



## An Overview of Carpet Manufacture: Design, Dyeing, Printing and Finishing

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### Abstract

A carpet is a textile floor covering made comprised of the top layer of a pile that is linked to a support. A pile was historically composed of wool, but synthetic fibres like as polypropylene, nylon, or polyester, which are less expensive than wool, have become popular during the twentieth century. Carpet tiles and broadloom are the most often utilised Textile covering floorings because to excellent qualities such as elasticity and dimensional stability. So, initially, we'll discuss carpet fibre structure and features, followed by carpet yarn and the printing processes that occur on it, with a focus on the inkjet printing technique.

**Keywords:** Carpets, Classification, Manufacture, Dyeing, Printing, Finishing

### Introduction

Textiles may be found all over the place. We wear them and also use them as carpets and rugs in our houses. While fabrics on our floors feel nice and add style and comfort to our spaces, we also want to ensure that they are safe to use. We also want them to be able to withstand years of use.

Carpet is a type of textile floor covering that is soft to walk on, easy to maintain, and has a sumptuous appearance. It usually has a top layer of pile that is linked to a backing. Table and wall coverings are also made of carpet. It is available in a range of forms, patterns, and colours, and is composed of natural and synthetic fibres. In a home, carpets serve to lower noise levels and limit heat loss through the floor. They're also more comfy to sit or lie on than a hard wood floor. The type of fibre used to form surface yarns is commonly used to classify carpets. The general fibre name for surface yarns may be found on the carpet sample.[1]

### Carpet Fibers and Yarn

Natural and synthetic fibres are the two types of fibres that carpet producers may use in their blends. Carpet yarns are distinct from yarns used in clothes and home textiles in terms of fibre characteristics.

#### Fibers used in the carpet surface

##### Wool

Wool, the most popular natural fibre and a fantastic renewable resource, is particularly well suited to being used as a carpet fabric because it combines high resilience to foot traffic with an incredible ability to maintain its appearance for years. Wool carpets are also fire resistant and provide an excellent anti-static flooring choice under typical conditions.[2] Wool is primarily of two types: wool for apparel use, which is 23  $\mu\text{m}$  and below, and the wool which is 24  $\mu\text{m}$  and upward is generally used in interior textiles that includes carpets/ rugs.[3]

Wool carpets are difficult to ignite and can obtain high degrees of flammability without the need of specific treatments. The capacity of a wool carpet to hide cigarette burns was deemed crucial for hospitality end uses since a little area of char could be

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swept from the carpet surface without leaving an unsightly black stain. Wool is naturally soil-resistant, and wool carpets may retain substantial amounts of soil without seeming unclean. They react well to cleaning, and the pile frequently rebounds effectively from flattening during the cleaning process, due to the use of warm water in the procedure. Wool's low abrasion resistance makes its use in low pile weight constructions problematic, however the usage of wool rich pile fibre mixes with the addition of say 20% nylon or other tough synthetic fibre considerably improves the carpet's abrasion resistance.[4]

However, the warm and luxurious connotation of wool often lends its use more often to the more prestigious carpet constructions.[1]

### **Silk**

Silk is rarely used in carpet because it is so fragile, but it adds a special touch to the best handcrafted carpets, notably those from the Middle East and India.[5]

### **Nylon fiber**

The most common carpet material is nylon (about 90 percent of residential carpets and 65 percent of all carpets). Nylon carpet fibre is an excellent choice for high-traffic areas since it is long-lasting, static-free, and resistant to soiling, staining, and mildew. Color is

retained in nylon strands that have been coloured after manufacture. Some nylon carpet fades in the sun. It is available in both continuous and spun fibres. Spun yarn is created by spinning together small lengths of fibre. Continuous strands are thus less prone to unravel.[3]

### **Acrylic Fiber**

Acrylic carpet fibre has the appearance and feel of wool but is less expensive. Acrylic carpet fibre has a low static charge and is resistant to moisture and mildew. It is frequently used in Velvet and Level Loop designs, as well as for bath and scatter carpets.[6] Wet and dry spinning are the two most prevalent methods for producing acrylic fibres. Melt spinning cannot generate acrylic fibres because they deteriorate when heated towards the melting point.[3]

### **Polyester Fiber**

When used in thick, cut pile textures, polyester carpet fibre is known for its rich soft "hand." It offers outstanding colour clarity and retention. Polyester is easy to clean and repels water-soluble stains. Polyester carpet fibre that are used in carpet are normally in the average of 15  $\mu\text{m}$  and it should be of trilobal cross section, bright, semi-dull, and of staple lengths, which are appropriate for processing in semi-worsted yarn-processing system.[3, 7]

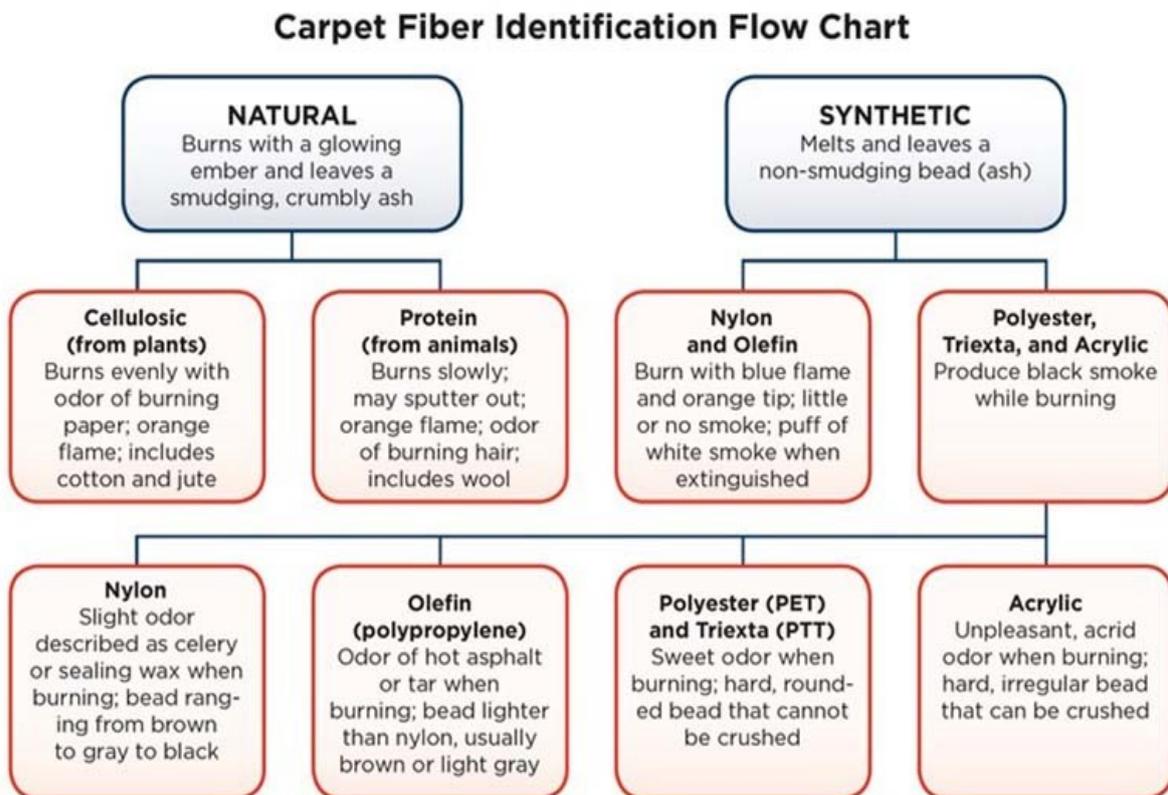


Figure 1: Fibers used for carpet production Fibers used in the carpet surface Wool

**Fibers used in the backing structure of Carpet**

**Jute**

Jute is an excellent carpet backing fibre. It is both cheap and limited in its extensibility. However, the long supply route, primarily from the Indian subcontinent, and the unpredictability of regular supply are significant drawbacks. Jute is extremely susceptible to bacterial assault, especially when moist.[8]

Jute yarn has long been the most common choice for the weft of woven carpets, and many woven carpets still use it. In Wilton carpets, jute is usually used as the 'stuffer' warp.[9]

Because of its low cost, high structural stability, and natural look, woven jute cloth (Hessian) is widely used as a supplementary backing fabric. However, unreliable supply has hampered its adoption among many industries. [10]

**Cotton**

have historically been used as warp threads in woven carpets. Cotton fibre in synthetic mixtures remains popular for this application.[8]

**Polyester**

High-tenacity polyester spun yarns have been utilised as warp yarns in woven carpet in recent years, but a more prevalent application is as a cotton polyester blend in chain warp yarns.

**Polypropylene**

Split film polypropylene yarns have been employed in woven carpet production as both warp and weft yarns. Polypropylene offered a less expensive alternative to cotton in the form of nominal 1000 d'tex yarn as a cotton substitute for Axminster weaving, but it resulted in lower weaving efficiency due to abrasion of the yarns by the reed and other weaving components, causing the yarn to fibrillate and entangle.

