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Protective properties of different fabrics using micronized pumice

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In this study, cotton and polyester fabrics have been coated with different pumice concentrations (3, 6, 9, 12 and 15%) and their physical properties (UV_ultraviolet protective and flame retardancy) are investigated. In addition, the surface properties of the fabrics are also analyzed by scanning electron microscopy, energy dispersive X-ray spectroscopy and contact angle analysis. The findings show that the ignition and yarn breaking times of the fabrics are delayed. The results of untreated fabric samples are compared with the sample coated with 15% pumice. Cotton fabrics shows 79% increase in flame time and 51% increase in yarn break time, while polyester fabric shows 29% increase in flame time and 62% increase in yarn break time. The ultraviolet protection factor values for 3% and 15% pumice-coated polyester fabrics are 50+ and provide excellent protection. It is concluded that the micronized pumice can be a new additive material in the textile industry, especially for use in protective textiles.

Keywords: Cotton fabric, Flame retardancy, Micronized pumice, Polyester fabric, Protective textile

1 Introduction

In today's textile industry, technical textiles have an important role. In recent years, fabrics produced from different natural or artificial materials play an important role in preparing protective technical textiles. Flame retardant textile products are used in the clothing of firefighters, defense industry and industrial plant workers[1,2], home textile products (carpets and curtains[3]), vehicles and various other textile products[4]. Cotton fabrics are generally used in home textiles, firefighting and military clothing because of their biodegradable, hydrophilic, high air permeability, softness and comfort properties[5-7]. However, the easy and fast flaming properties of cotton limit its use in these areas[8]. Since the high carbon and hydrogen contents of organic materials (cotton) cause burning easily, studies are carried out to improve the flame-retardant properties of cotton fabrics[9,10]. The same is true for polyester materials. Apparel products are also made of polyester-cotton blends[11,12], that are comparatively cheaper, more durable, breathable, less thermal stable and highly flammable. The flammability of such fabrics depends on many factors, such as weaving or knitting type, yarn and fibre structure, additives, and chemical treatment[13-15].

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Studies for reducing ignition and combustion in textile materials are being conducted since a long time[16]. Flame-resistant materials, such as asbestos, were used by the people in the Roman period, but after the 16th century, initial studies were carried out on flame-retardant textiles[17]. With the advancement of technology, the use of flame retardant protective textiles gained importance, to avoid the risks in forest fires that we have witnessed in living spaces and industry in recent history.

Bourbigot *et al.*[18] proposed three solutions to reduce the flammability properties of fabrics, namely (i) using natural flame-retardant textiles (high-performance fibre), (ii) using chemically modified textiles and (iii) adding flame retardants to synthetic and natural fibre for surface treatment. Taking these suggestions into account, the flame-retardant properties of cotton and polyester fabrics have been investigated in this study. For this purpose, different concentrations of flame-retardants such as high-temperature resistant micronized pumice stone compounds have been applied onto the synthetic and natural fibre, and their ignition and combustion properties are studied for their protective use in industry.

2 Materials and Methods

2.1 Micronized Pumice

Pumice stone is described as a natural lightweight aggregate in technical terminology. It is defined as a volcanic substance with disjointed voids, sponge-like, silicate-based, unit volume weight generally less than 1 g/cm^3, with a hardness of about 6 according to the Mohs scale, with a glassy texture[19]. Pumice is in the form of porous structures. For this reason, it is preferred as a thermal insulation material. The water absorption rates of the material (18.75%) and the apparent porosity values (20.88%) have clearly supported this fact. In addition, the specific gravity of the material is 2.302 gr/cm^3 and the oven-dry density is 0.982 gr/cm^3. Therefore, it proves to be a light material compared to other alternative materials. According to the EN 13055:2016 standard, the mass loss should not be more than 5% in the ignition analysis. In the glow loss analysis of the pumice material, the highest mass loss was found to be 1.0237% at 1220 °C. Hence, the pumice stone has been used in this study as a flame-retardant coating material on cotton and polyester fabrics. Since the pumice material used in this study is 40 micron in size, it is named as micronized pumice.

2.2 Fabrics

Two different fabrics (cotton and polyester), woven with a plain (1/1) structure, were used. Washed and bleached cotton fabric (258 g/m^2), having warp density 32 warps/cm and weft density 22 wefts/cm was used. The polyester fabric (262 g/m^2), having warp density 23 warps/cm and weft density 20 wefts/cm was used.

