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FR COTTON NONWOVENS AS FLAME BARRIER FOR MATTRESSES

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Abstract

The essential feature of California AB 603 (signed into law by Governor Gray Davis on August 12, 2001) is that every residential mattress sold in California after January 1, 2004, must resist open-flame ignition. One of the ways of achieving compliance of open-flame ignition is to use a fire blocking, barrier interliner in the manufacture of the mattresses. The fire blocker is designed to protect and prevent ignition of the major cushioning component materials of a mattress and to avert a self-propagating fire in the product. Limiting the fire involvement of the major cushioning component will significantly restrict the fire growth. Carded needlepunched nonwovens and/or carded perpendicular-laid highlofts made from FR cotton, developed at SRRC-USDA, will act as a fire barrier interliner. FR cotton should be more economical than the inherently FR textile fibers such as FR polyester, aramid and glass. The presentation will discuss:

(i) Evolution of an open-flame mattress standard,
(ii) Development of a FR greige cotton, and
(iii) Test evaluations of FR cotton nonwovens by the vertical method.

Introduction

California has always been in the forefront of fire safety. In 1970, California was the first state to enact a mattress fire standard. It was not until 1974 that the United States federal law, 16 CFR 1632 was mandated, requiring all residential mattresses sold in the U.S. to be resistant to cigarette ignition. The mattress industry has been extremely successful in producing bed sets that are cigarette resistant (in compliance with the provisions of the Federal Mattress Flammability Standard). Mattress and bedding fires have declined by 65% in recent years from about 70,000 in 1980 to 25,000 in 1996 [Damant, 53-60]. While the cigarette-caused bedding fires declined, fires caused by open flames are still a major source of residential bedding fires. Statistics show the following distribution [Damant, 53-60]:

- Open flame: 40%
- Cigarettes: 28%
- Other sources of ignition: 32%

Deaths and injuries from burns and smoke inhalation are problems of increasing concern prompting legislation. On August 12, 2001, California Governor Gray Davis signed into law Assembly Bill AB 603, mandating the California Bureau of Home Furnishings and Thermal Insulation (CBHFTI) to adopt, by January 1, 2004, an open-flame residential standard for mattresses and box springs (bed sets). The goal of the mandate is to achieve an increased level of fire safety. CBHFTI is the California agency that will be upgrading the flammability standards for mattresses, while at the national level, the Consumer Products Safety Commission (CPSC) will be proposing a first-ever national standard. There is no indication when CPSC will formally propose a federal open-flame standard that would apply to bed sets sold in the United States [Damant, Part 3]. Excellent literature reference on the flammability issue is provided by Gordan Damant, former chief of CBHFTI [Damant, 53-60, Part 2, Part 3].

The mattress bedding industry faces significant new challenges over the new legislation. This has brought together researches that can contribute toward compliance with the requirements of AB 603. The National Institute of Standards and Technology (NIST) has been conducting research sponsored by the Sleep Products Safety Council (SPSC).

One of the ways of achieving compliance of open-flame ignition is to use a fire blocking, barrier interliner in the manufacture of mattresses. A fire barrier nonwoven will be cost-effective and can be easily incorporated in the manufacture of mattresses. The fire blocker is designed to protect and prevent ignition of the major cushioning component materials of a mattress and to avert a self-propagating fire in the product. Limiting the fire involvement of the major cushioning component will significantly restrict the fire.

Presently, two of the nonwoven FR cotton barrier fabrics from SRRC are under test evaluation at the CBHFTI and the results are pending.

Since the last five years, SRRC has been developing (a) cotton-containing Perpendicular-Laid (P-laid) highlofts, and (b) FR cotton blend P-laid highlofts. FR cotton is more economical than the inherently FR textile fibers such as FR polyester, Basofil (melamine) and glass.

In the following sections, we have described the development of (a) FR cotton blend highlofts via finishing, and (b) FR cotton at SRRC that has led to the development of a fire barrier, interliner for mattresses.

Research at the Southern Regional Research Center: Finishing Cotton Blend Highlofts with FR Formulation

Perpendicular-laid highloft fabrics were developed by the Technical University of Liberec (TUL), Czech Republic in 1988. P-laid layering produces fabrics with fibers in predominantly upright position, Figure 1 [Holliday, Krcma, 74-78, Krcma, 1991, Parikh, Sep. 2001]. Georgia Textile Machinery, Dalton, GA, Fred Clark Felt Company, Beaumont, TX, and TUL have the perpendicular layering production lines and have cooperated with us in producing (a) cotton blend highlofts, and (b) FR cotton highlofts.

