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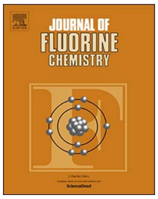

A novel technique for coating polypropylene yarns with polytetrafluoroethylene

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ABSTRACT

The article is devoted to an easy and effective method of giving polypropylene yarns the same extremely high chemical resistance as fluoropolymers yarns has. The method is based on the formation of an ultrathin, continuous and even coating of polytetrafluoroethylene on a surface of each filament forming yarn. The adhesion of a polytetrafluoroethylene coating to polypropylene is provided by applying of a diluted suspension of high-disperse polytetrafluoroethylene on a surface of a semi-hardened polypropylene yarn at the oiling stage. Later, the yarn is subjected to orientational stretching. In the process of stretching the coating becomes uniform and oriented thanks to an ability of polytetrafluoroethylene to pseudo-fluidity and a high coefficient of thermal expansion. The polypropylene yarn with a polytetrafluoroethylene coating gets an extremely high resistance to the influence of nitric acid and sodium hydroxide. Its frictional coefficient is close to the frictional coefficient of polytetrafluoroethylene and the strength is much higher than the strength of a common polypropylene yarn. The applied coating has a high resistance to the intensive abrasive action.

1. Introduction

Fibers and yarns with a high chemical resistance are in steady high demand. They are used for producing of fabrics for filtration of hot gases and strongly aggressive liquids, working clothes, acid proof stuffing for centrifugal pumps, etc. It is known that the highest chemical resistance is peculiar for fluorine-containing fibrous materials, especially polytetrafluoroethylene yarns (Teflon®, Toyoflon®, Polifen®). However, conversion of polytetrafluoroethylene (PTFE) into yarns impedes greatly because this polymer can't be transferred into melt without decomposition and doesn't dissolve in the known solvents. The essentially new method was developed to obtain fibers and yarns from PTFE. This method is different from the methods of obtaining other synthetic fibers [1]. It is based on spinning yarns from water dispersion of PTFE thickened by special polymer-thickener. Such yarns are exposed to fast heating to 380–390 °C. During this process the polymer-thickener is destroying and removing in the form of gaseous substance, and PTFE sinters before its decomposition. Fibers and yarns are subjected to additional orientational stretching at the increased temperature for strengthen. The described method is technologically difficult, power-consuming, environmentally hazardous and expensive.

Another method of obtaining chemically resistance fluorine-containing fibers is based on the use of soluble in organic solvents copolymers of tetrafluoroethylene [1,2]. In particular, Ftorin® fiber is obtained from the solution of copolymers of tetrafluoroethylene with vinylidene fluoride in acetone [2]. This method is simpler, but environmentally hazardous and expensive.

In the last decades, obtaining fibers from PTFE with the method of solid-phase spinning has begun. Its basis is the phenomenon of super plasticity of PTFE, which was found during the research of orientational deformation of polymers under hydrostatic pressure [3,4]. The new method is easier and safer. However, though the cost of fibers based on PTFE obtained with the new method is slightly lower, it is still extremely high. That is connected with the high cost of raw materials.

The perspective way to decrease material consumption and, thus, cost of fibers and yarns, is the substitution of PTFE yarns for two-component yarns. Their core consists of cheap thermoplastic fiber-forming polymer, for example, polypropylene, and on the surface, there is a PTFE layer. However, a number of PTFE properties make the solution of such task very difficult.

