Qabul qilindi: 25-sentabr 2026-yil • Ma’qullandi: 30-sentabr 2026-yil • Nashr qilindi: 05-oktabr 2026-yil

# IMPROVING THE PROPERTIES OF POLYMER COMPOSITE COATINGS FOR MECHANICAL ENGINEERING USING LOCAL MINERAL FILLERS

**Nazirov Bobur Ikromjon o‘g‘li,**

**Z.U.Maxammadjonov**

Associate Professor, Department of Automotive Engineering and Transport

Doctor of Philosophy (PhD) in Technical Sciences

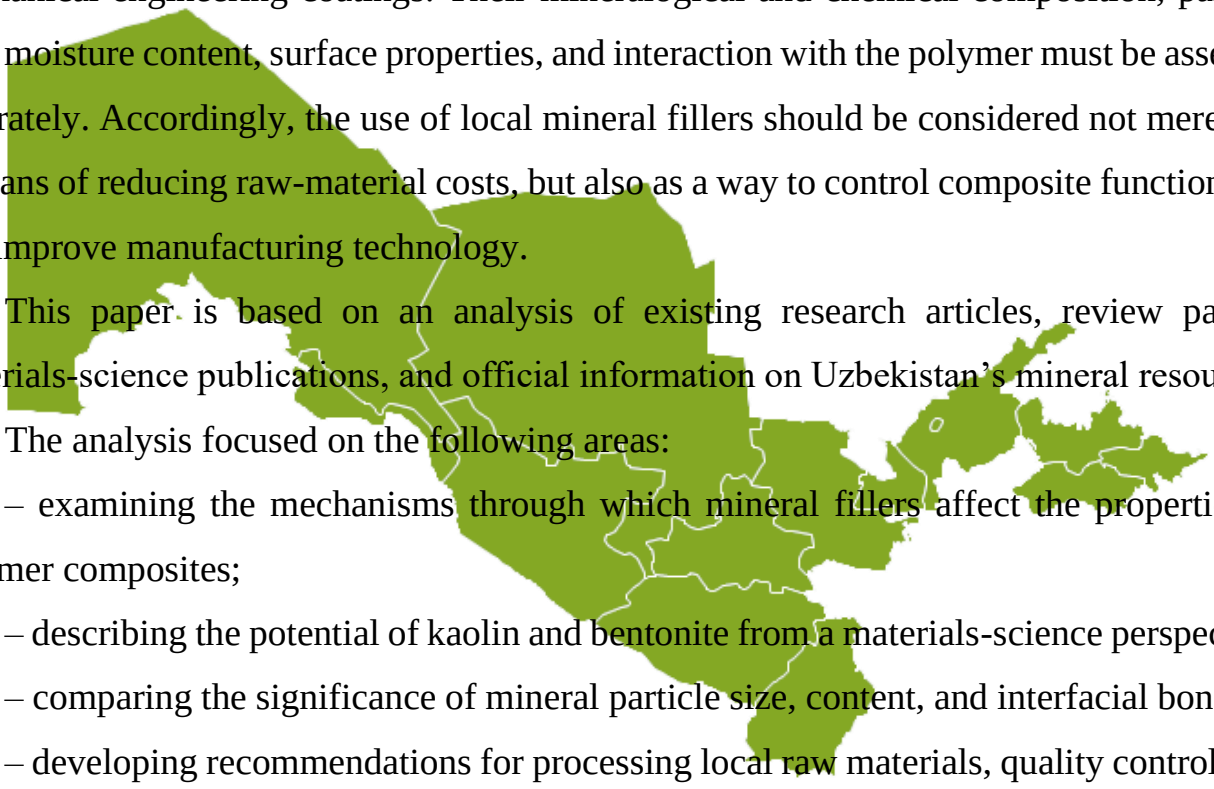
In modern mechanical engineering, increasing production efficiency, extending the service life of machines and mechanisms, and reducing maintenance costs are important objectives. During operation, machine components may be exposed to friction, mechanical loads, temperature fluctuations, moisture, and aggressive environments, all of which can cause wear and corrosion and thereby reduce their operational performance. Consequently, polymer coatings that protect metal surfaces and improve their functional properties are of considerable practical importance.

