New Features of Silver/Zinc Loaded Nanocomposite Textiles; Dyeability, Abrasion Resistance and Comfort

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ABSTRACT
This paper investigates the effect of nanoparticles on some new features of silver/zinc loaded nanocomposite fabrics. These fabrics have been fabricated from continuous nanocomposite multifilament yarns produced on a pilot plant melt spinning process with the take-up speed of 2000 m.min^{-1}. According to the results, the dyeability of nanocomposite fabrics with acidic dyes increased as compared to the pure PP. The electrostatic interaction between negatively charged group of acidic dye molecules and positively charged silver nanoparticles can improve dyeability. The results indicated close relationship between the abrasion resistance of fabrics and tensile properties of produced yarns including tenacity, modulus, and rupture work. The results also showed the increasing of the water vapor permeability at temperatures above 25 ^{o}C and decreasing permeability at temperatures below 25 ^{o}C for nanocomposite fabrics containing 0.1 wt% silver/zinc. This simplifies removing of body heat and sweat and consequently offers more comfort for garment, tent, curtain, etc. at temperatures above 25^{o}C. On the other hand, lower vapor permeability at a low temperature protects the body from cool weather through preventing loss of the body heat and weather flow. This nanocomposite fabric can smartly adapt the permeability with human body requirements by changing the environment temperatures.

Keywords: Silver/Zinc; Polypropylene; Dyeability; Acidic dyes; Smart comfortable textiles; Wear properties.

INTRODUCTION

In recent decades, with developing nanocomposites [1-8], nano-silver has found a high level of attraction because of its remarkable antibacterial activity [9-15]. Many investigations have been concerned with synthesized nano-silver of different shapes, sizes and methods [16-19]. Concurrently, polymeric silver nanocomposites have consistently attracted massive research interests. Numerous researches deduced the antibacterial properties of polymeric silver nanocomposites [1, 20, 21]. However, a new approach to investigate the effects of silver nanoparticles on other properties of nanocomposites would be put forward for their manufacturing scale-up and usages [22]. On the other hand, the dispersion of nanoparticles, as well as rheological and morphological properties of nanocomposites are affected by the spinning process conditions like spin line tension, etc. [20]. Therefore, the properties of the produced yarns at low speed spinning, with laboratory machine cannot be considered for high scale production. Consequently, producing fibers through a pilot plant or industrial process and providing desirable fiber to fabric processability is required to achieve an acceptable answer to the raised question. Moreover, exact evaluation of some properties of textiles like dyeability, comfort, wear properties etc. cannot be obtained using yarn especially as-spun yarns. On this basis, providing desirable fiber to fabric processability is necessary for a valuable investigation of these properties. This has been provided through our previous research [23]. In this research, the full characterized silver/zinc nanocomposite multi-filament yarns were used to produce the fabrics and investigate their properties including dyeability, abrasion resistance and water vapor permeability.

EXPERIMENTAL

Materials and Methods

The fabric production performed in our previous research [23] was as briefly follows: Polypropylene (iPP) granule and the silver/zinc masterbatch used to produce yarns containing 0.1, 0.2, 0.4, 0.6 wt% silver/zink nanocomposite as the antibacterial agent (A.A.) Therefore, the samples were termed as A.A. 0.1 to A.A. 0.6. continuous multifilament nanocomposite yarns 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% silver/zink nanoparticles. The samples have been drawn using Zinser D5203 drawing machine (Germany). The variable draw ratio was used to gain the constant breaking elongation of 50%. The mentioned 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 ^{o}C, draw ratio of 1.07, texturing 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, linear density, tensile and mechanical properties, shrinkage, crimp properties, etc. has been reported, in parallel with their bioactivity, in our previous paper [23]. 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. The produced fabrics have been examined in terms of dyeability, abrasion resistance and comfort, in this paper.

Characterization

An SDL International Textile Testing Solutions high temperature dyeing machine was used for dyeing the prepared nanocomposite and pure PP fabrics. The dying has been performed with 5% (owf) acidic dye (BEST acid Red FRILL). Dyeing, rinsing and reduction clearing were performed following Toshniwal et al., [24] but without leveling agent in dyeing bathes. Reflectance data were recorded using a Color Eye 7000A Spectrophotometer under illuminant D65, using a 2° standard observer. The K/S values were calculated according to the Kubelka–Munk Eq. (1) using normalized reflectance data between 0-1.

$$\frac{K}{S}=\frac{(1-R)^2}{2R} \quad (1)$$

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 was evaluated according to ASTM (E 96-80B) [25]. The significance of the discussed changes has been statistically checked by triplicate tests in each experiment and the average values have been reported.