Polypropylene is used as a weft yarn, frequently coloured to a natural jute colour, in weft yarns where high strength and cheap cost are favourable. The yarn has less tension stability than jute but is not damaged by water and is not susceptible to bacterial assault. [3]

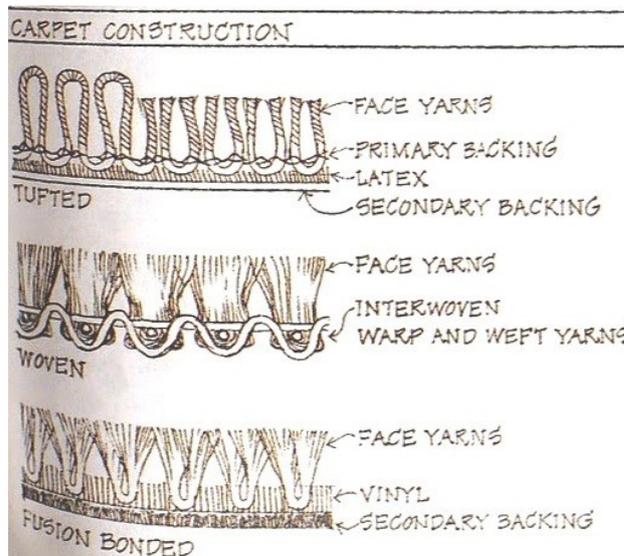


Figure 2: Carpet construction

**Carpet Manufacturing and Construction[1]**

**Classification of carpet types based on the method of manufacture**

Carpets can be classified according to the process of their manufacturing into as illustrated in

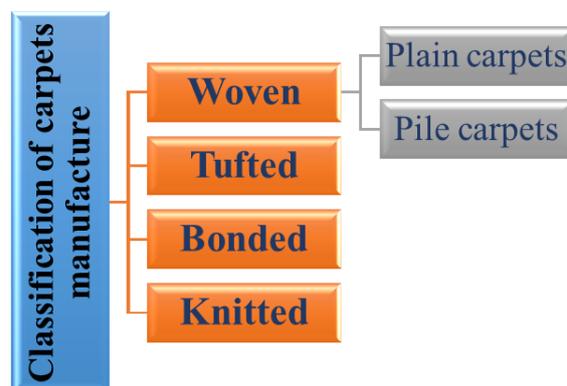


Figure 3.

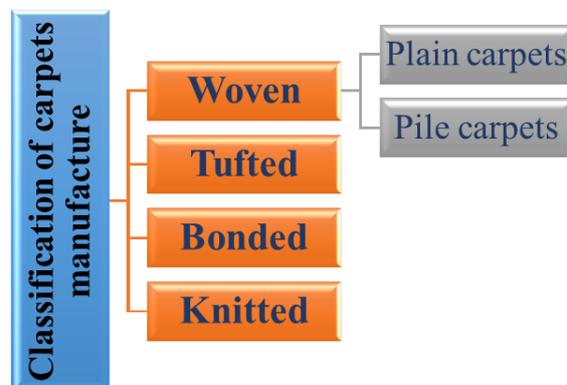


Figure 3: Classification of carpets according to their manufacture

### **Woven carpets**

Woven carpet is more durable and stable than tufted carpet, although it is less durable and more expensive to make. The fibres are interwoven with the backing in the conventional manner of carpet production. Velvet, Wilton, and Axminster are the three primary weaving methods.[11] Many colours may be used in Axminster and Wilton carpets, but the Wilton architecture of interwoven pile and backing allows for a limit of five colours to be employed. While the colour is not visible in the pile, it is woven into the backing, resulting in an extra-thick, robust carpet.

An overview of the various types of carpet are given in below figure 3.

### **Plain carpets**

Plain carpets are made out of warp and weft threads with no thread system to form the pile. Plain weave carpets are often produced by hand.[14]



**Figure 4** Plain carpet

### **Pile carpets**

Pile carpets contain an extra thread system that makes up the upper side of the carpet in addition to the main weave. The pile threads in loop-pile carpets look as loops on the carpet surface. The pile threads in cut-pile rugs seem sheared on the surface of the carpet.



**Figure 5** Pile carpets

### **Wire carpets**

These carpets have a layer of wire plush piles.



**Figure 6:** Wire carpet

### **Axminster carpets**

These are woven cut-pile carpets, where several warp pile threads in one longitudinal nep row are pulled out or lifted to form the pile.

### **Rapier-Axminster carpets**

The pile threads are inserted by a rapier, while the choice of the colored pile threads is controlled by a Jacquard system. Each pile nep corresponds to one rapier.

### **Chenille carpets**

Premade chenille ribbons are used as weft pile yarn.

### **Double carpets**

These carpets are manufactured as upper and lower sides by cutting open a double fabric produced in one processing step.

### **Knotted pile carpets**

Short pieces of pile thread are knotted around two or more warp threads between the weft threads.

### **Tufted Carpets**

The great majority of carpet manufactured nowadays is tufted. Tufting is the process of sewing face yarns onto a backing material using many specialised equipment. A thick latex coating secures the fibres to the pre-woven backing. For increased dimensional stability, a supplementary backing might be used.[12] Pile threads are inserted with needles or sewn into a textile fabric. For the carpet backing, the woven fabric needs to have good tenacity, uniformity, and shape stability.

The density of the backing fabric has to be such that the sewn, loose pile neps are stable during finishing, as they are inserted without loop formation. Suitable materials for this are jute as well as many other natural and synthetic materials such as polypropylene (PP) bands or spun bonds.[14]

**Bonded Carpets**

Bonded carpets have pile that is bonded, often heat-fused on to pre-made backing, as a result they are relatively inexpensive.

In carpet manufacturing, the pile threads are cut between the two basis fabrics. The distance between the two basis wovens corresponds to twice the pile height of the two carpets. In technical applications, double wovens with uncut piles are used more and more often.

**Knitted Carpets**

Knitted carpets, like woven carpets, can be classified as either flat or pile. Flat carpets are knitted and do not feature a pile-producing thread system. Pile carpets, on the other hand, are made up of a ground knit fabric and a pile that are both generated at the same time. On top of the carpet, piles are one or more thread systems or fibre bands. They are firmly attached to the ground layer. The pile thread is either tied in the ground or made into a stitch in the ground. Knitted carpets are distinguishable from cut-and-loop pile carpets. The ground layer is the layer between the pile layer and the back side of the carpet. Furthermore, warp-knitted carpets are among the carpets made using the knitwear manufacturing concept. They are warp-knitted textiles with pile threads tied in a ground material as a pile thread end or a pile loop.[15]

**Parameters for carpet design :**

- Pile height: height of the pile above the backing (mm)
- Number of punches: number of stitches per 10 cm
- Yarn mass,
- Weight: total weight minus weight of backing
- Beats/m<sup>2</sup>: number of tufts/m × tufted rows/m
- Surface pile density: weight of wear layer: pile thickness, 1000 g/m<sup>3</sup>

During carpet production, the following parameters are important:

- *f*Spacing: distance of two pinpoints in inches, for example, 5/64 in. = 1.98 mm
- Width: working width = fabric width without support edges
- Needle shift
- Pattern possibilities

All velour fabrics have to be sheared; loop-pile fabric skips this processing step

**Classification of carpet types based on the of Carpet Textures**

Classification of carpet types according to their textures can be demonstrated in Figure 7.



Figure 7: Classification of carpet types based on the Carpet Textures

**Velvet: (also known as plush, frieze and splash)**

Has an even, generally dense pile.

- Tends to show foot prints, which is desirable for shadowing (Takes away from the ‘flat look’)
- Resists crushing and bending
- Tends to show soil more than others, not the
- Best for stair covering.



Figure 9: Different carpet textures

**Shag carpet**

- Comes in varying yarn lengths (up to two inches)
- Gives grass like appearance
- Used for both formal and informal setting
- Does not wear well on stairs
- Look for dyed back, which camouflages wear.

Two qualities distinguish shag carpet from other carpet and rug styles. The length and configuration of the individual carpet strands utilised in the pattern are the initial considerations. In addition to longer pieces of yarn, the fibre is twisted in a loose design as opposed to the tight design employed in short loop carpeting procedures. The relaxed twist is paired with a design that places the individual yard strands closer together than in a traditional weave. As a result, the appearance of a shag carpet is similar to that of a patch of grass in which the blades or strands can lay in a number of various directions.[16]



Figure 10: Shag carpet

**Velvet Shag**

- A high, soft pile that easily shows indentation from traffic.

- Tends to mat in high traffic areas.



