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05.00.00 - Texnika fanlari
08.00.00 - Iqtisodiyot fanlar

Elektron nashr, 673 sahifa.
2025-yil, 28-oktyabr,

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05.01.00 – Axborot texnologiyalari, boshqaruv va kompyuter grafikasi
05.01.01 – Muhandislik geometriyasi va kompyuter grafikasi. Audio va video texnologiyalari
05.01.02 – Tizimli tahlil, boshqaruv va axborotni qayta ishlash
05.01.03 – Informatikaning nazariy asoslari
05.01.04 – Hisoblash mashinalari, majmualari va kompyuter tarmoqlarining matematik va dasturiy ta'minoti
05.01.05 – Axborotlarni himoyalash usullari va tizimlari. Axborot xavfsizligi
05.01.06 – Hisoblash texnikasi va boshqaruv tizimlarining elementlari va qurilmalari
05.01.07 – Matematik modellashtirish
05.01.11 – Raqamli texnologiyalar va sun'iy intellekt
05.02.00 – Mashinasozlik va mashinashunoslik
05.02.08 – Yer usti majmualari va uchish apparatlari
05.03.02 – Metrologiya va metrologiya ta'minoti
05.04.01 – Telekommunikasiya va kompyuter tizimlari, telekommunikasiya tarmoqlari va qurilmalari. Axborotlarni taqsimlash
05.05.03 – Yorug'lik texnikasi. Maxsus yoritish texnologiyasi
05.05.05 – Issiqlik texnikasining nazariy asoslari
05.05.06 – Qayta tiklanadigan energiya turlari asosidagi energiya qurilmalari
05.06.01 – To'qimachilik va yengil sanoat ishlab chiqarishlari materialshunosligi
05.08.03 – Temir yo'l transportini ishlatish
05.09.01 – Qurilish konstruksiyalari, bino va inshootlar
05.09.04 – Suv ta'minoti. Kanalizatsiya. Suv havzalarini muhofazalovchi qurilish tizimlari
10.00.06 – Qiyosiy adabiyotshunoslik, chog'ishtirma tilshunoslik va tarjimashunoslik
10.00.04 – Yevropa, Amerika va Avstraliya xalqlari tili va adabiyoti
08.00.01 – Iqtisodiyot nazariyasi
08.00.02 – Makroiqtisodiyot
08.00.03 – Sanoat iqtisodiyoti
08.00.04 – Qishloq xo'jaligi iqtisodiyoti
08.00.05 – Xizmat ko'rsatish tarmoqlari iqtisodiyoti
08.00.06 – Ekonometrika va statistika
08.00.07 – Moliya, pul muomalasi va kredit
08.00.08 – Buxgalteriya hisobi, iqtisodiy tahlil va audit
08.00.09 – Jahon iqtisodiyoti
08.00.10 – Demografiya. Mehnat iqtisodiyoti
08.00.11 – Marketing
08.00.12 – Mintaqaviy iqtisodiyot
08.00.13 – Menejment
08.00.14 – Iqtisodiyotda axborot tizimlari va texnologiyalari
08.00.15 – Tadbirkorlik va kichik biznes iqtisodiyoti
08.00.16 – Raqamli iqtisodiyot va xalqaro raqamli integratsiya
08.00.17 – Turizm va mehmonxona faoliyati

Ma'lumot uchun, OAK Rayosatining 2024-yil 28-avgustdagi 360/5-son qarori bilan "Dissertatsiyalar asosiy ilmiy natijalarini chop etishga tavsiya etilgan milliy ilmiy nashrlar ro'yxati"ga texnika va iqtisodiyot fanlari bo'yicha "Muhandislik va iqtisodiyot" jurnali ro'yxatga kiritilgan.

