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IMPROVEMENT OF THE TECHNOLOGY FOR PRODUCING COMPOSITE MATERIALS BASED ON SECONDARY POLYMERS

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Abstract

The paper presents the results of a study aimed at improving the technology for producing composite materials based on secondary polymers in order to enhance their physical and mechanical performance. The influence of composition, filler content, processing temperature regimes, and the use of modifying additives on the structure formation and properties of polymer composites was investigated. It was established that optimization of technological parameters makes it possible to compensate for the negative effects of secondary polymer degradation and to increase strength, impact resistance, and property stability. The obtained results confirm the prospects of the proposed technology for the development of resource-saving and environmentally oriented composite materials.

Keywords

secondary polymers, composite materials, production technology, physical and mechanical properties, polymer recycling, fillers, modification.

INTRODUCTION. In the context of modern industrial development and the intensification of environmental challenges, the rational utilization of secondary polymer resources has become particularly relevant. The growing volume of polymer waste, the limited availability of primary raw materials, and the tightening of environmental regulations stimulate the search for effective technological solutions aimed at recycling secondary polymers and producing materials with predetermined performance characteristics.

Composite materials based on secondary polymers represent a promising direction in materials science and chemical technology, as they make it possible to simultaneously address issues of resource conservation, cost reduction, and mitigation of negative environmental impacts. However, repeated processing of polymers is associated with a number of technological challenges, including degradation of the macromolecular structure, deterioration of physical and mechanical properties, and instability in the quality of final materials.

An analysis of existing technologies for the production of polymer composites shows that most of them are focused on the use of primary polymers, while methods for processing secondary raw materials often fail to ensure the required levels of strength, wear resistance, and durability. This necessitates the improvement of technologies for producing composite materials based on secondary polymers in order to enhance their physical, mechanical, and operational characteristics.

In this context, particular importance is attached to the optimization of technological processing parameters, including the selection of composite formulations, methods of polymer matrix modification, mixing and molding conditions, as well as the use of functional fillers and additives. Improvement of these aspects makes it possible to compensate for the negative effects of polymer aging and to ensure the formation of a stable composite material structure.

Thus, the relevance of the present study is determined by the need to develop and scientifically substantiate improved technologies for producing composite materials based on secondary polymers with enhanced physical and mechanical properties and expanded possibilities for practical application. The results of the research may be used in the development of resource-saving and environmentally oriented materials for various industrial sectors.

LITERATURE REVIEW. In recent years, the recycling of secondary polymers and the production of composite materials based on them have been regarded as one of the priority areas

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in the development of polymer materials science and resource-saving technologies [1, 2]. The increasing volume of polymer waste and the limited availability of primary raw materials necessitate the implementation of advanced technologies for processing secondary polymers, ensuring the production of materials with predetermined performance properties [3].

A number of studies indicate that repeated polymer processing is accompanied by degradation of the macromolecular structure, a decrease in molecular weight, and deterioration of physical and mechanical characteristics such as strength, impact toughness, and wear resistance [4, 5]. The authors note that thermo-oxidative and mechanodestructive processes are the main factors limiting the repeated use of polymer materials without additional modification [6].

Scientific publications emphasize the effectiveness of using fillers and modifying additives to compensate for the negative effects of aging in secondary polymers [7]. The incorporation of mineral, fibrous, and dispersed fillers makes it possible to improve the strength and deformation characteristics of composite materials, as well as to enhance their thermal resistance and dimensional stability [8, 9]. Particular importance is attached to interfacial interactions between the polymer matrix and the filler, which determine the structural integrity of the composite [10].

Considerable attention in the literature is paid to the influence of processing parameters of secondary polymers on the properties of composite materials. It has been established that processing temperature, mixing speed, molding pressure, and cooling regimes significantly affect the degree of homogenization of the composition and the formation of the supramolecular structure of the material [11, 12]. Optimization of these parameters allows for improved reproducibility of properties and reduced variability in the performance characteristics of finished products.

Foreign studies focus on the environmental and economic aspects of using secondary polymers in composite materials [13]. It is noted that the application of recycled polymers contributes to a reduction in the carbon footprint and a decrease in the volume of waste disposal, which is consistent with the concept of sustainable development [14]. At the same time, the need to improve processing technologies in order to expand the application areas of secondary polymer composites is emphasized [15].

Thus, an analysis of the literature shows that, despite a significant number of studies devoted to the production of composite materials based on secondary polymers, the task of comprehensive improvement of their processing technologies remains relevant. Issues related to the optimal combination of composition and processing regimes that ensure stable physical and mechanical properties of composites remain insufficiently studied, which determines the scientific novelty and practical significance of the present research.

