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Processing and Properties of Nanocomposite Filament Yarns with Various Filler Concentrations from Two Different Modification Methods

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Summary: In this research, the possibility of producing and processing nanocomposite polypropylene filament yarns with permanent antimicrobial efficiency has been assessed by comparing two different methods. Therefore two approaches were used to mix various blending contents of antimicrobial agents based on silver/TiO_2 nano particles with PP: 1) mixing of PP powder and inorganic nanocomposite powder as an antibacterial agent with the appropriate concentration in a twin screw extruder, preparing modified granules and feeding them to the melt spinning machine, 2) producing masterbatch by a twin screw extruder and blending it with PP in the melt spinning process. In both methods, pure PP and all other combined samples had an acceptable spinnability at the spinning temperature of 240 °C and take-up speed of 2000 m/min. After producing as-spun filament yarns by a pilot plant melt spinning machine, samples were drawn, textured and finally weft knitted. Physical and structural properties of as-spun and drawn yarns with constant and variable draw ratios were investigated and compared. Moreover, the DSC, SEM and FTIR techniques have been used for samples characterization. Finally antibacterial efficiency of knitted samples was evaluated. The experimental results indicated that the maximum crystallinity reduction of modified as-spun yarns reached 5%. But by applying method 2 (masterbatch), crystallinity of modified as-spun yarns remained unchanged compared to pure yarn. However, drawing procedure has compensated this difference. By applying the second method, the drawing generally improved the increase of tenacity and modulus of modified fibers, whereas in method 1 the opposite effect was noticed in the case of constant draw ratio. Although the biostatic efficiency of nanocomposite fibers was excellent in both methods, modified fabrics obtained from method 1 showed higher bioactivity.

Keywords: Ag/TiO_2; antibacterial; filament yarns; method of processing; nanocomposite

Introduction

Method of processing is a very important and critical variable in the production of nanocomposites. It acts as an important factor on dispersion and distribution of nanoparticles, interface interaction, microstructure and properties of nanocomposites.[1,2]

A broad range of micro-organisms coexists in a natural equilibrium with human body and living environments, but a rapid and uncontrolled multiplication of microbes can seriously lead to three undesired effects. The first of these is the degradation phenomena like coloring, discoloration and deterioration of fibers. The second one is the production of unpleasant odor and the third, which is the most significant effect, is an increase of potential health risks.[3–5]

Conventional fibers and polymers not only do not show any resistance against

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micro-organisms and materials generated from their metabolism but also they are most common materials for accumulation and proliferation of micro-organisms into the surrounding environments. In fact, several factors such as suitable temperature and humidity, presence of dust, soil, spilled food and drinks stains, skin dead cells, sweat and oil secretions of skin glands, and also finishing materials on the textile surfaces can make textiles as an optimal enrichment culture for a rapid multiplication of micro-organisms.[5]

Polypropylene fiber is one of the most widely used synthetic fibers in textile industry. In fact, some advantages of this fiber type such as cheapness, lightness, high chemical strength and high absorbency have made it suitable for many applications, such as carpets, automotive interior trim, films, packaging, cover stock, cables, napkins, wipes and so on. In particular, it is used for sanitary applications such as surgical masks, diapers, filters, hygienic bands, etc, where antibacterial effects are being sought.[6,7]

Silver is one of the safer antibacterial agents in comparison with alternative organic antibacterial agents that are often avoided because of the risk of their harmful effects to the human body. Silver has been described as being 'oligodynamic' because of its ability to exert a bactericidal effect on products containing silver, principally due to its antimicrobial activities and low toxicity to human cells.[3,8] Its therapeutic property has been proven against a broad range of micro-organisms (over 650 disease-causing organisms in the body) even at low concentrations.[9–11] Silver nanoparticles are a non-toxic and non-tolerant disinfectant.[12] Therefore bacteria do not show resistance against silver. Using silver nanoparticles leads to increasing the number of particles per unit area and thus antibacterial effects can be maximized.[6]

TiO_2 nanoparticles have unique properties (e.g. stable, long lasting, safe and broad-spectrum antibiosis).[9,13–15] Irradiation of anatase titanium dioxide by light with energy more than its band gaps generates electron-hole pairs that induce redox reactions at the surface of the titanium dioxide. Consequently, electrons in TiO_2 jump from the valence band to the conduction band, and the electron $(e^-)$and electric hole pairs (h^+) form on the surface of the photocatalyst. The created negative electrons and oxygen will combine into O_2^-, the positive electric holes and water will generate hydroxyl radicals. Ultimately, the produced various highly active oxygen species can oxidize organic compounds of cell to carbon dioxide(CO_2) and water (H_2O). Thus titanium dioxide can decompose common organic matters in the air such as odour molecules, bacteria and viruses.[16,17] Moreover, many investigations confirm that the addition of noble metals such as gold and silver (as well as what used in this research) increases the photocatalytic efficiency of titanium dioxide.[16] In addition, surface coating of nano-silver on titanium dioxide maximizes the number of particle per unit area in surface in comparison with using equal mass fraction of pure silver.