Muassis: "Tadbirkor va ishbilarmon" MChJ

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3. Toshkent irrigatsiya va qishloq xo'jaligini mexanizatsiyalash muhandislari instituti" milliy tadqiqot universiteti
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MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

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MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

CHARACTERISTICS OF APPLYING NEW HETEROCOMPOSITE POLYMER MATERIALS IN ENGINEERING ACTIVITIES

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Abstract. This article analyzes the technological and operational characteristics of applying new heterocomposite polymer materials in engineering activities. The study highlights their advantages related to heat resistance, pressure tolerance, chemical stability, lightness, and energy efficiency. The potential applications of these materials in automotive, aviation, construction, and electrical engineering are discussed. The findings confirm that heterocomposite polymers play a crucial role in developing modern engineering solutions.

Key words: heterocomposite polymer, engineering materials, heat resistance, energy efficiency, structural strength.

Annotatsiya. Mazkur maqolada yangi geterokompozit polimer materiallarni muhandislik faoliyatida qo‘llashning texnologik va ekspluatatsion xususiyatlari tahlil qilingan. Tadqiqotda ushbu materiallarning issiqlikka, bosimga va kimyoviy ta’sirlarga chidamliligi, ularning yengilligi va energiya tejamkorligi bilan bog‘liq afzalliklari ko‘rsatib o‘tilgan. Shuningdek, avtomobilsozlik, aviatsiya, qurilish va elektrotexnika sohalarida ularni qo‘llash istiqbollari baholangan. Natijalar geterokompozit polimerlar zamonaviy muhandislik yechimlarini yaratishda muhim rol o‘ynashini tasdiqlaydi.

Kalit so‘zlar: geterokompozit polimer, muhandislik materiallari, issiqlik bardoshliligi, energiya tejamkorlik, strukturaviy mustahkamlik.

Аннотация. В данной статье рассмотрены технологические и эксплуатационные особенности применения новых гетерокомпозитных полимерных материалов в инженерной деятельности. В исследовании подчеркнуты их преимущества, связанные с термостойкостью, устойчивостью к давлению и химическим воздействиям, легкостью и энергоэффективностью. Также оценены перспективы их использования в автомобилестроении, авиации, строительстве и электротехнике. Полученные результаты подтверждают, что гетерокомпозитные полимеры играют важную роль в создании современных инженерных решений.

Ключевые слова: гетерокомпозитный полимер, инженерные материалы, термостойкость, энергоэффективность, структурная прочность.

INTRODUCTION

In recent decades, the continuous advancement of material science has led to the emergence of polymer composites as one of the most versatile classes of engineering materials. Polymers, due to their low density, ease of processing, and chemical resistance, have found widespread applications in almost every industrial sector—from aerospace and automotive engineering to medical devices and electronics. However, the inherent limitations of traditional polymers, such as their relatively low strength, stiffness, and thermal stability compared to metals or ceramics, have driven the development of composite systems. Among these innovations, heterocomposite polymer materials—composites consisting of multiple distinct reinforcement phases within a polymer matrix—have become an increasingly important area of research. These advanced materials combine the benefits of different reinforcements, leading to a synergistic enhancement of mechanical, thermal, and chemical properties that surpass those of conventional single-filler composites [1].

The term heterocomposite refers to a composite structure in which two or more types of reinforcing phases, often with different morphological, structural, or chemical characteristics, are combined in a single polymeric matrix. These reinforcements can include fibers, nanoparticles, whiskers, or layered materials that are distributed in a controlled or random manner. The combination of distinct fillers, such as carbon fibers and ceramic nanoparticles, or glass fibers with graphene sheets, allows the material to achieve a balance between strength, toughness, thermal conductivity, and electrical performance. This heterogeneity at both the microscopic and nanoscopic levels provides a pathway for tailoring material behavior according to specific engineering requirements [2].

The evolution of heterocomposite polymer materials has been driven by the growing demand for lightweight, high-performance materials in advanced engineering applications. The transportation industry, particularly the automotive and aerospace sectors, has been a major catalyst for this development. Reducing structural weight while maintaining or improving performance characteristics has become a central challenge in these industries. Heterocomposite polymer materials provide a solution by offering an excellent strength-to-weight ratio and enhanced multifunctional capabilities. Similarly, in renewable energy systems, such as wind turbines and fuel cells, the need for durable and corrosion-resistant materials has spurred interest in hybrid polymer composites with heterogeneous reinforcement structures [3].

