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THE PHENOMENON OF NANOSTATE IN MATERIAL SCIENCE OF FUNCTIONAL COMPOSITES BASED ON INDUSTRIAL POLYMERS

Abstract*: The conceptual directions of creating functional composites based on polymer matrices for metal-polymer systems are considered. An algorithm for developing a methodology for the implementation of the nanostate phenomenon in materials science and technology of composites and metal-polymer systems is proposed. The methodological principles of the implementation of the nanostate phenomenon in materials science and technology of functional materials based on polymer matrices for metal-polymer systems with enhanced performance parameters are proposed.*

Key words*: nanostate, composite material, polymer matrix, methodological principles, metal-polymer systems.*
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Introduction

The implementation of the fifth and sixth technological modes in the economic development of the Belarus economic complex, in accordance with the requirements of the state strategy [1], involves the creation of a domestic material and technological base using convergent technologies [2 - 4]. In the presence of various expert opinions on the effectiveness of convergent NBIC-technologies in the post-industrial economy [3 - 7], it is advisable, based on a systematic approach, to carry out a comprehensive assessment of promising areas of using the existing ideas about the mechanisms of nanostate phenomenon manifestation in functional materials science. In making such an assessment, it is advisable to rely on the classical definition of nanostate, presented by the founder of nanomaterial science P. von Weimarn: "... between the world of molecules (atoms, ions) and microscopically visible particles, there is a special form of matter with a complex of new physicochemical properties inherent in this form ‑ it is an ultrafine or colloidal state that forms when the degree of dispersion (fragmentation) is in the region ($10^5 \div 10^7$) cm^{-1}, in which the films have a thickness, and the fibers and particles have a diameter across the range (1.0–100) nm" [8]. It seems reasonable and advisable to consider the possible mechanisms for implementing the nanostate phenomenon in the development of composite materials with a certain set of functional characteristics for various practical applications. Of particular interest are functional composite materials based on high molecular weight matrices (polymer, oligomeric, combined) which, due to a combination of operational and technological characteristics and economic parameters, are in some cases a non-alternative solution to the problem of industrial production of a new machines and mechanisms generation, including those implementing the principles of self-organization with external influences [9].

The purpose of this work was to evaluate the effectiveness of various directions of nanostate phenomenon manifestation in the development of compositions and technology of functional composites based on polymer matrices of industrial production.

Results and discussion

A systematic analysis of literature and our studies [10–16] made it possible to characterize the nanostate as a special form of existence of particles or elements of condensed matter, characterized by their activity in the processes of interphase interaction, due to the presence of intrinsic or acquired uncompensated and delocalized charge carriers of various nature with variable mobility and localization under the influence of external factors (temperature, mechanical, wave, friction, electromagnetic, radiation, etc.), which manifests itself in a certain size range, individual for each type of substance.

The proposed content of the definition of nanostate allows us to determine the conceptual directions of creating functional composites based on polymer matrices for metal-polymer systems of various types and purposes. The basic components of these areas, shown in Figure 1, are the foundations of materials science and technology that have formed at present, which can be formulated as several conceptual blocks.