In the test phase of the fabrics, coating pastes were prepared using different concentration of 40 µm micronized pumice (0, 3, 6, 9, 12 and 15%) and then applied on both cotton and polyester fabric samples, using an ATAÇ laboratory type coating machine. The 28×36 cm sized samples were coated with 80 g of paste using the coating machine, operating according to the principle of working in the air with the blade. The coating process was followed by drying at 110 °C for 10 min. Sample fabrics were then conditioned for 48 h under standard atmospheric conditions (65±2% RH and 20±2 °C). Ultraviolet (UV), contact angle, SEM and EDS analyses and flammability tests were done.

2.3 Coating Paste Recipe

Coating paste was obtained by adding RUCO-COAT PU 1130 and RUCO-COAT FX 8011 consistency paste chemicals and pumice stone at varying concentrations (0, 3, 6, 9, 12 and 15%). RUCO-COAT PU 1130, an anionic, water-based, aliphatic polyether polyurethane dispersion, is chemical-based, soft and hydrolysis resistant material used for high water column paste coating applications. RUCO-COAT FX 8011 is a formaldehyde-free crosslinker for water-based dispersions, such as polyurethane, polyacrylate or polyvinyl acetate. Blocked isocyanate, which does not contain N-methyl-2 pyrrolidone (NMP) and butanone oxime, has a chemical structure in anionic and liquid form. The thickening paste is a water-based synthetic thickener. Its chemical structure is acrylate-based and it is in liquid form. The coating paste was used to prevent pumice stone for separating from the surface by mechanical force during binding. The viscosity of the coating paste was 21000 rps and the *p*H was 8-8.5. The coating paste recipe includes: 950 g RUCO-COAT PU 1130, 50g RUCO-COAT FX 8011 and × g thickening paste.

Each coating paste of 200 g was prepared using 40 µm pumice at different concentrations (0, 3, 6, 9, 12 and 15%). The pumice ratios and sample codes applied to the coated fabrics are given in Table 1. The appearance of the coated fabrics is shown in Fig. 1.

Table 1 — Fabric codes for various thread samples

Cotton	Pumice concentration , %	Polyester
A0	Control sample	B0
A1	Coating paste	B1
A2	3	B2
A3	6	B3
A4	9	B4
A5	12	B5
A6	15	B6

Fig. 1 — Coated fabric samples

2.4 Flammability and Detailed Analysis

Bellmore TC-45 model test setup was used for flame retardancy (Fig. 2). By taking the average values of 3 warps and 3 wefts fabric samples, the 45º inclined flammability test was performed, using ASTM 1230 – 450 standard procedure.

The Jasco V-770 spectrometer was used to measure the UV transmittance (determination of UPF) values of the tested fabric samples. In accordance with the AS / NZS 4399 - 1996 38 standards, the wavelength range of 290 nm - 400 nm (UV region), was selected as the measurement wavelength. FEI Quanta FEG 250 EDAX / EDS scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDS) were used to study the surface morphologies of the sample fabric surfaces. KSV CAM 101 device was used to measure the contact angle of the fabrics.