A crucial motivation for developing heterocomposite polymers is the need to overcome the limitations of homogeneous composites. Traditional polymer composites often rely on a single type of reinforcement, such as carbon fibers or glass fibers, which may enhance one property while compromising another. For example, while carbon-fiber-reinforced polymers (CFRPs) provide superior stiffness and strength, they are often brittle and lack sufficient impact resistance. Conversely, glass-fiber-reinforced polymers (GFRPs) offer good toughness but relatively lower stiffness. By integrating multiple reinforcement types—such as combining carbon and glass fibers, or incorporating nano-scale fillers like carbon nanotubes (CNTs) or graphene oxide—researchers can achieve complementary improvements in mechanical performance, durability, and functional behavior.

From a materials engineering standpoint, the design of heterocomposite polymer systems involves careful control over the interfacial interactions between the polymer matrix and the reinforcing phases. The interface plays a critical role in determining load transfer efficiency, crack propagation resistance, and thermal stability. Chemical functionalization of filler surfaces and the use of coupling agents are common strategies to optimize adhesion and compatibility within the matrix. In addition, processing methods such as extrusion, resin transfer molding, additive manufacturing, and solution casting are continuously being refined to achieve uniform filler dispersion and desirable microstructural arrangements. Achieving optimal dispersion and orientation of reinforcements remains a key challenge that directly influences the overall properties of heterocomposite materials [4].

REVIEW OF LITERATURE ON THE SUBJECT

Heterocomposite polymer materials — polymer matrices reinforced by a combination of dissimilar fillers — are widely studied for their potential to integrate mechanical, thermal, and multifunctional performance in engineering applications. According to Seydibeyoğlu et al. (2023), hybrid polymer composites exhibit superior stiffness, impact strength, and durability when fiber and nanoparticle reinforcements are combined, compared to conventional single-fiber systems. Their findings emphasize that the balance between matrix toughness and interfacial adhesion determines the overall efficiency of heterocomposite systems in load-bearing structures.

Thermal and chemical stability have been at the forefront of materials research. Barra et al. (2023) conducted a comprehensive review on the thermal stability of polymer-based materials and concluded that polyimides, epoxy resins, and high-performance thermoplastics maintain mechanical integrity under prolonged exposure to heat and oxidation. They further observed that the incorporation of thermally conductive fillers — such as boron nitride and graphene — enhances heat dissipation and prevents local thermal degradation, making these composites suitable for aerospace and automotive components.

The role of interfacial engineering is also highlighted by Liu et al. (2024), who demonstrated that controlled surface modification of fillers through silane coupling and plasma treatments significantly improves interfacial bonding, stress transfer, and fracture resistance. Similarly, Mandal et al. (2023) investigated the surface modification of hetero-phase nanoparticles and reported that tailored chemical compatibility between matrix and reinforcement enables high dielectric stability and reduced energy loss — properties critical for electrical engineering applications.

From a practical manufacturing perspective, Monteiro et al. (2024) reviewed recent advances in hybrid nanocomposites for aerospace applications and identified resin transfer molding and additive manufacturing as key technologies for producing lightweight, defect-minimized composite components. Their research

emphasized that controlled layup orientation and curing parameters are essential to maintain uniform filler dispersion and structural isotropy during industrial-scale production.

In the automotive sector, Khan et al. (2024) explored composite reinforcement strategies for vehicle components and concluded that hybrid composites combining carbon, glass, and particulate fillers effectively meet the trade-off between cost, impact strength, and recyclability. Meanwhile, Zhang et al. (2023) demonstrated that hetero-structured fillers significantly improve the thermal conductivity of polymer composites, providing both structural and heat management benefits in electric vehicle systems.