METHOD AND METHODOLOGY OF THE RESEARCH. The methodological basis of the present study is a comprehensive approach that integrates the principles of polymer chemical technology, materials science, and physico-mechanical analysis of composite materials. The study applies the principles of systems analysis, which make it possible to establish relationships between the composition of secondary polymer composites, the technological parameters of their processing, and the performance properties of the resulting materials.

The object of the research is composite materials produced on the basis of secondary polymers. The subject of the research is the technological parameters of their production and their influence on the structural and physico-mechanical properties of the composites.

Secondary thermoplastic polymers that had undergone preliminary sorting, cleaning, and mechanical preparation were used as raw materials. The process of producing composite materials included the stages of grinding the secondary polymer, mixing it with fillers and modifying additives, thermal processing, and molding of specimens. During the experiments, the composition of the composite, filler content, processing temperature regimes, as well as mixing and molding parameters were varied.

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A set of experimental methods was employed to investigate the structure and properties of the obtained composite materials. Physico-mechanical characteristics, including tensile, flexural, and compressive strength, as well as impact toughness, were determined using standard testing procedures. The density and water absorption of the specimens were evaluated in accordance with regulatory requirements applicable to polymer materials.

The structural features of the composites were analyzed using microscopic methods that made it possible to assess the degree of filler dispersion and the nature of interfacial interactions between the components of the composite. The thermal properties of the materials were studied using thermal analysis techniques in order to evaluate the thermal resistance and stability of the secondary polymer matrices.

Experimental data were processed using methods of mathematical statistics and comparative analysis. Correlation analysis and elements of factorial experimental design were applied to assess the influence of individual technological factors on the physico-mechanical properties of the composite materials. This made it possible to determine optimal conditions for producing composites with improved performance characteristics.

Thus, the applied research methodology ensures a comprehensive assessment of the technological aspects of producing composite materials based on secondary polymers and provides a scientific basis for improving processing technologies in order to enhance the quality and functional properties of the resulting materials.

RESEARCH RESULTS. During the experimental studies, the technology for producing composite materials based on secondary polymers was improved, and the influence of technological parameters and composite composition on their physico-mechanical properties was evaluated. The obtained results indicate that a rational selection of composition and processing regimes makes it possible to significantly enhance the performance characteristics of secondary polymer composites.

Effect of Composite Composition on Physico-Mechanical Properties.

At the first stage of the study, the influence of filler content on the main physico-mechanical characteristics of composite materials was investigated.

Table 1. Effect of Filler Content on the Physico-Mechanical Properties of Composites

Filler content, wt.%	**Tensile strength, MPa**	**Flexural strength, MPa**	**Impact toughness, kJ/m²**
0	18.5	28.2	7.6
10	22.4	33.8	8.9
20	26.7	39.5	10.2
30	24.9	37.1	9.1

Analysis of the data in Table 1 shows that increasing the filler content up to 20 wt.% promotes an increase in strength characteristics and impact toughness of the composite material. A further increase in filler content leads to a reduction in mechanical performance due to deterioration of structural homogeneity.

Effect of Processing Temperature Regime. At the second stage, the influence of the processing temperature of the secondary polymer on the formation of the structure and properties of the composite materials was investigated.

Table 2. Effect of Processing Temperature on the Physico-Mechanical Properties of Composites

Processing temperature, °C	**Tensile strength, MPa**	**Elongation at break, %**	**Impact toughness, kJ/m²**
160	21.8	6.2	8.3
180	26.7	7.5	10.2
200	25.1	6.9	9.4

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The presented data indicate that the optimal processing temperature range is around 180 °C, at which the best combination of strength and deformation properties is achieved.

Effect of Modifying Additives. In addition, the effectiveness of using modifying additives to improve interfacial interactions in composite materials was investigated.

Table 3. Effect of Modifying Additives on Composite Properties

Modifier content, wt.%	Tensile strength, MPa	Flexural strength, MPa	Water absorption, %
0	26.7	39.5	1.8
2	29.4	42.6	1.3
4	30.1	44.2	1.1

The results presented in Table 3 demonstrate that the introduction of modifying additives leads to an increase in strength and a reduction in water absorption, indicating improved adhesion between the polymer matrix and the filler.

Comparative Evaluation of the Improved Technology.
To assess the effectiveness of the improved technology, a comparison was made between the properties of composites produced using the baseline and the modified technologies.