This research has been started from the modification of polymer powder as a common by-product of petrochemical companies. The processability of these starting materials prepared by two different methods and the characteristics of produced samples (fiber to fabric) have been investigated. Finally, the microbiological efficiency of the produced fabric has been further studied.

Experimental Part

Materials

Isotactic polypropylene powder, supplied by Navidzarchimie petrochemical company, Iran, was used as a polymer matrix for preparation of pure and modified granules in method 1 and preparation of modified masterbatch in method 2.

Isotactic polypropylene granule (SABIC PP 512 MN10), supplied by Sabic, Saudi Arabia, was used for mixing with prepared masterbatch during melt spinning process in

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Table 1.
MFI of the pure PP and modified masterbatch and granules.

Method	Sample	Melt flow index(gr/10 min)
1	Prepared granule of pure pp	26.20
	Prepared granule+0.20wt% filler	25.40
	Prepared granule+0.50wt% filler	24.80
2	Pure PP granule	22.90
	Modified masterbatch	28.10

method 2. The melt flow index (MFI) of this granule has been recorded in Table 1.

-The filler, Nanocid P101, kindly provided by Pars Nano Nasb Research department of Iran Nasb Niroo Co, Iran, is a nanocomposite of anatase TiO_2 with the carrier core coated with 1% wt of nanosilver particles. TiO_2 nanoparticles have a wide range of size under 80 nm and are covered imperfectly by silver nanoparticles having the size under 30 nm as stated by the supplier.

Methods

Two methods were used for preparation of polypropylene nanocomposite filament yarns.

Method 1: Modification of Granules

The development of bacteriostatic nanocomposite filament yarn has been realized in two stages:

- In the first step, the polypropylene powder and antibacterial agent were premixed and melt blended in a co-rotating-screw extruder (Brabender, Germany). Pure PP granules and nanocomposite granules containing 0.20 and 0.50wt% of silver/TiO_2 nanocomposite were prepared. The melt flow index (MFI) of pure and modified granules is reported in Table 1.

- In the second step, pure pp fiber and the composite fibers containing nano-filler were prepared by an Automatik pilot plant melt spinning machine (Germany). This machine has an extruder using two spinning nozzles. Two 36 holes spinnerets of 0.25 mm hole diameter were used for spinning partially oriented filament yarns at a spinning temperature of 240 °C and using a take up speeds of 2000 $m \cdot min^{-1}$.[18]

Method 2: Preparation of Masterbatch

- In the first step, polypropylene powder and the 20wt% silver/TiO_2 nanocomposite were premixed and melt blended in the twin screw extruder at the same conditions used for the granules modification. The melt flow index (MFI) of the prepared masterbatch is reported in Table 1.

- In the second step, melt spinning was carried out from direct mixing of virgin PP granules and the masterbatch obtained in the first stage at the same spinning conditions used in method 1. The same inorganic filler was used for both approaches.

Drawing

The drawn samples have been prepared with a Zinser D5203 drawing machine (Germany) using two different methods.

1– The constant draw ratio ($\lambda = 2.5$).
2– The variable draw ratio (The variable draw ratio was used to gain the constant breaking elongation of 50%) under the same conditions of 1. The above breaking elongation was selected for having a suitable further texturing process.

Texturing

A Scragg-Shirley minibulk false-twist texturing machine (England) was employed at the heater temperature of 150 °C, draw ratio of 1.07, texturing speed of 100 $m \cdot min^{-1}$ and applied twist of 2953 tpm. Textured yarns were finally weft knitted.

Characterization

Density-Based Crystallinity (Structural Analysis)

Density of nanocomposite yarns (ρ_t) has been measured according to ASTM D792

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using mixtures of distilled water and ethanol.

