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Influence of hydrophobic substance on enhancing washing durability of water soluble flame-retardant coating

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ABSTRACT

Flame-retardant textiles are used in many consumer products. Among halogen-free flame retardant substances, inorganic flame retardants are mainly based on phosphorus, antimony, aluminum and boron-containing compounds. These coatings are soluble in water and therefore are not subjected to washing. In this study, washing durability of the inorganic flame retardant has been improved by incorporation of the hydrophobic substance to the coating. Composition of the coating which is the flame-retardant, monoammonium phosphate (MAP), and the hydrophobic substances, poly(methylhydrogen siloxane) (PMHS) and poly(dimethyl siloxane) (PDMS)), were varied to find the optimum coating solution. The results of SEM and TGA analysis, as well as the burning and washing tests, revealed that the coating solution consisting of MAP:PMHS:PDMS = 5:2:1 wt.% was the optimum condition. It showed the increased residue on the TGA profile compared to the uncoated sample, and self-extinguish after removal of the ignition source. The flame-retardant property can be maintained after washing, making it feasible for variety of applications.

1. Introduction

In the past several decades, there have been many studies focusing on the development of flame-retardant materials. These materials include both natural (e.g. wood, cellulosic materials, etc.) and synthesis materials (e.g. polyester, nylon, etc.) [1–7]. Among them, cellulose-based materials could find potential applications in both the textile industry and packaging area. Moreover, it has gained more interest due to its environmentally friendly renewable resource [8,9]. However, they have a drawback because of thermal instability; they are unstable at temperature above 200 °C, producing volatile organic compounds. The thermal degradation products evolve large amount of heat, causing further degradation and burning [10–12].

Flame retardants are defined as chemicals that modified pyrolysis reactions or oxidation reactions by slowing down or hindering the burning process. Currently, the most commonly used flame retardants for cotton fabric are based on halogen, nitrogen and organic-phosphorous compounds such as Phoban and Pyrovatex CP [13,14]. However, the process finished Phoban and Pyrovatex CP have the shortcoming of releasing formaldehyde. The use of halogen flame retardant may generate poisonous substance. Commonly, inorganic flame retardants based on phosphorus, antimony, aluminum and boron-containing compounds are generally considered as environmental friendly flame retardants because they do not generate chemicals that are harmful to human and the ecosystem when they are burnt. According to previous studies, phosphorous-containing compounds are known for their effectiveness in providing flame retardancy to cellulose materials [1–3,15]. The treated fabric exhibited self-extinguishing behavior, and the phosphorus was found to reduce the decomposition temperature. However, these flame retardants are normally not subjected to washing because they are soluble in water [12].

In this study, washing durability of the phosphorous-containing flame retardant coating has been improved by incorporation of the hydrophobic substances to prevent dissolution of the flame-retardant constituent. The coating was deposited on the cotton fabric simply by immersion method, making it feasible for upscale production for practical use. The coated fabrics were characterized for their surface morphology and functionality, water repellency, thermal property and washing durability.

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2. Experimental procedure

2.1. Preparation of coated cotton fabrics

The bleached 100% cotton fabric was cut into small pieces of 10 cm × 10 cm in size. After cleaning with detergent, the fabric was dried at 50 °C for 1 h. The coating solutions were prepared by dissolving hydrophobic substances which were poly(methylhydrogen siloxane) (PMHS, Dow Corning) and/or poly(dimethyl siloxane) (PDMS, Aldrich) and flame-retardant substance which was monoammonium phosphate (MAP, 98.0%, Ajax Finechem Pty Ltd.) in deionized water at a composition given in Table 1. The resulting solution was stirred at room temperature for at least 15 min to obtain solution's homogeneity. The coating was performed by soaking the clean cotton fabrics in the solution for 2 h followed by drying at 50 °C for 2 h.

2.2. Characterization

Surface morphology was observed by using a field-emission scanning electron microscope (FE-SEM, JSM 6301F). Surface functionality was analyzed by using an attenuated total reflectance Fourier transform infrared spectroscope (ATR-FTIR, PerkinElmer) at a resolution of 4 cm^{-1} and a scan number of 64. To evaluate thermal stability, the uncoated and coated fabrics were stored in the desiccator for 24 h to keep them as dry as possible and to ensure the same dry degree for all the samples. Then, the sample was ignited for 1 s and the ignition source was removed. Burning behavior was observed and photograph was recorded after 3 and 10 s, as well as at the completion of burning. In addition, the thermogravimetric analysis (TGA) was carried out on a TGA/DSC1 (Mettler-Toledo). The analysis was performed under N_2 at the heating rate of 10 °C/min. The hydrophobicity was evaluated by measuring a water contact angle using a goniometer (ramé-hart instrument). To study washing durability, the coated fabric was vigorously stirred in tap water at 30 ± 5 °C at a stirring speed of 800 rpm. The washing was conducted for 5 cycles. After drying, the washed samples were subjected to SEM, ATR-FTIR and TG analyses, burn test and contact angle measurement.

