Kirk-Othmer Encyclopedia of Chemical Technology.

TEXTILES, FINISHING

Textile finishing includes various efforts to improve the properties of textile fabrics, whether for apparel, home, or other end uses. In particular, these processes are directed toward modifying either the fiber characteristics themselves or the gross textile end properties. Such modifications may be chemical or mechanical in nature. One modification that is not covered in this article relates to the dyeing of textiles and the dyestuffs employed for fibers; however, areas that involve chemical finishing designed to modify the normal dye receptivity and the growing use of enzyme treatments are included.

Fibers have been used by humans for thousands of years, but only in the twentieth century has there been such an explosion in fiber types available to the textile manufacturer. The advent of synthetic fibers possessing improved resiliency and dimensional stability has placed natural fibers, particularly cotton (qv), at an ostensible disadvantage. Before synthetics, various means to control the shrinkage, dimensional stability, and smooth-dry performance of cotton had been investigated, but the appearance of synthetics such as polyester has placed a greater sense of urgency on cotton interests to focus on the perceived deficiencies of natural fibers.

Textile finishing encompasses a broad range of approaches and may be directed toward needed properties such as shrinkage control or smooth-dry performance or toward developing properties for specific end uses such as flame retardance, soil release, smolder resistance, weather resistance, or control of static charges.

From a historical point of view, mechanical finishing processes have been directed toward improving shrink resistance via compressive shrinkage (Sanforized process) or calender finishing to give surface effects, which include shreinering, chintz finishing, and embossing. These latter effects are semidurable, and can be made more permanent by cross-linking with resins. However, such cross-linked fabrics seem to suffer greater loss in tearing strength when cross-linked in the calendered state. The need for calendered fabrics has decreased with the advent of cross-linked cotton, but compressive shrinkage to control garment shrinkage remains a significant component in textile mill practice, particularly for products that receive little or no resin treatments.

For fabrics of thermoplastic fibers, permanent effects are obtainable if heat and pressure are applied to soften the material. Processes dealing with carpets, nonwovens, and chemical modifications or additions that occur before the fiber is formed are not discussed herein (see Nonwoven fabrics).

1. Treatments with Chemicals or Resins

Resin treatments are divided into topical or chemical modifications of the fiber itself. Most chemical treatments of synthetic fibers are topical because of the inert character of the fiber itself and the general resistance of the fiber to penetration by reagents. By contrast, cellulosics and wool possess chemical functionality that makes them reactive with reagents containing groups designed for such purchases. Natural fibers also provide a better substrate for nonreactive topical treatments because they permit better penetration of the reagents.

2. Chemical Treatments

Chemical treatments of textiles encompass a variety of approaches. In one, the finisher may be attempting to form a chemical bond between the reactive group of the fiber (–OH group of cellulose) and the applied reagent. If the bond is resistant to hydrolysis, the property conferred to the garment, for example, smooth-dry performance, will be durable to laundering. If the bond is not durable, the change accomplished by finishing will gradually disappear.

Another approach in chemical finishing is to use reagent systems that are reactive with themselves but only to a limited extent or not at all with the fiber substrate. An example of such approaches are *in situ* polymer systems that form a condensed fiber system within the fiber matrix (1, 2). A third type of approach may be the deposition of a polymer system on the fiber substrate. Once deposited, such systems may show a strong affinity to the fiber and may be quite durable to laundering. Polyacrylate and polyurethane are examples of durable deposits on cotton, which last through numerous launderings (3).

2.1. Methods of Application

The predominant system used for finishing cotton and other cellulosics is the so-called pad, dry, and cure process. The padding is done normally by immersing the fabric in an aqueous solution, followed by squeezing it between two rollers, and finally drying and curing. This procedure places several requirements on the finishing components. Cross-linking agents and catalysts need to be water-soluble, and other bath components such as softeners are generally emulsified or dispersed in the bath. The amount of agent in the bath is controlled by the level of cross-linking desired in the fabric and by the percentage of wet pickup achieved in the padding operation. In conventional padding, wet pickup varies with fabric type, fiber content in blends, and pressure applied by pad rolls.

Following padding, the fabric is dried and cured. Removal of up to a kilogram of water per kilogram of fabric finished represents a substantial cost to the finisher. A reduction in the percentage of wet pickup is thus a desirable economic step, and several methods have been devised to accomplish this goal. In one system, the fabric is run against the bottom of a curved blade (4), the solution is applied by its flow down the surface of the blade into the fabric. The flow rate of the finishing agent is electronically controlled and meshed with the speed of the fabric to achieve the desired wet pickup, generally 25–30%. Another method to achieve reduced wet pickup in finishing is based on the use of a foamed finishing agent. As might be expected, this approach requires specialized finishing equipment (5–9). Other approaches utilized include specialized threading techniques in which padded fabric is run against dry incoming fabric to reduce wet pickup (10), and the use of a fabric loop in which the loop is immersed in the pad bath, squeezed to reduce wet pickup, then squeezed against the fabric being treated (11). This latter technique is very handy to small- and pilot-scale finishing for research investigation. Other so-called minimum application (MA) methods have also been developed. In the MA process developed in Europe, the fabric is passed over a lick roller, which supplies a controlled amount of solution to the fabric (12, 13). A number of installations utilize this method; wet pickup is low, usually about 30%. Engraved kiss rolls are also being used (14).

A second general approach to achieve reduced wet pickup is based on the use of the vacuum slot technology (15, 16). In this case the fabric may be padded conventionally, but is then run against a vacuum slot (17). This vacuum slot removes a certain amount of water solution from the fabric, so that a reduced level of wet pickup is achieved prior to drying. A lower level of wet pickup is achieved on blend fabrics than it is on 100% cellulosics using the vacuum slot technology.

Following fabric padding, the fabric in conventional processing is dried open-width in ranges at high temperatures, at processing speeds up to $\sim 90 - 183\mathrm{m}$ (100–200 yards) per minute. The fabric is then held in open-width in stentors for curing in a flat configuration. Temperatures ranging to 180°C require activated catalysts, which bring about cross-linking in a matter of seconds.

One concern in conventional processing is the achievement of uniform reagent application and uniform cross-linking (18). An area in which adequate treatment of all fibers is necessary is in flame-retardant finishing. One means of obtaining thorough treatment has been the use of vacuum impregnation, in which the fabric is first passed over a vacuum slot to remove air from the fabric interstices, followed by exposure to the phosphorus flame-retardant solution in the precondensate ammonia system (19).

The standard conventional finishing process has been modified to suit the purposes for different fabrics and garments. For example, tubular knits are frequently handled using specialized equipment to control tension and to get adequate padding. Some tubular knits are subjected to wet-on-wet padding, dried and cured in large drum dryers, and steam-treated to achieve a relaxed and nondistorted knit.

