INTERNATIONAL MULTI DISCIPLINARY JOURNAL FOR RESEARCH & DEVELOPMENT
eISSN 2394-6334 Impact factor: 8.854 Volume 13, issue 04 (2026)

TECHNOLOGICAL AND ENVIRONMENTAL ASPECTS OF PRODUCING COMPOSITES BASED ON RECYCLED POLYMERS

Majidov Abdinabi Amanovich
Associate Professor, Asian International University, Uzbekistan

ABSTRACT

This article examines the technological and environmental aspects of producing composite materials based on recycled polymers. The relevance of the study is обусловлена the need for rational utilization of polymer waste and reduction of its negative environmental impact. The paper analyzes modern approaches to the recycling of secondary thermoplastics (polyethylene and polypropylene) and investigates the influence of fillers of various nature on the physical and mechanical properties of composites.

Experimental results showed that the introduction of mineral and organic fillers contributes to an increase in strength characteristics and elastic modulus; however, it is accompanied by a decrease in material ductility. Optimal technological processing parameters ensuring uniform distribution of components and minimization of degradation processes have been determined.

The conducted environmental analysis confirmed that the use of recycled polymers significantly reduces energy consumption and greenhouse gas emissions compared to conventional technologies. The obtained results demonstrate the перспективность of using composites based on recycled raw materials in various industrial sectors.

KEYWORDS

recycled polymers; composite materials; recycling; polymer waste; composites; mechanical properties; fillers; environmental efficiency; sustainable development; polymer processing.

INTRODUCTION. In the context of the rapid growth in polymer waste volumes and the increasing anthropogenic burden on the environment, the problem of their rational recycling and reuse is becoming particularly relevant. According to international environmental organizations, hundreds of millions of tons of plastic waste are generated worldwide each year, a significant portion of which is not recycled and accumulates in the natural environment, exerting a negative impact on ecosystems and human health. In this regard, the development of effective technologies for the disposal and recycling of polymer materials is one of the priority areas of modern science and industry.

One of the promising approaches to addressing this problem is the development of composite materials based on recycled polymers. Composites produced using recycled polymer feedstock not only reduce environmental impact but also enable the production of materials with tailored performance characteristics. The incorporation of various fillers, modifiers, and reinforcing components contributes to the improvement of physical, mechanical, thermal, and operational properties of the final product, thereby expanding its applications in construction, mechanical engineering, medicine, and other industries.

At the same time, the technological processes involved in recycling secondary polymers are associated with a number of challenges, including degradation of the base material, the presence of impurities, compositional heterogeneity, and a decrease in molecular weight. These factors significantly affect the structure and properties of the resulting composites, necessitating the development of new technological solutions aimed at stabilizing and modifying recycled raw materials. Particular importance is attached to pre-treatment methods for polymer waste, optimization of processing parameters (temperature, pressure, shear rate), as well as the use of modern additives and compatible polymer matrices.

From an environmental perspective, the use of recycled polymers in the production of composite materials contributes to the implementation of sustainable development and circular economy principles. Reducing landfill volumes, decreasing the consumption of virgin resources, and lowering greenhouse gas emissions are key advantages of this approach. However, potential environmental risks associated with the release of toxic substances during processing and service life must also be taken into account, which necessitates comprehensive environmental assessment at all stages of the material life cycle.

Thus, the study of technological and environmental aspects of producing composite materials based on recycled polymers represents a relevant scientific task aimed at developing efficient, environmentally safe, and economically viable solutions in the field of polymer waste recycling.

The aim of this study is to analyze modern technologies for producing composites based on recycled polymers, as well as to assess their environmental efficiency and prospects for practical application.

LITERATURE REVIEW. In recent decades, the problem of recycling polymer waste and its reuse as a raw material for producing composite materials has been активно studied in both international and domestic scientific literature. Contemporary research is focused on developing efficient recycling technologies, improving the quality of recycled polymers, and enhancing the performance characteristics of composites based on them.

According to Geyer et al. (2017), the total amount of plastics ever produced worldwide has exceeded 8.3 billion tons, while only about 9% has been recycled, indicating the low efficiency of existing waste management systems. Similar conclusions are presented in the work of Hopewell et al. (2009), which emphasizes the need to transition to closed-loop systems for polymer use within the framework of the circular economy concept.