Despite remarkable progress, researchers consistently underline unresolved challenges. Seydibeyoğlu et al. and Barra et al. both noted the need for standardized testing protocols to compare hybrid formulations and validate their long-term fatigue performance. Liu et al. also emphasized the absence of predictive modeling tools that can integrate interfacial effects, filler interactions, and process variables into accurate mechanical forecasts. Environmental considerations have also been raised — Monteiro et al. and Khan et al. argue that lifecycle management and recyclability must become design parameters rather than post-production concerns, particularly as heterocomposite waste streams grow in volume.

In summary, the reviewed literature confirms that new heterocomposite polymer materials offer a robust pathway toward high-performance, multifunctional engineering solutions. As Mandal et al. and Liu et al. highlight, the success of these materials depends on three interrelated factors: intelligent hybrid reinforcement design, optimized interfacial chemistry, and scalable, defect-minimizing fabrication processes. Continued interdisciplinary research integrating materials science, mechanical engineering, and environmental design will determine the pace at which heterocomposite polymers transition from laboratory prototypes to industrial standards.

RESEARCH METHODOLOGY

The investigation of engineering properties—such as tensile strength, flexural modulus, impact resistance, fatigue performance, and thermal stability—forms the foundation for understanding and predicting the behavior of these advanced materials under various operating conditions [5]. The mechanical behavior of heterocomposites is not only influenced by the intrinsic properties of the polymer matrix and the reinforcements but also by the interfacial adhesion, filler distribution, and geometric configuration. Multi-scale modeling and experimental characterization have revealed that synergistic effects between micro- and nano-scale fillers can lead to property enhancements that exceed the simple sum of individual contributions. This synergism is particularly evident in hybrid nanocomposites, where nanoscale particles improve interfacial bonding and restrict crack propagation, while microscale fibers contribute to stiffness and load-bearing capacity.

Thermal and environmental performance are equally significant in determining the suitability of heterocomposite polymers for engineering applications. Many polymeric materials suffer from degradation at elevated temperatures or in chemically aggressive environments. The addition of thermally stable fillers such as silica nanoparticles, alumina, or boron nitride has been shown to improve thermal conductivity and stability, allowing for broader application ranges. Moreover, the incorporation of electrically conductive fillers, including carbon nanotubes, graphene, and metallic nanowires, has paved the way for multifunctional composites with self-sensing, anti-static, and electromagnetic interference (EMI) shielding properties. These characteristics are essential for next-generation smart structures and electronic packaging materials.

Another critical aspect of heterocomposite development is sustainability. With the increasing emphasis on environmental protection and resource efficiency, the use of bio-based polymers and natural fibers as components in heterocomposite materials has gained substantial attention. Natural fibers such as hemp, jute, and flax offer biodegradability and low cost, while synthetic nano-fillers can provide the mechanical and thermal reinforcement required for engineering-grade materials. Combining these elements results in sustainable hybrid systems that align with the principles of the circular economy and green engineering [6].

Recent studies have also highlighted the potential of additive manufacturing (3D printing) in the fabrication of heterocomposite polymers. Advanced printing technologies enable precise spatial control over the distribution and orientation of multiple fillers, making it possible to design gradient or functionally graded composites with tailored properties. This opens new opportunities in customized engineering applications, where material performance can be optimized for specific load paths, temperature zones, or electrical requirements within a single component.

ANALYSIS AND RESULTS

We determine and evaluate the results using the Lagrangian interpolation formula on the defined points [1-3]:

$$L(x_i) = f(x_i)\ i = 0,1,2,...,m\ \ m = 3 \quad (1)$$

we introduce a m-level polynomial:

$$l_k = \frac{(x-x_0)...(x-x_{k-1})(x-x_{k+1})...(x-x_m)}{(x_k-x_0)...(x_k-x_{k-1})(x_k-x_{k+1})...(x_k-x_m)} \quad (2)$$