Compared with metals, polymer materials are relatively lightweight, can be adapted to various shapes, and offer the possibility of tailoring their properties by incorporating additives. However, some neat polymers have limitations under high temperatures, prolonged mechanical loading, and abrasive wear. One way to mitigate these limitations is to produce composite materials by incorporating mineral fillers into a polymer matrix.

Mineral fillers can affect a composite’s hardness, elastic modulus, dimensional stability, thermal properties, and wear resistance. A 2023 review by Yadav et al., published in Composites Part A: Applied Science and Manufacturing, summarizes the role of fillers in determining the mechanical, thermal, and tribological properties of polymer composites [1]. This source highlights the need to consider the relationship between material composition and service requirements when selecting mineral or other fillers.

The relevance of this issue in Uzbekistan is associated with the potential to process

local mineral raw materials more extensively and use them to manufacture industrial products with higher added value. Data published by the U.S. Geological Survey on Uzbekistan’s mineral resources record deposits of kaolin and bentonite. In addition, official information published in 2023 described projects aimed at expanding kaolin processing and the production of finished products in the country [2; 3]. Nevertheless, the availability of local mineral raw materials does not in itself mean that they are directly suitable for mechanical-engineering coatings. Their mineralogical and chemical composition, particle size, moisture content, surface properties, and interaction with the polymer must be assessed separately. Accordingly, the use of local mineral fillers should be considered not merely as a means of reducing raw-material costs, but also as a way to control composite functionality and improve manufacturing technology.



This paper is based on an analysis of existing research articles, review papers, materials-science publications, and official information on Uzbekistan’s mineral resources.

The analysis focused on the following areas:

– examining the mechanisms through which mineral fillers affect the properties of polymer composites;

– describing the potential of kaolin and bentonite from a materials-science perspective;

– comparing the significance of mineral particle size, content, and interfacial bonding;

– developing recommendations for processing local raw materials, quality control, and optimization of composite composition.

This methodological approach makes it possible to synthesize findings from different scientific sources and identify technological directions that should be verified experimentally in future work.

A polymer composite coating consists of a polymer matrix, fillers incorporated into it, and, where necessary, other functional additives. The polymer matrix provides the coating’s integrity, while the mineral particles are used to modify selected physical, mechanical, and thermal properties.

The influence of mineral fillers is not limited to their chemical composition and crystal structure. Particle shape and size, surface area, distribution within the matrix, and interfacial

bonding with the polymer also affect the final outcome. For example, well-dispersed particles may help restrict deformation of the polymer matrix and transfer loads throughout the material. Conversely, regions where particles agglomerate may develop stress concentrations, making crack initiation more likely.

Mineral fillers do not necessarily improve all coating properties simultaneously. An increase in hardness and elastic modulus may be accompanied by reduced impact resistance or deformability. Therefore, when selecting a composite formulation, attention should be paid not only to a single mechanical indicator but also to the actual service requirements of the component.

In 2004, Leong et al. compared the mechanical properties and interfacial interactions of polypropylene composites containing talc, kaolin, and calcium carbonate [4]. Their work showed that different mineral fillers can produce different results even within the same polymer matrix. In the system they examined, talc-filled specimens exhibited higher values for certain strength and hardness indicators, whereas calcium carbonate had a positive effect on impact resistance. Although these findings cannot be directly generalized to other polymers or coatings, they support the need to select a mineral according to the intended function of the material.

Mineral fillers can serve the following functions in polymer coatings intended for mechanical engineering:

1. Controlling the coating’s hardness and elastic modulus.
2. Improving resistance to abrasive wear and scratching.
3. Increasing dimensional stability under temperature variations.
4. Influencing polymer curing and volumetric shrinkage.
5. Optimizing raw-material consumption and product cost.
6. Improving selected protective properties of the coating.

Achieving these outcomes requires the mineral to have an appropriate composition and purity, particle size, and compatibility with the polymer.

Kaolin is a raw material composed mainly of clay minerals belonging to the kaolinite group. Its properties depend on its mineralogical composition, particle size, content of

accessory minerals, and degree of beneficiation. Kaolin is one of the minerals used as a filler in polymers and coating materials. Its use may help control a material’s hardness, dimensional stability, surface appearance, and certain mechanical properties.

