mining techniques will result in the increase in profitability and production of the textile industry.

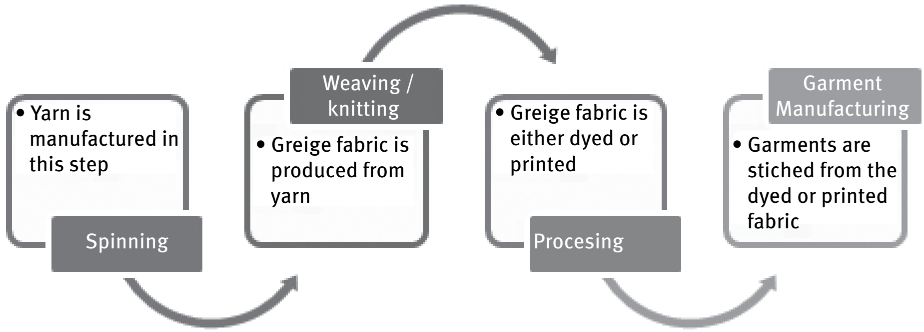

Fig. 11.1: Textile production process.

In this chapter we discuss the aspects and benifits of computer applications and information technology in the textile sector.

11.2 Industrial Applications

In textile industry, induction of computer and its applications has revolutionized the manufacturing techniques. Product development has become more innovative than ever. In addition to this, the time consumption in generating an idea and then its conversion to the final end product has also been reduced to a great extent. There are several other advantages that the manufacturing units are getting. Some are explained in the following sections.

11.3 Enterprise Resource Planning

Enterprise resouse planning (ERP) is a computer application specifically designed for the industrial and manufacturing units. It consists of several modules that operate in collaboration with each other and look after the overall industry. For each department ERP contains a dedicated module. ERP is the automation of a manufacturing industry from raw material to end product and all the procedure that are directly or indirectly involved in this process. Fig. 11.2 shows the major modules of an ERP software. ERP modules are explained as follow:

11.3.1 CAD

Computer-aided design (CAD) is frequently used for design and drafting, generating reports, three dimensional modelling, finite element analysis and as an input source

Fig. 11.2: Enterprise Resource Planning.

for computer-aided manufacturing (CAM). The process of CAD includes three phases: designing the geometric model, analysis of generated model against various physical quantities, optimization and visualization of computer graphics based on results and analysis. The advantage of CAD in textile industry is to design and analyse the product in a shorter span of time with almost zero cost of production. It helps in all the areas of textile process including selection of product design, visual merchandising and product development. The CAD has revolutionized the fabric-designing from graph paper and stencil to mouse and stylus. The CAD systems are developed in computer languages such as FORTRAN, Java and Python. The CAD system usually comes with either integrated module or stand-alone products. The examples of integrated module of CAD systems are computer-aided engineering (CAE), finite element methods (FEM), computer-aided manufacturing (CAM) including computer numerical control (CNC), photo realistic rendering and product data management (PDM). The stand-alone CAD systems include Auto-CAD, solid works, Real CAD pro, Rhino 3D and Iron CAD. The afore-mentioned stand-alone CAD systems are especially developed for mechanical engineering. There are other CAD systems such as TexGen, CoulorTEx, Modaris, TukaCAD, Lectra, ReachCAD, Opti-tex PDS, Audaces apparel, GT Resource which are especially designed for Textile industry [3]. Few of Textile CAD systems are tabulated in Tab. 11.1.

Tab. 11.1: Few textile based CAD system.

Sr. #	CAD system	Functions
1	TexGen	Specialized for two dimensional and three dimensional weave design [4, 5]
2	Modaris	Pattern design system [6]
3	JacqCAD	Jacquard designing, editing, creating loom control files, and punching of textile designs [7]
4	Textronic	Dobby design, Jacquard design, Carpet design, 3D Design, draft and peg plan [8]
5	DigiFab	Digital textile printing [9]
6	AVA Weave	Checks, stripes and dobby or jacquard designs, including yarn simulations and multiple colour ways [8]
7	Scotweave	Technical textiles for industrial, commercial and geo-textiles; dobby or jacquard designs. yarn design and cross section view, 3D weave, 3D visualization tool to see ScotWeave fabrics realistically draped over images of garments and other real-life objects [10]
8	Arahne	Dobby and jacquard designs, colour management, fabric price calculations, yarn consumption calculations, 3D fabric simulation [11]
9	WiseTex	Weave geometry [12]
10	DesignScope Victor	Dobby and jacquard designs, three dimensional weave designs [13]
11	Textile Vision	Colour management, two dimensional weave designs, yarn consumption calculations, frame plan [14]
12	Optitex	Virtual Prototyping; 2D CAD / CAM patterning and fashion designing [15]