This polynomial has a value 1 if $x = x_k$ and if $x = x_i$, $i \neq k$ it has a value 0. Using the above properties of the Lagrange polynomial, we write the polynomial in the following form:

$$L(x) = \sum_{k=0}^{m} f(x_k) l_k(x) \quad (3)$$

This equation is called Lagrange's interpolation formula if it satisfies all the requirements of the first condition. It is known that a polynomial $l_k(x)$ can be written in its simplest form by entering the following notation [4,5]:

$$\omega(x) = (x-x_0)(x-x_1)...(x-x_m) \quad (4)$$

The nodes of this polynomial interpolation are converted to 0 at the points $x_0, x_1, ..., x_m$.

$$(x-x_0)...(x-x_{k-1})...(x-x_{k+1})...(x-x_m) = \frac{\omega(x)}{x-x_k},\ (x \neq x_k), \quad (5)$$

$$(x-x_0)...(x-x_{k-1})...(x-x_{k+1})...(x-x_m) = \lim_{x\to x_k} \frac{\omega(x)}{x-x_k} = \lim_{x\to x_k} \frac{\omega(x)-\omega(x_k)}{x-x_k} \quad (6)$$

Depending on the number of given points of the argument, that is $m = 3$, the Lagrange interpolation formula given above can be written as follows:

$$L(x) = \sum_{k=0}^{m} f(x_k) l_k(x) = f(x_0)\frac{(x-x_1)(x-x_2)}{(x_0-x_1)(x_0-x_2)} + f(x_1)\frac{(x-x_0)(x-x_2)}{(x_1-x_0)(x_1-x_2)} + f(x_2)\frac{(x-x_0)(x-x_2)}{(x_2-x_0)(x_2-x_1)} =$$

$$= \frac{f(x_0)}{(x_0-x_1)(x_0-x_2)}[(x-x_1)(x-x_2)] + \frac{f(x_1)}{(x_1-x_0)(x_1-x_2)}[(x-x_1)(x-x_2)] + \frac{f(x_2)}{(x_2-x_0)(x_2-x_1)}[(x-x_0)(x-x_2)]$$

Table 1. Angren Kaolin

Material		x_0		x_1		x_2
Graphite	3	2,0	2,25	2,5	2,75	3
Angren Kaolin	20	20	25	30	40	50

$$L(x) = \sum_{k=0}^{m} f(x_k) l_k(x) = 20\frac{(x-2,5)(x-3)}{(2-2,5)(2-3)} + 25\frac{(x-2)(x-3)}{(2,5-2)(2,5-3)} + 50\frac{(x-2)(x-2,5)}{(3-2)(3-2,5)} =$$

$$= 40x^2 - 170x + 200 = 0 \quad (8)$$

$$4x^2 - 17x + 20 = 0\ \ x_{1,2} = \frac{17 \pm i\sqrt{21}}{8} \quad (9)$$

Table 2. Silk processing waste

Material		x_0		x_1		x_2
Graphite	3	2,0	2,25	2,5	2,75	3
silk processing waste	20	1,0	1,5	2,0	2,5	3,0

$$L(x)=\sum_{k=0}^{m} f(x_k)l_k(x)=1\frac{(x-2,5)(x-3)}{(2-2,5)(2-3)}+2\frac{(x-2)(x-3)}{(2,5-2)(2,5-3)}+3\frac{(x-2)(x-2,5)}{(3-2)(3-2,5)}=$$
$$=4x^2-18x+21=0$$

Table 3. Microhardness H, MPa

Material		x_0		x_1		x_2
Graphite	3	2,0	2,25	2,5	2,75	3
Microhardness H, MPa	181	210	216	212	205	195

$$L(x)=\sum_{k=0}^{m} f(x_k)l_k(x)=210\frac{(x-2,5)(x-3)}{(2-2,5)(2-3)}+212\frac{(x-2)(x-3)}{(2,5-2)(2,5-3)}+195\frac{(x-2)(x-2,5)}{(3-2)(3-2,5)}=$$
$$=-38x^2-955x-1743=0 \quad (11)$$