The general area of garment finishing has evolved over the years. Achievement of durable press (DP) garments in the 1960s involved padding fabric with resins, drying, and then processing fabric into garments that were subsequently cured. Although this process permitted the achievement of cured-in durable creases, it also brought along certain added problems. First, the uncured fabric generally exhibited a greater amount of formaldehyde release, which was a problem in sewing rooms. The presence of sharp creases and edges in these garments tended to exacerbate the abrasion problem of cellulosics. In a sense, this led to the marketing of blended cotton–polyester fabrics for these garments, particularly if good DP performance was desired. To a certain extent, post-curing of DP garments declined after this period, perhaps because heat setting could achieve a degree of creasing in blended garments. One specific area of garment treatment has endured, however, throughout the 1960s and 1970s. This is the vapor-phase formaldehyde process, in which a gaseous formaldehyde system is utilized to achieve garment application and curing of a cellulosic-containing fabric (20, 21). The preferred fabric substrate is again cotton–polyester.

The reemergence of this concept in the 1990s has revived garment finishing with resins. In this case, the garments are usually 100% cellulosic and are normally manufactured in the undyed state, dyed in garment-dyeing machines, and then given an application of resin in a garment machine. Fabrics are then smoothed and subjected to curing in garment form. In another modification, garments such as denim may be manufactured conventionally, then given a treatment using stones, enzymes, or a combination of both to produce a stone-washed appearance. Such garments are then given a resin treatment in a garment-dying machine, then smoothed and processed in a curing oven. The finisher must be extremely careful with these all-cotton garments as the abrasion problem may recur to curtail these developments (22).

To many textile chemists, finishing refers primarily to chemical or resin finishing. The principal chemicals used in early finishing processes were aminoplasts capable of cross-linking cellulose as well as of homopolymerization. These agents have not only the ability to improve smooth-dry performance and dimensional stability of fabrics, but also other useful properties. These include improving durable color appearance in fabrics both by preventing fuzzing of fabric surface and by retention of dyestuff; providing a means of grafting other chemical agents to cellulose; and improving strength retention in outdoor fabrics.

Although in the early days of resin finishing there was continued debate over the mechanism by which these agents achieved smooth-dry performance, by the 1950s most textile chemists believed that cross-linking was primarily responsible for achieving smooth-dry performance.

2.2. Fabric Preparation

Although for a standard woven fabric, desizing, scouring, and bleaching are usually performed to achieve a white fabric suitable for dyeing and finishing, for the purpose of this article, these processes are not considered finishing. Desizing, scouring, and bleaching are necessary so that a uniform fabric substrate is obtained. Nonuniformity and fabric impurities lead to problems that show up soon after the fabric is dyed. Resin treatments are generally acid-catalyzed and residual basicity can interfere with the desired cross-linking reaction.

Several other processes are also available. One fabric treatment is mercerization. This process is done to improve fabric strength, luster, and dye yield for those fabrics that are to be subsequently dyed. This improvement in strength, particularly tearing strength, is important because it leads to fabrics having better tearing strength and elongation after the fabric undergoes a cross-linking treatment (23). The impact of this pretreatment on the abrasion resistance of cross-linked fabrics, however, is not clear.

A second treatment that has gained a certain amount of use in modern textile practice is that of ammonia mercerization (24, 25). In this process, the fabric is processed in equipment designed so that the fabric is immersed in liquid ammonia. Ammonia ranges are extremely expensive to build and operate. Fabrics so treated must be priced accordingly in the open market and represent sufficient volume to keep the ammonia line in operation. The most widespread application of this equipment was used to process denim fabrics. Fabrics treated with liquid ammonia are generally softer and exhibit better smooth-dry performance than fabrics without such treatment. In addition, ammonia treatment combined with a low wet pickup cross-linking treatment can lead to fabrics having better abrasion resistance than those fabrics given a straightforward cross-linking treatment (11, 26).

Some research has been done to perform chemical treatments in the slashing or sizing operation, so that a permanent size could remain on the fabric subsequent to preparation. This permanent size would have utility in improving fabric resiliency and abrasion resistance (27, 28). Another approach was based on the use of a reactive cross-linking system in the slashing operation (28). This would confer a permanent cationic character to the warp threads, thus permitting fabric dyeing to achieve a mock-denim in a range of colors.

2.3. Cross-Linking of Cellulosics Fabrics

Essentially, any compound containing two reactive groups can be used to cross-link cotton. Exceptions are those that are too large to penetrate the fiber and perhaps those in which the reactive groups are widely separated. In the cross-linking reaction of equation 1, the fabric takes on a memory for its state at the moment of cross-linking:

$$2\ \text{cell}{-}\text{OH} + \text{HO}{-}\text{X}{-}\text{OH} \rightleftarrows \text{cell}{-}\text{O}{-}\text{X}{-}\text{O}{-}\text{cell} + 2\ \text{H}_2\text{O} \qquad (1)$$

Thus, if the fabric is flat and smooth, it will tumble dry in that configuration. On the other hand, if the fabric is cross-linked in a creased condition, as in a pleated skirt, the original pleated skirt configuration should return on laundering and tumble drying.

Fabric can be cross-linked either in the dry or the wet state. If fabric is cross-linked in the dry state, smoothness returns on tumble drying. By contrast, if fabric is cross-linked in the wet state, smoothness is achieved by line-drying the fabric. This concept has been demonstrated using formaldehyde in pad–dry–cure or wet cure processes (eq. 2) (29).

$$2\ \text{cell}{-}\text{OH} + \text{CH}_2\text{O}{\cdot}\text{H}_2\text{O} \rightleftarrows {}^{\text{H}^+}\ \text{cell}{-}\text{OCH}_2\text{O}{-}\text{cell} + 2\ \text{H}_2\text{O} \qquad (2)$$

The wrinkle recovery angle provides a measure of the degree of chemical modification. This is calculated by blending a small sample and measuring the recovery to the flat configuration (180°). Whereas the untreated cotton recovers approximately 90°, the cross-linked cotton sample recovers 120–140°. If this is measured on dry fabric, it is termed conditional wrinkle recovery angle; if on wet fabric, it is termed wet wrinkle recovery. At one point, wet wrinkle recovery was important, particularly in Europe. In the United States, the widespread use of clothes dryers has made conditional wrinkle recovery important.

The effect of cross-linking a fabric or garment can last throughout the life of the garment, provided that the cross-link is retained. However, cross-linking reactions are reversible, so removing the cross-links through hydrolysis restores most of the original properties to fabric.

Whereas cross-linking imparts the desired resiliency and shrinkage control, it does have several undesirable effects. The most objectionable side effects are reductions in tearing strength, breaking strength, and abrasion resistance. The moisture regain of cross-linked cotton is less than that of untreated fabric. Moisture regain can be retained by the use of swelling agents or occasionally by retention of cross-links (30, 31).

Another effect of cross-linking is reduction in accessibility of the fiber. Because of this, dyeing is normally performed before the fabric is processed. In a scheme of operation where fabric is dyed and cross-linked in the textile mill before being fabricated into garments, this approach is satisfactory. Since the rise of garment dyeing in the 1990s, which emphasizes just-in-time responses for color and style, an extensive finishing research effort to produce a dyeable cross-linked fabric was begun at the Southern Regional Research Center (New Orleans, Louisiana). Although these efforts have led to several chemical alternatives, the industry has opted for post-garment finishing using resins as the most reasonable alternative to this problem.