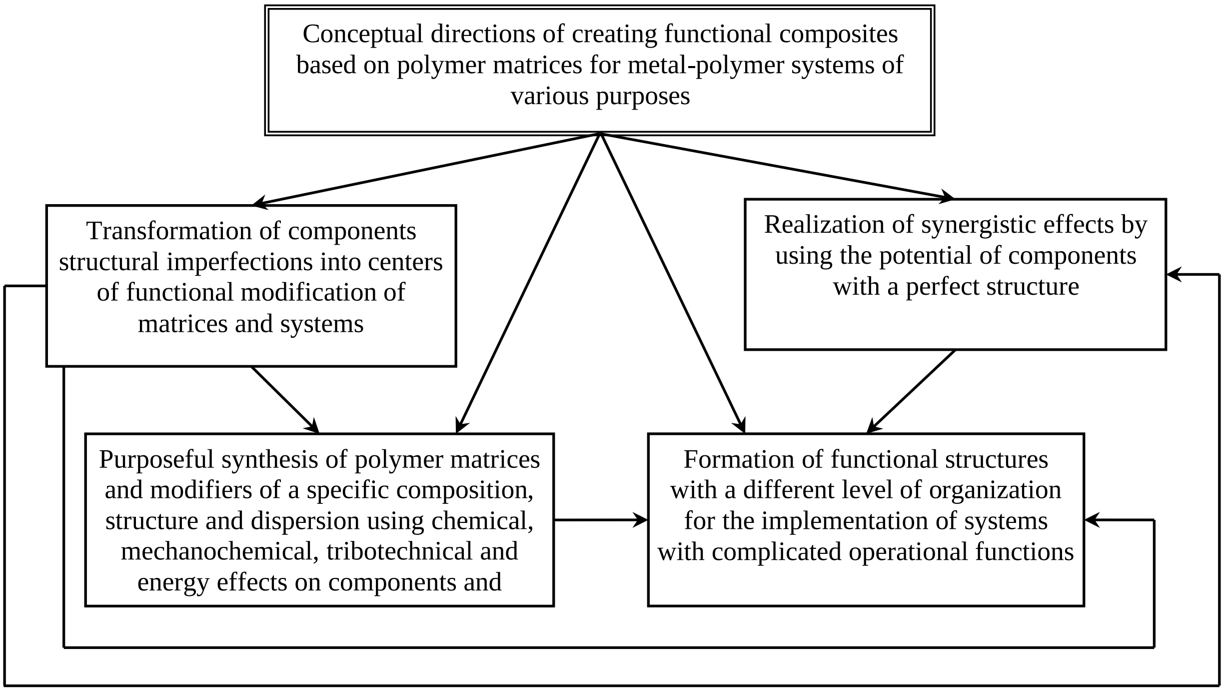

Figure 1 – Conceptual directions for creating functional composites based on polymer matrices for metal-polymer systems

The classical concepts of condensed matter physics and material science about the structural imperfection (defectiveness) of the components of polymer composites [17, 18] make it possible to consider their transformation into centers of functional modification of matrices and systems.

In this approach, it is possible to purposefully introduce into the defective regions of the polymer matrix (which are centers of fracture processes nucleation) of components that cause the formation of a structure with greater resistance to adverse factors (temperature, mechanical, chemical, etc.). In this case, there is possible mutual compensation of structural defects of the matrix binder and functional component (filler, reinforcing, tribotechnical, electric conductive, etc.) with the formation of a system with a synergistic combination of property parameters.

A characteristic example of the validity of this direction are studies carried out by the scientific school of Professor A. Machyulis. [19]. It is obvious that the use of industrial polymer matrices with various levels of structural imperfection of functional components exhibiting signs of nanostate as modifiers will allow develop composite technologies with an optimized structure and higher resistance to operational factors.

A promising conceptual approach to the creation of functional composites based on polymer matrices seems to be providing conditions for the realization of synergistic effects by using the potential of components with a perfect structure. This approach is based on the theoretical and experimentally proven fact of a decrease in the defectiveness of condensed systems upon reaching the dimensional boundaries characteristic of the manifestation of a nanostate. A similar approach can be implemented, for example, in the formation of boundary layers with an optimal structure due to a directed change in the mechanisms of interfacial interactions at the stages of formation and processing of composites [20].

The structural imperfection factor of industrial polymers, manifested in their polydispersity, presence of radical synthesis products, residual amounts of catalysts and monomers, which impedes the realization of potential in functional composites, can in some cases be successfully blocked by targeted synthesis using chemical, mechanochemical, tribotechnical, and energy effects on components and systems for their receipt, processing and operation of products [20].

Analysis of literary sources and our studies clearly indicate the impossibility of achieving optimal parameters of the characteristics of functional composites even when using high-strength components. This effect, called as “structural paradox”, is observed, for example, when reinforcing polytetrafluoroethylene with carbon-containing modifiers – carbon fiber, fullerenes, carbon nanotubes [20]. Therefore, the formation of functional structures based on polymer matrices with various levels of organization seems to be a very promising approach. This approach is implemented in systems with complicated operational functions considered in [9, 16].

