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## ANALYSIS OF METHODS TO IMPROVE THE STRENGTH AND HEAT RESISTANCE OF COMPOSITE MATERIALS

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Modern composites occupy an important place in the production of high-strength materials due to their lightness, strength, heat resistance, ability to retain their performance properties and the possibility of modification for certain tasks. The article presents modern methods of improving mechanical properties and heat resistance of metal and polypropylene-based composites, their key characteristics, as well as modern processing technologies and innovative combinations with other materials. Particular attention is paid to the prospects for the development of composites with high temperature resistance through the introduction of reinforcing refractory particles, the use of carbon fibers and nanotubes, phosphorus-containing flame retardants, lignin, elastomers, thermoplastics, which opens up new opportunities for their exploitation.

Modification of polypropylene using various fillers, such as polyamides, chalk fillers, and carbon nanoparticles, significantly improves its performance characteristics, including strength, thermal stability, and electrical conductivity. This opens up new horizons for the use of polypropylene composites in conditions of high loads and high temperatures, which is important for the sustainable development of the electronics industry and other high-tech areas.

Metal and polypropylene-based composites have the potential for application in high temperatures and aggressive environments due to the possibility of modifying their structure and composition. The methods and technologies presented in the article allow expanding their functional capabilities, including integration with innovative components.

**Keywords:** composite materials, heat resistance, polypropylene, nanocomposites, carbon nanotubes, fibers, thermoplastic elastomers, adhesion.

## АНАЛИЗ МЕТОДОВ ПОВЫШЕНИЯ ПРОЧНОСТИ И ТЕРМОСТОЙКОСТИ КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ

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Современные композиты занимают важное место в производстве высокопрочных материалов благодаря их легкости, прочности, термостойкости, способности сохранять свои эксплуатационные свойства и возможности модификации под определенные задачи. В статье представлены современные методы улучшения механических свойств и термостойкости композитов на основе металла и полипропилена, их ключевые характеристики, а также современные технологии обработки и инновационные сочетания с другими материалами. Особое внимание уделяется перспективам разработки композитов с высокой термостойкостью за счет введения армирующих тугоплавких частиц, использования углеродных волокон и нанотрубок, фосфорсодержащих антипиренов, лигнина, эластомеров, термопластов, что открывает новые возможности для их эксплуатации.

Модификация полипропилена с использованием различных наполнителей, таких как полиамиды, меловые наполнители и углеродные наночастицы, значительно улучшает его эксплуатационные характеристики, включая прочность, термостойкость и электропроводность. Это открывает новые

горизонты для использования полипропиленовых композитов в условиях высоких нагрузок и температур, что важно для устойчивого развития электронной промышленности и других высокотехнологичных областей.

Композиты на основе металлов и полипропилена имеют потенциал для применения в условиях высоких температур и агрессивных сред благодаря возможности модификации их структуры и состава. Представленные в статье методы и технологии позволяют расширить их функциональные возможности, в том числе за счет интеграции с инновационными компонентами.

**Ключевые слова:** композиционные материалы, термостойкость, полипропилен, нанокомпозиты, углеродные нанотрубки, волокна, термопластичные эластомеры, адгезия.

## КОМПОЗИЦИЯЛЫҚ МАТЕРИАЛДАРДЫҢ БЕРІКТІГІ МЕН ЫСТЫҚҚА ТӨЗІМДІЛІГІН АРТТЫРУ ӘДІСТЕРІН ТАЛДАУ

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Заманауи композиттер жоғары беріктігі бар материалдарды өндіруде маңызды орын алады, олардың жеңілдігі, беріктігі, ыстыққа төзімділігі, пайдалану қасиеттерін сақтау қабілеті және белгілі бір міндеттерге өзгерту мүмкіндігі. Мақалада металл және полипропилен негізіндегі Композиттердің механикалық қасиеттері мен ыстыққа төзімділігін жақсартудың заманауи әдістері, олардың негізгі сипаттамалары, сондай-ақ заманауи өңдеу технологиялары және басқа материалдармен инновациялық комбинациялар ұсынылған. Арматуралық отқа төзімді бөлшектерді енгізу, көміртекті талшықтар мен нанотүтіктерді, құрамында фосфор бар отқа төзімді заттар, лигнин, эластомерлер, термопластиктерді қолдану арқылы жоғары температураға төзімді композиттерді әзірлеу перспективаларына ерекше назар аударылады, бұл оларды пайдаланудың жаңа мүмкіндіктерін ашады.