There is no question that the bane of textile chemists in the area of cross-linking for smooth-dry performance is the loss of abrasion resistance. This has been a continuing problem when durable press is pushed to high levels of performance. Numerous approaches to this problem have been explored (32). However, the simplest solution has been to blend cotton with synthetic fibers. A 50–50 cotton–polyester fabric can have excellent smooth-dry performance and yet be able to endure numerous launderings.

2.4. Early Cross-Linking Agents

Formaldehyde, urea–formaldehyde, and melamine–formaldehyde were among the earliest agents utilized for resin finishes. Concerns about the safety of formaldehyde, the need for lower formaldehyde release values, and the safety of exposure to melamine have reduced the use of these early cross-linking agents by industry substantially.

Formaldehyde, which produces a finish that resists hydrolysis and is inert, durable, and unaffected by heat or bleach, may be the cheapest and most economical cross-linking agent for cotton fabric. However, despite much research and promotion (33–36), formaldehyde has had only limited use in practical heat-cure and vapor-phase applications. One has only to stand by an oven or range using formaldehyde as the agent to understand the odor problem attached to the use of this agent. Vapor-phase treatments in garments are still in use in the 1990s, but containment and removal of unreacted formaldehyde is a must (20, 21). One other problem concerning formaldehyde is that the lack of urea buffer tends to lead to greater damage to cotton in terms of strength retention.

Urea–formaldehyde and melamine–formaldehyde reagents are resin formers, which not only cross-link cotton but also copolymerize with themselves. These have been used both as simple cross-linkers or prepolymer systems. If too much of the polymerization is concentrated on the fiber surface, the fabric may be sufficiently stiffer that it takes on a boardy character. As such, the finisher must control the action of agent to give the desired crisp hand but prevent the development of boardiness. Melamines have been recommended for applications when complete shrink resistance is required. However, both finishes were rejected for the white-shirt market because of loss of strength when hypochlorite bleach is used on account of vulnerable NH groups and the ensuing discoloration (37).

2.5. Chemistry of *N*-Methylol Agents

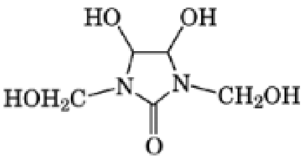
The reaction of dimethylolurea and cellulose is illustrated in equation **3**:

$$\mathrm{HOCH_2NH\overset{\overset{O}{\|}}{C}NHCH_2OH + 2\,cell{-}OH \rightleftharpoons cell{-}OCH_2NH\overset{\overset{O}{\|}}{C}NHCH_2O{-}cell + 2\,H_2O} \qquad (3)$$

First, it should be noted that the N-methylol group is activated by the carbonyl group. This reactive group is present in almost all N-methylol systems. Second, the reaction is an equilibrium reaction so that both forward and reverse reactions can occur. Third, the agent is not simply a dimethylol agent, but is predominantly a mixture of mono- and di-substituted ureas.

Because of this, there are free NH groups bound to the fabric. Some of these NH groups are converted to N–Cl on bleaching. Subsequent exposure to ironing or hot drying can generate hydrogen chloride that leads to strength loss and discoloration. The chemical mechanisms involved in chlorine decomposition and retention have been studied in detail (37, 38). The chloramide derived from the urea–formaldehyde finish forms and decomposes readily, leading to a heavily damaged fabric (39).

In order to overcome this problem, complete methylation of the NH groups is desired. Another approach is that certain molecular structures may yield cross-linkages where the presence of free NH groups is not a problem. It has been found that primary or unsubstituted amides that approach complete methylation are formamide, carbonates, and melamines. By contrast, the addition to secondary or mono-substituted amides as shown in equation **3** does not proceed to completion, so these type structures do not make good cross-linking agents. However, if these secondary amides are part of a ring system, such as dimethylodihydroxyethyleneurea (DMDHEU) **(1)**, a good agent can be obtained. This agent is produced by reaction of urea, glyoxal, and formaldehyde (40).



(1)

Formation of a fully methylated cross-linking agent does not ensure that the finish is immune from damage to bleaching. The curing stage does not proceed to completion when even the best of finishes is employed. Furthermore, garments are subjected to alkaline washes in normal laundering, and acid sours in commercial laundering. A satisfactory finish thus needs to withstand both types of finishes.

2.6. Mechanisms for Formation and Hydrolysis of Finishes

The general mechanism for acid-catalyzed formation and hydrolysis of *N*-methylol cellulose cross-links has been shown to pass through a carbonium ion intermediate as in equations **4** and **5** (41):

$$-\overset{O}{\overset{\|}{C}}NHCH_2OH + H^+ \rightleftharpoons -\overset{O}{\overset{\|}{C}}NHCH_2\overset{H^+}{\overset{\|}{O}}H \rightleftharpoons -\overset{O}{\overset{\|}{C}}NHCH_2^+ + H_2O \qquad (4)$$

$$-\overset{O}{\overset{\|}{C}}NHCH_2^+ + \text{cell}{-}OH \rightleftharpoons -\overset{O}{\overset{\|}{C}}NHCH_2O{-}\text{cell} + H^+ \qquad (5)$$

Based on the principle of microscopic reversibility, it has been reasoned that a highly reactive agent would form an easily hydrolyzed product (42). This proved true in practice and the industry has adopted the phrase "easy on means easy off" (43).

Hydrolysis resistance of a finish is important because fabrics are generally not afterwashed. There may thus be a considerable time lapse before fabrics receive the initial wash to remove the acid catalyst needed for cross-linking. Furthermore, cotton and rayon fabrics regain moisture on standing (44, 45). This combination of acid and moisture then has considerable time to act on the finish. Thus, the resistance of the finish to hydrolysis is of primary importance. On the other hand, finishes may need to be stripped or removed from the fabric to correct any errors in processing. Stripping, when necessary, must be performed in such a way so that excessive strength loss does not occur.

One such formulation for stripping utilizes treatment with 1.5% phosphoric acid and 5% urea for 30 minutes in an aqueous solution. Experiments performed using this agent have demonstrated that most *N*-methylol agents react with cotton but exhibit little or no modification of their structures during curing (46).

Alkaline conditions found in home laundering are generally not strong enough to cause significant hydrolysis of conventional finishes. However, the tendency of these finishes to release considerable amounts of formaldehyde after a strong alkaline home wash indicates that some breakdown of nonreactive pendent groups, if not the finish itself, may be occurring (47, 48).

2.7. Curing Catalysts for *N*-Methylol Agents

Many acid-type catalysts have been used in finishing formulations to produce a durable press finish. Catalyst selection must take into consideration not only achievement of the desired chemical reaction, but also such secondary effects as influence on dyes, effluent standards, formaldehyde release, discoloration of fabric, chlorine retention, and formation of odors. In much of the industry, the chemical supplier specifies a catalyst for the agent so the exact content of the catalyst may not be known by the finisher.