The choice of the conceptual direction of creating functional composites based on polymer matrices for metal-polymer systems of various designs is determined by their purpose, technological and economic factors affecting the effectiveness of the decision. At the same time, the expediency of realizing the phenomenon of nanostate of components to form the structure of a composite or system adequate to the intensity of the impact of operational factors is obvious. Regardless of the conceptual direction used, the algorithm of the methodological approach presented in Figure 2 seems reasonable.

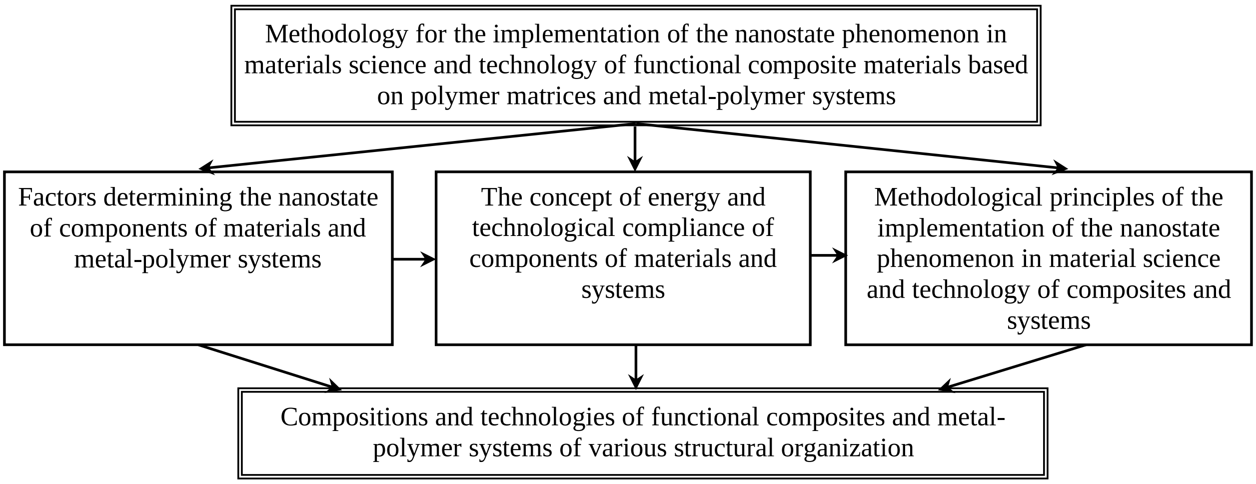

Figure 2 – Algorithm for developing a methodology for the implementation of the nanostate phenomenon in materials science and technology of composites and metal-polymer systems

Studies of the factors that determine the mechanisms of manifestation of the nanostate of the components of materials and systems allow, on the basis of the concept of energy and technological compliance [21], to develop methodological principles for creating functional composites and technologies for their manufacture and processing into products for metal-polymer systems with various levels of structural organization. In developing the principles, we proceeded from the prevailing material, technical, technological and personnel support of the production activities of enterprises of the machine-building complex of Belarus and a number of other states of the post-union space, which is focused mainly on IV technology. The principles proposed in Figure 3 can be implemented in a specific field of nanocomposite materials science –nanocomposites with enhanced performance parameters developed on the basis of polymer matrices of large tonnage production at enterprises in Belarus and other CIS countries.