First, The density of matrix (ρ_{PP}) was calculated from equation (1).[19]

$$1/\rho_t = w_f/\rho_f + w_{pp}/\rho_{pp} \quad (1)$$

Where ρ_f is the density of nanocomposite filler, W_f and $W_{pp}$are weight fractions of nanocomposite filler and PP, respectively, $\rho_f = 3.86$ gr/cm^3 was obtained from substituting $\rho_{silver} = 10.5$ gr/cm^3 and $\rho_{TiO_2} = 3.84$ gr/cm^3 in equation 2.[20]

$$1/\rho_f = w_{silver}/\rho_{silver} + w_{TiO_2}/\rho_{TiO_2} \quad (2)$$

Where W_{Tio_2} and W_{silver} are weight fractions of titanium dioxide and silver, respectively.

Finally density-based crystallinity (X_c) was calculated from equation (3).

$$X_c = \left(\frac{\rho_{pp} - \rho_a}{\rho_c - \rho_a}\right)\frac{\rho_c}{\rho_{pp}} \times 100 \quad (3)$$

Where $\rho_a = 0.8576\ g \cdot cm^{-3}$ and $\rho_c = 0.9363\ g \cdot cm^{-3}$ are the density of amorphous and crystalline areas.[21]

Differential Scanning Calorimetry (DSC)

Thermal properties were studied employing a TA Instrument Differential Scanning Calorimeter 2010 (U.S.A) at a rate of 5 °C/min. Crystallinity of studied samples was also calculated using the following equation.

$$X = \left(\frac{\Delta H}{(1 - w_f)\Delta H^*}\right) \times 100 \quad (4)$$

W_f is weight fractions of nanocomposite filler, ΔH refers to the measured melting enthalpy and ΔH^* denotes 100% crystalline polypropylene that equals 209 $J \cdot g^{-1}$.[22]

FT-IR Spectroscopy

The influence of silver/anatase Tio_2 nanocomposite on PP thermal degradation during melt spinning was recorded using a Nicolet FTIR instrument by taking the spectra between 400 and 4000 cm^{-1} at the ambient temperature. Following the work of Aslanzadeh and Haghighat Kish,[23] Rabello and White,[24] Castejon et al.[25] and Carlsson et al.,[26] the unaffected peak by degradation at 2720 cm^{-1}, associated to carbon–hydrogen bonds, was taken as the reference for normalizing the peaks (by dividing each absorbed intensity to the intensity at 2720 cm^{-1}).

Linear Density

The linear density of yarns was determined as an average of five measurements of the weight of 100 m of yarns.

Evaluation of Antibacterial Efficiency

Antibacterial efficiency was expressed according to AATCC 100 that is formulated as:

$$R(\%) = \frac{A - B}{A} \times 100 \quad (5)$$

Where A is the number of bacteria recovered from the inoculated test specimen swatches in the jar after 24 hours incubation with unmodified fiber and B is the number of bacteria according to "A" conditions, but with antibacterial modified fiber. Consequently $R(\%)$is the percentage reduction ratio which indicates biostatic efficiency.

Morphological Properties

The SEM micrographs were obtained by means of a Vega ©Tescan scanning electron microscopy applying 20 KeV acceleration voltage to gain approximately 40000× magnification.

Rheological Measurements

Melt-flow index was recorded as the mass (grams) of molten polymer passing through a fixed capillary under the constant pressure (2.16 kg) at 230 °C for 10 min (according to ASTM D1238).

Tensile Properties

Tensile properties were evaluated by an EMT 3050 tensile tester (Iran). The conditions of measurements were as follows: gage length of 100 mm for as-spun yarns, and 300 mm for drawn yarns, and deformation rate of 500 $mm \cdot min^{-1}$ (according to ASTM D3822-95a). Average values obtained from measurements of 10 samples.

Shrinkage

The shrinkage of as-spun and drawn samples was measured after the heating

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period of 10 min at 130 °C according to DIN 53840.

Results and Discussion

The effect of filler content fraction on the crystallinity of fibers has been summarized in Table 2. Increasing the fraction of antimicrobial agent by applying method 1 resulted in the reduction of crystallinity up to 5%. However, by applying method 2, crystallinity of as-spun yarns remained unchanged compared to the pure PP yarn (see Figure 1). This may be attributed to the better particle dispersion during mixing by the twin-screw extruder. However, after the drawing process, the difference of crystallinity between samples produced by each method was not substantial. It seems that drawing procedure has compensated this difference found at fiber fabrication. The drawing decreased the linear density of filaments. This reduction has resulted in compensating the effect of heat transfer rate difference between pure and modified fibers in method 1. However, dispersion improvement during drawing can cause an inverse result in method 2. In fact, there are several factors that affect the crystallinity, some of them decrease crystallinity, while others can increase and compensate the reduction in crystallinity. First, silver nanoparticles have a high thermal conductivity compared to polypropylene as a non-polar