Полипропиленді полиамидтер, бор толтырғыштары және көміртекті нанобөлшектер сияқты әртүрлі толтырғыштарды қолдану арқылы өзгерту оның беріктігін, термиялық тұрақтылығын және электр өткізгіштігін қоса алғанда, оның өнімділігін айтарлықтай жақсартады. Бұл электронды өнеркәсіптің және басқа да жоғары технологиялық салалардың тұрақты дамуы үшін маңызды болып табылатын жоғары жүктемелер мен жоғары температура жағдайында полипропилен композиттерін қолданудың жаңа көкжиектерін ашады.

Металдар мен полипропилен негізіндегі Композиттердің құрылымы мен құрамын өзгерту мүмкіндігіне байланысты жоғары температура мен агрессивті ортада қолдану мүмкіндігі бар. Мақалада ұсынылған әдістер мен технологиялар олардың функционалдығын, соның ішінде инновациялық компоненттермен интеграциялау арқылы кеңейтуге мүмкіндік береді.

**Түйін сөздер:** композициялық материалдар, ыстыққа төзімділік, полипропилен, нанокомпозиттер, көміртекті нанотүтікшелер, талшықтар, термопластикалық эластомерлер, адгезия.

**Introduction.** Modern industry is placing increasingly stringent demands on materials, especially in areas such as automotive, aerospace and construction. Traditional materials such as pure metal, plastic or carbon often cannot meet the requirements for a combination of lightness, strength and resistance to extreme temperatures. Composite materials bring out the best properties of different components with unique characteristics. Improving the mechanical properties and thermal resistance of composites such as polypropylene, metal and carbon fiber composites is an important factor in expanding their application and performance.

Composites are materials made up of two or more components depending on the natural conditions to achieve a unique advantage. The most widely

used types of composites include polymer, metal and carbon composites. However, their performance properties are often limited by fragility, insufficient heat resistance, or poor adhesion between phases [1-2].

The main components of composites include matrix (base), responsible for bonding and dependence, and reinforcing material (filler), increasing strength and mechanical performance. At the present stage of industrial development, composites are widely used in a wide variety of fields such as construction, metallurgy, transportation, medicine, electronics, etc. [3-6] The list of main types of composites is diverse and wide. These are reinforced polymers, composites for pipelines and fittings, metal matrix composites (MMC), heat resistant composites, carbon fiber and glass fiber composites, biocomposites, materials for surgical instruments, etc. [7-10].

Current composites have their own problems and limitations, which includes insufficient interfacial adhesion, brittleness under impact loading, limited thermal resistance, difficulty in processing and disposal, initial cost, lack of liquidity data, difficulty in developing hybrid materials and lack of uniform standard qualities [11-13].

Solving these problems requires a comprehensive solution, including the development of new technologies, optimizing production processes, improving environmental friendliness and reducing the cost of materials.

Despite this, composites remain in demand due to their excellent properties, such as high strength, lightness, corrosion resistance and the ability to create products with specified performance characteristics. Constant development of technologies, development of new types of composites and improvement of methods of their production allow to regulate the scope of their application, reduce costs and eliminate possible problems.

**Materials and methods.** *Metal-based composites.* Metal-based composites attract great interest. Their structure, which combines a metallic matrix with inclusions of non-metallic nature, allows them to overcome the boundaries of high strength, lightness, corrosion resistance and other unique properties unattainable for traditional materials. Such properties make them in demand in various industries including aerospace, automotive, energy and construction sectors [14-16]. The most common matrices are aluminum, magnesium, titanium, and iron. Reinforcing materials can be ceramic particles, fibers, carbon nanostructures and oxide compounds.

