A FIRE-BARRIER FABRIC OF PREDOMINANTLY-COTTON CONTENT

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Abstract

The traditional flame-retardant cotton fabrics often do not provide an effective fire barrier, which is an important and perhaps critical consideration today for many enduse applications. Furthermore, cotton fabrics that are chemically treated for flame retardancy are generally weaker, less tear resistant, and, hence, relatively less durable than their original greige versions. In fact, if the conditions of fabric preparation and FR finishing are less than perfect, the fabric could lose its tear strength substantially (up to 50%), mainly due to its high (~30%) FR-finish add-on. Scientists at SRRC have developed a predominantly-cotton fabric containing approximately 20% glass fiber which provides an excellent fire barrier and a high strength. The fabric is made with the improved glass-core yarns produced by a new, USDA-patentedcore-spinning process and is FR treated to impart fire retardancy to its cotton component. When exposed to a flame for 20 seconds in a flammability test, the finished fabric leaves a woven glass structure intact, providing an effective and economical fire barrier. The fabric also shows satisfactory levels of tensile and tear strengths, abrasion resistance, and laundering performance, suggesting that the fabric in its present stage of development may be suitable for certain firesafe applications such as institutional drapes and curtains, protective overalls and coverings, and some seat covers and upholstery, where the fabric's functional performance, in terms of durability and fire barrier characteristics, is much more critical than the fabric's mere appearance and other physical aesthetics. Although the core coverage and strip resistance of the yarns used are excellent and the best available anywhere, the fabric after it is dyed and FR finished still shows some core exposure - commonly known as the "grin-through" - which remains commercially unacceptable for certain appearance-stringent applications. Preliminary investigations with the so-called coupling agents to permanently dye, tint, or at least hide the exposed glass have not been fully successful.

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Introduction

A need for firesafe textiles to protect human life and property is growing rapidly, especially in the United States, Europe and Japan. For example, the U.S. military needs flame-retardant/fire-resistant (FR) fabrics for shelter tents, pilot's protective clothing, and bags and coverings (to protect important documents, computers, ammunition, and other fire-sensitive cargo). Large institutions such as hospitals, hotels, motels, and corporate headquarters now require firesafe fabrics for draperies, upholstery, mattresses, and wall coverings. Other industries require firesafe uniforms and overalls to protect their steel workers, firefighters, and utility workers from the hazards of fire and electric-shock.

Due to its excellent aesthetics, comfortable wear, universal appeal, and substrate properties, cotton still remains a preferred fiber for the fire-retardant clothing and other textile applications. However, the traditional FR-treated cotton fabric fails to inhibit an initial, rather small "primary" flame on one side or surface of the fabric from migrating over to the other side of the fabric and causing the so-called "secondary" fire which may be even more damaging. Generally, an easily combustible material such as foam or flesh present on the underside of a flame-retardant fabric causes the secondary fire and related damages and injuries. Furthermore, a FR-cotton fabric generally has a lower tear resistance/strength than that of its original, greige fabric, which usually is even weaker than an equivalent fabric made with strong synthetic fibers. The traditional flame-retardant cotton fabrics, therefore, are not fully satisfactory today for certain applications such as protective clothing, mattress/bed ticking, drapes, aircraft seats, institutional upholstery, and other similar applications. The 'fire barrier' and 'high strength' (for durability) are important properties for these critical applications.

A new, USDA-patented, filament-core spinning process has provided the lead technology in the development of a relatively strong and economical fire-barrier fabric of predominantly-cotton content and of almost 100% cotton surface. Using an electrical (E)-type glass filament (50 or 100 denier) as the reinforcing core material, bicomponent yarns of mostly cotton content and almost 100% cotton surface have been produced. The yarns have been successfully converted into a woven fabric using standard textile mill equipment and procedures. After the fabric is FR finished for its cotton component, it passes both the flame-retardancy and fire-barrier tests when subjected/exposed to a flame for 20 seconds in the both vertical and horizontal flammability tests. The flame simply chars away the cotton component in a limited area of the fabric, leaving intact a fire-barrier screen of woven glass structure. Essentially, this screen of incombustible glass fibers acts as a fire barrier. Being relatively much less expensive than most other inherently fire-resistant fibers such as Kevlar, PBI, etc., the glass fiber is also an economical alternative for certain firesafe textile applications. In this paper, the production and properties of a glass-core fabric of mostly cotton content are discussed.

