Multifunctional Melt-Mixed Ag/TiO$_2$ Nanocomposite PP Fabrics: Water Vapour Permeability, UV Resistance, UV Protection and Wear Properties

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Abstract: This research deals with the investigating the effect of nanoparticles on the various properties of nanocomposite fabrics produced from melt spinning of various blend ratios of prepared masterbatch containing Ag/TiO$_2$ nanoparticles. The results revealed that the wear properties of modified fabrics improved as compared to pure fabrics with a trend justified considering modulus or crystallinity of fabrics with opposite effects. About 40% UV protection enhancement has been obtained applying this kind of nanoparticles in the close relationship with the crimp contraction of textured yarns. A considerable improvement in the garment comfort has been recorded for nanocomposite sample containing 1 wt% nanoparticles. The lower permeability at low environment temperature and a higher at higher one, as compared to the pure sample, were obtained using this sample. It is highly interesting that these desirable changes in permeability can be achieved in the range of common environment temperatures (15-35°C) being adapted to the human body requirements. The changing point is about 25°C exactly meeting the body requirements by changing environment temperatures. A UV-induced solid state nanocomposite interaction increasing wear properties of UV-irradiated nanocomposite fabrics has been discovered.

Keywords: Masterbatch, UV-induced solid state nanocomposite interaction, Fabric comfort, Melt spinning, Abrasion resistance

Introduction

Polypropylene fibers are one of the most widely used synthetic fibers in textile industry especially considering their various application fields. In fact, some advantages of this fiber type, including cheapness, lightness and high chemical strength have made it suitable for many demands such as carpets, automotive interior trim, films, packaging, cover stock, cables, napkins, wipes, and so on [1]. However, PP applications are limited because of its low UV resistance [2]. In addition, one of the weak spots of knitted fabrics is their low abrasion resistance. Relatively low vapor permeability also limits the comfort of PP fabrics. Consequently, this paper has focused on the investigation of wear properties, UV resistance, water vapor permeability and UV protection properties of melt mixed PP knitted nanocomposite fabrics.

Film and fiber processing are the most difficult polymeric molding procedures. Most of the works on producing PP nanocomposite yarns have been limited to low speed spinning, with laboratory machine and/or producing thick monofilament as spun yarns. Toshiwal et al. [3] have produced clay/PP yarns with the take up speed of 31 m/min and evaluated their dyeability. Razamahefa et al. [4] have investigated the dyeing properties of clay/PP nanocomposite yarn produced with the low speed spinning and final linear density of 2000 dtex. Pavlikova et al. [5] have investigated rheological and morphological properties as well as tensile strength of clay/PP nanocomposite yarns produced with the take up speed of 150 m/min. Producing monofilament of bicomponent PP/Ag nanocomposite as-spun yarns and investigating their morphological and antibacterial properties have been reported by Yeo et al. [6]. Erdem et al. [7] have reported the UV protection properties of produced TiO$_2$ nanocomposite yarns. However, measuring the UV protection over yarns cannot be sufficiently accurate. Therefore, producing fabric can provide more suitable conditions. With respect to the fact that producing nanocomposite multifilament yarns via a pilot plant or an industrial process is required for preparing the fabrics [8], the effect of nanoparticles on the mentioned properties of fabrics made of fine nanocomposite multifilament yarns has not been reported in the literature as far as we concern. Therefore, investigating the aforementioned properties of melt mixed nanocomposite fabrics made of continuous fine multifilament nanocomposite yarns has been conducted in this article as a novel research.

