CHAPTER 2

LITERATURE REVIEW

2.1 Technical textiles-overview

Although 'technical' textiles have attracted considerable attention, the use of fibres, yarns and fabrics for applications other than clothing and furnishing is not a new phenomenon. Technical textile is comprised of textile materials and products manufactured primarily for their technical and performance properties rather than their aesthetic or decorative characteristics. It is not exclusively linked to the emergence of modern artificial fibres and textiles. Natural fibres such as cotton, flax, jute and sisal have been used for centuries in applications ranging from tents and tarpaulins to ropes, sailcloth and sacking. What is relatively new is a growing recognition of the economic and strategic potential of such textiles to the fibre and fabric manufacturing and processing industries of industrial and industrializing countries alike. In some of the most developed markets, technical products already account for as much as 50% of all textile manufacturing activity and output [1].

The important applications of technical textiles are in automobiles, geotechnical engineering, filtration, packaging, protection, sports, healthcare and medical textiles. Medical textiles are used in the field of medical, clinical, health and hygiene care primarily for their technical performance and functional properties. The medical textiles cover a huge range of applications such as aprons, adhesive tapes, bandages, beddings, castings, chitin, diapers, dressings, eye pads, gauzes, hosiery protective clothing, sutures, surgical clothing, surgical covers, sports applications, swabs, sanitary products, uniforms of hospital personals etc.

Healthcare and hygiene products in the medical sector covers a vast range of items including products used in the operating theatre or on the hospital ward. It ranges from wipes and sanitary wear through to surgical gowns, masks, respirators, uniforms etc. Medical garments are apparel designed for people with medical problems and/or medical personnel for the functions within protection and treatment domains. The Medical garments can be classified on the basis of their specified functions viz. protective, treatment, caring etc.

Recently number of apparel products, are developed especially for elderly and the disabled based on particular medical problems, restorative care functions and appropriate solutions for healthcare purposes. Examples are personal protective equipment (PPE), hip protectors (HP), pressure garments (PG), compression stockings (CS), wet dressings, vital signs monitoring garments, motion aware clothing, wearable sensors and smart diapers and so on. The development of these products is a challenge for the healthcare and clothing industries [2].

Surgical gowns were introduced primarily as a protective barrier to reduce surgical-site infection and protect the patient from the surgical team. They achieve this by controlling skin flakes and bacteria shed by the user and by preventing the direct transmission of microbes. It must also demonstrate good wearing comfort whilst keeping the surgeon and team comfortable, particularly in longer operations. Surgical isolation gowns serve a critical role in infection control by protecting healthcare workers, visitors, and patients from the transfer of microorganisms and body fluids. These gowns can be made from woven or nowoven fabric, disposable or reusable, light or medium weight, single or multi-layer, fluid resistant etc. The decision of whether to use a reusable or disposable garment system is a selection process based on various factors including sustainability, barrier effectiveness, cost and comfort. Environmental sustainability is increasingly being used in the decision-making process [3].

Recently number of advanced technical textiles products has been developed according to the application fields and availability of new high functional fibre. These mainly include products for resources and environmental issues, automobiles, civil engineering, protective uses, information technologies, electronics textiles and medical uses. The largest use of textiles is for hygiene applications such as wipes, babies' diapers (nappies) and adult sanitary and incontinence products. The smaller but higher value market for medical and surgical products include surgical gowns and drapes, sterilization packs, dressings, sutures and orthopaedic pads. At the highest value relatively tiny volumes of extremely sophisticated textiles for uses such as artificial ligaments, veins and arteries, skin replacement, hollow fibres for dialysis machines and so on [4]. Techtextil, a leading international trade exhibition for technical textiles, has been organized biennially since the late 1980s by Messe Frankfurt in Germany. Technical textiles are used basically on account of their specific physical and functional properties and mostly by other user industries. Depending on the product characteristics, functional requirements and end-user applications the highly diversified range of technical textile products have been currently grouped into 12 categories based on the application:

- Agrotech (Agriculture, horticulture and forestry)
- Buildtech (building and construction)
- Clothtech (technical components of shoes and clothing)
- Geotech (geotextiles, civil engineering)
- Hometech (components of furniture, household textiles and floor coverings)
- Indutech (filtration, cleaning and other industrial usage)
- Meditech (hygiene and medical)
- Mobiltech (automobiles, shipping, railways and aerospace)
- Oekotech (environmental protection)
- Packtech (packaging)
- Protech (personal and property protection)
- Sporttech (sport and leisure)

Technical textiles have an upward trend globally due to improving economic conditions. Technological advancements, cost-effectiveness, durability, user-friendliness and eco-friendliness of technical textiles have led to the upsurge of its demand. Indutech, Mobiltech, Packtech, Buildtech and Hometech together represent 2/3rd of current global market in value (Fig. 2.1). The demand for technical textiles is expected to grow from $ 165 Bn up to $ 220 Bn by 2025, at a CAGR of 4%. The current Indian technical textiles market is $ 19 Bn, growing at a CAGR of 12% (Table 2.1). It contributes to about 0.7% to India's GDP and accounts for 13% of India's total textile and apparel market.

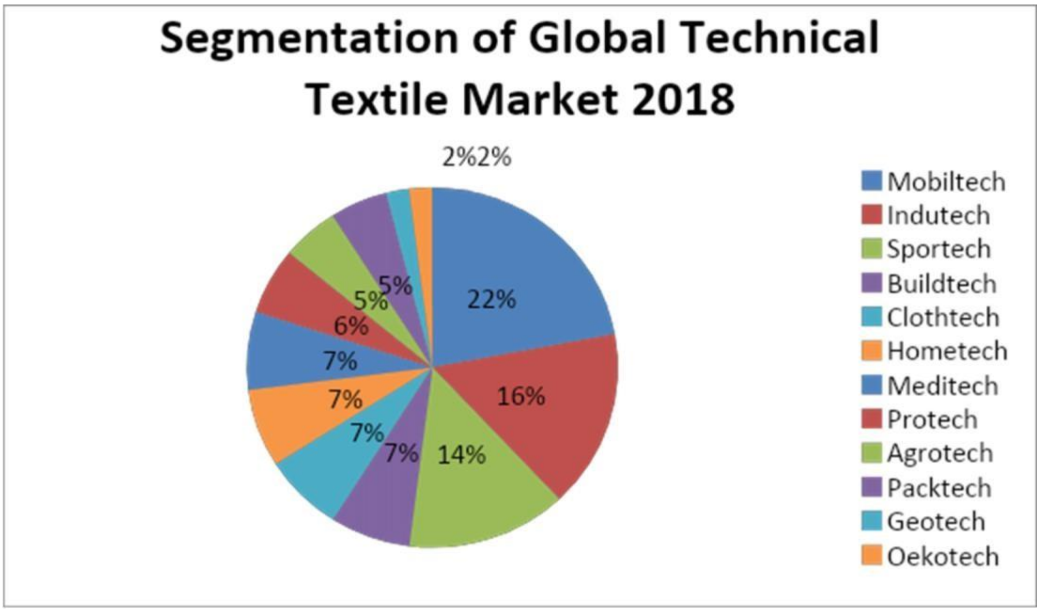

Fig. 2.1 Share of various segments in global technical textiles market (2018)

Table 2.1 Indian technical textiles market size (Rs. Crore)

Sr. No.	Segment	Market size 2015-16	Market size 2017-18
1	Packtech	38,733	48,318
2	Indutech	9,929	13,127
3	Hometech	9,274	12,145
4	Mobiltech	9,173	11,433
5	Clothtech	6,591	8,133
6	Sporttech	5,877	7,111
7	Meditech	4,281	5,142
8	Buildtech	3,577	4,587
9	Protech	2,722	3,139
10	Agrotech	1,191	1,614
11	Geotech	991	1,275
12	Oekotech	160	193
	Total	**92,499**	**1,16,217**

Technical textiles industry has immense potential due to changing economic scenario in developing countries. India has great potential to make an impact in the coming decade due to highly skilled and scientific/technical manpower and abundant availability of raw materials. Indian market shows a growth of 20% from $ 16.6 Bn in 2017-18 to $ 28.7 Bn by 2020-21. Fig **2.2** shows share of various sectors of Indian technical textiles market (2017-18) [5].

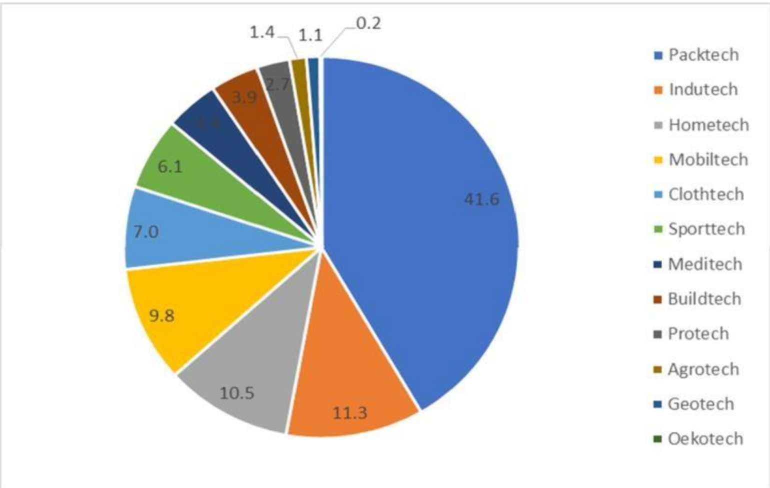

Fig. 2.2 Share of various sectors of Indian technical textiles market (2017-18)

2.2 Functional Characteristics of fibres for technical textiles

Japan is a forerunner in high function fibre development. The main direction in the high function fibre development is to utilize biomimetics i.e. to copy high order structure fibres like cotton wool and silk. Efforts have been focused on enriching human life by pursuing high function fibre materials day by day. Such fibre is a special class of fibres with specific functions being applied not only to clothing but also in industrial applications [6].

Mainly there are four-character classes of high functional fibres:

- Mechanical characteristics
- Chemical characteristics
- Physical characteristics
- Biological characteristics

Mechanical class fibres are associated with properties like wear and abrasion resistance, impact strength, tenacity, size, shape etc. Chemical class fibres are associated with chemical reactions, chemical affinity, fluid absorbency, chemical structural change, chemical inertness etc. Physical class fibres are associated with heat insulation, on transparency, sound proofing, high absorbency, wind break, electromagnetic characteristics, pressure effects etc. while biology class fibres are associated with anti-bacterial activity, anti-septic activity, bio- technology, medical and health care applications, body implants compatibility factor etc.

2.2.1 Mechanical characteristics

This may cover broadly the fibres for geotextiles, sports textiles, automobiles etc. The textile materials used for geotextiles can vary from fibres to fabrics. They function as reinforcing element for soil or cement or as a filter in drainage material to separate water and remove clay suspensions. Additional strength is needed and fibre form is particularly suitable because fibrous structure is characterized by molecular orientation in the direction of stretching. It is also use in high tenacity net covering steep embankment to prevent land slips. Most geotextile materials are lighter and stronger and are mainly fabricated from Polyethylene, Poly propylene, carbon, aramid, glass and their composites [1].

Woven or knitted fabrics are commonly employed for draining. A polyester or polypropylene fabric bag filled with sand is used to drain water and so reclaim soft, wet ground known as pack drain method. A pillow shaped knitted bag has been developed for river bank protection by Carl Mayer AG Germany.

The development for swimming costume will illustrate the concept of high function fibre. Of the total resistance while swimming, 5% is due to swimming costume. For instance, the resistance exerted on the body by water accounts for about 10 kg per square cm when one swims 100 m in 50 s. The friction against water will be less without a swimming costume, but water hits the body to deform, as a consequence one can swim faster with swimming costume, provided it fits body without air space and its surface should be smooth. Thus, polyurethane elastic fibre is the best material with two ways tricot construction for swimming costume. The next step is how to make its surface smooth.

If the fabric is coated to make its surface smooth, water trapped between costume and body would increase water resistance. Here, ultra-fine nylon and polyurethane fibres are knitted into high density fabric (Toray) employed at the Seoul Olympics. Lyospeck was developed for Atlanta Olympics with water repellent coating agent printed on it. Fish secretes viscose liquids to reduce the frictional resistance and dimples (like golf balls) smooth the water flow at the surface. A fabric with dimples and coated hydrogel was developed resulting in to low frictional resistance for Sydney Olympics. Apart from the fabric applications, carbon fibre reinforced plastic (CFRP) composites have now found application in sports goods. The first application of CFRP was for pole vaulting which was made from bamboo. After replacement by CFRP, world records have consistently improved. For archery bows CFRP now replaced by glass fibre reinforced plastic (GFRP) [7].

2.2.2 Chemical characteristics

Fibres are now increasingly used in the sea and below the sea. Such application needs resistance to sea water and corrosion. Fibre reinforced plastic from polythene fibres (PE) is used for boat hulls. PE fibres are also used for marine ropes and fish nets. Vectran fibre is used in swimming pool lane buoys. Glass fibres are used to make corrosion resistant pressure vessels large membrane structured containers to store oil and drinking water. Soft containers of Nylon and Polyester membrane based and coated with synthetic rubber are used to store food. To prevent propagation of oil slick, it is necessary to set up oil block to enclose oil slick area. Blocks are constructed by joining together flexible fences of glass fibre fabric with resin. Many textile or membrane structures are built deep in sea to produce an upward sea current, to enhance value of fishing ground. To prevent pollution mud to fishing ground during dredging operation, silt curtain is set up at the sea bottom near dredging area. Generally, membrane structures are employed to cover very large area.

2.2.3 Physical characteristics

(a) Electronics and fibres: Clean rooms are indispensable for the production of very large integrated circuits in the field of semi-conductors and bio technology. The demand for cleanliness is increasing in other production areas such as magnetic discs and cathode ray tubes. Dust generally comes from workers clothes, so functionalities such as safety, thermal insulation, wear comfort, working efficiency etc. are primary requisites for working cloths [7]. The main criteria for working cloths suitable for clean room are:

- The dust generated from under wears should not leak through working cloths and no dust must escape from clothing material itself,
- The clothing must be antistatic and dust proof,
- The clothing should be durable against washing,
- They should be moisture permeable and comfortable.

Polyester resin is mixed with carbon to make it electrically conductive, which can be woven into high density fabrics and eliminate static electricity induced by the low humidity atmosphere of the clean room. Aramid fibre is used when high fibre resistance is required. Cotton and wool fibre as are unacceptable as they generate dust. In short, required garment properties for use in clean room are dust proof, charge proof, durable, wearable and suitable for sewing.

The degree of cleanliness is evaluated in terms of number of dust particles per unit volume of atmosphere. The highest degree is quoted as class I, where a cubic foot of air contains one dust of maximum 5 micrometre diameter. So here in this case, robot working only can be assumed as the best, but actually robots also generate dust due to abrasion between moving parts. This condition is called ultra clean room where the dust generation is totally eliminated or minimum. Workers fouls clean room by dropping dandruff, old skin and dust from under wears. Toray has developed dust free working cloth, the neck is made of spandex, the edge of sleeve is double to prevent dust release, the fastener is positioned at the side and it is fitted with an integrated cap having a knitted interior to envelope the hair. Kanebo and Sharp Corporation have developed the sucking type dust free working clothing. This system is fitted with a small electric vacuum cleaner attached to waste which filters the air inside the clothing and exhausts clean air into atmosphere. The Asahi chemical industry makes M-bit suit.

Hepa (high efficiency particulate air filter) cloth can filter the air and collect fine particles of 0.3 to 0.5 micrometre diameter. It is a sandwiched structure of woven and non-woven fabrics. Teijin has developed the anti-static and dust proof clothing selguard- C, which is a two-layered polyester fabric laminated with the moisture permeable anti- static carbon containing 25 to 30 micrometre thick. Up to 2000 V is allowed for static electricity generated during wearing dustproof clothes. It is therefore ideal for use in the production of semiconductors and prevents the damage caused by electric discharge. Toyobo developed Elitron, is an electrostatic air filter made of Electret fibres having high dust filtration efficiency and low-pressure loss. These fibres retain positive and negative charges and collect dust from air by electrostatic forces. Elitron is now used in to air cleaners and air conditioners for cars and also various filters including dust proof masks.

(b) Fibres in space application: Applications include Space Station parts, space suit and satellite parts, which are extensively used in made in the making of space suit. The earth is surrounded with a thick layer of air that absorbs ultraviolet and other radiation. On the earth and beyond, this in space, value of gravity is different. The temperature in space is zero Kelvin, where as a spaceship surface temperature exposed to solar radiation can exceed 100^{o}C. A spacesuit, therefore, has vital functions in protecting the astronaut and assisting him in any activity necessary in the environment of space. It must, therefore, maintain temperature, humidity and atmospheric pressure by supplying Oxygen and water vapour and also protect against radiations from the galactic System, Solar wind and Solar flares, in addition to any hazard from micro meteorites, cosmic dust and atomic oxygen.

For extra vehicular activity, spacesuit must provide solar energy absorbency, resistance to heat and cold, gas permeability, thermal conductivity, mechanical strength, flexibility and process ability. A space suit is essentially an extra vehicular mobility unit comprising of three subsystems:

- Clothing section that is suit helmet gloves or shoes.
- Communication / control module.
- Life support system in which drinking water, urine connecting device and oxygen packs are available.

The Suit includes water cooled underwear, second air tight garment and outer protective coat. All three layers have specific functions. The water cooled under wear controls body heat, air tight garment maintains air pressure during work outside the space ship and special cloth protects against radiation and floating micro meteorites. The suit is divided into an upper and lower section the former covers the neck upper body and upper arms and is coupled with the built-in life support subsystem the lower section has a one body structure from the ways to the shoes the two sections are joined together by connecting ring to maintain air tightness.

2.2.4 Biological characteristics

Specialty fibres are used in various medical applications to improve biological performance improvement. The main applications are described in brief [7].

(a) Sutures: Two types of sutures are currently available - assimilated type such as catgut, and non-assimilated type such as silk or polyester filament. Catgut is made from collagen, extracted from ox bones. However, it is not suitable for implantation for biocompatible reasons. The human body normally rejects foreign materials and collagen is not an exception, when implanted into body. Another weakness is its strength, which deteriorate by half after a week in the body, despite the fact that 3 weeks are required for the recovery of an incision after surgery. Thus active investigations are on to make biocompatible suture of the assimilated type made from synthetic polymer.

A mono filament is preferable for use as a suture because of its smooth surface. Poly glycolic Acid is the synthetic polymer, currently used for suture of assimilated type but it is too hard material to make a mono filament suture. Thus it is now used to make multi filament or blended type of suture, which is coated with a plasticizer for smoothness. A monofilament with smooth surface can pass through skin without being caught and can be tightened with a single knot. The Polybutylene Terephthalate (PBT) is the most popular because of strength and smoothness. The poly glycolic acid suture is used currently for heart surgery in order to withstand the high pressure within the heart, but it is not fully assimilable by the body for one or two years. Johnson and Johnson have developed the suture with trade name Maxon, which appears to satisfy all the required criteria [8].

(b) Blood purification: Hemodialysis is indispensable for people suffering from kidney disease and the treatment can prolong up to 25 years or more. Long term use of artificial kidney lead to another problem, because some unwanted substances in the blood are not dialysed out, an immunological reaction can occur with repeated use, since the dialyser is a foreign substance to the human body. During dialysis, the leucocyte count in the blood decreases initially, this can be prevented by improving surface of the hollow fibres, used in dialyser through which blood circulates. Kidney troubles can be caused by proteins of molecular weight between 10000 to 30000.The blood also contains substances that must be retained, such as albumin, with the molecular weight of about 70000. Each hollow fibre manufacturer is now developing a suitable membrane, through which the harmful proteins of molecular weight around 20000 passes.

(c) Mechanical lung: Silicone or polypropylene (PP) hollow fibres are used for the fabrication of the mechanic lung to allow permeation of gases. It should function ideally for at least 2 to 3 weeks. However, the present mechanical lung last at most one week, because its ability to remove carbon dioxide falls off. A newer form of mechanical lung can also be used as a supplementary respiratory device over a longer term to assist the breathing of patients, suffering from acute lung or heart failure, or older people with week lung function. Mitsubishi Rayon Company has developed a micro porous PP hollow fibre for the manufacture of an artificial lung. Here gases freely pass through pores of PP hollow fibres, but not the blood, because of Hydrophobicity of PP membrane. PP hollow fibre exhibits good compatibility with blood and excellent gas permeability. However its long term use causes a leak of blood plasma components.

(d) Artificial blood vessels: Artificial blood vessels are now commercially available and are made mostly from polyester and Teflon. They are also used to replace thick arteries or veins of 6 mm, 8 mm or 1 centimeter in diameter. Polyester is bio compatible. Its anti-coagulant property is poor. Porous Teflon exhibits both properties. Thin blood vessels (< 3 mm) made from Teflon leads to other problems. Consequently, the coronary artery or the thin veins in hands or legs are replaced with blood vessels from other parts of body. The artificial blood vessel with inner diameter of 1.5 mm is developed with three layered structure –Collagen, heparin and Teflon. Inner layer of collagen and heparin imports good anticoagulant activity whereas middle layer of porous Teflon provides mechanical strength. It is coated with collagen to form outer biocompatible layer.

The task of producing artificial bile duct can be approached in a similar manner, but bile duct exhibits two contradictory properties very soft but very tough. The bile duct cannot be cut using a thread, but a soft polymer tube slices easily this way. A synthetic polymer material which resists thread tightening is generally too hard and causes other problems during surgery. The race is now on to develop a soft but tough synthetic polymers material suitable both for artificial blood vessels and bile ducts.

(e) Fibres for AIDS diagnosis and treatment: Asahi chemical industry co. has developed hollow fibre membrane. Bemberg microspores membranes (BMM) is used to filter out and isolate AIDS virus and hepatitis type B in blood. BMM is made from cellulose fibre. “Bemberg” Regenerated from cuprammonium solutions of cotton linters. Synthetic polymers are known to cause blood clotting as a result of protein adsorption. However, regenerated cellulose fibre is free from this problem. In order to allow proteins to permit but to isolate viruses using the same membranes, it is necessary to have homogeneous pores in the membrane that are larger than proteins but smaller than viruses.

BMM has a multilayer structure of 150 layers. The multilayer hollow fibre membrane is produced by wet spinning from cuprammonium solution of cotton linter mixed with an organic solvent. The concentrated phase forms a continuous organic solvent layer and dilute phase is made up of small organic solvent holes of a uniform size. The solution undergoes phase separation and produces hollow fibre of 100-150 layers of cellulose membranes with pores of Pre-determined diameter. BMM is now expected to be applied to diagnosis and treatment of AIDS. At present AIDS is diagnosed by antigen antibody reaction but using this method, the result is negative until an antigen is formed. Since BMM isolate the AIDS virus itself, AIDS diagnosis by BMM is possible even in the early stage of virus infection, even before the antigen is formed [7].

2.3 Eco-friendly fibres for technical textiles

Cellulose is the most abundant polymer occurring in nature. It is the structural material in plants and also occurs in certain bacteria and some marine organisms. Natural cellulose fibres such as cotton and flax are in the minor position of technical textile field. Bur regenerated fibres, high tenacity rayon is usefully used for high performance tyre and run flat tyre, because of having higher modulus, lower shrinkage and better adhesiveness at higher temperature than polyester. Lyocell fibres can be used for filters and wipers. It is also commercialized for tyre cord applications. This has lower moisture regain, higher modulus and equal tenacity as high tenacity rayon filaments [7].

In cotton fibres, cellulose is found in an almost pure form, except for absorbed water, but more commonly it is mixed with other substances. With the current concerns about climate change, the importance of cellulose is recognized as a way of locking up carbon dioxide. There are mainly three groups of natural cellulose fibres. The seed fibres are single plant cells. Kapok, which has a limited use as a buoyant material, is a hollow fibre with a thin cell wall. In contrast to this, cotton was the most widely used from eighteenth century. It is now second to polyester but far ahead of other textile fibres. It is grown through all the latitudes from the Mediterranean to Australia. The fibres grow out from the seeds in the cotton bowl to form a primary wall, which is then filled in with a secondary wall. At maturity, there is a small lumen at the centre of the fibre, which collapses on drying to give the convoluted form of cotton fibres. Both bast and leaf fibres are multicellular. Helix angles of fibrils in the cells are less than in cotton, thus giving higher tensile moduli. Extraction of fibres from stems or leaves is by biological or chemical retting and mechanical action. Flax is the high quality fibre from which linen is made. In medieval times, hemp was the dominant European fibre and it is now coming back into use. The leaf fibres are coarse and are mainly used in ropes and cords. Polypropylene has replaced the coarse plant fibres to a major extent. Trees are the most abundant source of cellulose. Wood is a composite of many small cells. Although wood can be broken down into small fibres and can be dispersed in water to be reassembled as paper, it is not possible to extract these in a way that makes textile processing possible.

Manufactured cellulose fibres have a strong growth potential in global market in competition with synthetic polymers. Their role will increase in sectors such as packaging materials, chemicals, medicine and hygienic products. Annually about 180 million tons of various cellulose pulps are consumed worldwide, most of in paper and paperboard manufacture [9].

Acetate and triacetate fibres: The term acetate fibres relates to fibres made from cellulose acetate. The difference between acetate and triacetate fibres is in the number of cellulose hydroxyl groups that are acetylated. Cellulose acetate was the first man-made thermoplastic fibre. These fibres are quite different from viscose and are characterized by high elongation at break and poor abrasion resistance, though resistance to pilling is very good, and they can be textured. The dry strength of the two types is similar, though triacetate fibres have higher strength in the wet state. The main end-uses for the filament yarns are in linings, dress wear and household furnishing. Staple acetate fibres are the major product used for cigarette filters. Triacetate fibres are used in sportswear, garments and woven fabrics that keep their shape. Due to their low moisture absorption, fabrics made from them are easily washed and dry very quickly. Fabrics made from blends of triacetate and wool is very popular, combining advantageous properties of both types of fibres: the warmth of wool and the drip-dry properties of triacetate.

