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Mini Review

Recent Innovations in Flame Resistant Fabrics

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Abstract

The article reviews some recent significant trends in flame resistant fabrics. Multilayered protective fabric assemblies comprising a Nomex III woven outer layer, Nomex nonwoven thermal liners and a modacrylic/cotton woven inner layer have been studied for heat protective performance. In another interesting development, the flame retardant functionality has been imparted in cellulosic fabric using mixed formulation of banana pseudostem sap (BPS) and boric acid (BA).

Keywords: Multilayered fabric; Thermal protection; Bannana pseudostem sap; Cotton

Introduction

In addition to the other hazards like toxic gases & chemicals, radioactive agents and biological agents, the oxygen deficient atmosphere, radiant heat and convective flames of different intensity are the most important hazards that a firefighter face during firefighting and related operations. Based on tolerance time to cause burn injury at different heat fluxes and air temperatures, firefighting environment can be classified in routine, hazardous and emergency categories [1]. Primary role of the protective clothing is to protect the person from such heat and flames. Firefighters' protective clothing is designed to give protection from long term exposure at moderate heat fluxes and short term exposure to high heat fluxes. At the same time, protective clothing should be comfortable to wear under the normal working condition [2].

Cellulosic cotton textile is flammable as it catches flame readily and poses a serious risk to health and life of a living being. Significant efforts have been made from the past to improve the flame retardant property of cellulosic textiles using various synthetic chemicals and many of them are available in the market. The most simple and common ecofriendly formulation used is borax and boric acid mixture [3]. However, larger quantity of chemicals used in this formulation, detoriates the quality of the treated fabric.

Influence of some factors on thermal protective performance of multilayer fabrics

During firefighting operations, the persons involved are exposed to hazards of steam being generated from the hose spray onto fires particularly in a closed and hot environment [4]. Firefighters also get wet during suppression of fire using hose lines, as large amount of water creates mist and splash back. Outer shell of the turnout gear is exposed first to the external environment. Though usually treated with water repellent finishes, outer shell will absorb and soak some amount of moisture and then tend to diffuse through the subsequent layers [5]. The other way of moisture accumulation in firefighter turnout clothing is due to sweating, which gets accumulated in the inner layers [6]. Water accumulated in turnout clothing in these ways is associated to the stored energy and steam burn phenomena. Effect of presence of moisture on protective performance of firefighter protective clothing in low-level radiant heat exposures has been studied by Barker et al. [7] and it is found that with increasing added moisture to the protective clothing, the predicted burn time (s) at the specified heat flux decreases up to certain level of moisture content (20%) and then increases [7]. In a study on thermal protective performance of firefighter gloves under radiant heat exposure and conductive/compressive test, it was found that wet gloves resulted more protection in radiant heat, whereas in conductive/compressive tests wet gloves with moisture barrier showed more protection and less protection without moisture barrier [8]. Stull have mentioned that insulation of protective clothing is affected by amount of moisture, location of moisture, construction of the clothing materials, intensity and duration of heat exposure etc [9].

In the present study, experiments have been carried out to observe the effect of preconditioning of multilayered clothing assembly, effect of added water on the outer layer fabric of a multilayered clothing assembly, and effect of presence of an impermeable Teflon barrier with added water on outer layer fabric on the radiant heat protective performance of the fabric assemblies [10]. Front side of the fabric assemblies is exposed to a radiative heat flux, and temperature rise on the other side of the fabric was recorded with a copper calorimeter. Typical calorimetric traces, generated on exposure of the different fabric samples to radiant heat have also been explained (Table 1).

Table 1: Basic physical properties of the fabrics.

Fabric	Fibre	Construction	Bulk Density ×10^3 g/m^3	Areal Density, g/m^2	Thickness mm	Air Permeability cm^3/cm^3/s
Woven outer layer	Nomex 93% Kevlar 5%, Antistatic fibre 2%	Twill	500	220	0.44	6.5
Thermal liner-1	Nomex	Needle punched	47	200	4.24	102.0
Thermal liner-2	Nomex	Needle punched	58	200	3.45	64.0
Innermost layer	Modacrylic/cotton	Plain woven	478	195	0.41	17.0

Presence of moisture in the fabric assemblies causes the temperature trace to be shifted further and increase the burn injury time. Though the effect of different conditioning environment is little on protective performance of firefighter clothing assembly, pre-drying of fabric assembly reduces heat protective performance. In the case when no barrier is used after the outer shell fabric, externally added water tends to diffuse and wick inside the inner layers and increases fabric thermal conductivity, causing nonlinearity in the temperature curves. Presence of moisture or water to a definite amount can increase time of protection. However, too large amount of water can increase thermal conductivity and can cause an early burn injury. As water has large heat capacity stores thermal energy get gradually released and absorbed by skin to cause burn injuries even when little damage of the fabrics have taken place. At the same time, practical firefighting situation is unpredictable, and to what extent firefighter clothing becomes wet, cannot be said beforehand. Temperature dependent specific heat alone cannot explain nonlinear temperature traces obtained. Initial distribution of moisture, specific heat, thermal conductivity which depend on local moisture/water content, heat of evaporation, rate of diffusion in the fiber, air and water system need to be considered to explain this satisfactorily. Putting an impermeable barrier causes an improvement in heat protective performance of fabric assemblies in all cases.