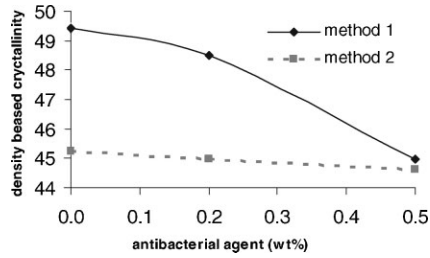

Figure 1.
Density based crystallinity of as-spun yarns.

polymeric matrix. Therefore, these particles can accelerate quenching rate of nanocomposite fiber. This acceleration results in the shorter available time at the temperature in which maximum velocity of crystallization growth can take place. Consequently, the opportunity of crystal growth for PP matrix is limited. Second, the silver may sometimes be a function of nucleating agent (because nanoparticles act as a type of impurities in the PP matrix) which can cause the temperature of maximum crystallization rate to be increased. Fast passing this point can reduce crystallization growth. On the other hand, nucleation effect during the crystallization of PP accelerates crystallization of PP matrix. In fact, increasing the fraction of antimicrobial agent may result in some agglomeration which possibly declines the space resistance of particles against the orientation of polymer chains. The effect of particles on heat transfer rate

Table 2.
Crystallinity, shrinkage, linear density of as-span and drawn yarns.

Method	Sample type Property	As-spun			Drawn C.D.R[1]			Drawn V.D.R[1]		
		0.00 N.A.A	0.20 N.A.A	0.50 N.A.A	0.00 N.A.A	0.20 N.A.A	0.50 N.A.A	0.00 N.A.A	0.20 N.A.A	0.50 N.A.A
1	Crystallinity	49.43	48.52	44.98	52.27	53.60	51.16	50.06	47.49	48.42
	Shrinkage	2.38	2.47	2.98	4.63	4.32	4.40	4.77	5.25	5.96
	L.D[2] (*Tex*)	13.32	14.34	14.32	6.34	6.35	6.29	8.21	7.79	7.85
	Draw ratio	–	–	–	2.500	2.500	2.500	1.922	2.016	2.016
2	Crystallinity	45.23	44.96	44.60	49.56	48.47	48.42	47.86	48.91	46.62
	Shrinkage	2.11	1.75	1.86	4.49	4.48	4.29	4.41	4.25	4.53
	L.D[2] (*Tex*)	14.37	14.43	14.46	6.22	6.27	6.26	8.21	8.39	8.50
	Draw ratio	–	–	–	2.500	2.500	2.500	1.905	1.870	1.849

N.A.A indicates weight percentage of nanocomposite antibacterial agent.
1- C.D.R and V.D.R Indicate drawn yarns with constant draw ratio and variable draw ratio respectively.
2- L.D indicates linear density.

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will be negligible, because of this agglomeration which leads to decrease the specific surface of the particles and also increase their migration to surface.

Due to these contradictory effects or because of low concentration of active filler, the crystallinity of modified as-spun PP fiber produced by applying method 2 has remained unchanged. More reduction of crystallinity of as-spun yarns by applying method 1 may refer to the increasing of particle dispersion during mixing by the twin screw extruder.

After drawing, because of the decrease in the linear density of filaments, the effect of heat transfer rate difference between pure and modified fiber is compensated compared to similar as-spun nanocomposite filament yarn. This phenomenon has resulted in compensating the effect of heat transfer rate difference between pure and modified drawn yarns in method 1. However, dispersion improvement during drawing can cause an inverse result in method 2. Therefore in two aforementioned methods, it was seen poor relationship between the crystallinity changes of drawn yarns.

The measured crystallinity of as-spun fibers based on DSC method showed also the similar trend (slight decrease) to the density based crystallinity (see Table 3 and Figure 2).

In method 1 when ΔHc was used for crystallinity evaluation, this reduction was higher. The evaluation of crystallinity based on ΔHc is independent of polymer history. Consequently, crystallinity reduction of composite fiber can be related to spatial resistance of particles against crystal growth. However, spin line tension may compensate the effect of spatial resistance of particles. Thus reduction of crystallinity based on ΔHm was lower. However by applying method 2 this effect was not observed, because some possible agglomeration could reduce the specific surface and space resistance of particles against the orientation of polymer chains.

SEM was carried out to observe particle dispersion on the nanocomposite filament yarns. The SEM observation showed the nanoparticles have relatively good dispersibility (Figure 3).

As it was expected, the changes in shrinkage of the different samples showed a behavior inverse to the changes observed in crystallinity (Table 2).