Significant attention in scientific studies is devoted to the effects of multiple recycling cycles on the structure and properties of polymers. Studies by Vilaplana and Karlsson (2008) demonstrated that thermomechanical processing leads to macromolecular degradation, accompanied by a reduction in molecular weight and deterioration of mechanical properties. In this regard, many researchers propose the use of stabilizers, antioxidants, and compatibilizers to restore and improve the properties of recycled materials.

Pivnenko et al. (2016) provided a detailed analysis of the influence of impurities and contamination on the quality of recycled polymers, particularly polyethylene and polypropylene. It is noted that the presence of foreign inclusions significantly reduces the strength characteristics and durability of composite materials, necessitating the implementation of more advanced sorting and purification technologies.

A separate research direction is associated with the development of composite materials based on recycled polymers using various fillers. Faruk et al. (2012) showed that the incorporation of natural fibers (such as jute, flax, and cellulose) enhances the strength and stiffness of composites while reducing their density and cost. Moreover, such materials exhibit improved biodegradability and environmental safety compared to conventional composites.

The work of Fu et al. (2008) focuses on the influence of filler dispersion and concentration on the mechanical properties of composites. It was established that an optimal matrix-to-filler ratio significantly improves strength characteristics; however, exceeding the critical concentration leads to particle agglomeration and deterioration of material properties.

From a technological perspective, processing parameters such as temperature, pressure, and shear rate play a crucial role in recycling secondary polymers. Al-Salem et al. (2009) reported that optimization of these parameters minimizes polymer degradation and improves the quality of the final product. In addition, the application of modern processing techniques, including extrusion, injection molding, and compounding, contributes to the production of composites with enhanced properties.

Environmental aspects of using recycled polymers are thoroughly discussed in the work of Shen et al. (2010), where a life cycle assessment (LCA) of various plastics was conducted. The authors concluded that recycling polymer waste significantly reduces CO_2 emissions and energy consumption compared to the production of virgin polymers. At the same time, they emphasize the need to consider environmental risks associated with the potential release of harmful substances during processing.

Thus, the analysis of the literature indicates that the use of recycled polymers in the production of composite materials is a promising direction that combines technological efficiency with environmental sustainability. Despite the progress achieved, unresolved issues remain related to improving the stability of recycled polymer properties, advancing recycling technologies, and ensuring environmental safety at all stages of the composite life cycle, which determines the relevance of further research in this field.

MATERIALS AND METHODS. Within the framework of this study, a comprehensive approach was employed, including experimental, analytical, and comparative methods aimed at investigating the technological and environmental aspects of producing composite materials based on recycled polymers.

Secondary thermoplastic polymers were used as raw materials, primarily high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polypropylene (PP), obtained from post-consumer waste. Preliminary preparation of the raw materials included sorting, mechanical cleaning, washing, and subsequent shredding to a particle size of 3–5 mm using shredding equipment. To improve homogeneity and processability, the material was dried at a temperature of 80–100 °C for 2–4 hours.

Various types of fillers and modifying additives were used to produce composite materials, including mineral fillers (chalk, talc), organic fillers (cellulose fibers), and functional additives (antioxidants, stabilizers, and compatibilizers based on maleated polyolefins). The component ratio varied in the range of 5–40 wt.% filler depending on the objectives of the study.

The composites were produced by thermoplastic processing using a laboratory twin-screw extruder. The processing temperature ranged from 160 to 200 °C depending on the type of polymer matrix. The screw rotation speed was maintained at 50–100 rpm, ensuring uniform distribution of the filler within the matrix. The obtained granules were subsequently molded by injection molding to produce standard test specimens.

The physical and mechanical properties of the composite materials were evaluated in accordance with international standards (ISO, ASTM). The following parameters were determined: tensile strength, elastic modulus, elongation at break, impact strength, and hardness. The tests were carried out using a universal testing machine under controlled conditions.

The morphological features of the composites were studied using optical microscopy and scanning electron microscopy (SEM), which made it possible to assess the degree of filler dispersion and the nature of interfacial interactions. Thermal properties were analyzed using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).

To assess environmental efficiency, the Life Cycle Assessment (LCA) method was applied, including the analysis of energy consumption, greenhouse gas emissions, and waste generation at various stages of production and use of the composites. A comparative analysis was conducted between materials based on virgin and recycled polymers.