(a) Cupro fibres: The term cupro relates to regenerated cellulosic fibres produced by the cuprammonium method. The cuprammonium process is very similar to the viscose process. Cellulose is dissolved in a mixed solution of copper salts and ammonia, then the solution is pressed into a coagulation bath using a spinneret head where the cellulose is subjected to regeneration, giving a multifilament yarn. The raw materials in the cupro process can be wood pulp or cotton linters. Cupro fibres have a good drape and are easy to wash. The main application of these fibres is in forming multifilament yarns for woven fabrics and linings. The process nowadays is exploited by only two companies, Bemberg (Italy) and Asahi (Kasei, Japan).

(b) Lyocell fibres: New generations of cellulosic fibres were invented in the 1980s. The process employs an organic solvent (N-methyl-morpholine N-oxide) to prepare a solution of cellulose from which fibres are spun by extrusion to a spinning bath. The name Lyocell is the generic name used by BISFA (International Office for the Standardization of Man-made Fibres) and the Federal Trade Commission (USA). Lenzing (Austria), a leader in that technology, is the sole producer in Europe selling the fibres under the brand name Tencel. The company operates Lyocell plants in Austria, Great Britain and the USA. Other producers are located in the Far East: Shanghai Shuanglu Chemical Fibre Co., Hanil and Hyosung in South Korea, and the Formosa Co. in Taiwan. Initially there were problems with high investment costs and difficulties in reusing the maximum amount of the expensive solvent. The problems were solved at the end of the 1980s and now more than 99% of the solvent is recovered after the spinning and recirculated to the process. The physical and structural properties of Lyocell fibres differ from those of viscose fibres. They are characterized by higher strength, lower elongation, and a high degree of crystallinity and molecular orientation. The outstanding strength of Lyocell fibres is the reason why they are an ideal candidate in yarn and fabric processing. Lyocell fibres combine the desired properties of viscose fibres (wearing comfort, water inhibition, biodegradability) with the excellent features of polyester fibres (high strength). Lyocell fibres are mostly used for apparel fabrics, especially outerwear. In technical sectors, due to their tendency to fibrillation, they can be applied to the manufacture of non-woven, filters and special papers.

(c) Modal fibres: Modal and polynosic are names that are used for regenerated cellulose fibres with high tenacity and high wet modulus. Both types of fibres have high wet modulus, i.e. resistance to extension in the wet state, higher ratio of wet to dry breaking tenacity, high polymerization degree of cellulose and micro-fibrillar structure. Such properties assure their dimensional stability in wet conditions, which is the most important feature from a practical point of view. High wet modulus fibres are resistant to stress and shrinkage, so keep their original shape. Blends of modal or polynosic fibres with other polymers such as flax, wool, polyester or polypropylene provide fabrics with improved properties, i.e. unchanged appearance and reduced shrinkage and better uniformity.

(d) Viscose fibres: The most popular cellulosic fibre is viscose, which is defined by BISFA as ‘cellulose fibres obtained by the viscose processes. The viscose method dominates in the production of cellulose fibres with an approximately 80% share. The method had been invented at the beginning of the twentieth century, offering for nearly half a century the sole man-made fibres among textile raw materials. It was only after World War II that synthetic fibres began to rapidly penetrate the market, crowding viscose fibres out of their dominant position. In the viscose route, Carbon disulphide (CS2) is used, causing water and air pollution with Sulphur compounds, and the danger of fire and explosion. As an industrial poison, it is also a serious menace to operators. These factors resulted in many plant shut-downs and a decrease in production. Yet, despite all adversities, the viscose method survived. It has been greatly improved by the leading producers with respect to environmental pollution and work safety.

Viscose fibre is a versatile textile raw material that may be compared to natural fibres like cotton, wool, linen and silk. In textiles, they offer a high wearing comfort by being soft and cool. The prime attribute of viscose fibres is their hydrophilicity. Additionally, the high water retention of viscose fibres is an advantage during wet processing and is connected with the quick liquid absorption of the end product. The disposal of biodegradable viscose fibres is easy. The fibre properties can be adjusted according to the needs of the customers. For example, fineness, length, wet strength and crimping can be easily controlled by varying the spinning conditions. It can be easily dyed and do not shrink during heating. Viscose fibres and their blends with other fibres are mostly used in the textile industry for clothes production, linings, furnishing fabrics and the manufacture of hygienic materials where high absorption properties are required. Novel cellulosic fibres, alternative to viscose fibres, can be obtained from biomodified cellulose pulp using cellulolytic enzymes. Enzymatic modification of the cellulose structure causes an increase of cellulose reactivity and solubility.

2.4 Advanced technical textiles

These are textile materials and products manufactured primarily for their technical performance and functional properties rather than aesthetic or decorative characteristics. The values of technical textiles are highly based on their technical performance and functional properties. The term "advanced technical textiles" means technical textiles which have at least some technological advancement in the material and/or in the application [4]. Polyester, nylon and PP fibres are considered as three major manmade fibres for advanced technical textiles. High mechanical performance fibres such as carbon fibre and aramid fibre, and high heat resistance fibres such as silicon carbide (SiC) fibre are also introduced recently for advanced technical applications. Several functional fibres such as separation function; optical, electric conductive, adhesive fibres etc. have very important applications. Introduction of nano fibres and micro fibres have changed the world of textiles.

2.4.1 Fibres for advanced technical textiles

Generally, the fibre materials among several forms of materials are used for certain specified technical products. The textile products in which some of the configuration functions of fibre are effectively utilized can have the highest value in terms of the ratio (performance/cost) [10]. The configurationally functions of fibre consist of four properties:

- flexible (pliable),
- high ability in its axial transmission of a physical quantity as mechanical load,
- high specific surface area,
- technological easiness in transformability into textile structures woven or non-woven.

Unlike in case of apparel use, the high specific surface area often becomes the most important element for technical textiles. For advanced technical textiles, the maximization in the value of the ratio (performance/cost) is pursued in their developmental process using advanced materials and/or advanced application technologies. The performance of textiles is generally dependent on material of fibre, configuration of fibre and assembly structure of fibre including hybrid structure with other kinds of materials/parts. It must be noted that the range in selecting these three structural elements in advanced technical textiles is by far wider than in apparel textiles. Fibre materials used for apparel textiles are quite concentrated to some specific kinds of fibres viz. Cotton, Wool, silk, Polyethylene-terephthalate (PET) etc. On the other hand, in technical textiles, PET, nylon and polypropylene (PP) are three major conventional fibres are mainly used. Advanced fibre materials are much diversified by their performances, functions and specialty uses. An optimization targeting for raising the value of the ratio (performance/cost) for a specific product is strongly pursued in technical textiles, which causes the selection of the optimum fibre material in terms of the ratio, the performance required is quite diversified according to the wide variety range of application products. Hence the co-existence of so many kinds of fibre materials is possible.

Depending on functional characteristics various technical textile fibres have been used in number of applications in advanced technical textiles (Table 2.2).

Table 2.2 Selective list of applications in advanced technical textiles

Sustaining resource and environment products	Water treatment and water production	Filtration, bio-reaction, reverse osmosis, ultra-filtration, and oil separation
Automobile	Rubber composite parts, Car interiors, Noise control sheets	Filter for diesel engine gas ,bag filters, air filters, removal of toxic gas, solvent recovery, Material for battery and fuel cell
Medical/biological, hygienic	Medical/biological, Paramedical, Hygienic	Filter for Virus removal, leukocyte removal filter, scaffold, DNA chip, Sanitary napkin, Incontinent diapers
Protection/safety	Bullet proof, stab resistance, fire-fighting suit, chemical protection, radio-active protection, cold protection	
Electric and information Technologies	Print circuit, electric conduction, electric insulation, optical fibre communication	
Construction, civil engineering	Acoustic uses for construction, reinforcement for construction, geo- textile, miscellaneous material geo technical engineering	
Agriculture, horticulture, Aircraft, Space e-textiles	Fibre reinforced composites	

(a) **Conventional fibres:** Conventional synthetic fibres such as polyethylene terephthalate (PET), polyamide (PA) i.e. nylon and polypropylene (PP) can be converted into technical textiles using developments in advanced fibre production technologies.

- **PET (polyethylene terephthalate):** PET fibre is used in a wide variety of fibre forms such as multi-filament, textured yarn, staple fibre, mono-filament, chopped fibre and spun bond non-woven. PET fibre is most popular among fibres in technical textiles due to fairly good balance in cost and performance properties. Its mechanical properties, dimensional properties, heat resistance, light-degradation resistance and light-colour fastness are practically fairly good. But it is rather inferior in anti-hydrolysis. Disperse dyeing under high pressure is generally adopted however pigmented PET is also available. Some modified PET fibres also available for specific function as adhesiveness, flame-retardancy, anti-pilling, anti-bacteria and soil-guard. The fibre is most widely used among fibres for technical textiles viz. tyre-cord, air-bag and seat belt, sail cloth, sewing thread, geo-textiles, fishing net and non-woven. Its excellent toughness is utilized in tyre reinforcement and floor covering in the form of bulked continuous filament. The high flexibility is useful for compactness in airbags.
- **Polypropylene:** polypropylene (PP) have poor dyeability hence usually it is dope dyed by blending of pigment. Such a low melting point of PP as 160°C is often insufficient for uses in technical textiles. Creep and stress relaxation of PP are also too high for some uses. These characteristics of PP fibre cause some limitation in the uses of technical textiles. On the other hand, it has advantages in the following points: most economical as material, small in energy consumption for fibre production, smallest in specific gravity as material among conventional fibres. It is highly hydrophobic and fairly feasible for waste recycling. Its commercially available fibre forms are staple fibre, multi-filament and directly spun non-woven such as spun bond and melt blown. There is also split fibre yarn produced by high uni-axial stretching of film. PP fibre is positively used for number of products in which its disadvantages can be out-of- problem such as diaper, pad, napkin, wiper, geotextiles, needle-punch carpet, oil absorbing material, packaging, rope, tape and net are typical examples of its application products.
- **Polyamide:** Polyamide fibres (PA), Nylon 66 and Nylon 6 are main conventional fibres in the group. Important properties are very strong (weight for weight stronger than steel wire), very tough, have outstanding abrasion resistance, recovery from stretch is

better than of most other fibres, and they can be spun as fine as silk. In addition to nylon stretches appreciably before it breaks so that a lot of energy is expended before rupture. This high "work of rupture" makes nylon a tough fibre, and very suitable for use in ropes, harnesses, arresting cables and parachute fabrics. The nylon has got applications in hosiery, carpet, upholstery, umbrella cloth, parachute cloth and the industrial goods such as ropes, fishnets, seat belts, tire cords etc.

Aromatic polyamide fibres (aramid fibres) have outstanding mechanical characteristics and excellent thermal resistance hence used as high performance fibre in number of applications. Protective clothing in hostile environments where heat, chemicals and radiation are present, industrial filters and hollow fibres for desalination by reverse osmosis are some of its applications. The initial motivation for the development of high performance fibers came from the aerospace industry seeking fibers for use in light but stiff, strong and tough composite structural parts. Nomex ™ is produced by Du Pont in USA and Conex™ having a different structure by Teijin in Japan. The poly(*p*-phenylene terephthalamide) (PPTA) fibre was commercially released by Du Pont under the trade name Kevlar™, having outstanding modulus, strength, toughness and temperature resistance. Kevlar has been produced in two grades 29 and 49, and successfully used in a wide range as a textile fibre and as a reinforcing material. The range was extended by the addition of new Kevlar grades, 149 and 981, and by competitive fibres Twaron™, from Akzo, Holland and Technora™ from Teijin Co., Japan [1].

Properties of the conventional synthetic fibres are summarized with p-aramid fibre as a reference (Table 2.3). The specifications of various properties of these fibres are considered for the suitability of the fibre for the required performance in a given application of the technical textiles. At first except in the case that high thermal resistance or high specific function is needed, a suitable fibre material have to be selected among these conventional fibres. Then other specification items such as yarn thickness and single filament thickness, fibre length, fibre cross-sectional shape, oil used on fibre, fibre crimp, fibre/yarn tensile strength, breaking elongation, modulus, dimensional stability and grade of functional modification should be considered for the selection. The advantages and limitations, useful for the selection of these fibres are summarized and listed in Table 2.4 [6].

Table 2.3 Comparison of fibres properties of conventional fibres

Fibre Type	Specific Gravity	Melting Temp (°C)	Glass Transition Temp (°C)	Tensile Strength (MP)	Breaking Elongation (%)	Tensile Modulus (GP)	LOI (%)
PET	1.38	260	70 (50% RH)	510-690	15-40	6-11	18-21
Nylon66	1.14	260	35 (50% RH)	350-550	18-36	3.0-6.5	20-21
Nylon6	1.13	220	20 (50% RH)	450-700	20-32	2.5-3.4	20-21
PP	0.91	160	-15	410	25-60	6.4	18-20
P-aramid	1.14	-	300	2760	3.3	58	29

Table 2.4 Comparison of advantages and limitations of main commodity fibres

Fibres	Advantages	Limitations
PET	• Balanced in Physical Properties • Excellent in toughness and wearing resistance • Low in modulus	• Easy in hydrolysis • A little less in wearing resistance • Easy in yellowing
PA (Nylon)	• Excellent in strain recovery • Excellent in chemical resistance	• Fairly expensive as conventional fibres • High in energy consumption for fibre production • Very poor in dye-ability
PP	• Low specific gravity • Low in energy consumption for fibre production	• Low in heat resistance • High in creep and stress relaxation

(Abbreviations: PET, Poly-Ethylene-Terephthalate; PA, Poly amide; PP, Poly-Propylene)

(b) Unconventional fibres: Carbon, glass, inorganic and organic fibres are certain unconventional fibres possessing unique properties hence used in technical textiles for various applications. These fibres have higher specific gravity as compared to most conventional fibres. Their potential can be explored using the optimising principle of the (performance/cost) ratio. Various physical and mechanical properties are summarised and compared (Table 2.5) [1].

Table 2.5 Various Properties of non-conventional fibres

Fibre Classification	Fibre material	Specific gravity	Strength (MPa)	Modulus (GP_a)	Breaking elongation (%)
	Carbon	1.8	3600	400	1.7
	Glass	2.6	3400	78	4.0
Inorganic	Stainless	7.9	2400	180	1.5
	Si-C	2.4	3000	190	1.5
	Alumina	3.4	1800	300	1.0
	Boron	2.5	3600	400	0.8
	p-aramid	1.4	2900	95	3.5
Organic	PBO	1.5	5800	180	3.5
	Ultra-high MWPE	1.0	4000	95	4.0
	Polyacrylate	1.4	3400	75	3.9

- **Carbon fibre:** There are two kinds of carbon fibre by its precursor – polyacrylonitrile and pitch. Carbon fibre is produced by carbonizing these precursor fibres under tension. The diameter of single filament is ranged from 6 to 12um. Carbon fibre is mostly used as reinforcing fibre for advanced composites whose major matrix is epoxy resin. Pitch carbon fibre has lower breaking elongation, lower compression strength and is more expensive than acrylonitrile carbon fibre, but pitch carbon fibre is generally higher in modulus and in axial heat conductivity. Then it is applied only for such specified end-use as space satellite frame and precision roll. Hence its consumption amount is much less than that of acrylic carbon fibre.

  The price of carbon fibre widely ranges according to its grade. It shows a wide distribution in the mechanical properties by several grades. The price of the fibre type having lower mechanical performance is generally lower. The largest advantage in the use of carbon fibre reinforced composites is weight reduction comparing to customary materials. Its price was so expensive that it was selectively applied to high weight sensitive end-uses such as aero-space and some special sports goods. With a technological progress for improving impact strength, they are now going to be widely used for structural parts of commercial aircraft. Recently an increase in their consumption amount for industrial fields has become significant by the combination effect of technological progress in their application, lowering of fibre price and strong needs caused by social environmental problems. Hence it is forecasted that its high annual growth rate will also be kept in the future [10].

- **Metal Fibres**: Various metal fibres such as stainless steel, aluminium, copper are also used in number of applications. Metallic threads are made from very thin metal filaments (diameters ranging 2 to 80microns). The metal fibres are produced either through a bundle-drawing process or shaved off the edge of thin metal sheeting.

  Metallic threads and yarns may be knitted or woven into a textile and used to form Interconnects between components. They may also be used as electrodes for monitoring electrical physiological activity such as electrocardiogram (ECG) signals. While metals provide good conductivity there are some drawbacks of integration into clothing. Metal threads tend to be heavier than most textile fibres and their brittle characteristics can damage spinning machinery over time and also they may be uncomfortable to wear due to abrasion.

- **Adhesive fibres:** There are two types of adhesive fibre by its structure, the fibre whose whole part is composed of adhesive material, and the bi-component fibres whose sheath part is composed of melt adhesive material. The latter is widely used as a binder for non-woven, paper and fibrous cushion.

- **Polylactic acid fibre:** Polylactic acid fibre (PLA) is a kind of aliphatic polyester made from lactic-acid. The most important feature of the fibre is the fact that its consumption energy and carbon dioxide gas exhaust up to fibre production are lowest. In addition, it is usually carbon-neutral, because its raw material is vegetable. It has even better weather resistance and flame retardancy than that of PET. But it is gradually degraded in soil and quickly degraded in activated sludge. Its value of specific gravity, glass transition temperature, and modulus are situated about in the mid-way to that of nylon and PET. PLA fibre is made of L-stereoisomer have melting point 178°C. But L and D stereo-complex PLA fibre have melting point 279°C. Its major end-uses are materials for civil engineering, agriculture and horticulture, fishery and marine, sanitary and medical uses and living disposal goods.

2.4.2 Nano-fibres for technical textiles

Nano fibres can be generated from both natural and synthetic polymers having different physical properties. Natural polymers include collagen, cellulose, silk fibroin, keratin, gelatine and polysaccharides such as chitosan and alginate. Synthetic polymers include poly lactic acid (PLA), polycaprolactone (PCL), polyurethane (PU), poly (lactic-co- glycolic acid) (PLGA), poly (3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), and poly (ethylene-co-vinylacetate) (PEVA), polybutylene terephthalate (PBT), polyethylene tere- phthalate (PET), thermoplastic polyurethrane, low molecular weight polyethylene, polyamides (PA), and polyvinylidine fluoride which are used in a variety of products from fuel filtration to masks. These micro fibres display some unique properties, for instance they have an extremely high surface to weight ratio compared to the rest of the non-wovens. Tight pore size, large surface area to mass, high pore volume, and low density make them an apt choice for filtration. Some nanofibres are smaller than human hair and even tinier than pollen. Nanofibres play a huge role in shaping the medical textiles of the present and the future.

Nanofibres can improve and help in the process of healing wounds. It is used in aiding acute wounds like burns, surgical, and traumatic wounds because nanofibres allow gases and liquids to pass and at the same time keep the bacteria at bay, in order to avoid any infections. Ulcers and chronic wounds are covered with medical bandages developed using nanofibres with relevant polymers. A technology with multiple layers of nanofibres in different combinations is used for effective cleaning, protection, and to prevent contamination of the wound. The different layers include materials like chitosan, polyvinyalcohol, gelatin, collage hyaluronic acid, carboxylmethylcellulose, and polyurethane. Since most of the human organs and tissues are in the form of nanofibre like structures, using scaffold made up of nanofibres in tissue re-engineering and repair can be of very good use. Nanofibres with anti-adhesion properties are used in post-surgical tissue adhesion of internal organs. The nanofibres used for such purposes possess the ability to dissolve into the body without causing any toxicity. Since they do not stick, it can keep organs away [10].

All polymeric nano fibres are unique for their large surface area-to-volume ratio, high porosity, appreciable mechanical strength, and flexibility as compared to micro-fibre counterparts. Compared to conventional fibres, nano fibres are lightweight with small diameters, controllable pore structures ideal for use in applications such as filtration, sensors, protective clothing, tissue engineering, energy storage etc.

(a) Applications in medical field: Biomedical nano fibres are of increasing interest for a range of applications relevant to the fields of material science and biomedical engineering due to its renewable nature, anisotropic shape, excellent mechanical properties, good biocompatibility, tailorable surface chemistry, and interesting optical properties. The main areas of biomedical nano fibres research are photonics, films and foams, surface modifications, nano composites and medical devices. These tiny nano fibres have huge potential in many applications, from flexible optoelectronics to scaffolds for tissue regeneration. It can be spun from biodegradable polymers with additives for intended functionality and structure and size (close to human cells dimension) can be controlled thus optimized for tissue engineering.

- Nano fibre membrane from biopolymers can be used as a bioactive material or drug carrier. Active pharmaceutical ingredients incorporated into it for fast release of drugs especially for poorly soluble drugs. Nano fibre layers produced from biopolymers (chitosan, gelatin, collagen, polykaprolakton) used as a wound dressing for significant support to healing process. On the basis of in vitro and in vivo experiments, nano fibre materials have shown significant benefits on contaminated wounds by adding antibacterial drugs to the nano fibre. Granulation of new dermal tissue can be enhanced by adding growth factor materials to support proliferation of dermal tissue. The wound can be covered by a nano fibre layer or fibre carrier composite material.

- Nano fibre materials made from biopolymers (collagen, polycaprolactone, polylactic acid, etc.) are possible substrates for growing cells. With appropriate mechanical and structural properties of the material, it is possible to prepare scaffolds suitable for implanting by different types of cells. Nano fibre substrates effectively support cell proliferation and enable tissue replacement prepared from a patient´s cells. During the preparation of scaffolds, it is possible to incorporate bioactive materials, growth factor, and eventually other drugs such as an immunosuppressant.

- Barrier textiles containing hydrophobic nano fibre layers, for example polyuretan or polyvinyldenfluorid are an effective barrier for microorganism penetration (viruses, bacteria, molds). The barrier textiles are basically prepared as a “sandwich”, where the nano fibre layer is enclosed between a carrier layer and a covering layer. Spun bond or melt blown non-wovens may be used as a carrier and covering layer. The composite sandwich is produced by laminating the covering layer to the carrier layer.

(b) Applications of cellulose nano fibres: Due to morphology physical properties, cellulose nano fibre is used in filter material, high gas barrier packaging material, electronic devices, foods, medicine, and health care. Antibacterial and deodorant sheets have been developed using cellulose nano fibres (CNF) viz. 'Hada Care Acty' adult diapers by Nippon Paper Crecia Co; and 'Poise' incontinence pad of Crecia. Made from wood- derived fibre (pulp) by fibrillation of bundle of wood fibres to the nano level of several hundredths of a micron and smaller, cellulose nano fibre is the world's most advanced biomass material.

The cellulose nano fibre is derived from plant fibres, it creates low environmental impact in its production and disposal. Trees are composed of wood fibres, which in turn are made of cellulose nano fibres, aggregations of cellulose molecules. Fig. 2.3 shows the flow diagram of cellulose nano fibres manufacture and its relative size as compared to wood fibre [9].

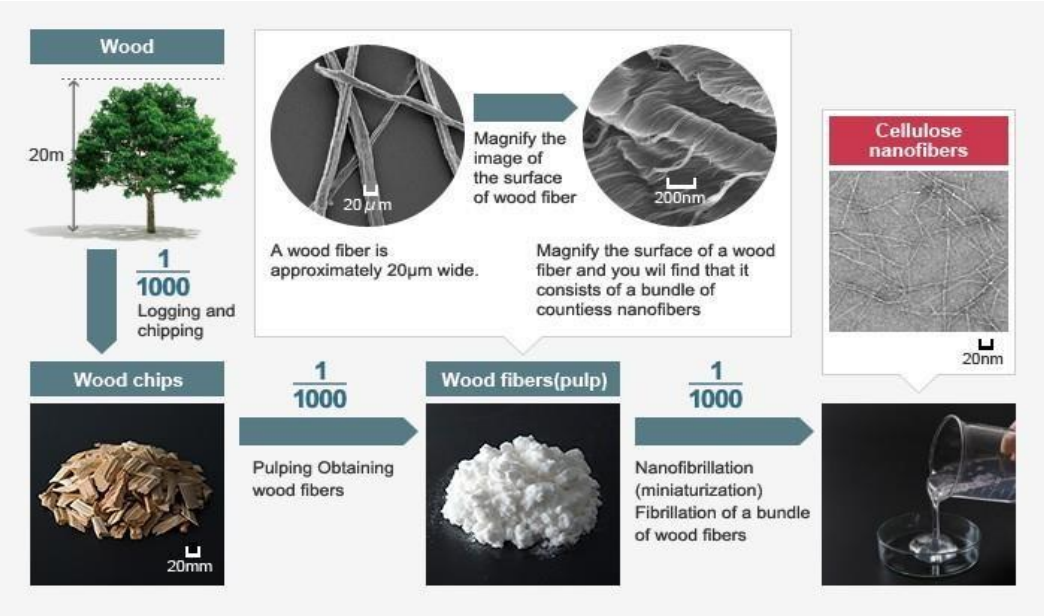

Fig. 2.3 Relative size of wood chips, wood fibre and cellulose nano fibre

2.4.3 High performance fibres for technical textiles

Various technical textiles are produced to meet the functional requirements of their intended end-use. With the advent of new technologies, the growing needs of technical yarns in the wake of health and hygiene of consumers are being fulfilled without compromising the issues related to safety, human health and environment. Some novel technical yarns such as UV protected yarns, anti-static yarns, anti-stress yarns, anti-allergic yarns, metal yarns and antimicrobial yarns are developed for these purpose. Moreover, some of the very newly derived high mechanical performance fibres are also developed for range of technical textiles.