One of the main advantages of metal composites is the ability to fine-tune their properties by changing their composition and structure. This is a way to optimize synthesis processes such as powder metallurgy, mechanical alloying, reinforcement casting and additive technologies. For example, the addition of carbon nanotubes to an aluminum matrix can increase the density of a strong material without significantly increasing its mass [17-19].

Special attention is paid to the study of mechanical, thermal and electrical properties of metal composites, as well as their behavior under extreme operating conditions. Studies of thermal resistance and durability open new horizons for the application of materials in aggressive environments or at high temperatures [20-21].

One of the promising structural materials with improved characteristics are materials obtained by means of various types of reinforcement, such as metal matrix CMs (composite materials) consisting of a metal or alloy as a continuous matrix and a reinforcing component in the form of particles, as well as short or continuous fibers [22-26]. In metal matrix CM, the main metal matrices are aluminum, titanium, copper, and magnesium alloys. According to literature data, in CMs with aluminum matrix reinforced with carbon fiber, wetting of fibers is carried out to a sufficient extent, which can improve mechanical properties [27-30].

Metal composites based on titanium matrix have high specific strength and elastic modulus, high temperature resistance and low density, which makes them attractive for aerospace, automotive and military applications, but the use of titanium alloys as structural materials under conditions of high friction and wear is limited due to their low tribological properties [31-32]. Nevertheless, the

addition of refractory particles to titanium and its alloys is an effective way to improve mechanical and wear properties.

The paper [33] presents studies on fabrication and evaluation of the effect of the content of various reinforcing elements on the properties of metal composite materials (MCMs) based on titanium alloys. Introduction of refractory particles $TiB_2$, $B_4C$, SiC and TiC into titanium and its alloys is an effective way to increase mechanical, wear-resistant and corrosion-resistant properties with simultaneous reduction of material density, and also contributes to the expansion of the area of application of MCMs. The size and distribution of reinforcing particles in the matrix and their chemical activity have a great influence on the microstructure and mechanical properties. Carrying out heat treatment process helps to increase the mechanical properties. Metal composites reinforced with solid particles have an advantage (compared to MCMs reinforced with continuous fibers) in the form of isotropic properties, are cheaper to produce and can be further processed.

In [34], the compound $B_4C$ was used as a reinforcing element to improve the mechanical, corrosion, and tribological properties of the titanium alloy of the composition Ti-6Al-4V (hereinafter referred to as the alloy composition in % (by mass)), noting its thermodynamic stability and high mechanical properties. The alloy of composition Ti-6Al-4V and ceramic powder $B_4C$ with an average particle size of 30 microns were used for the production of MCM samples by powder metallurgy. MCM samples were made with the content of 5 and 10 % (by mass) of $B_4C$. As a result of the study of physical and mechanical properties of the samples, it was found that the density of MCM decreases with increasing content of reinforcing particles, but the difference between theoretical and experimental density increases with increasing $B_4C$ content, which is explained by the increase in porosity with increasing content of $B_4C$ particles (Fig.1, a). The hardness and corrosion resistance increase with increasing amount of reinforcing B4C particles (Fig.1, b).

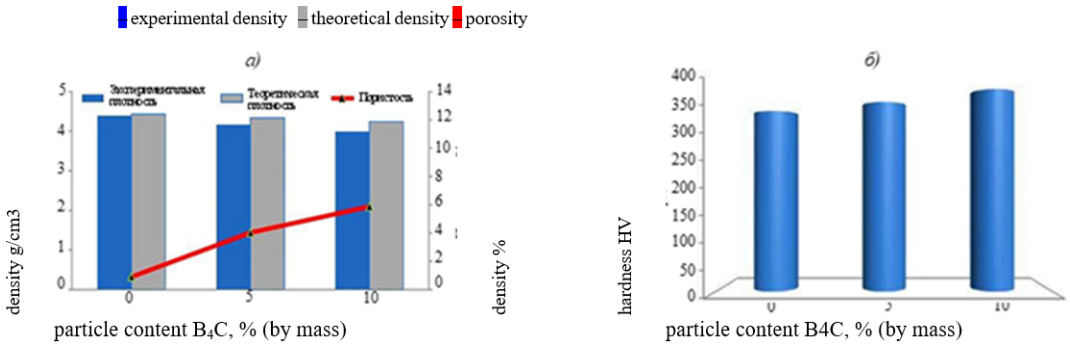



**Fig.1 - Effect of the content of ceramic $B_4C$ particles on the properties of MCM composition (Ti-6Al-4V) + $B_4C$ on density (a) and hardness (b) [34]**