Types of catalysts used include mineral or organic acids and latent acids such as ammonurea salts, amine salts, and metal salts (49). One type of catalyst used in early commercial processing was amine hydrochloride. However, the fishy odor evolving from this material has caused this type of catalyst to be discarded. Metal salt catalysts such as magnesium chloride or zinc nitrate have been widely used over the years. However, because of effluent concerns, zinc salts have fallen into disuse. Magnesium nitrate has been suggested as an alternative catalyst (50).

Magnesium chloride is a very effective catalyst but has been deemed too mild for modern textile mill speeds. Catalysts that have come to the fore are mixed catalysts (51), which are usually a combination of a metal salt and an organic acid such as glycolic or citric acid. The predominant combination is probably magnesium chloride and citric acid. These catalysts are particularly suitable for the high speeds, high temperatures, and short (15 s) curing cycles utilized by many textile mills. Although organic acids, such as glycolic or citric acids, can lower pad bath pH below that observed when using metal salt catalysts, such acids are mild and tend to do less damage in terms of strength and loss of abrasion resistance (52). The exact nature of the complex by which metal salts act as catalysts has, however, eluded researchers (53, 54).

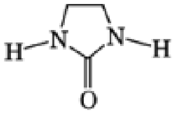
2.8. Melamine and Other Amino-*S*-Triazines

In the case of melamines, hypochlorite does not cause fabric degradation but does lead to yellow fabric (55). Commercial melamine derivatives used in finishing since the 1940s have generally been mixtures. A partially methylated di- or trimethylol melamine is an excellent polymer-former as well as an effective cross-linking agent. However, this polymer-forming characteristic can lead to poor shelf life and complications in finishing because the degree of self-polymerization before fabric treatment is a hard-to-control variable. Some highly methylated melamines have been shown to be effective cross-linking systems, showing only minor side deficiencies as a result of yellowness after bleaching (56).

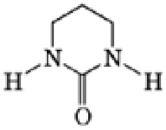
Melamines have found utility as rotproofing and weatherproofing cellulosics (57, 58), as binders for pigments and for transfer printing of cotton and cotton blends (59), as well as in numerous other applications. Guanamines have been suggested for many of the same applications as melamines, but the similar chemical structures of the two are likely to add to the same problems encountered with melamines.

2.9. Triazones, Urons, and Alkylene Ureas

Triazones, urons, and alkylene ureas were the first commercial *N*-methylol cross-linking agents for reducing or eliminating the hypochlorite bleach problem (60). These agents are still commercially available. The products are similar in structure and fully methylated products having a slight excess of formaldehyde are obtained. However, the release of formaldehyde by these agents has contributed to their decrease in popularity. The systemic names for these bis(hydroxy methyl) agents and their common names are tetrahydro-1,3,5-triazine-2(1*H*)-one (triazone), 2-imidazolidinone (ethyleneurea) **(2)**, and tetrahydro 2-(1*H*)-pyrimidinone (propyleneurea) **(3)**.



(2)



(3)

There was a tendency to use these resins mixed with urea–formaldehyde or melamine-type resins. Preparation of pure triazones or uron resins is difficult and expensive (61, 62). Furthermore, the basic nature of the amine nitrogen in triazone permits the use of mixtures of triazones with other agents to yield finishes that retain strength in hypochlorite bleaching.

The evolution of triazones, from initial synthesis in 1874 to development as a generally used textile finishing agent in 1957, has been described (60). Five triazone formulations have shown improved resistance to acid hydrolysis and to damage from hypochlorite bleach. By using a special synthetic approach, 5-alkyl triazones containing C_8, C_{12}, and C_{18}-alkyl groups were prepared (63). Only the C_8-alkyl triazones produced a significant improvement in wrinkle recovery on reaction with cotton.

The synthesis of triazones by the methods of Burke (61) or Paquin (62) appears to be fairly general. This is a type of Mannich reaction in which the product may be formed either by the addition of dimethylol urea with a primary amine, or from the addition of an amine–formaldehyde condensate with urea. Triazones prepared from ethylamine have received the most commercial interest (64). Again the mixture of triazone and urea–formaldehyde is said to be cheaper than a pure triazone finish. However, for these types of finishes, odor problems arising from by-product formaldehyde or amines were a matter of concern. Although this problem could be overcome by an afterwash, such a solution is not feasible in modern textile mill practice (64). Triazones are used less often in the 1990s because of odor problems, high levels of formaldehyde release, and lower levels of resistance to acid hydrolysis.

The chemistry of the urons and their use in textile finishing have been studied (65, 66). Interest in this system stems from the low cost of the starting materials: urea, formaldehyde, and methanol. Again, fabrics finished with the crude urons are vulnerable to strength losses during hypochlorite bleaching, but similarly finished fabrics finished with pure urons do not exhibit this problem (67). Because of the low cost of 1,3-bis(methoxymethyl) uron, this agent continues to be of some commercial interest, although no longer widely used.

Of the alkylene ureas, 1,3-dimethylolethyleneurea (DMEU) has had widespread usage in the United States as a replacement for earlier resins such as urea–formaldehyde (68), whereas 1,3-dimethylolpropyleneurea (DMPU) has been used more widely in Europe. These finishes yield fabrics that have excellent smooth-dry performance under mild curing conditions. However, they are extremely vulnerable to acid hydrolysis. In commercial laundry practice in the United States, an acid sour is an integral step in processing that leads to hydrolysis of much of the cross-links. For this reason as well as for formaldehyde release considerations, the industry has moved to cross-linking agents that produce finishes having a greater resistance to hydrolysis.

The ease of hydrolysis of a DMEU-treated fabric has been used to produce bicolored cotton fabrics. This was accomplished by applying a thickened DMEU solution in a print configuration to the pile of fabric, curing the resin, and dyeing the fabric. The DMEU-treated areas resisted dyeing because of the cross-links. Subsequently, the DMEU-crosslinks were removed via an acid hydrolysis and the entire fabric was overdyed to achieve the desired bicolored effect (69).

A general summary on the preparation, physical and chemical properties, and information relative to uses for ethylene urea is available (68). The widespread interest in ethyleneurea is reflected by the number of organizations holding patents in this area.

DMEU represented the first cross-linking agent that was a pure chemical rather than a mixture of components. As such, it provided research workers a tool to investigate the changes that take place in cellulose with cross-linking in a more exact manner (70–73).

Although cyclic ureas solved the problems associated with hypochlorite bleaching, a demand was arisen in the 1960s for garments that have higher levels of smooth-dry performance. This was termed durable press or permanent press. Such high level of performance brought on a higher level of chemical treatment for the individual garment or fabric. As a result of these fabrics, the formaldehyde release in the garment manufacturing plant and the necessity for finishes having a greater resistance to hydrolysis have led to new series of cross-linking agents.

2.10. Delayed Cure and Permanent Press

The 1960s witnessed an explosive growth in finishing technology resulting from the debut of delayed cure systems. These systems were designed so that the chemical agent was applied in the textile mill but final curing was delayed until after the garment was fabricated and pressed into the final desired configuration. This approach has led to garments having a new, higher level of performance. Thus garments not only can be smooth-drying, but also have desired shapes fixed into them, eg, the permanent crease of trousers.