Highloft fabrics are usually made with synthetic fibers. The concept of introducing cotton into P-laid fabrics was the focus of the research effort at SRRC [Parikh, Sep. 2001, 550-554, 32-36]. The major problems with the use of cotton are its flammability and lack of resiliency. Compressional resistance and elastic recovery of highlofts containing cotton tend to be inferior to those of synthetic fibers. Furthermore, highlofts containing cotton are categorized with highly combustible brushed pile fabrics, flannelettes, and they are characterized by high rates of flame propagation. The technology had to be developed to make highloft fabrics containing cotton competitive with highlofts of 100% synthetic fibers.

P-laid cotton blend highlofts varying in cotton contents (27mm thickness), were produced using cotton comber noil (16mm, 3.4Mic), coarse polyester staple (65mm, 15 denier), and core/sheath, bicomponent, co-polyester binder fiber (55mm, 4 denier, crimped). All of the fabrics had a thirty percent (by weight) co-polyester bonding fiber content. The cotton percentage and the corresponding polyester percentage were adjusted to make a total of 100 percent. Cotton fiber (CN) of 0, 20, 40, 60, 70 weight percent were respectively blended with polyester of 70, 50, 30, 10, 0 weight percent, producing three fiber composite fabrics. The highloft identification contains percent content of comber noil (CN) followed by a dash and "P" for P-laid layering. For example, CN_{40}-P refers to a P-laid highloft containing 30 percent of bonding fiber, 40 percent of comber noil cotton, and 30 percent of polyester.

Georgia Textile Machinery

All three fibers were individually opened and intimately blended. The blended fibers were carded and the carded web was processed at Georgia Textile Machinery. The company supplied one square meter of highlofts with varying cotton content to SRRC for the investigation. The P-laid line consisted of a vibrating lapper and a through-air bonding chamber (Figure 2). The carded web was fed into a through-air bonding chamber via the vibrating lapper. The P-laid batt was bonded during its passage through the through-air chamber. Bonding/curing conditions used were 160ºC for 1 minute. At this temperature the sheath of the bicomponent co-polyester fiber melts and bonds the core to the surrounding fibers.

FR Formulations

Two formulations (F1 and F2) were developed to impart both flame retardancy and compressibility to the highlofts. In formulation F1, dimethlyloldihydroxyethleneurea (DMDHEU - ultra low formaldehyde) was used to improve the resiliency of the cotton. A mixed catalyst system of magnesium chloride hexahydrate and citric acid (1:1) was used to carry out the low temperature cure. A low temperature cure was essential to maintain the dimensional stability of the highloft fabric. Triton X-100 (a nonionic surfactant) was used to ensure efficient wetting of the highloft. Diammonium phosphate/urea was used as flame retardant system. Formulation F2 essentially contained all the ingredients of formulation F1 except urea, additionally it contained a cyclic phosphate ester, a flame retardant chemical for polyester (Ecco Flameproof PE 100, Eastern Color and Chemical Company, Providence, RI).

The finishing technique involved treating all of the highlofts by thoroughly wetting and saturating them with the formulation. The saturated fabrics were centrifuged on the spin cycle of a Kenmore washing machine (70 Series model 110) for 1 to 4 minutes to obtain wet pickup of more than 110%. The samples were dried thoroughly in a forced-air oven at 85ºC for 30 to 40 minutes and cured at105ºC for 10 minutes.

Test Methods

Test evaluations were carried out under standard atmospheric conditions, 65% R.H. and 70ºF. The compressional study was carried out on a Gustin-Bacon Measure-matic thickness gauge described in detail in our earlier papers (7,8). Flame retardant properties of the highlofts were analyzed using the vertical flame test (ASTM D 6413). This test involves hanging a sample two inches wide by ten inches long vertically over a Bunsen burner. The flame from the Bunsen burner is one and a half inches high and the sample is adjusted to project ¾ inch into the flame. The flame burns for twelve seconds. Measurements are made of the time that the flame persists after the Bunsen burner is extinguished, the time that the red afterglow persists, the length of the main charred area at the bottom of the sample, and the overall char length including scorch from flashing. By these measurements, it is possible to differentiate between the effectiveness of a number of finishing treatments.

Discussion

The composition and density of the P-laid fabrics studied are shown in Table I. Their compressibility and flame retardant finishing results are discussed. To obtain a multifunctional treatment, it is necessary to combine several agents into a single pad-bath formulation. An important property of a finishing agent is its compatibility with other finishing agents. Chemicals used in the present formulations were compatible (Tables II and V).