It is known that a lot of two-component polymeric fibers of core-cover type are obtained by the method of electrospinning [5–7]. In particular, the authors of this work [8] managed to obtain fibers with the core made of poly(ε-caprolactone), and the cover consisting of Teflon® AF, which is the copolymer of perfluorodimethyldioxole and tetrafluoroethylene. These fibers were obtained with the help of coaxial

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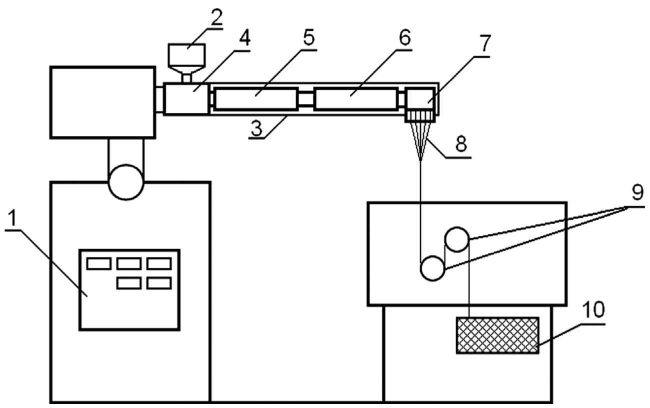

Fig. 1. The scheme of the stand for spinning of synthetic yarn from melt SFPV-1: 1 – control and measuring panel; 2 – bunker; 3 – extruder; 4 – extruder loading zone; 5 – polymer melting zone; 6 – melt stabilization zone; 7 – filament extrusion device set; 8 – melt streams; 9 – spinning disks; 10 – receiving device.

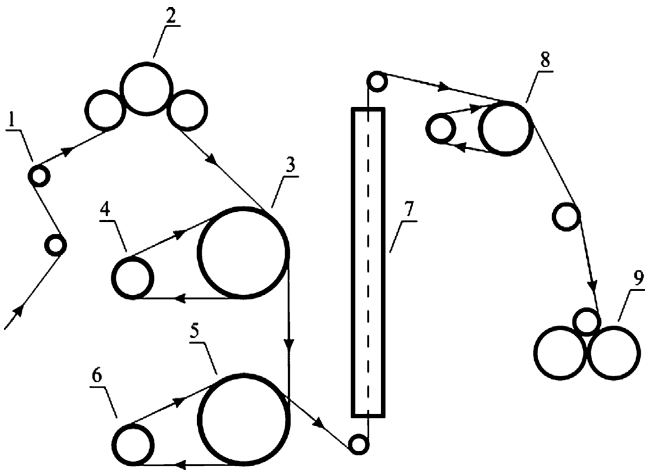

Fig. 2. The scheme of the stand for orientational stretching of synthetic fibers: 1 – yarn guides; 2 – supplying device; 3 – top warmed disk; 4, 6 – free rollers; 5 – lower warmed disk; 7 – thermoelectroplasticizer; 8 – compensating device; 9 – receiving device.

electrospinning. However, unlike Teflon AF which has a less chemically resistant, PTFE, having a zero-dipolar moment, isn't suitable for electrospinning. Due to the low adhesive ability of PTFE, the formation of steady coating on the surface of a polypropylene filament by applying of PTFE dispersion with the help of ordinary impregnation or spraying is also impossible. The coating made of PTFE and applied on synthetic fibrous materials by the method of magnetron evaporation is also unsteady to operational influences. In the present work, in order to provide adhesion of PTFE to polypropylene, the applying of PTFE suspension on the surface of semi-hardened polypropylene yarn during its spinning from the melt at the oiling stage was used. Through stretching of yarns with the applied PTFE at the increased temperatures, the orientation and redistribution of PTFE were provided. This led to the formation of ultrathin continuous, even coating [9].

2. Materials and methods

The polypropylene (PP) yarns with PTFE coating were obtained on the laboratory plant imitating the manufacturing process of production of polypropylene yarns from melt. It consists of two laboratory stands, their schemes are given on Figs. 1 and 2: stand for spinning (SFPV-1) (Fig. 1) and stand for orientational stretching (OSV-1) of synthetic yarns (Fig. 2). The photos of the stands and the examples of their use for obtaining PP yarns, bulky modified with metal-containing nanoparticles or ultradisperse PTFE, are presented in the works [10–13]. The spinning stand SFPV-1 (Fig. 1) is equipped with the automated control panel of spinning process, the extruder, in which the melting of polymer takes place. Besides, it is equipped with the filament extrusion device with 24 holes (Ø = 0,4 mm) for making streams from the melt, the spinning disks, and also the receiving device for winding of ready-made yarn to the spool. During the experiment the temperature of zones of the extruder was: the zone of preheating $T_1 = 200\,^\circ C$, the zone of melting $T_2 = 225\,^\circ C$, the zone of stabilization of melt $T_3 = 236\,^\circ C$, the zone of heating of a spinning head $T_4 = 236\,^\circ C$. The work was practiced with the feed speed of melt 20 g/min. The speed of spinning disks was 100 m/min.

