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Impact On Human Health Of Particles Produced As A Result Of Car Brake Mechanism Wear

Zebo Alimova[1], Kamola Karimova[2], Bakhytzhan Kedelbaev[3]

[1]Professor, Tashkent State Transport University Tashkent, Uzbekistan

[2]Jizzakh Polytechnic Institute, I.Karimov st.130100,Jizzakh, Uzbekistan

[3] M. Auezov South Kazakhstan State University

Abstract. In this article, details of the brake mechanism and the method of determining the concentration of metals in the particles formed from the wear of tires as a result of the movement of cars, as well as a comparative analysis of road dust formed on asphalt-concrete roads of different composition are covered. In cities' traffic-related sources are a substantial source of particulate pollution. The following categories of traffic-related particles exist: brake mechanism details, formed as a result of tire wear and wear to the road surface, accumulate due to turbulence caused by traffic, and exhaust particles released as a result of incomplete combustion of fuel and volatilization of lubricants during combustion. The method of determining the metal concentration in the formed particles, data on the physical and chemical properties of the particles are presented. Information is given on the negative impact on human health of the particles formed as a result of wear of the details of the car brake mechanism.

Keywords: car wheels, traffic safety, asphalt-concrete composition, road dust, metal, road dust, metals, human health.

Introduction.

The amount of particulates produced by car brake mechanisms, tires and pavement wear is not regulated according to state standards, but it has a large negative impact on the environment compared to exhaust gases. Nevertheless, due to the lack of epidemiological and toxicological studies, there is no accurate information about their health hazard in our country. This requires different type of study efforts to develop beneficial and appropriate evidentiary legislation and mitigation techniques to safeguard human health.

Numerous intricate factors and various scientific approaches, includes various fleets of vehicles, Weather conditions, driving patterns (such as rural, urban, and highway), operational characteristics (such as vehicle speed, acceleration, and deceleration), and physical elements (such as vehicle weight, brakes, tires, asphalt composition and qualities) are all taken into consideration. and data on methods for quantifying particles generated by vehicle traffic are scarce and uncertain.

The United Nations' European Economic Commission on Noise and Tires is creating standardized test procedures to gauge the overall quantity of particulate matter generated by brake systems and tire wear in vehicles [1]. The Particulate Matter Measurement Program Working Group has recommended a minimum allowable amount for measuring the harmfulness

of brake particles, but is not known to be final. Research on the formation or measurement of road dust samples is in the initial stage. The detection of particles produced by the movement of cars requires additional investment.

The development of effective biomarkers of the effect of particles in blood or urine will also significantly help in studying the health effects of solid harmful particles produced by the movement of vehicles. But considering other sources of air pollution and poor nutrition, this is a very complex process.

To date, the experimental studies carried out by scientists have studied the acute biochemical, inflammatory and physiological properties of specific components of solid harmful particles generated by the movement of vehicles in the environment.

Condensed and oxidized metal vapor dust formed by the wear of brake system parts as a result of car movement is one of the most dangerous substances for human health. The spectrum of their harmful effects is wide - it has a positive effect on the work activity of systemic organs (including reproductive organs), hematopoietic organs. There are almost no non-toxic metal particles in the particles formed by the corrosion of brake system parts as a result of vehicle movement.[2]

Most metal particles damage the dust cleaning mechanism of the human respiratory tract, depriving it of protection from dust.

The information concerning the negative impact on human health, when particles of metal produced as a consequence of brake mechanism wear to enter the body through water and air, is shown in Table 1 below.

Table 1. The Impact of the dust formed as a result of the wear of brake mechanisms on the body when it enters the body through water and air

Metall	***MPC: In the water (mg/l) and In the air (mg/m3)***	***Biomarkers of early intoxication in the human body***
Aluminum	*0,5 mg/l 0,1 mg/m3*	*Neurotoxic effect*
Melt	*0,001 mg/m3*	*Lung damage Heart and lung failure*
Iron	*0,3 mg/l*	*Blood diseases. Allergic reactions.*
Cadmium	*0,01 mg/m3*	*Multipolar action - from hypertension to carcinogenesis*

Cobalt	*0,1 mg/l 0,5 mg/m3*	*Disorders of the functional central nervous system, thyroid gland. Chronic rhinopharyngitis.*
marganese	*0,1 mg/l 0,3 mg/m3*	*violation of the central nervous system's functioning status, anemia*
Copper	*1,0 mg/l*	*Damage to the fetus, childbirth and lactation. Liver and kidney damage. Changes in metabolism.*
Molybdenum	*0,25 mg/l*	*Endemic goiter, gouty diseases, skin diseases*
Nickel	*0,1 mg/l 0,5 mg/m3*	*Damage to the heart, liver, upper respiratory tract, organs of vision*
Lead	*0,03 mg/l 0,01 mg/m3*	*Damage to the central nervous system, kidneys, hematopoietic organs, beriberi*
Thallium	*0,01 mg/m3*	*Damage to the central nervous system, gastrointestinal system, liver, kidneys. Pain in the legs, sleep disturbance.*
Chrome .	*0,5 mg/l 0,01 mg/m3*	*Liver and kidney dysfunction. Bronchitis. Dermatitis, eczema*
Zinc	*1,0 mg/l*	*Changes in the work of the central nervous system, damage to the kidneys and liver, anemia.*

Some components of the dust formed as a result of wear brake mechanisms are harmful not only to people, but also to the source of food - agriculture. Industrial production is interrelated with the decrease in the productivity of agricultural crops and the increase in the number of diseases.[2]

Methodology

According to the results obtained from a limited number of epidemiological studies, special attention is paid to the composition elements or source factors of particulate matter produced by the movement of certain vehicles. The harmful factors of Zn in the road dust produced by the movement of cars on the human body include the following acute and chronic cardiovascular diseases. It also indicates that changes in the work of the central nervous system, damage to the kidneys and liver, and the development of anemia-related diseases are possible. These studies have provided some insights, but the results are often mixed and require further research.

In my scientific research work, determination of the amount of particles during car braking was carried out on I. Karimov street, 4r32 "Yangiyer-Pakhtakor-Chimkurgan" highway and 4r32 "Yangiyer-Pakhtakor-Chimkurgan" highway of Jizzakh region. 76-77 kilometers of the highway were paved[3,4,5]. According to the conducted research, the element composition of the particles formed as a result of car braking was analyzed.