Similar studies [35-37] confirmed that the wear rate of the composite material decreases with increasing in situ formed TiB and TiC particles, and concluded that TiB and TiC particles improve the wear properties of the composite material.

The influence of sintering temperature and the content of $B_4C$ particles on the properties of composite material obtained by powder metallurgy was investigated in [38]. The increase in hardness and compressive strength of the composite material increases with increasing sintering temperature and increasing the content of reinforcing component.

In [39] the influence of $B_4C$ particles and laser energy density on microhardness of composite material of Ti-6Al-4V composition obtained by selective laser sintering was investigated. When obtaining the composite material, $B_4C$ particles react with titanium and in the in situ process TiC and

TiB particles are formed in different proportions, the microhardness increases by 30-80 % depending on the laser energy density.

Currently, high-modulus carbon fibers are the most suitable material for creating composites with titanium matrix. Selective reinforcement of titanium plates of small thickness allows to provide control of high reactivity of "titanium/carbon" compound and to create suitable processing methods [40-42].

Laminated structures consisting of alternating layers of metal sheets and fiber-reinforced polymer-matrix composites are also used in aircraft parts structures. Compared to conventional monolithic metals, they have high specific strength and stiffness, excellent fatigue resistance characteristics, and increased fire resistance [43].

To improve the mechanical properties of CMs with layered structure, including metal plastic layer and intermetallic layer (Ti-Al3Ti), various continuous fibers - carbon (C), silicon carbide (SiC) and aluminum oxide ($Al_2O_3$) - are introduced. Using various processing techniques, a number of intermetallic metallic layered CMs of systems such as Ti-Al, Ni-Al, Nb-Al and Ti-Cu are obtained. It is believed that the application of such titanium-aluminum layered CMs with high physical and mechanical properties is potentially possible in aerospace and armor protection applications. Using a novel rapid prototyping technique, ultrasonic consolidation was applied to fabricate three-dimensional structures via additive manufacturing from metal foil. During the ultrasonic consolidation process, ultrasonic frequency vibration combined with nominal force was used to generate static and oscillating shear forces between the metal foil layers that formed a solid-state bond. Moreover, ultrasonic consolidation was used to join dissimilar materials such as Ti-Al, Cu-Al, and Fe-Al at low temperatures (~480 °C). Thus, ultrasonic consolidation can be used as an auxiliary method to disperse fiber bundles into individual fibers in the alloy matrix prior to CM formation [44-46].

In [47], studies were conducted to determine the mechanical characteristics of CM produced by die casting method using AA6061 matrix aluminum alloy, which is reinforced with carbon fiber. The studies showed that increasing the content of reinforcing component from 0 to 10% (vol.) allows increasing the torque from 24.5 to 52 N-m, tensile strength from 283 to 315.5 MPa, as well as increasing the impact strength at 10% (vol.) of carbon fiber up to 12.2 J [47].

The microstructure of the CM of AA6061 grade aluminum alloy and carbon fiber shows that the carbon fibers are evenly distributed in the matrix, and interfacial adhesion is present (Figure 2).