The initial application of this technique was performed on all-cotton fabric, but it soon became apparent that 100% cotton garments did not have a level of abrasion resistance to perform satisfactorily. As a reaction to this, cotton and commercial interests launched extensive research to find new approaches for enhancing the abrasion resistance of all-cotton fabrics. Examples of such approaches involved polymer deposition, surface polymer application, two-step cross-linking and fixing systems, wet cure, steam cures, grafting reactions, as well as various other approaches for controlling cross-link distribution (32). However, none of these systems has caught on to a substantial and enduring degree.

Two factors emerged to turn the focus of durable press: the discovery that incorporation of a level of nylon or polyester in the fabric can substantially increase the garments' abrasion resistance, and the realization that the marketplace preferred cotton–polyester blends in delayed cure operations, even though 85% cotton–15% nylon fabric yields a suitable product. The 50% cotton–50% polyester fabric seemed particularly appropriate because it contained sufficient cellulosic to benefit from a chemical finish and sufficient synthetic to provide strength and abrasion resistance.

Two types of approaches are available. In one, the fabric is padded with the cross-linker finish, dried, then sent to the garment cutter. The garments are then pressed and cured. In the second, the fabric is cured in fabric form, then fabricated into garments. It is then pressed and recured in hot-head presses. This double curing is particularly hard on the cellulosic fiber in terms of strength and abrasion resistance.

This change of putting a curing step after garment fabrication has put a new set of standards in place for the finishing industry. First, a change of resin type was dictated. An agent that released a minimum amount of formaldehyde in cutting and sewing rooms was required. Second, the agent needed to be unreactive in the time and conditions to which fabric is subjected before the final curing. Third, the matter of chlorine bleach resistance faded in importance because a truly permanent-press fabric required little or no ironing. This situation also required stronger interaction between various segments of the industry, such as chemical suppliers, finishers, dryers, garment makers, and garment component suppliers (74, 75). By 1965, at least six permanent or durable processes were recognized and the patent situation on processing was confused. The principal chemical change brought on by this foray into durable press was the emergence of the urea–glyoxal formaldehyde adduct, 1,3-dimethyl-4,5-dihydroxyethyleneurea (DMeDHEU) (40), as the dominant cross-linking agent in the United States.

Although delayed cure cotton was the primary impetus in the rise to durable-press performance, the emergence of DP blends had the effect of reducing the importance of a true delayed cure. The industry tended to revert back to precure fabrics and the utilization of hot-head presses to set in creases, using the thermoplastic characteristics of the synthetic components as well as a touch of recure from the hot-head presses.

2.11. Sources of Formaldehydes in Textiles and Formaldehyde Analysis

Modern textile mill finishes need to be concerned with formaldehyde in the finishing garment plants and in the textile product itself. Formaldehyde can be present in the air, in cross-linking agent pad baths, and in the finished fabrics. The maximum concentration of formaldehyde in the air of workplaces should be dictated; in work areas, concentrations in air above 1 ppm are unusual. The free formaldehyde in finishing formulations has been substantially reduced and mill conditions in finishing areas and garment plants have been greatly improved.

Free formaldehyde is a mixture of formaldehyde, formaldehyde hydrates, and low molecular oligomers. It imparts a characteristic odor to padding bath or padded fabrics (76, 77). Cellulosics fabrics are capable of retaining large quantities of free formaldehyde, which are gradually evolved. Because all finishes degrade to some extent, extractable formaldehyde and releasable formaldehyde must be considered with respect to user exposure.

Extraction tests are used primarily in Japan and Europe, a release test is used in the United States, and standard tests have been compared based on the sources of formaldehyde present in a finished fabric (76, 78–80). Finished fabric may contain free formaldehyde, or formaldehyde released from unreacted N-methylol moieties.

The analytical methods (81–83) for the determination of free formaldehyde in the presence of N-methylol compounds are based on a low temperature (0–5°C) titration, which involves the reaction of sodium sulfite and formaldehyde (eq. 6).

$$Na_2SO_3 + HCHO + H_2O \longrightarrow NaOH + CH_2\,(NaSO_3)\,OH \qquad (6)$$

The analyses can be carried out in the presence of N-methylol groups. On fabric, the formaldehyde bisulfite compound is decomposed by excess sodium carbonate and the liberated sulfite is titrated with 0.1- or 0.01-N iodine solution (76). Commercial fabrics are seldom washed and dried before being used, and the free formaldehyde content may be between 50 and several hundred ppm, depending on finishing and storage conditions.

In the determination of free formaldehyde in solution, eg, commercial reagents and pad bath formulation, the conditions of analysis allow hydrolysis of the N-methylol groups, usually between $<1\%$ and several percent.

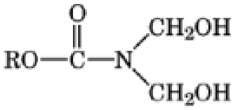
The NaOH formed is titrated with hydrochloric acid (82). Because of an incomplete reaction of sulfite with free formaldehyde, these low temperature methods (83) detect only 80–90% of the free formaldehyde present. Skill is important for correct results.

Extraction methods at higher temperatures are used in some countries. These values are referred to as free formaldehyde contents even though the origin of part of the formaldehyde reported is the nitrogenous finish or unreacted cross-linking reagent on the treated fabric. These test methods have originated with the industry. In Japan, however, test methods were regulated by law in 1975. Guidelines were published in 1972. An extraction of treated fabrics at 25°C was involved. The mandatory standards involved an extraction at 40°C. An industrial method used in Europe (84) requires extraction at 22°C, followed by determination of total formaldehyde content of the extract. Use of this method identifies finished fabrics that have a high content of unreacted cross-linking agents.

Researchers had noted the release of formaldehyde by chemically treated fabric under prolonged hot, humid conditions (85, 86). The American Association of Textile Chemists and Colorists (AATCC) Test Method 112 (87), or the sealed-jar test, developed in the United States and used extensively for 25 years, measures the formaldehyde release as a vapor from fabric stored over water in a sealed jar for 20 hours at 49°C. The method can also be carried out for 4 hours at 65°C. Results from this test have been used to eliminate less stable finishes.

2.12. Control of Formaldehyde Release

Once the sealed-jar test became a factor in measuring the formaldehyde release of fabrics supplied to garment cutters, limitations were placed on the allowable limits acceptable to the garment producers. These limits brought to the fore two classes of reagents: those based on DMDHEU, and those based on the *N,N*-dimethylolcarbamates **(4)** (88).

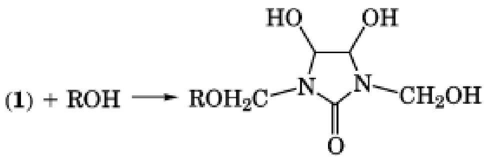


(4)

Prior to 1965, it was not unusual for unwashed finished fabrics to release 3–5000 ppm of formaldehyde when tested by an AATCC test method. Formaldehyde release was reduced to the level of 2000 or less by application of DMDHEU or dimethylolcarbamates. This level was reduced to approximately 1000 in the mid-1970s. Modification of the DMDHEU system and use of additives demonstrated that release values below 100 ppm were achievable. As of this writing (1997), good commercial finishing ranges between 100 and 200 ppm of formaldehyde release.