In method 1 and 2, the changes of mechanical properties of modified as-spun fibers compared to pure PP fibers produced by the same method were not substantial. Only breaking elongation changes corresponded inversely to the crystallinity variation in method 1 (see Table 4).

For investigating the effect of silver/anatase TiO_2 nanocomposite on PP degradation, FTIR was used. This possible degradation may originate from active oxygen species generated by the catalytic activation of Ag/anatase TiO_2.

Generally this phenomenon can lead to two inverse effects on tenacity: The first is a reduction of molecular weight which can decrease tenacity and the second is obtaining a narrower PDI (polydispersity index) which can increase tenacity. On the other

Table 3.
Thermal and structural properties of as-spun yarns obtained from DSC method.

	N.A.A[1] (wt%)	Melting temperature (°C)	Crystallization temperature (°C)	Melting enthalpy (J/g)	Crystallization enthalpy (J/g)	Crystallinity (%) (X_{Tc})[2]	Crystallinity (%) (X_{Tm})[3]
Method 1	0.00	163.2	121.0	88.94	107.10	51.24	42.56
	0.50	162.5	119.5	85.02	97.26	46.77	40.88
Method 2	0.00	159.8	120.4	92.66	99.58	47.65	44.33
	0.50	160.0	119.0	86.41	94.83	45.60	41.55

1- A.A indicates weight percentage of antibacterial agent.
2- X_{Tc} indicates the crystallinity evaluated by Crystallization enthalpy.
3-X_{Tm} indicates the crystallinity evaluated by Melting enthalpy.

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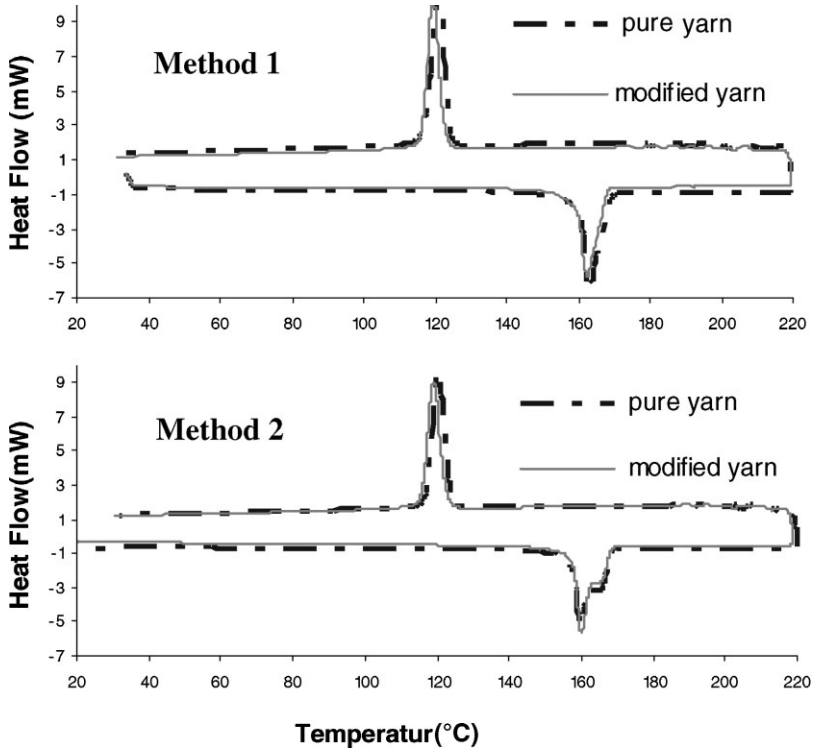

Figure 2.
DSC diagram of as-spun yarns. Modified yarns in this figure contain 0.50wt% of nanocomposite antibacterial agent.

hand degradation phenomenon in backbone of chain (C–C bond) can cause two other possible effects. First, generation of free radicals that can migrate to the surface during usage in form of cloths and display some health risks for people. Second, generated free radicals can act as active sites for attachment of nanoparticles to polymer and enhance compatibility. The ideal condition occurs when free radicals are generated on the branch of chain (C–H or C–C bond). Consequently the increasing of compatibility would be obtained without any risk of health care. However, the FTIR observation did not show noticeable influence of silver/anatase TiO_2 nanocomposite on PP degradation (see Figure 4).

The influence of the draw ratio on the tensile properties has been summarized in Table 4. Generally the changes of tensile properties for the sample comprising 0.20wt% of nano-filler were not significant in method 1. Consequently, changes of tensile properties of this sample have not been discussed.