The finishing technique adopted for the present study was saturate-centrifuge-dry-cure. The conventional pad-dry-cure was not suitable because of the thickness of the highlofts. Table III shows the percent wet pickup and percent add-on obtained with formulation F1. Wet pickups of 110% plus were necessary to impart improvements in both flame retardancy and the compressional resistance (Table III). Finish add-ons (22% to 45%) with formulation F2 are shown in Table VI. Fabrics finished with low wet pickup produced inferior FR performance.

Improvements in Compressibility

Compressibility results using formulation F1 only are discussed. (The compressibility results using formulation F2 show similar improvements.) Chemical finishing with DMDHEU and the flame retardant system was carried out with the objective of simultaneously improving compressional and FR properties of P-laid highlofts . Finishing imparted greater resistance to compression and better recovery from compression to the highlofts. Typical compressional and recovery curves before and after finishing of the fabrics, CN20-P and CN40-P, are shown in Figures 3 and 4. At maximum compression (52 gf/cm^2), a treated low level cotton fabric, CN_{20}-P, was compressed only 10% compared to 33% for the untreated fabric and it recovered to 99% compared to 96% for the untreated fabric (Figure 4). Percent thickness recovery of the finished fabrics is shown in Table IV.

Improvements in Flammability

Cotton ignites under flame, the flame propagates, and an after-flame continues after the flame source is removed. Flameless smoldering (after-glow) continues until the entire cotton fabric has been consumed. Vertical flame test results of unfinished fabrics are shown in Table VII. Unfinished fabrics, CN_{20}-P and CN_{40}-P, burned and the flame consumed 100% of the fabric. Flammability of polyester fiber is different from that of cotton. After-flaming and after-glow are absent in the 100% polyester fabric (CN_0-P). Under flame, the polyester fabric melts where the flame impinges and the molten polyester drips away creating an arc-shape dent in the fabric.

Both of the formulations contained diammonium phosphate as the flame retardant. Flame retardant agents containing phosphorous are very effective on cellulosic substrates because they impart good char forming properties and lower the decomposition temperature of the material.

Flammability test results of finished fabrics with either of the formulations, F1 or F2, showed consistently excellent results without any after-flame or after-glow (Table VIII). The importance of suppressing after-glow on cotton cannot be over emphasized. It is the after-glow that causes the untreated control sample to burn its entire length, after the source of ignition is removed. The hot glow persists and propagates from fiber to fiber giving off large volumes of obnoxious fumes. This phenomenon continues until the entire sample is charred. It is worth noting that the after-glow is extremely hot, even hotter than the flame itself, and can cause severe burns to anyone coming in contact with the glowing cotton. The flammability damage sustained to the finished fabrics was limited to charring in the vicinity of the instigating flame (Figure 5). Thus, a high degree of protection was given to these flammable fabrics.

Alternative Way of Producing FR Cotton Highlofts

P-laid highlofts containing cotton are environmentally benign and are biodegradable (to an extent of their cotton contents). FR finished highlofts are value-added products because of their excellent flame retardant properties. However, these FR highlofts have a boardy hand (because of heavy add-ons of chemicals). Boardy hand will not be acceptable in the commercial exploitation of FR highlofts. An alternative way of finishing has been planned which would produce the same excellent FR properties in the highlofts but without a boardy hand. We have developed FR cotton highlofts by a two-step approach: (a) developed inexpensive FR cotton fibers, and (b) using FR cotton developed FR highlofts with or without blending with polyester fibers.

Two-Step Approach: Developing Flame Retardant Cotton Fibers and Using FR Cotton to Develop Flame Barrier Nonwovens

FR Finishing of Cotton Fibers

Mechanically cleaned cotton (1500 to 2000 g) was wetted in 0.5% Triton X-100 solution, the excess solution was squeezed out, and the wetted fibers were filled uniformly in a pillow case. The pillow containing fibers was immersed in the formulation (Table IX) and the fibers were saturated with the solution. The pillow was centrifuged on a spin cycle of a Kenmore washing machine for 2 to 4 minutes to obtain a wet pickup of about 120%. The fibers were tumbler dried on a Kenmore dryer for about an hour. Add-on was about 20%. Finished cotton fibers exhibited excellent FR properties with soft hand.

The FR finished cotton was supplied to Fred Clark Felt Company, Beaumont, TX and to TUL, Czech Republic to produce P-laid highlofts and evaluate them for FR properties.