Kaolin from Angren is processed on an industrial scale in Uzbekistan. According to the official product information published by Angren Kaolin, certain beneficiated grades are intended for industrial applications such as plastics and cable products [3]. This provides a practical basis for examining the potential use of local kaolin in polymer-based materials.

The effectiveness of kaolin in a composite depends on particle size and distribution. Fine, uniformly distributed particles may increase the area of interaction with the polymer matrix. However, increased particle agglomeration may lead to defects within the composite and a possible deterioration in its mechanical properties.

Another important feature of kaolin is the possibility of modifying its surface properties. Chemical treatment of the mineral surface or the use of compatibilizing additives may improve compatibility with certain polymer matrices. Such approaches are intended to strengthen interfacial bonding between the mineral particles and the polymer.

Promising applications of kaolin in mechanical-engineering coatings include controlling the hardness, dimensional stability, and wear resistance of protective coatings. However, the extent to which these properties change in a particular coating can only be established for the relevant formulation and test conditions.

Bentonite generally contains layered clay minerals such as montmorillonite. The structure and surface properties of these minerals make them of interest for evaluation as functional fillers in polymer composites. Bentonite properties may vary according to the deposit’s mineralogical composition, exchangeable cations, moisture content, and degree of beneficiation.

The formation of composites from layered clay minerals and certain polymers can affect mechanical, thermal, and barrier properties. The distribution of the mineral layers within the polymer matrix is particularly important. Good separation and dispersion of the layers in the polymer may improve selected properties, whereas their restacking or agglomeration may limit the expected benefits.

USGS information on Uzbekistan’s mineral resources records bentonite associated with the Arab-Dasht and Khovdak deposits [2]. This indicates that local bentonite could be evaluated for use in polymer composites. However, the specific grade, mineralogical composition, and suitability of bentonite from these deposits for mechanical-engineering coatings must be examined separately.

When using bentonite in polymer coatings, particular attention should be paid to its moisture content, dispersion, and compatibility with the polymer. Surface modification or compatibilizing additives may be necessary in some systems. Therefore, there is insufficient basis for describing bentonite as categorically superior or less effective than kaolin; the advantages of each mineral depend on the coating formulation and the properties required.

In addition to kaolin and bentonite, calcium carbonate, talc, silica, and other mineral fillers have been widely studied in polymer composites. Some can help increase hardness and elastic modulus, while others may help control impact resistance, surface quality, or thermal properties [4; 5]. However, selecting a local mineral raw material based solely on its name or the presence of a deposit is insufficient. Its chemical composition, harmful impurities, particle size, moisture content, and degree of beneficiation required for production must be assessed. The costs of reducing the raw material to a fine particle-size fraction and, where necessary, modifying its surface should also be considered. Accordingly, local mineral fillers should preferably be selected using the following criteria:

– availability of a local raw-material source and reliability of supply;

– the mineral’s chemical and mineralogical composition;

– particle size and particle-size distribution;

– compatibility with the polymer matrix;

– effect on the required mechanical and thermal properties of the coating;

– costs of preparation, drying, grinding, and surface modification;

– safety requirements during manufacturing and use.

Mineral particles can resist deformation of the polymer matrix and thereby increase the composite’s hardness and elastic modulus. This effect, however, is not determined by mineral hardness alone. Bonding between the particles and matrix, particle size and shape,

and distribution throughout the composite are also important. If interfacial bonding is inadequate, voids may form around the mineral particles under external loading, or the particles may detach from the matrix. This can adversely affect coating strength. Increasing the mineral-filler content therefore does not always improve mechanical properties.

Leong et al.’s work on mineral-filled polypropylene demonstrates that different filler types can affect mechanical properties in different ways [4]. This finding also indicates that formulations containing local kaolin or bentonite need to be optimized individually, without presupposing specific outcomes.