Inorganic high mechanical performance fibres generally have higher heat resistance and higher weather resistance than organic fibres. But they have much higher specific gravity and are so brittle as to be easily snapped. On the other hand, organic mechanical high performance fibres are much lighter and excellent in anti-snapping. But some organic fibres such as ultra-high molecular weight polyethylene (UHMWPE) fibre have low melting temperature. The ratio (compression strength/tensile strength) of organic fibres is fairly low in contrast to inorganic fibres. They have a rather strong tendency to be easily fibrillated. Some organic fibres such as p-aramid are fairly sensitive to sunlight. All the mechanical high performance fibres except glass fibre are fairly expensive.

The three major conventional fibres viz. PET, nylon and PP fibres with certain modification have high potential for use in advanced technical textiles. Fibres like carbon fibre and aramid fibre are preferred for high mechanical performance, whereas Silicon is mainly recommended as high heat resistance fibre. Several kinds of functional fibres such as separation function, optical, electric conductive, adhesive are also useful. Specialty material fibres such as PVA and PLA, modified fibres for specific function and various nano-fibres viz. organic nano fibres, carbon nano-tube and nano-fibre also shows excellent performance in number of applications.

Technologies for fibrous materials for contributing to environmental and resource matters like water treatment including bio-reactive treatment system using membrane hollow fibre, desalination using Ro hollow fibre, purification of water work using UF or MF hollow fibre, purification of recycle industrial liquids have been discussed in detailed by T. Matsuo [10]. The mechanical properties of various high-performance fibres are given in Table 2.6.

Table 2.6 Mechanical properties of various high-performance fibres

Fibre Type	Strength (GP_a)	Modulus (GP_a)	Tenacity (cN/dtex)	Modulus (cN/dtex)	Elongation (%)	Degradation Temp(°C)	Regain (%)
p-aramid	2.9	72	20	490	3.6	550	6.5
high modulus	2.9	110	20	780	2.4	550	2.5
high tenacity	3.4	97	23	670	3.3	550	5.5
zylon AS	5.8	180	37	1150	3.5	650	2.0
(PBO) HM	5.8	270	37	1720	2.5	650	0.6
Dyneema SK60			29	990	4.0	146	0
(UHMWPE) SK71			37	1230	4.0	146	0
UM	3.4	106			2.7	350	0.2
Vectran HT	3.4	75			3.9	330	0.2

2.5 Smart and interactive textiles

Smart material is a generic term for a material that in some way reacts to its environment. Smart materials can be classified in many different ways, depending on their transforming function viz. property change capability, energy change capability, discrete size/location or reversibility. They can also be classified depending on their behaviour and function as passive smart, active smart or very smart. Another way of classifying them depends on their role in a smart structure, as sensors or actuators. Thus, they can be divided into passive smart, active smart and very smart materials. Passive smart materials can only sense the environmental conditions or stimuli; they are sensors. Active smart materials will sense and react to the condition or stimuli, they also have actuation characteristics. Very smart materials can sense, react and adapt themselves accordingly. The higher level of can be achieved from those intelligent materials and structures capable of responding or activated to perform a function in a manual or pre-programmed manner. Few concepts for interactive textiles have been developed. The concepts are based on the following sensors: pressure sensors, sound sensors, strain sensors and light sensors; and actuator: shape memory alloys, light emitting diodes, electroluminescent materials, photovoltaic cells, optical fibres, thermos-chromatic and photo chromatic inks. It should be mentioned that some materials are both sensors and actuators, such as thermo and photo chromatic inks.

The materials of our surroundings are being “intellectualized”. Technological developments have allowed performing the same function with fewer components today. These materials can interact, communicate and sense. Miniaturization not only means the production of smaller components, but the elimination of components. Mechanisms, that previously had to be manufactured by different materials and as separate objects, can now be made of one single material. Examples of this reduction of components and matter are; a complex sensor system replaced by a piezoelectric film and the mechanical keyboard replaced by the membrane. Here we are using conductive metallic yarns like silver, stainless steel, carbon fibre yarns with electrical properties.

Polymeric or carbon coated threads; conductive yarn, conductive rubber, and conductive ink have been developed for sensors or used as an interconnection substrate. Conductive yarns and fibres are made by mixing pure metallic or natural fibres with conductive materials. Pure metallic yarns can be made of composite stainless steel or fine continuous conductive metal-alloy Combination of fibres with conductive materials can be completed by the following methods:

- Fibres filled with conductive material (e.g., carbon or metallic particles);
- Fibres coated with conductive polymers or metal.
- Fibres spun with thin metallic or plastic conductive threads.
- Metallic silk, organza, stainless steel filament, metal clad aramid fibre, conductive polymer fibre, conductive polymer coating and special carbon fibre have been applied to the manufacture of fabric sensors.
- Materials such as metallic, optical fibres and conductive polymers may be integrated into the textile structure, thus supplying electrical conductivity, sensing capabilities and data transmission. Organic polymers may provide a solution to overcome the stiffness of inorganic crystals such as silicon. These materials are light, elastic, resilient, mechanically flexible, inexpensive and easy to process.

Smart textiles/garments can perform all or one of several functions; sensing the surrounding environment, and responding to environmental stimuli by integrating functions from the textile structure; energy required to ‘drive’ the textile function may be derived from a mechanical, thermal, magnetic, chemical, kinetic or electrical stimulus [11].

In Smart e-textiles, electronic properties included in the textile fibres/yarn, emphasis on the integration of sensors and electronics in the textile/finished product itself rather than that being carried as a separate electronic device. Currently, power-generating devices, sensors and transmitters can be woven or knitted into the fabric, stitched onto the garment, embroidered or printed directly onto fabrics, with various degrees of success. The electro- conductive textiles have applications not only as medical textiles, but also in electromagnetic shielding, in heating pads and in a range of sensors [12].

Applications of smart textiles in healthcare range from surgical uses of a single fibre to complex wearable and auxiliary systems for personalised care [13]. The ability to identify that an individual has declining health and subsequently alert healthcare providers, potentially allows smart textiles to be used in preventive medicine and in managing pre-existing disease, whether as an inpatient or in the wider community.

EU project, BIOTEX, developed a range of e-textile sensors that can measure sweat rate and the electrolyte concentration and pH of the sweat, allowing for potential monitoring of both the fluid and electrolyte status of patients and a multi-layered flexible braided structure has been developed which acts as a moisture sensor based on capacitance changes within the braid caused by changes in relative humidity in the adjacent environment. Unlike thin film devices, the properties of the braided structure were such as to enable it to be compatible with the other textiles in bandages or clothing and it was found to be highly sensitive for relative humidity between 22% and 94% [14].

Measurement of cardiorespiratory parameters, electromyography and electroencephalography can be achieved with garments and fabrics which consist of a sensor to monitor physiological parameters, conductive yarns and an interface that can interpret and collect incoming data prior to transmission to a remote location, for example, by Bluetooth [15].

In addition, an American company produced one of the earlier garments released that allowed for physiological measuring. The garment called the LifeShirt® (VivoMetrics, Vivosense; San Diego, USA) had attachments that monitored blood pressure, EEG, temperature and pulse oximetry. Whilst no longer available for sale, production of this garment did highlight the possibilities for future design and the breadth of clinical application for which design and manufacture may be suitable [16]. Other garments produced have been used for a range of applications, including home monitoring for episodes of sleep apnoea. In orthopaedics and sports medicine, a knee sleeve with in-built goniometers was trialled. These consisted of developing a textile goniometer that coupled two knitted piezo-resistive layers through an electrically-insulating layer. This would appear to have many potential applications for post-operative physiotherapy in orthopaedics and sports medicine. Optical fibre Bragg-Grating sensing was developed some time ago and proves to be a useful technique for monitoring posture and pressure [17]. Attention has also been directed at how smart textiles may improve prosthetics for amputees. For example, electronic skin has sensory capabilities whilst textile-based sensors can be worn over prosthetics. Flexible, stretchable piezo-resistive fabrics are available for a range of pressure-sensing applications that can be incorporated into robotic limbs [18].

2.5.1 Inherently conductive polymers

Inherently conductive polymers have both sensing and actuation properties. The electrical conductivity of these polymers is known to be caused by their conjugated double bond chain structure. Some commonly had known ICPs include polyacetylene, polypyrrole, polyaniline, and polythiophene. Polypyrrole (PPy) is most suitable as it has high mechanical strength with high elasticity, is relatively stable in air and electro active in both organic and aqueous solutions. Polypyrrole has be used in the development of organic piezo-resistive sensors by depositing thin layers of PPy, by polymerization process, onto fabrics with high elasticity such as nylon lycra® or high compressibility such as polyurethane foam. Conductivity changes results from external deformation of the material. The major advantage of this approach is that the sensors retain the natural texture of the material. However, the problem with these devices is a variation in resistance over time, and a high response time.

2.5.2 Shape memory materials

The shape memory materials (SMMs) can deform from the current shape to a previously set shape, usually due to the action of heat. A strip of metal is heated with a lighter and finds its original shape. In garments the scale is smaller. When these SSMs are activated (at a certain activation temperature), air gaps between close layers of clothing are increased. This is to give better insulation and protection against extremes of heat or cold. In clothing, the temperatures for the shape memory effect to be activated should be near body temperature.

SM Polymers are more flexible than the alloys. Thermoplastic polyurethane films have been made which can be put in between layers of clothing. When the temperature of the outer layer of clothing has fallen sufficiently, the film responds so that the air gap between the layers of clothing becomes broader. This out-of-plane deformation must be strong enough to resist the weight of clothing and movements of the wearer. If the outer layer of clothing becomes warmer, the deformation must be reversed. Some alloys are capable of a two-way activation, triggered by changeable weather and varying physical activity.

2.5.3 Optical fibres

Plastic optical fibres may be easily integrated into a textile. They have the advantage of not generating heat and are insensitive to EM radiation. Optical fibres may serve a number of functions in a smart garment such as transmit data signals, transmit light for optical sensing, detect deformations in fabrics due to stress and strain and perform chemical sensing. Plastic optical fibres can be woven into a textile, however bending of the fibres is an issue during the manufacturing process and also with the end product as mechanical damage causes signal loss. Fig. 2.4 shows commercially available Luminex® fabric woven using optical fibres capable of emitting its own light. It has aesthetic appeal for the fashion industry, also used in safety vests and potential to be used for data transmission.

Coating a fabric with nano particles is being widely applied to improve the performance and functionality of textiles. Conventional methods of adding various properties to fabrics may not last after washing and wearing. However nanotechnology can add permanent effects and provide high durability fabrics. This is due to the large surface area-to-volume ratio and high surface energy of nano particles. Coating with nano-particles can enhance the textiles with properties such anti-bacterial, water-repellence, UV-protection and self-cleaning, while still maintaining breathability and tactile properties. Nano-Tex has a range of coated products, to resist spills, repel and release stains, and resist static improving the performance and durability of everyday apparel and interior furnishings.

Fig. 2.4 Self illuminating optical fibres

2.5.4 Application of smart textiles

Being able to monitor physiological variables and communicate the relevant information has the potential to revolutionise healthcare by enabling remote monitoring of patients, thus reducing overall admissions to hospital, the duration of stay, and perhaps identifying early onset of disease. In a fiscally-tight public health care sector, these enhancements proffer benefits. In 2018, the global smart textile industry was estimated to show a projected compound annual growth rate of 4.9% by 2025, owing to a combination of the rising geriatric population, ongoing technological advancements and stringent legislative framework mandating the use of medical textiles. Indeed, a further analysis of the market suggests that compound annual growth rate may be higher, at approximately 9.5%, during the period 2018-2027 [19].

In a similar manner, the market for smart textiles continues to grow as applications across several industries are found. The global smart textiles market is expected to exhibit a compound annual growth rate of 30.4% through to 2025 and rise to a valuation of US$5.5 billion by 2025. This is expected to be driven by growth in medical, sport and fitness and military and defence applications [20].

For example in case of smart textiles in medical applications several issues to be resolved:

- Acceptance by both patient and health professional needs to be achieved
- Sterility and the efficacy of the sensing function in the presence of any form of moisture such as bodily fluids, needs to be considered
- Efficacy following cleaning requires investigation when the product is designed for re-use
- The security of the data being collected and (possibly) transmitted
- Finally, what happens when the smart textile malfunctions?

All five factors are critical to the success of smart textiles. Important ethical considerations surround the information/data collected and forwarded. From a clinicians' point of view, bedside skills and the importance of a thorough history and examination ought not to be negated for readily-accessible and measurable data.

(a) Health: The development of wearable monitoring systems is already having an effect on healthcare in the form of 'Telemedicine'. The wearable devices allow physiological signals to be continuously monitored during normal daily activities. This can overcome the problem of infrequent clinical visits that can only provide a brief window into the physiological status of the patient. Representative examples are: Wireless-enabled garment with embedded textile sensors for simultaneous acquisition and continuous monitoring of ECG, respiration, Electromyography (EMG) and physical activity.

The smart cloth embeds a strain fabric sensor based on piezo resistive yarns and fabric electrodes realized with metal-based yarns sensitized vest including fully woven textile sensors for ECG and respiratory frequency detection and a portable electronic board for motion assessment, signal pre-processing, and Bluetooth connection for data transmission. Wearable sensitized garment that measures human heart rhythm and respiration using a three lead ECG shirt. The conductive fibre grid and sensors are fully integrated (knitted) in the garment (Smart Shirt).

(b) Life belt: Life belt is a trans-abdominal wearable device for long-term health monitoring procedures for both the parents. This life belt is very useful in case of pregnant women working in remote areas and faces certain health problems (e.g. high blood pressure, kinetic problems requiring immobilization, multiple pregnancies). Life belt is a support tool for the obstetrician, who is enabled to monitor patients remotely, evaluate automated preliminary diagnosis of their condition based on collected and analysed vital signs, access patients' medical data at any time and most importantly be alerted.

(c) Life jacket: Life jacket is a medical device worn by the patient that consequently reads blood pressure or monitors the heart rate; the information is transferred to a computer and read by medical staff. A specialized camera in the form of headwear has been developed to be worn by paramedics. Visual information captured by the camera can be transferred directly to medical staff at the hospital enabling them to advise instantly on appropriate treatment. Cuff-less BP can be measured from the radial pulse waveform by arterial tonometry by using this life jacket.

(d) Military/defence: All countries are exploring how smart clothing can be used to improve the safety and effectiveness of military forces. In extreme environmental conditions and hazardous situations there is a need for real time information technology to increase the protection and survivability of people working in those conditions. The performance and additional capabilities would be of immense assistance for the defence forces and emergency response services. The requirements for such situations are to monitor vital signs and ease injuries while monitoring environment hazards such as toxic gases. Wireless communication to a central unit allows medics to conduct remote triage of casualties to help them respond more rapidly and safely.

(e) Fashion and entertainment: As the technology is becoming more flexible various electronic devices and components clothes becoming truly portable devices. Already there are textile switches integrated into clothing for the control of such devices. While technology may be hidden through invisible coatings and advanced fibres, it can also be used to dramatically change the appearance of the textile, giving new and dazzling effects. Light emitting textiles are finding their way onto the haute couture catwalks.

(f) Sportswear: Sports are area of the important smart clothing developments. In general a number of important functions can be implemented using smart devices or clothing. These include monitoring heart rate, breathing, body temperature and other physiological parameters; measuring activity, for example determining the number of steps taken, the total distance travelled; acting to actively stimulate muscles e.g., using electrical muscle stimulation; work against activity to provide 'smart' resistance training; Record aspects of performance, such a foot pressure or specific joint movements; protect against injury. Global Positioning Systems (GPS) incorporated into walking shoes which allow the user to be tracked by mountain rescues services. They can also be used to monitor the where about of young children. Gloves that contain heaters, or built in LED's emitting light so that a cyclist can be seen in the dark.

2.5.5 Non-woven fabrics for infection control

EDANA's infection control conference, Prague covered many aspects of infection control, ranging from infections such as Avian-Flu, SARS, Ebola and HCAI (Health Care Associated Infections) and the critical role the nonwovens industry is playing in this field. Barry Cookson, director, laboratory of Healthcare Associated Infection, Colindale, U.K. have highlighted the paradox of HCAI [21]. It is estimated that about one-third of HCAIs are preventable by improvements in infection control which is a feasible goal and is achieved much faster and more efficiently with industry/health care/public policy partnerships, which foster teamwork, synergies and exchange of best practices, he said.

Russell et.al [21] confirmed that the use of barrier fabrics and the medical devices to protect the staff and patients is more necessary now than ever. It is therefore critical for those procuring medical devices to be knowledgeable about them and make the correct choices regarding quality and suitability for purpose. By preventing infection will save money, but savings to the hospital or agency are usually reflected in other budgets—not in infection control. There is challenge to produce better barrier fabrics, offering even better protection under the most difficult circumstances while microbes continually change their properties. There are critical areas that help determine the effectiveness of infection control, ranging from the environment, design and preparation of the operating room to the preoperative preparation of personnel and the patient. Using the right surgical barrier and protective gowns, masks and head-foot wear are some means to achieve the protection from infection.

For few decades nonwovens have been preferred for medical fabrics used in the operating room for the prevention of disease and infection. The principal advantage of nonwovens is that they are used only once on one patient and incinerated after use, thus avoiding the need for handling and the consequent potential for spreading contaminants. For use in the operating room single-use medical nonwovens meet all the requirements stipulated by EN 13795: the avoidance of bacterial penetration and the spreading of contaminants, water- repellency, which is not only a matter of comfort, but is essentially aimed at preventing bacteria from penetrating the fabric softness, breathability and drape-all relating to the comfort of the user.

Nonwovens provide the additional attributes of low linting and cost-efficiency. Hydro entangled carded spun laced fabrics are very comfortable, offering optimal breathability, drape, moisture vapour permeability and other comfort related properties. Their barrier properties, however, compare less favourably with other types of nonwoven fabrics. SMS- nonwoven, which is a polymer-to-web sandwich construction including at least two spun laid webs and large number of melt blown webs provides the highest water penetration resistance without the need for additional, subsequent repellency treatment and still, it is air permeable. Better results can be achieved only with fully impervious film laminates, which are also breathable. The introduction of an increasing number of melt blown webs in the SMS is viewed as a way of increasing water repellency, bacterial barrier properties and resistance to water penetration above 800 mm water column.

The nonwovens industry has demonstrated the ability to rapidly respond the disasters with products that aid in the prevention of disease transmission, and it continues to develop enhanced performance materials to meet these demanding applications. Over 100,000 tons of nonwovens were used in the fight against SARS in China in 2003. Owing to outstanding bacteria filtration capabilities, barrier properties, splash resistance and breathability, nonwoven was used in masks and protective apparels during the crisis.

A trend toward outsourcing sterilization is growing and is supported by a number of decision makers inside the hospital who do not think that sterilization activities are a core business of the hospital. Packaging not only makes it possible to store sterile medical devices and to use them when needed, it also makes it possible to have the devices treated in a specialized and dedicated unit namely the central sterilization department. The choice of packaging for nonwovens is extremely important as it has to meet its primary aim which is to guarantee the sterility of the content until the time of use. Sterility always implies that the packaging is intact because otherwise the microbial barrier is compromised.

2.6 Synthetic fibres and pollution

Over the last few decades there has been a major shift in the materials chosen by manufacturers, designers and consumers alike. Whereas natural fibres dominated the scene fifty years ago, we now see an abundance of synthetic and man-made materials taking centre stage. The industry is overrun with polyester, acrylic and nylon. The reason behind this shift is no secret. Synthetics are cheaper and easier to produce in large quantities but it is damaging the environment in a big way contributing an overwhelming amount of chemicals, waste and carbon emissions.

Synthetic materials made from petrochemicals are not readily biodegradable, leading to the long-term pollution. Unlike nylon, polyester is easy to recycle, reducing some of the waste accumulating in the landfills. It also makes up a quarter of all the soda bottles; but polyester and nylon blend can take up to 40 years to decompose if not discarded responsibly [22 100].

With the unending discussion about renewable energy and fossil fuel, and the harm it is causing to our environment, the unhealthy carbon emission, depleting the ozone layer and ultimately bringing about the impending catastrophic global warming. Environmental scientists warn about, to decide if we all want this planet to survive our next generations.

Carbon emission must be minimized to keep our environment and ecosystem sustainable, the oil rigs must be stopped and the world should move to the more environmentally sustainable source of energy. The textile industry contributes to environmental degradation by 10% of global carbon emissions, which scarily huge damaging the ecosystem.

The production of textiles using synthetic fibres by choice of manufacturers and apparels designers, and the shift in the demand of more organic clothing material by consumers, the natural fibres which dominated clothing production materials may soon be a thing of the past. The textile industry is dominated by synthetics and microfibres which are cheaper, but it is damaging the environment on a massive scale. The danger of these synthetic fibres and fabrics are terrible to the environment.

2.6.1 Health risks of synthetic fibres

Although these synthetic fibres might be less expensive than the natural fibres and easier to produce in large quantities, they pose higher health risks to the consumers. Polyester is strongly linked to hormonal disruption and even the formation of breast cancer cells. This health risk is not only suffered by the consumers, but factory workers also face this health hazards. The process of manufacturing of polyester, nylon and other fibres from petroleum is long, toxic and nasty process; and the workers including children exposed to terrible conditions, and face various debilitating health issues.

2.6.2 Environmental risks of synthetic fibres

The planet earth is being poisoned without repair because of these synthetic fibres. It is reported that the clothing industry is accountable for over 20% of industrial water pollution in the world. Some of these chemicals which are waste products of the manufacturing process are drained into various water bodies; most of these chemicals are impossible to break down, meaning the water is forever polluted no path to redemption.

Beyond its evident pollution of oceans, synthetic polymers can also present environmental problems. The Environmental Working Group organization shows that the DuPont Co. leaked contaminates used in their production of Teflon into watersheds. According to U. S. Environmental Protection Agency, this chemical accumulates in the gills of fish and can travel up the food chain. Even beyond their persistence in oceans and water pollution from their production, synthetic polymers are a significant challenge on land because they are often disposed of in landfills permanently and slowly leaking toxins into soil as time passes.

According to the Clean Air Council organization, Americans use estimated 100 billion synthetic plastic bags, each year, and only 1% is recycled. These can leach harmful chemicals in the soil, their longevity and non-biodegradability means new landfills will be a constant need as synthetic polymer use continues and grows. These plastics bottles clog the waterways so even marine life isn't safe. The synthetic materials deposition has been found in intestinal tract of fishes. Seabirds too have been found dead, and cause of death has been ingestion of synthetic fibres that they thought was food.

Fabrics and chemicals have different impacts depends on what they are made with. The production of nylon emits nitrous oxide, a greenhouse gas 300 times more dangerous to the ozone layer than carbon dioxide. The production of polyester requires plenty of water in various process, the contaminated water after usage is flushed back into the waterways. Most dyes are made from hazardous chemicals which are used mostly for production of garments. The unused dyes are then washed into rivers and waterways, polluting the environment.

2.6.3 Long-term adverse effects of synthetic products

Synthetic materials are non-biodegradable, synthetic products take a long time to decompose, creating long-term pollution. Nylon is hard to recycle, making them hard to decompose, so accumulates in landfills. Polyesters are easy to recycle, which makes them less harmful to the society. Recycled polyesters are used to make eco-fashion hence eco- friendly. Synthetic waste product derived from textile factories to dyes are mainly flushed into waterways and sewers, making the environment more harmful and dangerous.

Only Americans dump each year about 10 million tons of synthetic garments in to landfill which is equivalent to 80 pounds per person. The environmental protection agency (EPA) estimates that diverting all of those often-toxic trashed textiles into a recycling program would be the environmental equivalent of taking 7.3 million cars and their carbon dioxide emissions off the road. According to the United Nations Industrial Development Organization, each person worldwide contributes nearly 20 tons of harmful carbon dioxide and nitrous oxide emissions based purely on the production of synthetic fibres. Nonetheless, a polyester and nylon blend can take up to 40 years to decompose if not discarded responsibly.

Water is essential to life and is naturally abundant on earth, though our existing sources are becoming more and more polluted every day. Polyester uses huge amounts of water in the final cooling process; the machinery used also requires lubricants that can seep into the supply. Nylon requires less water to produce than even natural materials, but on the other hand, synthetic materials still require large amounts of dyes in order to obtain the desired colours, much of which goes down the drain and ultimately out to the ocean. Thus, the use of these strong dyes along with other harmful chemicals, including carcinogens, can create significant damage to the water and air.

The textiles and allied industry also plays a huge role in polluting drinking water. The process is so toxic, that these industries are shifted to Asian countries viz. China, Indonesia and Bangladesh etc. due to the availability of cheap labour and lax environmental regulations. This leads to significant damage to local areas. There is an increasing alertness to the idea that this makes environmental issues as matter of social discrimination. However, pollutants rarely stay in one place and one can see the effects across the globe as the polluted air and water spreads worldwide.

2.6.4 Environmental impact of medical waste

Disposable hospital supplies trash such as plastic syringes, single-use gowns, sterile packaging, surgical instruments and much more are piling into dump is hazardous to the environment. While the amount of waste is difficult to quantify, a report from the Ontario Hospital Association estimates hospitals are responsible for at least 1% of non-residential landfill waste. Hospital waste comes from areas like food, electronic and paper waste, but the biggest source is clinical care. It’s estimated that North American operating rooms alone are responsible for 20%-33% of total hospital waste. US study found that a single hysterectomy produced 20 pounds of waste in plastic, packaging, drapes, and so on (bio-waste was not included). The problem may be getting worse due to patient safety, cost and convenience, more and more clinical instruments and supplies are being marked as ‘single use’ and dispose out. The use of disposable items in health care i.e. IV tubing, for example, has been thrown out since the 1960s because it is near impossible to adequately clean. Disposable surgical drapes have been used for the last 20 years, says Victoria Noguera, Director of Preoperative Services and Gynaecology at Women’s College Hospital. But the shift toward disposables is still continuing ‘with disposable [surgical] instruments being the latest in that trend,’ according to Cassandra Thiel, School of Medicine and Wagner Graduate School of Public Service of New York University [3].