Table 2. The share of Zn (Zinc) in the particles formed as a result of vehicle braking

I.Karimov avenue			***4r32 "Yangiyer-Paxtakor-Chimqo'rg'on" highway***			***4r32 "Yangiyer-Paxtakor-Chimqo'rg'on" on 76-77 kilometers of the highway***		
Element	*Weight, %*	*Total weight, %*	*Element*	*Weight, %*	*Total weight, %*	*Element*	*Weight, %*	*Total weight, %*
Zn	*0.87*	*0.13*	*Zn*	*0.79*	*0.12*	*Zn*	*0.67*	*0.13*

In my scientific research work, determination of the amount of particles during car braking was carried out on I. Karimov street, 4r32 "Yangiyer-Pakhtakor-Chimkurgan" highway and 4r32 "Yangiyer-Pakhtakor-Chimkurgan" highway of Jizzakh region. 76-77 kilometers of the highway were paved[3,4,5]. According to the conducted research, the element composition of the particles formed as a result of car braking was analyzed.

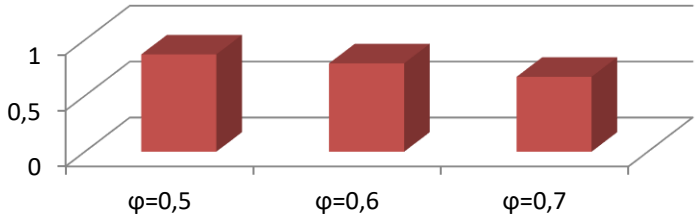


Figure 1. The share of Zn (Zinc) in the particles formed as a result of vehicle braking

Toxicological evidence examining the relative risk of harm and toxicity of particulate matter generated by vehicle traffic is also limited. Several forms of particulate matter from vehicular traffic have the potential to cause adverse effects in the lungs.

Table 3. Share of Mo (Molybdenum) in particles formed as a result of vehicle braking

I. Karimov avenue			***4r32 "Yangiyer-Paxtakor-Chimqo'rg'on" highway***			***4r32 "Yangiyer-Paxtakor-Chimqo'rg'on" on 76-77 kilometers of the highway***		
Element	*Weight, %*	*Total weight, %*	*Element*	*Weight, %*	*Total weight, %*	*Element*	*Weight, %*	*Total weight, %*
Mo	*0.47*	*0.13*	*Mo*	*0.35*	*0.10*	*Mo*	*0.31*	*0.09*

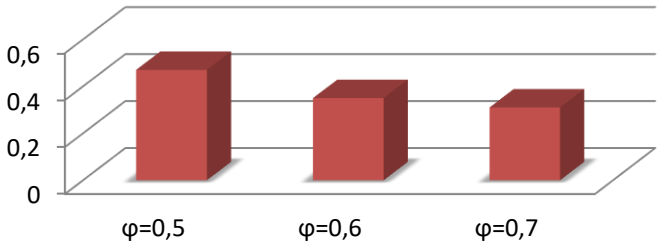


Figure 2. Share of Mo (Molybdenum) in particles formed as a result of vehicle braking

Results

Due to the fact that many metals, which have a harmless effect on the human body, can catalyze oxidation reactions, it is necessary to take into account their contribution (the ability of particle pollution will lead to harmful oxidation reactions) to the oxidation fraction of environmental particles. In fact, previous studies have shown that they contribute significantly to this indicator, and the ability of PM2.5 and PM10 particle pollution to cause harmful oxidation reactions showed a higher index in the peripheral part of the road surface. Also, it is necessary to pay more attention to the non-metallic components of the particles produced by the movement of cars, in particular, to the organic components produced by braking. Additionally, given that tissues and cells can control the intake of metal ions and store them in endogenous chelation proteins such ferritin and metallothionein. Their true risk may not be reflected in models of acute exposure and cumulative exposure over longer periods of time.

Currently, it is not known whether there are groups of people who are more sensitive to the health effects of particles generated by the movement of cars. Individuals with genetic problems in the biotransmission of these metals (for instance, those with hereditary hemochromatosis) are thought to be at greater risk given the high level of Cu, Zn, and Fe in the particulate matter produced by the movement of some vehicles [6]. Fe, Zn, and Cu are also important for microbial

development, and therefore future researches are needed to investigate changes in inherent immune people' respiratory microbiomes.

According to the results of the study explained above, it is important to develop a minimum and low-harm standard for road dust generated by the wear of brake mechanisms, tires, and pavement materials, and to legislate these norms. Strategies for developing standards include developing brake materials with decreased wear characteristics. These include figuring out rubber substitutes for tires, car brakes, and handling tire wear particles, using high-vacuum cleaners rather than dust collectors, and high-pressure water washing of road surfaces to reduce road dust. Also included are general measures to improve wheel-to-ground contact, reduce speed, encourage smooth driving style and lowering vehicle mass. Such projects should continue to use innovative technology. In order to reduce the harmful particles produced by the movement of vehicles, it is necessary to ensure that the construction of roads with the addition of crushed tire rubber as a modifier to the road surface is not associated with high toxicity, the effectiveness of the solutions and should be carried out in conjunction with studies that determine its safety. It is projected that the advantages for human health from this uncontrolled kind of vehicle pollution may become even greater in the coming years.

Thus, the percentage of Zn (zinc) in the particles formed as a result of car braking:

I.Karimov branch street - 0.87%. 4r32 "Yangier-Pakhtakor-Chimkurgan" highway in the territory of Jizzakh region, Pakhtakor district is 0.79% and 76-77 kilometers of the 4r32 "Yangier-Pakhtakor-Chimkurgan" highway road coverage was 0.67%. The amount of molybdenum in the dust samples taken from the asphalt concrete coating prepared by adding road bitumen, crushed stone, sand and granules of car tire rubber used as a modifier to the composition was found to be 20% less than the dust samples taken from the ordinary road coating.

Conclusion

The share of Mo (Molybdenum) in particles formed as a result of car braking: I.Karimov avenue - 0.47%. 4r32 "Yangier-Pakhtakor-Chimkurgan" highway in the territory of Pakhtakor district, Jizzakh region is 0.35%. And the 4r32 "Yangier-Pakhtakor-Chimkurgan" highway has a road coverage of 0.31% between 76-77 kilometers. The amount of molybdenum in the dust samples taken from the asphalt concrete coating prepared by adding road bitumen, crushed stone, sand and granules of automobile tire rubber used as a modifier to the composition was found to be 16% less than the dust samples taken from the ordinary road coating.

Particles created by the movement of cars mainly affect children or babies in strollers, because the highest concentrations are on the ground, that is, on the surface of the road surface.

Particles produced by the movement of vehicles are useful for identifying the types of different metals and for better understanding of their health risks. Further research on the human health effects of traffic-related particulate matter should also be considered.