RESULTS AND DISCUSSION

Dyeability

Weak PP dyeability is one of the most important weaknesses of this polymer [26]. Considering the remarkable advantages of this polymer in textile industry including its cheapness, lightness and high chemical strength as well as its wide usages in many demands such as carpets, automotive interior trim, films, packaging, cover stock, cables, napkins, wipes, and so on, in this paper improving PP dyeability by acidic dyes has been investigated as a supplementary feature of its silver/zinc nanocomposites in addition to its antibacterial activity. *Figure 1* shows k/s of pure and nanocomposite yarns dyed by the acidic dyes. As it can be clearly concluded, the dyeability of nanocomposites increased as compared to the pure PP. The calculated values of CV% at the maximum values of K/S for A.A.0-A.A.0.6 were 2.59, 0.36, 1.7, 2.91, and 1.78, respectively. The electrostatic interaction between negatively charged group of acidic dye molecules and positively charged silver nanoparticles can improve the dyeability with acidic dye [22]. Dyeability was improved by increasing silver ratio of yarns. Extra dyeability of sample containing 0.1wt nanoparticles as compared to A.A. 0.2 and A.A. 0.4 can be referred to some structural properties of this sample like decreasing the crystallinity of drawn yarns with variable draw ratio and increasing the crimp contraction of textuered yarns of this sample [23].

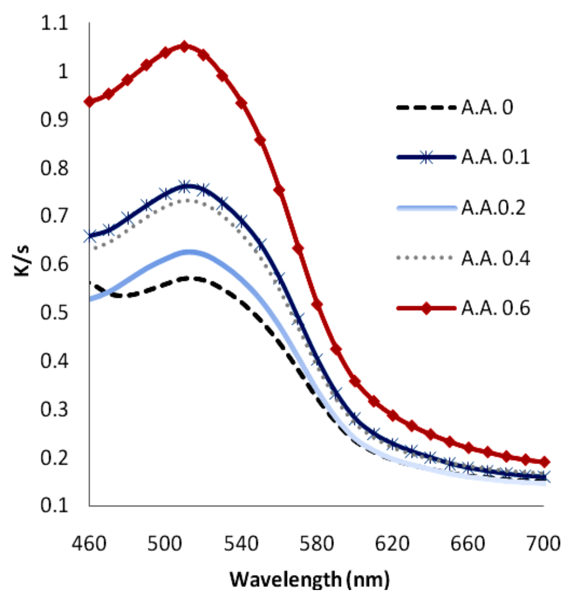

FIGURE. 1. Dyeability of pure and silver/zinc loaded fabrics.

Crystallinity of as-spun, drawn yarns with constant draw ratio and drawn yarns with variable draw ratio have been measured and reported in our previous paper [23]. 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. Then, the drawn yarns with variable draw ratio were used in texturing and fabric production. Therefore, the trend of crystallinity of drawn yarns with variable draw ratio has been considered for discussion about fabric dyeability.

Abrasion Resistance

One of the weak spots of knitted fabrics is their low abrasion resistance [27, 28]. Possibility of the improvement of PP abrasion resistance using silver based particles has been investigated in this section. Weight reduction of samples during the abrasion test has been recorded in *Figure 2*. 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 appropriate criteria for the evaluation of fabric wear resistance. The slope of the weight reduction for each sample, equaled the first derivative of weight reduction, as indicated in *Table I*. According to the results, the improvement of abrasion resistance in the case of A.A. 0.2 is more than A.A. 0.6. This trend of abrasion resistance was completely in agreement with the trend of tensile properties of the loaded yarns. In fact, tenacity, modulus, and rupture work of textured yarns containing 0.2 wt% particles is more than 0.6wt% particles (*Figure 3*). The broken point recorded for this sample is about 2.5 times greater than the pure sample which means 133% improvement of abrasion resistance by using 0.2 wt% particles. The rate of weight reduction of samples changed from 2×10^{-5} for this sample to 5×10^{-5} for pure sample. Consequently, the rate of weight reduction of pure sample is 2.5 times faster than that of the nanocomposite sample.