According to a Toronto doctor who wishes to remain anonymous, for procedures outside the OR, scissors, suturing equipment and so on used to be resterilised and wrapped in washable linen (which would be used in the procedure). These instruments have all been switched over to the disposable kind. And the surgical trays are now wrapped in plastic, which is also thrown out. If a piece of equipment breaks in a tray and all the instruments of the entire tray has to be thrown out generating huge amount of garbage. More cost-effective disposable products have also come on to the market because of advances in manufacturing technology. Also, manufacturers may be erring towards more ‘single use’ items to avoid liability when they’re not certain a product can be 100% sterilized. Recently, says Ann Mitchell, clinical director of obstetrics and gynaecology at The Ottawa Hospital, breast pump equipment once sterilized by hospitals was suddenly marked as single use, meaning the plastic tubing had to be thrown out after each feed. When hospital leaders questioned the move, the company compromised and marked the equipment as single patient, so that one patient could use the same equipment during the course of the hospital stay.

In US, several organizations are calling for more environmental products. To start with, four major health care companies and two NGOs launched the Green health Exchange, an organization that will investigate and promote green alternatives. Of course, green products can often be more expensive than more waste-creating alternatives, because they have smaller markets and may use more expensive raw materials. Still, in cases where the environmental benefits are high, companies are willing to pay premiums to meet corporate social responsibility goals. ‘The US is much further ahead on this than Canada,’ explains Ed Rubinstein, director of ECES at the University Health Network (UHN), Toronto [23].

Still, it remains voluntary for hospitals to implement green disposal and/or procurement programs. The best way to reduce waste coming from operating rooms and patient wards is to financially incentivize change. Provincial and local governments can increase the costs of waste for hospitals and reward hospitals that can demonstrate landfill reduction. But now there are organic gowns that actually dissolve after use. The innovative technology, also used for surgical drapes and other disposable supplies that hospitals consume voraciously--is expected to drastically reduce the amount of medical trash dumped in landfills. The paper- thin gowns, similar in texture to Handi Wipes, disintegrate when immersed in hot water. ‘This technology will change the way that medical waste is disposed-off,’ said Rick Setian, Isolyser HealthCare, the company that developed the material [24].

When one of the new green gowns is discarded by a patient or doctor, it is tossed into an industrial-sized washing machine, heated to 190^0 F and agitated for 45 minutes. The gown disappears, leaving only a teal-coloured fluid, which is drained and pumped to the nearest waste water plant, just like any other dirty water. The material, called Orex, is being used to make disposable surgical supplies such as gowns, drapes, sponges and towels. In the future, the manufacturer says, the material may be used to make nonmedical products such as disposable diapers. The organic polymer used in Orex has long been found in soluble products such as the coating on many pills. 'It will eliminate as much solid waste from the landfills as possible,' said Chris Van Gorder, chief executive officer of Anaheim Memorial Hospital, which he said is the first in the country to use the new product. The 250-bed facility used to generate about 200,000 pounds of surgical waste a year. With the new procedure, 44%, about 88,000 pounds, goes down the drain instead of being buried in a dump, a savings of about $18,000 for the hospital.

2.7 Coating of textiles

Modifying the yarn and fabric structures by coating the textiles thermo-physiological comfort characteristics can be improved by improving the transmission characteristics of heat, moisture and air through the fabric, and the tactile comfort can be improved by proper rearrangements of fibres in yarns and fabrics.

2.7.1 Materials for coating

The some of the most commonly used materials for coating the various textiles are:

- PVC coated polyester fabrics (PVC = polyvinylchloride)
- PTFE coated glass fabrics (PTFE = polytetrafluoroethylene) and of these PVC coated polyester is more widely used than PTFE coated glass due to compromises made in the ratios between cost, performance and durability.
- Silicone coated glass fabrics
- PTFE coated PTFE fabrics
- ETFE foils (ETFE = ethylene-tetrafluoroethylene copolymer)

Other materials in use are: aramid (aromatic polyamide) and LCP (liquid crystal polymer based on aromatic polyester). The top coats are based on polymeric materials such as: acrylic, polyvinylidene fluoride (PVDF) or polyvinyl fluoride (PVF) for PVC coated polyester fabrics, and fluoroethylenepropylene (FEP) for PTFE coated glass fabric.

Base fabrics for coating are generally woven obtained by inserting weft yarns between two layers of warp yarns at 90° to the warp yarns, following a construction designed by the number of yarns per cm and a weave pattern. The main weave patterns used in membrane are plain weave or a 2-2 basket weave [25 101]. Woven fabrics are characterized by:

- Areal density in gsm
- Number of yarns per cm in weft and in warp
- Weave pattern
- Crimp of the yarns in weft and warp
- Count of warp and weft
- Count of warp and weft

2.7.2 Various types of coating

Generally, after weaving a special finish is applied to the fabrics. The purpose of this very thin layer is to increase the chemical and physical compatibilities between the fabric and its first coating. A better compatibility means firstly, a good wettability of the fibres by the finishing material at the processing stage, and secondly, after wetting a good physical and chemical adhesion between fibre and finishing material.

For example, for polyester fabrics, the use of low-wick yarns means that a hydrophobic compound has been put onto the fibre in order to have the best fibre resin compatibility so as to avoid moisture diffusion at the fibre/resin interface. For glass fabrics, a “base coat” is applied to provide a solid anchoring of the PTFE coat. It also determines the flexibility characteristics of the finished coated products. Depending on the expected properties, different formulations can be used. For low reactive materials, like aramid fabrics, a special chemical modification of the surface of the fibres is necessary to avoid delamination between coating and fabric.

Protection of the fabric is generally achieved by applying a resin coating in paste form. Coatings have specific chemical formulations which make the basic resin suitable for processing as well as increasing the levels of performance of particular characteristics such as fire fungal resistance, and colour pigmentation. The coating process is specific to each chemical resin used. A coating is characterized by weight of fabric in gsm and thickness measured as either the total thickness of the finished product or as the distance between the top of the fabric’s yarn and the outer surface of the coating.

(a) **PVC coating:** The PVC formulation is a flame-retardant type, as it has to comply with several strict flammability regulations. These have a distinct impact on the composition of the plasticized PVC. For the direct coating process, the PVCs used are “paste” PVCs made of either suspension PVC or emulsion types, and containing significant quantities of emulgators. The choice of those polymers in the production process of the coated fabric is critical in the way that the type and concentration of the emulgators have an impact on the processing, thermal properties and surface aspects. The second major component in the coating is the plasticizer. Plasticizers may be chosen out of a series of phthalates, phosphates, chlorinated products or other esters.

Concerning flame-retardant properties, the phosphates are of the most preferred plasticizers, where in terms of flame-retardant efficiency, the product is more efficient with a higher amount of acryl groups. Upon using phosphates however, one should keep in mind that these molecules have a high tendency to migrate and are susceptive to biological attack. As a matter of fact they act as a feedstock for bacteria and fungi. Phthalates on the other hand are the most widely used plasticizers. Their very good compatibility with PVC however makes them irreplaceable in the formulation of soft PVC. As phosphates, they are also susceptible to migration, and hydrolysis. The latter occurs more strongly with the branched ones rather than with the linear types. Chlorinated paraffin is the third type of plasticizers. They are extremely efficient in plasticizing in combination with an adequate flame-retardant property, but they also have a very strong tendency to migrate to the surface, resulting in a strong dirt pick-up. To render the fabric its lustre and beauty, the PVC is always pigmented, mostly in white. Also type and concentration of the pigment play an important role in the colour, UV stability and opacity. As with the plasticizers, the pigments may affect the light stability and surface properties as dirt pick-up.

To overcome the weathering problem and dirt pick-up the PVC coating is stabilized with molecules acting as thermal stabilizers, oxidation stabilizers and UV light stabilizers. In order to fulfil the flammability criteria, flame retardant additives are added such as antimony oxide, aluminium trihydrate, phosphates, etc. The excellent flame retardant properties of the PVC coated textile itself however is intrinsically given by the chlorine of the PVC. Together with the antimony oxide the chlorine radicals in the gas phase exhibit high recombination efficiencies, killing in this way the flame instantaneously. The phosphates and aluminium hydroxides on the other hand act as an endothermic surface barrier preventing further pyrolysis of the burning material. The recycling of PVC coated fabrics is possible using a process which allows the separate recycling of the PVC resin and the polyester fibres by selective chemical dissolving. The used materials are mechanically cut into small pellets approximately 20mm to 60mm long. In this step all heterogeneous materials, such as metallic parts, can be removed. The plasticized PVC is dissolved in a kenotic solvent at 115°C while PET fibres remain in suspension in the medium. PET fibres are recovered by filtration and drying. The PVC solution is then precipitated at room temperature using a non-solvent like water. In this step, it is possible to introduce additives in order to restabilise the resin. The precipitate is spin-filtered to give a free flowing powder whose granulometry is about 350µm. This powder can be used for compounding without any other treatment. Water and solvent are 'phase separated' and 'separated recovered' for reuse. The whole process works in a completely closed loop and each of the two components are reused.

(b) **PTFE coatings:** Textile membranes are also manufactured by dip coating glass fabrics with PTFE dispersion. Drying and sintering at 350°C- 380°C finish the coating process. PTFE is a unique polymer with outstanding properties, which cannot be achieved by most other polymers. These remarkable properties are closely related to the molecular structure characterized by long chain molecules consisting of recurring tetra fluorethylene monomer units. The carbon-fluorine compound has dissociation energy of 460kJ/Mol and represents one of the strongest bonds in organic chemistry. The PTFE chain adopts a slightly twisting helix with a carbon-based core and an outer sheath of fluorine atoms, which completely shields the chain backbone from chemical attack. Since PTFE's upper limit of continuous service temperature is +260°C it can be used in hot climatic zones. The lower limit of the continuous service temperature is -200°C. Temperature variations have no influence on the lifespan. Plasticizers are not necessary for flexibility and impact strength at low temperatures. PTFE has a low thermal conductivity (0.25 – 0.50W/Km) and good insulating properties. PTFE is under normal conditions inflammable. Only if the environment contains more than 95% oxygen will PTFE fail to resist fire. PTFE has a high melt viscosity, which prevents the forming of droplets of molten coating during a fire. PTFE is resistant against the strongest corrosive substances, like hydrochloric acid, hydrofluoric acid, sulphuric acid and nitric acid, hot sodium hydroxide solution, hydrazine or nitrogen oxides. PTFE is not soluble in most common solvents, such as alcohols, esters, ketones and petrol. Therefore the PTFE membranes are inert against all environmental pollutants such as industrial and traffic exhaust gases. The molecules are macroscopically non polar. Its surface energy is one of the lowest known (approx. 18.5 mN/m) and leads to the anti-adhesive nature of PTFE. Therefore, the PTFE membranes do exhibit good self-cleaning and water repellent properties. Because of its hydrophobic properties, PTFE is an excellent protection for the textile reinforcement of the membrane, since glass filaments lose their tensile strength in contact with humidity. PTFE is totally resistant to UV and IR-radiation. PTFE membranes show no ageing or embrittlement due to UV/IR-radiation. Unlike PVC this performance is achieved without the need of plasticizers, antioxidants, UV-absorbers etc., which could migrate out.

(c) **Top coat:** Top coats are lacquered in order to ensure good cleanability, good slip and processing, and they offer an efficient barrier for plasticizer migration and weather influences. Most liquid lacquer systems for PVC coated polyester fabrics are made out of acrylics, PVDF/acrylic mixtures, PVDF (polyvinylidene fluoride). PVF (polyvinyl fluoride) films can also be used and provide a good resistance and the lowest erosion during ageing. Fluoropolymers have a better resistance to UV than acrylics. Attention should be given to the fact that one always has to make compromises between, for example, optimised weldability, optimized weathering resistance and aesthetic performance. For PTFE coated glass fabrics the top coat consists of FEP (fluoro ethylene propylene copolymer) to enhance waterproofness, fungal resistance and weldability due to a lower softening point of FEP than PTFE

(d) **Silicon coating:** Silicone coating is based on silicone rubbers which are obtained by cross-linking during processing, of silicone macromolecules: Different formulations of silicone, combined with different coating processes, allow the production of materials adapted to different uses. Basically, silicone rubbers combine elasticity and mechanical resistance in a wide range of temperature (-50°C to +200°C) even aggressive atmosphere conditions. Despite a lot of advantages, such as ease of handling, when compared to PTFE coated fabrics the dirt collection and “seam ability” of silicone coated fabrics have been limiting factors. However recently developed surface treatments are helping to counterbalance these defects.

So, on the basis of the performed theoretical considerations, design of the coated textile products and corresponding properties, it is possible to make a target product which will meet all requirements. In the case of the multi-layered textile composites, it is necessary to define material anisotropy in the weakest directions, which are also the most responsible for deformation. In these places deformations in form of changes in material dimensions per unit of length are created and the required shape results. By use of woven fabrics as the basic layer of textile structured multi-layered composites in laminating a relatively high anisotropy occurs which can be reduced by polymer coating. However, due to an exceptionally good strength in the warp and weft direction and its abrasion resistance, breaking and good physiological properties its presence will be relatively widespread in relation to knitted and nonwoven fabrics.

The use of the fabric on the composite front side provides great design possibilities such as printed fabric for camouflage military clothing etc. By coating polyurethane paste to textile materials, materials known as artificial leather is obtained. They occupy an important place on the market. Artificial leather is unthinkable without the textile substrate. In most cases these are woven or knitted fabrics which transfer their properties to the final properties of artificial leather. Since they are materials mostly used as outerwear or upholstery fabrics, their physiological properties are essential. Air, water and water vapour permeability, their strength and durability depend on the properties of individual properties of coated materials and final products. Since structured multi layered materials consist of different materials and various binders, besides material comfort it is important to pay great attention to their compatibility in different conditions.

The target product to meet market requirements can be produced by appropriate selection of recipes for polymer coating, and by determination of construction parameters of the textile fabric as well as raw materials and production conditions. Subsequent investigations should include multi axial testing of a series of models with different woven and knitted fabrics in order to reduce anisotropy, especially of the materials being less strong and having higher elongation. A change in polymer coatings and their properties related to textile materials affect final properties of multi layered materials. Likewise, adding a target polyurethane coating and after treatment, even the selection of colour can provide a target product with appropriate properties.

2.8 Anti-microbial materials and its application

There are two different aspects in antimicrobial finishes, the first is the protection of the textile user against the microorganism and the second aspect is the protection of textile itself from microbial damage as these materials attack on microbes. The use of antimicrobial finishes to prevent unpleasant odours on intimate apparel, under wear, socks and athletic wear is an important requirement in these days. Since the odours are produced by the bacterial decomposition of sweat and other body fluids, controlling the growth of such bacteria reduces or eliminates the problem. In addition to the above application, antimicrobial finishes are particularly important for industrial fabrics meant for tents, screens, tarpaulin, fabrics used in hospitals, nursing home, schools, hotels and in public areas.

Drug resistance is a serious global problem, and spread of the resistance poses additional challenges for clinicians and the pharmaceutical industry. Use of herbal medicines in the developed world continues to rise because of their rich source of novel drugs. Their bioactive principles form the basis in medicine, nutraceuticals, pharmaceutical intermediates and lead compounds in synthetic drugs. Plant based products/ extracts are cheaper alternatives to the development of synthetic drugs. Screening medicinal plants for biologically active compounds leads to development of less expensive new antimicrobial agents with improved safety and efficacy. These compounds after possible chemical manipulation provide new and improved drugs to treat the infectious diseases [26].

2.8.1 Mechanism of antimicrobial finishes

The antimicrobial finishes products can be divided into two types based on the mode of attack on microbes. First, in which chemicals can be considered to operate by a controlled-release mechanism. The antimicrobial agent is slowly released from a reservoir either on the fabric surface or in the interior of the fibre. This ‘leaching’ type of antimicrobial can be very effective against microbes on the fibre surface or in the surrounding environment. The second type consists of molecules that are chemically bound to fibre surface. These products can control only those microbes that are present on the fibre surface, not in the surrounding environment. ‘Bound’ antimicrobials, because of their attachment to the fibre, can potentially be abraded away or become deactivated and lose long term durability. Antimicrobial finishes that control the growth and spread of microbes are called biostats, i.e., bacteriostats and fungi stats. Actually bacteriocides and fungicides kill microbes.

2.8.2 Antimicrobial finishes

Various types of chemicals are used for producing antimicrobial finishes. Controlled release chemicals Triclosan is one of the most widely used antimicrobial product. Although it is effective against most bacteria, it has poor anti-fungal properties. Quaternary ammonium salts have been found to be effective as antibacterial agents and used for swimming pools. Organo silver compounds (silver ions) can be used to impart antimicrobial properties in the fibres. Bound chemicals Octadecylamino dimethyl trimethoxysilylpropyle ammonium chloride and poly hexa methylene biguanide are few chemicals used as bound chemicals for antimicrobial activity [26].

Chitin is one of the most abundant polysaccharides found in nature, derived from marine shells. It is made up of a linear chain of acetyl glucosamine group. Chitosan is the deacetylated compound of chitin. The process of deacetylation involves in the removal of acetyl groups from the molecules of chitin leaving behind chitosan, with a high degree of chemically reactive amino group. Owing to this, chitosan has two advantages over chitin. In order to dissolve chitin, toxic solvents such as lithium chloride and dimethyl acetamide are used, whereas chitosan is readily dissolved in dilute acetic acid. The second advantage is that chitosan possesses free amine groups (-NH2) which are the active sites for many chemical reactions, including the reaction with cellulose.

Chitosan, which is obtained by alkaline treatment of chitin, is the new range of chemical used for antimicrobial treatment. Chitosan can be applied by microencapsulation or by reactive bonding to cellulose and by crosslinking of chitosan using crosslinking chemicals. The advantages of the antimicrobial finish with chitosan include high absorbency properties, moisture control and promotion of wound healing, non-toxic and biodegradable properties.

Azadirachta Indica (A. Indica) (Neem) plant; extracts from bark, leaves shown to exhibit antimicrobial effects against a wide variety of microorganisms. Depending on the type of antimicrobial material, suitable cross linking agents are also added while applying the finishes on the fabrics for better overall performance of treated fabrics including water repellence and durability.

2.8.3 Antimicrobial activities on cotton fabrics

Number of researchers has carried out studies on antimicrobial characteristics of cotton fabrics using various antimicrobial finishes and cross linking agents. In of the studies the cotton fabrics and cellulose films treated with fluorocarbon resin (Asahi Guard AG-480) with and without crosslinking agents (isocyanate blocked copolymer and aziridine) were washed and subsequently heat treated. It was observed that water repellency of the fabrics decreased with washing and recovered with heat treatment. The decreased water repellency with washing was controlled by using the resin with a crosslinking agent. To investigate surface tension and surface chemical composition of the fabrics after washing and subsequent heat treatment, the contact angle to water and critical surface tension of the films were measured along with an ESCA analysis of the fabrics. Adding cross linking agents to the fluorocarbon resin treatment controlled the decrease in F1s intensity and the increase in O1s intensity with subsequent washing.

Chitosan have been used to treat cotton fabrics to impart antibacterial activities successfully since last decade. The antimicrobial activity of chitosan is influenced by a number of factors viz., the type of chitosan, the degree of deacetylation, molecular weight and pH. The antimicrobial activity of chitosan is higher at lower pH values. Cotton fabric samples were treated with chitosan of different concentration, molecular weight and degree of deacetylation to study their effect on antimicrobial activity. Treated samples were subjected to antimicrobial tests using the bacterial strains E. coli and the Hay bacillus. Bacteria reduction was evaluated using the modified Quinn method. E. coli was effectively inhibited at 0.3 g/L chitosan solution and the Hay bacillus at 0.5 g/L. To bond the chitosan to the fabrics chemically, glutaric dialdehyde was chosen as the crosslinking agent. Cotton fabrics treated with glutaric dialdehyde and chitosan showed a good ability to inhibit bacteria reproduction. IR spectra of the surface of cotton fabrics and SEM pictures of fibres were presented.

Tavaria et al studied the antimicrobial action of chitosan upon selected skin S. aureus. They isolated S. aureus from normal skin of 24 volunteers and studied their survival upon contact with chitosan impregnated cotton fabric. Low and high molecular weight chitosan were used at two concentrations. Chitosan treatment effectively reduces the growth of S. aureus, by up to 5 log cycles, thus unfolding a potential towards control and even prevention of related skin disorders.

Shin et al (2001) investigated the effect of the molecular weight of chitosan on antimicrobial activity using the chitosan of molecular weight of 1800, 100,000 and 210,000 and similar degrees of deacetylation (86–89%). Cotton fabrics were treated with the chitosan by the pad–dry–cure method. Chitosan with molecular weight of 100,000 and 210,000 effectively inhibited S. aureus at 0.5% treatment concentration. Chitosan with a molecular weight of 1800 was effective against S. aureus at 1.0% treatment concentration. E. coli were effectively inhibited by chitosan with a molecular weight of 210,000 at 0.3% treatment concentration and by chitosan with a molecular weight of 1800 and 100,000 at 1.0% treatment concentration.

Proteus vulgaris was effectively inhibited by chitosan with molecular weight of 100,000 and 210,000 at 0.3% treatment concentration whereas chitosan of molecular weight of about 1800 require 5% concentration to exhibit same degree of inhibition. None of the chitosans significantly inhibited Klebsiellapneumoniae and Pseudomonas aeruginosa below 1.0% treatment concentration. They concluded that chitosan with high molecular weights were more effective in inhibiting bacterial growth than chitosan with low molecular weights.

Lee et al carried out study to produce antimicrobial fabric through Poly Carboxylic Acids (PCAs). An N-halamine precursor phenyl hydantoin (M-APH), which was rendered antimicrobial through exposure to chlorine bleach, was synthesized and was applied on cotton fabric using poly-carboxylic acids as cross-linking agents. Butane Tetra Carboxylic Acid (BTCA) and M-APH treated cotton fabric resulted in increased wrinkle recovery angle and chlorine content. The antimicrobial efficacy of BTCA/M-APH treated cotton fabric against gram positive bacteria Staphylococcus aureus (S. aureus) and gram-negative bacteria Escherichia coli (E. coli) showed a 6 log reduction within 1 minute of contact time. Application of M-APH on cotton fabric along with poly-carboxylic acids provided a good bonding between M-APH and cotton cellulose. At lower curing temperature (140^{o}C-160^{o}C), M-APH dominated the reaction with BTCA, however, at higher curing temperature (200^{o}C- 220^{o}C), the nucleophilicity of cellulose was increased and it became more competitive with M-APH. In a single application process, treatment with BTCA/M-APH produced cotton fabric having durable press properties as well as antimicrobial activities. Chlorine rendered the antimicrobial property on cotton.

Mondy et *al*. tried to impart antimicrobial properties in cotton through polycarboxylic acids (PCAs) cross linking and found successful. For producing antibacterial textiles, the conventional finishing processes have high productivity and low processing costs, but textiles finished in these ways exhibit low durability against laundering. Therefore, cotton fabrics were bleached with hydrogen peroxide, finished with triclosan, and then treated with PCAs; BTCA and CA as crosslinking agents to provide durable antibacterial properties (Orhan et al 2009). The surface of fibres treated with BTCA had a greater crosslinked area, and the surfaces of fabrics treated with CA were exposed to greater amounts of deformation due to the mechanical and chemical influences after 50 launderings. The bleaching and finishing treatments did not dramatically affect the breaking strength. However, the polycarboxylic acid treatment (both BTCA and CA) alone showed reductions in the breaking strength when the acid concentration was increased. The polycarboxylic acids were fairly effective against bacteria under test, even at lower concentrations. Adding polycarboxylic acids to the antibacterial finishing recipes enhanced the durability which was tested for up to 50 launderings and the durability of the recipes containing BTCA was much superior to that of the recipes containing CA.

Possibilities of using colloidal nano silver and BTCA in imparting durable antibacterial property in cotton were explored by Montazer et al. Colloidal nano silver was applied on the surface of cotton fabric and stabilized using BTCA. The properties of antimicrobial activity and resistance against creasing were imparted in the samples of fabric as a result of the treatment with silver nano colloidal and BTCA. The antimicrobial property of samples was evaluated against two pathogenic bacteria including E.coli and S. aureus. The durability of applied nanoparticles, colour variation, wettability and wrinkle recovery angle of the treated samples were investigated. The presence of nano silver particles on the surface of treated cotton fabric was proved using EDS spectrum as well as the SEM images. Furthermore, the creation of cross-links was confirmed by the means of both ATR–FT-IR and Raman spectra. In conclusion, it was observed that BTCA played a prominent role in stabilizing silver nanoparticle and imparting durable antibacterial activity.

Microwave curing was employed by Budimir et *al.* (2012) in an attempt to produce antimicrobial cotton medical textiles treated with an antimicrobial finish based on citric acid. The purpose of this study was to examine antibacterial and antifungal activity of these fabrics. The ability to effectively reduce the number of gram negative, gram positive bacteria and yeast was evaluated, specifically comparing the antibacterial activity after two different drying/curing methods. Citric acid and diethyl tetradecyl trimethoxysilyl propyammonium chloride were used for hygiene and disinfection purposes of medical textiles in this study. It was applied by pad dry process and its fixation to cellulose hydroxyl groups was enhanced either by high curing temperatures or microwaves.