3. Results and discussion

3.1. Surface morphology

Fig. 1 shows SEM images of the uncoated and coated fabrics. The uncoated fabrics (Fig. 1(a)) has a typical longitudinal fibrous structure with very smooth surface. The fabric coated with only MAP (COT-1, Fig. 1(b)) shows similar feature as the uncoated fabric, indicating very thin coating layer. On the other hand, for the fabrics coated with the PMHS (COT-2, Fig. 1(c)) and the PMHS and PDMS (COT-3, Fig. 1(d)), rough coating consisting of small aggregated particles, ~5–15 μm in size, randomly distributed over the cotton surface. Such rough surface feature is beneficial for reducing water wetting because it enhances hydrophobicity. Color of the

Table 1
Chemical composition, water contact angle and percent residue of uncoated and coated samples before and after washing.

Sample	Concentration (wt.%)			Contact angle (°)		Residue (%)	
	MAP	PMHS	PDMS	As-prepared	After washing	As-prepared	After washing
COT	–	–	–	–	–	11.06	–
COT-1	5	–	–	–	–	40.45	15.78
COT-2	5	5	–	124.10 ± 3.00	121.07 ± 3.91	37.96	15.29
COT-3	5	2	1	131.13 ± 1.48	128.48 ± 1.59	47.48	29.13

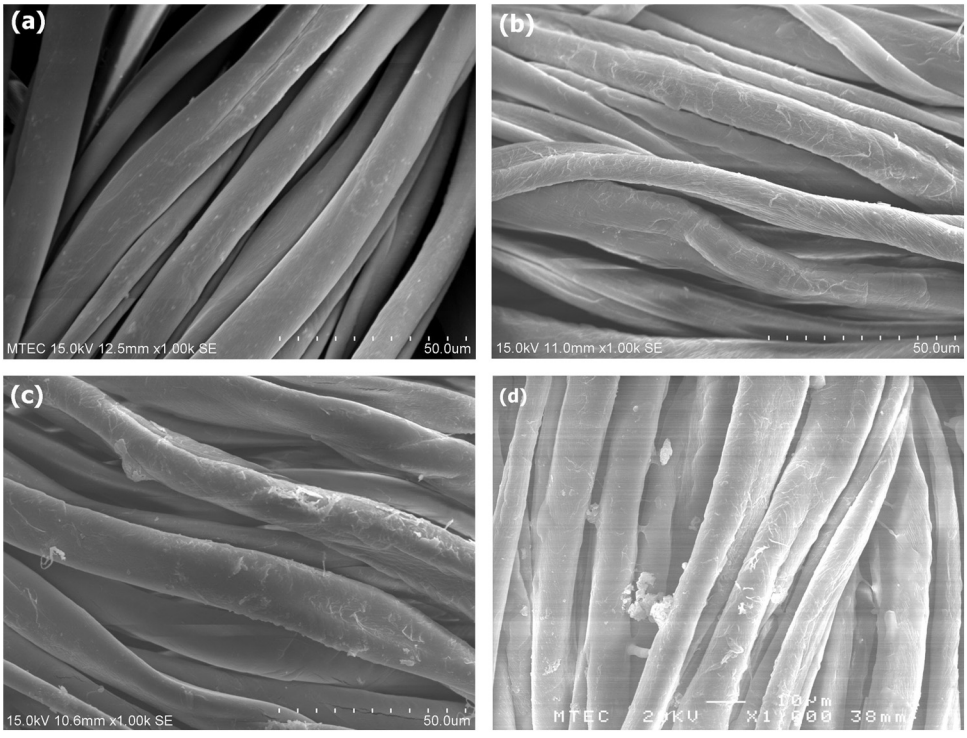

Fig. 1. SEM images of (a) uncoated cotton fabric (COT), and (b)–(d) cotton fabrics coated with COT-1, COT-2 and COT-3 solutions, respectively.