On the first and on the second spinning disks the PTFE suspension was applied on semi-hardened PP yarns at the oiling stage.

After spinning and applying of the PTFE suspension, the PP yarns were subjected to orientational stretching and thermostabilization with the use of the OSV-1 stand (Fig. 2).The process was carried out for common yarns at the following temperatures in stretching zones: $T_1 = 118–120\,^\circ C$ (the top warmed disk), $T_2 = 120–122\,^\circ C$ (the lower warmed disk), $T_3 = 123–125\,^\circ C$ (thermoelectroplasticizer), at the speed of 3–20 m/min. The stretching of the yarns with the PTFE coating was carried out at higher temperatures: $T_1 = 120–135\,^\circ C$, $T_2 = 123–140\,^\circ C$, $T_3 = 125–165\,^\circ C$. In a number of experiments the PP film with the applied PTFE was subjected to orientational stretching.

For obtaining of PP yarns the isotactic polypropylene of "Balen" 01250 brand ("Ufaorgsintez", Ufa, Russia) with the melt index 25 g/10 min and with the temperature of melting 169 °C was used.

For formation of PTFE coating the PTFE suspension was used ("Halopolymer", Perm, Russia). The suspension is a suspended matter of PTFE 0.06-0.4 μm in water. For stabilization and improvement of dampening the surface-active substances in the quantity 9–12% of dry polymer weight were infused in the suspension. The containing of dry PTFE in the suspension makes 65 wt.%. For application to yarns the diluted suspension with the concentration 1–16% wt.% was used.

For a number of experiments as a model of PP filament a film from isotactic polypropylene of "Balen" 01250 brand with 30 μm thickness ("Europack-Ivanovo Ltd", Ivanovo, Russia) was used. The PTFE suspension with the concentration similar to the concentration used for obtaining of modified yarns was applied on the surface of PP film. The films with the coating were subjected to orientational stretching at the OSV-1 stand with multiplicity 5 at the temperatures similar to the temperatures of yarns stretching.

Infrared spectra were measured with the help of FTIR spectrometer "Nicollet" of "Avatar ESP 360" type by the method of multiple attenuated total reflectance (MATR) with the use of ZnSe crystal with 12-fold reflection in the range from 600 to 1600 cm^{-1}.

The estimation of the surface content of fluorine was carried out based on the energy-dispersive X-ray (EDX) spectrums. Scanning of the surface of fibrous material was carried out with the scanning electronic microscope JSM 6380LA by JEOL, the subsequent analysis – by means of the embedded X-ray spectrum analyzer JED-2300.

The thickness of PTFE coating of an unoriented PP yarn was measured on the cross sections of the filament using a "Micromed-1" optical microscope equipped with a web camera (1.3 MP). The thickness of the coating of the PP yarn after orientational stretching was calculated based on the multiplicity of the orientational stretching.

The images of the surface layer of PP material were obtained with the atomic force microscopes Solver P 47-PRO NT-MDT and SMM-2000.

The coefficients of friction of PP yarns were evaluated with the device of V.V. Taleparovskaya system [14] at 30 parallel measurements. The frictional force was measured between a stationary sample and sample which vertically moving along the axis of the filaments. The samples had a planar shape and they were formed from parallel segments of PP filaments.

The diameters of elementary yarns (filaments) were controlled with the "Lanatester-2" device by "Metrimpeks". The basic mechanical