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Injuries and fatalities caused by burns are nearly always due to ignition of the victim’s clothing, because when clothing catches fire, the extent of burn injury increases. The age of the victim and the percentage of body burn directly correspond to chances of survival. Between 1997 and 2006, in the United States alone, the total reported number of serious clothing-related burn injuries was roughly 4,300... annually.¹

During the past few decades, significant advances have been made in the flame-resistant (FR) clothing market. And, as with other technologies, the more significant each breakthrough is, the faster the science advances as a whole. The expanding need for arc-rated (AR) clothing has further accelerated development of flame-resistant technologies and has been marketed as a separate category of FR.

But with all the advances of the current industry, the search for ways to protect people—whether in industry, the military, or the general public—from burn injury caused by the ignition of fabrics began a long time ago.

The “Pre-History” of FR

The flame resistant properties of asbestos, which comes from the Greek word for “inextinguishable,” were known as far back as 4000 BC, when the “long hair-like fibers” were used for wicks in candles and lamps.

The first known use of asbestos in textiles dates back to ancient Egypt around 2000-3000 BC, when the bodies of pharaohs were wrapped in asbestos to prevent deterioration.

Herodotus reported around 450 BC that asbestos was being used to produce flame-resistant textiles for shrouds. Bodies were wrapped in cloth made of woven asbestos fibers and placed on funeral pyres. Because the fabric wouldn’t burn, the ashes inside the shroud didn’t mix with the ashes from the fire and could be placed in an urn or sepulcher separately.

The Romans also used asbestos cloth to make dinner napkins that they cleaned by tossing them into a fire, and they even used asbestos in the wicks of the Vestal Virgins’ eternal flame.²

King Charlemagne, around 755 AD, used asbestos fabrics for a more practical safety purpose. He had tablecloths made of the fireproof mineral to prevent the accidental fires that were common at feasts and celebrations of the time.³

By the turn of the first century, asbestos mineral fibers, mined in Cyprus and Northern Italy were being used in cremation cloths, wicks, paper, and other items, specifically as flame-resistant applications. Then, in 1095, French, German, and Italian knights of the first crusade put asbestos fabric to a decidedly gruesome use when they used catapults to lob sacks of burning tar and pitch into walled cities during sieges.

During the 1600’s and 1700’s, asbestos is known to have best mined and used all across Europe, as far east as China and as far north as Russia. In English public theatres, where crowds and special effects like cannons made fire an ever-present threat, the curtains were often made with asbestos fibers for fire safety. By the 1800’s asbestos paper was being used in Italy for bank notes, and around 1850, the Parisian Fire Brigade wore asbestos jackets and helmets.⁴

Even with the widespread use of asbestos as a miracle cloth, the dangerous negative health effects were documented in those who mined it, wove it, or otherwise worked with it. Although the use of asbestos continued, and even boomed, during the Industrial Age and after, the science of flame-resistant textiles was already beginning to move in a different direction.

Cellulosic Fabrics: The Dawn Of Modern FR

The earliest evidence of cellulosic, or plant-based, fabrics being treated with flame retardant appeared in the mid-sixteenth century. Obediah Wylde, in 1735 was granted the first known “FR” patent in Great Britain for a mixture of alum, sulfate, iron, and borax. This finishing treatment was probably the most significant contribution to flame-resistant textile science in recent times.5

Nearly 100 years later in 1821, across the English Chanel, a French chemist achieved another milestone in flame resistance. Joseph Gay-Lussac carried out the first systematic study of flame-retardants using cellulosic materials. Professor A.R. Horrocks, describes his process in Flame-retardant Finishing of Textiles:

For example, a finish for linen and jute is described based on a mixture of ammonium phosphate, ammonium chloride and borax. He concluded that the most effective flame-retarding salts either had low melting points and so formed glassy deposits over the fibre surface, or decomposed into non-flammable vapours which diluted the flammable gases derived from the cellulose. These ideas laid the foundation for the early theories of flame retardancy of textiles.6

Other treatments emerged based on Gay-Lussac’s research, but all were plagued with the same problem: the processes were complicated and, because the mixtures were water-soluble, they quickly washed out when laundered.