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Methodology For Developing Nanocomposite Engineering Materials Based On Polymer Matrices

Antonov A.S.[1], Riskulov A.A.[2], Struk V.A.[1], Avliyokulov J.S.[2]
[1]Yanka Kupala State University of Grodno, Grodno, Belarus
[2]Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. The methodology for developing nanocomposite engineering materials based on industrial thermoplastics are considered. The necessity of implementing the factor of energy and technological compliance of components is demonstrated to achieve a synergistic effect of nanoscale modifiers on the structure of the thermoplastic matrix, which enhances the performance characteristics of nanocomposite products. Technologies for ensuring the energy state level of dispersed particles of various natures, compositions, and production methods are proposed.

Keywords: thermoplastic polymers, factor of energy and technological compliance of components, algorithm for implementing the methodological approach, nanocomposite material, energy state.

Introduction.

The modern development of various branches of economic activity is based on the expanded use of nanocomposites in the design of machines, mechanisms, technological equipment of chemical production, products made of functional materials of a new generation called *nanocomposites*, which ensure the achievement of increased parameters of performance characteristics by innovative developments [1–4]. In the brand range of nanocomposite materials, a special place belongs to nanocomposites based on polymer, oligomeric and combined matrices, which, according to a number of operational parameters and manufacturability of processing, are non-alternative materials for the production of functional products for the technological equipment of the petrochemical complex, the production of shut-off and control valves for thermal power engineering, motor transport, agricultural machinery, functional elements of special equipment used in health care.

Studies carried out in various scientific schools have shown that the parameters of the performance characteristics of nanocomposite materials based on high-molecular matrices are largely determined by the intensity of physical and chemical processes at the matrix-modifier interface, which depend on a special state of nanosized particles called the nanostate [2]. The achievement of the nanostate phenomenon by the nanocomposite material component has a decisive effect on the structure parameters that characterize the stress-strain, tribological, adhesive and other functional characteristics of products for various purposes. At the same time,

there are no systematic studies of methodological approaches to the implementation of the phenomenon of nanostate in materials science and technology of nanocomposite materials based on industrial polymers. Therefore, the study of the mechanisms of structure formation of nanocomposite materials based on various matrices obtained by thermomechanical combination of thermoplastics is an urgent problem of domestic materials science and technology of nanocomposite materials, which is of great scientific and applied importance.

The aim of the study was to develop a methodology for the formation of the optimal structure of nanocomposite materials based on industrial thermoplastics, oligomers and combined matrices with increased parameters of performance characteristics and technologies for their processing into products for a given functional purpose.

Research

Nanodispersed particles of carbon-containing (graphite, ultradispersed detonation diamond (UDD), carbon nanotubes (CNT), shungite, carbon fibers (CF)), metal-containing (oxides, salts of organic acids) and silicon-containing (mica, tripoli, opal, clay) compounds, as well as products obtained by technological effects on natural and synthetic semi-finished products (UPTFE) produced at industrial enterprises in Belarus, Russia and Uzbekistan were chosen as the main objects of the study. crushing and heat treatment of dispersed semi-finished products at temperatures of 400–1200 °C.

Thermoplastic polymers and oligomers, the most common in materials science and technology of polymer materials, were used as components for the production of combined matrices and composites for various purposes: *aliphatic polyamides* such as PA6, PA6.6, PA11, PA12, *polyolefins* such as polypropylene (PP), high-density polyethylene (LDPE), low-density polyethylene (HDPE), *polyesters* such as polyethylene terephthalate (PET), polybutylene terephthalate (PBTP) primary and regenerated, *fluorinated compounds* such as polytetrafluoroethylene (PTFE), fluorine-containing oligomers "Foleox", products of thermogas-dynamic synthesis of PTFE, produced under the "Forum" trademark, positioned as ultrafine polytetrafluoroethylene (UPTFE).

Polymer primary materials were used in the state of industrial supply in the form of granules, powder obtained by cryogenic dispersion of granules at a temperature of minus 186 °C.

The structure and properties of nanocomposite materials and products made of them were studied using modern methods of physical and chemical analysis: IR spectroscopy (Specord), EPR spectroscopy (Bruker), X-ray diffraction (Drone 3.0), differential thermal (Q-1500) analysis, optical (MF-2), scanning electron (ISM-50A, Nanolab-7) and atomic force (NT-206)

microscopy. The energy state of nanoscale modifiers and composite materials was evaluated using EPR spectra and thermally stimulated current (TSC) spectra.

The indicators of the deformation and strength characteristics of the developed materials were evaluated using specialized Z010 Zwick equipment. Tribological characteristics were determined on universal or original friction machines according to the schemes "indenter – disk", "shaft – partial liner".

The analysis of literature sources devoted to materials science and technology of functional composites based on polymer matrices indicates the special prospects of micro-sized modifiers, including nano-sized particles of various composition, structure and production technology. The most promising multi-purpose modifiers are natural silicon compounds – clays, micas, zeolites, products of detonation, thermogas-dynamic and plasma-chemical synthesis – nanoceramics, ultrafine detonation diamond (UDD), ultrafine powders of diamond and diamond graphite (UDD-G), fullerenes, carbon nanotubes (CNTs), thermally split graphite (TSG), metal particles and oxides obtained by thermolysis of metal-containing precursors and sublimation of metal melts. A number of features of the modifying effect of low-sized particles have been established, which determine the effectiveness of their application.

Physical and physicochemical processes of interfacial interaction are due to the transfer of electrons during the formation of intermolecular, supramolecular, interfacial structures, which led to the choice of the maximum value of thermostimulated current (TSC) in the temperature range adequate to the technological modes of production, processing of composites and operation of metal-polymer units as a determining parameter for assessing the energy state of system components.

The ideal structure of a nanocomposite material based on a high-molecular matrix can be represented as a combination of a matrix component (M), a dispersed particle (P) and a boundary layer (L) (Fig. 1).

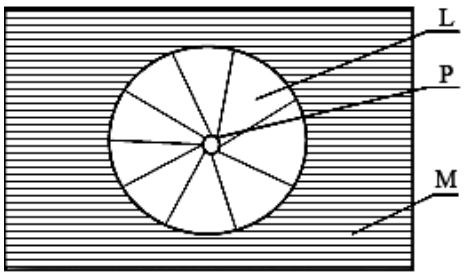


Figure 1 – Structure of nanocomposite material [2]:
L – boundary layer; P – dispersed particle; M – matrix component

Based on generally accepted considerations, the bulk concentration of the nanoscale filler C_V is determined from the expression (1):

$$C_V = \left(1 + \frac{m_M}{m_C} - \frac{\rho_M}{\rho_C}\right)^{-1}, \quad (1)$$

where m_M, m_C is the mass of the modifier and binder particles; ρ_M, ρ_C is the specific gravity of the modifier and binder.