Experimental

Materials and Methods

In fact, this research has been started from the modification of polymer powder as a by-product of petrochemical companies [9]. The fabric has been produced in our previous research [9] briefly as follows: Polypropylene (iPP) powder and the Ag/TiO$_2$ nanocomposite powder were premixed and melt blended in a co-rotating screw extruder (Brabender, Germany) for masterbatch preparation. Pure PP fibers and the nanocomposite fibers containing 0.20, 0.35, 0.50, 0.75, 1.00 wt% of silver/TiO$_2$ nanocomposite were prepared...
during melt spinning by an Automatik pilot plant spinning machine (Germany) from mixing of virgin PP granule and concentrated master-batch containing 20 wt% Ag/TiO₂ nanoparticles. All the prepared samples are introduced in Table 1. The drawn samples have been prepared with a Zinser D5203 drawing machine (Germany). The variable draw ratio was used to gain the constant breaking elongation of 50%. The above breaking elongation was selected to be suitable for further texturing. A Scragg-Shirley minibulk false-twist texturing machine (England) was employed with the heater temperature of 150°C, draw ratio of 1.07, texting speed of 100 m·min⁻¹ and applied twist of 2953 tpm. A full characterization of as-spun, drawn and textured yarns (including morphological properties (SEM), density-based crystallinity, thermal analysis (DSC), linear density, tensile and mechanical properties, shrinkage, crimp properties, etc. has been reported, in parallel with their bioactivity, in our previous paper [9]. A three-ply textured yarn, made of the three textured bobbin yarns, of each full-defined sample was finally weft knitted on a single circular knitting machine operating 120 needles with 8.9 cm (3.5 inch) diameter to prepare each fabric sample.

Characterization

A martindale abrasion tester machine was employed to measure the resistance of fabric samples to abrasion, according to ASTM D4966. Water vapor permeability (WVP) of prepared pure and nanocomposite fabrics evaluated according to ASTM (E 96-80B) [10].

Evaluating the color changes of wool fabrics dyed by a highly UV sensitive dye (0.5 % (owf) Methylene Blue) supported by pure and nanocomposite produced fabrics under UV irradiation was considered to compare the UV protection properties of samples [11,12]. The dying of wool fabrics was performed in the dye baths including 0.5 % (owf) Methylene Blue using a 40:1 liquor ratio. The fabrics were performed in the dye baths including 0.5 % (owf) Methylene Blue using a 40:1 liquor ratio. The dying of wool fabrics under UV irradiation was considered to compare the UV supported by pure and nanocomposite produced fabrics [10].

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Weight percentage of nanoparticles (Ag/TiO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP0</td>
<td>0.00</td>
</tr>
<tr>
<td>NP0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>NP0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>NP0.5</td>
<td>0.50</td>
</tr>
<tr>
<td>NP0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>NP1</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 1. Introducing of produced samples

The results revealed that nano-filler improved the wear properties of the modified fabrics as compared to the pure temperature. UVC irradiations were provided by UVC lamp (G30T8 TUV3 foot 30W germicidal UVC30) located 10 cm above the covered samples for 8 h. After UV irradiation the color changes were studied based on reflectance data using a Color Eye7000A Spectrophotometer. ∆E% was calculated according to equation (1).

\[
\Delta E(\%) = \left[ \left( \frac{\Delta E_p - \Delta E_C}{\Delta E_p} \right) \times 100 \right]
\]  

(1)

Where \( \Delta E_p \) and \( \Delta E_C \) are color differences of each wool fabric supported by pure and composite samples, respectively which are calculated according to equation (2).

\[
\Delta E_{Pure} = \left[ \left( L_0 - L_{Pure} \right)^2 + \left( a_0 - a_{Pure} \right)^2 + \left( b_0 - b_{Pure} \right)^2 \right]^{0.5}
\]  

(2)

Briefly, \( L_g \) has been evaluated as the hank length of reeled yarn after loading of 2 cN/dtex for 10 s. \( L_z \) is the hank length of the reeled yarn after diminishing of the load to 0.01 cN/ dtex for 10 mins. The average of five measurements for each sample has been reported in our previous paper [9].

Results and Discussion

Wear Properties

Weight reduction of samples during the abrasion test has been recorded in Figure 1. The slope of the weight reduction and the number of rubs at the breaking point can be extracted from this figure. These two factors are the desirable criteria for the evaluation of fabric wear resistances. The slope of the weight reduction for each sample equaled the first derivative of weight reduction has been indicated in Figure 1. The number of rubs at the breaking point has been also reported for each sample in Table 2.

The results revealed that nano-filler improved the wear properties of the modified fabrics as compared to the pure...