Figure 11: Velvet Shag

### **One-level looped**

Level loop pile is created by weaving even yarn loops into the carpet backing at both ends. Higher loops give a more opulent look while also providing longevity and track resistance due to their robust loops. Level loop piles with short and densely packed loops keep dirt out of carpet and make it easy to clean, making it perfect for high traffic areas.[17]

- Tightly woven looped carpet
- Very strong, withstands water and stains
- Wears well on stairs



Figure 8: level looped carpet

### **Two-level looped**

- Or sculptured
- Has sculptured effect, very durable
- Wears on stairs

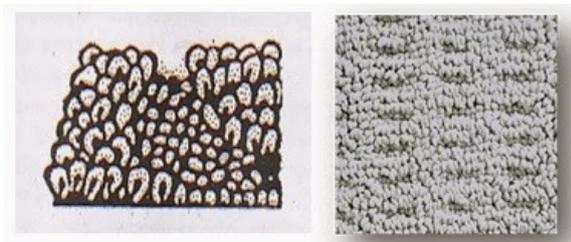


Figure 9: Two-level looped carpet

### **Carpet Durability**

The main factors that affect the durability of a carpet are:

- Fiber weight – The heavier the fiber weight, the harder wearing the carpet will be.
- Pile density – The higher the density, which depends on the tightness of the yarn twist, the better.
- Yarn stitches per inch – The more the better, improving the crush resistance of the carpet.[1]

### **Properties of Carpet**

- Carpet offers thermal resistance, retaining warm air longer and making the space more comfortable to sit in.
- A carpet may enhance the attractiveness and design of a room.
- Carpet softens slips and falls.
- Carpet insulates floors by creating a psychological sense of warmth.
- Carpets are easier to maintain and clean.
- It can reduce noise by absorbing noise.
- There are hundreds of patterns, cuts, and colors.
- Carpet retains allergies, dust, and other impurities and holds them in place until they can be properly cleaned.
- The carpet business is reducing carpet's environmental effect through the "3 Rs" - Reduce, Reuse, Recycle.[18]

### **Dyeing of carpets yarns**

Color is an important consideration for buyers when selecting carpet. Color creates the ambience for the area while also influencing its care and upkeep. Buyers may avoid bright colours because they "show the dirt," or they may choose a multi-colored rug because lint blends into the face of the carpet. As a result, this chapter focuses on colour from theory to application.[12].

### **Dyeing Methods**

Fiber or yarn dyeing is often done in huge vats with the dye liquor being moved through the fibres to ensure close contact of the dye liquor with the fibres. Yarn dyeing is accomplished by suspending skeins of yarn in an agitated dye solution, with extra movement of the Yarns possible during the dyeing process. Yarns can also be dyed while wrapped in bundles on perforated spindles or spools. The dye solution is then passed back and forth between the packets. The package dye process may also be used to colour carpet rolls. Package dyeing is frequently done in closed systems at high temperatures and pressures. Jig dyeing involves moving a carpet piece back and forth through a dye bath from one spindle to another, whereas a dye beck with a winch is used to move a continuous piece through the dye liquid. The

following procedures, which are all batch operations, are depicted graphically in (Figure 13)[12].

Several specific processes for applying dispersion colours to polyester have been developed. Unless dyeing is done at 100°C or above, the pace of dyeing is quite sluggish. To accomplish quick dyeing, dyeing with dispersion colours from aqueous solutions at 120°–130°C is typical, but necessitates the use of closed high-pressure equipment. Jet dyeing was recently introduced, allowing not only high-temperature dyeing but also impingement of the dye into the moving carpet using a venturi jet system. Carriers can also be inserted to allow dyeing of polyester at atmospheric pressure and temperatures below 100°C.

A novel method for continuously dyeing polyester with dispersion colours includes sublimating disperse dye into polyester under heat and partial vacuum using a process known as thermosol dyeing. Polyester with dispersion dye applied to the fibre surface is briefly heated around 200°C under partial vacuum. The molecular mobility inside the polyester is significant at this temperature, allowing the dye vapour to permeate the fibre. When the dispersed dye cools, it becomes permanently trapped and cemented within the fibre.[12].

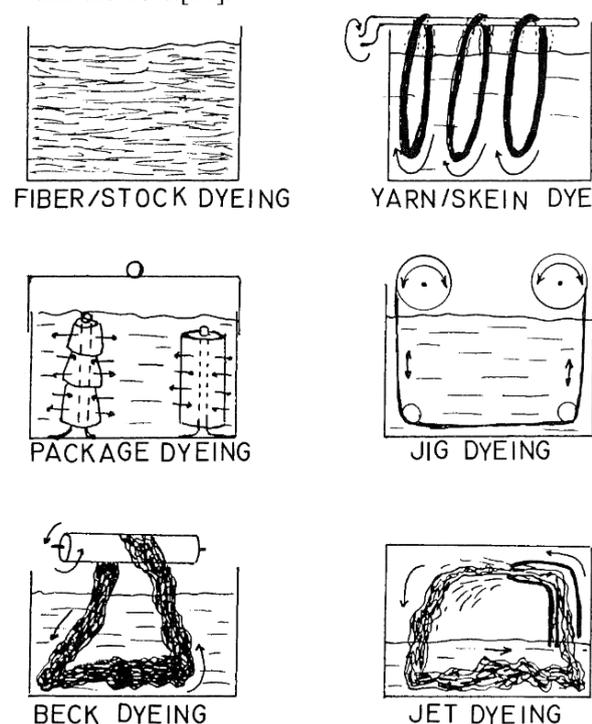


Figure 10: Dyeing processes.

#### Physical Factors Affecting Dyeing

Temperature, duration, and auxiliary chemicals added to the dye bath or printing paste can all influence the rate of dyeing (dyeing kinetics) and/or total dye absorbed by the fabric (dyeing thermodynamics). The rate of dye migration from solution to the fibre surface, the rate of dye diffusion at the fibre interface,

and the rate of dye diffusion in the fibre matrix all influence the dyeing rate of the fibre. The impact of dye diffusion to the fibre in the dye bath is substantially eliminated by agitating the dye solution. In most circumstances, the rate of dye passage across the fiber-liquid interface is fast; hence, the pace of dyeing is completely governed by the velocity of dye movement inside the fibre matrix. The rate of "strike" of dye onto the fibre and diffusion in the fibre increases as the dyeing temperature rises, whereas the total amount of dye present in the fibre at equilibrium drops. Dyeing is often done at a temperature higher than the glass transition temperature ( $T_g$ ) of the fibre, since the molecular segments of the polymers inside the fibre are more mobile and allow for faster dye diffusion above that temperature[12].

#### Chemical Reagents

A variety of chemical reagents (auxiliaries) are added to the dyebath to affect the dyeing process in some way. To improve dye diffusion, acids or bases can be added to the dyebath to cause charge creation in the fibre. Common inorganic salts, such as sodium chloride or sodium sulphate, can be added to a dyebath to function as levelling agents, slowing the process of dyeing and providing more equal colouring. Anionic detergents, for example, can operate as levelling agents while simultaneously allowing for the quick and thorough fibre wetting required for even colouring. To bind or chelate hardwater calcium or magnesium ions that may interfere with dyeing, water-softening agents such as sodium hexametaphosphate are used. Organic solvents and/or specific chemical reagents may be used to boost dye solubility and rate of penetration into the fibre [12].

Carrier molecules are typically aromatic organic chemicals that can be emulsified in water and have affinity for the polyester. The carriers penetrate the polyester, open up the fiber's molecular structure (frequently leading in fibre swelling), and help in the passage of the dispersed dye across the dye solution-fiber interface and into the fibre. Aromatic hydrocarbons such as diphenyl and methyl-naphthalene, phenolics such as o- and p-phenyl phenol, halogenated aromatics such as di- and tri-chlorobenzenes, aromatic esters such as methyl salicylate, butyl benzoate, and diethyl phthalate, and benzaldehydes are all suitable carriers. Carriers must be removed after dyeing, and their presence in mill effluents is problematic due to their toxicity[12].

#### Dyes applied to fiber classes

##### Dyeing of Protein Fibers

Protein fibres are the best to dye because they have so many reactive functional groups. Under acid or neutral conditions, they may be coloured with a wide spectrum of colours.

Amino groups in protein fibres are protonated to generate  $\text{NH}_3^+$  or protonated amino groups when they are exposed to acid. They may bind pigments containing acid anions, such as acid dyes, in this state (Figure 14). Protein fibres are dyed to rapid colours using special premetallized acid dyes with appropriate solubility. Protein fibres are highly good at forming complexes with multivalent metal cations. By mordanting acid and mordant dyes with metal salts, they can be rendered extremely quickly; chromium salts are particularly efficient as mordants. Protein fibres may be coloured with cationic or basic dyes at neutral or slightly acid pH, but the dyed fiber's fastness is weak without mordanting with tannic acid or other cationic dye mordants [12].

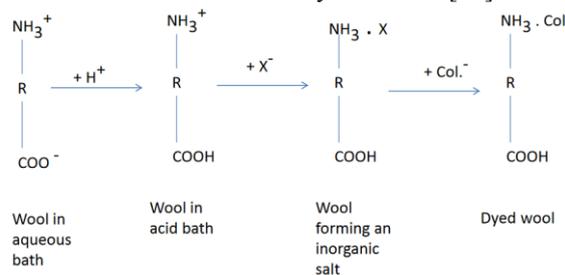


Figure 11: mechanism of wool dyeing with acid dyes [12]

### Dyeing of Polyamide Fibers

Polyamides may be dyed using a wide range of colours. The fibres colour like protein fibres like wool because the polyamides include both acid carboxylic and basic amino end groups and have a high moisture regain. Polyamides display some of the colouring qualities of other synthetic fibres such as polyesters and acrylics because their molecular structure is somewhat more hydrophobic, more regular, and more densely packed than protein fibres. Polyamides, such as nylons 6 and 6,6, may be coloured easily using anionic dyes like acid, metallized acid, and mordant dyes, as well as cationic dyes like basic dyes. Acid dyes on nylon can be efficiently mordanted for added fastness. At temperatures above  $80^\circ\text{C}$ , disperse dyes may easily colour polyamides. Because of the nylon component, numerous dye types may successfully colour the constituent fibre of nylon, however dispersion dyes are favoured for deep dyeing. Nylon 6 and 6,6 are dyeable with acid dyes in light, medium, or deep shades, or specifically dyeable with cationic dyes [12].