Materials and Methods

Yarn and Fabric Formation

Figure 1 shows a schematic of the latest USDA-patented filament-core spinning process for producing a coaxial, glass-core/cotton-wrap, bicomponent yarn [Sawhney *et al.*, 1990;Sawhney and Folk, 1996]. The two cotton rovings, preferably of equal size, and a package (bobbin/cone) of glass filament are creeled as shown. The rovings are conventionally drafted on a standard roller drafting system which is slightly modified with suitable roving guides and spacers, as shown. The glass filament is threaded through a suitable yarn-tensioning device and, after being guided by means of appropriate guides, is positioned exactly between the two drafted cotton strands just behind the front pair of the drafting rollers. The filament obviously does not require drafting. The two drafted strands of cotton (or, any other staple fibers for the sheath) and the glass filament (or, any other function-specific fiber for the core) emerge from the front-roller nip onto a grooved bar. As shown, the filament feeds directly into a special groove in the bar. Due to the peculiar spinning geometry and also the spinning tension, the glass-core filament always remains taut and constrained in the groove. The two drafted cotton strands slide onto the two sloped portions of the bar, one on each side of the groove, and merge with the twisting/rotating filament, thus forming a so-called fibrous "sandwich" comprised of the glass core in the center and a drafted ribbon of cotton sheath over and under the core. The fibrous sandwich is finally twisted by the conventional ring and traveler mechanism, producing a truly co-axial, well-covered, strip-resistant bicomponent yarn. The twist torque developed in the core component by the ring and traveler arrangement provides the required energy to spin, wrap and interlock the two streams of cotton (sheath) fibers around the glass core, in a sort of semi open-end spinning manner producing an almost 100%-covered yarn. The basic difference between the conventional core-spinning process and the USDA-patented core-spinning process is in the yarn formation. The conventional spinning process consists of forming a yarn at the front-roller nip by twisting the two constituent fibers, viz., the core and the sheath fibers, lying side by side on the front bottom roller. This process essentially produces an undesirable "barberpole" yarn with inadequate core-coverage and strip-resistance. In the USDA process, on the other hand, the yarn is actually formed by twisting, in the groove of a remote bar, a sort of pre-fabricated "sandwich" formed by the three strands of constituent fibers. In this process, a unique twist-control pin inhibits the twist from flowing past the grooved bar, thereby preventing barber poling of constituent fibers and producing a "true" core-wrap yarn with excellent core coverage and strip resistance. A uniform "inverse delta" formed by the two cotton strands in front of the front drafting rolls essentially eliminates or minimizes the traditional barber poling effect and improves the core coverage. As shown, the two cotton strands are optimally staggered with respect to the central core, which to an extent also improves the core-coverage and the sheath-strip-resistance. The staggering of the two cotton strands mainly depends on the fiber properties, the yarn specifications, and the spinning parameters.

Applying the USDA core-spinning system discussed above, a 33-tex bicomponent warp yarn and a 45-tex bicomponent filling yarn were produced using a 50-denier, E-type glass filament core and a run-of-the-mill carded cotton wrap for each yarn. Table 1 exhibits some typical properties of glass and cotton fibers. Equivalent warp and filling yarns of 100% cotton were produced using the conventional ring spinning system. Without any unusual processing difficulty or any yarn stripping, the warp and filling yarns were converted into a bottom-weight, 5-end warp-satin fabric employing standard mill procedures of winding, warping, slashing, and (rapier) weaving. The thread count of the fabric was 36 ends and 22 picks per cm.

Chemical Finishing

Scouring. Since glass fiber is damaged by caustic scouring at high temperature, the glass-core fabric was solvent scoured using perchloroethylene emulsion.

Dyeing. The cotton-covered glass-core fabric was conventionally dyed with Direct Blue (Dye No. 5) which dyed only the cotton component and left any uncovered glass core (~3%) undyed and exposed, showing a slight "salt and pepper" effect on the fabric surface. Glass as such was undyeable with the dye used.