11.3.2 CAM

Computer-aided manufacturing (CAM) is the use of computer software to control machine tools and related machinery in the manufacturing of work pieces. The CAD technology together with CAM technology is called CAD / CAM. The main objective of CAM is to improve productivity and efficiency. The application of CAM ensures that results are consistent with high accuracy in large production scale. The CAM is frequently used to store textile designs for repeat printing orders. Various types of CAM machines have been developed for the textile industry. These machines are based on computer-numerical control (CNC) programming. In textile processing, these machines are used to pick up the fabric from store, spread and cut the fabrics, label and transport the cut fabric pieces for assembly and to move the cut fabric pieces around the factory on an overhead conveyer. These machines are also used for automatic buttonholing and automatic embroidery [17, 18].

The CAM is frequently used in dobby and jacquard designs and also to control the servo motor for positive control of let-off and take-up mechanisms. In dobby and Jacquard designs, CAM is used to prepare and archive weave designs for both electronically and card controlled dobbies [16]. With the help of CAD / CAM, achieving good quality with high accuracy in shorter span of time has become possible. It eases the modification of pattern changing.

iTextile project [2] is a good example of CAD / CAM designing in textile industry, which is based on intelligent searching system for the development of smart woven fabric database as shown in Fig. 11.3.

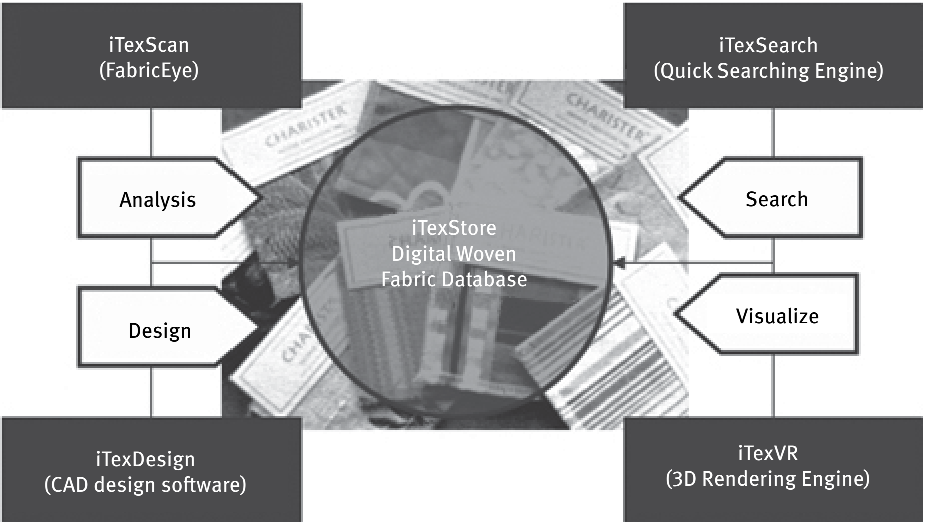

Fig. 11.3: iTextile Project.

The establishment of professional woven fabric database platform, including detailed specification from commercial CAD software for weave diagram design (loom draft, denting plan and draft plan).

The digital scanning engine using FabricEye for this database, can collect and analyse the dual-side images of fabrics for the purpose of create image-indexing for each weave pattern style.

The quick searching engine for this database, it is a specific searching engine for fabric materials, which can do searching in three kinds of ways: image, colour and key word.

The rendering engine for 3D fabric simulation is used to demonstrate and visualize the fabric design based on 3D rendering and simulation technology, and also provides the on-line interactive design and evaluate the fabric design directly.

All these intelligent searching systems are connected to CAM, which help to convert fabric database into a product.

11.3.3 Other Areas ERP Helping

ERP is not only helping in the design (CAD) and manufacturing (CAM) process of the product but it also looks after the overall process of the textile industry. ERP deals with almost all the departments starting from procurement, production, distribution, accounting, human resource, corporate performance and governance, customer services and sales. It also covers the areas of business intelligence, enterprise assets management, e-commerce and other business related strategies.