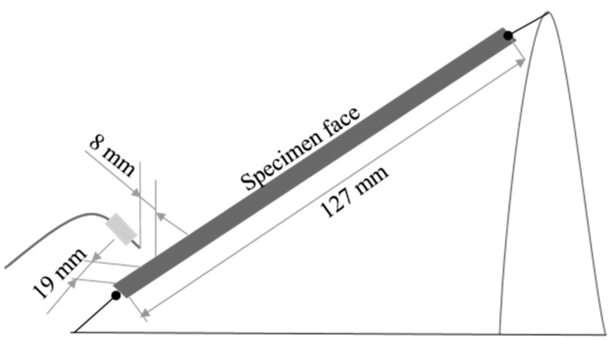


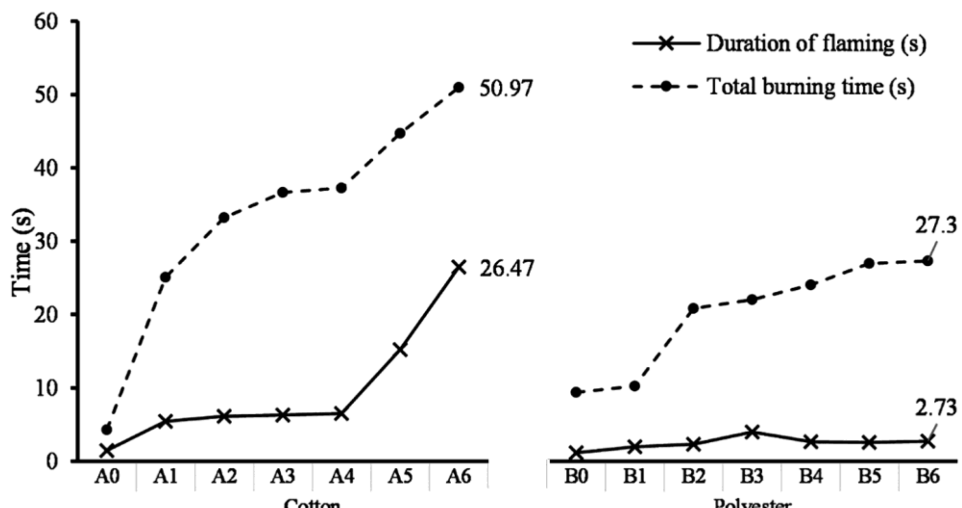
Fig. 2 — Schematic representation of 45° inclined flammability tester

3 Results and Discussion

The 45° inclined flame retardancy tests of the cotton and polyester fabric samples are repeated three times for each coating ratio. Ignition time and yarn break time are recorded by averaging these three test values (Fig. 3).

It is observed that cotton fabrics exhibit flame-retardant properties, while polyester fabrics do not show flame-retardant properties due to rapid ignition. The flaming time of the untreated cotton fabric sample (A1) improves by 79% and the yarn breakage time improves by 51% as compared to the sample with 15% pumice (A6). In case of polyester fabric, it is observed that flaming time improves by 29% and the yarn breaking time improves by 62% . The effect for the pumice ratio used on flame retardancy is shown in Fig. 3. This increase is related to the increase in pumice concentration. The increase in flaming and yarn breaking time in cotton with 12% pumice concentration (A5 fabric) is clearly seen in the graph (Fig. 3). The increase in pumice stone concentration positively affects the cotton fabric. However, the melting tendency of the polyester fabric causes it to melt and burn rapidly even during the coating with pumice stone. Therefore, the flame retardancy properties of polyester fabric coated with pumice stone are lower than that of cotton fabric.

Textile materials show different reflectance, transmission and absorption rates of UV radiation.



	A0	A1	A2	A3	A4	A5	A6	B0	B1	B2	B3	B4	B5	B6
Duration of flaming (s)	1.47	5.45	6.14	6.28	6.52	15.21	26.47	1.15	1.97	2.32	3.97	2.65	2.58	2.73
Total burning time (s)	4.28	25.06	33.21	36.66	37.23	44.73	50.97	9.37	10.23	20.82	22.02	24.05	26.98	27.3

Fig. 3 — Flame retardant test results of coated fabrics

UV analysis is performed at UVA (315–400 nm), UVB (290–315 nm) and UPF (290–400 nm) regions according to EN 13758-1 and 2:2007 standards. It is observed that the cotton fabric samples posses low UV absorption, while the polyester-containing fibre shows high absorption (Fig. 4).

The UPF, UVA and UVB reference values according to AS/NZS 4399:1996 standard are given in Table 2. The UVA, UVB, UVR and UPF values of the cotton and polyester fabric samples are given in Table 3, which are compared with these reference values.

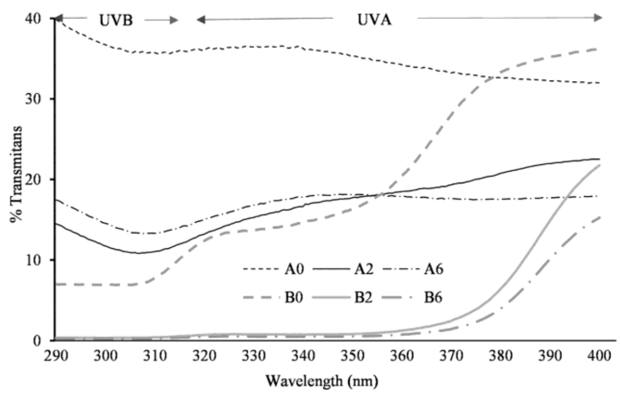


Fig. 4 — Transmittance measurement graph of cotton and polyester fabric samples

Table 2 — Assessment chart as per AS/NZS 4399:1996 standard (UVR—solar ultraviolet radiation in the range 280 - 400 nm)