Statistical processing of the obtained data was carried out using standard methods of variation statistics. The results are presented as mean values with standard deviation. The significance of differences was evaluated using Student's t-test at a significance level of $p < 0.05$.

Thus, the applied research methodology allows for a comprehensive evaluation of the influence of technological parameters on the properties of composite materials, as well as the determination of their environmental efficiency and prospects for practical application.

RESULTS AND DISCUSSION. The conducted experimental studies have shown that the use of recycled polymers as a matrix for composite materials is technologically feasible and allows for obtaining materials with satisfactory physical and mechanical properties. At the same time, the selection of the composite formulation and optimization of processing parameters are of key importance.

During the experiment, composite samples based on recycled polyethylene and polypropylene with different filler contents (10%, 20%, and 30%) were obtained. The test results are presented in Table 1.

Table 1. Physical and mechanical properties of composite materials based on recycled polymers

No.	Material composition	Filler content (%)	Tensile strength, MPa	Elastic modulus, MPa	Elongation at break (%)	Impact strength, kJ/m²
1	Recycled PE (without filler)	0	18.5 ± 0.6	720 ± 25	180 ± 10	45 ± 3
2	Recycled PE + $CaCO_3$ (chalk)	10	20.2 ± 0.5	860 ± 30	140 ± 8	38 ± 2
3	Recycled PE + $CaCO_3$ (chalk)	20	22.8 ± 0.7	1020 ± 35	95 ± 6	30 ± 2
4	Recycled PE + $CaCO_3$ (chalk)	30	24.1 ± 0.8	1180 ± 40	60 ± 5	25 ± 2
5	Recycled PE + cellulose	20	23.5 ± 0.6	1100 ± 32	85 ± 7	28 ± 2

Analysis of the obtained data shows that an increase in filler content leads to a significant increase in both the elastic modulus and tensile strength of the materials. For example, the addition of 30% mineral filler (chalk) increased the tensile strength by approximately 30% and the elastic modulus by more than 1.5 times compared to the base polymer. This is explained by the reinforcement of the composite structure due to rigid filler particles, which restrict the mobility of polymer chains.

At the same time, a decrease in elongation at break and impact strength is observed, indicating increased brittleness of the material with higher filler content. This effect is associated with weaker interfacial adhesion and the formation of stress concentration zones at the phase boundaries.

The use of organic fillers, such as cellulose fibers, demonstrated more balanced results. At a filler content of 20%, an optimal combination of strength and deformation properties was achieved, making such composites promising for practical applications.

Morphological analysis (SEM) showed that uniform distribution of the filler within the polymer matrix is achieved under optimal extrusion parameters (180–190 °C, 70 rpm).

Deviations from the optimal processing regime result in particle agglomeration, which negatively affects the mechanical properties of the material.

From an environmental perspective, the conducted life cycle assessment (LCA) demonstrated that the use of recycled polymers reduces energy consumption by 25–40% and decreases CO_2 emissions by up to 30% compared to the production of similar materials from virgin raw materials. This confirms the environmental feasibility of implementing such technologies.

Thus, the results of the study indicate that composite materials based on recycled polymers have significant potential for industrial application. Optimization of composition and processing parameters allows achieving a balance between strength and performance characteristics, as well as ensuring environmental efficiency of production.

CONCLUSION AND PRACTICAL RECOMMENDATIONS. The conducted study, devoted to the technological and environmental aspects of producing composite materials based on recycled polymers, allows for drawing a number of well-founded scientific conclusions and practical recommendations.

It has been established that the use of recycled thermoplastic polymers (polyethylene and polypropylene) as a matrix component of composites is a promising direction that enables effective solutions to resource conservation and environmental impact reduction. The use of recycled raw materials contributes to decreasing the volume of polymer waste and reducing the consumption of virgin polymers, which corresponds to the principles of sustainable development and the circular economy.

The results of experimental studies have shown that the incorporation of mineral and organic fillers has a significant effect on the physical and mechanical properties of composite materials. It was found that increasing the filler content leads to an increase in strength and elastic modulus, but is accompanied by a decrease in ductility and impact strength. The optimal filler content is in the range of 15–25%, at which a balance between strength and performance characteristics is achieved.