11.3.4 Machine Monitoring

The machine monitoring module of the ERP for textile provides the layout of the factory, indicating machines with interactive graphics, colours, symbols and icons depicting their status. This module aids the managers to monitor the machine efficiency and its current status (i. e. running or stopped), stoppages and their causes, order running on a specific machine, etc. Along with this, it also monitors the performance of the worker operating the machine and performance of the machine regarding to a particular type of product. All these features help in the instant identification of any problem, which leads to the maximum throughput and increase the overall productivity.

11.3.5 Report Generation

As ERP stores all the data in the central database, it allows the user to generate customized reports. These reports give detailed insight of the key performance indicators. This module is very much customizable according to the user requirements and needs. The key factor which users want to highlight, becomes easily accessible. Different types of reports help managers to get the intuition of the business progress, and to take better decisions. These reports also help to develop and reframe the production / marketing strategies according to the latest changing trends. It is also possible to improve customer relationship by undermining the customer purchase and sale patterns.

11.3.6 Production Plan

This module of ERP is somewhat like a plan board, with extensive graphical interface. It integrates with the machine monitoring module and central database, giving the view of the production plans. Its basic or fundamental functionality is to ensure the availability of the raw material required for the production along with the use of production capacity at its maximum. It can calculate the time needed for an order to complete and then scheduling the respective order on the relevant and suitable (highly efficient for that particular order) machine. Production orders can be added automatically or manually by the manager from the marketing module. Along with this it also allows the user to define time and quantity of raw material required for that particular order. With the use of this module, scheduling of the production order can be done on the level of individual steps involved in manufacturing. Reliable delivery dates can be communicated with customers as it schedules the target dates for each production step.

11.3.7 Inventory Management

Inventory management deals with the management of the inventory of all the resources and the raw materials like fibre, yarn, grey fabric, apparel, chemicals and dyes and finished products. It also deals with the work-in-progress (WIP) and production stocks. Monitoring and providing the technical details about the product like piece length, width, weight and defects of the fabric. Product and materials are reported as the product travels through the production process. Average price, shelf life, expiration date, quality grade, original batch, etc. are also maintained by this module.

11.3.8 Maintenance

This module keeps track and gives maintenance overview of the machines. It schedules the machine maintenance according to the production plan. It keeps track and monitors maintenance activities; lubrication of machine parts, replacement of faulty parts, etc. are required on which machines. It also maintains spare parts and accessories store rooms. Generation of reports on the maintenance activities, machine breakdowns and use of spare parts are also possible.

11.3.9 Machine Setting

The electronic and mechanical settings of the machine are recorded in this module. Settings are stored with respect to the product barcode, which can be retrieved and reapplied. This gives the flexibility to reapply the most promising settings for a specific product to obtain the optimal result and efficiency.

11.3.10 Quality Management

The major task of quality management module is assurance of required product quality as demanded by the customer. This module monitors and controls the quality of incoming goods. This module also helps to control product quality during production processes and their laboratory testing. Textile product is marked against its quality and the product history is maintained in this module. It also ensures the quality by generating timely reports and also provides tracking in case of customer claims and provides graphical display of test results.

11.4 Image Analysis

Digital Image analysis is the most common technique, used to identify the weave and colour repeat of fabric. A high resolution image of woven fabric, converted to digital data, is used for recognition of weave pattern. This digital data is transmitted and reflected, to identify the warp and weft overlaps, number of yarns, size and colour by comparing them with grey scale values.

11.5 Data Mining

Data Mining is an inter-disciplinary subject of information technology, driving its roots from data management, artificial intelligence, machine learning and statistics. It is also known as the knowledge discovery from data (KDD), which is a process of extracting useful information from data. Fig. 11.4 depicts the Data mining steps to extract useful information.

With time, technology has progressed at a very fast rate. This erupting progress, computerization of society along with cheaper, powerful storage devices makes it possible for the data to be stored in huge amounts of terabytes and petabytes. Each and every field of life starting from business society, banking, finance, science, engineering and medical sciences are getting benefit from data mining. All of these fields are the sources for generating massive data sets, which includes sales transactions, stock trading records, product descriptions, sales promotions, company profiles and performance, and customer feedback. But the problem is humans are incapable of analysing this amount of data. This problem gave rise to the birth of an emerging and most rapidly growing field, "Data Mining". Data mining not only analyses the data but also presents the useful knowledge, extracted from the data in some presentable and interpretable format that can be easily comprehended by humans. Different techniques involving artificial intelligence and machine learning algorithms have been developed, that enable the computers to automatically explore the dataset, analyse and extract the information useful to our problem solution.