Determination of antibacterial activity of finished products was performed according to ISO 20743:2007 standard before the washing and after the 10 washing cycles. Antibacterial activity was tested against E.coli, S. aureus and Candida albicans. Obtained results were confirming the possibility of eco-friendly CA application, for the purpose of antimicrobial finishing of cotton medical textiles. Prevention of nosocomial infections with the citric acid was possible using both curing methods (convection and microwave) and furthermore, the treatment was durable up to 10 washing cycles. Citric acid, as one of the suitable active substances was cross-linked to the cellulose hydroxyl groups by the formation of ester linkages. Its antimicrobial effectiveness against the chosen microorganisms proved to be the best against S. aureus.

2.8.4 Antimicrobial activity of Azadirachta Indica (Neem)

Azadirachta Indica (A. Indica) belongs to the family Meliaceae, commonly known as neem. It is used in traditional medicine as a source of many therapeutic agents. A. Indica (leaf, bark and seed) are known to contain antibacterial, antifungal activities against different pathogenic microorganisms and antiviral activity against vaccinia, chikungunya, measles and coxsackie Bviruses. Azadirachta Indica (neem) is a multipurpose tree with multiple health benefits. Different parts of the plant are shown to exhibit antimicrobial effects against a wide variety of microorganisms.

The study of antimicrobial efficacy of aqueous extracts of leaf, bark and seeds of A. Indica against human pathogenic bacteria (Staphylococcus aureus, Enterococcus feacalis, Proteus mirabilis and Pseudomonas aeuroginosa) and fungi (Aspergillus fumigatus and Candida albicans), determined the minimum inhibitory concentration (MIC) using Agar well diffusion method and micro-broth dilution method. Results showed that leaf extract exhibited strong antimicrobial activity against bacteria and fungi at all the concentrations tested (500μg/ml, 1000μg/ml and 2000μg/ml). Antimicrobial activity of bark extract was found to be moderate on bacteria and fungi (effective at 1000μg/ml and 2000μg/ml), whereas seed extract exhibited least antimicrobial activity. Minimum inhibitory concentration (MIC) of leaf and bark extract was found to be in the range of 500µg/ml to 2000µg/ml for all the tested microorganisms, whereas the seed extract did not inhibit the microorganisms at all the concentrations tested except Candida albicans (1000µg/ml). The results suggest that aqueous extracts of Azadirachta Indica leaf and bark exhibit high antimicrobial activity.

Leaf, bark and seed oil have been shown to exhibit wide pharmacological activities including; antioxidant, antimalarial, anti-mutagenic, anti-carcinogenic, anti-inflammatory, anti-hyperglycaemic, antiulcer and anti-diabetic properties. The biological activities are attributed to the presence of many bioactive compounds in different parts. The study was designed to investigate the comparative antimicrobial activity of neem leaves, bark and seed aqueous extract against human pathogenic bacteria and fungi. A number of factors such as, thickness and uniformity of the gel, size of the inoculum, temperature and pH that affect the accuracy and reproducibility of the agar diffusion method were also taken into consideration to obtain reliable results.

Raw materials (leaves bark and seed) are required to be cleaned, shade dried for one week and pulverized to coarse powder. This powder can be used as antibacterial finish material in number of application including medicine in pharmaceutical sector. Neem seed oil is produced from the seeds of the neem tree (Azadirachtaindica). It contains diterpenois and triterpenoids (limonoids); nimbin, gedunin, azadirachtin, nimbidinin, salanin. Azadirachtin is the most studied triterpenoid in neem oil. Nimbin is another triterpenoid which has been credited with some of neem oil's properties as an antiseptic, antifungal, antipyretic and antihistamine. Neem oil also contains several sterols, including campesterol, beta- sitosterol and stigmasterol.

2.9 Textile adhesives

An adhesive is a material used for holding two surfaces together by specific interfacial phenomenon among them. The most adhesives must wet the surfaces, adhere to the surfaces, develop strength after it has been applied, and remain stable. The surface preparation before applying the adhesive is of prime importance. In most cases after applying the adhesive to the surfaces, certain constant pressure needs to apply for effective bonding to be generated. The raw materials for adhesives are mainly polymeric materials, both naturally occurring and synthetic (Table 2.7) [27].

Table 2.7 Various types of raw material of textile adhesives

Natural	Synthetic	Inorganic
• Starch and dextrin • Gelatine (animal, fish, vegetable glues) • Asphalt and Bitumin • Natural rubber • Resins, Shellac	• Cellulosic • Vinyls • Acrylics • Reactive acrylic bases • Synthetic rubbers • Aldehyde condensation resins • Epoxide Resins • Amine Base Resins • Polyester resin • Polyolefin Polymers	• Soluble silicates • Phosphate cements • Hydraulic cements • Miscellaneous cements (glycerine, liquid sulphur and aggregate, and oxides and nitrides)

The useful way to classify adhesives is by the way they react chemically after they have been applied to the surfaces to be joined. There is a huge range of adhesives, and one appropriate for the materials being joined must be chosen. For a material to perform as an adhesive it must have four main requirements:

- It must wet the surfaces - that is it must flow out over the surfaces that are being bonded, displacing all air and other contaminates that are present.
- It must adhere to the surfaces - That is after flowing over the whole surface area it must start to adhere and stay in position and become 'tacky'.
- It must develop strength - The material must now change its structure to become strong or non-tacky but still adherent.
- It must remain stable - The material must remain unaffected by age, environmental conditions and other factors as long as the bond is required.

2.9.1 Adhesion theory

Several theories of adhesion exist which are based on surface-chemical phenomena. There are three main theories of adhesion: adsorption, electrical and diffusion. There is no simple theory of adhesion, and the truth for any one system is probably a combination of adsorption, electrostatic attraction and diffusion. It is generally considered that there is no generalized, unified theory of adhesion since the phenomenon is known to exist between a great diversity of material types. In some special cases, either pure adsorption, or electrical or diffusion attractive forces are found at an adhesive-bound interface. More frequently, one finds adhesion to be a synergistic combination of all of these driving, attractive forces. This is especially true in the case of practically all adhesive bonding situations.

(a) Adsorption theory: The attractive forces between materials are interpreted in terms of the atomic and molecular species that exist at an interface. This theory regards adhesion as one particular property of a phase interface wherein polar molecules or groupings will be orientated in an ordered way. The forces are initially involved in this mechanism are the van de Waals' forces - the orientation, induction and dispersion effects. If a molecule, which is large enough to contain a polar group and anon-polar part as separate and distinct entities, approaches an interface at which the dielectric constant changes it will orientate itself. It will move so that its non-polar part will be in the medium of lower dielectric constant and its polar part in the medium of high dielectric constant. This process takes place in adsorption.

(b) Electrical theory: This theory explains adhesive attraction forces in terms of electrostatic effects at an interface. This is based on the phenomenon of a electrical double layer formed at the junction of two materials. At any boundary an electrical double layer is produced and the consequent coulombic attraction might account for the adhesion and resistance to separation.

(c) Diffusion theory: In this theory adhesion is attributed to intermolecular entanglements at the interface. This is applied to the union of high polymers. The fundamental concept is that adhesion arises through the interdiffusion of the adherent and the adhesive. It is based upon the chain nature of the structure with the consequent flexibility and the ability of the chains to undergo Brownian movements on a sub-molecular scale. When the adhesive is applied in solution (most probably) and if the adherent is sensibly soluble in the solvent the substrate molecules will also diffuse to an appreciable extent into the adhesive layer.

Overall, the clean-cut boundary between the adherent and the adhesive disappears and is replaced by layer representing a gradual transition from one polymer to the other. A major difference in this theory is that it implies a three-dimensional volume process rather than a two-dimensional surface process.

2.9.2 Adhesive types

Adhesives can be classified into three main types and combinations of these products but essentially all adhesives can be grouped into following categories.

(a) **Chemical reactive type:** Basically, an adhesive of this type is applied in a low molecular weight form; and after the application a polymerization reaction is allowed to take place. This polymerization can be achieved by two component packs i.e. supply the produce as a two-component pack- base plus hardener. The Polymerization can be achieved by relying on moisture either on the surface of the adherent or in the atmosphere to affect a cross- linking mechanism on some other 'natural' component. In this case the adhesive is supplied as a single component. The final method of curing a chemical reactive type is by utilizing heat to polymerize the adhesive components.

(b) **Thermoplastic type:** The adhesives in this class are thermoplastic in nature, when heated to a sufficient temperature, they will flow and wet the substrates and then set and develop bulk strength on cooling. The ideal 'Hot Melt' adhesive is a solid up to a temperature of 80ºC but will then melt sharply to give a low viscosity fluid that is capable of wetting the adherents followed by rapid setting upon cooling. They normally contain a base high molecular weight polymer together with tackifying resins and viscosity depressants.

(c) **Evaporation or diffusion types:** In adhesives of this class the adhesive polymers is essentially in its final form. However, wetting of the adherent is achieved by dissolving or dispersing the polymers in a suitable solvent. There are two systems: solvent based systems and Water based systems. There are very few polymers of sufficient molecular weight to be attractive as adhesives that will dissolve in water. However, dispersions or emulsions are also very important.

2.10 Medical textiles

Requirement for higher level of medical treatment has been increasing the importance of textiles for medical uses. The medical textiles cover a huge range of applications pertaining to hygiene and medical sector. The various polymeric materials either natural or synthetic fibres, yarns, fabrics, composites or even garments are used. These are used in different forms like staple fibre or spun yarns; monofilament or multifilament yarns; braided, knitted, woven or nonwoven fabrics; garments and composites.

Advantages of textiles used in medical field are:

- Cross infection is reduced
- Protection of care providers
- Cost effective
- The comfort level is higher e.g., gowns
- Engineered to have high barriers to blood and other body fluids.
- compatible with various types of sterilization techniques
- In OT's they protect the user from static electricity
- flexible, soft and comfortable

2.10.1 Fibres used in Medical textiles

Various textile fibres of natural origin and manufactured fibres of natural polymer and synthetic polymer are used for medical applications (Fig. 2.5). These fibres should be non-allergic, non-toxic and non-carcinogenic. This includes natural fibres like cotton to manmade fibres like polyester and nylon. Other fibres viz. poly-tetra-fluro-ethylene (PTFE), polypropylene; carbon fibres, chitin, chitosan are also used [28].

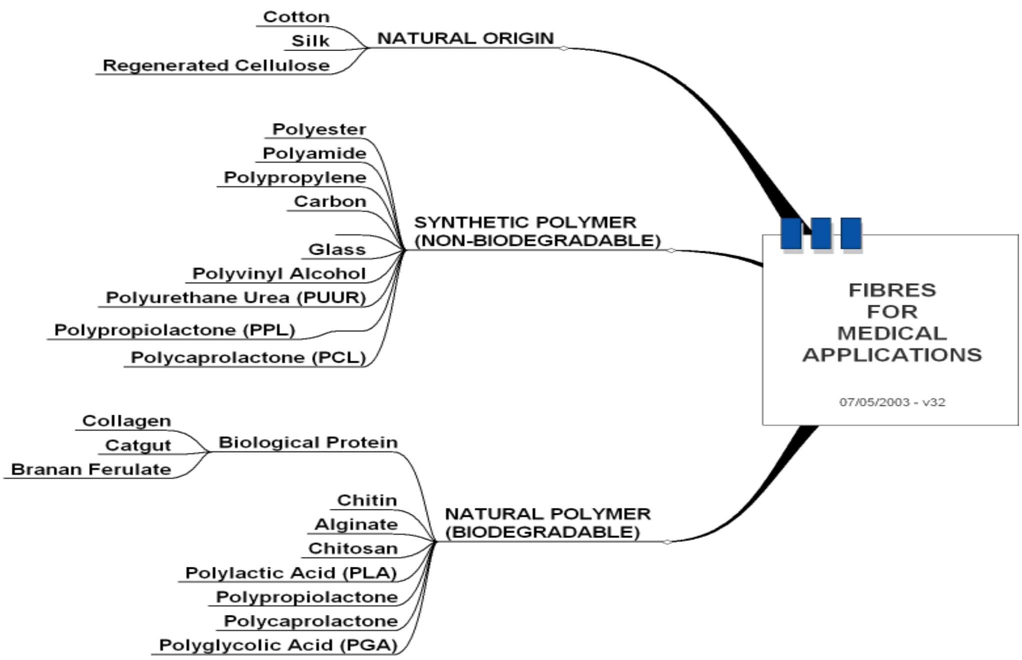

Fig 2.5 Various fibres used in medical textiles

Among the various fibres used in medical textiles alginate, cotton, collagen, viscose, polyurethane etc. are biodegradable while carbon, glass, polyester (PET), polypropylene (PP), polyvinyl alcohol (PVA) etc. are non-biodegradable. Other fibres used are like silk, high density polyethylene (HDPE), polyacetol, polyglycolide, polymethyl methacrylate, polylactide (PLA), polyglactin, silicon, stainless steel etc. The various physical forms of these fibres are used including hollow fibres. Biomedical fibrous materials are also used in various applications in healthcare and related sectors. Hence there is huge potential for fibre and textile technologies to be effectively utilized in medical applications.

2.10.2 Criteria and properties of medical textiles

The textile materials have to possess some features in terms of their properties to be utilized as bio-medical products. Materials should be sterilizable with minimum or least change in chemical and physical properties. The type of sterilization technique being used depends upon fiber characteristics from which the product is made. The various sterilization techniques are autoclaving, ethylene oxide usage and radiation usage. For safe and effective use of textiles in medicine it is necessary to meet with a number of basic requirements and specific criteria such as:

- Acceptable compositional purity and free from any surface contaminants
- Good dimensional stability and ability to retain crimping
- High elasticity and elastic recovery
- Non toxicity and non-carcinogenicity
- Conformance to technical specifications
- Sterile
- Anti-Allergenic
- Anti-Bacterial
- Environment friendly
- Economical
- Material should be non-slippery in nature
- It should be flame proof
- Waterproof under wet conditions, if required
- Dyes used must be fast and non-irritant

The important property is absorbency being governed by structural element and being improved by addition of absorbent co-polymers. It should retain chemical and physical properties during its use i.e. for orthopedic fiber reinforced composites; the material should have property to retain a certain profile of mechanical properties over desired implantation period. Similarly synthetic vascular grafts materials are expected to meet certain porosity and elasticity requirements of textile materials in the medical field is credited to their excellent physical properties, such as strength, extensibility, flexibility, suppleness, air and moisture permeability and wicking.

The medical textiles mainly comprise of various implantable and non-implantable surgical fabrics. It also include some special medical textile products including extra corporeal devices as implants such as ligaments, vascular grafts, prostheses, mechanical lungs, heart valves, blood vessels, artificial joints, artificial kidneys, artificial heart, artificial skin, etc. The various applications of textile materials in medical and healthcare industries may be broadly categorized as shown in Fig. 2.6 [29].

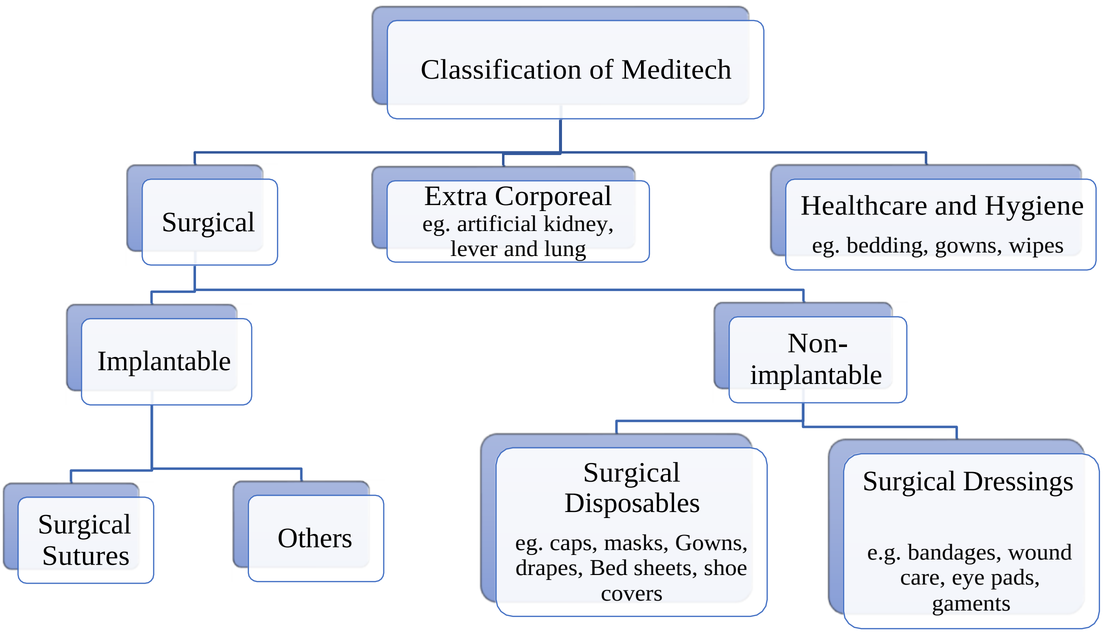

Fig. 2.6 Classification of medical textiles

(a) Implantable Medical Textiles: These are materials implanted on or in the human body to either support or replace the functions of internal organs (Table 2.8). These materials are used in effective repair to the body whether it be wound closure (sutures) or soft tissue implants (artificial ligaments, skin, tendon, cornea and contact lenses etc.), orthopedic implants (artificial joints and bones), cardiovascular implants like vascular grafts and heart valves replacements surgery like vascular grafts, artificial ligaments etc.

Carbon fibre is a popular material for tissue repair in ligaments, bones and joints. These are made using different textile structures such as braided, knitted or woven using either monofilament or multifilament. Different types of grafts available are Teflon woven, Decron woven, Terelyne knitted and Terelyne woven. Suspensors and reinforcing surgical meshes are used in plastic surgery for repairing defects of the abdominal wall and surgical treatments of hernia in urology. Hydrophobic felt dressings are high porosity textiles made from man-made fibres designed for treatment of burns and dermatological defects.

Table 2.8: Implantable materials

Fibre type	Fabric structure	Applications
Collagen, Catgut, Poly glycolide, Polylactide fibre	Monofilament, Braided, Biodegradable	Sutures
Polyester, Polyamide , PTFE fibre, Polypropylene, Polyethylene fibre	Mono-filament, Braided	Non-biodegradable Sutures
PTFE fibre, Polyester, Silk, Collagen, Polyethylene fibre, Polyamidefibre	Woven, Braided	Artificial tendon
Polyester, Carbon fibre, Collagen	Braided	Artificial ligament
Low density polyethylene fibre, Artificial cartilage chitin	Non-woven	Artificial skin
Poly (methyl methacrylate) fibre, Silicon fibre, Collagen		Eye-contact lenses, Artificial cornea
Silicone, Polyacetyl fibre, Polyethylene fibre		Artificial joints/bones
PTFE fibre, Polyester fibre	Woven, Knitted	Vascular grafts
Polyester fibre	Woven, Knitted	Heart valves

(b) Non-implantable Materials: These are used for applications on the body and may or may not make contact with skin. Wound care dressings, bandages, orthopedic plasters, gauzes, lint and waddings are the main non-implantable medical textiles (Table 2.9).

Table 2.9 Non-implantable materials

Fibre type	Fabric structure	Applications
Cotton, Viscose, Lyocell	Non-woven	Absorbent pad
Alginate fibre, Chitosan, Silk, Viscose, Lyocell, Cotton	Woven, Non-woven, Knitted	Wound-contact layer
Viscose, Lyocell, Plastic film woven	Non-woven	Base material
Cotton, Viscose, Lyocell, polyamide fibre, elastomeric-fibre yarns	Woven, Non-woven	Simple non-elastic and elastic bandages
Cotton, Viscose, Lyocell, elastomeric-fibre yarns	Woven, Non-woven, Knitted	High support bandages
Cotton, Viscose, Lyocell, elastomeric-fibre yarns	Woven, Non-woven, Knitted	Compression bandages
Cotton, Viscose, Lyocell, Polyester, Polypropylene, Polyurethane foam	Woven, Knitted	Orthopaedic bandages
Cotton, Viscose, Plastic film, Polyester fibre, Glass fibre, Polypropylene fibre	Woven, Non-woven, Knitted	Plasters
Cotton, Viscose, Lyocell, Alginate fibre, Chitosan	Woven, Non-woven, Knitted	Gauze dressing
Cotton	Woven	Lint
Viscose, Cotton linters, Wood pulp	Non-woven	Wadding
Polylactide fibre, Polyglycolide fibre, Carbon	Spun laid, Needle punched non-woven	Scaffold

- **Bandages:** These are narrow cotton or linen, plain weave cloth of low texture, either woven or knitted. Various types of bandages are: Cotton and rubber elastic bandage- for sprains and strains, Cotton rubber elastic net bandage- net fabric of lace construction, Plaster of paris bandage - cloth impregnated with a mixture of calcium sulphate, Orthopedic cushion bandage and Crepe bandage – elastic in nature; special weave allows it to stretch twice its length.

- **Surgical Dressings:** They are used as covering, adsorbent, protective, and supports for injured or diseased part. The main are; ‘primary wound dressings’ which are placed next to the wound surface and generally made from cellulosic nonwoven and ‘absorbent’ type is similar to wound pads used in surgery, manufactured from well-bleached, cleaned cotton fabrics. Absorbent lint is plain weave cotton fabric, warp nap raised on one side by a linting process, used as external absorbent and protective dressing; as antiseptic adsorbent and protective dressing in first aid treatment. Surgical cotton gauze provides absorbent materials of sufficient strength for surgical dressing.

Development of self-adherent dressing is minimizing the stripping of stratum corneum layer due to repeated application of adhesive dressings to the surface of the skin.

- **Protective eye pad:** Scientifically shaped 70 x 70 mm pad to fit over the eye used in outpatient clinic and industrial medical department.

- **Adhesive tapes**: It is narrow, plain weave fabric coated with adhesive paste, used with other pads to conform them on the injury.

(c) Extra Corporeal Devices: Extra corporeal devices are mechanical organs that are used for blood purification and include artificial kidney (dialyser), artificial lever and mechanical lung etc. (Table 2.10) [30].

- **Artificial Kidney:** It is a tiny instrument made with hollow hair sized cellulose fibers or hollow polyester fibre slightly larger than capillary vessels. The fabric is used to remove waste products from patients' blood.

- **Artificial Liver:** It is made with hollow viscose, to separate and dispose patient's plasma and supply fresh plasma.

- **Artificial Heart:** It is an 8-ounce plastic pump lined with dacom velour to reduce damage to blood and is a chambered apparatus about the size of human heart. Silastic backing makes the fabric impervious to emerging gas that is not desirable in the blood.

- **Mechanical lung:** This is made with a hollow polypropylene fibre or a hollow silicone membrane. It is used to remove the carbon dioxide from patients' blood and supply fresh oxygen.

(d) Therapeutic Textiles: The products used for treatment and cure of diseases due to ill health, such as heating pads, neck belts etc.

(e) Healthcare Textiles: It is an important area of medical textiles having vast range of products, but they are used either in the operating theatre or in the hospital wards for hygiene, care and safety of the staff and patients. The healthcare garments can be woven, knitted or non-woven, washable or disposable viz. gowns, caps, masks, drapes, blankets, bed sheets, pillow cases, uniform and protective clothing of doctors and nurses, diapers, wipes and surgical hosiery products. (Table 2.11).

Table 2.10: Extra corporeal materials

Role	Fabric structure	Applications
Remove waste products from patient's blood	Hollow polyester fibre, Hollow viscose	Artificial kidney
Separate and dispose patients' plasma and supply fresh plasma	Hollow viscose	Artificial liver
Remove carbon dioxide from patients' blood and supply fresh oxygen	Hollow polypropylene fibre, Hollow silicone membrane	Mechanical lung

Table 2.11 Healthcare and Hygiene materials

Fibre Type	Fabric Structure	Applications
Cotton, Polyester fibre, Polypropylene fibre	Woven, Non-woven	Surgical gowns
Viscose	Non-woven	Surgical caps
Viscose, Polyester fibre, Glass fibre	Non-woven	Surgical masks
Polyester, Polyethylene	Woven, Non-woven	Surgical drapes/cloths
Cotton, Polyester fibre, Polyamide, Elastomeric fibre	Knitted	Surgical hosiery
Cotton, Polyester fibre	Woven, Knitted	Blankets
Cotton	Woven	Sheets, Pillow cases
Cotton, Polyester fibre	Woven	Uniforms
Polyester fibre, Polypropylene fibre	Non-woven	Protective clothing, Incontinence diaper/sheet
Superabsorbent fibres	Wood Non-woven	Absorbent layer
Polyethylene fibre	Non-woven	Outer layer
Viscose, Lyocell	Non-woven	Cloths/Wipes

Significantly developed market of non-wovens is especially consumable textiles for operation theatre etc. In order to avoid contamination, the disposable non-woven health care textiles are more common as compared to woven fabrics. The advantages of using non-woven materials in medical and surgical textiles are shorter production cycles, lighter weight, flexibility and versatility and lower production costs. Chitin nonwoven is used as artificial skin, which adheres to the body and stimulating new skin formation, and thus resulting into accelerated healing rate and reduces pain.

2.10.3 Medical device directive

With the introduction of the medical device directive in full, the documentation for the production of implants is required, with all certification tests performed by accredited testing laboratories. Accordingly materials and products which are introduced into the human body, either temporary or long term, must be tested in the laboratory, on animals, and then on patients. All impurities harmful to the patient must be excluded at all stages of the production process. This may require clean room conditions with class 100,000 partially 10,000 (particles/cubic-feet). Polymers used for resorbable implants are particularly sensitive to hydrolysis and must be processed under non-humid condition preferably lower than 40% relative humidity. Toxic substances, such as catalyst used in polymer synthesis, stabilizers for thermal processing, and spinning lubricants, must be avoided or later extracted. If stabilizers are not used, the thermal and shear stresses during processing must be minimized. Spinning lubricants, which are not easily extracted, is generallyavoided [28].

