COMBUSTION PROPERTIES OF COTTON FABRIC TREATED BY BORON DOPED SILICA SOL

by

Qiang-Hua ZHANG[a], Wei ZHANG[a], Guo-Qiang CHEN[a], and Tie-Ling XING[a,b*]

[a] College of Textile and Engineering, Soochow University, Suzhou, China
[b] Xinyuan Cocoon and Silk Group Co., Ltd, Haian, China

Original scientific paper
DOI: 10.2298/TSCI1504345Z

Cotton fabric was treated with pure silica sol and boron doped partner through sol-gel method in order to improve its thermal and combustion properties. The results of thermo-gravimetric analysis, micro combustion calorimeter, and smoke density test of control showed that the finished cotton fabric had excellent thermal stability and mild combustion behavior with lower heat release rate. Furthermore, the smoke density test also indicated the safety performance of the boron doped silica sol treated cotton fabric in the fire.

Key words: *combustion properties, cotton, thermal gravimetric analysis, heat release rate, smoke density*

Introduction

Cotton, as a natural cellulose fiber with good hygroscopicity, favorable softness and good stability in alkaline solution, has been extensively used as clothing and household textiles ranging from sleepwear, bedding to curtain. However, cotton is a flammable material with low thermal stability and rapid combustion. It can be easily ignited by flame and rapidly induce fire disaster, which severely confines its application in the field of flame-retardant textile for the increasingly strict demand on flame retardant standard. Therefore, it is necessary to improve the thermal stability and combustion property of cotton fabric.

Sol-gel method, as a technology of material surface modification, has been successfully introduced into textile functional finishing field to endow fabric with certain function including hydrophobicity, UV-resistance, flame-retardancy, *etc*. [1]. In the present work, the pure silica sol and boron doped silica sol were synthesized using tetraethoxysilane as precursor and zinc borate (ZB) as additive [2, 3]. The prepared sols were then entrapped onto cotton fabric through pad-dry-cure method to form an oxide film with 3-D net structures on the substrate; meanwhile the film could firmly adhere to the cotton fabric. And the combustion properties of pure silica sol treated cotton fabric of (cotton-Si) and boron doped silica sol treated one (cotton-Si/B) were also investigated.

* Corresponding author; e-mail: xingtieling@suda.edu.cn

Experimental analysis

Thermal gravimetric analysis

In order to investigate the influence of the Si/B and Si sol coatings on the thermal stability of cotton fabric, thermal decomposition of the treated samples were measured by thermo gravimetric (TG) analysis in N_2, and the results were compared with the cotton-control. In fig. 1, the TG curves of the treated and control cotton samples are presented.

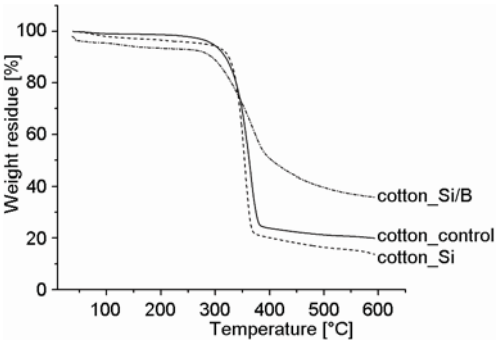

Figure 1. The TG curves of cotton samples

It can be seen from fig. 1 that the samples of cotton-Si and cotton-control manifest a similar decomposition behavior with the temperature increasing. The major mass loss, derived from decomposition of the glycosyl units and the depolymerization of such units into volatile products [4], take place at 320 °C~ ~380 °C. However, before 200 °C, a slight lower weight loss for the cotton-Si than the cotton-control was found, which might be attributed to the loss of bound water in the silica sol. With regard to 360 °C~380 °C, a more dramatic decrease occurred in the cotton-Si sample than the cotton-control. This could be owing to the incomplete hydrolysis of the sol-gel process, in which the unhydrolyzed ethyoxyl would accelerate the degradation of cotton substrate. In the final stage, the two samples generated about 15%~19% weight residues. However, the cotton-Si/B curve shows some obvious difference from cotton-control. Firstly, there was a wider temperature range from 280 °C to 400 °C for the cotton-Si/B, indicating the cotton-Si/B had a mild manner of thermal degradation because of the presence of ZB doped into the silica sol matrix. The ZB doped silica sol could melt into a dense impenetrable glass coating cover on the substrate surface insulating heat and oxygen at high temperature [5]. Moreover, the combined effect of silica sol with ZB made this coating cover more stable. Consequently, in the end of the decomposition, about 600 °C, much higher weight residue of cotton-Si/B than cotton-control was seen.

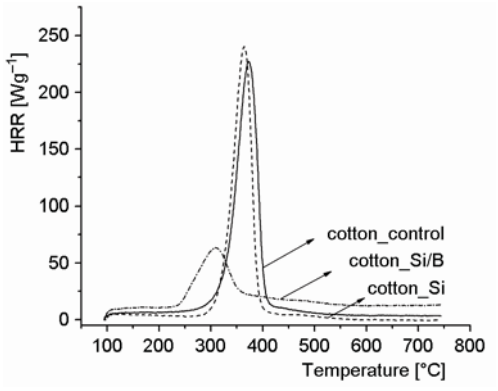

Figure 2. The HRR curves of cotton samples

Micro combustion performance

The combustion behavior of the treated and control cotton samples were conducted by the micro combustion calorimeter (MCC), and the heat release rate (HRR), total heat release (THR) of combustion, heat release capacity (HRC), and temperature of maximum HRR (T_{max}) were shown in fig. 2 and tab. 1.