Several factors were utilized in bringing formaldehyde release down. In particular, resin manufacturer executed more careful control of variables such as pH, formaldehyde content, and control of methylolation. There has also been a progressive decrease in the resin content of pad baths. The common practice of applying the same level of resin to a 50% cotton–50% polyester fabric as to a 100% cotton fabric was demonstrated to be unnecessary and counter productive (89). Smooth-dry performance can be enhanced by using additives such as polyacrylates, polyurethanes, or silicones without affecting formaldehyde release.

One technique that has been employed to lower formaldehyde release has been the alkylation of the *N*-methylol agent (90–93) with an alcohol (eq. **7**):



(7)

Alkylation involves reaction with an alcohol or polylol before formulation of a pad bath or by adding certain alcohols or polyols to the pad bath (94–99). In the latter case, the methylol agent is alkylated during the drying and curing steps. DMDHEU is used almost exclusively for this purpose. The degree of alkylation is only partial, in the order of 15–30%. However, even this low degree of alkylation suffices to lead to fabrics having formaldehyde release values of 100–400 ppm. Another chemical approved to lower formaldehyde release values involves the use of scavengers to tie up free formaldehyde or *N*-methylol groups (100). These low formaldehyde release values, however, did cause certain problems and some adjustments in test procedures were made for analyzing fabrics that have low formaldehyde release values (99, 101, 102).

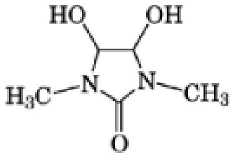
2.13. Carbamates

Carbamates as finishing agents were an alternative to DMDHEU for a number of years and have gained wide commercial usage (88). Examples of carbamates used for commercial purposes were methyl, ethyl, isopropyl, isobutyl, hydroxyethyl, and methoxyethyl carbamates. Although the carbamates are vulnerable to forming *N*-chloro agents on bleaching, the *N*-chlorocarbamate is so stable that it does not lead to fabric damage. For many years carbamates gained substantial use because of price considerations and because they give an excellent white for fabrics such as linens or white shirting. However, their usage has declined substantially because it is much easier to control formaldehyde levels by using the DMDHEU system.

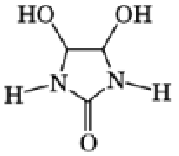
Other methylol agents have found use overseas besides the dimethylolpropyleneurea. There are other propylene ureas, including the 5-hydroxy- and 4-methoxy-5,5-dimethyl derivatives; the synthesis and finishing characteristics of these agents have been described (103, 104). Research has also developed agents containing a tertiary amino group to provide a cross-linker having an internal buffering moiety (105).

2.14. Nonformaldehyde Finishing

The concern for formaldehyde release prompted interest in the development of cross-linking systems that did not contain formaldehyde. A number of systems were investigated but generally these systems seemed to fall short in performance (106, 107). For example, 1,3-dimethyl-4,5-dihydroxyethyleneurea (DMeDHEU) **(5)** has been used in Japan since 1974. This same agent has been marketed in the United States and elsewhere, but generally the level of smooth-dry performance is substantially lower than the level achievable with DMDHEU. The cost of dimethylurea also raises the overall cost of DMeDHEU above that of DMDHEU.



(5)

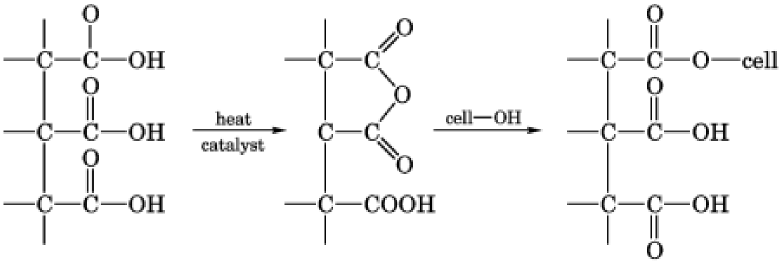


(6)

Dihydroxyethyleneurea (DHEU) **(6)** is also a cross-linker, but is extremely vulnerable to hydrolysis in an alkaline home laundering. Another approach toward formaldehyde-free agents has been the use of glyoxal in the bridging group between cyclic DHEU and related ring systems (108).

2.15. Carboxylic Acids and Cross–Linkers

Perhaps the most intensely recorded research involving nonformaldehyde cross-linkers in more recent years is the work based on the use of polycarboxylic acids as cross-linking agents (109–115). Thus, in late 1988, it was shown that cotton fabric could be cross-linked with an agent such as 1,2,3,4-butanedicarboxylic (BTCA) to yield fabric quite comparable to DMDHEU in terms of smooth-dry performance. There has always been some question of the durability of such ester linkages to strong acid or basic conditions, but this type of cross-linked fabric has been found durable to repeated home launderings. The reaction has been postulated to go through an anhydride intermediate to form a linkage with cellulose. Anhydride formation and reaction with cellulose to form the second bond to cellulose complete the cross-link (eq. **8**).



(8)

Several factors emerged to slow commercial acceptance of this finish. First, regarding DMDHEU, the polycarboxylic acid finish utilized much more expensive chemicals in both the agent and catalyst. Second, curing conditions tend to be more demanding in either time or temperature. Because BTCA is a commercially available material, an effort was made to make the price of this material more acceptable to the industry. Failing this, considerable effort has been expended for an acceptable product using a cheaper chemical such as citric acid. Although this material does lead to an evidently acceptable DP finish, yellowing during curing and a lower level of durability to laundering also result. However, the yellowing can be suppressed by incorporation of basic reactive additives in the finish (116). More recent research has focused on the use of simpler carboxylic acids such as maleic or malic acid. Another approach to the agent problem has been the use of *in situ* polymerization with materials such as maleic acid or combinations of related materials (117, 118).

Hand in hand with this research on finding a suitable carboxylic acid chemical for cross-linker has been the search for an economical catalyst system. The catalyst found to be most effective for the esterification reaction was sodium hypophosphite (NaH_2PO_2). This material was also costly and out of range for the textile industry. Because weak bases function as catalyst, a range of bases has been explored, including the sodium salts of acids such as malic acid.

As of this writing (1997), researchers are exploring combinations of acids, additives, and catalysts to achieve a suitable economic finish. However, commercial application of these finishes would require costs akin to that of DMDHEU as well as compliance with formaldehyde release levels by consumers, regulators, and the textile industry. Another possible impetus could be marketing considerations. Nevertheless, this work has sparked intense effort in the use of cross-linkers containing ester cross-links and has broadened the scope of cross-linker research.

3. Special Finishing

3.1. Stone and Enzyme Treatments

In the 1980s, stone washing of heavyweight denim fabrics burst on the scene. The initial treatments consisted of various methods of tumbling garments using high ratios of pumic stones in garment-dyeing equipment. This treatment using stones was designed as a method of producing denim trousers having special effects in terms of softness, a worn look, and/or a modification of color appearance. This technique was hard on both fabric and equipment, but the premium price advantages of such garments in the marketplace seemed to justify the extra care and expense necessary for production (119–122). Care must be taken in processing as holes in garments or torn pockets, etc, may result. Although there was a period when such garment holes were fashionable, this trend seems to have abated.