Self extinguishing cotton fabric

Phosphorous based flame retardants along with nitrogenous and sulphur compound are the most-effective formulation reported so far, due to their synergistic effect. Consequently, from the last fifty years, different flame retardants based on the composition of phosphorous, nitrogen, and sulphur has come into the market for imparting flame retardancy. Among all these chemicals used for flame retardancy, Tetrakis phosphonium salt (Proban process) and N-alkyl phosphopropionamide (Pyrovatex process) derivatives are widely dominate commercially [11]. However, as such formulations need to be applied in an acidic condition; the cotton fabric loses its tensile strength and becomes stiffer. Besides, such a treatment is expensive and non-ecofriendly due to the involvement of larger quantity of chemicals, high temperature curing process and toxic formaldehyde emission during treatment if the process is not properly controlled [12]. Antimony in combination with halogen, though could impart good flame retardant property, but still is not very successful due to the negative impact of halogen compounds in the environment [13]. Therefore, as now-a-days sustainability and eco-friendliness are the major concerns for the researchers and textile industries, some intumescent based flame retardants, which work by charring and foaming mechanism, have come into the market. For example recently researchers have used sodium metasilicate nonahydrate for making a fire retardant cellulosic jute textile [14]. A composition of nano zinc-oxide and polycarboxylic acid have also been developed by the researchers to make the fire retardant process environment friendly [15]. However, such treatment cannot satisfy the handle, strength and the fire resistant durability requirements of the fabric. Recently, researchers have also used plasma treatment with various polymerisation gases to impart the fire retardancy property to the cellulosic fabric. Though the plasma process is water free and ecofriendly, but it is very costly and also the imparted flame retardant property is not wash durable [16]. Hence, there is the need to develop more cost-effective, environment friendly and sustainable fire retardant products, which when applied to cotton fabrics, will maintain its quality and flame retardant durability to a great extent. A very few researches have so far been reported on imparting fire retardancy to cellulosic fabric using natural products [17-21]. Recently, the researchers reported that DNA from herring sperm and solomon fishes can be applied to the cotton fabric to make it thermally stable. Attempts have also been made to impart fire retardancy in cotton fabrics with whey proteins, casein and hydrophobins due to their phosphate, disulphide and protein content, as they can influence the pyrolysis by an early char formation. However, a limited application of waste plant bio-molecules has been made for imparting flame retardant finishing to any textile and/or polymeric material till date to the best of our knowledge. As some of the plants contain phosphate, phosphate, chloride, silicate and other minerals, metal oxides and mineral salts, they offer immense potential to be utilized to impart flame retardancy to cellulosic and non- cellulosic textiles. In our earlier publications, we have reported a detailed study of imparting fire retardant to cellulosic cotton fabric, using spinach juice and wastage banana pseudostem sap (BPS) [22-25]. However, the main drawback of that finish is the presence of smoke and afterglow, during burning, which is very dangerous for the users of the textiles. Therefore, for arresting afterglow, and smoke, and for making the developed process more effective and user friendly, an attempt has been made in the present research to use a mixed formulation of BPS and boric acid. The treated fabric has been evaluated by different flammability tests, besides thermal and chemical characterization (Figure 1-3).

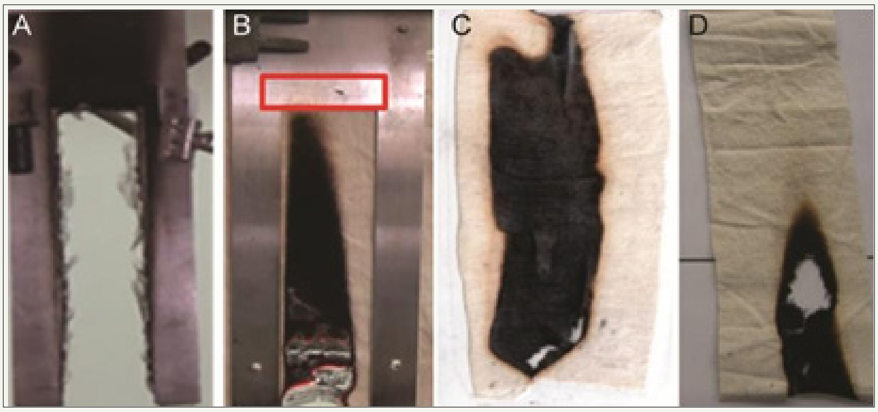

Figure 1: Vertical burning behaviour of control (A) , BPS (B) , 3% BA (C), and BPS +3% BA (D) treated cotton fabrics after 60s of burning [Red marked portion shows gelatine like viscous material after complete burning of the BPS treated cotton fabric].

