COST EFFECTIVE APPROACHES TO IMPART FLAME RESISTANCE TO COTTON NONWOVENS

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Abstract

Recent changes in the flammability laws require improvements in the flame resistance of cotton-containing consumer goods such as upholstered furniture, mattresses, and pillows. Cotton, synthetic fibers, fabrics, and foam are the basic constituents of these goods, often the first to be engulfed by a fire. Hence there is a need to impart certain degree of flame resistance based on their end use. In case of real fires, these improvements in flame resistance would provide more time for people to escape a fire with less fire injuries and save life as well as property. Depending upon the applications the fire-safety standards are separately drafted.

To achieve higher degree of flame resistance it is necessary to incorporate additional chemicals into cotton nonwovens that lead to a spike in the product cost. These chemicals play a synergistic role in the combustion process to slow down burning, reduce flame spread, or even extinguish the fire. Moreover there are laws forbidding the use of some flame-retardant chemicals that raise concerns about environmental and health hazards. The investigations being carried out at the University of Tennessee to impart flame resistance to cotton nonwovens with special consideration to the cost of chemicals, cost of the treatment and the flammability test response are presented here.

Introduction

Cotton is comfortable, a natural product, a renewable resource, and environmentally friendly. Cotton based nonwoven battings [1] have been used in bedding products for years. The main purpose of the mattress is to provide adequate sleep comfort [2]. Research indicates that the natural fibers such as cotton and wool can take perspiration away from the skin and keep one cooler and more comfortable [3]. Presently the scientific research on sleep products is focusing on the flame retardancy regulations (open flame standard 16 CFR Part 1633) effective since July 1, 2007. The primary objective of all sleep product manufacturers is FR treatment of their products to meet these standards. This highlights the vast market potential for a viable FR barrier product with improved flame retardancy to meet the flammability regulations.

Obadiah Wyld first published research work on FR treatment of natural fibers in 1735. In the last century, boric acid treatment of cotton became a popular FR treatment to meet cigarette ignition resistance standards, but today it is inadequate to meet the open flame standard, and hence advanced FR treatment is considered. Performance limitations are determined by stability of the chars produced following interaction of the FR chemicals and the fiber when exposed to the fire [4]. Presently pretreated cellulosic FR fibers are available at reasonably low cost. Furthermore, there are synthetic fibers such as aramids, polyamide imides, carbonized acrylics, and melamines that are inherently flame resistant [5], but these fibers are very expensive, and hence introduce a spike in the cost of the product. Similarly there are chemicals such as metal hydroxides, phosphorus compounds, and melamines to impart FR properties. This research is focused on developing a flame retardant highloft nonwovens using feedstock consisting of cotton, FR fibers and FR chemicals that are commercially available in sufficient quantities at a reasonably low price. Thus, the product would be tailored precisely for sleep products (such as pillows, mattress pads, or barrier material in mattress sets) such that they conform to the latest open flame standard.

Experimental details

In this research, mechanically cleaned gray cotton and other commercial grade FR fibers obtained from various industries and organizations were used. A rough estimated of the cost of FR fibers and FR chemicals relative to cotton (Relative cost of cotton =1, Base cotton price \$0.60 per lb) is shown in Table 1. Experiments were carried out to produce nonwoven webs using these fibers, with cotton as the major fiber component. The fibers were mixed in the desired proportion using a carding machine (SDS Atlas) to prepare a blend of fibers (~300mm wide webs), which is expected to be uniform throughout the product. Binder fibers were blended to assist in through-air bonding. These binder fibers have a low melting (~80°C) polyester sheath with the regular polyester core melting at ~250°C. The process conditions for through air bonding were optimized to impart sufficient strength for further handling, loftiness and appearance. Table 2 shows the various combinations of fibers used to produce the nonwoven webs.

Carded webs with a basis weight of ~300g/m^2 and a thickness of ~15mm were prepared and used in all experiments. FR chemicals such as boric acid, phosphates, silicates, and nanoclays are applied to the blended fiber web as a solution or slurry (~20% concentration) in the presence of a necessary dispersing agent, and bonding or crosslinking agent using the Mathis Laboratory Equipment (Two Roll Padder Type VFM and Oven/Dryer Type KTF-S) for dipping, coating, padding, hot air assisted curing, and drying. The various sets of samples produced are listed in Table 2. The process conditions were optimized to obtain sufficient adherence without appreciable loss in loftiness and appearance.