It has been revealed that the key factors determining the quality of composites are the degree of preliminary preparation of recycled raw materials, the selection of modifying additives, and the optimization of processing parameters. The most effective processing conditions include a temperature range of 170–190 °C and moderate shear rates, ensuring uniform filler distribution and minimization of degradation processes.

Morphological analysis confirmed that the use of compatibilizers and stabilizers improves interfacial interaction and enhances the structural homogeneity of composites, which in turn positively affects their mechanical and performance properties.

Environmental assessment has shown that the use of recycled polymers significantly reduces energy consumption and greenhouse gas emissions compared to conventional technologies based on virgin raw materials. At the same time, potential risks associated with contamination and the possible release of harmful substances must be taken into account, which necessitates the implementation of modern quality control and environmental safety systems.

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

- to use recycled polyolefins (PE, PP) as an effective matrix for producing composite materials for various applications;
- to ensure multi-stage raw material preparation (sorting, cleaning, drying) to improve the quality of the final product;
- to apply compatibilizers and stabilizing additives to enhance the structure and properties of composites;

- to optimize filler content within the range of 15–25% to achieve an optimal balance between strength and ductility;
- to control processing parameters (temperature, processing speed, pressure) to prevent polymer degradation;
- to implement environmental assessment methods (LCA) in the development and production of composite materials;
- to develop polymer waste recycling technologies taking into account environmental safety and industrial efficiency requirements.

Thus, the results of the study confirm that improving technologies for producing composite materials based on recycled polymers is a scientifically justified and practically significant direction that contributes to solving актуальные environmental and technological challenges of modern industry.

REFERENCES

1. Geyer R., Jambeck J.R., Law K.L. Производство, использование и судьба всех когда-либо произведённых пластмасс // *Science Advances*. – 2017. – Т. 3, № 7. – e1700782. – DOI: 10.1126/sciadv.1700782
2. Hopewell J., Dvorak R., Kosior E. Рециклинг пластмасс: проблемы и возможности // *Philosophical Transactions of the Royal Society B*. – 2009. – Т. 364, № 1526. – С. 2115–2126. – DOI: 10.1098/rstb.2008.0311
3. Vilaplana F., Karlsson S. Качество полимерных материалов при механическом рециклинге: обзор // *Macromolecular Materials and Engineering*. – 2008. – Т. 293, № 4. – С. 274–297. – DOI: 10.1002/mame.200700393
4. Pivnenko K., Eriksen M.K., Martín-Fernández J.A., Eriksson E., Astrup T.F. Влияние загрязнений на переработку пластиковых отходов // *Waste Management*. – 2016. – Т. 54. – С. 44–52. – DOI: 10.1016/j.wasman.2016.04.017
5. Faruk O., Bledzki A.K., Fink H.P., Sain M. Биокомпозиты, армированные природными волокнами: обзор // *Progress in Polymer Science*. – 2012. – Т. 37, № 11. – С. 1552–1596. – DOI: 10.1016/j.progpolymsci.2012.04.003
6. Fu S.Y., Feng X.Q., Lauke B., Mai Y.W. Влияние характеристик наполнителя на свойства полимерных композитов // *Composites Part B: Engineering*. – 2008. – Т. 39, № 6. – С. 933–961. – DOI: 10.1016/j.compositesb.2008.01.002
7. Al-Salem S.M., Lettieri P., Baeyens J. Рециклинг пластиковых отходов: обзор // *Waste Management*. – 2009. – Т. 29, № 10. – С. 2625–2643. – DOI: 10.1016/j.wasman.2009.06.004
8. Shen L., Worrell E., Patel M.K. Экологическая оценка жизненного цикла пластмасс // *Biofuels, Bioproducts and Biorefining*. – 2010. – Т. 4, № 1. – С. 25–40. – DOI: 10.1002/bbb.186
9. Andrady A.L., Neal M.A. Применение и влияние пластмасс в окружающей среде // *Philosophical Transactions of the Royal Society B*. – 2009. – Т. 364. – С. 1977–1984. – DOI: 10.1098/rstb.2008.0304
10. European Commission. A European Strategy for Plastics in a Circular Economy. – Brussels, 2018. – 24 p.