### Dyeing of Polyester Fibers

Polyester fibres are extremely difficult to dye using traditional dyeing procedures due to their high crystallinity and hydrophobicity, unless the fibre has been changed, as in the case of modified terephthalate polyesters. Disperse dyes can be used to colour polyester fibres. Dyeing hydrophobic fibres such as polyester fibres using dispersion dyes may be

thought of as a dye transfer procedure from a liquid solvent (water) to the fibre. To make an aqueous dispersion, disperse dyes are mixed with water and a surface-active ingredient. Because disperse dyes are more substantial to the fibre than to the dye liquor, their insolubility allows them to leave the dye liquid. Heat enhances the energy of dye molecules and speeds up the dyeing of textile fibres. Heating the dye liquid slightly expands the fibre and helps the dye permeate the fibre polymer system. As a result, the dye molecule occupies the amorphous portions of the fibre. Once within the fibre polymer system.

When dyeing reaches equilibrium, the following equilibria are established:

- Dye dispersed in the bath  $\leftrightarrow$  Dye dissolved in the bath.
- Dye dissolved in the bath  $\leftrightarrow$  Dye adsorbed on the fiber.
- Dye adsorbed on the fiber  $\leftrightarrow$  Dye diffused in the fiber.

### Dyeing of Acrylic Fibers

Acrylic fibres are a popular synthetic fibre made from polyacrylonitrile by addition polymerization using acrylonitrile as the monomer.

Most commercial acrylic fibres are acrylonitrile copolymers with monomers of vinyl compounds, such as vinyl alcohol, acrylic acid, vinyl chloride, vinyl acetate, methacrylic acid, and methacrylate esters. It is done because dyeing homopolymers is extremely challenging. Acrylic fibres have a negative charge.

They can be classified into two categories, according to the definition.

- Acrylic fibre: The copolymer contains at least 85% acrylonitrile by weight.
- Modacrylic: The copolymer must include at least 35% acrylonitrile but no more than 85% by weight.

Acrylic dyeing can be done using two different types of dyes.

- Disperse Dyes: They have a poor affinity for fibre and are only ideal for light to medium shades.
- Basic Dyes or Cationic Dyes: Basic/cationic dye is the most extensively used and acceptable type of dye for acrylic dyeing. They may create dark and deep hues with excellent colour fastness.
- Acrylic Dyeing with cationic Dyes

### The procedures for using basic dyes to dye acrylic yarn or fabric.

- Heat the dyes in hot water until they are completely dissolved.

- Preparation of a dyebath with retarder and sodium acetate as a buffer. Controlling the dyeing rate by dyeing at pH 5 is a good idea. Level dyeing necessitates the use of a retarder.
- Soak the cloth for 10-15 minutes in a blank dye bath containing the retarder at 40°C.
- Raise the water to a boil by gradually increasing the temperature.
- Let the dyeing process continue for about an hour.
- After the dyeing is finished, carefully cool the dyebath to 50-60°C to avoid wrinkles in the cloth building up right away.
- Remove excess dyes and chemicals by washing with water and then with soap.

**The dyeing mechanism**

- The basic dyes' coloured cations (ionised) are first absorbed on the acrylic fibre surface. Adsorption is the technical term for this.
- At the dyeing temperature, they diffuse into the fibre interior.
- The dye cations are retained in the fibre material due to strong electrostatic attraction. They have excellent wash fastness due to their tight connection.

If the dye molecules are exhausted unevenly at first, uneven dyeing may occur. As a result, it's critical to keep a check on the dye molecules' initial rate of exhaustion or strike. This is done by the retarder.

To aid in the levelling of a dyeing, retarders can be added to the dyebath. Anionic retarders produce soluble adducts with the dye in solution in a reversible manner. Cationic retarders, on the other hand (such as quaternary ammonium compounds), compete for adsorption and ionic binding at the fibre. A scheme of a polyacrylic dyeing is shown in below Figure (15)

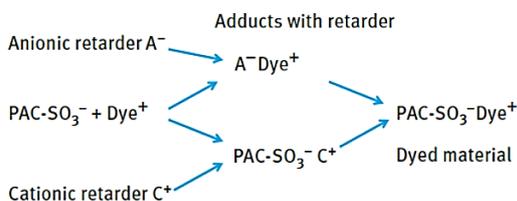


Figure 12: Dyeing using cationic dyes and retarders

**Printing Techniques**

Carpet printing methods include flatbed screen printing, rotary screen printing, discharge to white, colour discharge, and resist style, as well as digital printing methods like as ink jet printing inkjet printing. Representations of the printing and printed style processes are found in .[12]

Printing and printed style processes [19]

**Direct style**

The printing is done directly on the undyed and pre-treated carpet. This approach produces a printed look on an undyed basis. Digital printing is a straightforward method of printing.

**Discharge style**

A woollen carpet is coloured with dischargeable colours and then printed with discharge printing paste in this technique. Then comes the steaming and washing. Dyes in the printed area are eliminated by releasing chemicals, giving the dyed piles a white appearance.[1]

**Colour Discharge style**

In this technique, a woollen carpet is first coloured with dischargeable colours before being printed with a paste including non-dischargeable colours and discharging chemicals. Then comes the steaming and washing. Dyes in the printed area are degraded by releasing chemicals, resulting in a variety of coloured effects on the dyed heaps.

**Resist style**

In this technique, a woollen carpet is printed with resist paste before being coloured using the padding process. Then comes the steaming and washing. Because of the resistance provided by resistant chemicals, dyes in the printed region are not fixed, resulting in a white appearance on the printed piles.[19]

**Transfer Printing**

Heat transfer printing, a variant of thermosol dyeing, may be used to print polyester with dispersion colours. Dispersion dyes are printed onto paper, then the polyester carpet and printed paper are brought together under pressure with enough temperature to produce disperse dye diffusion into the polyester. [12]

**Digital printing**

This is a type of direct printing. PLC computers are used in digital printing to dispense a sequence of inkjets through a printing head, or set of printing heads that traverse over the breadth of the fabric as the fabric moves forward below the printing heads.

Inkjet printers use two technologies: drop-on-demand (DOD) and continuous inkjet (CI) (CIJ). DOD technology consists mostly of two techniques that employ thermal pulse principles (or bubble-jet) and piezoelectric principles.

The print heads are controlled by computer software and only deliver a drop of ink in accordance with the print design or programme.

CIJ printers generate a continuous stream of ink droplets, with drop selection controlled by

electrostatic charge, which may be deflected when no print is required.[20]

#### **Advantages of digital printing on carpets**

Digital inkjet printing has some considerable advantages over conventional printing because no screen is required.

- To achieve the final colour, the print pattern is made digitally and the ink droplets are blended together on the cloth surface. In contrast, the final colours in traditional printing are pre-mixed with print thickener/auxiliaries and applied straight to the cloth surface.
- Because the print design concept is altered digitally, the setup time for producing short runs, sampling, or proofreading is significantly reduced.
- All expenses associated with screen engraving, paste production, strike-offs, downtime, and waste are fully removed.
- There are no screen registration issues, and the pattern repeat distance along the cloth is no longer limited by the actual size of the screen. This allows the print designer a lot more leeway.
- Because dyes are delivered in colour cartridges, ink jet printing does not require the use of typical print thickeners. They are ready for use as soon as they are attached to the printer.
- When compared to traditional screen-printing processes, inkjet printing uses less water and uses less energy.[20-22]

#### **Steaming**

In contrast to textile steaming, dye fixing on printed carpets is done without any interim drying. This is due in part to the significant amount of energy necessary to dry the carpet, and in part to the fact that the steaming time is much decreased when the operation is performed on wet carpet.

The first requirement of the steamer is that it should be capable of transporting the material through its interior without affecting the resiliency of pile and bulk. Also, dyes should be allowed to spread on to other parts of the print.

The second requirement is that the steam quality should be such that the dyes are fixed as rapidly as possible, without 'bleeding' or any loss of colour value of print. Printed wool carpets carry quite large amounts of paste which take time to heat in the steamer before fixation commences. The carpet steamer has a speed of 10–20 m/min and a steam time of 3–6 minutes for fixing. It's preferable if you keep the carpet horizontal throughout the whole steaming process. Steaming horizontally during the first 3 minutes, on the other hand, creates enough fixation to avoid marking off. Air-free saturated steam at 98–

102°C is essential for optimal dye fixing. There may be a lack of colour yield repeatability if steaming conditions change throughout a run or from one batch to the next.[19]

#### **After wash**

Unfixed dyes must be removed from carpet fibres, which necessitates washing. The carpet should be cleansed after steaming to remove any supplementary materials, unfixed colour, and thickening. In contrast to the process of textile printing, cool water is employed to reduce heat energy.