Table 4. Comparison of the Physico-Mechanical Properties of Composites

Parameter	Baseline technology	Improved technology
Tensile strength, MPa	22.4	30.1
Flexural strength, MPa	33.8	44.2
Impact toughness, kJ/m²	8.9	10.5
Water absorption, %	1.9	1.1

The obtained data confirm that improving the technology for producing composite materials based on secondary polymers results in a significant enhancement of their physico-mechanical and performance properties.

DISCUSSION. The results obtained in the course of the study confirm that improving the technology for producing composite materials based on secondary polymers is an effective means of enhancing their physico-mechanical and performance characteristics. Analysis of the experimental data makes it possible to identify consistent relationships between composite composition, processing parameters, and the properties of the resulting materials.

As shown in Table 1, increasing the filler content up to 20 wt.% leads to a significant increase in tensile and flexural strength, as well as impact toughness of the composite material. This effect can be explained by the reinforcing action of the filler and a more uniform distribution of stresses within the polymer matrix. With a further increase in filler content, a decrease in mechanical performance is observed, which is likely associated with poorer particle dispersion and the formation of structural defects acting as stress concentrators.

The results presented in Table 2 indicate a substantial influence of the processing temperature regime on the formation of the composite material structure. An optimal processing temperature of around 180 °C provides sufficient flowability of the polymer matrix and effective wetting of the filler, thereby promoting improved interfacial interaction and enhanced strength characteristics. Increasing the temperature beyond the optimal value leads to partial thermal degradation of the secondary polymer, which negatively affects its mechanical properties.

The introduction of modifying additives, as shown in Table 3, has a positive effect on the physico-mechanical and performance characteristics of the composites. The increase in strength and the reduction in water absorption indicate improved adhesion between the polymer matrix and the filler, as well as a denser and more homogeneous composite structure. This effect is particularly important for composites based on secondary polymers, which are prone to reduced interfacial strength due to degradation processes.

Comparative analysis of the properties of materials produced using the baseline and improved technologies (Table 4) demonstrates a clear advantage of the proposed technological

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approach. Increases in strength indicators and impact toughness, along with reduced water absorption, indicate enhanced operational reliability of the composite materials and expanded possibilities for their practical application.

It should be noted that the obtained results are consistent with data reported in the literature, which emphasize the effectiveness of an integrated approach that includes optimization of composite composition and processing parameters of secondary polymers. At the same time, the present study complements existing research by providing a systematic analysis of the influence of key factors on the formation of the structure and properties of composite materials.

Thus, the discussion of the results confirms the feasibility of improving the technology for producing composite materials based on secondary polymers and substantiates the prospects of its application in the manufacture of materials with enhanced physico-mechanical characteristics and increased stability of properties.

CONCLUSIONS AND RECOMMENDATIONS. As a result of the conducted research, an improved technology for producing composite materials based on secondary polymers was developed and experimentally validated, aimed at enhancing their physico-mechanical and performance characteristics. The obtained data confirm the significant influence of composite composition and processing parameters on the formation of the structure and properties of polymer composites.

Based on the analysis of the experimental results, the following main conclusions were formulated:

First, it was established that the rational selection of filler content is a key factor in improving the strength characteristics of composite materials based on secondary polymers. An optimal filler content of approximately 20 wt.% was identified, at which the maximum increase in tensile and flexural strength, as well as impact toughness, is achieved.

Second, it was shown that the processing temperature regime of secondary polymers has a substantial effect on the physico-mechanical properties of composite materials. An optimal processing temperature of around 180 °C ensures the formation of a homogeneous composite structure and promotes improved interfacial interaction between the polymer matrix and the filler.

Third, it was determined that the introduction of modifying additives enhances adhesion between the components of the composite, which is manifested by increased strength characteristics and reduced water absorption of the composite materials.

Fourth, comparative analysis demonstrated that composite materials produced using the improved technology exhibit significantly better physico-mechanical and performance indicators compared to materials manufactured using the baseline technology, thereby confirming the effectiveness of the proposed technological approach.

Based on the obtained results, the following practical recommendations are proposed:

First, in the industrial production of composite materials based on secondary polymers, it is advisable to use compositions with an optimal filler content of about 20 wt.%.

Second, strict control of the processing temperature regimes of secondary polymers is recommended, maintaining them at a level that ensures preservation of the polymer matrix structure and minimizes degradation processes.

Third, to enhance the stability of properties and operational reliability of composite materials, the use of modifying additives that improve interfacial interactions between the polymer matrix and the filler is recommended.

Fourth, the proposed improved technology is advisable for implementation at enterprises engaged in the recycling of secondary polymers in order to produce resource-saving and environmentally oriented composite materials for various industrial sectors.

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