It can be seen from fig. 2 that the curve of cotton-Si sample shared the analogous shape with the cotton-control, and the peak heat release rate (pHRR) are 237.8 W/g at 364 °C, and 222.2 W/g at 373 °C (tab. 1), respectively. It can be seen that the pHRR value of cotton-Si was

higher than the cotton-control by 15.6 W/g, and the temperature reaching it also lowered by 9.6 °C. This might be owing to the thin coating of -Si-O-Si– network, which would break in some areas during the combustion, thus creating latent channels to concentrate and leak out the formative flammable gas [6]. But the THR value of cotton-Si was lower than that of the cotton-control by 1.0 kJ/g. This demonstrated in a certain degree that the pure silica sol coating somewhat had a little positive effect on the change of the cotton's combustion behavior. However, there is a greater reduction in pHRR value by 77.0% from 222.2 W/g to 51.0 W/g for cotton-Si/B sample compared to the cotton-control sample. In addition, the value of THR and T_{max} of the cotton-Si/B sample also have a great decrease by 54.7% and 62 °C than that of cotton-control, respectively. These indicate that the Si/B sol coating on the cotton fabric can efficiently reduce the heat feeding back to the substrate surface because of the insulating cover of flame and oxygen in combustion, as well as the thermal decomposition rate and degradation temperature, which was in accordance with the TG analysis.

Table 1. Combustion data of the cotton samples

Sample	HRC [$Jg^{-1}K^{-1}$]	pHRR [Wg^{-1}]	THR [kJg^{-1}]	T_{max} [°C]
cotton-control	225	222.2	11.6	373.6
cotton-Si	240	237.8	10.6	364.0
cotton-Si/B	53	51.0	4.8	302.0

Smoke density test and morphology of the sample char

The smoke suppression situation is depicted in fig. 3. It can be seen that the cotton--control maintained the smoke density value of 52.94 (/g) after the time of 653 seconds, as to cotton-Si 79.13 (/g) after 661 seconds, and cotton-Si/B at 22.00 (/g) after 173 seconds. It can be concluded that the presence of the ZB indeed help decrease the release of smoke during the combustion of cotton fabric. It can also be founded that the pure silica sol couldn't reach the goal of reducing smoke release, which was probably ascribed to the incomplete -Si-O-Si– network.

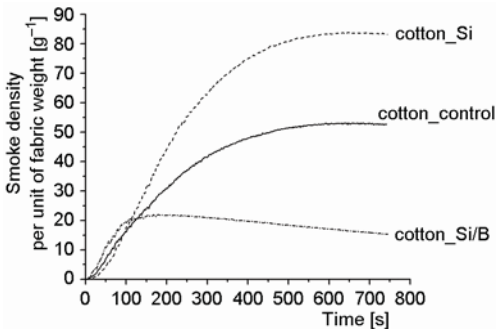

Figure 3. Smoke density curves of cotton samples with time

Figure 4 presents the scanning electron microscopy (SEM) images at 1000 magnifications of the samples which were putted in muffle furnace for 3 minutes at the temperature of 650 °C. It can be seen from the images that the control sample has already become ashes with random and incomplete yarn texture shape after the combustion, while the treated ones still maintain relative integral structure. This could be attributed to the shield effect exerted by the sol coated on the substrate surface, which helped the fabric keep its original shape of structure. However, there was a more complete -Si-O-Si– network with less crack and flaw in cotton-Si/B than that of the cotton-Si, indicating that the doped ZB could make the -Si-O-Si– structure more stable, which was in good coordination with the explanation of TG and MCC analysis.

Conclusions

Cotton fabric treated with boron doped silica sol could extremely decrease the thermal degradation temperature, pHRR, and smoke density during the combustion. There was a

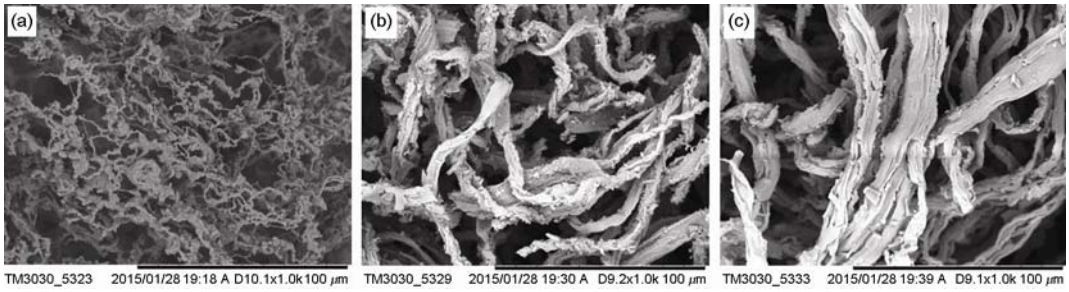

Figure 4. The SEM images of (a) cotton-control, (b) cotton-Si, (c) and cotton-Si/B

good combined effect between the ZB and the silica sol. The moderate combustion behavior and excellent smoke suppression of the Si/B sol coated cotton fabric also indicated the safety performance in the fire hazard.

Acknowledgment

This work is supported by National Natural Science Foundation of China (No. 51203107) and PAPD (A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions) and sponsored by Qing Lan Project.

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Paper submitted: January 10, 2015
Paper revised: March 14, 2015
Paper accepted: March 25, 2015