By applying method 2, generally the drawing process improved the increase of tenacity and modulus of modified fibers, whereas in method 1 an opposite response was noticed in the case of constant draw ratio. In method 2, applying variable draw ratio has improved the increase of tenacity and modulus of modified fibers in comparison with pure PP sample. By applying higher draw ratio, (drawing with constant draw ratio) this effect has enhanced. Therefore it can be concluded that the drawing can increase the particle dispersion and improve tensile properties. Increasing modulus and tenacity can be justified with the mechanism of energy dissipation via voiding, dewetting phenomena, chain slippage, increasing the length of crack path (zig-zag route) in polymer/filler composite.[27]

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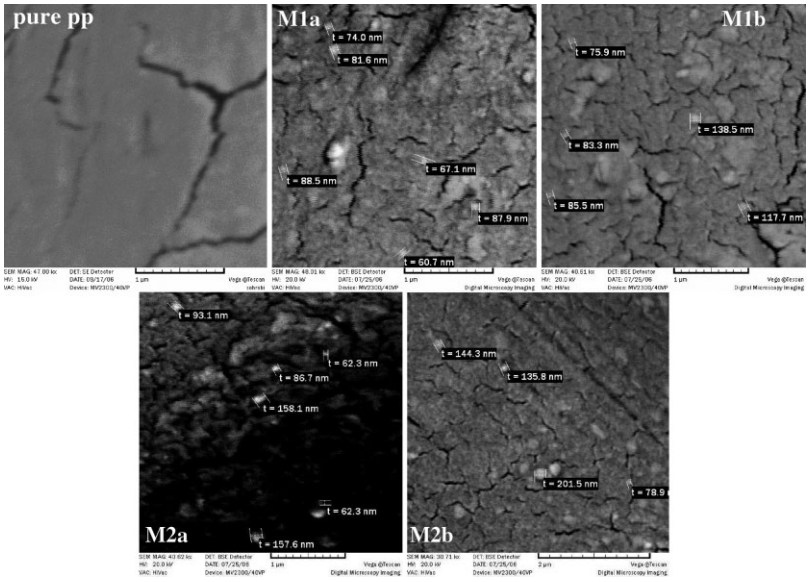

Figure 3.
SEM micrograph of drawn yarn surface with constant draw ratio, M1a and M2a indicate yarns containing 0.20 wt% nanocomposite antibacterial agent in method 1 and 2, respectively. M1b and M2b indicate yarns containing 0.50 wt% of nanocomposite antibacterial agent in method 1 and 2, respectively.

In method 1, after drawing with variable draw ratio, the increase of tensile properties in modified samples was more significant than for pure PP sample. Applying a variable draw ratio, has improved increasing of tenacity and modulus of modified fibers. While the constant draw ratio, which was higher than the variable one, had an adverse result. Probably, the increasing of particle dispersion during mixing by the twin screw extruder and spinning process has been so large that the higher draw ratio could not improve the dispersion. On the other hand, spatial resistance of particles

Table 4.
The change percentage of tensile properties of samples compared to the pure PP.

Aample type	Method	Properties				
		N.A.A[1] (wt%)	Tenacity (%)	Initial modulus (%)	Breaking elongation(%)	Rupture work (%)
As-spun yarns	1	0.20	3.00	7.53	1.91	6.59
		0.50	4.33	6.17	2.74	8.19
	2	0.20	6.09	0.16	−7.56	−3.10
		0.50	4.84	6.07	−10.52	−6.23
Drawn yarns with the constant draw ratio	1	0.20	−6.19	−10.90	3.30	−2.52
		0.50	−7.58	−6.93	7.83	2.21
	2	0.20	13.22	11.50	−1.41	11.11
		0.50	11.64	10.85	−4.23	5.44
Drawn yarns with the variable draw ratio	1	0.20	−3.92	−1.76	5.25	2.83
		0.50	2.67	8.36	−6.58	−4.01
	2	0.20	7.64	6.21	2.61	11.02
		0.50	6.72	7.02	6.27	15.20

1- N.A.A indicates weight percentage of nanocomposite antibacterial agent.