- The dip-squeeze method is often supplemented by vigorous water jets, with perhaps two sets operating in tandem. Some or all of the jets may need to be reduced to retain the pile texture of wool carpets. It's also a good idea to avoid splashing water on the carpet's face.
- The spray/vacuum system of afterwash economises on water usage and reduces effluent. If remaining colours and chemicals have to be removed effectively, a multi-head spray-vacuum equipment is necessary. The main goal of the afterwash for wool is to maintain the fiber's high reputation for dirt resistance by eliminating impurities that might cause soiling during wear.
- In perforated drum wash units, good washing can be achieved with the liquor passing through the pile and the carpet. To minimise cross-staining on light shades, the carpet should be run through a gently alkaline solution when it exits the steamer for heavy shades. The alkali assists in the elimination of unfixed dye, which enhances the prints' wet fastness.[1]

#### **Improving the type of thickener used for carpet inkjet printing**

Chang E. Zhou *et al.*, the investigation of For carpet inkjet printing, a polyacrylate-based thickener is used. The surface tensions of polyacrylate-based thickener-based printing inks are suitable for inkjet printing. The percentage of printing ink removed is appropriate for the inkjet printing machine's unique construction. The viscosity is susceptible to tap water and dye, although it has excellent storage stability. Carpet printing using printing ink including a minimal amount of thickener offers an excellent colour yield and fastness. When printing ink with a polyacrylate-based thickening is used in practical applications, the concentration of the thickener can be modified to meet the needs of the printing effects and the textile qualities.[22]

Other study, Polyacrylates, polyacrylic acids, and cationic starch were combined to make an associative thickener, which was then improved using the OATS approach. With the doses of 1.0 percent polyacrylate

ASK, 0.1 percent polyacrylate SC, 1.0 percent polyacrylic acid HT, and 0.4 percent cationic starch UK, the associative thickener had the best viscosity. PEG (0.2%), polyamide (0.3%), and polyacrylic acid DY (1.0%) were added to improve the performance of the associative thickener for digital printing of nylon carpet. The stability of the paste made with the associative thickener was equivalent to that of the electrolyte and temperature, as well as the paste's PVI and storage stability. The associative thickening gave the nylon fabric about the same washing-off properties, colour yield, and colour fastnesses as the commercial thickener used in digital printing.[20]

### **Finishing process of carpets**

To meet the specific demands of the client, a range of value-added carpets finished with specialised functional effects is produced. In general, we all know that in high-traffic areas such as hotel lobbies or living rooms, a carpet that is sturdy, abrasion-resistant, and constructed of strong synthetic fibres such as nylon, polyester, polypropylene, acrylics, or their mixes is required. These synthetic fiber-based carpets are not only less expensive, but they are also easier to maintain and may be achieved with a variety of custom effects and finishes by combining various additives and colours. This is not always the case when carpets are used in bedrooms, where traffic is low and hence expensive carpets of wool fibre that outperform in quality can be employed. Carpets used in dining or play areas where food is regularly served and spillage is possible are anticipated to have excellent resistance to water and oil-based stains. Stain-resistant nylon, polyester, or polypropylene is a good choice in these situations. However, because to its oleophilic characteristics, polypropylene resists greasy stains to a far lesser extent.

Carpet finishing can be done physically, chemically, biochemically, or physicochemical, and the durability of such finishes can be temporary or permanent [23]. The purposes of the numerous functional finishes used on carpets are one way these finishes are categorised. Stabilization treatments include soil-release finishes; comfort finishes include softening finishes; appearance retentive finishes include abrasion resistance, anti-fiber shedding, and carpet back coating; and safety-related finishes include flame retardant and water repellent. Biological control finishes include antibacterial and fragrance finishes [23].

In today's world, when environmental protection and human health have taken centre stage in product development, carpets and their finishes that were acceptable two or three decades ago are no longer acceptable to the modern-day environment and sustainability sensitive customer. As a result, some of the old chemicals used for speciality finishing have been discovered to be non-eco-friendly, and they occasionally contain formaldehyde-based finishing

compounds, which are now proven to be dangerous to human health. It is also bad for the health of shop floor employees who finish carpets using formaldehyde-based finishing products, because the fumes of excess formaldehyde during the curing process are likely to be swallowed by the workers. As a result, only formaldehyde-free finishing chemicals should be utilized. The finishing technique should also be chosen in such a way that it does not create discoloration during processing or throughout the carpet's service life. Fixing these treatments should be done at temperatures less than 150°C to avoid distortion of the thermoplastic carpet backing. Fibers with poor moisture retention qualities should be utilised to provide appropriate moisture evacuation in a reasonably short period of time before the finishes cure. In general, the finishing process itself must be affordable and cost competitive while providing superior performance attributes[24].

Colors, patterns, fiber choices, pile heights, and specialised finishes are all required for carpets used in various places for various purposes and conditions, in addition to aesthetic features. As a result, this section outlines the different value addition and new approaches utilized in current carpet finishing.

### **Fire retardant finishes**

Important elements with respect to flammable materials are combustibility, ignitability, flame spread, and heat release. Secondary effects are smoke development, toxicity, and corrosiveness of gases [24]. All of these considerations are crucial in the development of flame-retardant systems for certain substrates. Traditional flame retardants for textile materials, such as those containing nitrogen or phosphorus components, degrade at lower temperatures and leave more char residues than untreated cellulose. The most widely utilized chemicals for imparting fire-retardant ability to cellulose material include borax and boric acid combination, phosphorous- and nitrogen-based compounds such as diammonium hydrogen phosphate, urea, and other similar chemicals. Researchers have recently advocated for the use of nitrogen, sulphur-based ammonium sulphionate as a fire-retardant substrate[25-27].

By using a gas-phase mechanism, halogen-based compounds can impart flame-retardant properties; however, this method is not generally employed due to the production of hazardous gases like as furanes during processing, and the treatment is also not long-lasting. Because of its strong fire-retardant quality and outstanding wash durability, formulations based on tetra hydroxiphosphoniumchloride (THPC) and melamine resin, Pyrovatex and melamine resin swamped the commercial market over time. A spray, dry, and cure procedure is used to modify cotton-based carpet materials using polycarboxylic acid crosslinking systems to impart flame-resistant

qualities as assessed by the standard test for textile floor covering materials (pill test). Although phosphorus-based catalysts like sodium hypophosphite or sodium phosphate are particularly good in catalysing the cellulose reaction, non-phosphorus catalysts like sodium bicarbonate and carbonate are also quite effective. Butanetetracarboxylic acid (BTCA), citric acid, and maleic acid are polycarboxylic acids that are employed, and BTCA has the greatest overall performance of all.[27].

### **Mechanism of flame retardance**

The demand for jute-based products in fields such as furniture upholstery, ornamental fabrics such as wall coverings, curtains, draperies, automotive fabric, and, most importantly, carpet backing has recently increased, and to meet this need, flame-retardant finishing on jute textiles is required. The flame-retardant chemical may char the fuel, quell the combustion reaction, absorb heat, release cooling gases, or substitute oxygen in the combustion process. Phosphorous-containing flame-retardant chemicals include THPC, tetrakis(hydroxymethyl)phosphonium sulphate (THPS), tetrakis(hydroxy-methyl)phosphonium hydroxide with ammonia (THPOH-NH<sub>3</sub>), vinyl phosphonate, zirconium, titanium, and other metal complexes like potassium hexafluorotitanate (K<sub>2</sub>TiF<sub>6</sub>) and potassium hexafluoro (K<sub>2</sub>ZrF<sub>6</sub>)[23, 26].

In the presence of flames, combustion is a gas-phase activity that uses oxygen from the environment. As a result, the textile degrades prior to the combustion process, with some of the degradation products transforming into flammable volatile species that, when combined with oxygen, ignite the flame. If the heat created during combustion is substantial, it may readily be transmitted to the textile substrate, resulting in additional deterioration and a self-sustaining combustion cycle (Figure 7).

If fibres and textiles are not intrinsically flame retarded due to their chemical composition and thermal and fire properties, they must be treated with additives that may contain halogen, nitrogen, phosphorus, sulphur, boron, metals, and other elements to become flame retarded. The aforementioned additives can be included into synthetic fibre spinning operations or placed on the synthetic or natural fiber/fabric surface to provide a protective layer/coating. Both finishing and coating processes can be used: in the former, the fiber/fabric is impregnated with a solution or a stable suspension containing the FR additive; in the latter, the fiber/fabric is coated with the FR additive. The coating process, on the other hand, entails applying a continuous or discontinuous layer/film on both sides of the material. [28-33]

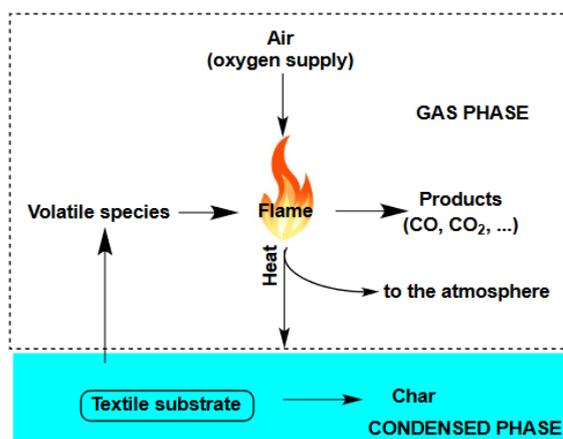


Figure 13: Scheme of the textile combustion cycle.