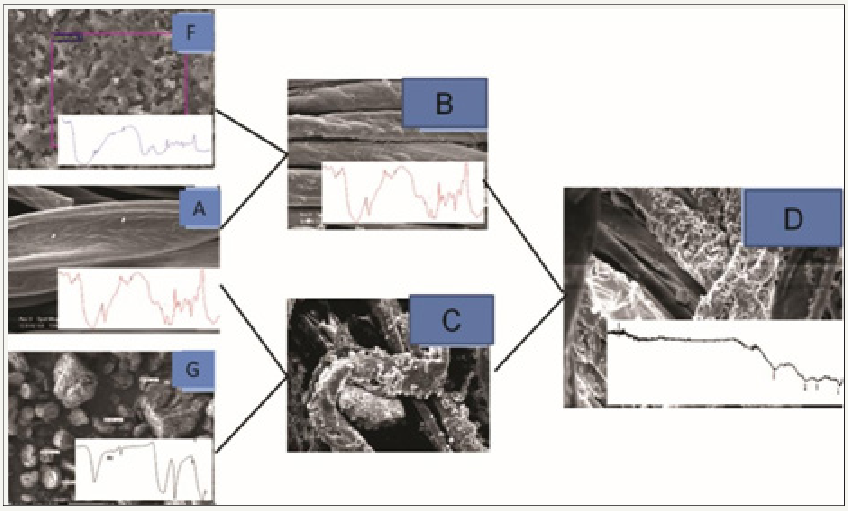

Figure 2: Fabric surface morphology and FTIR spectrum of the BPS only (F), cotton (A), BA only (G), BPS treated (B), 3% BA treated (C) and (BPS+3% BA) treated (D) cotton fabric.

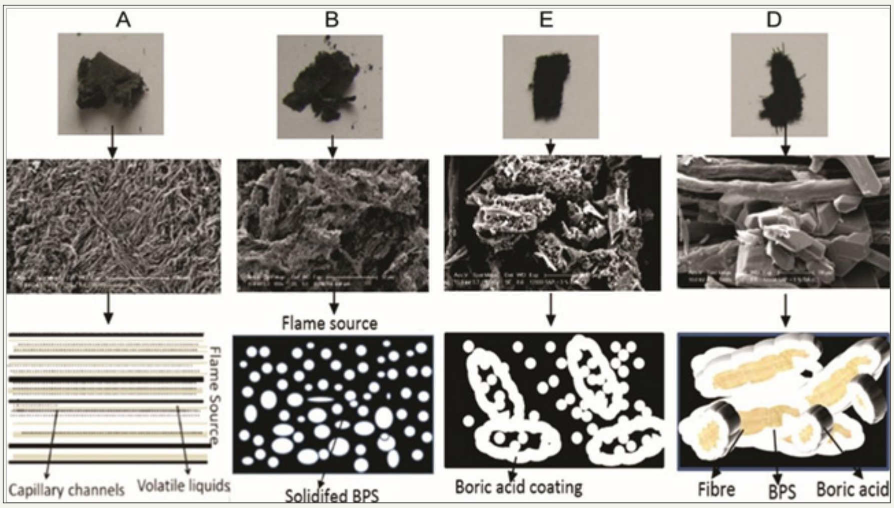

Figure 3: Char picture and morphologies of the control (A), BPS treated (B), BPS +1% BA (C) and BPS+3% BA (D) treated fabrics.

The present study has enlightened about the flame retardancy effect of the mixture of BPS and BA. It has been found that the mixed formulation of BPS and 3% BA is the most suitable for imparting flame retardancy in the cellulosic products in a condensed phase intumescent mechanism. The mixture after application forms an intumescent layer on the fabric surface, which has a self extinguishing effect that lowers the temperature and heat generated from the textile during heating [26]. The char morphology of the

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treated cotton fabric shows a thick intumescent coating with the presence of long chain aromatic compounds. This reported process can be used beneficially for imparting flame retardancy to household table lamp cloth and also, as a covering material of non permanent structures like those used in making tents for pilgrims, militaries, book fair, festival, religious purposes and such on, where a large quantity of textile is used and the wash durability is not a major concern.

Conclusion

Effect of conditioning and presence of water on the outer layer fabric has been studied on heat protective performance, against radiant heat flux. It is observed that the radiative heat protective performance of firefighters' protective clothing assembly can be improved in presence of a water tight barrier layer used just after the outer layer when the outer layer fabric is wet. Conditioning of the assembly in a particular environment can also significantly affect thermal protective performance. The extracted sap is mixed with different concentration of BA and applied onto the pre-mordanted bleached and mercerized cotton fabrics at elevated temperature. It is found that BA acts as a strong afterglow and smoke arresting agent, when applied at the concentration of >2% (w/v). Flame retardant characteristics of both the control and the treated fabrics have been analyzed in terms of limiting oxygen index, vertical flammability and temperature generation profile during burning. The (BPS+3% BA) treated cotton fabric sample shows the LOI value of 42 and the specific char length of 14cm after vertical flammability test. The thermal degradation and pyrolysis mechanism are also studied; using both thermogravimetric analysis and fourier transform infrared spectroscopy. Besides, the charring morphology and mechanism of both the control and the treated fabric is analyzed in detail by scanning electron microscopy and FTIR analysis. A char structure model and the mechanism of char formation have also been proposed.

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