For the thickness of the modified (boundary) layer h, condition (2) must be met in order to achieve the maximum inoculation effect:

$$4/3\pi(r + h)^3 \cdot n \cdot K = 1, \quad (2)$$

where K is the coefficient that takes into account the overlap and compactness of the modified boundary layer, r is the radius of the modifier particle, and n is the number of particles. Given that $m_M >> m_C$, the expression (2) can be represented as (3):

$$\frac{h}{r} = \left(\frac{\rho_M}{\rho_C \cdot C_C \cdot K}\right)^{1/3}. \quad (3)$$

From this expression it follows that in the case of a uniform distribution of the inoculant particles, when they are located at points corresponding to the densest packing of balls with radius $r + h$, and there is no overlap of the modified regions, the coefficient $K = 0.74$. With a typical ratio of $\rho_M / \rho_C = 4$ and a modifier content of 0.1%, we get $h \approx 15 \cdot r$.

The formation of a transition (boundary) layer in a nanocomposite material ensures a change in the parameters of its characteristics due to the formation of physical and chemical bonds. This conclusion is confirmed by model studies of the thermal conductivity parameters of composites based on epoxy resin modified with Al_2O_3, SiO_2 of various dispersions.

Multicomponent functional materials based on high-molecular matrices are systems, the parameters of characteristics (stress-strain, tribological, adhesive, thermophysical, etc.) of which are determined by the structure at various levels of organization, formed by physical and physicochemical processes, the mechanisms and kinetics of the flow of which depend on the composition of components and the parameters of technological impact on them in the process of formation and processing. In the interfacial region of the system, a complex of physical and physicochemical reactions takes place simultaneously with a predominance of one or several, for which the most favorable conditions are realized, determined by the value of the activation energy – the prevailing reactions [3].

A methodological approach to the formation of functional composites based on polymer matrices with different technological prehistory, based on the establishment of the prevailing

physicochemical reaction at the matrix-component interface, made it possible to establish a correlation between the parameters of the structure and energy characteristics of the components (energy state). The analysis of the energy factor of materials science and technology of composite polymer materials and metal-polymer systems is carried out (Fig. 2) [2, 5].

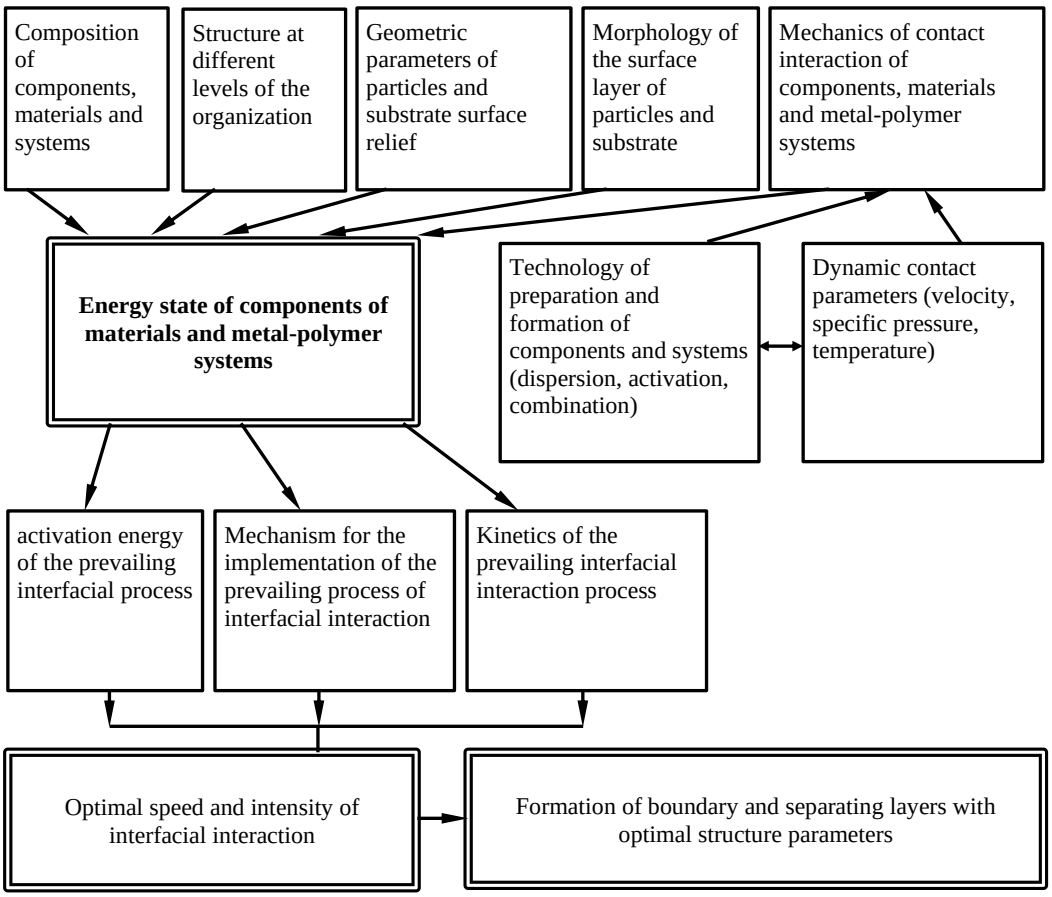


Figure 2 – Energy factor of materials science and technology of composite polymer materials and metal-polymer systems [5]

To characterize *the energy state*, a complex parameter was used, which is the aggregate result of the transformation of the initial individual parameters of the components (structure, composition, morphology, shape, size) under the influence of technological and operational factors. A characteristic feature of the proposed methodological approach is the possibility of purposeful intensification of the prevailing interfacial reactions in the composite or metal-polymer system by forming the energy state of components with certain parameters of electrophysical characteristics.

Based on the concept of energy and technological correspondence of components, approaches are proposed for the formation of systems with optimized parameters of structural characteristics at various levels of organization: supramolecular, intermolecular, interphase.

In accordance with the concept of energy and technological correspondence [6–9] (Fig. 3), it was determined that *the energy compliance of components* implies the possibility of their achieving an aggregate energy state that corresponds to the activation energy of the prevailing physicochemical process that determines the mechanisms for the formation of the optimal structure of the system at the supramolecular, intermolecular, interfacial levels of organization in composites or metal-polymer systems.