2.10.4 Market potential and growth

The demand for meditech products is dependent on the health and hygiene sector. The expenditure on healthcare segment is steadily on the rise in India, predominantly by the private sector, which is expected to drive the demand for meditech products. Government policies aimed at boosting the supply in health and hygiene sector are likely to positively impact the demand for meditech products. In line with these developments, Indian meditech industry is expected to achieve a growth of 8-9% year on year, over the next three years. Incontinence diapers and contact lens are expected to achieve significant growth, followed by artificial implants [31].

Imports of technical textile component under Meditech constitute about 28% of domestic consumption under this segment, by value. Demand for products such as artificial implants, technical textile component of baby diapers and incontinence diapers is met by imports; the nonwoven material required for medical applications (e.g. diapers) is primarily imported. Majority of imports are from Thailand, Singapore, Taiwan and China.

By value around 12% of the technical textiles produced under Meditech in India are exported. Surgical sutures and surgical dressings are the key export products, with their exports constituting over 86% of the total exports under this segment. The key export markets are Bangladesh, the UK, Sri Lanka and Netherlands.

The global Meditech industry is expected to reach US$20.23 billion by 2022 from US$14.94 billion in 2014. The growth is primarily attributable to the rise in elderly population, ongoing technological advancements and increase in health consciousness. Non-implantable products accounts for about 30% of the global medical textile industry on account of increasing incidence of injuries, rising prevalence of diabetes and obesity. The global sutures market was valued at US$2.80 billion in 2014 and is expected to reach US$3.59 billion by 2020, growing at a CAGR of 4.2% between 2014 and 2020. On the other hand, global hygiene product market will grow to US$78.9 billion, over 551 billion units, by 2018 [29].

2.11 Medical garments

Medical garments are apparel designed for people with medical problems and/or medical personnel for particular functions. The specified functions of medical garments determine the rigid requirements for designing the clothing with particular choice of appropriate medical textiles. As medical garments are healthcare products with functional-oriented design, most traditional medical clothing is mainly focused on their functional values i.e. the effectiveness of the clothing to provide the required protection or clinical treatment for a certain category of patients or medical personnel. Medical garments can be classified on the basis of their specified functions into three main functional domains: Protective, treatment and caring [2].

(a) **Protective:** One of the basic functions of medical garments is to provide protection for medical personnel or patients from bacteria, physiological liquids, biological pollution and various harmful substances. Most significant examples are scrubs, masks, patient gowns, surgeons' clothes, surgical gowns and laboratory coats.

(b) **Treatment:** Medical garments can also have a significant impact on healing or for treatment purposes. Post-operative compression garments play a vital role in the recovery process in cosmetic surgery. For example, pressure garments (PGs) are the major treatment modalities for hypertrophic scars, and compressive stockings are commonly used for the prevention and treatment of varicose veins.

(c) **Caring:** Some users with physical and mental disabilities would suffer from an inability to dress them and would have difficulties in dressing due to their impairments. Some of them even need long-term care and assistance in their daily life. These people or patients require some types of adapted tailored apparel to suit their special physical and psychological requirements.

Corresponding to rapid exploitation in biomedical science, there is a large space for new development and modification in the design of medical garments. With a great concern, user-oriented apparel for healthcare should be produced to fulfil the requirements for restorative care training and convenient long-term nursing, as well as to provide a better ameliorant and make people more likely to want to wear them than they to the conventional medical garments.

2.11.1 Various medical garments

In a hospital or other health-care setting, the personal protective equipment used by health-care workers may include protective clothing, face and eye shields, gloves and surgical facemasks or respirators. The health and safety regulations that apply in the case of the presence or likely presence of biological agents (such as viruses, bacteria, fungal spores etc) are designed to provide a framework of actions to control risk from exposure to hazardous substances. The Health and Safety Executive (HSE) stressed that no PPE is 100% effective. The HSE also stressed that the level of protection offered is dependent on the outcome of a thorough risk assessment based on the inherent characteristics of the hazard, including routes of transmission and the type(s) of activities being performed as well as the correct selection, training, donning, use, doffing, storage, decontamination (of reusable items) and waste disposal. If employers cannot prevent exposure to a biological agent, they should take steps to ensure that it is controlled adequately, applying good practice; the need is stressed to use each requirement where, and to the extent that it is applicable.

(a) **Medical drapes and surgical gowns:** All medical workers and health care workers (HCWs) are in touch with patients during medical procedures [2]. They are likely to be exposed to different infections and microorganisms, which can cause disease transmission if sufficient protection is not provided in the work environment. Medical drapes and surgical gowns are typical medical protective clothing, and play an important role in minimizing disease transmission and protecting both medical professionals from coming into contact with infectious materials or pathogens and patients from possible contamination. These are outer garments to be worn in occupational exposure conditions in which blood or other potentially infectious materials may pass through and reach the HCWs' clothes and skin. Medical drapes and gowns could be classified as disposable, limited use and reusable garments on the basis of their service life

(b) Hip protectors: The aging process causes degeneration of nerves, joints and muscles, and the incidence of falls becomes high in elderly people. Most hip fractures occur as a result of sideways falls, directly impacting the hip bones of proximal femurs. Hip fractures can be devastating injuries that result in disability, functional impairment and mortality in elderly people. Hip protectors (HPs) are medical devices consist of plastic shields or foam pads fitted in pockets of specially designed underwear that aim to reduce the impact of a fall onto the hip and thus the risk of a hip fracture. HPs commonly used to reduce the risk of hip fractures from falls in elderly people who have compromised weaker bone micro-architecture and are at a high risk of falling.

Generally, HPs are specially designed underpants with protective shields, which are either hard shields or soft pads to be placed bilaterally along the hip to cover the greater trochanter. HPs are made of different models with different designs and materials. On the basis of the way of installation of protective shields, HPs can be classified into two main categories: viz. Underpants with sewn-in shields and Underpants with detachable shields, which are inserted inside the pockets located bilaterally over vulnerable hip areas. Over 70 0000 hip fractures occur annually in the United Kingdom and the total cost of care is over £2 billion with 10% mortality at 30days and up to 30% mortality at one year. Many people stop wearing hip protectors because they find them uncomfortable and impractical. New designs are under investigation of protecting the hips that may lend themselves to clever design, improved comfort and fit and higher levels of acceptance [32].

(c) Pressure garments: Pressure garments (PGs), which are also known as compression garments, are tight-fitting garments made of elastic materials. Hypertrophic scars are thickened, hard areas of scar tissues, which are commonly the result of thermal, electrical and chemical burns when the skin is damaged beyond a critical depth. If the skin is severely damaged down to the reticular dermis, the papillary dermis normal pressure would be destroyed and hypertrophic scars would occur due to overgrowth of scar tissue. Hypertrophic scarring may result in cosmetic disfigurement, pruritus, skin hypersensitivity, joint contractures and functional disability. Functional and cosmetic disability can be quite marked, depending on the site of injury and the extent of damage. Pressure therapy has proven highly successful in preventing severe hypertrophic scar formation. PGs are worn to exert pressure over wounded areas to help the skin heal smoothly in order to avoid scarring that would otherwise occur. The range of pressure found to be of therapeutic value in the management of hypertrophic scars lies between 10mmHg (1.3kPa) and 35 mmHg (45kPa).

(d) Compression stockings: Compression stockings, also known as graduated CSs, medical gradient stockings, medical leg wear, embolism stockings, varicose stockings, compression tights or support stockings, are specially designed elastic tights for exerting steady pressure on the legs to help blood flow through the veins and back to the heart that can improve circulation. Medical compressive stockings have been used for many years as a mechanical pressure method for deep vein thrombosis prophylaxis and treatment of varicose veins, deep vein thrombosis, and recurrence of leg ulceration and control of lymphoedema.

(e) Wet dressing: Wet dressings, also known as wet-wraps or wet compresses, can be applied as compresses of moist dressings on skin. Repeated compresses of moist dressings can relieve symptoms of either acute or chronic skin conditions such as crusting, oozing and swollen or pruritic dermatoses. Wet dressings are very useful for diverse types of AD (common form of eczema). They can also improve hydration for dry lichenified lesions on skin and are useful in the management of other dry skin conditions (xerosis) such as icthyosis vulgaris. They can also be an extremely effective treatment for acute itchy skin rashes.

Alginates are natural polysaccharides that occur in seaweed. They are salts of alginic acid present in certain species of brown seaweeds such as Giant kelp (MacrocystispyriJera), Horsetail kelp (Lamina riadigitata) and Sugar kelp (Lamina riasaccharina). Alginic acid consists of two monomers, D-mannuronic acid (M) and L-guluronic acid (G). The relative proportion of mannuronic to guluronic acid in alginate fibre significantly affects the properties of the end product. The yarn made from alginate has a dry strength comparable with that of viscose, but its poor wet strength makes it unsuitable for manufacturing textile materials. Following the 'moist healing' concept, alginate fibre has become one of the most important materials for wound dressing. It is established that a moist condition is more suitable for wound healing. When alginate dressing absorbs exudates from wound, a jelly like material is formed and a moist environment is created during the course of healing. At the same time calcium alginate rapidly releases calcium ions in exchange for sodium ions on contact with blood, which stimulate both platelet activation and blood coagulation to a greater, extend. In addition to generating a moist healing environment, alginate dressings facilitate a high absorbency of exudates from the wound.

In most instances, the wet dressings are two to three layers of moist clean gauze sheeting, which are wetted with the cool salt solution, Burow's solution (Domeboro astringent solution) or acetic acid (vinegar solution), and wrapped on the affected area of the patient's skin. The use of single-layer tubular bandages or dampened garments to control widespread AD is also very common.

(f) Superabsorbent material used in disposable healthcare products: Superabsorbent materials (SAMs), which are made from superabsorbent polymers (SAPs), have the property of absorbing and retaining huge amount of aqueous solutions. Superabsorbent polymer materials can uptake water as high as 100,000%. The absorbent hygiene products can be made thinner because smaller amount of SAPs can absorb the same volume of aqueous liquid as larger amount of fluff. For this reason, they are widely adopted in the manufacturing of disposable healthcare products such as diapers, feminine care products and adult incontinence products. SAPs are originally either natural or synthetic materials.

(g) Wound dressing: Wound dressings are materials used to cover wounds. Wounds may be caused from different mechanical injuries (e.g., abrasions, cuts, bites and invasive surgery) or burns, which may be caused by thermal, chemical, electrical and radiation injuries. Some types of chronic ulcerative wounds, which are caused from pressure sores or leg ulcers, may commonly occur among elderly people. The function of wound dressings is to provide protection to the injured wounds and safety from contamination and further injuries.

The wound dressings should be easy to apply, easy to remove and able to leach toxic components. Traditional wound dressings include various types of gauzes, such as bandages, woven, nonwoven or knitted gauzes and so on. They are often made from cotton or yarn by a simple woven technique. The appropriate wound dressing for each wound at its particular stage depends on the amount of exudates, tissue growth and healing factors. Thus, no single dressing will be suitable for use in all situations.

(h) **Incontinence diapers:** Incontinence is a problem that commonly occurs in the elderly and adults with particular illnesses. People who have difficulty in managing continence may need the support of incontinence products to contain urine leakage to maintain personal hygiene care to have a better quality of life and carry out their daily lives confidently. Diapers are the most common absorbent products that can provide healthcare hygiene support to those with an incontinence problem. Adult diapers are either disposable or reusable, and they are generally applied for moderate or heavy incontinence management.

Surgical apparel are devices that are intended to be worn by operating room personnel during surgical procedures to protect both the surgical patient and the operating room personnel from transfer of microorganisms, body fluids, and particulate material. Examples include surgical caps, hoods, masks, gowns, operating room shoes and shoe covers, and isolation masks and gowns. Surgical suits and dresses, commonly known as scrub suits, are excluded. Following is the classification [33].
Class I (general controls) - for surgical apparel other than surgical gowns and surgical masks
Class II (special controls) - for surgical gowns and surgical masks

2.11.2 Medical gowns

Medical gowns are examples of personal protective equipment used in health care settings. They are used to protect the wearer from the spread of infection or illness if the wearer comes in contact with potentially infectious liquid and solid material. They may also be used to help prevent the gown wearer from contaminating vulnerable patients, such as those with weakened immune systems. Gowns are one part of an infection-control strategy. A few of the many terms that have been used to refer to gowns intended for use in health care settings, include surgical gowns, isolation gowns, surgical isolation gowns, nonsurgical gowns, procedural gowns, and operating room gowns.

Surgical gowns were introduced primarily as a protective barrier to reduce surgical-site infection and protect the patient from the surgical team. They achieve this by controlling skin flakes and bacteria shed by the user and by preventing the direct transmission of microbes. Finally, a surgical gown must also demonstrate good wearing comfort whilst keeping the surgeon and team comfortable, particularly in longer operations

In 2004, the FDA recognized the consensus standard American National Standards Institute/Association of the Advancement of Medical Instrumentation (ANSI/AAMI) PB70:2003, ‘Liquid barrier performance and classification of protective apparel and drapes intended for use in health care facilities’ [3]. New terminology in the standard describes the barrier protection levels of gowns and other protective apparel intended for use in health care facilities and specifies test methods and performance results necessary to verify and validate the newly defined levels of protection:

- **First level:** Minimal risk, to be used, for example, during basic care, standard isolation, cover gown for visitors, or in a standard medical unit
- **Second Level:** Low risk, for example, during blood draw, suturing, in the Intensive Care Unit (ICU), or a pathology lab
- **Third level:** Moderate risk, for example, during arterial blood draw, inserting an Intravenous (IV) line, in the Emergency Room, or for trauma cases
- **Forth level:** High risk, for example, during long, fluid intense procedures, surgery, when pathogen resistance is needed or infectious diseases are suspected (non-airborne)

2.11.3 Design considerations of surgical gowns

Surgical gowns could be classified as disposable, limited use and reusable garments on the basis of their service life. A disposable medical garment cannot be cleaned or reused after a single use. Some medical drapes and gowns can be cleaned and maintained for reserving only for a limited usage. It becomes unusable when it is heavily soiled or damaged after several uses whereas the reusable medical garments are designed for repeated cleaning and reasonable durability for longer life with acceptable performance. They are rendered unusable if damaged on being used or contaminated during medical procedures. Basic considerations in surgical gowns are:

- Infection
- Infection transmission
- Viruses, bacteria and associated diseases
- Comfort
- Thermal properties
- Air permeability

If the fabric used in surgical gown has pore sizes less than the size of the microbes, then the microbes cannot pass to body of the healthy person. For the microbes like virus, which is in the micro level, a special woven structure has to be developed along with antimicrobial coating to the fabric [34]. But it is evident with a coated material that the comfort of gown deteriorates, which is an important requirement during major and prolonged operation. So it is required to impart a waterproof breathable coating to the fabric such that the water-based permeable fluids like blood, serum, etc. cannot penetrate but maintain the comfort of wearer.

The basic requirements of textile materials for producing medical gowns are their liquid barrier performance and breathability along with abrasion resistance and sterile concerns. The ideal material should be an efficient liquid barrier with high breathable properties, which could prevent the transmission of microorganisms from non-sterile to sterile areas. The major source of contamination in wards or surgical rooms is lint from fabrics used in clothing or wipers. As lint from clothing may act as a carrier of microbes, bacteria and viruses may infect wounds; this could increase the risk of nosocomial infection and foreign body reactions.

These unwanted particles might complicate the wound healing process. Therefore, sterile lint-free drapes and gowns should be worn in surgical rooms to preserve sterile or aseptic conditions, protect medical personnel from pathogens originating from patients and also protect patients from bacterial transmissions from medical personnel. In the late 1990s, Goad and Taylor developed a tightly woven fabric for medical clothing in a plain weave pattern. This lint-free medical fabric is made from 100% polyester yarns and treated with flame-resistant, water repellent and antimicrobial finish [2].

It is also important to ensure absolute barrier to viruses along with providing comfort. Different types of microorganisms are present in hospitals like bacteria, virus etc. Their growth is dependent according to the surrounding conditions. Acinetobacterbaumanni, Enterobacteraerogens, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Micrococcus luteus etc. are some hospital borne pathogens. Morphologically either they are G +ve or G –ve and are responsible for various hospital acquired infections (HAI), Pneumonia to serious blood or wound infections, skin and soft tissue infections, UTI, ENTRIC, Haemorrhage and Necrosis, Atopic dermatitis, Impetigo, Scaled skin syndrome etc. The size and associated infectious diseases caused by various virus and bacteria have been listed in Table 2.12 and Table 2.13 respectively [34].

Table 2.12 Size of highly infectious disease virus

Species	Diameter (µm)	Associated diseases
Serratia marcescens	0.45	Extra-intestinal infections Nosocomial Infections
Pseudomonas aeruginosa	0.50-1.0 (1.5-4.0 length)	Endocarditis, Pneumonia, Osteomyelitis, Nosocomial Infections, Meningitis, Septicaemia
Staphylococcus aureus	1.0	Pneumonia, Osteomyelitis, Myocarditis, Acute Endocartis Meningitis, Toxic Shock syndrome,
Mycobacterium tuberculosis	1.0 – 5.0	Tuberculosis
Bacillus anthracis	1.0-1.5 (3.0-5.0 length)	Anthrax Infection

Table 2.13 Size of diseases causing bacteria

Species	Diameter (µm)	Associated diseases
Bacteriophage X174	0.025-0.027	Test virus used by Nelson Laboratories to test 2H Technology
Hepatitis Virus (HBV)	0.042-0.047	Hepatitis B
Adenovirus	0.07-0.09	Respiratory Infections
HIV	0.08-0.11	Acquired Immuno Deficiency Syndrome
Filoviruses	0.08 (0.79- 0.97 length)	Eboloa Virus
Bunyaviridae	0.08-0.12	Hanta virus
Orthomyxoviridae	0.08-0.12	Influenza A, B and C
Coronaviridae (SARS)	0.10-0.12	SARS
Varicella-Zoster Virus	0.11-0.12	Herpes
Cytomegalovirus	0.12-0.20	Pneumonia, Hepatitis, Retinitis and Encephalitis
Variola Virus	0.14-0.26 (0.22-0.45 length)	Small Pox

Gowns should be designed to provide a continuous barrier to the anterior areas of users and have long sleeves with tight fitting cuffs that provide an adequate overlap with gloves at the wrist and should not have seams or closures that could allow liquid penetration, particularly of blood or body fluids. Medical gowns can be used as examination or isolation gowns and must be designed with long sleeves for complete protection; sleeveless gown designs are not suitable for use as isolation gowns. The current gown design is generally composed of a body portion and two separate sleeve portions [4].

Comfort issues of wearing are dependent on complex interactions between the permeability and flexibility of fabric, climatic, physiological and psychological variables, also related to product design. A combination of factors, such as temperature, humidity, air movement and so forth, may influence the wearing comfort. Due to the desirable protective capability of medical gowns, air permeability would become the main determinant for wearing comfort. In general, high liquid barrier performance materials for medical gowns have low air permeability, that is, the single-layer polyolefin film gowns offer maximum protection but are uncomfortable because the air permeability of such fabric is low. Fabric permeability required maintaining equilibrium for various work rates and working temperatures is given in Table 2.14 [34]. The various assumptions considered are:

- Internal RH: 100%
- External RH: 50%
- Internal Temp: 33° C
- External Temp: 20-30° C
- Internal air exchange: 50 %
- External air speed: up to 4 m/s
- Wearer: 70kg man

Table 2.14 Fabric permeability required to maintain equilibrium

Work rate	Air flow rate (l/m^2 /min)			MVTR (g/m^2/24h)		
Temperature	10° C	20° C	30° C	10° C	20° C	30° C
Low	-	-	360	-	-	1020
Moderate	-	80	720	-	360	2076
High	-	320	1110	-	1392	3156
Very High	120	560	1470	640	2400	4140

There is a wide array of impervious materials used for producing gowns for their liquid barrier performance and breathability. The ideal material for gowns would be an efficient liquid barrier with a high breathable property. Single-use gowns are most commonly made from nonwoven materials alone or in combination with materials such as plastic films that offer increased protection from liquid penetration. For reusable gowns, the ability to maintain complete barrier effectiveness despite multiple washings is necessary, because these may lose barrier properties from abrasion and get damaged during wear and the breakdown of fabric during laundering and sterilization.

Surgical gowns are designed to protect patients and staff from cross-contamination, so protection is crucial when choosing a surgical gown. However, an uncomfortable surgical gown could put an entire procedure at risk. Material that is breathable, soft, quiet and flexible enables staff to remain focused on the job at hand. And ergonomic elements improve the fit of the gown and provide greater freedom of movement.

2.11.4 Textiles for construction of surgical gowns

Traditionally, one or more layers of sterile woven cotton cloth were used as an aseptic barrier but when a gown became ‘wet’, it acted as a sieve and allowed bacteria to pass through the fabric. Cotton fabric used at this time had a pore size of 80-100μm, too large to prevent the passage of skin cells and bacteria; an interposition with a waterproof layer reduced the passage of bacteria. Implant surgery further drove the development of surgical gowns made from long-staple cotton, and designed the total body exhaust gown. It had to be connected to a power source; when utilized in a laminar flow theatre, the rate of surgical site infection has been shown to be significantly less than when an ordinary gown is used.

There has been continual work directed at the ideal fibre, construction of fabric and construction of the garment and garment design recommendations have been made, particularly related to the ease of hygienic doffing. The pore size in woven fabrics is an important factor in microbial transmission, as is the repellency of the fabric; testing and modelling showed that more-compact structures achieved by shorter thread floats and higher thread densities made the fabrics more water-resistant but less-permeable to air; the statistical models were thought to be of help in determining the appropriate compromise between protective properties and comfort [35].

Cotton/Cotton-Polyester comprising microfilament and multilayer woven fabrics were most popular for surgical gowns constructions. Polypropylene (PP) with a coating of Polyethylene is also used in the healthcare field. The PP is good for disposable protective garments as it is comfortable and good in dimensional stability during autoclave sterilization. The PE coating provides a strong barrier to fluids and a high level of protection for wearer. The reusable textile materials are woven fabrics, including tightly woven cotton, cotton poplin reinforced with polyester, double-layer linen cotton and fabrics made from multifilament polyester yarns. Due to the high costs of laundering and sterilization for reuse, most medical drapes and gowns nowadays are disposed of after single use, and nonwoven materials are commonly adopted for producing disposable medical garments. The three most commonly used nonwoven fabrics for surgical gowns and drapes are:

- Spun laced;
- Spun bond–melt blown–spun bond (SMS); and
- Wet-laid

Most protective medical garments are made of three-layered SMS fabrics. Many hospital garments are made of SMS–PP nonwoven composites, in which the added barrier membranes are incorporated in the middle layer to prevent the passage of blood borne pathogens or disease-causing microbes. Additional spun bond and melt-blown web layers are also used for making nonwoven composite multilayer fabrics, for example, four layers with two layers of melt blown webs sandwiched between two layers of spun bond fabric layers, or five layers with three layers of melt blown webs sandwiched between two layers of spun bond layers. Different nonwoven compositions for surgical gowns are classified base on the functionality characteristics as primary, classic, ultimate and fluid protection plus (FPP) (Fig 2.7).

Fig. 2.7 Various nonwoven material compositions for surgical gowns

Various compositions of spun bond and melt blown materials makes excellent combination for filtration and absorption property and can provide a more breathable and comfortable barrier for the wearer. The ‘primary’ is SMS nonwoven of PP fibres, ‘classic’ is spun laced nonwoven of polyester and ‘ultimate’ is SMS soft nonwoven of PP fibres. The FPP is composite with 2 layers i.e. polyethylene film and PET/PE nonwoven comfort layer. The constructional and functional specifications for each fabric are:

Primary - SMS

- Fluid repellent for adequate protection
- Nonwoven polypropylene fibres
- Spun bond for strength, melt blown for repellency
- Lightweight for added comfort
- Complies with EN 13795 standard/high performance

Classic - Spun laced

- Fluid repellent spun laced for all types of surgeries
- Nonwoven pulp/polyester fibres
- Treated to provide increased repellency to low surface tension fluids i.e. blood
- Soft and breathable for high comfort
- Complies with EN 13795 standard, high performance /AAMI Level 3

Ultimate - Soft SMS

- Highly fluid repellent material for advanced protection
- Nonwoven polypropylene fibres
- Spun bond for strength, increased melt blown for higher repellency
- Treated to provide increased repellency to low surface tension fluids i.e. blood
- Very soft and breathable for ultimate comfort
- Complies with EN 13795 standard/High Performance and AAMI Level 3

Fluid Protection Plus (FPP) - two-ply laminate

- Highest protective material, impermeable to body fluids all over
- Micro porous polyethylene film and PET/PE nonwoven comfort layer
- Ultra-light, breathable material for thermal comfort
- Micropores allow air and moisture to move from the body to the outside of the gown and the film protects against blood and fluid penetration, the comfort layer against the skin increase the comfort of the gown
- Complies with EN 13795, high Performance, AAMI Level 3 and ASTM F16703

2.11.5 Performance standards for surgical gowns

Regulatory standards for surgical have been developed and continuously updated by the American National Standards Institute (ANSI) and the Association for the Advancement of Medical Instrumentation (AAMI). Four levels of performance are designated, from Level 1 (lowest barrier performance) to Level 4 (highest barrier performance). Within the each category, standardized test methods and minimum performance levels have been determined for gowns, drapes, and other protective apparel [36].

- Level 1: When tested for impact penetration, critical zone components must have a blotter weight gain of no more than 4.5g.
- Level 2: When tested for impact penetration and hydrostatic pressure, critical zone components must have a blotter weight gain of not more than 1.0g and a hydrostatic resistance of at least 20cm.
- Level 3: When tested for impact penetration and hydrostatic pressure, critical zone components must have a blotter weight gain of no more than 1.0g and a hydrostatic resistance of at least 50cm.
- Level 4: When tested for resistance to Bacteriophage Phi-X174, critical zone components must show an AQL of 4%.