The difficulties of maintaining a textile plant in which rocks were strewn through the plumbing system have led to the use of cellulose enzymes (123–130). These enzymes, which hydrolyze the 1,4-glycoside bond of the cellulose molecules, can also lead to a soft fabric having a different surface effect, eg, a denim fabric. The other effect produced by such enzymes has been termed biopolishing, which arises because the enzyme tends to hydrolyze cellulose in protruding fibers, thus giving the fabric a smooth or glossy appearance. This reduction of fuzzy appearance in certain fabrics or garments is a commercially valuable property.

With respect to the action of the enzyme itself, a loss of weight on account of cellulose hydrolysis, as well as loss in strength properties, occurs. Therefore, control of concentrations, temperature, and other processing conditions is important to achieve a product having the proper balance of properties.

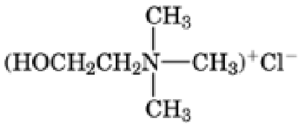
In commercial practice, treatments may use stones only, enzymes only, or a combination of both. The desired end product determines the method employed. In certain stones-only treatments, stones may be soaked in bleach or oxidizing agents such as permanganate. Some techniques for differential dyeing use stones soaked in dyes, or soaked in finishes designed to lead to random dyed cotton garments (131, 132). The technique of combining stones and enzymes offers the advantage of improving productivity from a garment machine. Much, but not all, of this type of finishing is applied to garments. A further step has been utilized in which enzyme-softened garments have been given a smooth-dry finish using the cross-linking agent added as part of a garment's treatment. The garment is subsequently cured in a garment-curing oven.

3.2. Modifying Dyeing

3.2.1. Characteristics of Cotton

The long-term approach in producing colored, smooth-dried garments has been to dye the fabrics first in a textile mill, then to apply the cross-linking finish, and, finally, to prepare the garments. In certain cases, the fabrics were only sensitized using cross-linker (dried only) before being converted to garments which were subsequently cured. This was termed delayed cure.

However, this procedure required color selection much before shipping of the garments to the retailer. It was considered better for just-in-time merchandising if the garment could be dyed just before product shipment. Therefore, an intense effort was made to produce a dyeable smooth-dye fabric. Although several functional moieties were grafted to cellulose and evaluated (133–141), the moiety that seemed to hold the most promise was the quaternary group. The addition of this group to cotton led to a cationic cotton, which was dyeable using anionic dyes. The reactive module first used for this purpose in conjunction with a cross-linking system was choline chloride **(7)** (133–140).



$$(\mathrm{HOCH_2CH_2}\overset{\mathrm{CH_3}}{\underset{\mathrm{CH_3}}{\mathrm{N}}}\mathrm{-CH_3})^+\mathrm{Cl}^-$$

(7)

Reactive additive used for this purpose must contain a functional moiety, in this case alcohol group, by which the additives can be attached to cotton via the cross-linker. Other reactive additives have also been similarly employed. Although this technique has not gained commercial acceptance, use of cationic systems may yet find a place because of the high affinity of cationic cotton for anionic dyes. Because of concerns for uniformity, however, the industry has opted to employ garment dyeing as the first step, followed by garment application of resin and oven curing.

3.2.2. Outdoor Fabrics

The use of cotton in outdoor fabrics has a long history in terms of tents, tarps, and other applications. However, there has been an increasing use of synthetics in the 1990s, particularly in tents and awnings. Cotton in outdoor usage needs protection for mildew and algae, protection against sunlight, and a degree of waterproofing and water oil repellency (qv). Another property that is sometimes required of outdoor fabric is flame retardancy.

Early waterproofing treatments consisted of coatings of a continuous layer impenetrable by water. Later water-repellent fabrics permitted air and moisture passage to improve the comfort of the wearer. Aluminum and zirconium salts of fatty acids, silicone polymers, and perfluoro compounds are applied to synthetic as well as natural fibers. An increase in the contact angle of water on the surface of the fiber results in an increase in water repellency. Hydrophobic fibers exhibit higher contact angles than cellulosics but may still require a finish (142).

The microorganisms that grow on cotton have undesirable effects, particularly in terms of loss of strength and of aesthetic effects from staining of the fabric from mildew. Microorganisms are a more serious problem in hot, moist climates than in dry, arid areas. The familiar greenish color of cotton tents results from the so-called pearl grey finish of primarily chromic oxide. This finish provides a degree of protection against mildew and actinic degradation. A variety of phenols, metal salts, and complexes such as copper 8-quinolinolate have been used and demonstrated to be effective in resisting mildew and algae attack (143, 144). For many years, mercury salts found wide usage for this purpose. Because of environmental concerns, however, such usage has been dramatically reduced (see Fungicides, agricultural).

For resistance to actinic degradation, the use of certain forms of titanium oxide is an alternative to chrome salts. Another approach has been the use of polymerized methylol melamine on cotton (145). In this case, the action of sunlight leads to gradual breakdown of the melamine polymer after several years. After this, actinic degradation of cotton proceeds as it does in unprotected cotton.

3.3. Flame Retardants

The amount of research expended to develop flame-retardant (FR) finishes for cotton and other fabrics has been extremely large in comparison to the total amount of fabrics finished to be flame retardant. The extent of this work can be seen in various reviews (146–148). In the early 1960s, a substantial market for FR children's sleepwear appeared to be developing, and substantial production of fabric occurred. In the case of cotton, the finish was based on tetrakis(hydroxymethyl)phosphonium chloride (THPC) or the corresponding sulfate (THPS). This chemical was partly neutralized to THPOH, padded on fabric, dried under controlled conditions, and ammoniated. The finish was subsequently oxidized, yielding a product that passed the test for FR performance. This process is widely preferred to the THPOH–NH_3 process.

A number of flame-retardant finishes have been developed for outdoor cotton fabrics. Various experimental and commercial finishes have been compared (149). Most noteworthy is that THPOH–NH_3 finishes do not perform as well outdoors as the THPOH–NH_3 precondensate finishes. Likewise, antimony oxide–halogen finishes perform exceptionally well on outdoor fabrics.

In the case of polyester, acetate, or triacetate fabrics, a tris(2,3-dibromopropyl)phosphate, generally referred to as Tris, was padded onto the fabric and forced into the fiber using a thermal treatment. However, in 1977, the Consumer Product Safety Commission labeled Tris as carcinogenic and banned its use on children's sleepwear. Although Tris was not used on cotton, the ban seemed to affect all sleepwear finishing, so the total volume of treated goods was substantially reduced. The other effect of this ban was the modification of the children's sleepwear standard so that thermoplastic fibers that melt at relatively low temperatures can pass the test without any chemical treatment. Because FR finishing is expensive, the chemical finishing of cotton is not economic for most of the children's sleepwear market.