Water Vapor Permeability

Low vapor permeability also limits the comfort of PP fabrics [28]. Consequently, this section has focused on the investigation of the effect of loaded silver/zinc particles as antibacterial agent on the water vapor permeability of the produced yarns. *Figure 4* shows the water vapor permeability of pure and nanocomposite samples after 4 hr. versus environment temperatures. As shown in this figure, at high environment temperatures, the maximum permeability has been recorded for nanocomposite sample containing 0.1 wt% nanoparticles.

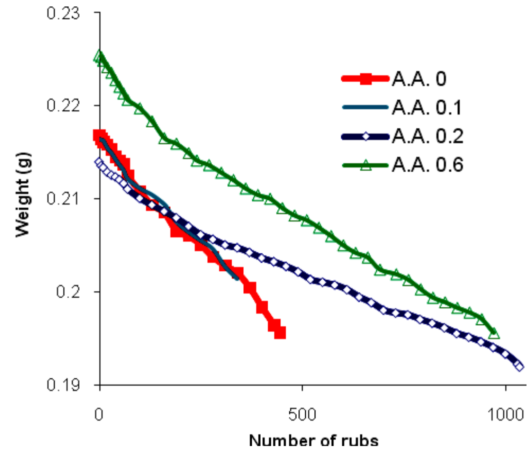

FIGURE 2. The weight reduction versus number of rubs.

TABLE I. Wear properties of samples.

Sample Code	The Weight Reduction Speed (g/Rub No.)	The Number Of Rubs At The Breaking Point	CV%
A.A. 0	5×10^{-5}	445	2.81
A.A. 0.1	4×10^{-5}	340	3.31
A.A. 0.2	2×10^{-5}	1035	1.19
A.A. 0.6	3×10^{-5}	970	0.91

According to the results, the permeability of this sample at 22°C is about 11.2% lower than the pure PP. By rising temperatures, the rate of increasing vapor permeability for this sample has been increasingly enhanced. When temperatures changed from 22-30°C, about 122% enhancements in permeability was recorded for the nanocomposite sample as compared to only 21% for pure pp fabrics. Similarly, by increasing the temperatures to 35°C the improvement of the permeability was 220% for the nanocomposite sample while 130% for pure PP. According to statistical analyses, the differences between pure PP and nanocomposite containing 0.1 wt% silver/zinc nanoparticles were statistically significant in all considered temperatures except 25°C. CV% values for pure sample were 2.34, 1.46 and 2.87, and for A.A.0.1 were 4.03, 1.77 and 1.86 at temperatures of 22, 30 and 35°C, respectively.

Increasing the permeability at temperatures above 25°C simplifies removing the body heat as well as sweat and consequently offers more comfort for garment, tent, curtain, etc. The lower vapor permeability at temperatures lower than 25°C protects the body from cool weather through preventing loss of body heat and weather flow. Therefore, the lower permeability at low temperature, and the higher at higher one can provide more comfortable textiles.