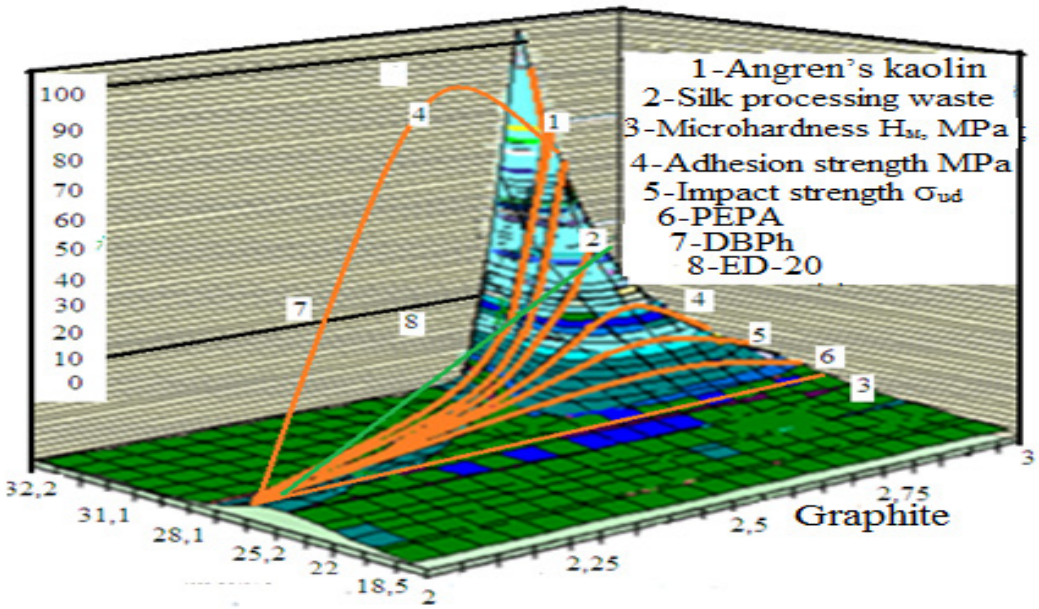

Figure 1. Spatial graph of the main components of HCPM and their optimization [3]

$$x_{1,2}=\frac{9\pm i\sqrt{255}}{4} \quad (10)$$

Table 4. Adhesion strength MPa

Material		x_0		x_1		x_2
Graphite	3	2,0	2,25	2,5	2,75	3
Adhesion strength MPa	24,5	32,5	33,2	28,2	26,6	25,1

$$L(x)=\sum_{k=0}^{m} f(x_k)l_k(x)=32,5\frac{(x-2,5)(x-3)}{(2-2,5)(2-3)}+28,2\frac{(x-2)(x-3)}{(2,5-2)(2,5-3)}+25,1\frac{(x-2)(x-2,5)}{(3-2)(3-2,5)}=$$
$$=2,4x^2-81x+59,2=0 \quad (12)$$

Table 5. Impact strength

Material		x_0		x_1		x_2
Graphite	3	2,0	2,25	2,5	2,75	3
Impact strength	18,5	22	25,2	28,1	31,1	32,2

$$L(x)=\sum_{k=0}^{m} f(x_k)l_k(x)=\text{2}\ ,5\frac{(x-2,5)(x-3)}{(2-2,5)(2-3)}+\text{8}\ ,2\frac{(x-2)(x-3)}{(2,5-2)(2,5-3)}+\text{3}\ ,1\frac{(x-2)(x-2,5)}{(3-2)(3-2,5)}=$$

$$=-4x^2+159x-2\ ,4=0 \qquad (13)$$

The IR spectrum shows that the absorption line of the epoxy oligomer forming the basis of the obtained composites is asymmetric in the valence region of the bonds –CH– epoxy groups 2920-3050 cm^{-1} and also asymmetric in the structure 1234, cm^{-1} –C–H and 1176, 1115, 1077 cm^{-1} –C–H generates symmetric valence oscillations. 2868 cm^{-1} IR- spectroscopy has lines from vibrations in the fields to the end bonds of –CN_2– epoxy groups as well as to the 752 cm^{-1} –CH_2– aliphatic bonds. The absorption lines in the 1340cm^{-1} fields belong to the groups holding carbon and hydrogen. It can be seen from the IR spectra that there are absorption lines in the 3000-3500 cm^{-1} and 3346-3214 cm^{-1} areas, which are characteristic of the NH_2 group. For the primary amines C-N, 1251, 1200, 1178, 1160, 1135 and 1066 cm^{-1} symmetrical valence bonds can be seen to be suitable (Figure 2).