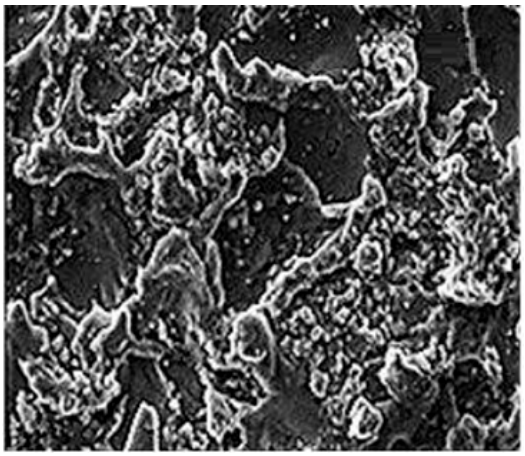


**Fig.2 - Microstructure of composite material made of aluminum alloy AA6061 and carbon fiber [47]**

In similar works [48-50] the authors describe in detail the physical and mechanical characteristics of materials with different matrix alloys (content of reinforcing carbon fibers - from 5 to 50 % (vol.)) and the mechanisms of failure of composites after the tests. In [48-49], studies of thermophysical and mechanical properties of CMs obtained by powder metallurgy on the basis of aluminum matrix reinforced with carbon fibers were carried out. It was found that when the volume content of carbon fiber increases, hardness, electrical conductivity and strength decrease: from 71 to 56 HB, from 30.9 to 14.5 cm and from 529 to 214 MPa, respectively, thermal conductivity increases to 155 W/(m-K), and the temperature coefficient of linear expansion (TCLE) decreases - from 36-10-6 to 8-10-6 K-1 [48].

Among the basic properties of composite materials, heat resistance and heat resistance, the ability of a material to retain its original strength

at high temperature, are of particular importance for the most common structures [51-53]. For other types of heat-resistant materials, such as those based on minerals (ceramics, refractories with various mineral fillers and binders), the concept of refractoriness is applicable, i.e. the ability of the material to resist destruction without deforming during operation at temperatures not lower than 1580 °C [54]. Composite materials with ceramic matrix have high heat resistance, relatively high compressive strength, but tensile strength and impact strength have low values. The scientific direction of solving the problem of increasing the strength of composite material is the necessity of transferring a significant part of the load to reinforcing elements [55-57].

It is of scientific and practical interest to solve the problem of increasing the strength and heat resistance of composite material of the metal-ceramic system by changing the macrostructure of the introduced reinforcing material and matrix composition.

The most common methods of molding composite materials are pressing and sintering, which in some cases is not economical, for example, molds are difficult to manufacture, this disadvantage significantly increases the cost of products. The use of slurry with hydrophilic tooling to remove moisture and give primary technological strength to the composite material, provides cost reduction and increased cost-effectiveness [58-60].

In work [61], the analysis of properties of composite materials is given, increase of heat resistance and heat resistance of composite material on the basis of stabilized silica, wastes of metallurgical and glass industries, was achieved by improving the structure of composite material, introduction of reinforcing elements. For the production of composite material was used an economical method of molding into hydrophilic tooling.

Slip is a suspension in the form of liquid dispersion medium and solid fine-dispersed phase, for example, in the form of SiO2 and Fe, crushed to the size of 0.5...10 microns, as well as additives: stabilizing volumetric transformations of SiO2 during heating or cooling (Na2O); increasing sedimentation stability of slip (refractory clay). This material is fluid in the stage of preparation and pouring, plasticity while in the mold and strength after partial dehydration of the slip, for example, in a gypsum mold. The combination of stabilized silica-based slurry, reinforcing components, glass production waste and hydrophilic tooling reduces energy consumption by 18% and increases the cost-effectiveness of manufacturing products of the metal-ceramic system in comparison with traditional methods of composite materials forming [61].

Despite the obvious advantages, the development of metal-based composites involves obtaining a criterion for uniform distribution of reinforcing particles and the need to accurately determine the interactions between components. However, modern advances in computer modeling, nanotechnology, and experimental techniques offer new opportunities to overcome these difficulties. Thus metal-based composites continue to be the basis of research that will shape the development of high-tech materials in the future. Their unique properties and potential applications in a wide range of regions make them the object of close attention of the scientific community and industry.

*Polypropylene-based composites.* Today, polymer composites are of particular interest and are being actively introduced into various fields due to their unique properties, including high elasticity, strength, stiffness and high specific strength.