Fred Clark Felt Company
Using 70/30 FR cotton/ co-polyester binder fiber blend, Fred Clark Company produced flame retardant cotton P-laid heavy-weight highlofts (800 to 900 g/m^2). These highlofts were examined to withstand flame of acetylene torch for 15 seconds (a more severe test than the vertical flame test).

TUL
SRRC also supplied FR cotton to Dr. Jirsak of TUL to produce lightweight (200 g/m^2) P-laid highlofts. Dr. Jirsak reported excellent FR qualities of the highlofts.

CBHFTI
Using FR cotton, we prepared FR Nonwoven Carded/Needlepunched Cotton samples of 521 g/m^2 and 375 g/m^2. We have submitted these samples to CBHFTI for their evaluation.

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Table 1. Fabric Composition and Density.

Sample #	Cotton (CN) (%)	Bonding Fiber (%)	Polyester (%)	Thickness (mm)	Areal Density (g/m^2)	Density (kg/m^3)
CN_0-P	0	30	70	26.44	808.58	30.58
CN_{20}-P	20	30	50	26.34	687.16	26.09
CN_{40}-P	40	30	30	27.10	880.91	32.51
CN_{60}-P	60	30	10	26.87	764.66	28.46
CN_{70}-P	70	30	0	26.92	855.08	31.76

Table 2. Formulation F1.

Chemicals	Formulation (%)
DMDHEU (permafresh UF)	10.0
Diammonium Phosphate (Dibasic)	10.0
Urea	10.0
Triton X-100	0.7
$MgCl_2$, $6H_2O$	1.0
Citric Acid	1.0
H_2O	67.3
Total	100.0

Table 3. Finish Wet Pickup and Add-On with Formulation F1.

Sample #	Wet Pickup (%)	Add-On (%)
CN_0-P	161	61
CN_{20}-P	107	26
CN_{40}-P	139	44
CN_{60}-P	170	48
CN_{70}-P	148	42

Table 4. Thickness Recovery, using formulation F1 (% of initial thickness).

	5 minutes of recovery			
Treated Fabric	6.89 (gf/cm^2)	13.78 (gf/cm^2)	34.44 (gf/cm^2)	51.67 (gf/cm^2)
CN_0-P	99.7	99.4	99.0	98.8
CN_{20}-P	99.4	99.0	98.8	98.3
CN_{40}-P	99.3	99.1	98.7	98.4
CN_{60}-P	99.1	98.5	97.8	97.2
CN_{70}-P	99.2	98.6	98.1	97.5

Table 5. Formulation F2.

Chemical Composition	Formulation (%)
DMDHEU (permafresh UF)	10.0
Triton X-100	0.7
Diammonium Phosphate (Dibasic)	20.0
Ecco Flameproof PE 100 (Cyclic Phosphonate Ester)	6.0
Citric Acid	1.0
$MgCl_2$, $6H_2O$	1.0
H_2O	61.3
Total	100.0

Table 6. Finish Add-On with Formulation F2.

Sample	Initial Weight (g)	Weight after Centrifuge (g)	Wet Pickup (%)	Weight after DryCure (g)	Add-On (%)
CN_0-P	23.8	41.6	75	32.3	36
CN_{20}-P	17.8	38.0	113	26.0	45
CN_{40}-P	21.1	45.0	113	27.2	29
CN_{60}-P	20.2	43.1	113	25.3	25
CN_{70}-P	19.7	44.3	124	24.1	22

Table 7. Flammability of Unfinished Fabrics.

Sample #	After-flame Time (sec)	After-glow Time (sec)	Remarks
CN_0-P	0	0	No flaming, polyester drips away making arc shaped dent 3.05cm(width) x 5.08cm(height) where flame touches the sample, 5% of sample consumed
CN_{20}-P	166	148	Flaming, burning, after-glow is continued until 100% of sample consumed
CN_{40}-P	142	803	Flaming, burning, after-glow is continued until 100% of sample consumed
CN_{60}-P	30	164	Small flame, flame spread up on sides only, after-glow is continued charring 40% of the fabric surface
CN_{70}-P	10	180	Small flame, flame spread up on sides only, after-glow is continued charring 25% of the fabric surface

Table 8. Flammability of Finished Fabrics (either F1 or F2).