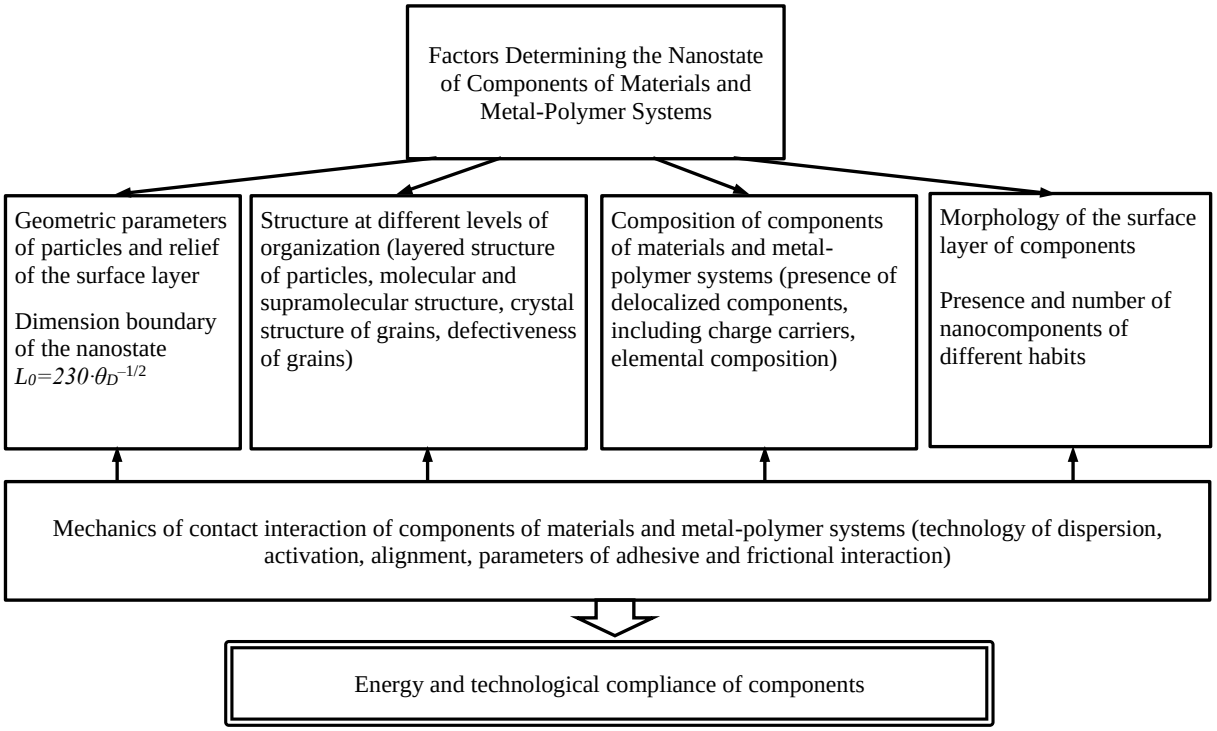


Figure 3 – Factors that determine the concept of energy and technological compliance

For the practical implementation of the principle of energy compliance of components, it is necessary not only to have a certain combination of initial parameters (thermophysical, dimensional, electrophysical, structural, elemental, etc.), but also to be able to change them in the specified ranges of values under technological influences on composites (deformation, mechanochemical, temperature, ionizing, laser, etc.) in the processes of preparation, formation, processing of composites into functional products and operation of metal-polymer systems of a certain design.

The possibility of forming an interfacial (boundary) layer of an optimal structure that provides a given service life of the product and the metal-polymer system determines *the technological compliance of the components of* functional materials or structures, which is understood as the possibility of achieving the specified values of energy parameters *at a certain stage of the formation of the composite, the product and the structural design of the unit*, ensuring the course of the prevailing process of interfacial interaction with a given intensity. The absence of such compliance does not allow to realize the potential of individual components in the selected technological process of manufacturing a system or individual products in the required volume, since it can manifest itself in different ranges of temperature, mechanochemical, physical and chemical effects, not ensuring the achievement of the necessary value of the activation energy of the optimal process at a specific technological stage, leading to a negative phenomenon called a structural paradox.

By selecting an adequate technological impact, conditions are created for the transformation of the initial energy state and the achievement of the nanostate directly in the zone of interfacial interaction, which ensures the course of the prevailing physicochemical process of forming the optimal structure of the boundary layer in the "matrix – modifier" or "nanocomposite material – metal substrate" systems.

Physical, physicochemical, mechanochemical processes occurring in the systems are due to the transfer of electrons during the formation of supramolecular, intermolecular, interfacial structures, which led to the choice of the maximum value of thermostimulated current (TSC) in the temperature range adequate to the technological modes of production, processing of composites and operation of metal-polymer units as a determining parameter for assessing the energy state of system components.

A characteristic feature of dispersed particles used for inoculation of polymer matrices is the presence of an uncompensated charge with a long relaxation time, which is confirmed by the data of EPR spectroscopy and studies conducted by Prof. M. P. Tonkonogov, Prof. A. I. Gusev, et al. [10–12].

Along with special parameters of electrophysical characteristics due to composition and structure, material particles can be in alluviality, the ideas of which were developed in the studies of P. von Weimarn, Suzdalev I. P., Ajan P. M., under certain parameters of technological impact that change the parameters of the size, geometric characteristics and morphology of the surface layer. The presence of nanoscale components in dispersed particles that form the surface layer is the most important factor determining the activity of modifier particles in the processes of structure formation of polymer matrices at various levels of organization. Therefore, the

technology for activating dispersed particles of modifiers used in the production of functional composite materials should ensure the formation of nanoscale components in the surface layer that ensure the implementation of the determining process in the interfacial zone with the required intensity for specific compositions and technologies for obtaining and processing into products for various functional purposes [2].

Conclusion.

The conducted set of studies on modeling the processes of formation of the structure of material objects with a pronounced manifestation of the nanostate made it possible to determine effective directions for the selection of dispersed particles for the production and processing of nanocomposite materials based on matrix binders of industrial production of regenerated products based on them for the manufacture of metal-polymer structures with optimized parameters of operational characteristics.

An algorithm for the implementation of the methodological approach has been developed, which allows, on the basis of factors that determine the nanostate of the components of the system for a specific purpose and design, to choose the technology for their implementation at a specific stage of the process, taking into account material, economic, ergonomic, environmental and other aspects.

The given research was carried out within the framework of integrated assignment 8.4.1.51 "The concept of multilevel modification in materials science and technology of nanocomposites based on thermoplastic blends" of R&D " Mechanisms of the influence of the energy factor in the multilevel structuring of polymer nanocomposites " and R&D "Development of compositions and technology of import-substituting nanocomposite semi-finished products based on thermoplastic blends for the production of products with high parameters of characteristics using additive technologies" included in the subprogram “Multifunctional and composite materials” of the State programs for scientific research “Materials science, new materials and technologies” in 2021-2025.

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Methodology Of Nanocomposite Materials For Manufacturing Special-Purpose Products

Klochko P.V.[1], Riskulov A.A.[2], Struk V.A.[1], Avliyokulov J.S.[2]

[1]Yanka Kupala State University of Grodno, Grodno, Belarus

[2]Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. This article discusses the methodological principles for creating nanocomposite materials based on thermoplastic matrices for the production of special-purpose products. Formulations of composite materials are proposed for the manufacture of injectors designed for the introduction of functional components under extreme conditions, nozzles for the treatment and prevention of otorhinolaryngological diseases, tribological coatings for the splined connections of drive shafts, and rollers for belt conveyors. It is demonstrated that the implementation of the nanoscale state phenomenon of modifiers with various compositions and structures leads to a synergistic effect, enhancing the performance characteristics of nanocomposites based on industrial thermoplastics.