Polypropylene is one of the most widely used polymers in the world. Since its commercial introduction in the 1950s, polypropylene has established a reputation for its unique properties and versatility in application [62].

Polypropylene can be easily molded and extruded to produce complex shapes. It is able to retain its size and shape when exposed to high temperatures and loads. It combines low density and high strength, making it ideal for use in the manufacture of lightweight but strong products [63].

Modern technologies make it possible to combine polypropylene with natural and synthetic fibers. This

opens up new possibilities for creating materials with improved thermal and mechanical properties. The addition of synthetic fibers and fillers (such as carbon or glass fibers) can improve the strength and stiffness of polypropylene products, which expands their application [64].

The improvement of these materials through the addition of carbon nanotubes (CNTs) and fibers is an active area of research aimed at improving their performance [65].

Modification of polypropylene with carbon nanotubes and fibers allows to significantly improve the mechanical properties of composites, in particular, their impact resistance and stiffness. It was found that the addition of carbon nanotubes can increase the impact resistance of the composite up to seven times, which makes such materials competitive with more expensive analogs. Mechanical stiffness and resistance to deformation under load are also significantly increased by the inclusion of continuous carbon fibers, which expands their application areas, including high and low temperature conditions [66].

The need to use carbon nanotubes arises due to their unique properties, including high thermal conductivity, strength and the ability to form conductive networks within the polypropylene structure. Studies show that the introduction of CNTs into PP composites leads to a significant improvement in mechanical properties due to a more homogeneous distribution of reinforcing additives and their strong interaction with the polymer matrix [67].

Many CNT modification techniques, including covalent and non-covalent modification, are used to achieve the best results in the creation of composites. These methods help to improve the dispersion of fillers in the polymer matrix, allowing for more robust interfacial interactions. CNT modification allows the attachment of functional groups such as epoxy, hydroxyl and carboxyl groups, which also helps to improve the bond strength between the matrix and filler [68].

In addition, oxidation of carbon nanotubes carried out using various oxidizing agents such as $H_2SO_4$, $KMnO_4$, $H_2O_2$ and $HNO_3$ allows the introduction of functional groups on their surface. This leads to the formation of defective sites, which can adversely affect the engineering properties, but this approach significantly improves the adhesion of CNTs in the polymer matrix, which is the cornerstone of an efficient composite structure [69].

The introduction of nanotubes into the structure of polypropylene composites provides improvements in properties such as strength, heat resistance and mechanical stiffness, making them competitive with more expensive materials [70].

Studies show that PP and nanotube-based composites exhibit significant improvements in mechanical properties such as impact resistance and stiffness. Carbon nanotubes contribute to increased strength and resistance to deformation under loading due to their high strength and ability to form conductive networks within the polymer matrix. In particular, the use of metallocene polypropylene in combination with carbon fillers improves the strength and ductility of composites [71].

Melt extrusion is the preferred method of producing PP-CNT composites because of its ability to create homogeneous materials through mixing of components at high temperatures. However, lack of control during the extrusion process can lead to thermal fracture and residual stresses that negatively affect the properties of the composites. To increase the dispersion of CNTs in the polymer matrix, various modifications and blending methods are actively investigated, indicating the importance of controlling the extrusion process to achieve optimal performance [72].

Modifications of carbon nanotubes are necessary to ensure high-quality interfacial adhesion between PP and CNTs. The grafting of maleic anhydride (MA) onto polymer chains significantly improves the compatibility of CNTs with the polymer matrix and also helps to reduce the surface tension. This allows for better dispersion of CNTs and formation of efficient percolation networks. Studies show that the use of modified compatibilizers such as styrene-ethylene/butylene-styrene copolymer leads to a significant improvement in the mechanical and thermal properties of composites [73].

The high flammability of polypropylene limits its use in applications requiring fire resistance. To solve this problem, active research is directed to the use of phosphorus-containing flame retardants (phosphorus fire retardant additives), which show high efficiency in reducing the flammability of polymeric materials [74].

