Nanocomposite coatings for protective firefighter uniforms with improved performance characteristics

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Introduction. It is known that the intensive development of science and technology generates the emergence of increasingly complex emergencies, which are accompanied by fires, including man-made disasters. This circumstance requires more and more sophisticated means of protecting rescuers. Fireman's clothing, as a means of protection, is designed to compensate for the influence of dangerous and harmful factors and contribute to the high and stable performance of the rescuer. Trends and prospects for the development of modern protective clothing were considered in [1]. The conclusion is made about the prospects of creating new types of fibers and polymers, as well as the feasibility of improving existing fire resistant materials due to changes in their structure and surface properties.

This report is devoted to a review of current achievements in the field of obtaining polymer coatings for protective clothing using nanotechnology. New types of coatings based on various polymer binders with the use of inorganic nanoparticles (hydroxides, layered silicates, carbonates, metal oxides) as fillers and flame retardants, as well as methods of their application are considered. Attention is focused on the advantages of nanosized fillers, which consists in their high dispersity (the average size does not exceed 100 nm), which allows to distribute the particles uniformly in the matrix and significantly reduce the concentration of the filler. Textile materials can be given such properties as fire resistance, superhydrophobicity, as well as self-cleaning properties. It is shown that in nanocomposite polymeric materials, nanoparticles interact with the polymer matrix not at the macro level, but at the molecular level. As a result of this interaction, a material is formed that has high adhesion strength of the polymer matrix to the nanoparticle.

Table 1 – Effect of nanoparticles on characteristics of polymer compounds

Polymer / filler	Nanoparticle Size, nm	Nanoparticle C,%	Characteristic	Ref.
Polypropylene + zinc borate $ZnO·3B_2O_3$	80	5	Burning speed is reduced 5 times	[2]
Polypropylene + double hydroxide	100	5	Increase in oxygen index and coke number	[3]
Polypropylene + layered zinc hydroxide $Zn_3Al(OH)_8[(C_{18}H_{33}O_2)_{1/2}·mH_2O$	100 5	5	Increase in coke number from 1 to 20 %	[4]
Silicone rubber + Schungite mineral	50		Tensile strength is increased 7 times	[1]

Data presented in table 1 illustrate the effect of nanoparticle on operational characteristics of polymer compounds. A method for increasing the fire resistance of textile materials by modifying their surface and obtaining grafted siloxane coatings comprising of phosphorus containing groups is described. The effectiveness of the use of organosilicon compounds, in particular, AGM-9 monomer, is shown to better combine inorganic oxide nanoparticles with a polymer matrix.

Data presented in table 2 illustrate the synergistic effect of nanoparticle on operational characteristics of polymer compounds.

Table 2 – Synergistic effect of nanoparticles on operational characteristics [5]

Polymer	Filler Comp. 1	Filler Comp. 2	Characteristic
Polypropylene	$ZnO·3B_2O_3$	APP	Reduction of the burning rate by 40%
Polyvinyl chloride	ZnO	APP	Decrease in decomposition rate by 20% and heat release in 2 times
Polyvinyl alcohol	$ZnO·3B_2O_3$	APP	burning speed reduced 8 times, and heat release in 3 times

Data presented in table 3 show the advantages of multifunctional coatings.

Table 3 – Multifunctional nanocomposite coatings

Composition	Functionality	Ref.
Nanocomposite polyphenylene sulfide fibers with carbon nanotubes and highly dispersed carbonyl iron	Good mechanical properties and highly screening ability in relation to electromagnetic waves	[6]
Cotton fabrics with multilayered carbon nanotubes	The coating has electrical conductivity and screening properties. The surface structure is similar to superhydrophobic.	[7]
Cotton textile materials, polyethyleneimine, latex, APP	Fabrics with such a combined coating have superhydrophobic and self-cleaning properties, and their fibers are able to form a layer of coal during combustion, giving the tissues self-extinguishing properties.	[7]

Methods for increasing the fire resistance of tissue bases are considered. It has been shown that method of molecular assembly, consisting in the sequential grafting of fibers of the organosiloxane oligomer (containing aminomethylene and alkoxy groups) and phosphorus-containing acids to the fiber makes it possible to increase fire resistance with a low content of flame retardant. It has been shown that creation of intermediate layers by the method of chemical nanoscale assembly for chemical binding of fire retardants to inert media due to colloidal particles of tin hydroxide allows control the adhesive properties of coating. It gives a possibility for sorption on smooth and chemical inert surface of dielectric due to formation of intermediate adhesive layer consisting from $Sn_xCl_y(OH)_z$ nanoparticles.

Summary. Prospective technological directions for the production of polymer nanocomposite coatings for protective firefighters outfits have been determined. It has been shown that effective method of increasing fire resistance is the method of molecular assembly of micro- and nano- scale functional coatings. This technique consists in sequential grafting to the fibers of the tissue of the organosiloxane oligomer and phosphorus acids. For a protective outfit with an improved set of operational and ergonomic properties, a promising way consists in development of combined coatings for cotton textile materials that provide fire resistance and superhydrophobic properties.

[1] E.V. Tarakhno, L.A. Andryushchenko, et al., Problems of Fire Safety. 36 (2014) 243 [2] A.A.Sertsova, S.I. Marakulin, et al, Russian chemical journal. 59, 3 (2011) 78-85. [3] Yurtov E.V., Sertzova A.A., Marakulin S.I. Nanostructures - flame retardants of polymer materials. // Russian technologies and new materials. London, October 29, 2014 [4] Patent 2614957 RU [5] O.V. Reva, V.V. Bogdanova, et al. Proceeding of Sviridov readings, Minsk (2013) 158 [6] Kulpinski P., Czarnecki P., Niekraszewicz B., Jeszka J. K. Functional nanocomposite poly(phenylene sulphide) fibres — preliminary studies, Fibers and Textiles in Eastern Europe, 24, 4 (2016) 7.