Other experimental variables are mixtures of FR Chemical 1 & FR Chemical 2 as shown in Table 3. Proprietary dispersion agents (0.5% based on the additive) were added while preparing a solution/slurry of chemicals in water (20% concentration). Similarly proprietary-bonding agents (~1% based on the additive) were added and mixed in the slurry just before the application. Calculated amount of solution/slurry was weighed and incorporated into the nonwoven web using Mathis equipment through the dip, squeeze (0.5bar pressure), and cure-dry process at 125°C.

The samples produced in the experiments were analyzed after conditioning the samples for at least 24 hours under standard laboratory conditions, which are 21°C +/- 1°C and 65% +/- 10% relative humidity.

Table 1 FR Fibers and Chemicals Relative Cost

	Relative cost		**Relative cost**
FR Fibers		**FR Chemicals**	
Aramids	18.92	Phosphorus compound	1.93
Acrylic (oxidized)	7.57	Boron compound	1.30
FR Cellulose	1.33	Citric acid	1.58
Ceramic	809.63	Magnesium compound	0.52
Glass	2.27	Urea	0.87
Melamine	12.11	**Others**	
PBI	136.20	Binder Fiber	1.25
PBO	98.37	Dispersant	31.48
PEEK	113.50	Bonding Chemical	19.17
FR Polyester	2.50		
Silica Fiber	5.00		

Table 2 Cotton -FR Fiber Nonwovens

	Control	Combination I	Combination II
Relative Cost per lb	1.04	2.77	1.70
LOI	19	22	22
% Binder Fiber	15	15	15
% Cotton	85	50	50
% Cellulosic FR	0	20	20
% Synthetic FR 1*	0	15	0
% Synthetic FR 2*	0	0	15

Table 3 FR Chemical Treated Nonwovens

	Control	Set 1	Set 2	Set 3	Set 4
% FR Chemical 1*	0	5	10	15	20
Add on relative cost $/lb	0	0.08	0.16	0.25	0.33
LOI	22	26	28	29	32
% FR Chemical 2*	0	5	10	15	20
Add on relative cost $/lb	0	0.11	0.23	0.34	0.46
LOI	22	29	32	34	38

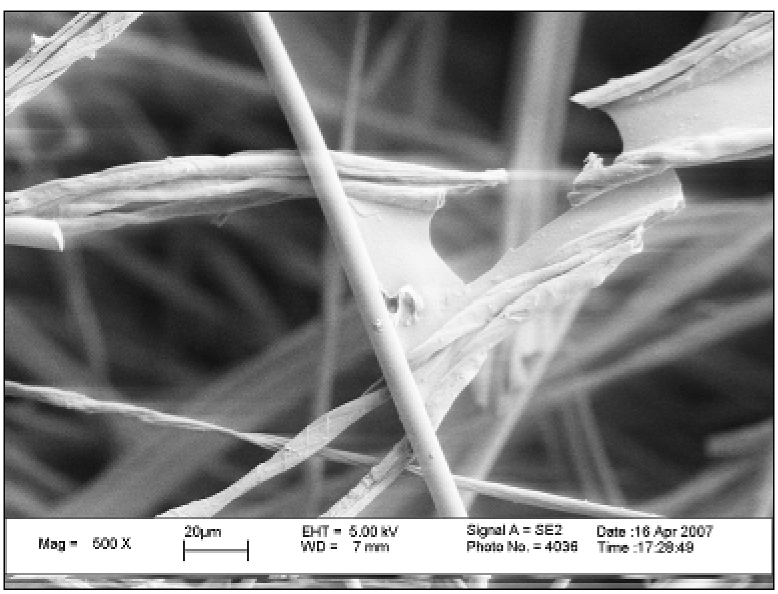

Figure 1 SEM Picture of the Char

The FR nonwoven webs produced were evaluated for flammability, mechanical properties, morphology, and the nature of adhesion between the chemical and the fiber. Initial samples were tested for Limiting Oxygen Index (LOI) levels using the General Electric Flammability Tester according to ASTM D2863 method. After the preliminary screening, the sample pads were subjected to California Technical Bulletin 604 (TB604) or 16 CFR Part 1634 a laboratory scale flammability test [6].