It was nearly another 100 years before William Henry Perkins, in 1912, developed the first known fire-retardant process that was durable enough to withstand multiple launderings. In describing the treatment in Historical Aspects of Polymer Fire Retardance, Raymond R. Hindersinn writes, “[it] consisted of impregnating the fabric with aqueous solutions of sodium stannate and ammonium sulfate. A subsequent heat treatment converted the chemicals to insoluble stannic oxide which was believed to be the active retardant.”7 The result was a durable flame-resistant fabric that could be laundered repeatedly, but the reputed afterglow and smoldering was said to consume it completely.

Research and development in flame-resistant textiles slowed down until the outbreak of WWII. It was then that the U.S. Army Quartermaster Corps (QMC) took an interest, and the science of FR got a boost. A 1942 patent describes a finishing process developed in the 1930s that proved invaluable during the war.8 This treatment was used extensively in tents, canopies, uniforms, and other outdoor cottons. However, it was not without its problems. Quartermaster Corps: Organization, Supply, and Services, a 1952 Army publication about the WWII experience, describes the decision to use the new process:

As a protection against incendiaries, the QMC... decided to treat Army canvas with a fire-resistant finish. This “746” finish had been developed during the thirties through the cooperative efforts of private industry, the Department of Agriculture, and the QMC. The application of the finish to 15.5-ounce duck increased its weight by nearly 50 percent...9

The doubling of the fabric’s weight was a serious issue, but the Army was so impressed with the treatment that it opted to substitute the 15.5-ounce duck cotton with 12.29-ounce duck.10

This “746” treatment, also called “FWWMR” (fire, water, weather, and mildew resistant), was based on a fire retardant composed of antimony oxide and chlorinated organic compounds and evolved into the first commercial fire retardant system which could be called “durable

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5 O Wyld, BP 551 (1735).
7 Raymond R. Hindersinn, Fire and Polymers, Chapter 7, 1990, pp 87-96, ACS Symposium Series, Volume 425, Publication Date (Print): May 9, 1990 (Chapter) DOI: 10.1021/bk-1990-0425.ch007
8 U.S. Pat. 2,229,612 (Oct. 20, 1942), E. C. Clayton and L. L. Heffner (to William E. Hooper and Sons Co.).
10 Ibid.
cotton.” Variations on this finish remained the central durable fire retardant finish into the 1970’s, in terms of total yards produced.11

The Flammable Fabrics Act

When the U.S. Congress passed the Flammable Fabrics Act in 1953, it was meant to ban “easily ignitable fabrics” in clothing from entering the market, which at that time referred to brushed or high pile cellulosics that were used in sweaters and children’s costumes.12 It stated that, “...no article of wearing apparel or fabric subject to the Act and Regulations shall be marketed or handled if such article or fabric, when tested according to the procedures proscribed...is so highly flammable as to be dangerous when worn by ‘individuals.’” The specified test was originally part of a voluntary commercial standard introduced by the Department of Commerce then called “Flammability of Clothing Textiles, Commercial Standard (“CS”) 191-53, and was used to define three classes of flame intensity:

- **Class 1** – Normal Flammability
- **Class 2** – Intermediate Flammability
- **Class 3** – Rapid and Intense Burning

Although there was a need for some kind of legislation to address the long series of accidents related to flammable apparel, the act, the standard that came out of it, and the test itself were harshly criticized. The NFPA called CS 191-53 an “imprecise and a misleading measure of flammability,” and when, in the late 1960s, the American Society of Pediatrics examined 124 garments that were involved in 84 fatal fires, it found that all of them had passed that test. Professional organizations and government officials alike called the act inadequate and declared that it instilled in the public a false sense of security. Since 1953, the Flammable Fabrics Act has been amended multiple times to include interior furnishings, all wearing apparel, children’s sleepwear, but most changes have been opposed and resisted by the textile industry.13 It wasn’t until 1972 that Congress passed the Consumer Product Safety Act (CPSA) that established the Consumer Product Safety Commission and gave it authority to issue and amend flammability standards. And fairly recently, in 2007, the Consumer Product Safety Commission proposed new rules addressing, among other things, updates and clarifications to the original test.14

While the initial act was insufficient and imprecise, requiring its many amendments, it caused the mainstream textile industry to focus more attention and resources on developing flame-resistant fabrics and fibers.

