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Improvement of the mechanical and thermal properties of polyester nonwoven fabrics by PTFE coating

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Abstract: Polyester (polyethylene terephthalate) is one of the most widely used polymers in textiles. Despite all the advantages of this polymer, its low thermal resistance limits its use in filters and protective textiles. On the other hand, polyester nonwovens are used in many products as wipes, filters, and padding. The surface properties of polyester nonwovens are often not perfect for a specific application and need to be modified. Different ways, including coating, have been developed to modify their surface properties. Therefore, in the present study attempts were made to investigate the improvement of the thermal resistance of a polyester nonwoven by coating. A polytetrafluoroethylene (PTFE) coating was applied to improve the thermal and flame resistance of this fabric. The mechanical properties of coated samples were examined as well. According to the results, surface coating using PTFE is effective in terms of flame retardancy and controlling the thermal shrink of polyester nonwovens. The mechanical properties of the coated samples were also improved.

Key words: Polyester nonwoven, PTFE coating, thermal resistance

1. Introduction

The global growth of the nonwoven industry is very fast and nonwovens are used in many products such as wipes, filters, and padding. The surface properties of nonwovens are very important in their applications. However, their surfaces are often not suitable for a specific application. Industrial applications of nonwovens are limited by the intrinsic properties of their fiber-forming polymers. Different ways, including coating, have been developed to modify the surface properties of nonwovens.

Polyethylene terephthalate (PET) is one of the most important synthetic polymers due to its excellent properties and wide range of uses in the manufacturing of fibers and nonwoven textiles.^{1,2}

PET, with its semicrystalline structure, has high-value physical properties, like fatigue resistance, rigidity, and dimensional stability, and high-value mechanical properties.^{3,4} The chemical properties of PET make it easily flammable. Various techniques, such as making composites and nanocomposites, coating, and grafting, have been used to produce flame-retardant polymers.⁵ The thermal properties and flammability of polymers can determine their applications. Consequently, many studies have investigated these properties of polymers.^{6–8}

Several methods and manufacturing stages may be needed to add flame resistance to PET textiles. Fire-retardant comonomers, nonreactive fire-retardant additives, surface treatments, chemical grafting, and finishing (coating, printing, dyeing, etc.) are the main methods to produce a fire-retardant textile.⁹ Evaluations of flame retardancy involve many aspects, such as ignitability, fire spreading rate, development of heat, toxic

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gas and smoke, afterglow, and dripping.¹⁰ The flame-retardant materials added to PET polymers during the melt spinning stage must be able to tolerate 260–300 °C in a specific period of time.¹¹ The efficiency of a flame-retardant agent may differ according to polymer type, polymer processing conditions, and so on. It must preserve the polymer's properties as well.¹² One of the most important issues in the use of flame-retardant agents is environmental concerns.¹³

Polytetrafluoroethylene (PTFE) is a well-known flame-retardant agent. It has been widely used in various coated textiles. Although its use is not cost-effective, it is a popular solution for coating textiles and other applications. PTFE has distinct advantages including high resistance to UV radiation, oxidation, and weathering. Moreover, its use is common as a nonstick material, especially in long-term clean surfaces. Its use in a wide range of temperatures is one of the most important properties of PTFE that has made it profitable.¹⁴ PTFE is also a polymer with high-value properties such as resistance to a variety of chemical solvents, a low friction coefficient, and biocompatibility.¹⁵

Zhu et al. produced PTFE nanofibers by an electrospinning process using liquid PTFE dispersion and a small amount of polyvinyl alcohol (PVA) (PTFE/PVA = 5:1) during heat treatment.¹⁶

Xiong et al. also produced PTFE nanofibers using PVA and PTFE emulsions (PTFE/PVA = 70:30) by electrospinning. They reported that the content of PVA must be kept to a minimum to ensure fiber formation.¹⁷

Dong et al. used polyvinylidene fluoride (PVDF) and PTFE polymers to produce a waterproof surface through electrospinning on a porous surface. PVDF was dissolved in a solution containing dimethyl acetamide (DMAC) and acetone, and then different PTFE percentages were added. The results indicated that increasing the amount of PTFE produced a better waterproof effect.¹⁸