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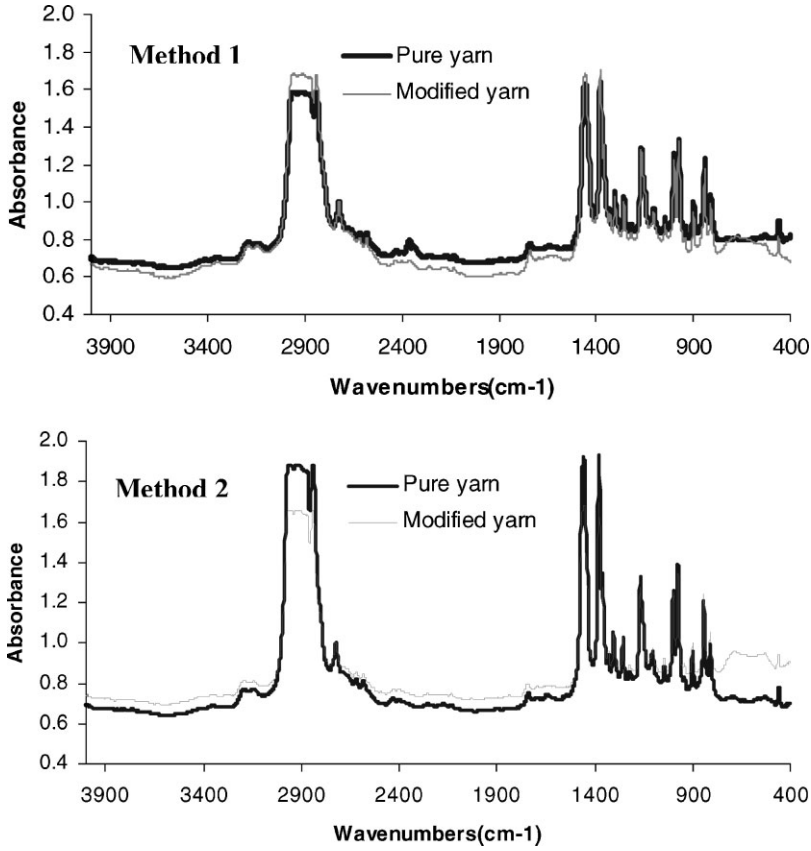

Figure 4.
FTIR diagram of as-spun yarns. Modified yarns in this figure are containing 0.50wt% of nanocomposite antibacterial agent.

against chain orientation has had more effect on the tensile properties. The reduction of crystal size intensified by both the quenching rate acceleration and nucleation effect of particles may also lead to this adverse effect. Neither the breaking elongation nor the rupture work had significant changes in both methods.

Since the polymer used for matrix of fibers was different in two aforementioned methods, only the change percentage of properties of modified samples compared to similar unmodified sample has been considered in each method.

The antibacterial activity of silver/TiO_2nanocomposite in fabric was evaluated after the specific contact time and calculated by reduction percent of Staphylococcus aureus ATCC 25923. The Staphylococcus aureus is a pathogenic microorganism that causes many diseases (e.g. toxic shock, purulence, abscess, fibrin coagulation, endocarditis). Moreover it is resistant to common antimicrobial agents.[3,28,29] Almost all tests for evaluation of textile antibacterial effectiveness have proposed testing this bacterium. Also it has been deduced that antibacterial efficiency of silver composite against Kleb.pneum and Escherichia colli is higher than Staphylococcus aureus.[30] Thus the Staphylococcus aureus was selected for evaluation of antibacterial efficiency in this research.

Figure 5 shows that samples had been attacked by the huge bacteria mass, during antibacterial test. However, the modified

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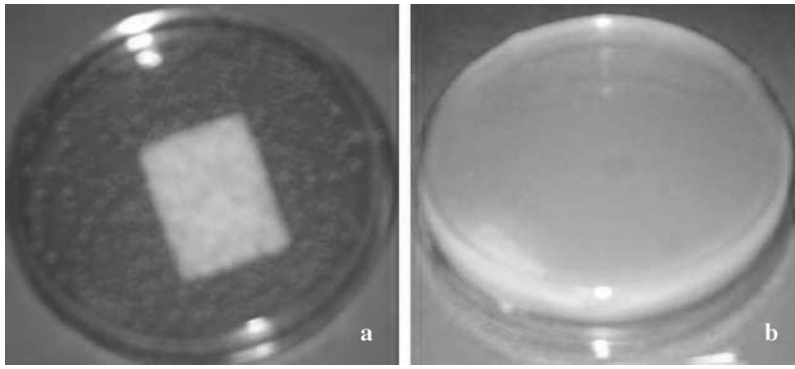

Figure 5.
The mass of bacteria recovered from the inoculated pure fabric, a) immediately after inoculation and b) after 24 h incubation.

Table 5.
Antibacterial efficiency of produced fabric.