The protective barrier choice should be based upon anticipated exposure to fluid. Table 2.15 provides barrier performance levels as par ANSI/AAMI PB70 for various procedures [36]. Table 2.16 and Table 2.17 provide accepted standards for various barrier performance and non barrier performance standards. The entire front of the gown (areas W, X, and Y) is required to have a barrier performance of at least level 1. The critical zone compromises at least areas W and X. The back of the surgical gown (area Z) may be non-protective (Fig. 2.8) .

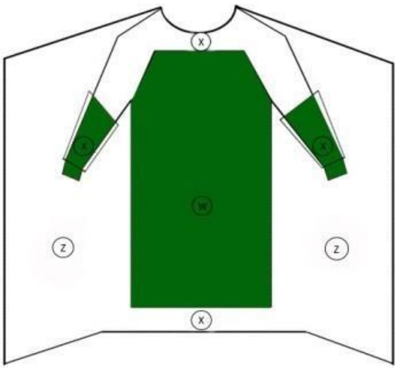

Fig. 2.8 Critical zones for surgical gowns

Table 2.15 ANSI/AAMI PB70: Barrier performance levels for various medical procedures

Examples of procedures	Risk of exposure to fluid, or spray splash, pressure on gown	Barrier performance
Simple excisional biopsies, lumps and bumps, ophthalmology and ENT	Minimal	Level 1
Tonsils and adenoids, endoscopic GI, MIS, open hernia repair, orthopaedic procedures with tourniquet, interventional radiology	Low	Level 2
Arthroscopic orthopaedic procedures, endoscopic urological procedures, Mastectomies, open GI and GU procedures	Moderate	Level 3
Hands in body cavity, ortho without tourniquet, open CT, trauma or C-Sections	High	Level 4

Table 2.16 Levels of performance at an AQL of 4%

Level 1	AATCC 42:2000	</= 4.5 gm.
Level 2	AATCC 42:2000 AATCC 127:1998	</= 1.0 gm. >/= 20 cm
Level 3	AATCC 42:2000 AATCC 127:1998	</= 1.0 gm. >/= 50 cm
Level 4	ASTM F 1671:2012	Pass

Table 2.17 Standard tests for various non barrier property

Grab tensile strength	ASTM D5034:1995
Snag resistance	ASTM D5587:1996 ASTM D2582:2000
Linting	IST 160.1:1995
Heat loss	ASTM F1868:1998 PART C
Water vapour transmission	ASTM E96:20
Flammability	16 CFR Part 10 (CPSC CS-191-53), UL 2154 NFPA 702 1980 (withdrawn)
Sterilization	Sterilization method and validation
Reusable laundering instructions	Recommended number of uses Method for Tracking Number of Uses
Biocompatibility testing	ISO 10993 PART 10, Skin irritation Skin sensitization

2.11.6 Selection of surgical gown

A surgical gown serves two main purposes; to decrease the transmission of skin flora from health care staff and to protect the staff against the blood-borne pathogens of the patient. The protection should be reproducible and maintained during the whole surgery, even in the event of the gown getting wet with blood, sweat or fluid. Bacterial strike-through is a function of the material used, fluid exposure and pressure applied. There is a lack of proper consensus on which type of gown to use due to the heterogeneity of materials and production techniques used in making gowns and other surgical factors i.e. the lack of a proper method to determine bacterial strike-through and its relationship to Surgical Site Infection (SSI).

The operating room (OR) is critical to a hospital's success, and to its business model, responsible for generating between 40-60% of the facilities' revenue. The operating room is also a significant cost centre, account for approximately 33% of the hospital's supply costs. Additionally, the OR is also a major source for producing medical waste, most notably by the use of disposable surgical products. When considering how to reduce the volume of waste in the operating room, it makes sense to first revisit the old adage of Reduce-Reuse-Recycle. When conducting a comparative analysis, surgical services managers need to consider the lifecycle costs of disposable items beyond the acquisition cost.

Selecting reusable garments result in significant environmental benefits compared to disposable garments. By selecting reusable isolation gowns, healthcare facilities can add these quantitative benefits directly to their sustainability scorecards [37]. Disposable surgical gowns, towels, and basin stand covers are routinely used for most surgical procedures and disposed of as regulated medical waste after a single use. Studies have shown that replacing these products with reusable textile items, which can typically be reused 75 times or more, can reduce surgical waste by an average of 65% [3].

The materials used in reusable gowns have undergone a dramatic change. Despite these facts, recent studies still favour disposable gowns as having a more solid, reliable and reproducible bacterial impermeability. With reusable gowns, these properties seem to fade with wetting or repeated wash. While reusable gowns, being more pliable and breathable, may seem more comfortable, this may dispel its concept of being an effective bacterial barrier. Various factors need to compare among the reusable and disposable gowns for the selection of surgical gown (Table 2.18).

Table 2.18 Comparison of reusable and disposable surgical gowns

Reusable	Disposable
Protection/comfort for surgical team	Offer poor thermal comfort
Protection/comfort for patient	Demonstrate inferior breathability
Budgetary constraints /cost reductions	Increase overall cost
Environmental responsibility	Environmentally detrimental
Ease of use	Not resistant to tearing
Reduce need for supplementary products	Increase need for production
Reduce cost associated with lost/discarded instruments	Direct relationship to increase cost with lost/ discarded instruments

Reusable gowns have been advocated based on economic and environmental basis. However, proper analysis of these aspects is hard to perform due to many factors that should be taken into consideration such as production, transport, storage, disposal, decontamination, sterilization and unexpected loss and damage, especially of reusable gowns. Even if an economic analysis might favour reusable gowns due to their environmental impact and jobs related to their production, one should consider their main purpose is to reduce SSIs [38].

There has been a move towards disposable nonwoven gowns that do not require laundering and thus reduce the requirement for a laundering facility, although it has been determined that disposable nonwoven fabric gowns made from polypropylene or 55/45 cellulose/PET were less-comfortable than re-usable woven fabric gowns made from micro-fibre polyester reinforced with a permeable membrane or 65/35 PET/cotton [39]. The nonwoven fabrics being used can be modified by laminating the fabric and by using plasma treatments.

Whether the surgical gown is of the disposable or re-usable type, it was demonstrated using synthetic blood, isopropanol and artificial sweat, that wetting by any such liquid from the wearer or the surgical environment may compromise the barrier properties of the gown material. Gown replacement protocols should take this into account [40]. The transfer of bacteria through contact between fabrics was found to be aided by the presence of moisture and the application of friction. Of seven different fabrics (cotton, silk, viscose, wool, polyester, polypropylene and a polyester-cotton blend), bacterial transfer was found to be highest for polyester followed by viscose rayon, whilst polypropylene showed the least transfer [41].

The decision of whether to use a reusable or disposable garment is a selection process based on factors including sustainability, barrier effectiveness, cost, comfort performance, environment impact and costing aspect (Fig. 2.9). Looking at the safety aspect, surgical gowns are intended to be worn by operating room personnel during surgical procedures, to protect both the surgical patient and the operating room personnel from the transfer of microorganisms, body fluids, particulate matter, and other potentially infectious materials (OPIM) and associated microorganisms. The safety of patients and staff depend on selecting the correct level of protection best suited for the procedure. Proper use, care and adherence to manufacturers' recommended processing guidelines, will ensure continuous, safe, barrier integrity.

Looking at the comfort aspect, higher level of comfort is needed for longer procedures to keep performing at one's best. Major factors are softness, breathability, conformability and design and fit of the gown. A 2010 study found that most surgeons and surgical technologists preferred the reusable healthcare textiles, at levels 2 and 3, for shorter procedures. For longer procedures, almost all the OR personnel overwhelmingly rated the reusable level 4 gowns with breathable laminates more comfortable. Eighty-six percent (86%) of the participants rated the comfort of the reusable gowns as superior. The ease of use for reusable was rated superior by 87%. Only 6% of participants rated the disposable gowns as superior [36].

Looking at the environmental aspect, increase in waste disposal costs, warehousing costs, costs associated with additional purchasing transactions, hidden costs (instrument loss, requirement for supplement products such as warming aids, unused pack components, double draping to resist tearing), requirement of multiple layering with due to inferior tensile strength which poses risk for tearing, requirement of high volume of product to support consistent supply. Medical waste is a necessary by-product of any hospital environment; however, the majority of regulated medical waste is produced in the OR from the use of disposable surgical supplies (i.e., surgical drapes, gowns and more) [3].

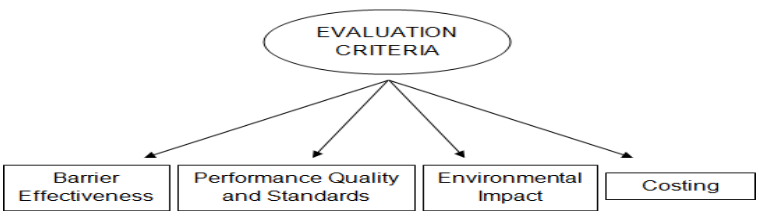

Fig. 2.9 Evaluation criteria for selection of surgical gown

According to Health Care without Harm, 4 million tons of general waste is produced by healthcare facilities in the United States each year. Using reusable surgical products provides a means to decrease regulated medical waste in the OR by an average total of 65% as well as reducing the cost of waste disposal. Disposing of waste, accounts for approximately 20% of a hospital's environmental services budget. Wastes issues begin with the purchasing department when materials are purchased that eventually become waste requiring disposal. Reducing the amount of disposable surgical materials purchased is an important step towards reducing the amount of regulated medical waste generated

Looking at the costing aspect, there are many cost issues to examine when considering the use of reusable drapes and gowns versus disposable drapes and gowns. It is important to differentiate between the cost-per-use and the actual purchase price. Third party processing/laundering can be very cost effective due to economies of scale, while regulated waste and disposal costs tend to be significant with disposables. The routine disposal of unused items in disposable packs, results in unnecessary product and disposal costs. This further supports the use of reusable custom packs. There are many intangible or hidden factors as well. The number of handling steps, recovering lost instruments, non-doubling of tray drapes, and savings in water and energy use are all advantages in the argument for reusable [36].

- Reports emerging from facilities which have converted portions of their program to reusable clearly show cost savings and environmental benefits from these changes.
- Winter Haven Hospital in Florida converted to a reusable surgical textile program in 2001 for their surgical pack program. In five years, cost savings was found ($10 per procedure as compared to single-use disposable products) to total of $625,000.
- A life cycle analysis of AAMI Level 3 surgical gowns used at the University of Minnesota Medical Center-Fairview found that using reusable gowns instead of disposable gowns would save 254,000 pounds of waste per year and $360,000.
- A Senior Sourcing Director for Kaiser Permanente in San Diego reported that use of reusable surgical gown and basin sets reduced the organization's regulated medical waste by 30 tons, at a savings of 3.8% in 2010.
- The University of Maryland Medical Center reported that in 2010, it avoided disposal of 138,748 pounds of waste as a result of using reusable supplies; using the average cost of regulated medical waste (RMW) of $0.28 per pound, this amounts to an approxim ate savings of $38,800 annually in avoided waste disposal fees.

2.12 Environmental impact of medical waste

Products that can be reused are often viewed more favourably with respect to environmental impact than single-use disposable options. True environmental impact depends on system and boundary conditions established for a particular application and use profile. Life cycle assessment (LCA) has been developed as an analytical tool to evaluate a product's environmental performance. The framework for the LCA is defined according to the ISO 14040 guidelines. The LCA is the most comprehensive and widely used tool to quantitatively compare the environmental impact of products or processes including raw material extraction, production processes, and end of life impacts of the system. Isolation gowns serve a critical role in infection control by protecting healthcare workers, visitors, and patients from the transfer of microorganisms and body fluids. Environmental sustainability is increasingly being used in the decision-making process.

Eric Vozzola et *al*. studied the environmental impact of isolation gowns using the full product life cycle [37]. This study analyzed all activities from the extraction of fossil materials from the earth to the end- of- life disposal of reusable and disposable surgical gowns. The researchers included calculations for laundry and wastewater treatment operations and compared the environmental effects of the two surgical gown systems. The basis of comparison was 1,000 isolation gown uses in a healthcare setting. At the healthcare facility, compared to the disposable gown system, the reusable gown system showed a 41% reduction in blue water consumpt, a 28% reduction in energy consumption, a 93% reduction in solid waste generation and a 30% reduction in greenhouse gas emissions, ion, (Fig. 2.10).

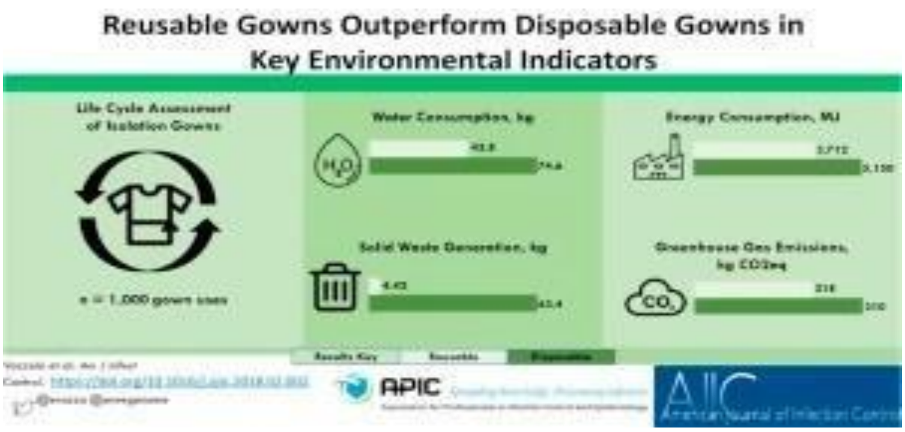

Fig. 2.10Various environmental factors of Reusable and disposable gowns

Reusable systems outperform disposable systems in all key environmental impacts. Selecting reusable gowns can help healthcare facilities meet sustainability goals. Environmental benefits are also expected for other reusable medical textiles. Health care facility administrators and leaders who endeavour to use environmentally sustainable practices require current data for decision making. Perioperative nurses can use this information to assist facility leaders as they make informed decisions related to gown system selection.

The synthetic fibre production, fabric production, various chemical finishing processing of surgical textiles, their transportation to hospital, laundries and disposition to land fill sites generates environment pollutants. A various factors such as acidification Eco-toxicity, global warming, ozone depletion etc. have adverse environmental impact due to possible environment pollution. It can also pose human health issues especially carcinogenic, non-carcinogenic and respiratory problems.

Although the per unit weight of the multi-use gown is nearly three times that of the disposable gown, when comparing the products over the course of 50 use cycles, the multi-use gown results in considerably less overall solid waste generation at the point of disposal. Adjustment must be made to consider the comparative solid waste generation at the end of 50 use cycles. Under this scenario, the weight of multi-use gown waste is approximately 6% that of the disposable gown waste. This means for every 1,000 surgical gowns required, the weight of disposable gown solid waste generated would be 300 pounds, while the weight of multi-use gown solid waste generated would be 17.2 pounds.

The study briefly describes the results of an environment impact comparing reusable polyethylene terephthalate (PET) surgical gowns with disposable polypropylene (PP) gowns, used in a healthcare setting. The analysis compares the solid waste generation at the point of disposal and the relative environmental impact factors for gowns required for 50 surgical procedures: one multi-use gown with 50 wash cycles compared with 50 disposable gowns. Differences in transportation requirements and laundering exist between the two systems. General system boundaries for the two surgical gown options are shown in Table 2.19 [34].

Table 2.19 General system boundaries for surgical gowns

	Reusable gown	Disposable gown
Raw material	Petroleum based	Petroleum based
Process impacts	PET Production PET Fibre/Fabric Production Gown Production	PP production PP extruded Film production Gown production
Transportation	US Producer to hospital Hospital/Laundry round trip (50) Hospital to disposal	China to hospital Hospital to disposal
Times through process	1	50

Fig 2.11 shows a comparison between the normalized environmental impacts of the two cases, 50 single-use disposable PP gowns and one multi-use PET gown laundered 50 times. The reusable gowns have an improved environmental profile compared with the single use gowns in all human health and most environmental impact categories. The improved environmental profile coupled with the significant decrease in solid waste generation described suggests that, in this case, the multi-use surgical gown option is the more environmentally preferred option.

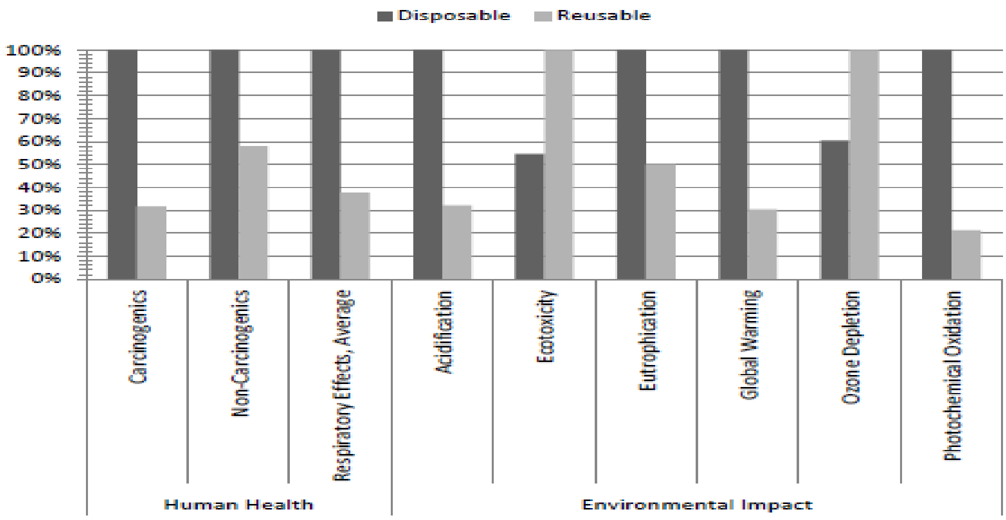

Fig. 2.11 Environmental impacts of reusable gowns

2.13 Growth control of microorganisms

There are many different methods used to control the growth of microorganisms. However, the modes of action (MOAs) of microbial control measures generally fall into one of four basic categories:

- Alteration of Cell Wall: The bacterial cell wall maintains the integrity of the cell, allowing it to keep its shape even when placed in a hypotonic environment. When the cell wall is weakened or disrupted, it can no longer function to prevent the cell from bursting due to osmotic effects (water rushing into thecell).
- Alteration of Plasma Membrane: A cell's outer membrane contains cytoplasm and all the cells internal contents, as well as controlling the passage of chemicals into and out of cell. When damaged, the plasma membrane may allow cellular contents to leak out.
- Interference with Protein Structure: Protein function depends on the 3-D shape of the molecule. Extreme heat, or certain chemicals, can denature, or change the shape of a protein. A denatured protein can no longer carry out its function within the cell.
- Interference with Nucleic Acid Structure: Nucleic acids (DNA and RNA) can be damaged or destroyed by chemicals, radiation, and heat. The result can be the production of fatal mutations to the DNA or interference with protein synthesis through action on RNA.

The basic principle for testing any control agent, (whether temperature, chemical or antibiotic) is always the same:

- Expose the organism to the agent.
- Remove the agent.
- Put the organisms in favourable growth media.
- After incubation, look for reproduction of organisms.

2.13.1 Microbial control

Methods used to control the growth of microbial can be placed into two broad categories, physical and chemical. Physical methods either exclude microbes, or reduce their numbers in a solution, or on the surface of a fomite (any non-living material which might come into contact with the individual). Chemical methods involve the application of specific chemical agents which inhibit growth or kill microbes on fomites or the surface of skin. The selection of an appropriate technique is important, since many physical and chemical agents can cause damage to the cells and tissues of the individual as well as the microbe.

Agents of microbial control either sterilize or disinfect. Sterilizing agents kill all living things, thus removing the living source of contagion. Disinfecting agents kill some microbes, but inhibit the growth of others. Most techniques only provide disinfection. Also, several factors influence the effectiveness of any method of microbial control. These include population size, susceptibility of the microorganism to the agent, concentration of the dose used, and the duration of treatment.

(a) Physical methods:

- **Filtration:** Filtration is the passing of either a solution or gasses through a device which traps microbes on one side of a container or space, preventing them from passing to the other. Filters are materials which have pores (openings) of varying sizes. Particulate matter larger than the pore size in a filter is excluded from passage and is thisphysically excluded. The earliest form of filter used in microbiological was cotton, a fibrous material derived from plants. Cotton fibres form a densely packed matrix which offers a torturous path for particulate matter containing microbes to pass, while still allowing air to do so. This is only true however, as long as a cotton plug, filter, or bandage remains dry, since water clings to each fibre allowing microbes' unrestricted access [31].

  In most cases, cotton has been replaced as a filter by ceramic filters and synthetic plastics such as nitrocellulose which offer very small pore sizes (0.2 m to 0.45 m) without taking up as much space. Since these materials are not fibrous, all but the very smallest microbes can be removed from a solution passing through them. This solution, called a filtrate, is generally free from contaminants so long as the original pre-filtered solution did not contain organisms such as mycoplasma bacteria or viruses, both of which are smaller than most filters. As a consequence, filtration should be considered an agent of disinfection rather than sterilization.

- **Desiccation:** Desiccation (drying) is the removal of moisture from the body of an organism. Many bacteria are very sensitive to water loss and can be killed simply by removal of water. For example, Treponemapallidum, the agent of syphillis, is so intolerant to water loss that it will die within twenty seconds on the surface of a dry fomite. The physical preservation of foodstuffs by drying has been practiced by humans for thousands of years and in most cases does reduce the number of potentially pathogenic microbes. One process, called Lyophilization or freeze-drying, is used to rapidly remove water from the body of an organism under very cold temperatures in a partial vacuum. This process does not kill organisms such as bacteria, but does inactivate their metabolic processes. Lyophilization is used to preserve living bacterial cultures for storage and transport. To restore the freeze-dried cells, an individual has only to rehydrate them in a nutrient broth solution and incubate the culture at the optimum temperature for growth of the microbe.

It is important to note, however, that not all microbes are killed or inactivated by desiccations. Bacteria which form spores such as members of the genera Bacillus and Clostridium, cyst-forming protists, and viruses can withstand drying, simply becoming inactive until moisture becomes available. For this reason, desiccations can only be considered a form of disinfection.

- **Radiation:** Radiation describes a physical phenomenon which occurs when matter releases energy, atomic particles, or both. Radiation can affect the chemical makeup of the cell by altering or disrupting the structure of biological molecules. Ionizing radiation strips electrons away from biological molecules. Both gamma and X-radiation are ionizing forms. Ultraviolet radiation is absorbed by the pyrimidine bases cytosine and thymine in DNA.

  When two thymine or cytosine molecules lie adjacent to one another on a nucleoside, ultraviolet radiation with wavelengths between 250 nm and 280 nm causes them to have a greater affinity for one another than for their complementary adenines on the opposite nucleoside. The two bond together, forming a dimer, which disrupts the normal sequence of nucleotide bases. This kind of mutation prevents the cell from producing proteins which may be necessary for normal metabolism to occur. Some cells can repair this damage if exposed to visible light through a process called photo reactivation (light repair), wherein the dimer is nicked by a restriction endonuclease, then cut away and replaced by DNA polymerase. The new thymine or cytosine bases are then bonded to their complementary adenines or guanines by DNA ligase. Since light repair can occur, the use of ultraviolet radiation has only disinfecting activity and cannot be considered a sterilizing agent.

- **Temperature:** Excess heat energy can cause proteins to become denatured, meaning that they lose their normal three-dimensional shape. Effective temperature for the reduction of microbes is measured as the thermal death point (TDP) of each organism, which is the temperature at which all growth stops. Thermal death time (TDT) is the amount of time it takes to kill all of the microbes in a sample, and the decimal reduction factor (DRF) is the amount of time at a specific heat necessary to reduce the population of microbes in a sample tenfold.

  The most common methods of applying excess heat energy are flaming and incineration, which completely destroy all life. Flaming of inoculating loops and needles, as well as the tops of glass culture tubes and flasks insures that no contaminating microbes can infect sterile media. Applying dry heat by forcing hot air onto the surface of an object can be used in a similar fashion, though many spore formers are capable of withstanding this.

  The application of moist heat, such as boiling, steaming, and pasteurization (application of high heat to a solution for a short period of time), is also commonly used. These methods work well for most microbes, but are incapable of killing organisms which are thermoduric (capable of withstanding elevated temperatures) or are spore formers. For example, the spores of Clostridium botulinum, the bacterium which causes botulism, can be boiled for up to five hours and still remain viable.

  The most effective application of moist heat is through the use of a device called an autoclave. The autoclave works on the principle of saturated steam. The inner chamber is raised to an air pressure of 15 lb/inch^2, and then steam at a temperature of 121^{o}C is injected. The steam strikes the surface of the object to be sterilized and condenses into water as its excess heat energy is released. This condensation creates a partial vacuum which draws more steam to the object. Saturated steam is extremely effective as a sterilizing agent, at least 1500 times more effective than the application of dry heat. Autoclaves are usually operated in cycles between 15 and 90 minutes, and can be used to sterilize glassware, surgical implements, soil, water, and microbiological media such as broths and agars. They cannot, however, be used to sterilize hydrophilic powders which would clump, or hydrophobic oils since microbes suspended in oils would only be subjected to dry heat. Also, while contaminated bandages can be placed in an autoclave, the toxins or exon enzymes left behind by killed microorganisms such as Clostridium perfringens (the agent of gas gangrene) may still be capable of causing host cell damage, so these should be rinsed thoroughly with sterile water prior to reuse.