Some coatings used in mechanical engineering operate under friction and exposure to abrasive particles. Under such conditions, the wear resistance of the polymer is one factor affecting component service life. A 2005 review by Friedrich, Zhang, and Schlarb examined the effects of different fillers on the sliding-wear properties of polymer composites [6]. The authors summarized how filler type, particle size, and filler content may influence wear. Mineral particles may reduce surface deformation or alter the wear process in some composites. However, if the particles are not sufficiently bonded to the matrix, they may detach from the coating and act as third-body particles, potentially accelerating wear. Thus, high mineral hardness does not, by itself, guarantee high wear resistance in the composite.

Coatings based on local mineral fillers can be assessed using criteria such as the coefficient of friction, mass or volumetric wear, surface damage, and detachment of the coating from the metal substrate. The test method and friction conditions should be clearly specified.

Some polymers may soften, deform, or change dimensions when exposed to temperature variations. Mineral fillers can influence the thermal response of a polymer matrix and, in some cases, restrict thermal expansion and improve dimensional stability. However, this effect depends on the mineral’s thermal properties, particle distribution, and interaction with the polymer. In addition, a coating’s temperature resistance depends not only on the mineral filler but also on the polymer matrix itself and its degree of curing. Composites intended for use on mechanical-engineering components should therefore be evaluated for temperature-induced deformation, thermal cycling, and, where necessary,

thermal ageing.

One of the main factors affecting polymer-composite properties is the interfacial bonding between mineral particles and the polymer matrix. Because minerals and polymers differ in their chemical nature, forming sufficiently strong bonds between them is not always straightforward. Interfacial bonding can be improved by physically or chemically modifying the mineral surface, using compatibilizing additives, and optimizing the mixing process. A review published in Polymer Composites in 2025 identifies filler-surface functionalization and control of interfacial interactions as important approaches to determining the mechanical and protective properties of polymer-composite coatings [5].

When local kaolin or bentonite is used, the need for surface modification depends on the mineral’s initial properties and the polymer matrix. It is therefore inappropriate to regard modification as a mandatory technological step in every case. Its effectiveness and economic feasibility should be established through appropriate comparative evaluation.

The analysis of the scientific literature indicates that the use of local mineral fillers is a promising way to control the mechanical, thermal, and tribological properties of polymer-composite coatings for mechanical engineering. Mineral particles can affect the polymer matrix’s hardness, elastic modulus, wear resistance, and dimensional stability. However, the final outcome depends on the mineral type, particle size, filler content, and interfacial bonding with the polymer.

Evaluating the kaolin and bentonite available in Uzbekistan’s mineral-resource base for polymer composites creates opportunities to produce higher-value-added products from local resources. In particular, the industrial processing of Angren kaolin provides a practical basis for assessing it as a potential filler for mechanical-engineering coatings. Nevertheless, the quality characteristics of each type of local raw material must be determined, and its compatibility with the polymer must be verified.

**References**

1. Yadav R., Singh M., Shekhawat D., Lee S.-Y., Park S.-J. The role of fillers to enhance the mechanical, thermal, and wear characteristics of polymer composite materials:

A review // Composites Part A: Applied Science and Manufacturing. — 2023. — Vol. 175. — Article 107775. — DOI: https://doi.org/10.1016/j.compositesa.2023.107775

2. U.S. Geological Survey. The Mineral Industry of Uzbekistan in 2022. — Minerals Yearbook, Volume III: Area Reports—International. — URL: https://pubs.usgs.gov/myb/vol3/2022/myb3-2022-uzbekistan.pdf

3. Angren Kaolin. Company information and beneficiated kaolin products. — https://angren-kaolin.uz/uz/company/

4. Leong Y. W., Abu Bakar M. B., Mohd Ishak Z. A., Ariffin A., Pukánszky B. Comparison of the mechanical properties and interfacial interactions between talc, kaolin, and calcium carbonate filled polypropylene composites // Journal of Applied Polymer Science. — 2004. — Vol. 91, No. 5. — P. 3315–3326. — https://doi.org/10.1002/app.13542

5. Maalihan R. D., Domalanta M. R. B., Corrales A. C. C., Caldona E. B. Advances in interfacially engineered surface-functionalized fillers for multifunctional polymer composite coatings // Polymer Composites. — 2025. — Vol. 46, No. 7. — P. 5857–5881. — DOI: https://doi.org/10.1002/pc.29358