UPF rating	Effective UVR transmission, %	UVR protection category
≤ 15	≥ 6.7	Insufficient protection
15 - 24	6.7 - 4.2	Good protection
25 - 39	4.1 - 2.6	Very good protection
≥ 40	≤ 2.5	Excellent protection

Table 3 — UVA, UVB, UVR and UPF values of cotton and polyester fabric samples

Samples	UVA %	UVB %	UVR %	UPF
A0	34.39 Nonrateable	37.01 Nonrateable	35.07 Nonrateable	2.78 Nonrateable
A2	18.13 Nonrateable	12.2 Nonrateable	15.16 Nonrateable	8.22 Nonrateable
A6	17.25 Nonrateable	14.79 Nonrateable	16.02 Nonrateable	6.99 Nonrateable
B0	22.57 Nonrateable	7.60 Nonrateable	15.08 Nonrateable	10.82 Nonrateable
B2	4.92 Good	0.39 Excellent	2.65 Very good	50+ Excellent
B6	3.27 Very good	0.25 Excellent	1.76 Excellent	50+ Excellent

The UPF value of fabrics indicates the amount of protection against the harmful effects of sun rays. The average UVA permeability value of the fabric is another parameter, indicating the suitability of protection against UV rays. The average transmittance value for UVA and UVB rays should be less than 2% for technical textiles and 5% for protective textiles[20]. The fact that the coated UVB value of the polyester (B2 and B6 samples) are less than 2% and the UVA value is less than 5%, indicates that the obtained coated fabrics can be used for technical textiles and protective textiles. However, for cotton fabrics, the high UVA and UVB transmission values of coated (A2 and A6) samples show that these fabric samples would not provide sufficient protection. The effective UVR transmission range for the claimed protection category is given in Table 2.

The UPF values are 8.22 and 6.99 for A2 and A6 cotton fabrics and 50+ and 50+ for B2 and B6 polyester fabrics respectively. It is observed that the UPF value of both cotton and polyester fabrics coated with pumice stone provide better protection than the uncoated fabric samples. On the other hand, B2 and B6 polyester fabrics provide excellent protection, and the UPF value increases proportionally with the pumice concentration.

The chemical composition analysis from the EDS spectra shows uniform distribution of aluminium, silicon and potassium elements on the fabric surface. The difference between 3% and 15% pumice coating is evident in both fabric types, as reflected in the EDS spectra (Table 4). It is observed that pumice has a high validity of SiO_2 and Al_2O_3. The increase in their values is compatible with the elemental analysis of the fabric surface coated with pumice stone.

In addition, SEM images of the samples reveal that the coated surfaces are homogeneously covered, and the fibres observed in the raw samples are covered with micronized pumice-added material (Fig. 5).

Table 4 — Chemical component analysis results of sample fabrics

Fabric	% C	%O	%Al	%Si	%K	%Na
A0	54.94	45.06	-	-	-	-
A2	73.49	25.96	0.13	0.37	0.05	-
A6	75.55	21.84	0.49	1.57	0.16	0.39
B0	70.48	29.52	-	-	-	
B2	75.97	23.43	0.17	0.42	-	-
B6	76.00	21.12	0.59	1.75	0.19	0.35