Nagi et al. designed a device for PTFE coating. PTFE particles are dispersed in Freon and then sprayed onto the substrate. Since Freon is so volatile, before the particles arrive at the substrate it evaporates. In this way, pure PTFE remains in the form of a bulky layer with a density of about 1.7 g/m on the surface.¹⁹

In order to produce superhydrophobic surfaces, Burkarter et al. employed the electrospray technique to deposit PTFE films on fluorine containing titanium oxide (FTO)-coated glass slides. The results show that the PTFE liquid suspension on a hot surface creates a nanoscale structure. Since PTFE has a fluorine group, it has a low energy level and, as a result, adds hydrophobicity to the surface.²⁰

Due to these properties mentioned, using PTFE for surface modification needs highly reactive materials or methods like plasma radiation.^{21,22} An alternative technique to use PTFE's low flammability is to coat it on the target surface as a shell. PTFE nanoparticle dispersion coatings can also be used to protect polymers.²³ While PTFE presents distinct merits, it also has some remarkable disadvantages that could affect human safety and health. These harmful characteristics of PTFE dust include eye or skin irritation. Temperatures higher than 300 °C cause polymer fume fever, which is a temporary condition with flu-like symptoms and eye and respiratory irritation. Temperatures higher than 400 °C lead to thermal decomposition of fluorinated thermoplastics and may release carbonyl fluoride, which hydrolyzes to hydrogen fluoride and carbon dioxide by reacting with moisture in the air. Thermal decomposition products may also include carbon monoxide and oxides of sulfur (Safety data sheet of Fluorofab®(antistatic black PTFE-coated glass fabrics), Green Belting Industries Limited, 381 Ambassador Drive, Mississauga ON L5T 2J3, Canada).

In the present study, coating PTFE on PET nonwoven fabrics was investigated by spraying a PTFE nanoparticle dispersion on fabrics followed by heat fixation. The aim was to produce a flame-retardant PET fabric for industrial use.

2. Results and discussion

Uncoated and coated specimens were tested in vertical flame tests. In this experiment, the burn length was studied. The results showed that the burn length of the coated specimens was about 10% lower compared with the uncoated samples. The average length of burning for the coated samples was 1.9 cm and for the uncoated specimens it was 2.1 cm. Due to the relatively low weight ratio of the one-sided surface coating on layers, it seems that the coating had a significant effect on reducing burn length. Figure 1a shows the uncoated sample and Figure 1b shows the coated sample after the vertical flame tests.