Phosphorus flame retardants have unique properties that provide low toxicity and the ability to form a protective layer on the surface of the material when exposed to high temperatures. This protective layer promotes thermal decomposition of the flame retardant, forming a carbon residue that serves as a barrier to flame propagation. These mechanisms of action make it possible to significantly increase the fire resistance of polypropylene composites [75].

Studies conducted by various research groups have confirmed that the addition of phosphorus flame retardants to PP significantly improves its mechanical and thermal properties. The addition of phosphorus flame retardants to PP increases the tensile strength and stiffness of composites at high temperatures, which improves their performance without degrading the basic properties [76].

Phosphorus-containing flame retardants are a promising alternative to halogen-containing flame retardants, which were previously widely used but criticized for their toxicity and negative environmental impact. In contrast, phosphorus-containing additives help to reduce flammability while remaining safer for humans and nature [77].

The retrofitting of polypropylene with phosphorus-containing flame retardants opens new horizons for the application of composites in products that require high fire resistance. For example, the study of new methods of modifying composites, such as blending with carbon nanotubes (CNTs), improves thermal stability and mechanical properties while maintaining environmental safety [78].

To achieve higher performance characteristics of polypropylene composites with phosphorus-containing flame retardants, it is necessary to continue the optimization of compositions and technologies of their processing. This includes the study of new polymer modifications and the use of alternative fillers, which can lead to the creation of stable and functional materials that meet modern requirements [79].

Polypropylene is one of the most popular thermoplastics with good mechanical and physical properties. However, various modification methods are being investigated to enhance its functionality and performance, including the use of biopolymers such as lignin and chitosan. These additives not only improve the mechanical properties of composites but also make them more environmentally friendly [80].

Modification of polypropylene with chitosan fibers can significantly improve its strength and impact resistance. Chitosan, being a biopolymer with good adhesion to the polymer matrix, contributes to the improvement of tensile and impact performance. Experiments have demonstrated that composites with modified fibers provide a significant improvement in mechanical properties compared to unmodified samples [81].

The use of esterified lignin as a modifier is important for achieving high adhesion between composite components. Lignin, being a secondary natural polymer, shows excellent binding properties, which improves the structure of the final material. Studies show that the presence of lignin helps to create strong interfacial interactions between chitosan and polypropylene, which enhances the strength and durability of the composite [82].

The process of mixing the components at high temperatures, such as 190°C, ensures uniform distribution of fillers in the polypropylene matrix. Homogeneity of distribution is critical to achieving optimum strength and strain resistance. Studies in this area show that lack of homogeneity can lead to poor mechanical performance and reduced material stability [83].

The resulting polypropylene-based composites with modifiers such as lignin and chitosan have a wide range of potential applications in industries such as packaging and construction. These fields require lightweight and strong materials that can withstand mechanical stresses. The improved

performance of modified composites opens up new opportunities for their use in various sectors including automotive and consumer products [84].

Composites based on thermoplastic elastomers have attracted considerable attention due to their unique properties that provide high flexibility, strength and resistance to external influences. Of particular interest is the combination of styrene thermoplastic elastomers with polypropylene, which makes them promising for applications in the construction industry and other areas where high strength and durability of materials are required [85].

Thermoplastics are classes of polymers that combine the properties of thermoplastics and elastomers. They are recyclable, making them convenient for manufacturing processes, while providing the elasticity characteristic of rubber bands. Studies show that blends of styrene thermoplastic elastomers and polyolefin elastomers can improve the performance of materials, which has initiated a number of scientific studies in this area [86].

One of the key tasks in improving composites based on thermoplastic elastomers is to increase their resistance to thermal oxidative degradation. Studies show that the introduction of antioxidants, heat-resistant fillers and modifiers can significantly improve the performance characteristics of materials and their durability [87].

Improving the fire resistance of thermoplastic elastomers is also an important aspect for their use in building structures. The use of minerals such as aluminum hydroxide and other flame-retardant additives shows promising results in improving the fire-retardant properties of composites, making them safer for use in high temperature environments [88].