Keywords: nanocomposite material, industrial thermoplastic, nanostate phenomenon, special-purpose products, nanoscale modifier, synergistic effect.

Introduction.

The practical implementation of an innovative strategy for the functioning of economic systems at various levels involves the expansion of the range of domestic composite polymer materials for the manufacture of structural elements for various functional purposes [1]. A special place in polymer and metal-polymer structures is occupied by special-purpose products used in treatment technologies, life support in extreme situations and during the special actions. Composite materials are used for manufacturing, which have a special set of characteristics that meet specific operational requirements, and high manufacturability for processing on modern equipment [2, 3].

In recent decades, technologies for the manufacture of functional products using the 3D prototyping method have been intensively developing, which involve the use of materials with special characteristics for their implementation, providing the necessary performance parameters in conditions of special application. A promising direction in the creation of such materials is the implementation of the concept of multi-level inoculation of industrial polymers, proposed in the works of employees of the educational institution "Yanka Kupala State University of Grodno" and implemented in machine-building structures - cardan shafts, automobile shock absorbers, etc. [3].

In this regard, the development of compositions and technologies of composite materials based on thermoplastics for the manufacture of special-purpose products, for the control of the

parameters of the structure and service characteristics of which modifiers of a multi-level mechanism of action are used, are relevant.

The purpose of this study was to develop composite materials based on industrial thermoplastics modified by nanodispersed components with a special energy state for the manufacture of special-purpose products.

Research.

For the development of functional composites, industrial thermoplastics were used - aliphatic polyamides (PA6, PA6.6 produced by the branch "Khimvolokno Plant" of JSC "Grodno Azot"), polyolefins (LDPE, HDPE produced by the plant "Polymir" of JSC "Naftan"), polyesters (PET, PBTF produced by the plant "MogilevKhimvolokno") primary and regenerated according to the technology of JSC "Belvtorpolimer".

To modify the base thermoplastics, dispersed particles were used, including those realizing the effect of the nanostate: chitosan (CT) obtained using the technology of the Institute of Chemistry and Physics of Polymers of the Academy of Sciences of Uzbekistan (Tashkent, Republic of Uzbekistan), organically modified clay based on Na^+-montmorillonite (Scientific and Production Closed Joint Stock Company "Sinta", Belarus), carbon-containing components – ultrafine detonation diamond (UDD), ultrafine powders of diamond and diamond graphite (UDD-G) (Scientific and Production Closed Joint Stock Company "Sinta", Belarus), formates and oxalates metals and other particles.

As a functional component in the development of composite materials for the manufacture of polymer and metal-polymer structures, a polyamide resin (PR) based on rosin amides with diethylenetriamine, developed at the educational institution "Belarusian State Technological University", produced under the brand name ProChemDuo LLC "PromKhimTechnologies" (Belarus), was used.

Composites were obtained by thermomechanical alignment on injection molding machines with screw plasticization under the modes regulated for the basic thermoplastic. For the research, standard samples or filaments were used, which were obtained on a Rondol twin-screw extruder.

To produce model samples using the 3D prototyping method, a Stratasys Fortus 450mc 3D printer was used, which implements FDM printing technology with an extruder nozzle diameter of 0.4 mm.

The study of the structure, morphology, parameters of thermophysical, rheological characteristics of composites was carried out by IR spectroscopy (FT-IR NEXUS Fourier transform spectrometer), differential thermal analysis (Termoscan-2), differential scanning calorimetry (DSC-2 calorimeter), plastometry (PTR-LAB-02 extrusion plastometer), X-ray

fluorescence analysis (CEP-01 ElvaX X-ray energy spectrometer), X-ray diffraction analysis (Dron-3M diffractometer).

The parameters of the deformation and strength characteristics of composite materials were evaluated on a tensile machine IR 5047-50-11, by dynamic indentation (IPM-1K unit), strain gauge (T2020 DC10 SH strain gauge), Charpy impact strength (CEAST 9050 pendulum pile driver).

The parameters of the energy characteristics of the dispersed particles and model samples were studied by the method of TSC analysis (thermally stimulated currents) on the ST-1 device.

In the nomenclature of special-purpose products, a special place is occupied by injectors for the introduction of functional components in extreme conditions. For a reasonable choice of polymer materials for the manufacture of the injector structure, model studies were carried out, which made it possible to optimize the design solution (Fig. 1) and the technology of manufacturing elements by modern methods - injection molding and 3D prototyping. the presence of a body, rod, retainer, placed in a certain sequence.

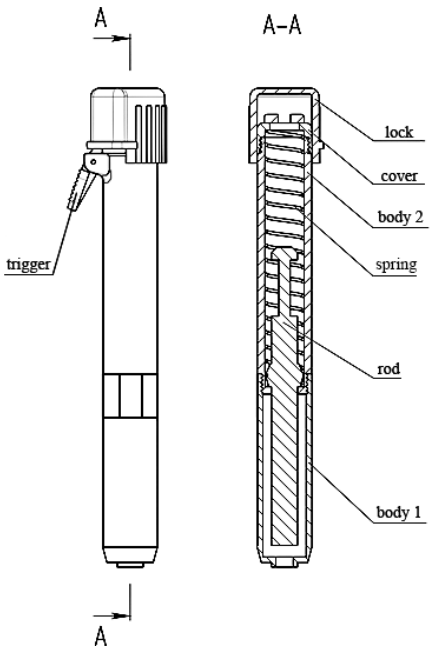
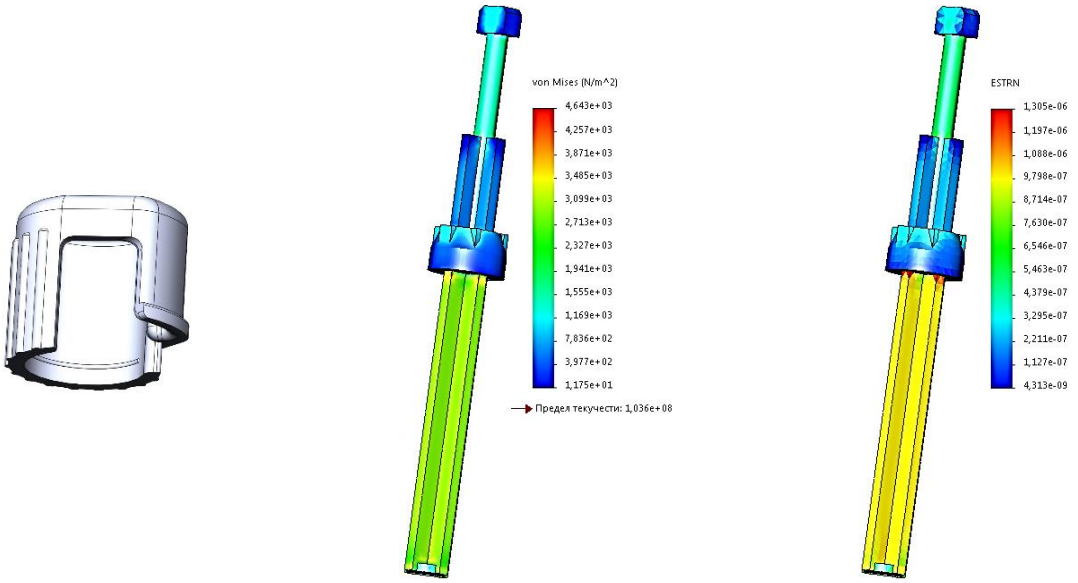