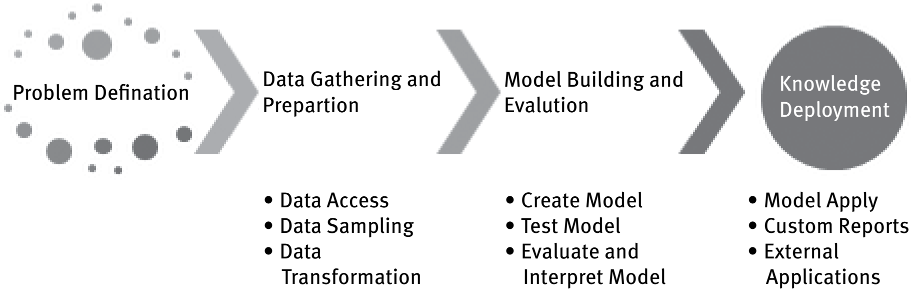

Fig. 11.4: Data mining Steps.

References

[1] S. Adanur, *Handbook of weaving*. 2000: CRC press, Boca Raton, London, New York, Washington D. C. pp. 384–392.

[2] T. G. Lab, *iTextile*. 2009 [cited 2015 July 12]; Available from: http://www4.comp.polyu.edu.hk/~gama/new/index.htm.

[3] A. Dwivedi, and A. Dwivedi, Role of computer and automation in design and manufacturing for mechanical and textile industries: CAD / CAM. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 2013. 3(3): 2278–3075.

[4] M. Sherburn, and A. Long, *TexGen open source project*. 2010.

[5] H. Lin, L. P. Brown, and A. C. Long. *Modelling and simulating textile structures using TexGen*. in *Advanced Materials Research*. 2011. Trans Tech Publ.

[6] M. Stott, *Pattern cutting for clothing using CAD: How to use Lectra Modaris pattern cutting software*. 2012: Elsevier, Cambridge, UK.

[7] Kallivretaki, A., Vassiliadis, S., & Provatidis, C., Computational Modelling of Textile Structures: Electronics and Computing in Textiles. 2012: Politeknik NSC Surabaya EBook collection, Surabaya, Indonesia. pp. 32–44. Retrieved from http://ebook.nscpolteksby.ac.id/.

[8] P. Sinha, *Computer technology and woven textile design / or CAD*. 2012.

[9] S. Gordon, *Color management and RIP software for digital textile printing.* Kimberly Clark Corporation, iulie, 2001: p. 1.

[10] D. Brown, M. Morgan, and R. McIlhagger, *A system for the automatic generation of solid models of woven structures.* Composites Part A: Applied Science and Manufacturing, 2003. 34(6): 511–515.

[11] A. Weave, *ArahWeave® 7.1 User's manual.*

[12] I. Verpoest, and S. V. Lomov, *Virtual textile composites software WiseTex: Integration with micro-mechanical, permeability and structural analysis.* Composites Science and Technology, 2005. 65(15–16): 2563–2574.

[13] T. Company, D. *Jacquard*. [cited 2015 July 02]; Available from: http://www.designscopecompany.com/.

[14] shinersoft. *Textile vision*. [cited 2015 July 02]; Available from: http://www.shinersoft.net/textile-design.

[15] K. Anderson, *Patternmaking: past to present.* Retrieved February, 2005. **12:** 2006.

[16] S. Adanur, *Handbook of weaving*. 2000: CRC press, Boca Raton, London, New York, Washington D.C. pp. 135–137.

[17] P. B. Jhala, *Application of CAD / CAM in the Textile Industry*, in *CAD / CAM Robotics and Factories of the Future '90*, S. Dwivedi, A. Verma, and J. Sneckenberger, Editors. 1991, Springer Berlin Heidelberg. pp. 317–322.

[18] S. Jayaraman, *Computer-Aided Design and Manufacturing: A Textile-Apparel Perspective*, in *Mechatronic Design in Textile Engineering*, M. Acar, Editor. 1995, Springer Netherlands, pp. 239–269.

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