Cotton Finishing: Wash-Wear, Stain-Resistance, Flame-Resistance

Following WWII, research and development on cotton textiles continued in earnest at the Southern Regional Research Center, in New Orleans, LA—the same facility that had worked with the Quartermaster Corps during the war. This time, much of the work was commercially driven. Synthetic, low-maintenance fabrics, such as polyester, were gaining market share over cotton, which was care-intensive.15

Efforts to apply a finish to cotton, in order to make it more manageable and easy to iron, met with the same troubling result as many promising flame-resistant finishes—the fabric was weakened significantly.

The process of “cross-linking” strengthened cotton by chemically reinforcing the way that its ladder-like cellulose molecules stick together. The added strength made finished cotton fabrics wrinkle-resistant, or “wash-wear,” and the idea of strengthening the fabric carried over to other applications—stain-resistance and flame-resistance.

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Interest in cross-linking prompted J. David Reid, of Southern Regional Research Laboratories, to republish some earlier papers about flame-retardant finishing methods for cotton. Citing recent chemical research in cross-linking of polymers, in 1956 Reid published “Review of Three Recent Developments in Flame-Retardant Treatments for Cotton” which revisited three approaches he found promising.  

While flame-retardant cotton finishes continued to improve, the struggle to balance fabric strength with the durability of the flame-resistance to laundering continued for decades.

**FR Cotton**

FR Cotton is 100% cotton processed with a flame retardant finish—with a phosphorous active ingredient—that causes the cotton to char rather than ignite when exposed to flame.

Although there are several suppliers using the ammonia cure process to manufacture FR cotton goods, Westex, Inc. (now part of Milliken & Company) was the first to durably impart FR properties to cotton, meaning the flame-resistance would remain intact for the life of the garment when laundered and maintained correctly. Westex introduced Indura® in 1987, then in 1996 debuted an improved version called Indura Ultrasoft. Ultrasoft is 88% cotton blended with 12% high-tenacity nylon to increase abrasion resistance, overall durability and wear life. FR cottons and cotton blends are comparatively economical solutions for workers needing protection from either flash fire or electric arc. A further improvement in FR finishing was realized by Milliken & Company in recent years when their researchers found a unique way to utilize nitrogen and phosphorous to deliver FR characteristics to cotton blends containing even higher percentages of synthetic fibers, specifically 35% polyester.

**Meta-Aramidss**

Meta-aramids—such as Nomex®, Conex®, and Kermel®—are engineered at the molecular level to be flame-resistant. The compound itself is not flammable, so no additives are needed; the fiber is extruded, spun into yarn, and woven into fabric.

Experiments by DuPont researcher, Dr. Wilfred Sweeny, led to the development of a nylon derivative capable of withstanding high temperatures, and his work earned him the Lavoisier Medal in 2002.

Originally known as HT-1, the revolutionary fiber was later marketed as Nomex®. Because of its crystalline structure, the fiber was not dyeable, so Nomex® fabrics were originally intended for non-apparel industrial applications where resistance to high heat was necessary, commercial laundry presses, for example. Over time, scientists at Georgia-based, Southern Mills, (now TenCate Protective Fabrics) found a way to dye Nomex® and that discovery opened a vast new array of possibilities for the use of Nomex® in apparel fabrics. The earliest wearers of Nomex® clothing following its introduction in 1967 were racecar drivers. The first firefighter turnout coats made with the first-ever Nomex® outer shell were specified and ordered by the Cleveland Fire Department in 1970. At that time, a turnout coat (then firefighters wore long coats and tall rubber boots but no turnout pants) made of Nomex® was ten times the price of the modern day standard which was heavy weight cotton that was intentionally wet down prior to a firefighter entering a burning building.

Meta-Aramidss are quite versatile, but they also have weaknesses including high thermal shrinkage, poor moisture regain (amount of moisture a dry fiber absorbs from the air) and, as described previously, are difficult to dye. Blending aramids with other fibers to compensate for these detractors is a common solution. In fact, the most common Nomex® fiber used in apparel today is actually a blend provided by DuPont of 93% Nomex®.

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5% Kevlar® for improved thermal stability and 2% carbon suffused fiber to dissipate nuisance static. Attempts to improve the comfort of Nomex® by improving its hand and moisture management capabilities included blending it with cellulose fibers. Nomex® marketers keyed in on the dependable delivery of flame resistance due to the inherent nature of the fiber as the value afforded by its relatively high price.