Figure 1. Developed injector design for the introduction of functional components under extreme conditions

The presence of a spring allows you to inject the contents of an ampoule with a special drug using a rod in the necessary conditions of use. For the manufacture of injector elements by injection molding, model studies were carried out to assess the parameters of the casing cover in order to optimize them (Fig. 2). This made it possible to establish the optimal dimensional

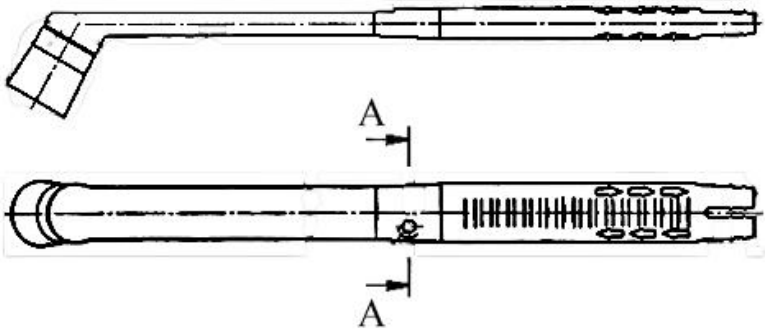
parameters of the elements and the rheological characteristics of the melt necessary for processing by injection molding.



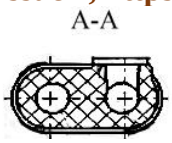
a) b) c)

Figure 2. Retainer model (a) and results of the stress-strain analysis of the rod model in the evaluation of Von Mises stresses (b) and strains (c)

Model studies of the design of the nozzle for hydrovacuum aspiration were carried out during its manufacture using injection molding and 3D printing technologies. A packing design has been developed that makes it possible to manufacture the structural elements of the packing by injection molding, the feature of which is the presence of two elements connected by a sealing element, and a channel for manual control of the drug flow (Fig. 3).



a)



b)

a) – general view; b) – cross-section

Figure 3. Design of the nozzle for hydrovacuum aspiration

Functional special-purpose products also include some designs of units used under special conditions of operational impact – cardan transmissions, brake chambers, shock absorbers. Model ideas about the mechanisms of friction and wear of the spline connection of the propeller shaft are considered to ensure the design features of its design that meet the technical conditions of operation. In order to achieve this goal, the 3D model of the propeller shaft was evaluated in the Pro/Engineer Mechanica environment (Fig. 4).

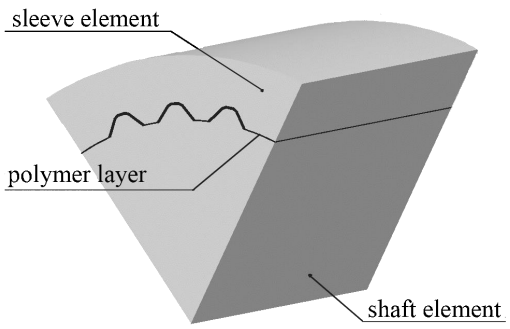


Figure 4. 3D model of the spline connection of the propeller shaft

According to the technical documentation, the shaft must withstand a torque of 5500 kN·mm without destruction. Taking into account that the model of the spline connection is 1/8 of the real structure, the load was assumed to be equal to 687.5 kN·mm. The results of model studies showed that the maximum stresses are concentrated in the area of separation of the spline joint by a layer of composite coating based on a thermoplastic polymer. In the LS-DYNA environment, a "bushing-shaft spline" system was modeled at different polymer coating thicknesses of 100–200 μm. The design stresses arising in the model transmission in the "start-stop" mode showed that polymer coatings with a thickness of 100–200 μm can significantly reduce the load parameters during operation (Fig. 5).



Figure 5. Dependence of stress arising in the spline of a model driveshaft at a coating thickness of 100 µm (1) and 200 µm (2)

Based on model studies, recommendations were obtained for the creation of a composite material and primer. The model experiments carried out made it possible to develop new designs of special elements and to determine directions for the development of composite materials for their manufacture using effective technologies.

Structural, rheological and stress-strain characteristics of aliphatic polyamides modified with tall rosin polyamide resin (PR) and nanoscale components are considered. The close molecular structure of PR and industrial polyamides (PA6, PA6.6) ensures the compatibility of the matrix and the inoculant when changing the set of characteristics parameters (Fig. 6). Modified composites based on PA6 have higher parameters of strength and rheological characteristics (Fig. 6, Curves 1, 2).

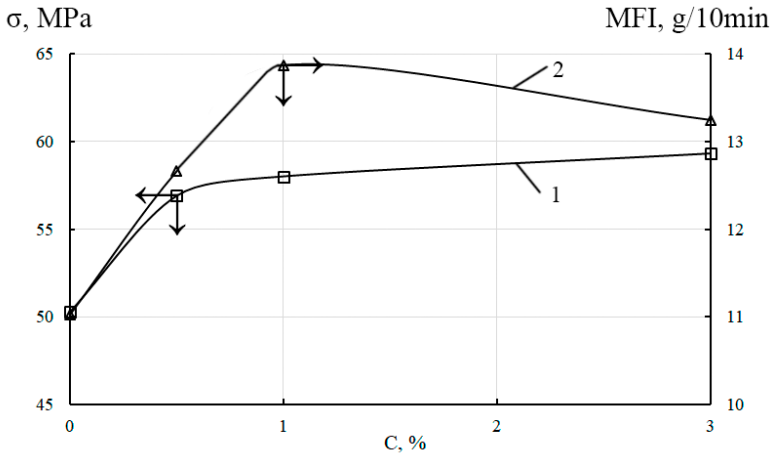


Figure 6. Dependence of tensile strength σ (1) and MFI (2) of polyamide 6 on PS content

The possibility of using PR as a primer base for obtaining functional coatings based on polyamides is considered.