Since the core coverage of the yarn produced by the USDA process generally varies from 95 to 99 %, a separate attempt was made to explore a possibility of "covering or hiding" any exposed glass fibers by permanently dyeing or tinting them with a cotton dye, using a coupling agent [Jang and Yeh, 1993,Plueddemann, 1982]. This involved a pretreatment of the glass fiber surface with a silane. Silanes are coupling agents that are generally used to improve performance of reinforced plastics by enhancing fiber/matrix interfacial strength through both physical and chemical bonds [Mallick, 1988]. They are also widely used to protect the fiber surface from harsh environmental conditions. A coupling agent basically has two different functional groups: one which will bind with the fiber, and the other which will bind with the (fiber) matrix. In other words, a coupling agent acts as a bridge to bind two materials together, leading to a strong interfacial bonding.

Two different silanes, viz., Dow Corning Z-6020 and Z-6070, were tried separately. Their respective chemical formulae were:

$(CH_3O)_3Si(CH_2)_3NHCH_2CH_2NH_2$ and $Cl(CH_2)_3Si(OCH_3)_3$

Their chemical structure could be represented by: R'- Si $(OR)_3$

In aqueous solution, they are hydrolized to form: R'-$Si(OH)_3$.

[i.e., R'- Si $(OR)_3 + 3H_2O$-- R'- $Si(OH)_3$ + 3HOR].

When glass fibers are immersed into the aqueous solution of the silane, the reaction shown in Figure 2 occurs. When the treated glass fibers are incorporated into a resin matrix, the functional group R' in the silane reacts with the resin to form a chemical coupling between the fibers and the matrix, as shown in Figure 3. The reaction allows the coupling agent to bind with the fiber glass and enables the fiber matrix thus formed to absorb the traditional cotton dye. In short, the reaction permits the two fibers, viz., glass and cotton, to be sort of union-dyed, using a cotton dye only.

Using standard procedures and treatments recommended by Dow Corning for the two silanes, the fiber glass in both fiber and fabric states was dyed with Direct Blue [Dow Corning]. Briefly, the glass fiber was dipped into 0.5% aqueous solution of the silane for 15 seconds and then dried at 105C in an oven. The aqueous solution was prepared by simply adding the silane to water and stiring; 0.1% acetic acid was added to adjust pH to obtain optimum performance. Both treated and untreated fibers were dyed with 2% naval royal blue, i.e., the same dye that was used for the glass-core fabric discussed previously. The procedure was repeated with the other silane.

F R Finishing. The solvent-scoured, conventionally dyed glass-core fabric was FR finished with a standard Retardol commercial finish. Retardol AC is s stable solution of a formulated tetrakishydroxymethyl phosphonium chloride-amide (THPC-amide) precondensate, designed for a durable flame-retardant treatment of cellulosic textile fabrics. The fabric was treated with 30% Retardol (solids solution) by weight of the fabric. The wet pick up was ~70%. The treated fabric was ammoniated (1 m/min); oxidized (with 1% H_2O_2 based on the weight of water) for 30 minutes; rinsed twice for ten minutes each; padded and dried for 2 minutes.

Testing

Yarn and fabric testing was conducted according to the standard ASTM or AATCC test methods, where applicable. Due to non-availability of the horizontal flammability test at SRRC, a subjective non-standard test was done with the FR-treated cotton fabric made with 2-plied, 50-denier glass core yarns in both warp and filling.

Results and Discussion

Table 2 shows the important, function-specific properties of the FR-finished glass-core fabric made with the 50-den glass-core, singles yarns. As seen, the tensile and tear strengths are satisfactory for this type of fabric. Since glass fiber, unlike cotton, is not affected by the FR finish, the fabric did not appreciably lose its tear strength. The most interesting feature of the fabric, however, is its fire-resistance/fire-barrier characteristic. As reflected by the char length in the standard vertical flammability test, the fabric shows an acceptable level of fire retardancy. In the horizontal flammability test, the fabric (made with 2-plied, 50-denier glass-core yarns) has its cotton component charred, leaving a screen of the woven glass (core) intact. By preventing the flame to migrate to the other side of the fabric, the glass screen provides an effective fire barrier. Incidentally, representatives of an English company have reported that the glass-core fabrics made with the USDA technology have passed both the standard vertical and horizontal flammability tests for certain rigid applications in U.K..