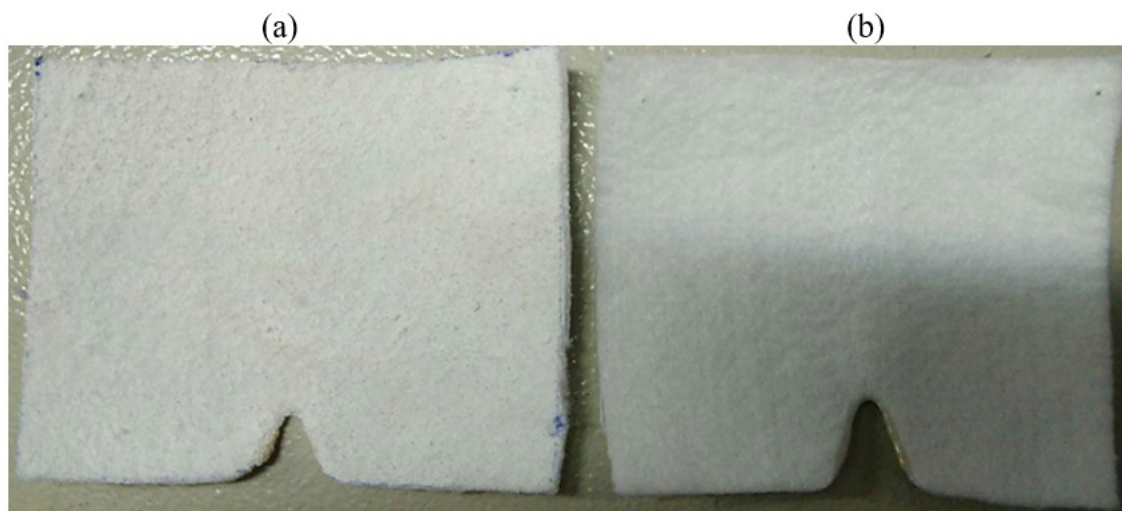


Figure 1. The burn lengths of polyester layers: (a) coated, (b) uncoated.

The 10×10 cm samples were placed on a hot plate at $160\text{ }^{\circ}\text{C}$ to investigate their thermal deformation. Figure 2 shows the dimensional variation in the samples over time. The thermal shrinkage of the coated samples was nearly constant after 5 s, while the uncoated samples shrunk and lost their original shape completely.

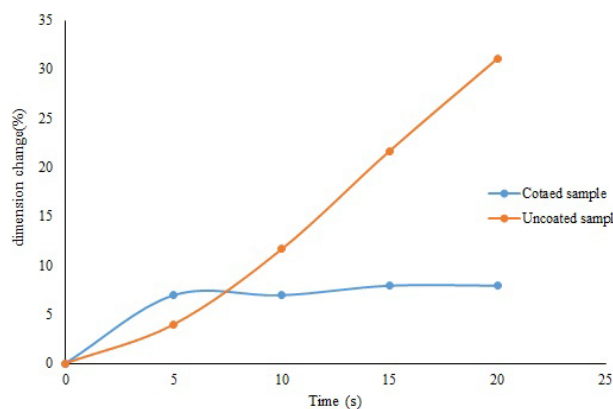


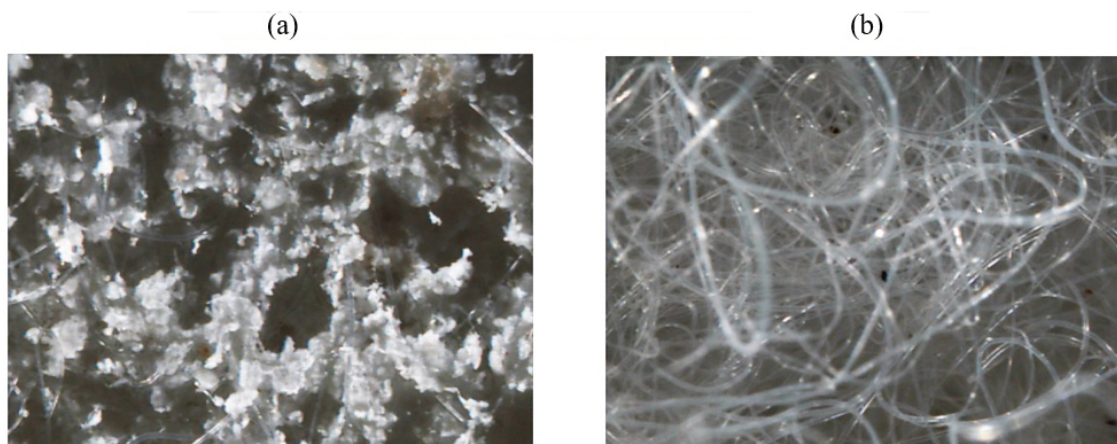
Figure 2. The percentage of thermal shrinkage over time.

Specimens were also subjected to surface flame testing. Table 1 shows the variation in the dimensions of 8×8 cm uncoated and coated samples over time. As shown in this table, the coated specimens had less dimensional losses over time, and their dimensional changes stopped after 20 s. The coated samples were not pierced over 80 s, while the uncoated samples were pierced and destroyed in 10 s.

Table 1. The surface flame test results.