After the burn tests, the char was observed for the structural integrity and intumescent behavior. Scanning Electron Microscope (SEM) photographs were obtained using a Leo 1525 surface scanning electron microscope in back scatter mode with Gemini column at system vacuum of about $1.3x10^{-5}$torr and at an acceleration voltage ~5kV. SPI Module sputter coater was used to coat the samples with gold for 5 seconds at 20mA plasma current to reduce charging while scanning. SEM pictures were taken to understand the morphology. Pictures were taken at the desired magnification focusing on various fibers, fiber-to-fiber bond points, adhered additives, etc. Further, the same sample was analyzed for Energy Dispersive X-ray Spectrum (EDS) to identify the elements (Al, P, Si, etc.) present in the sample.

Results and Discussions

The cotton-rich nonwoven webs containing 15% binder fibers achieved optimum thermo-bonding at the hot air temperature of 175°C and residence time of 3 minutes, to impart sufficient strength for further handling. The SEM picture of the after burn char (Figure 1) shows a reinforcing grid of undestroyed FR fibers supporting the char formed out of cellulosic fibers with the FR additives still present and strengthening the char. Moreover, the char containing FR Chemical 2 exhibited improved structural integrity. At the same time the char containing FR Chemical 1 was fluffy and loose.

The EDS test confirmed presence of Al, P, Si; the constituents of FR chemicals bonded to the nonwoven web .By blending cotton with FR fibers (35%), the LOI value increases from 19 for cotton to 22 (Refer Table 2). Flame retardancy is further improved by chemical treatment. LOI results (Refer Table 3) indicate further increase in LOI from 22 to 38 as the chemical loading increased up to 20%. Moreover, the results show superior performance of FR Chemical 2 compared to FR Chemical 1. Generally LOI >28 is classified as FR. LOI of ~32 is desirable for most of the applications. This is achieved by incorporation of ~10% FR Chemical 2. In all samples, if the fiber is intrinsically FR and does not melt or burn at all, then it can function as a char-reinforcing grid.

The LOI test results relate only to the behavior of the test specimens under the test conditions in the laboratory and used to study FR mechanism. In real fires the conditions are entirely different: oxygen depletes, room temperature rises, and hence the LOI values are used as indicators only.

Figure 2 Sample Pad after the TB604 Test

(Char on the fire side and change in color on other side)

Commercial mattresses are required to pass the expensive test 16 CFR Part 1633, Open Flame Standard for Mattresses. Small industries and researchers cannot afford this test. Hence for our further research we used TB604 test set up. In this test a pad sample passes the test if the flame does not create a void of more than 50mm in diameter. FR properties of the barrier pads produced with FR fibers (35%) exceed the specific requirements of

TB604. After the test, the entire char formed on the sample pad (shown in the Figure 2) was intact with no holes created by the fire (not even a pinhole). Other side of the sample did not char and had slight change in color. This demonstrates that the product of this research would be a suitable candidate for bedding products to comply with the latest open flame standard.

Conclusions

By blending cotton with FR fibers (35%) the LOI value increases from 19 for cotton to 22. FR Chemical treatment enhances the flame retardancy by increasing LOI value up to 38. Out of two chemicals tried, FR Chemical 2 is found to have larger effect on LOI at a lower cost than that of FR Chemical 1. Incorporation of FR Chemical 2 to a level of ~10% increases LOI value to 32, which should be sufficient for most of the applications. FR properties of the pads containing 35% FR fibers passed the Laboratory scale flammability tests TB604 or 16 CFR Part 1634, in fact exceed the specific requirements of TB604. After the test, the entire char formed on the sample pad was intact with no holes created by the fire. Moreover, other side of the sample did not char, instead had slight change in color. This demonstrates that the product of this research could be tailored precisely for sleep products (such as pillows, mattress pads, or barrier material in mattress sets) such that they comply with the latest open flame standard.

The SEM pictures show that chemical binders assist FR chemicals to adhere onto the fibers, present even after the burning that strengthens the char. The EDS confirms presence of applied chemicals in the web. In all samples if the fiber is intrinsically FR and does not melt or burn, then it can act as a char-reinforcing grid. These interactive combinations impart high FR properties to the sleep products with the performance that exceeds TB604 requirements at a reasonably low cost.

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