Table 2 also shows that the glass-core fabric is almost three times less air permeable than the equivalent greige cotton fabric. This perhaps indicates that the low air porosity and, obviously, the small air pockets of the FR-finished glass-core fabric also contributed to the fabric's improved fire resistance. The fabric's abrasion resistance, bursting strength, and laundering sustainability also seem to be satisfactory for certain applications. The fabric appearance, however, remains a matter of concern. The fabric still lacks the total core coverage and reportedly is deficient in certain other aesthetical characteristics. The figure below shows a computer scan of the dyed and FR-finished, 50-denier (singles) glass-core fabric. As seen, the fabric's under face shows a slight "salt and pepper" effect (i.e., about 2 % core exposure - commonly known as the glass "grin-through" - on the fabric surface), which is objectionable and commercially unacceptable for certain intended applications. The reason for the fabric face being much better "covered" than its under face (when both the warp and filling yarns were essentially similar) is that the warp yarns, which, incidentally, make up 80 % of the fabric face in a 5-end warp satin, were sized and, hence, protected against severe mechanical actions during weaving. In other words, a strong size film around the yarn did not permit any disturbance or disorientation of the cotton sheath to cause the core exposure. The filling yarn, on the other hand, formed 80% of the fabric underside. However, unlike the warp, it was not sized and, hence, protected during weaving. The complex mechanical action of beat-up in weaving causes some disorientation of the filling yarn's sheath, resulting in some exposure of the glass core (see Figure 4). The investigations with the coupling agents to permanently dye or tint the glass to eliminate the grin-through problem have not been fully successful. The preliminary results are not very encouraging.

Conclusion

A glass-core yarn of an almost 100% cotton surface can be produced using the new, USDA-patented, filament-core spinning technology developed at SRRC. A woven fabric made with the yarn has a predominantly-cotton content. The fabric can be FR finished to impart flame retardancy to its cotton component. When exposed to the flame in the standard vertical flammability test, the finished fabric retains an effective fire-barrier screen of glass. In the horizontal flammability test, this glass screen prevents the flame from migrating from one side of the fabric to the other, thereby reducing the chance of any bigger or more serious, secondary fire. Furthermore, this mostly-cotton fabric interestingly retains most of its original (greige) tear strength (i.e., even after the application of FR finish), since glass being chemically inert is generally not affected by the finish. The fabric's greater strength retention obviously makes it relatively more durable than the traditional flame-retardant cotton fabric, which experiences a significant loss of tear strength and hence durability.

Although in its present stage of development the glass-core fabric is not yet in the realm of the fine quality apparel in the classic sense, it may be quite viable for certain applications because of its improved functionality and economics. For example, in heavily printed drapes, curtains, upholstery, and protective clothing and coverings, the fabric's fire and/or electrical resistance to curb the so-called "secondary fire" is far more critical than its mere or desirable aesthetics. Furthermore, the glass fiber being relatively much less expensive than other inherently fire-resistant fibers should also offer an economic advantage for certain applications. Depending on the denier and quality grades of available fire-resistant fibers, the glass fiber costs about $5-10 a kg, while the other inherently fire resistant fibers such as PBI, Kevlar, and carbon may cost $ 50-100 a kg. However, no specific economic comparisons have been conducted in this study.

In summary, unusual fabrics of unique properties and functional performance can be engineered and economically produced for many new and exciting textile applications by using the USDA-patented core-spinning systems. Because of its excellent absorption and substrate properties, cotton fiber should obviously be the first choice for the wrap component of these fabrics.

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Notes and Disclaimer

The Southern Regional Research Center is one of several research facilities of the Agricultural Research Service, the U.S. Department of Agriculture.

The USDA-patented filament-core ring spinning process has been exclusively licensed to Firesafe Products Corporation, NY, NY, who must be contacted for any commercial application of the material presented here.

The names of the companies and their products are mentioned solely for information. The U.S. Department of Agriculture does not endorse them over others not mentioned.

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Table 1. Typical properties of glass and cotton fibers.