In the presence of FR additives, the self-sustaining combustion cycle of Figure 16 can be interrupted, resulting in the extinction of the flame or a reduction in the burn rate. They can, for example:

- Reduce the produced heat to the minimum required to continue the combustion process.
- Change the pyrolysis process to reduce the number of flammable volatiles produced while encouraging the formation of char, a carbonaceous residue that also inhibits heat and mass transmission between the textile material and the flame.
- Cut off the oxygen/air supply to the flame.
- When the cloth reaches the ignition temperature, release flame inhibitors (such as chlorinated and brominated chemicals).
- Limit or prevent additional pyrolysis by lowering the heat flow back to the cloth.
- When the textile comes into contact with a flame or a heat source, it is more likely to create a char or an intumescent protective coating.

### **Flame Retardants for Cellulosic Fibers**

The production of levoglucosan is an essential thermal degradation process in cellulosic (cotton) and lignocellulosic (jute) fibres. Levoglucosan and its volatile pyrolysis products are extremely combustible molecules that account for the majority of cellulosic fibre combustion (Figure 18). As a result, cellulose flame retardants can prevent the development of levoglucosan. Phosphoric acid crosslinking and esterification of cellulose polymer chains reduces the synthesis of levoglucosan and catalyses cellulose dehydration and carbonation, making them efficient flame retardants. The most effective long-lasting cellulose flame retardant is based on phosphorus- and nitrogen-containing compounds that can react with the fibre or create crosslinks in the structure. During the early stages of fibre pyrolysis, the formation of phosphoric acids catalyzes the dehydration process of cellulose and generates char at the expense of volatile

gas generation, making them the most effective cellulose flame retardants. The presence of nitrogen, on the other hand, is important because it has a synergistic impact with phosphorus[26, 34].

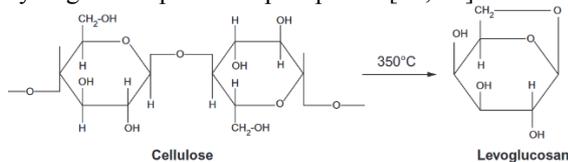


Figure 14: Degradation of cellulose under heat

#### **Flame Retardants for Wool Fibers**

Wool, which is more difficult to ignite and burns with a low flame velocity due to its inherent decreased flammability, burns more quickly than untreated natural fibres such as cotton, linen, and silk. The natural high nitrogen (15-16%), sulphur (3-4%), and water (10-14%) content of wool contribute to its intrinsic flame retardancy. Wool, on the other hand, takes more oxygen in the surrounding atmosphere to burn.[35].

Zirpro's technique, which is based on the exhaustion of negatively charged hexafluoro zirconium or titanium compounds onto positively charged wool in an acidic atmosphere, improves the flame retardancy of wool significantly. However, while Zirpro treatment is the most widely used durable flame retardant finishing process for wool, some suitable compounds such as protic acids (i.e. formic acid and hydrochloric acid) have potential and can be used in combination with zirconium or titanium salts to improve flame retardancy in wool fabrics[36]. As a result, flame retardant agents such as Tetrakis Hydroxymethyl Phosphonium Condensates (THPC), N-methylol dimethyl phosphonopropionamide derivatives (MDPA), and ammonium phosphate derivatives have been used to improve the flame retardancy of wool fabrics by forming a high thermally protected insulation char layer. Gashti et al. looked into the use of ZrO<sub>2</sub> nanoparticles as a flame retardant, and discovered that stabilised nano-ZrO<sub>2</sub> particles improve the flame retardancy and electromagnetic reflection of wool fibres[37]. Furthermore, Forouharshad et al. studied the flame retardancy of wool using zirconium oxychloride in a variety of acidic conditions and obtained good findings [38].

#### **Flame Retardants for Nylon Fibers**

Nylon textiles and blends have been widely employed as protective garment materials, however they are very flammable. As a result, flame retardant finishing with efficient flame retardant systems is necessary. Although aramid fibres such as Nomex and Kevlar are naturally flame-resistant, their expensive cost limits their wide range of uses. Only additions to the polymer melt and topical finishes, such as hydroxyl-functional organophosphorus oligomer, phosphorous and bromine-containing

chemicals, have been marketed to impart flame retardancy into nylon. Possibly due to a few issues in the flame retardant finishing of nylon, such as a decrease in reactivity and the creation of melting drip during combustion, which generally enhances fire spread[35].

Nylon-6,6 has been widely used in both military and civilian settings for many years. The issue of the melting drip has not been successfully resolved. An intumescent flame retardant system including ammonium polyphosphate, melamine, and pentaerythritol, for example, was shown to be efficient in preventing melting drop during the burning of nylon-6,6 fabric[39]. The results showed that at 750°C, the char rest of treated fabrics/blends was over 13 percent, with the maximum value reaching up to 24 percent, which is substantially greater than the char rest of untreated fabrics/blends. Furthermore, numerous nano-based techniques that use silica nano-sols modified with phosphorus compounds like diethyl phosphite or phenyl phosphonic dichloride have been developed to improve the fire and heat resistance of nylon materials [40].

Chen et al. have investigated the heat release characteristics and flammability of a cross-linkable organophosphorus flame retardant system treated nylon/cotton blend fabric. They discovered that the presence of the organophosphorus flame retardant system reduces peak heat release rate (PHRR) and temperature at peak heat release (TPHRR) and increases char formation for both cotton and nylon as single fibres, degrading the progression of treated nylon/cotton blends/fabrics and lowering flammability[41].

#### **Flame Retardant Finishes to Polyester Fibers**

Polyester fibres were discovered in the mid-1940s and have been produced on an industrial basis since 1947. Polyester is a special material that is the first option for garments and is presently employed in the production of carpets, despite its high combustibility and weak resistance to flame or fire. The addition/treatment of cyclic organophosphonate, phosphorous, or bromine-containing compounds as active ingredients is appropriate for improving flame retardancy and mechanical qualities. Trisdibromopropyl phosphate, sometimes known as 'Tris,' was a bromine-containing phosphate ester that was one of the most beneficial flame-retardant finishes for polyester. In a study, the result showed that the photochemical induction for vinyl phosphonic acid bonded to diverse textiles made of polyester, cotton, and polyamide in the presence of a cross-linking agent and a photo initiator. As a consequence, the photochemically changed textiles had a strong flame retardancy performance, and this efficient flame retardant finishing system can withstand one textile laundering cycle[41].

Recently, a microencapsulated FR was discovered to be useful in producing fire retardancy for a nonwoven substrate. Using the impregnation technique, melamine-formaldehyde polymer shell microcapsules containing resorcinol bis(diphenyl phosphate) were coated by an outer thermoplastic wall (polystyrene or poly(methyl methacrylate)) before being applied to a core/sheet-type bi-component PET/co-PET spunbond on a nonwoven substrate, resulting in improved fibre flame retardancy[42]. Furthermore, Alongi et al. published a comprehensive research on the development of water-based flame-retardant coatings for polyester and polyester-cotton blends [43]. The deposition of nanostructured coatings on textiles appears to be the most attractive and performance-appropriate technique in this context.

#### **Flame Retardant Finishes to Polypropylene Fibers**

Polypropylene produces the most fibre for a given weight due to its low specific gravity (34 percent lighter than polyester and 20 percent lighter than nylon). Polypropylene fibre is a valuable commodity that gives good bulk and cover and is commonly used in garments, upholstery, floor coverings, medical, geotextiles, and automotive applications due to its light nature. Furthermore, its lightweight, cost efficiency, strong mechanical qualities, and minimal reactivity to many chemicals make it extremely valuable. It was the first industrially commercialized synthetic stereoregular polymer product. Polyethylene fibers burn with a relatively smoke-free flame and without leaving any char behind at an incredibly fast pace due to their aliphatic hydrocarbon nature, which burns at a faster rate than wood and other cellulosic materials and hence has a highly flammable characteristic[44].

Furthermore, the chemical structure's lack of polar groups makes it difficult to react with a variety of flame retardants. In other words, polypropylene fibres have a very poor affinity to bind the addition flame retardants, and significant concentrations (>20 percent w/w) are required to give the requisite fire protection to goods. The next issue with polypropylene pyrolysis occurs at around 520°C and is caused by an abundance of unsaturated volatile fuel fragments, which exacerbates the flame retardation problem because less-volatile molecules act as secondary fuel sources, decomposing further and forming toxic substances to some extent. At around 350 °C, sustained flame combustion of polypropylene results in incomplete combustion, which produces CO evolution and several other hazardous chemicals that have been linked to significant reactions[40].

Chen et al. described the use of poly (2-hydroxypropylene spirocyclic-pentaerythritol bisphosphonate) for flame retardant finishing of polyethylene terephthalate, which minimizes its flammability [45]. The addition of polymeric

nanoparticles, an emerging topic in the field of material science, improved the physical and chemical characteristics of FRs. Carbon nanotubes are functionalized in a recent study by flame retardant wrapping and covalently bonding maleic anhydride polypropylene to form a compact char layer with good interfacial adhesion. As a result, the resulting polypropylene/functionalized carbon nanotube composite has significantly improved flame retardancy and mechanical qualities[46].