Method	N.A.A[1] (wt%)	Number of bacteria in 1 ml $\times 10^{-3}$	Percentage of biostatic efficiency
1	0.00	11200	0
	0.20	84.7	99.24
	0.50	5.5	99.95
2	0.00	11200	0
	0.20	95.0	99.15
	0.50	48.4	99.57

1- N.A.A indicates weight percentage of nanocomposite antibacterial agent.
-Number of bacteria at the beginning in 1 ml of solution recoverd from the inoculated fabric was estimated 1980.

fabrics showed still a high percentage of biostatic efficiency (more than 99%) (Table 5).

Increasing the fraction of antimicrobial agent resulted in the improvement of bioactivity (Figure 6). Although modified fabrics obtained from method 1 showed the better bioactivity, the required bioactivity was achieved by applying both methods. (Table 5). It can be related to the lower molecular weight of PP matrix in this method compared to methods 2. Higher molecular weight can reduce the release rate of particles from matrix to surface.

Consequently, the required antibacterial performance of PP fibers is achieved by applying antibacterial agent with the concentration range of 0.20 and 0.50 wt%. From the application point of view, it is particularly important that sufficient antibacterial effect can be attained at relatively low concentrations of filler in both methods.

Conclusion

In this research, two various methods for investigation of possibility of producing and processing nanocomposite polypropylene filament yarns has been compared. For this purpose, various formulations of nanocomposites based on silver/TiO_2 nanoparticles were employed. In fact, this research has been started from the modification of polymer powder as a by-product of petrochemical companies. The processability of these starting materials and the characteristics of produced samples (fiber to fabric) have been investigated. Finally, the micro-

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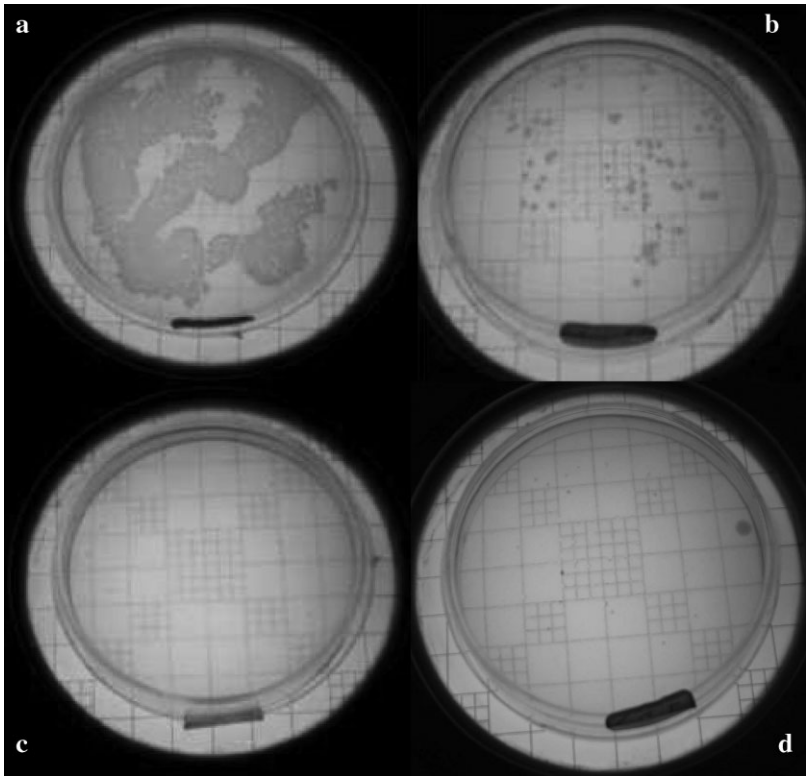

Figure 6.
The designed qualitative test for evaluation of antibacterial efficiency, method 1: a) pure pp, b) fabric containing 0.20wt% nanocomposite antibacterial agent, c and d fabric containing 0.50wt% nanocomposite antibacterial agent in method 1 and 2, respectively.

biological efficiency of the produced fabric has been further studied.

The experimental results revealed that all samples showed good spinnability at the spinning temperature of 240 °C and take-up speed of 2000 m/min on a pilot plant melt spinning machine. It was observed that the biostatic efficiency of nanocomposite fibers was excellent. However none of the applied blending percentages displayed the bacteriocide efficiency. The required bioactivity was achieved by applying both methods. Nevertheless, modified fabrics obtained from methods 1 showed the better bioactivity.

Increasing the antimicrobial agent by applying method 1 resulted in the reduction of crystallinity up to 5%. However, by applying method 2, crystallinity of as-spun yarns remained unchanged. Drawing procedure has compensated this difference. Drawing has improved the increase of tenacity and modulus of modified fibers in method 2. While in method 1 the inverse observation was noticed in the case of constant draw ratio which was higher draw ratio than the variable one.

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