The problem of rubber waste utilization remains relevant, and the use of crumb rubber as a filler for thermoplastics provides an opportunity not only to solve environmental problems, but also to expand the application area of such composites. Studies have proven that the addition of crumb rubber to polyethylene and polypropylene can improve certain mechanical characteristics such as impact strength and flexibility [89].

The key factors affecting the mechanical properties of composites are matrix characteristics, filler particle size and the level of adhesion between components. Optimization of these properties can be achieved by various methods such as changing the mixing technology, using modifiers and adhesion promoters [90].

The study of composites based on thermoplastic elastomers, particularly their blends with polypropylene and styrene thermoplastic elastomers, has become an important aspect because of the increasing demands for durability and safety of building materials [91].

Thermoplastic elastomers, including blends with polyolefin elastomers, have flexible, strong and resistant properties. This allows them to find applications in the construction, medical and automotive industries, where high strength and durability of materials are required [92].

Also the practical significance of the research lies in the development of new formulations of composites based on thermoplastic elastomers, which allows to create materials with improved performance characteristics. The created composites are characterized by high resistance to thermo-oxidative degradation and reduced flammability, which makes them suitable for the production of window seals, cable products, roofing membranes and other construction products [93].

The introduction of crumb rubber into the composition of thermoplastics solves the problems of utilization of waste rubber products and expands the practical applications of plastics. The resulting rubber plastics are used in waterproofing, production of roofing materials and rubber tiles, while optimizing their mechanical properties [94].

Studies show that different temperatures and rubber filler content significantly affect the deformation and strength of composites. In particular, certain concentrations of crumb rubber contribute to the transition of the material from brittle fracture to macrouniform plastic deformation, which opens up opportunities for

targeted modification of the properties of rubber plastics [95-96].

Incorporation of waste-derived graphene into polymer composites can increase their mechanical and thermal performance while improving flexural and tensile strength. This supports the trend towards lighter and greener materials, which helps to reduce the carbon footprint in the automotive and other industries [97].

**Results and Discussion.** Research into polymers with improved conductive properties opens new horizons for flexible electronics. The development of conductive polymer nanocomposites can contribute to the creation of more reliable and durable flexible electronic devices, which will be a significant step forward in technology development [98].

Modification of polypropylene using various fillers such as polyamides, chalk fillers and carbon nanoparticles significantly improves its performance characteristics including strength, thermal stability and electrical conductivity. This opens new horizons for the application of polypropylene composites in high stress and high temperature environments, which is important for the sustainable development of the electronics industry and other high-tech fields [99].

Research and development of polypropylene-based nanocomposites using various fillers open new horizons in the construction industry, improving the mechanical characteristics and thermal stability of materials. Special fillers help to accelerate crystallization processes and increase resistance to environmental influences, which makes such composites competitive for use not only in construction, but also in the packaging and automotive industries [100].

Thus, polypropylene composites are a promising area in materials production due to their versatility, availability and modification possibilities, such as carbon nanotubes, phosphorus-containing flame retardants, lignin, elastomers, thermoplastics and others. These modifications allow to significantly improve mechanical properties, heat resistance, flame retardancy and expand their application in high-tech and industrially important areas.

**Conclusions.** Research in the field of increasing the strength and heat resistance of composite materials is one of the promising areas in the field of chemical technologies and materials science, opening up wide opportunities for the development of innovative solutions.

Metal and polypropylene-based composites have the potential for application in high temperatures and aggressive environments due to the possibility of modifying their structure and composition. The methods and technologies presented in the article allow expanding their functional capabilities, including integration with innovative components.

The review shows that the use of modern modification methods, such as the introduction of reinforcing refractory particles, improvement of interfacial interaction, the use of carbon fibers and nanotubes, phosphorus-containing flame retardants, lignin, elastomers, thermoplastics allows to significantly increase the strength characteristics and heat resistance of composites.

The prospectivity of developments in this direction is due to the growing requirements for materials used in the metallurgical industry, construction, transportation, energy. Special attention should be paid to the development of hybrid materials that combine the advantages of polymers, metals and carbon fibers. Future research should be aimed at optimizing upgrading technologies and studying their performance characteristics of composites.

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