#### **Anti-microbial Finishing**

Carpets are frequently utilized in a variety of organizations, including hospitals, workplaces, schools, and airports, as well as in the home. Carpet is used mostly for comfort, acoustics, aesthetic value, thermal qualities, fall prevention, and so on. Carpets, on the other hand, can serve as a significant host for the development of microorganisms while meeting these conditions. Because of the limited penetration of the pile, common cleaning methods such as shampooing and vacuuming cannot efficiently clean carpets. The pile structure of carpets promotes the growth of germs by trapping soil, dander, food particles, drink drops, and a large amount of pet waste, all of which serve as nutrition for bacteria. Microorganisms may grow extremely quickly in a humid and warm environment, and when they produce particular enzymes, they cause fiber degradation, product discoloration, cross-contamination, bad odor, and, in some cases, rashes in users when they come into contact with exposed skin. As a result, the true solution to this problem is to prevent the growth of bacteria, fungus, and other microorganisms inside the visible and hidden sections of carpets, and hence the use of antimicrobial finishing agents is critical[12].

Antimicrobial agents are not necessarily all compounds that are destructive to bacteria. A chemical must meet specific characteristics in order to be considered an effective antibacterial agent. First and foremost, it must be effective against a wide range of microorganisms. Simultaneously, it should be user-friendly, such as non-toxic, non-irritant, and non-allergenic for customers. It must be able to withstand many washings, dry cleanings, and ironings, among other things. It should have no negative impact on the substrate and should be suitable with dyeing and other finishing techniques[47].

#### **Mechanism of antimicrobial finishes**

Leaching and non-leaching antimicrobial agents are the two types of antimicrobial agents (see Figure ). [48]

Leaching type: The finishing agent is released gradually on the surface of the fabric or from inside the fabric to the surrounding environment and spreads slowly, and this type of finishing agent is

effective against germs on the fabric's surface or in the environment[49].

Non-leaching type: This type of finishing agent is chemically connected to the fabric's surface, therefore it only acts on the microorganisms on the fabric's surface, not on the environment around the fabric, and the death of bacteria occurs when the microbe travels towards the finishing agent, not the other way around[49].

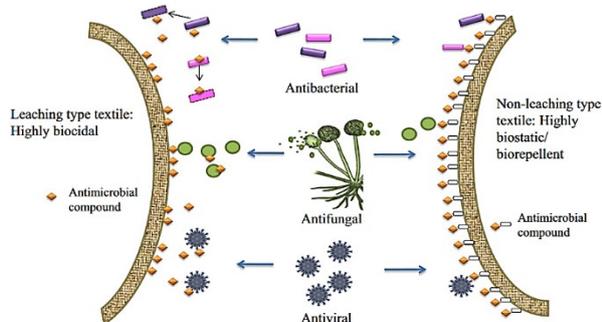


Figure 15: Mechanism of antibacterial finishes.

**Silver as antimicrobial agent**

Silver's history as an antibacterial in human health care is extensive and fascinating. Water purification, wound treatment, bone prosthesis, reconstructive orthopaedic surgery, cardiac tools, catheters, and surgical equipment are among the applications of treated textile with silver. Ionizable silver may now be incorporated into textiles for therapeutic purposes, reducing the risk of infection and improving personal cleanliness[49-51].

Silver nanoparticles, in comparison to other salts, have a significant antibacterial effect due to their extremely large surface area, which allows for more contact with microbes[52]. Silver nanoparticles (Ag NPs) enter the cells of microorganisms and attach to the thiol groups of enzymes and DNA. Essential physiological functions such as cell wall synthesis, membrane transport, and DNA group synthesis are hindered or deactivated when AgNPs are present in the cell. AgNPs interact with proteins' thiol groups, disrupting their enzymatic activities. Furthermore, the binding of metal ions to bacteria's DNA causes them to lose their capacity to reproduce. Silver as an antimicrobial agent was used to demonstrate the mechanism of antibacterial coatings. (see Figure ).

In the presence of oxygen, AgNPs can potentially hasten the development of highly harmful reactive oxygen species (ROS) in cells. While ROSs are normal byproducts of cell respiration, their creation in high numbers causes "oxidative stress," which damages microorganisms' lipids, proteins, and DNA, ultimately destroying their cells. The following reaction depicts the creation of reactive oxygen species:[53]

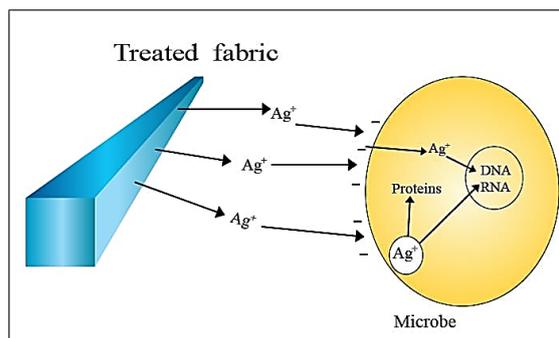
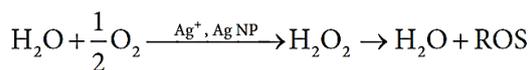
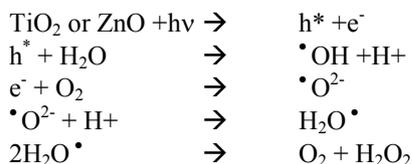


Figure 20: Mechanism of antibacterial finishes using silver as an antimicrobial agent

**Titanium dioxide and Zinc oxide nanoparticles as antimicrobial agents**

Antimicrobial efficacy of Titanium dioxide and Zinc oxide nanoparticles against Gram-negative and Gram-positive bacteria, fungi, moulds, and viruses is also remarkable. Their oxidative photo catalytic behaviour, which is typical of semiconductor photo catalysts, explains this. The antibacterial activity of ZnONPs has been found to be considerably enhanced when they are activated by light (photo catalysis). Several methods can be used to explain the photocatalytic destruction of microorganisms. The generation of ROS, such as superoxide anions (O<sub>2</sub><sup>-</sup>), H<sub>2</sub>O<sub>2</sub>, and hydroxyl radicals (OH), is thought to be involved in the photo catalytic process of ZnO NPs as follows [53, 54]:



ZnONPs' photocatalytic process also inhibits fungal development by altering cell function, causing bacterial cells to deform. Lipid peroxidation frequently results in DNA damage and alters cell membrane shape.

**Natural compounds**

Textiles based on eco-friendly agents are in high demand these days, not only because they assist to greatly offset the detrimental effects of synthetic agents on textile materials, but also because they comply with regulatory bodies' legal criteria.

The manufacture of more attractive and highly practical value-added textiles has gained worldwide prominence, based on environmentally sustainable plant-based products characterised by

biocompatibility, biodegradability, and non-toxicity, in addition to newly discovered properties such as mosquito repellent, UV protection, antimicrobial activity, and water repellent[55]. Natural bioactive compounds have lately attracted the textile industry's interest as potential substitutes for manufactured finishing agents. Because of their biocompatibility, antibacterial activity, antioxidant activity, and UV protection. *Mentha longifolia*, *Trigonella foenum-graecum*, orange, mango, psidium guava, bananas, tamarind, onion, and other natural finishing agents are suggested as sources of natural finishing agents [56].

Other natural compounds, such as cyclodextrins, might be used to generate sustainable antibacterial textile finishing. These cyclic oligosaccharides contain a lipophilic inner chamber and a hydrophilic outer surface. The textile industry is increasingly using cyclodextrin and its derivatives (-cyclodextrin, -cyclodextrin, and -cyclodextrin)[57]. chitosan is frequently utilized in antimicrobial textile preparation and processing Because of its antibacterial and anti-odor properties. Chitosan is a cationic polymer derived from the alkaline deacetylation of chitin. Chitosan hydrogel applied to cellulosic fabric shown antibacterial action against *S. aureus*, *E. coli*, and *Listeria monocytogenes*[58].

### **Water, oil, and stain-repellent finishes**

The notion of easy maintenance has risen in popularity in the carpet industry over the last few decades. Consumer need for a low-maintenance carpet substrate has resulted in the development of repellent coatings. Humans have been drawn to biological surfaces with high hydrophobicity, such as lotus leaves, duck feathers, butterfly wings, red rose petals, and fish scales.

Carpets benefit from coatings that repel water, oil, and stains. Because to the accumulation of soil from shoes and water–oil-based stains, carpets are readily stained. The primary goal of repellent finishes is to ensure that no liquid spills on the carpet and wets its surface. The liquid drop should stay on the surface and slide off effortlessly. Naturally, such a need can only be accomplished if the contact between the fiber surface and the liquid is minimized.

### **Mechanism of repellence**

Because this repellence is with regard to the fiber's surface, it may be enhanced by lowering the free energy on the fiber's surface. We know that if the liquid drop's cohesive forces are stronger than the

adhesive forces between the fibre surface and the liquid drop, the drop will not spread on the fibre surface. As a result, the repellent surface must have a lower critical surface energy or surface tension than the liquid's surface tension (the internal cohesive interaction)[26]. As a result, several low-surface-energy compounds are employed for finishing or coating the fibre materials in order to reduce the surface energy of the material.

Contact angles (refer to Table 1) of fiber surfaces with relation to liquids are frequently tested to assess repellent efficacy [59] [60, 61].

Table (1): Contact angles and wettability.

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### **Chemistry and classification of repellent finishes**

There are a variety of compounds that may be employed to produce repellent carpet surfaces, which are in high demand nowadays. The degree of repellence is also affected by the kind and chemical nature of the fiber-finish combination, as well as the quantity of its addition, among other factors.