	Glass	Cotton
Type	"E"	Upland
	(Electrical type)	(UHML=1.10; UI=80-82; Strength=22-25g/tex; E=6.2%
Fineness (dia./micron)	10 um (round)	3.9 mic. (maturity 0.9%)
Linear density	50-den	1.5-2 den (175 ug/m)
Specific gravity	2.54	1.54
Tensile modulus (Gpa)	72.4	~7.8
Tensile strength (Gpa)	3.45 (100-150) x 10^3	25 g/Tex. (1.5-2.0 g/den)
Strain to failure/ rupture (%)	4.80	11.0
Moisture regain (%)	<1.0	8.4
Combustion	Does not burn; stable ~900F; softens 1224F.	Burns ~500F

Table 2. Properties of cotton-wrapped glass-core, FR-finished fabric*

Weight (g/m^2)	260
Thread count per cm (WxF)	36 x 22
Weave	5-end satin
Tensile breaking strength (kgf)	43.0 (48.7)**
Std. Dev. (SD) of tensile breaking strength (kgf)	1.1
Breaking strain (%)	8.5
SD of breaking strain (%)	0.7
Tear strength (kgf)	3.4
SD of tear strength (kgf)	0.01
Air permeability (m^3/min/m^2)	12.4
S.D. of air permeability (m^3/min/m^2)	0.25
Fire resistance (char length in cm)	4.5
Residue after 30-sec exposure to flame	A solid fire barrier of woven glass structure
Abrasion resistance (cycles):	
-Stoll-Flat	898
-SD Stoll-Flat	9.0
-Stoll-Flex	2222
-SD Stoll-Flex	75
Scott ball bursting strength (kgf)	62.1
SD of Scott ball bursting strength (kgf)	9.8
Durability to household laundering (cycles)	50***

* Relevant properties are in the warp direction only.
** Greige fabric
*** This information was provided by an outside source who tested the fabric.

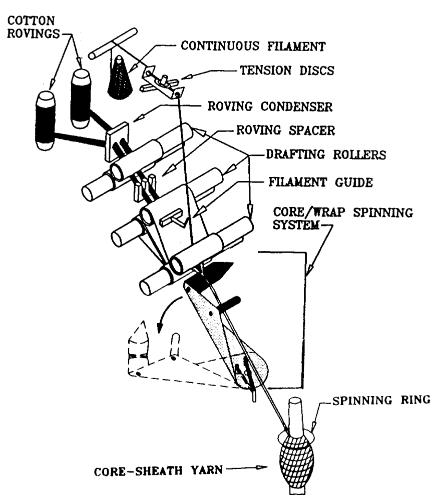

Figure 1. A schematic of the USDA-patented filament-core spinning system.

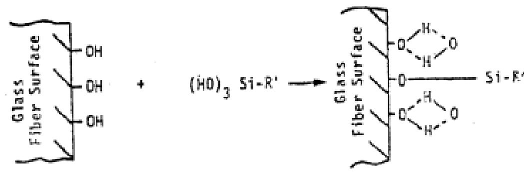

Figure 2. Reaction with silane.

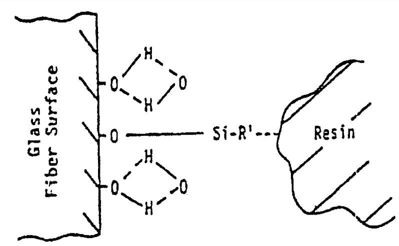

Figure 3. Reaction of silane-treated fibers with a resin matrix.

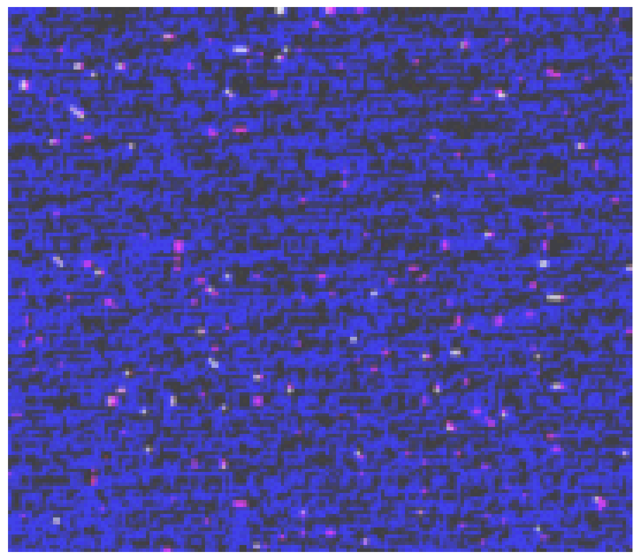

Figure 4. A computer scan of the underside of a glass fabric.