Sample #	After-flame Time (sec)	After-glow Time (sec)	Remarks
CN_0-P,	0	0	No flaming, no after-glow, polyester drips away making arc shaped dent 4.00cm(width) x 1.05cm(high) where flame impinges the sample, 99% of sample protected
CN_{20}-P, CN_{40}-P, CN_{60}-P, CN_{70}-P	0	0	No flaming, no after-glow, great integrity, charring only where flame impinges, 3.7cm(w) x 0.6cm(h), protecting nearly 100% of sample

Table 10. Typical FR Formulation used to finish cotton fibers.

Chemical	%
Diammonium Phosphate	10
Urea	10
Triton X-100	0.5
Polyethylene Emulsion	1.5
Citric Acid	10
Water	68
Total	100

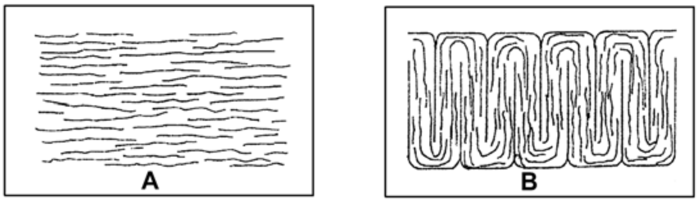

Figure 1. A) Cross laid fabric. B) Perpendicular-laid fabric.

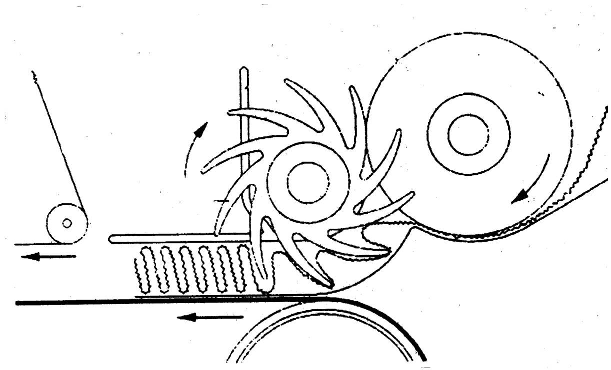
Figure 2. Perpendicular-Laid Line.

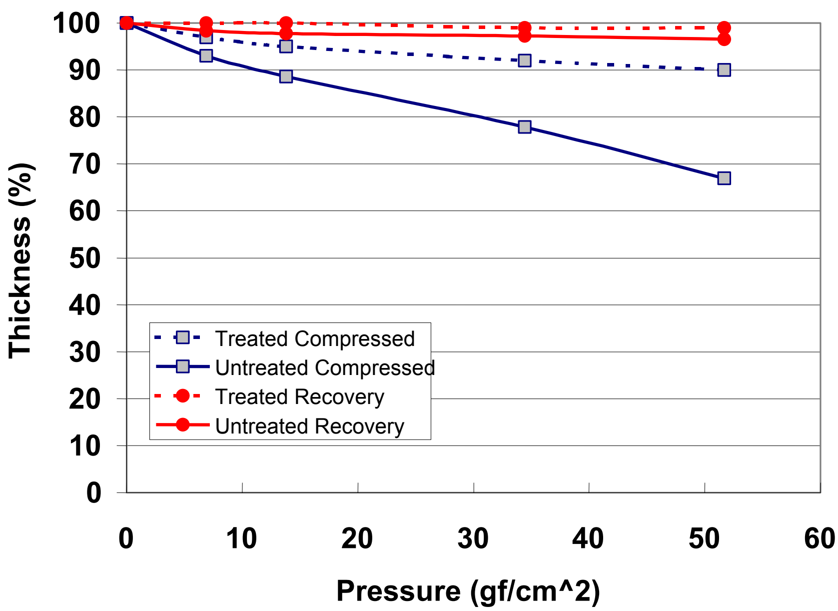

Figure 3. Compressive Curves for Treated and Untreated CN20-P Fabrics.