#### ***Paraffin wax based non-durable repellents***

It has a traditional repelling finish. They solely give water repellence. These are emulsions containing zirconium salt. The most affordable repellents are paraffin wax emulsions. They repel water well but are not resistant to washing[62]. These treatments can be applied to textiles or carpets by padding, spraying, drying, and so on. [63, 64]

#### ***Derivatives of fatty acids***

Long-chain fatty esters with very long liner chains of carbon atoms with hydrogen attached give a high degree of hydrophobicity, and hence vegetable oils, which are high in fatty acids, are employed in the development of such repellents. The fatty acid esters are produced via acidification, acylation, and esterification of these vegetable oils. These fatty acid esters make fabrics water repellent [65, 66].

#### ***Silicone-based water repellents***

Silicone polymers have alternating silicon and oxygen atoms in their molecular chains, with hydrogen or organic functional groups filling the remaining silicon valences. Silicones have several applications in the textile sector, including defoamers, softeners, water repellents, and so on[67, 68].

#### ***Fluorocarbon-based compound***

Perfluoroalkyl group compounds are commonly employed to change carpets and thereby offer

resistance to water, oils, and stains. These compounds build films around the fiber and provide repellence by lowering the critical surface tensions of fiber surfaces, reducing adhesion and restricting aqueous or oily material absorption into the fiber surface. As a result, many liquids, such as water or aqueous solution-based compounds used in everyday life, such as curry, coffee, tea, and so on, that have the potential to stain carpets can be resisted by utilizing such finishes.

Electrochemical fluorination of hydrocarbon structures and telomerisation of tetrafluoroethylene (TFE) with iodopentafluoroethane are two common methods for producing perfluoroalkyl compounds. Textile polymeric fluorochemical repellents are essentially solution or emulsion copolymers comprising perfluoroalkyl-containing acrylate or methacrylate esters.

Because fluorinated compounds are expensive, they are usually mixed with traditional water repellents such as silicones, aluminium salt-wax emulsions, zirconium salt-wax emulsions, and so on[69]. To achieve stain resistance and water repellence, fluorinated finishes produced using the sol gel process were applied to a nylon carpet [70]. Despite their high performance, perfluorinated chemicals are bio-accumulative and have a high risk of harming human health. As a result, the usage of perfluorinated chemicals is prohibited due to environmental and human health concerns[71]. As a result, there has been an increase in research to replace fluorocarbon-based water and soil repellents. One example is the use of modified aqueous fluorocarbon-free silicone emulsions [72].

### Self-cleaning carpets

Self-cleaning textiles are a modern intelligent textile product that has piqued the interest of numerous academics. Because of their micro and Nano-hierarchical surface morphology and low surface energy, self-cleaning textiles are inspired by the lotus leaf effect, which can reject water droplets and debris from the surface [73, 74]. The basic principle of self-cleaning is the ability to create spherical water droplets that simply roll off the surface and effectively clean the surface of dirt particles. One of these materials' benefits is their capacity to self-clean without the need of typical laundry techniques[75, 76].

Because nanoparticles alone may diffuse well across varied substrates more uniformly and generate hierarchical morphology, nanotechnology is playing an important role in the creation of self-cleaning surfaces. The attachment of photocatalytic nanoparticles will result in increased self-cleaning characteristics. Photocatalysts include nanoparticles such as titanium dioxide and zinc oxide. They are utilised to give the cloth self-cleaning and anti-bacterial characteristics[75, 77].

### Mechanism of self-cleaning using photo catalyst

When TiO<sub>2</sub> and ZnO NPs are exposed to light with a higher energy than their band gap, electrons jump from the valence band to the conduction band, creating electron (e<sup>-</sup>) and electric hole (h<sup>+</sup>) pairs on the photocatalyst's surface (figure 21). The interaction of negative electrons with oxygen will result in the formation of free-radical oxygen O<sub>2</sub><sup>-</sup>. Positive electric holes and water will generate hydroxyl radicals OH<sup>•</sup>. Because both products (O<sub>2</sub><sup>-</sup>, OH<sup>•</sup>) are chemically unstable, when an organic substance, such as dirt, pollutants, or bacteria, falls on the surface of the photo catalyst, it can react with O<sub>2</sub><sup>-</sup> and OH<sup>•</sup> to generate carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O)[74, 78].

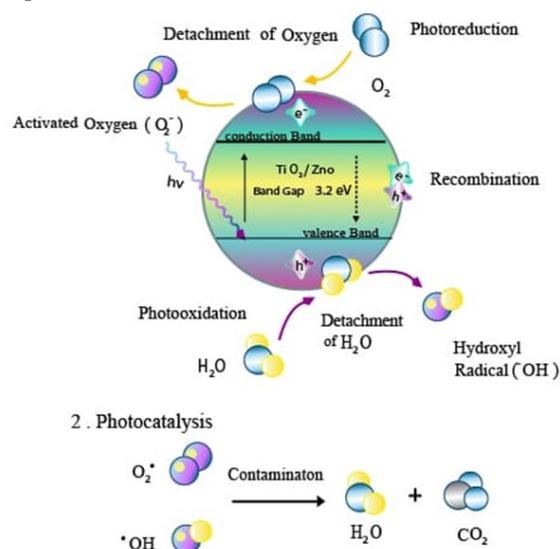


Figure 16: photocatalytic activity of TiO<sub>2</sub> nanoparticles [48]

### Carpet finishing with the softeners

As the name implies, a softener finish is a sort of finishing compound that may provide softness to a textile material. It is one of the most significant tactile enhancements that textile items may receive.[79]. Although this may be accomplished in a variety of ways, the most typical and relevant to textile carpet materials are mechanical or chemical methods. The fabric's or carpet's handle is really individual. However, it goes without saying that using a softener improves the substrate's so-called hand feel[79].

### Mechanism of softening

The electrical charges produced between the softener molecule and the textile surface cause contact. Almost all water-soluble fibres have a negative zeta potential. The softener's fatty acid component, or hydrophobic component, is insoluble in water, and the hydrophilic component contributes to its capacity

to disperse in water. The softener's ionic end interacts with the negatively charged surface.

These softeners are often classed based on their ionic nature and polarity: anionic, cationic, non-ionic and amphoteric, reactive, and silicone kinds.

#### **Cationic softeners**

They have a hydrophobic long chain that is securely connected to their hydrophilic groups and may thus dissolve or scatter in water. Cationic softeners have good exhaustion qualities because to the presence of negative charge on the cloth. The hydrophobic component adheres to the cloth surface, resulting in softness. They are resistant to washing due to ionic interaction between them and the fibre surface, and they have a high affinity for the fibre. The softening procedure with them is fairly inexpensive, and the cloth is produced fluffy even at the lowest active substance concentration of 0.2 percent. It also increases the tear strength, abrasion resistance, and sewability of synthetic fibres, as well as their antistatic qualities [80]. Other types of softeners include those containing amino salts, imidazoline and amine esters, polyamines, fatty alcohol, and so on.

#### **Anionic softeners**

These softeners have anionic groups that are oriented outward due to the presence of anionic groups in the softener molecule. This, in turn, allows them to build a hydration layer, which improves wettability and antistatic properties. This type of softener is generally represented by the formula  $RSO.M$  or  $ROSO.M$  (where R=alkyl, aryl; M=Na, K).[81]. They are sulphated or sulphonated products that are generally utilised as lubricants for yarns or fibres while also providing softness and pliability, alkali stability, and yellowing resistance [80]. Soaps, fatty acid sulphates, alcohol and ether, sulphonates of alkyl aryl and fatty acids, fatty acid sulphosuccinates, and other products come within this group.

#### **Amphoteric softeners**

When both anionic (carboxyl) and cationic (amide) groups are present in the structure, amphoteric softeners are formed, which have no compatibility difficulties when used with other finishes. However, the amount of softness they provide is restricted. [79]. Softeners of this category include substituted amino acids, amine oxide, amphoteric imidazoline, betaine, and sulphobetaines, among others.

#### **Silicone softeners**

Silicone softeners are polydialkylsiloxanes with a typical structure of  $R_2SiO$ , R representing the alkyl chains. They are water repellent, chemically robust, and temperature stable. A wide range of silicon softeners in emulsion form may be created by carefully selecting various organic groups attached to silicon. They are made by dissolving silicone oil in

water in the presence of the appropriate emulsifier[72].

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## نظرة عامة على صناعة السجاد: تصميم وصباغة وطباعة وتجهيز

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### الملخص

السجادة عبارة عن غطاء أرضي من القماش يتكون من الطبقة العلوية من الوبر المتصل بدعامته. كان الوبر يتألف تاريخياً من الصوف، لكن الألياف الاصطناعية مثل النولي بروبيلين أو النايلون أو البوليستر، وهي أقل تكلفة من الصوف، أصبحت شائعة خلال القرن العشرين. بلاط السجاد والنول العريض هما أكثر الأرضيات استخداماً للنسيج بسبب الصفات الممتازة مثل المرونة وثبات الأبعاد. لذلك، في البداية، سناقش بنية ألياف السجاد وميزاتها، متبوعة بخيوط السجاد وعمليات الطباعة التي تحدث عليها، مع التركيز على تقنية الطباعة النافثة للحبر.

**الكلمات الدالة:** السجاد، التصنيف، التصنيع، الصباغة، الطباعة، التجهيز