(b) Chemical methods: Chemical agents for the control of microbial growth are either microbiocidal or micro biostatic. Microbiocidal agents are sterilants which kill all living cells. Micro biostatic agents kill some cells and inhibit the growth of others. The spectrum of activity exhibited by any microbiocidal or micro biostatic agent is an important factor in choice, and should be considered, along with potential harmful effects on the user.

- **High-level germicides:** These are called agents of cold sterilization, since no heat needs to be applied to increase their activity. These are generally alkylation agents, which kill by adding ethyl or methyl groups to nucleic acids or proteins. While the agents are capable of killing vegetative cells, spores, and inactivating viruses, some take up to several hours to complete their germicidal activity.

  Aldehydes, such as formaldehyde and gluteraldehyde, fix tissues by alkylating and forming cross-links between adjacent proteins. They are commonly used as fixative compounds for electron microscopy, preservatives of specimens and cadavers, in some synthetic plastic compounds, and can be used to sterilize anaesthesia tubing and surgical implements. Aldehydes can fix living tissues such as mucus membranes and have the ability to vaporize or outgas from compounds containing them, so they should be handled with caution. b-propiolactone is a liquid alkylating sterilants with a high boiling point (155^{o}C). It is generally used to sterilize bone used in grafts. It quickly breaks down into nontoxic compounds when it comes into contact with organic matter, but can burn skin.

  Ethylene oxide (carboxide) kills vegetative cells and spores. It is a liquid at temperatures below 10.8^{o} C, but rapidly sublimates into a highly inflammable gaseous state above this temperature. It is generally used in a chamber similar to an autoclave at 60^{o} C for 1-10 hours, where it is mixed in a 9:1 ratio with carbon dioxide (90% CO_2, 10% ethylene oxide), which reduces its toxicity. Carboxide can be used to sterilize surgical implements and glassware, but these fomites must be allowed to degas before use, since residues can stimulate mutations in bacteria.

Ozone (O_3) occurs naturally in the upper atmosphere, where it serves to shield the surface of the earth from solar radiation, and is produced as an exhaust gas by vehicles and industry, acting as a pollutant in the lower atmosphere. Applied properly in a chamber, ozone is a powerful oxidizing agent which kills cells and spores on the surface of glassware, surgical implements, and bandages. An advantage of sterilization with this compound is that it outgases quickly, leaving no toxic residues as can ethylene oxide and b-propiolactone.

- **Intermediate-Level disinfectants and antiseptics:** Phenol (carbolic acid) is one of the earliest disinfectant compounds to be used in health care facilities and laboratories. Phenol kills microorganisms by denaturing proteins and destabilizing cell membranes, is bactericidal, fungicidal, and virucidal at high concentrations, but is not effective against bacterial endospores, and is effective against many potential pathogens, including mycobacteria, staphylocci, streptococci, and gram-negative coliforms, such as E. coli. It can be used to disinfect garbage cans, surgical operating facilities, laboratory equipment, feces, urine, and sputum, but it is very corrosive at higher concentrations and its fumes can be lethal. Because of its toxicity, this compound is generally used as a solution between 2% to 5% in concentration, and many less toxic derivatives have been produced.

Since phenol has such a broad-spectrum of activity, it is used as a standard by which to judge how well other disinfecting compounds work. The phenol coefficient (PC) is a mathematical value used to compare the effectiveness of a test disinfectant to that of phenol, and is derived from the following formula:

$$PC = \frac{\text{Dilution of a test disinfectant necessary to kill a standard population of bacteria}}{\text{Dilution of phenol which has the same effect}}$$

Halogens are a family of elements with a high affinity for electrons. This affinity makes them very reactive with biological molecules, and they can serve to disrupt enzyme activity, break down lipid structure, and produce oxidizing agents such as singlet oxygen (O). The halogens most commonly used as disinfectants are chlorine and iodine.

- **Low-level disinfectants:** Hydrogen peroxide is a good low-level disinfectant agent when used in concentrations of 3% or lower. Higher concentrations are caustic to human skin, and cannot be used. Alcohols such as ethanol and isopropanol are effective antiseptics and disinfectants when used in concentrations between 70% and 80%. Alcohols kill microbes by denaturing proteins, dehydrating (100% concentration), and as nonpolar solvents which disrupt the phospholipid structure of the cell membrane, but are relatively ineffective against spores and viruses.

  Heavy metals such as mercury, silver, and copper tend to combine with sulphur groups in the proteins of microbes, causing them to denature. This oligodynamic activity makes the heavy metals useful in small concentrations. These are some of the earliest used agents for the control of microorganisms.

  Detergents and soaps are composed of lipids and compounds having basic pH, such as sodium hydroxide. These break up surface tension, act as wetting agents which release particles attached to the surface of objects, and destabilize the phosphate portions of the plasma membrane of microorganisms.

2.13.2 Finishes for surgical gown effectiveness

Textile goods are excellent substrate for growing microorganisms. For the last fifty years, the prevention of microbial attack on textile materials has become increasingly important to consumers and textile producers. Several dangerous, infectious and blood borne bacteria and viruses, such as pseudomonas, caudida, S.aureus and E.coli, are in attendance in hospital locations which are conductive for increase of the micro-organisms. Especially for surgical gowns, drapes, masks, sheets, and pillow cases, there is an increasing need to care for medical staff from infection by blood borne pathogens such as HIV and HBV.

With the advent of the germ theory of disease, it became obvious that disease could be spread by organisms too small for the eye to see. Pioneers such as Ignaz Semmelweis and Joseph Lister utilized techniques such as the washing of hands and disinfecting of surfaces to decrease the likelihood of infection. In time, hospitals, clinics, and laboratories began to adopt these methods and improve upon them.

(a) Antimicrobial finish: A variety of different organic and inorganic substances are being used to achieve antimicrobial functionality on textiles. There has been an increasing demand for functional textiles with antimicrobial properties. Recently, nano silver application on functional textiles is one of the most discussed and investigated methods. Textiles treated with nano silver antibacterial coating constitute attractive properties such as improved resilience against microorganisms, better protection against colonization of odour-forming bacteria along with much better hygiene in clinical practices.

Nano silver particles synthesized from silver nitrate ($AgNO_3$) and sodium citrate ($Na_3C_6H_5O_7$) are impregnated into raw cotton fabrics to develop antimicrobial properties. To investigate the antimicrobial activity of the treated cotton fabric, E. coli bacteria tests are performed.

It is very well known that silver ions have effective antimicrobial/antibacterial activity on Staphylococcus aureus and Escherichia coli along with others (e.g., Proteus vulgaris, Pseudomonas aeruginosa). In some cases (for example for *Staphylococcus aureus)* bacterial effect largely dominates over the effect of antibiotics in the intensity. In this regard, clinical physicians have special interest in ionic silver. In a study, antibacterial/antimicrobial activity tests revealed that concentrated nano silver application result in 99% decrease in Staphylococcus aureus and Escherichia coli along. It was also observed that there were no micro-organizational reproductions in nano silver impregnated fabrics.

Based on the antimicrobial/antibacterial activity test results on the Nano silver impregnated fabrics, it was suggested by the physicians that such applications might be useful in the control of hospital infections and further studies were suggested for specific cases in clinical practices.

(b) Blood repellent finish: Gowns should be able to avoid strike through or wetting out of the fabric, and so surgical gown materials should have not only antimicrobial properties but also blood barrier properties. Nanotechnologies open a new world in the area of textiles, but many aspects remain unclear, with special emphasis on environmental and health and safety aspects. A variety of classes of chemicals have been introduced to pass on water repellence to the fabrics. Out of them fluoro polymers are importantly used as repellent agent in industry as well as by researchers.

When a drop of liquid on a solid surface does not increase, the drop will assume a shape that appears constant and exhibits an angle, called the contact angle. The angle is characteristic of the particular liquid/solid interaction; therefore, the equilibrium contact angle serves as an indication of wettability of the solid by the liquid. The interfacial forces between the liquid and vapour, liquid and solid and solid and vapour all come into play when determining whether a liquid will spread or not on a smooth solid surface. The equilibrium established between these forces determines the contact angle θ (Fig. 2.12).

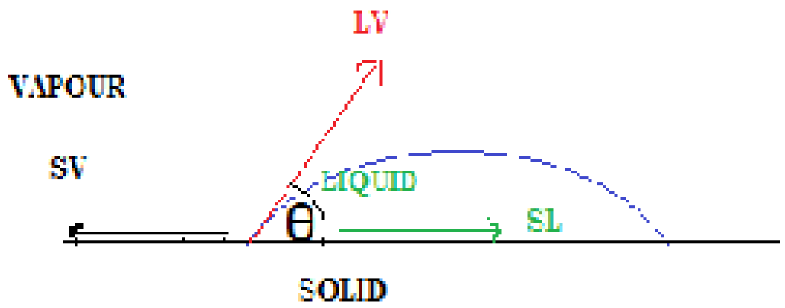

Fig. 2.12 Physical chemistry of wetting agent

Where θ = the contact angle

SV = the solid-vapour interfacial free energy

LV = the liquid-vapour interfacial free energy (surface tension of the liquid)

SL = the solid-liquid interfacial free energy

Then $SV = LV \cos\theta + SL$

The surface tension of the fabric has to be greatly lesser then that of blood and body fluids whose surface tension ranges between 42 dynes/cm and 60 dynes/cm to produce repellence. The surface tension of fluoro polymer water repellent agent is 10 dynes/cm, which is lower than any other usually used water repellents. This can be used for imparting the blood repellence to the fabric.

(c) Water repellent finish: Hydrophobicity on surface can be achieved through coatings with contact angle of water and aqueous solutions much larger than 90°. A thin non-wetting layer on the near-surface a few Nanometres thick, provides water-repelling functions. Super-hydrophobic Nano coated textile surfaces are characterized by larger contact angles i.e. exceeding 130° and such coating may provide water, oil and stain repelling properties along with other properties such as easy and self-cleaning. Wettability of a surface can be described by the contact angle. Surfaces exhibiting water contact angle higher than 130° are classified as super hydrophobic.

Coating the raw cotton fabric with methyl tri-ethoxysilane ($CH_3Si(OC_2H_5)_3$), phenyl tri-methoxysilane ($C_6H_5Si(OCH_3)_3$), and alcosols synthesized from these two compounds using sol gel techniques produce hydrophobic surfaces. Contact angle measurements, easy-cleaning and surface wettability (AATCC 22- 2005 water repellence spray test method) tests are performed on these surfaces.

Results of water repellence test for methyl tri-ethoxysilane ($CH_3Si(OC_2H_5)_3$), and phenyl tri-methoxysilane ($C_6H_5Si(OCH_3)_3$) treated surfaces revealed that methyl tri-ethoxysilane ($CH_3Si(OC_2H_5)_3$) treated surfaces has AATCC 100 which means "high repellency"; On the other hand, for phenyl tri-methoxysilane ($C_6H_5Si(OCH_3)_3$) treated surfaces, AATCC grade is 90 which also means "good repellence".

2.14 Testing of surgical gown materials

Plenty of textile products are developed for medical and hygienic use. These products were developed using different textile materials. Gradually these were improved to overcome the limitations of older products. This is also true for surgical gown materials. As it has been mentioned earlier, different materials are used to produce surgical gowns and they have their advantages and limitations. Different types of finishes are also applied to the fabrics to enhance the properties of surgical gowns. Surgical gowns were introduced primarily as a protective barrier to reduce standards relating to items surgical-site infection and protect the patient from the surgical team. They achieve this by controlling skin flakes and bacteria shed by the user and by preventing the direct transmission of microbes.

Finally, a surgical gown must also demonstrate good wearing comfort whilst keeping the surgeon and support team comfortable, particularly in longer operations. Currently, for the UK and USA there are a series of standards applied to protective clothing items such as surgical gowns [42].

(a) British Standards relating to items and materials:

- BS EN 13795-1:2019: Surgical clothing and drapes- Requirements and test methods for Surgical Drapes and Gowns.

- BS EN 13795-2:2019: Surgical clothing and drapes- Requirements and test methods for Clean air suits
- BS 3314:1982: Specification for protective aprons for wet work, and
- BS EN 455-1, 2, 3, 4 :2020, 2015, 2015, 2009: Medical gloves for single use,

The latter relate to non-textile latex, nitrile and vinyl products, included for completeness.

Standards relating to performance requirements and test methods:

- BS EN ISO 22610:2006/2018: Surgical drapes, gowns and clean air suits, used as medical devices, for patients, clinical staff and equipment. Test method to determine the resistance to wet bacterial penetration
- BS 3546:2001: Coated fabrics for use in the manufacture of water penetration resistant clothing
- BS EN 14126:2003: Protective clothing. Performance requirements and tests methods for protective clothing against infective agents

(b) United States: standards from ASTM and AATC

ASTM International, Standards and Specifications [43]:

- ASTM F1670/F1670M-17a: Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Synthetic Blood
- ASTM F1671/F1671M-13: Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Blood-Borne Pathogens Using Phi-X174 Bacteriophage [44].
- AATCC TM127-2017, Water Resistance: Hydrostatic Pressure Test
- International standards
- ISO 16603:2004 Clothing for protection against contact with blood and body fluids — Determination of the resistance of protective clothing materials to penetration by blood and body fluids — Test method using synthetic blood.
- ISO 16604:2004 Clothing for protection against contact with blood and body fluids — Determination of resistance of protective clothing materials to penetration by blood-borne pathogens — Test method using Phi-X 174 bacteriophage.

Various test method standards used to analyze the fibre, yarn and fabric pertaining to surgical gown manufacture are listed in Table 2.20, Table 2.21 and Table 2.22 respectively.

Table 2.20 Fibre testing standards

Test / Property	Standard procedure
Trash content - Non-lint content of cotton	ASTM D 2812-07 (2012)
Single fibre length - Over length fibre content of manmade fibres, Determination of fibre length	BISFA 1998 Chapter-5
Denier, Single Fibre Tenacity (SFT) – Denier, Tensile properties of single fibre	ASTM D 3822-07, BISFA –1998 (Chapter-6)
Crimp/ Crimp frequency of manmade fibres	ASTM D 3937-2012
Neps in cotton fibres(AFIS-N), Length, Maturity (AFIS L & M)	ASTM D 5866-05, Uster standard method
Cotton properties in High Volume Instrument (spectrum)(length, strength, trash, colour)	ASTM D 5867-2012
Determination of cotton fibre maturity (Sodium hydroxide swelling method)	IS: 236:1968 (Reaffirmed 2010)
Moisture Test - mass determination and Moisture Content & Moisture Regain	ISO 6741-1:1989

Table 2.21 Yarn testing standards

Test/ Property	Standard procedure
Twist in single spun yarn; untwist-retwist method Twist in double yarn, Twist in yarn-direct counting	ASTM D 1422-1999 (Reaffirmed 2008) ASTM D 1423/2002 (Reaffirmed 2008)
U% Imperfection (Unevenness), Unevenness of textile strands using capacitance testing equipment	ASTM D 1425M-2009e1
Lea count: Linear density of yarn by Skein method Lea strength: Breaking strength of yarn in Skei form	ASTM D 1907M-12 ASTM D 1578-93 (2011)
Appearance - Grading spun yarns for appearance	ASTM D 2255M-2009
Co-efficient of friction - yarn to solid material	ASTM D-3108-07
Yarn hairiness (Zweigle) by photoelectric apparatus	ASTM D 5647-07 (2012)
Single yarn Strength, Single yarn tensile characteristics	Uster standard, ASTM D 2256M-2010e1
Classmate fault (UCM III,Quantum,UCM-5) - Classifying and counting faults in spun yarns in electronic tests	ASTM D 6197-99 (Reapproved 2011)
Single yarn strength (UTJ4), single yarn tensile characteristics by Uster Tensojet 4	Uster Standard

Table 2.22 Fabric testing standards

Test/ Property	Standard procedure
Yarn count based on short-length specimens/fabric	ASTM D 1059-01
Tearing strength in Elmendorf method- Tearing strength of fabric by Falling Pendulum	ASTM D 1424-2009
Ends/Picks -Fabric Count of woven Fabric	ASTM D 3775-08, IS-1963-1981 (Reaffirmed 2008)
Mass per unit area (Fabric Weight)	ASTM D 3776 -09, IS 1964-2001 Reaffirmed 2010
Yarn crimp% in fabric -Yarn crimp of Yarn take up in woven fabrics	ASTM D 3883-04 – (2012)
Breaking force and elongation in Strip method (Tensile strength)	ASTM D 5035-11, IS 1969-1985 (Reaffirmed 2010)
Breaking force and elongation in Grab method (Tensile strength)	ASTM D 5034-09
Stiffness -Determination of Stiffness of cloth : Warp bending length and Weft bending length	BS 3356-1990
Assessment of Drape of fabrics- Drape coefficient	Source : BS – 5058 : 1973
Pilling test – Determination of pilling resistance of fabrics	IS:10971-1984 (Reaffirmed 2010)
Stiffness – Stiffness of fabric by the circular bend procedure	ASTM D –4032-08 (2012)
Width of fabric - Width of textile fabric	ASTM D –3774-96 (2012) (option-B)
Thickness of fabric - Determination of thickness of woven and knitted fabrics	IS 7702-1975 (Reaffirmed 2012)
Bursting strength-Determination of bursting strength and bursting distension of fabrics: diaphragm method	IS 1966-1975 (Reaffirmed 2006)
Air permeability in fabric	ASTM D 737-04 (2012)
Water resistance -water resistance : hydrostatic pressure test	AATCC-127:2003 Option 2
Liquid strike through time – nonwoven cover stock (baby diaper)	EDANA 150.5-02
Wet back -nonwoven cover stock (baby diaper)	EDANA 151.2-99

2.15 Development in fabrics for health care

Due to advent of new technologies, the number of recent developments reported in case of various applications of fabrics for healthcare. Some of these are briefly described.

2.15.1 Bamboo charcoal blended union fabrics

Hospital textiles such as bedding, clothing, surgical gowns, etc. are expected to fulfil comfort and hygienic properties viz. moisture management, thermal conductivity, breathability and microbial and odour resistance. Activated carbon is efficient in adsorbing odorous volatile micro-organisms, thereby reducing the odour and growth of micro-organisms of textiles. Bamboo charcoal is a non-graphite activated carbon made from the pieces of 5 year old plants, by carbonizing in an oven at 800^0C, and converted into powder which can be used to spun in to fibre with pure cashmere, or cotton: by adding the powder during spinning in the spinning solution; or established bamboo charcoal composite polymer master batch in the stage of synthesizing fibre. Bamboo charcoal viscose fibre also can be produced from natural cellulose pulp by dissolving bamboo charcoal micro powder milk and then spinning the solution by extrusion and solidification. Polyester-based bamboo charcoal (PBBC) fibre is produced in the similar way from polyester master batch 50% bamboo charcoal content. Similarly, bamboo charcoal nylon fibres also can be produced.

Bamboo charcoal has countless small cavities, three times more mineral constituent and four times better absorption rate than wood charcoal. Its surface area of $300m^2/g$ is also10 times than that of the wood charcoal. The unique properties of bamboo charcoal include uniform composition, high porosity, anti-bacterial and anti-fungal property, breathability, thermal regulation, odour control, absorption and emission of far infrared energy, preventing static electricity build-up, and good wash durability. These fabrics can absorb and disperse sweat fast, making them feel dry and comfortable. They also do not stick to the skin on hot summer days. Bamboo charcoal fabrics absorb and decompose benzene, phenol, methyl alcohol, and other harmful substances. As the bamboo charcoal nanoparticles are embedded in the fibre rather than simply coated on the surface, these fabrics are washable without diminished effectiveness of the charcoal powder's special qualities, even after 50 washes. It was found that antimicrobial activity, blood repellency and odour resistance are higher for bamboo charcoal fabrics than 100% bamboo/cotton union fabrics and 100% cotton fabrics [45].

Lyocell, which is a high performance, solvent spun, 100% cellulosic fibre, ideal for use in many woven and nonwoven applications. The advantages of lyocell include more softness, gentle to the skin, high absorbency, excellent water management property, cool and dry to touch, strong retardation to bacterial growth, and excellent wet strength. Abu-Rous et al. made an effort to explain the functional and wellness properties of lyocell textiles using the nano and porous structures of lyocell which is radically different from the other known cellulosics. Union fabrics are produced by incorporating lyocell yarn in different proportions with PBBC yarn [45].

- 100% PBBC fabric is produced by weaving PBBC yarn in both warp and weft
- 75% bamboo charcoal and 25% lyocell-blended union fabric is produced using PBBC yarn in warp direction and both lyocell combined with PBBC yarn in weft direction.
- 50% bamboo charcoal and 50% lyocell-blended union fabric is produced using PBBC yarn in warp direction and lyocell yarn in weftdirection.
- 25% bamboo charcoal and 75% lyocell-blended union fabric is produced using PBBC yarn and lyocell yarn in warp direction and lyocell yarn alone in weft direction.

By considering the basic quality requirements of antimicrobial and comfort characteristics of the medical textiles, 75% PBBC: 25% lyocell blended union fabric possesses optimum fabric strength, higher microbial resistance, good thermal conductivity, higher moisture transmittance in terms of water absorbency, water wicking, and water spreading behaviour. These developments for medical textile have high potential for the healthcare textiles.

2.15.2 Textile finishing with partial application of micro particles

Woven barrier fabrics for filtration and operating room textiles feature permeable pore channels between yarn interlocking points (mesopores), which create an increased risk of penetration by contaminated fluids and particles. These pore channels can be reduced in size by high-density weaving resulting in deteriorated drapability and performance characteristics. Fluid-tight and particle-tight woven fabrics with adjustable porosity can meet the barrier requirements without impairing the physiological properties of the textile, by partial application of micro particles into the mesopores. There, they form a meshed structure forming reduced pores size without being entirely obstructed. The simultaneous retention of pores between the individual filaments in the fabric guarantees preservation of the physiological characteristics of the textile.

A targeted, partial application of the microparticles into the mesopores of the PES woven fabrics was successful in significantly reducing the structurally large pores. The examination of the pore size distribution revealed a total reduction of the pore proportion of larger pores (>/= 4 mm) from 20.19% to 7.50% and at the same time an increase of small pores (</= 4 mm). After binding the particles to the fibre surface by a thermal post-processing method, the particles form a porous structure in the mesopores. This woven fabric is sufficiently dense to serve as barriers against air/fluid-borne particles, but still display a resistance to water vapour permeability below the guidance value of $8m^2$ Pa/W, ensuring high wearing comfort [46].

The effectiveness of the finishing was evaluated by extensive characterization of the woven fabrics before and after particle application, supplemented by a comparative study of selected textile-physiological properties with highly dense barrier fabrics. It revealed comparatively better air permeability and drapability with lower bending stiffness. The barrier effect against airborne and fluid-borne particles, their pathways, was also analysed by means of a new test method allowing the realistic simulation of practical use. This proved a reduced particle penetration after finishing, expressed by an area reduction of fluorescent particles by 80%.

For PES woven fabrics, treatments with atmospheric pressure plasma or a wet-chemical treatment with alkali are the solutions. To induce connections between the particles, and the mesopores of the woven fabric, an additional targeted functionalization of the particle surface is required. Using functionalized particles, multi-functionality becomes an option, adding features such as antistatic and flame resistance, or antibacterial properties to the fabric.

2.15.3 Barrier effect by permanent thin layer of micro particle

The use of functionalized micro- and nano-particles may be considered as an important area in the field of thin-layer technology [47]. By using functionalized micro- and nano-particles as coating substrates, these functionalities may be transferred onto textiles to create super hydrophobic surfaces or antibacterial properties by the immobilization of silver nano-particles, respectively. The cores of the smallest particles may be applied on textile materials by thin layer technologies (sol-gel process, plasma, spraying etc.) creating layer-thicknesses in the micro/nanometre range. Compared to fully coated materials, thin-layer techniques ensure the preservation of textile-physiological properties like drapability or breathability. PET fabrics, as operating room (OR), clean room, or protective textiles are expected to exhibit a barrier against particle-loaded fluids which serve as carrier media for microorganisms.

The barrier properties of the fabric, defined by the construction-dependent pore morphology (meso- and micropores) and surface properties should be imparted with high wearing comfort of safety garments. Through partial finishing in the yarn intersections it is possible to improve the barrier effect in these critical areas. The textile-physiological properties are secured through adhesion of the micro-pores (pores between the single filaments). Compared to nano-scaled particles which are mainly deposited on the fibre surface, micro particles are more likely to be placed between the single filaments, which positively support partial coating in the yarn interstice. Combined with an application technique based on vacuum- filtration, porous structures composed of micro particles have been created in the meso-pores without pore closure.

To achieve the permanent particle bonding to the PET fabric surface, chemically active surfaces have to be created on both the particles as well as the PET filaments. Textile fabrics made of PET possess a polar, hydrophobic, and inert surface, i.e. no reactive groups which could interact with bonding partners are present. However, due to its good chemical resistance and superior physical properties PET entails very good prerequisites for numerous means of surface-functionalization and -modification. These characteristics are an ideal basis for improved adhesion properties and thus for successful bonding of functionalized particles to the fabric surface.

Studies on the stability of nano-particles on textiles showed that a covalent bonding between particles and textile is to be preferred. These prerequisites may be transferred to micro- particle. Furthermore, plasma surface treatment is a widely used technique for textile finishing. The choice of different reactive gases makes it possible to create many reactive groups at the surface, which enable a functionalization of the textile surface towards improved wetting behaviour. Another technique to activate textile fabrics is alkali treatment. This is a wet chemical pre-treatment in which the textile is treated by alkaline solution. Alkaline hydrolysis causes splitting of the ester groups present in PET. This results in elevated surface energy levels and thus in more likeliness to interact with other compounds. Initiators functioning as adhesion agent are an additional method to support particle bonding to the fabric surface. The aim is the realization of PET-surfaces with permanently bonded functionalized particles. For this purpose, different particle systems can be considered.