The melt drip action of synthetics in certain industrial and combat situations has expanded the market considerably. Although there are many versions of THP-based products, the THPOH–NH_3 type predominated in the early 1960s. Subsequently, the precondensate ammonia finish has become dominant. In this case, the THP salt and urea are prereacted together to form the precondensate. Processing is analogous to the THPOH–NH_3 finish (150, 151). The precondensate has the advantage of lowering the emission of phosphorus and formaldehyde odors during the drying step and the incorporation of a higher nitrogen content in the FR polymer. The latter substitutes a low cost nitrogen group for a part of the higher cost polymer component.

Another fire-related problem that has seen some research effort is that of smolder resistance of upholstery and bedding fabrics. Finishing techniques have been developed to make cotton smolder-resistant (152–156), but the use of synthetic barrier fabrics appears to provide a degree of protection. Work also has provided a means of producing cotton fabrics that have both smooth-dry and flame-retardant performance (150, 151). In this case, the application of FR treatment should be performed first, and DP treatment should be modified to accommodate the presence of the FR polymer on the fabric.

In addition to FR treatments that are durable to laundering and weathering, work has also been done on a variety of treatments for the production of FR fabrics using inorganic salt mixtures. These treatments have usually been used on drapes and related materials that are not exposed to laundering or washing.

A light-weight fabric generally requires a higher add-on of FR polymer or reactant than a heavy-weight fabric. A fabric that has caused finishers considerable grief is the 50% cotton–50% polyester blend. There is some indication that antimony–halogen finishes are effective for this purpose (157). There have also been efforts over the years to utilize blends of a FR fiber and cotton. Certain combinations utilizing modacrylic or aramid fibers appear to permit use of diminishing levels of treatment with increasing synthetic content (158) (see Flame retardants).

4. Miscellaneous Finishing

Comfort has been a merchandising point for cotton and much of cotton's success has stemmed from this property (159–162). This has not, however, prevented cotton interests from trying to modify the moisture regain or content of finished fabrics (163–165). One unique finish imparts temperature-adaptable characteristics to cotton and particularly cotton blends (166–169). This technique uses a deposition of polymers of cross-linker (DMDHEU) and various polyethyleneglycols.

A variety of chemical products and fabrics are reputed to be antibacterial and to prevent odors and the spread of infection (170). One such finish is based on an organosilicon quaternary ammonium chloride compound (171). Chemical finishing of cotton has also been directed toward improving soil release (172, 173), antistatic treatments (174), and rot resistance (175, 176).

4.1. Finishing of Wool

Wool (qv) competes for markets where warmth, wrinkle recovery, and ability to set in creases are important. Wool problems relate to shrinkage, particularly to its tendency to felt. This is caused by scaly structure, which tends toward fiber entanglement when wet and subjected to mechanical action. In order to compensate for this tendency, wool needs to be set and also made shrinkproof if it is to be laundered.

Setting is an important step in the finishing of wool fabrics to impart dimensionally stable shape and hand. The mechanism of setting involves bond fusion and rebuilding of disulfide linkage. Chemicals used for this purpose are thiols, bisulfates, and thioglycolates (177). The problem of felting has been solved by altering the scaly structure of wool. Processors have used chlorination or some oxidation treatments. The chlorination step is followed by the application of a polymer to achieve desired shrinkage control.

In the CSIRO process, a reactive polyurethane prepolymer is applied to a garment from perchloroethylene. The garment is then pressed and subsequently steamed in an oven. A second polymer may sometimes be used in conjunction with the prepolymer. When this is employed, the process is termed the Serolan BAP Process (178). A number of alternative treatments are being investigated to achieve finishes that are more environmentally friendly (179).

Novel finishes have been developed from the traditional chlorination of wool (180). One, the IWS soft-handle process, gives an extremely soft hand to the wool fibers and reduces the prickly effect when wool is worn next to the skin (181). The other, the soft-handle luster treatment, improves the luster. This improvement is most apparent in knitted wool jersey fabrics.

Ozone is being investigated for shrinkage prevention (182). Wool and blends of wool, cotton, and polyester have been finished to provide improved flame-retardant, durable-press, and shrinkage properties (183, 184). Fabrics of these types are often used for uniforms or protective clothing (185).

Blends of wool and cotton (80:20) are being used more and more. For durable-press properties, resins, catalysts, and polymeric additives in finishing systems must be adjusted (186).

4.2. Finishing of Synthetics

Although finishing is not as important to synthetics as it is to cotton and other cellulosics, there are still many opportunities for its use in synthetics. However, the finishing of synthetics, particularly polyester fabric, is not directed toward improving resiliency and smooth-dry performance by chemical treatments as in the case of cellulosics. In the case of polyester fabric, simple heat-setting treatment suffices to set the fabric for desired smoothness and resiliency. Most heat setting of synthetics is done before dyeing and printing, and fabrics are maintained in a smooth configuration in a hot-air oven using a stenter or a perforated drum dryer. The general conditions for heat-setting various synthetics have been described (187). The optimum setting temperature range for polyester is between 210 and 215°C. If the fabric is set after dyeing and finishing, all previous operations are to be carried out open-width and dyes must be fast to heat-setting temperatures. One synthetic normally set after dyeing is triacetate.

A concern for polyester fabrics in general is the hydrophobic character of the fiber. In order to improve the comfort characteristics of these fabrics, several approaches have been developed. In contrast to cotton, fiber engineering can be used to produce a fiber having better water absorption or wicking characteristics. Techniques to control the shape of the spun fiber and/or the incorporation of soluble removable components in the spinning mix are used to reduce hydrophobic character (188, 191). However, the most common chemical treatment employed for improving the hydrophilic character of polyester is the use of aqueous sodium hydroxide solutions, which leads to a softer fabric having a less synthetic hand (192). Different effects are noted for increasingly vigorous treatments. These include lowering pilling tendency, increased water wettability and water wicking, decreased soiling problems, as well as increasing weight loss and production of silklike and fine denier fabrics (189, 191–195).

The alkaline solutions can remove water-soluble polymers in the spinning mix and inert products such as titanium dioxide. Basic treatments can also hydrolyze a certain amount of the polyester itself. For some silk-like applications or for producing fine denier fabrics, this basic treatment can produce a 10–30% weight loss of polyester (190, 196). Certain polyesters such as anionically modified polyester can undergo more rapid weight loss than regular polyester (189).

A number of after-treatments with polyester copolymers carried out after sodium hydroxide processing are reported to produce a more hydrophilic polyester fabric (197). Likewise, the addition of a modified cellulose ether has improved water absorbency (198). Other treatments used on cotton and blends are also effective on 100% polyester fabrics (166–169). In this case, polymerization is used between an agent such as DMDHEU and a polyol to produce a hydrophilic network in the synthetic matrix (166–169).

Synthetic fabrics can also be finished to achieve a number of specific characteristics (199). For example, increased electrical conductivity can improve the antistatic character of polyester. Similarly, finishes that improve hydrophilic character also improve properties related to soil release and soil redeposition (199, 200).

Other characteristics for which finishes have been designed include water repellancy (201), antipilling (202), and flame retardancy. For synthetics, an inherently flame-retardant fabric may be produced either by changing the polymer structure or by incorporating an agent into the fiber melt. Other agents, usually based on halogens, phosphorus, or both, may be applied after weaving (203).

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