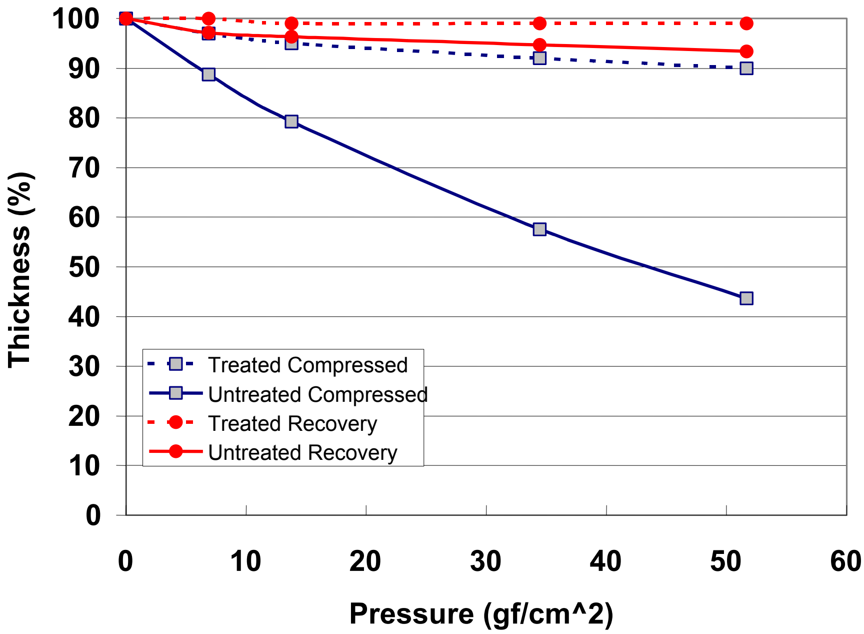

Figure 4. Compressive Curves for Treated and Untreated CN40-P Fabrics.

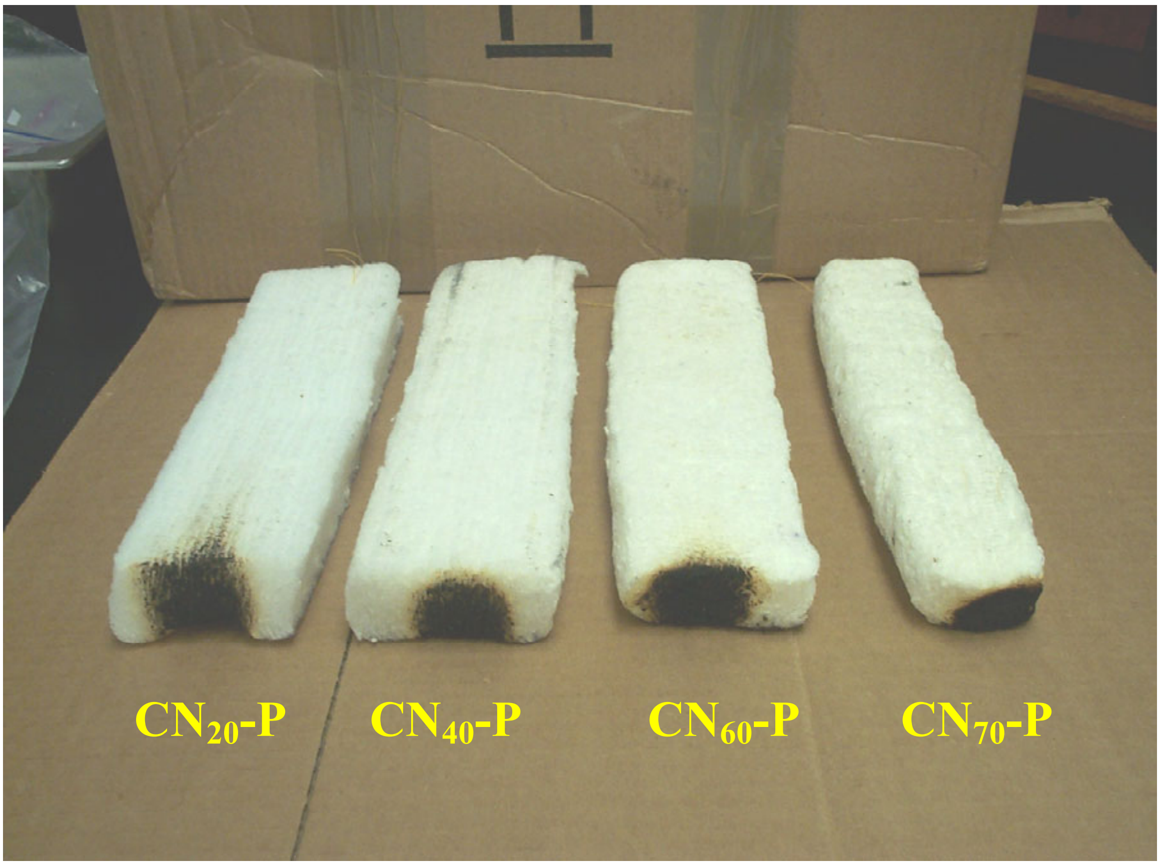

Figure 5. Charred where flame impinges finished fabric.