“Inherent” Versus “Treated”

The terms “inherent” and “treated” have become commonly used descriptors of the two groups of FR fabrics and refer to the way FR properties are imparted to each. Applying these terms to FR fabrics was meant to imply that inherently FR fabrics were more dependable in their delivery of FR performance than its “treated” counterpart because the active ingredient was “built into” the fiber and would not wash away or wear out.

It is true that cotton must undergo a chemical process, or “treatment,” because it is naturally flammable, and early garments made of “treated” fabrics did lose their FR properties over time and after repeated washings, the same is not true of today’s FR Cotton and cotton blends. In fact, the process of treating flame resistant cotton has become so reliable that most suppliers of fabric produced in this way will guarantee the durability of the FR performance for the life of the garment so long as it is cared for and maintained according to manufacturers’ instructions.

Modacrylics

Modacrylics are a synthetic copolymer combining naturally flammable acrylic materials with flame-retardant chemicals prior to fiber extrusion. Union Carbide began commercial production of modacrylics in 1949 in the United States. Modacrylics and acrylics, which are of nearly identical composition, remained in the same category, with no official differentiation until 1960, when Federal Trade Commission separated the fibers into their own separate categories.²⁰ Although modacrylics are flame-resistant, like many other FR fibers, they will burn when directly exposed to flame. However, they do not melt or drip, and they self-extinguish when the source of ignition is removed.

Modacrylics are soft, durable, and resilient, and because they dye easily, hold their shape, and dry quickly, they are used in a wide range of apparel and other textiles. This includes everything from wigs and faux fur to outerwear, paint rollers, and carpet. One weakness of modacrylic fiber is its relatively low softening temperature. This characteristic gives modacrylic a propensity to shrink significantly when exposed to heat; even the heat of tumble-drying can cause shrinkage and other thermal damage to the fiber. Because of this, modacrylics are only used successfully in flame resistant fabrics when they are blended with other fibers that can provide needed thermal stability to prevent shrinkage.

Due to these vulnerabilities, modacrylics are not widely used in firefighting turnout gear, but are often used in secondary FR clothing applications. This became especially true in 2000, when NFPA added arc-rated PPE requirements to NFPA 70E® and many FR fabric suppliers initiated research to create modacrylic-rich fabrics which were inherently FR and satisfied the growing demand for PPE Category 2 protection from electric arc.

Conclusion: The Future Of FR

As advances in FR science and technology incrementally build upon themselves, the progress made in flame-resistant fabrics and garments has been rapid. It was only a few decades ago that the available flame-resistant clothing selection was limited to just two choices.

With so many improvements and so many more options—such as new fiber blends and combinations, along with significant design improvements—the industry will only grow stronger and keep people safer.

The challenge for fabric manufacturers and clothing designers and producers now is to provide the same

degree of protection in the development of lighter weight fabrics without sacrificing durability. Due to comfort issues many workers only wear FR clothing because they are required to. The ultimate goal is to improve comfort so they will want to wear it.

Lighter weight fabrics will improve wearer comfort in terms of range and ease of motion, and they will also keep wears cooler in hot, stressful conditions.

Improvements in the appearance of FR fabrics will also make PPE more appealing and wearable, which will in turn make workers more likely to use it. As FR knits get better, wearers have more options, and new FR garments that look and feel like non-FR retail clothing enter the market, the likelihood that workers will wear it will increase. As an example, FR denim that is tinted, sanded, and/or stonewashed will be much more attractive and acceptable than denim that looks stiff and uncomfortable.

While workers and employees who are required to wear flame-resistant clothing will certainly benefit from these advances, interest in flame-resistant apparel is likely to expand beyond “traditional” flash fire and arc flash hazard protection into markets whose workers would benefit from FR clothing but rarely wear it. Protection preparedness could go beyond these hazards to provide an additional level of protection to employees not exposed to an immediate, known hazard, but who work in the vicinity of a potential hazard.

FR science, technology, and design continue to improve comfort, appeal, and cost effectiveness; so, the safety expectations of the general public who are not necessarily exposed to known occupational hazards will only increase.

While idea of fabric and apparel that resist fire has a long history, truly effective and reliable FR solutions are relatively new. And while the statistics surrounding clothing-related burn injury remain alarmingly high, the pace of FR science and technology development promises advances that will offer even more protection.

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To learn more about OSHA regulations, occupational hazard assessment, and FR outfitting standards, contact:

Customer Care

800-223-3372