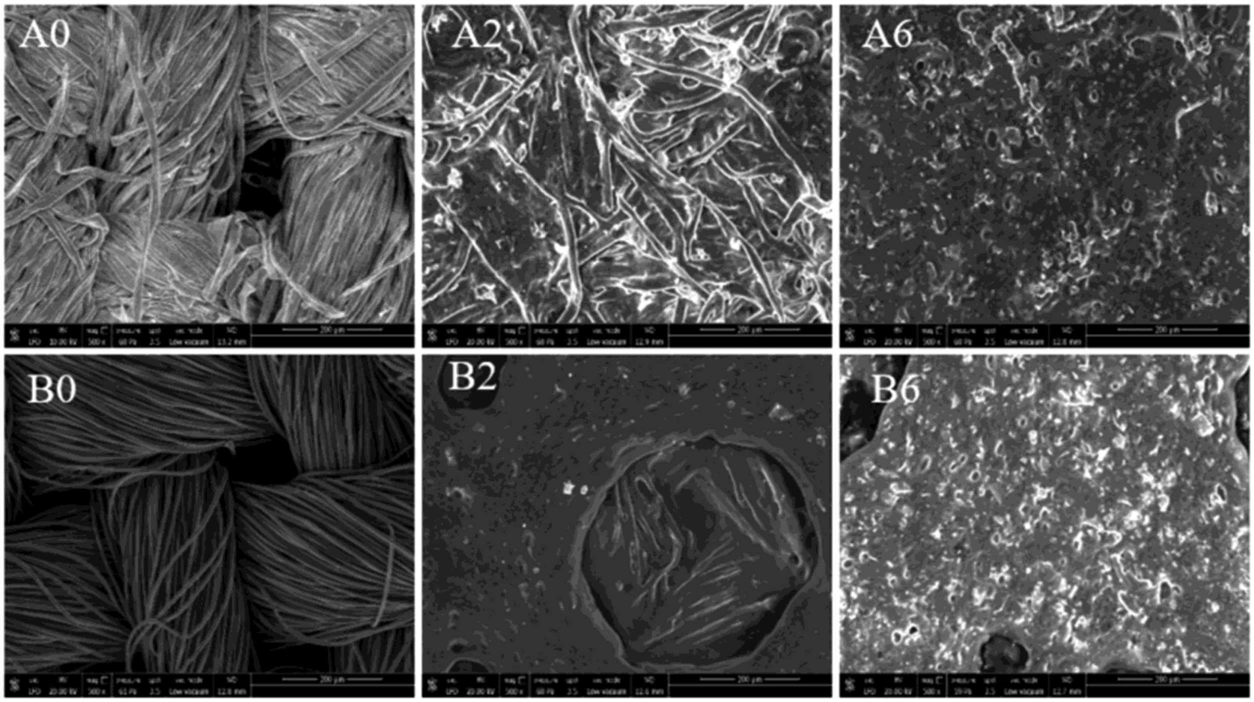


Fig. 5 — SEM images of cotton and polyester fabrics (A0–Untreated cotton fabric, A2–Cotton fabric coated with 3% pumice, and A6–Cotton fabric coated with 15% pumice; and B0–Untreated polyester fabric, B2–Polyester fabric coated with 3% pumice, and B6– Polyester fabric coated with 15% pumice)

Fig. 6 — Contact angle measurement values

When the cohesive force between a liquid and its molecules is less than the adhesion force, the liquid adheres to the solid and wets the solid. If there is a decrease in surface tension, the wetting property of the liquid increases. The contact angle value is used to determine this feature[21]. The contact angle is a measure that numerically indicates the amount of solid material wetted by the liquid. If the contact angle is less than 90°, the liquid wets the surface and this surface is defined as hydrophilic. At a contact angle greater than 90°, the liquid does not wet the surface and this surface is defined as hydrophobic[22]. Their finding shows that the cotton fabrics are hydrophobic, with the highest contact angle value for 3% pumice coated fabric (Fig. 6).

Although the contact angle value increases in polyester samples due to the pumice coating, these fabrics still show hydrophilic properties. In the untreated polyester fabric, the contact angle could not be measured and full spreading is observed. The highest contact angle is obtained with 3% pumice on both cotton and polyester samples. Since the pumice material alone has a water absorption value of 18.75%, it is observed that the water repellency and contact angle values decrease as the pumice ratio increases.

4 Conclusion

In this study, pumice has been used for coating with different concentrations (3, 6, 9, 12 and 15%) of cotton and polyester. The experimental analysis results are examined. The pumice material has a high ratio of SiO_2 and Al_2O_3, which is also revealed by the positive effect in all experimental results. A significant delay is observed in the burning time of both cotton and polyester fabrics coated with pumice as compared to raw fabrics. It is also observed that the flame retardant properties of the cotton fabric coated with 15% pumice change positively. In addition, the UPF value of polyester fabrics coated with pumice provides excellent protection, making them suitable for protective textiles.

The findings show that the use of pumice stone will be efficient in the production of fire-retardant fabrics. These data will also be the basis for studies on technical and protective textiles.

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