Time (s)	Samples' dimensional changes			
	Uncoated	CV%	Coated	CV%
0	8 × 8 cm	0	8 × 8 cm	
10	7.5 × 8 cm	4	7 × 7 cm	4.5
20	7 × 7.5 cm	3.3	Sample was perforated and damaged	-
30	7 × 7.5 cm	2.6	-	-
40	7 × 7.5 cm	3.1	-	-

Figure 3a shows images of uncoated layers and Figure 3b shows PTFE coated layers. Figure 3b shows a uniform surface coating of PTFE particles.

**Figure 3.** Nonwoven surface: (a) uncoated, (b) coated.

The air permeability of the coated fabrics and the tensile properties of the samples were measured by Shirley air permeability apparatus (MO215 type) and Instron Testing Machine (TM-SM model), respectively. An Instron jaw speed of 1.7 mm/s was used for testing 10 samples with 15 × 2.5 cm dimensions. A bending length test was also carried out by a Shirley instrument based on cantilever beam principals and on 10 samples with 15 × 2.5 cm dimensions.

Uncoated and coated specimens were subjected to air permeability, strength/elongation, and bending tests. The results are shown in Table 2.

Table 2. The effect of PTFE coating on the properties of layers.

Specimens	Strength (MPa)	Elongation (%)	Bending length (cm)	Air permeability mL/s
Uncoated	7.1	90.6	5.1	173
CV%	4.3	2.7	4.8	3.3
Coated	8.2	98.8	4.7	70
CV%	5.6	3.6	7.5	5.5

The results show that the addition of PTFE to the layers' surface reduces the air permeability of samples.

That is a normal occurrence in the field of coated nonwoven layers. The air permeability of Nomex-coated nonwovens, which are currently used in local industries, was also tested and 70 to 80 mL/s was obtained. Therefore, the air permeability of the PTFE-coated samples is in the range suitable for industrial application.

The strength and elongation tests indicated improvement of mechanical properties by PTFE surface coating. Strength and elongation were increased 17% and 9%, respectively. The increasing elongation can be explained by the changes in the fibers' shape due to the high temperature. These changes can be associated with reduced rates of orientation and crystallinity. Increased strength can also be the result of increased fiber contact in the nonwoven fabric substrate and the greater involvement of the fibers through the presence of a PTFE layer.

The bending length was reduced by 8%, but this did not have any significant effect on the flexibility of the samples. The heat setting of PTFE particles on fabric decreases fiber orientation, on the one hand, and the increase in the specific weight of the samples due to the presence of PTFE, on the other hand, can explain the reduction in bending length.

3. Conclusions

It is not possible to dissolve PTFE in conventional solvents, and only its particles can be separated in acetone. In this research PTFE was used to coat polyester nonwoven layers. One side of the layers was coated by spraying an acetone/PTFE powder suspension followed by thermal plate heating to create a connection between the layers and PTFE particles. A smooth and uniform coating was created.

The coated layers exhibited good air permeability and an increase in strength, elongation, and resistance to heat shrinkage. In addition, the surface flame resistance time was also increased. It seems that this method is useful for increasing the thermal resistance of ordinary polyester nonwoven filters in order to use them in high temperature industries.

4. Experimental

The PET needle bond nonwoven fabrics (350 g/m²) were provided by Nano Fanavaran Khavar Company (Iran). PTFE powder, 0.05–0.5 μm particle size, was purchased from Shandong Dongyue Polymer Material Co. (China). Acetone was purchased from Merck Chemical Co.

PTFE is insoluble in common solvents; thus, the PTFE dispersion was prepared using acetone as a mediator. A uniform suspension was prepared by sonication dispersion method. The suspension contained 30%, by weight, of PTFE particles. A spray was used to deposit PTFE on the PET nonwoven layers. Ironing at 210 °C was applied to fix PTFE particles on the PET nonwoven layers.

The flammability properties of the nonwoven fabrics were determined using a Shirley flammability tester (M233A type) according to ASTM D6413-99. Samples were also subjected to a surface flame test under the same conditions.

The morphology of products was determined by means of a Projectina microscope (Projectina, Altsttten SG Switzerland) with magnification of 400.

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