As follows from the works of V.L. Fleisher, N.V. Chernaya, and M.V. Andryukhova, polyamide resin (PR) based on tall rosin is characterized by the presence of functional groups — NH — CO — which enter into adsorption interaction, forming a product thermally stable up to 503 K (Fig. 7, Curve 1). Heat treatment of a sample of PR at a temperature of 573 K for 0.5 hours leads to the intensification of thermal-oxidative processes with the formation of oxide groups, which are capable of forming chemical bonds with a metal substrate and adsorption bonds between macromolecules (Fig. 7, Curve 2) [4].

Morphological studies of the primer obtained by treating the metal substrate with an aqueous solution of PR or a composition based on it (Fig. 8) show a developed structure of the surface layer capable of activating the adhesion interaction with the polyamide coating of PA6, PA11, PA12 by a mechanism similar to the action of the Primgreen primer.

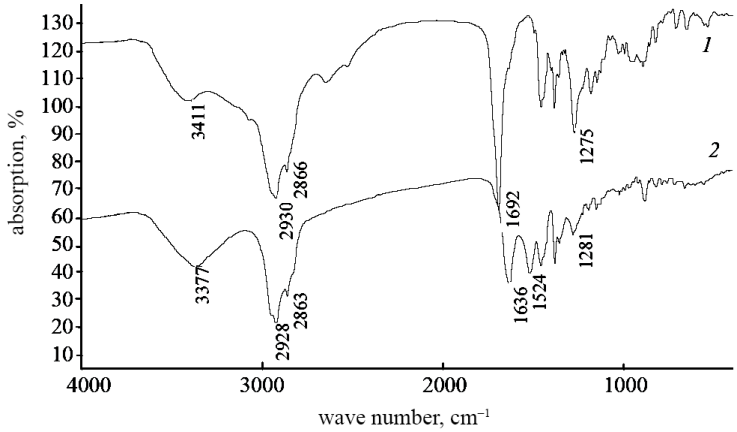
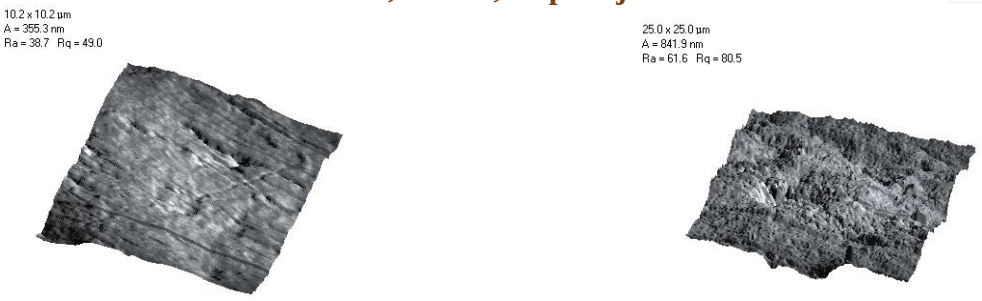


Figure 7. IR spectrum of polyamide resin (PR) raw (1) and heat-treated at a temperature of 573 K for 0.5 h (2) [4]



a) b)



c) d)

Figure 8. Morphology of the surface layer of a sample made of steel initial (a) and after application of Primgreen primer (b), PR resin (c) and composition based on PR and disperse modifiers (d).

The layer thickness is 5 – 10 µm. Treatment temperature 573 K for 0.5 h.

Scan field 25×25 µm

In order to form the optimal structure of the primer and polymer coating that provide the necessary parameters of the stress-strain, tribotechnical and adhesive characteristics of the metal-polymer structure, the implementation of the concept of the nanostate of the modifying component that provides a synergistic effect is effective. Nanosized carbon-containing particles (UDD, UDD-G), cellulose-containing particles (acetide cellulose, microcellulose, carboxyl cellulose), products of copper formate (oxalates) thermolysis were used for the research.

Studies have shown that nano-sized particles of various compositions and production technologies have a complex effect on the structural and technological parameters of polyamide-6-based compositions. A change in the melt viscosity parameter and the parameters of deformation and strength characteristics was established, which indicates the formation of adsorption bonds of the physical type between the nanoparticle and the polyamide macromolecule. The formation of such bonds reduces the activity of the macromolecule in the processes of interaction with oxygen, increasing the resistance of the composite to the effects of elevated temperatures.

The studies carried out made it possible to develop directions for the formation of composite materials for the manufacture of special-purpose products, using as modifiers polyamide resin based on tall rosin and dispersed particles of various production technologies that implement the effect of the nanostate [5–11].

For the manufacture of structural elements of the injector, nozzles for otorhinolaryngology, propeller shafts of trucks, metal-polymer rollers of belt conveyors, composite materials based on industrial thermoplastics with modifiers that implement the effect of nanostate have been

developed. Elements of functional special-purpose products can be produced using traditional injection molding technology or using 3D printing technology [8–11].

Conclusion.

On the basis of the studies carried out, the choice of polyamide resin (PR) based on aminoamides of rosin resin acids as a multifunctional modifier of aliphatic polyamides, composite modifiers based on them, intermediate layers (primers) of metal-polymer structures is substantiated. The mechanism of inoculation of matrix polyamide PA6 (PA6.6) with polyamide resin (PR) and low-melting polyamides, based on high-molecular plasticization, which provides change in the set of parameters of products made of filaments obtained using 3D printing technology.

Based on the concept of multi-level inoculation, compositions of composite materials based on polyamides containing PR and dispersed components have been developed, which have performance parameters 1.1–1.3 times higher than analogues.

Compositions based on PR for inoculation of filaments based on polyamides by diffusion treatment are proposed, intended for the manufacture of functional products by 3D printing with similar parameters of characteristics in different directions.

Nanocomposite materials have been developed for the manufacture of original domestic designs of products – injectors for the introduction of functional components in the field and extreme conditions, nozzles for the treatment and prevention of otorhinolaryngological diseases and metal-polymer rollers for belt conveyors.

The given research was carried out within the framework of integrated assignment 8.4.1.51 "The concept of multilevel modification in materials science and technology of nanocomposites based on thermoplastic blends" of R&D " Mechanisms of the influence of the energy factor in the multilevel structuring of polymer nanocomposites " and R&D "Development of compositions and technology of import-substituting nanocomposite semi-finished products based on thermoplastic blends for the production of products with high parameters of characteristics using additive technologies" included in the subprogram “Multifunctional and composite materials” of the State programs for scientific research “Materials science, new materials and technologies” in 2021-2025.

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