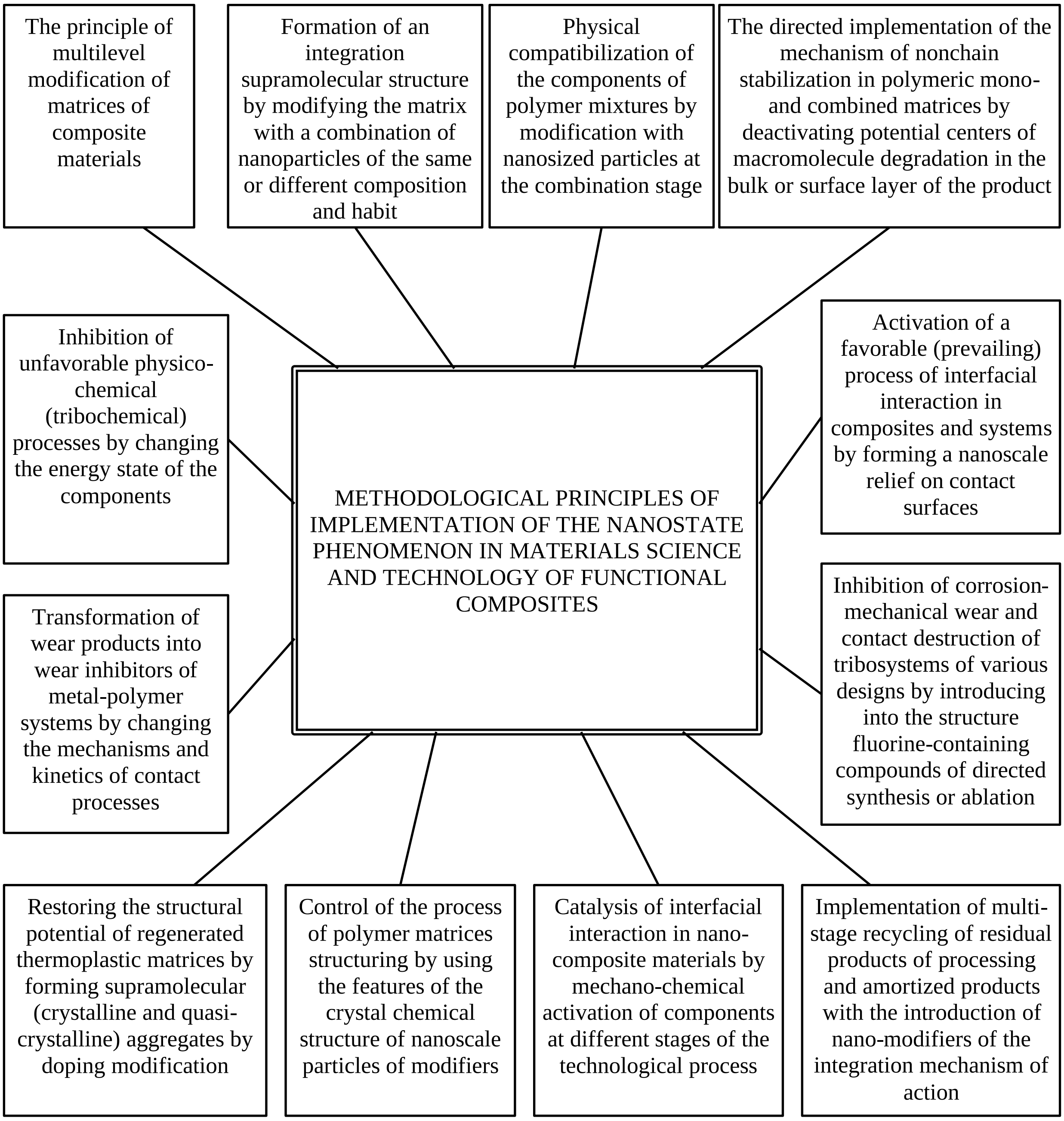

Figure 3 – Methodological principles for the implementation of the nanostate phenomenon in materials science and technology of functional composites based on industrial polymer matrices and metal-polymer systems

The principle of multi-level modification of matrices of composite materials can be implemented by introducing into matrix binder combinations of reinforcing and structural components that form a supramolecular, intermolecular and phase structure of the optimal type and ratio. Inhibition of adverse physicochemical (tribochemical) processes in metal-polymer systems is achieved by changing the energy state of the components. Transformation of wear products of metal-polymer systems into wear inhibitors is possible by changing the mechanisms and kinetics of contact processes.