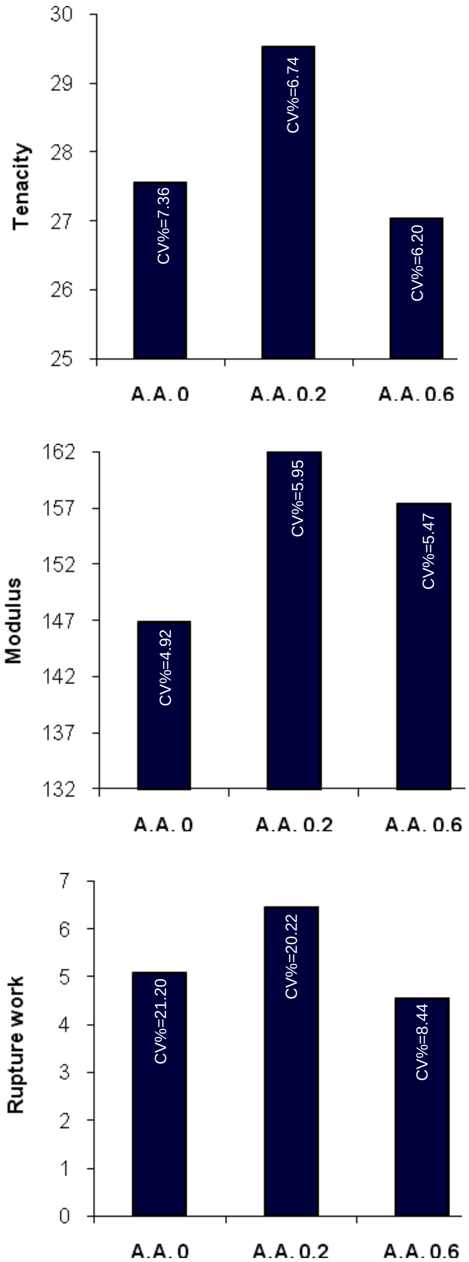

FIGURE 3. The trend of tensile properties of textured yarns [23].

It is highly interesting to notice that the changing point is about 25°C, exactly meeting the body requirement by changing environment temperatures, which is really a worthwhile achievement. Consequently this nanocomposite sample can provide more comfortable textile for different applications such as garment, tent, curtain, etc.

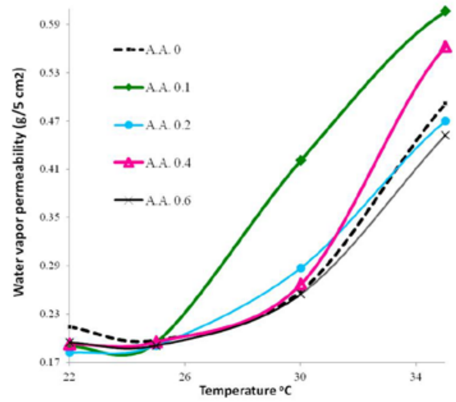

FIGURE 4. The water vapor permeability of fabrics versus environment temperatures.

It is also interesting to point out that the similar result has been achieved by using Ag/TiO_2 nanoparticles by a slight shift in the changing point (about 27°C) in our previous study [28]. However the amount of Ag/TiO_2 nanoparticles was more than silver/zinc nanoparticles to obtain the optimum. Inorganic nanoparticles are impermeable materials. At a low temperature nanoparticles may act as a barrier and prevent permeability. Nanoparticles can also limit the movement of polymeric chain because of steric hindrance of particles against chain motion [29]. Increasing kinetic energy at a high temperature can compensate this effect. Therefore, at a high temperature decreasing crystallinity caused by nanoparticles can be effective as a key factor which leads to the increase of the amorphous regions and hence, the permeability [28]. The drawn yarns with variable draw ratio as the feed yarns for texturing and fabric production had the least crystalinity using 0.1wt% silver/zinc nanoparticles as reported in our pervious study [23]. Moreover, changes in yarn properties such as linear density, crimp contraction, etc., and thus fabric structures such as cover factor can also be effective. The associated effect of all mentioned factors led to this improvement of permeability for the sample containing 0.1wt% silver/zinc nanoparticles in this study.

CONCLUSION

The effect of nanoparticles on some new features of zinc/silver loaded nanocomposite fabrics as antibacterial textiles has been investigated. The fabric was produced of continuous fine multifilament nanocomposite yarns spun at 2000 m/min on a pilot plant scale with a remarkable potentiality for mass production. The results revealed the improvement of dyeability of nanocomposite fabrics as compared to pure PP through the electrostatic interaction between negatively charged groups of acidic dye molecules and positively charged silver nanoparticles. Abrasion resistance of modified fabrics improved as compared to pure fabrics with a trend justified considering the tensile properties of the silver/zinc loaded yarns including tenacity, modulus, and rupture work of textured yarns used to produce fabrics. A considerable improvement in the garment comfort has been recorded for nanocomposite sample containing 0.1 wt% antibacterial agent. The lower permeability at low environment temperature and the higher at higher one, as compared to the pure sample, achieved using this sample. It is highly interesting that these desirable changes in permeability can be achieved in the range of common environment temperatures being adapted to the human body requirements. The changing point is about 25^{o}C exactly meeting the body requirements by changing environment temperatures. Then, this nanocomposite fabric can smartly adapt permeability with human body requirements by changing the environment temperatures. In this way, the fabric improves the comfort of textiles for different applications such as garment, tent, curtain, etc.

ACKNOWLEDGEMENTS

Incorporation of Ciba Co. Switzer-land, for kindly providing nanoparticles is highly appreciated by the author.

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