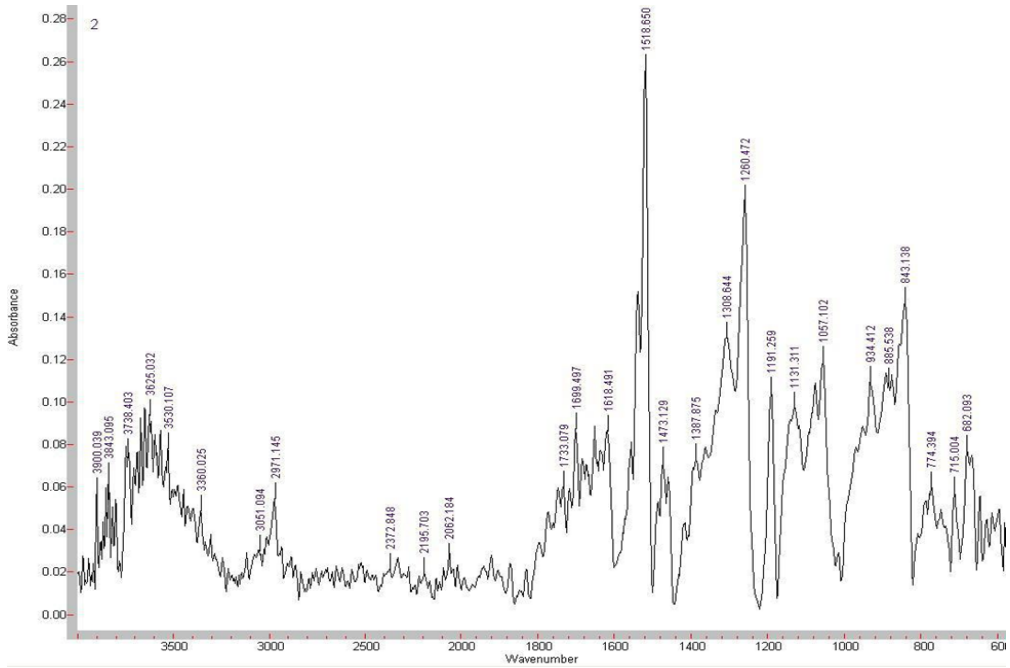

Figure 2. IR spectrum analysis of the proposed composition HCPM.

CONCLUSIONS AND SUGGESTIONS

The absorption lines in the 970, 912 cm^{-1} areas belonging to the epoxy ring (CH_2CHO-) can be seen to be characteristic of the asymmetric valence oscillation of the ring.

The aromatic rings in the epoxy resin show absorption lines in the 1607, 1506, 1452, 825 cm^{-1} areas.

Absorption lines in the 450-550 cm^{-1} regions of the IR spectra can be seen in the -C-C- groups, and in the 500-1000 cm^{-1} regions, the bonds between the metals partially formed by kaolin and wollastonite can be seen (Fig. 3). The main difference is that with the increase in the proportions of fillers added to them, the absorption lines are mainly in the 450-550cm^{-1} areas of the IR spectrum and in the 500-1000 cm^{-1} areas and in the 3000-3500 cm^{-1} areas due to hydroxides. [4-8].

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Musahhih: Zokir Alibekov

Sahifalovchi va dizayner: Iskandar Islomov

2025. № 10

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Axborot va ommaviy kommunikatsiyalar agentligi tomonidan
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