Doping modification of regenerated thermoplastics with nanosized particles at a content of 0.01 - 1.0 wt. % ensures the formation of supramolecular crystalline and quasi-crystalline aggregates, providing restoration of the structural potential of the material incorporated in the synthesis.

An effective direction for improving the structural parameters of industrial thermoplastics is the introduction into the melt of nanoscale particles of a certain habit – lamellar, spherical, or whisker.

The catalysis of interfacial interaction processes in nanocomposite materials is possible by mechanochemical activation of mixtures of components in the presence of nanoscale modifiers that activate radical transformations with the formation of copolymer products.

Optimization of structural parameters at various levels of organization is possible with multi-stage recycling of residual technological products and amortized products from polymer and composite materials using nanomodifiers of integration action.

The principle of inhibiting corrosion-mechanical wear [21] and contact fracture by introducing into the mixture system nanoscale fluorine-containing ablation or directed synthesis products allows to improve the tribological parameters of metal-polymer conjugations due to the formation of a nanocomposite separation layer.

Formation of nanorelief, which increases the adsorption and mechanical components of the adhesive interaction, is effective with the help of directed energetic effects of a high intensity for manifestation of interfacial processes that ensure the formation of boundary layers of optimal structure in composites containing reinforcing fillers (carbon, glass, and other fibers).

The implementation the principle of non-chain stabilization of polymeric mono- and combined matrices by introducing nanosized components at the plasticization stage and manufacturing products using diffusion technologies makes it possible to obtain nanocomposites for products with increased resistance to thermo-oxidative environments, including tribochemical influences.

An effective principle for the formation of nanocomposites based on mixtures of thermoplastics is physical compatibilization carried out by nanoscale modifiers due to the formation of a spatial network of adsorption-type physical bonds. When a combination of nanosized particles with different habit and temperature range of nanostate manifestation is introduced into the polymer matrix, nanocomposites are formed with an integrated supramolecular structure, which ensures the achievement of increased parameters of deformation-strength, adhesion and tribotechnical characteristics.

Consideration of the structural features of functional composites based on polymer matrices obtained using various methodological principles for the implementation of the nanostate phenomenon is the subject of a special publication.

Testing the developed methodological principles for the implementation of the nanostate phenomenon in materials science and the technology of composites and metal-polymer systems in various versions confirmed their effectiveness and expediency of practical application [13, 16, 20, 22, 23]. It is necessary to emphasize the characteristic feature of the developed methodological principles for creating functional composite materials based on polymer matrices, which consists in orienting them to the existing technological base of domestic industrial enterprises, which is formed on the basis of traditional equipment for producing composites and processing them into products. This aspect not only corresponds to the priority areas of scientific, technical and innovative activity in the Republic of Belarus for 2021–2025 (priority area "Materials science, nanomaterials and nanotechnologies") and the Strategy "Science and Technologies: 2018–2040" developed by the NAS of Belarus, but also expands the branded assortment and the scope of production of functional nanocomposite materials based on large-capacity polymer matrices produced by domestic enterprises. Thus, the approach to nanomaterials and nanotechnologies as "providing or infrastructural technologies" [6], developing modern materials science and the innovative functioning of the domestic industrial complex, is fully implemented.

Conclusion

A systematic analysis of the development of domestic materials science and technology of functional composites indicates an insufficient level of realization of the potential of industrially produced polymer materials using modern achievements in the physical chemistry of polymers and condensed matter physics.

The conceptual directions of creating functional composites based on industrial polymer matrices for systems with enhanced performance parameters, realizing the nanostate phenomenon of material objects at various stages, are proposed. An algorithm has been developed for the implementation of the nanostate phenomenon in materials science and nanocomposites technology, which forms the conditions for the energy and technological correspondence of components and the methodological principles for its implementation in materials science of polymer composites. The proposed methodological principles form the basis for expanding the branded assortment and volume of production and application of functional nanocomposite materials with increased performance parameters based on large-capacity industrial polymers.

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