UDC 66.017
DOI: 10.15587/1729-4061.2023.280474

USING OF MICROSILICA FOR IMPROVEMENT OF PHYSICAL AND MECHANICAL PROPERTIES OF EPOXIDE-BASED COMPOSITE MATERIAL

Gulnara Kokayeva
Corresponding author
Candidate of Technical Sciences, Associate Professor
Department of Technological Machines and Equipment**
E-mail: g.kokayeva2000@gmail.com
Rimma Niyazbekova
Doctor of Technical Sciences, Professor*
Mira Serekpayeva
Master of Technical Sciences
Department of Science Management**
Ainur Ibzhanova
Master of Technical Sciences*
Amirbek Bekeshev
Candidate of Technical Sciences, Associate Professor
Department of Physics
K. Zhubanov Aktobe Regional University
Moldagulova str., 34, Aktobe, Republic of Kazakhstan, 010000
*Department of Standardization, Metrology and Certification**
**S. Seifullin Kazakh Agro Technical Research University
Zhenis ave., 62, Astana, Republic of Kazakhstan, 010011

Utilization of industrial waste and secondary raw materials, in particular, in the production of metallic silicon and silicon-containing alloys, which include silica vapors (microsilica), is the main task of implementing environmental policy and solves the problem of their storage and negative impact on the environment, in order to reuse them in polymer composites. The use of microsilica as a filler in composite materials based on epoxy resins contributes to a positive effect on the basic properties of the resin, and also makes it possible to use the composite material as coatings and parts in the repair of machinery and equipment. The aim of the work was to establish the positive effect of microsilica as a filler in composite materials based on ED-20 epoxy resin on improving the physical and mechanical properties of composite materials. Within the framework of this work, studies were conducted to test composite materials based on ED-20 epoxy resin, differing in different filler content of 2, 5, 10, 15 wt. % on impact strength, tensile strength and modulus of elasticity, adhesion and impact strength of the coating.

The analysis of the obtained results showed a positive effect of microsilica as a filler in composite materials based on ED-20 epoxy resin on the physical and mechanical properties of the composite material. The optimal filler content was determined, which is 2 % of the mass of the ED-20 epoxy resin, while an increase in adhesion, toughness of the composite material by 45 %, tensile strength and modulus of elasticity by 21 % and 5 %, respectively, and the strength of the coating on impact by 32 %, compared with the addition of microsilica in ED-20, which shows the prospects of using microsilica as a filler in composite materials

Keywords: filler, microsilica, epoxy resin, composite material, impact strength, tensile modulus

Received date 02.05.2023
Accepted date 28.07.2023
Published date 31.08.2023

How to Cite: *Kokayeva, G., Niyazbekova, R., Serekpayeva, M., Ibzhanova, A., Bekeshev, A. (2023). Using of microsilica for improvement of physical and mechanical properties of epoxide-based composite material. Eastern-European Journal of Enterprise Technologies, 4 (12 (124)), 18–25. doi: https://doi.org/10.15587/1729-4061.2023.280474*

1. Introduction

Metal processing and mining are industries supporting a lot of spheres including building industry. However, at present they cause environmental pollution. Ores and minerals treatment consumes a lot of energy, water, and heat. These result in emitting considerable amount CO_2 to the atmosphere, sewage and other wastes to water and soil. Although there are a lot of studies related to enhancing production and more effective raw materials treatment due to constraining harmful emissions into the environment, still negative impact of metallurgic and mining industry on the environment is widely discussed. The issue of raw materials treatment products is also problematic [1].

It is a well-known fact that production waste in the form of powders, such as microsilica, ashes, blast furnace slag etc. is a subject of numerous scientific researches on their recycling in different industries [2]. Construction is one of the promising areas where this kind of wastes can be used. So, the existing composite materials are enhanced with recycled production wastes. This trend has a few advantages [3]. The first one is in positive impact on the environment. Another benefit is that a new material can be produced with altered properties and improved structure. One of the examples of such material is cement-based composites improved by silica fumes (micro- and nanosilica) and fly ashes [4].

Thus, research in the field of improving the characteristics of epoxy resins and the development of new fillers is relevant, since they are aimed at creating more durable, stable and functional materials that can be applied in various industrial and technical fields.

2. Literature review and problem statement

In the study [1], high mechanical strength is noted, but there are properties of poor toughness. In the article [2], studies were conducted and water resistance and high electrical strength were justified, but low impact strength is noted. As a result of the study [3], good adhesion to metals and resistance to aggressive chemicals have been proven, but brittleness and low impact strength are also noted. The solution to these problems can be the results of studies of adhesive strength, where this indicator has been improved due to the introduction of andesite flour [4]. Improvement of acid resistance and crack resistance due to the addition of diabase powder [5]. Increasing the impact resistance of epoxy resins by adding a mixture of nanoscale particles [6].

Also, an important aspect is the availability of fillers from an economic point of view. Thus, studies [7] have shown that when choosing a filler, it is necessary that it meets all the technical requirements for obtaining composite materials based on epoxy resin: cheapness and availability of raw materials; high acid resistance; low density; moderate abrasiveness; low dispersion (no more than 120 microns); temperature resistance.

Cheapness and availability of raw materials: the filler must be affordable and have a low cost to ensure the economic feasibility of production [8]. High acid resistance: the filler must have the ability to sustainably resist the effects of acidic media, which is an important property for various industrial and technical applications [9]. Low density: the filler should have a relatively low density, which contributes to the creation of composite materials with a light weight. Moderate abrasiveness: the filler must have the ability to provide a moderate degree of abrasiveness so as not to damage the surfaces when using composite materials [10]. Low dispersion: the filler should have a small dispersion (no more than 120 microns), which means that its particles should be relatively small and evenly distributed in the epoxy resin matrix [11]. Temperature resistance: the filler must have the ability to withstand high temperatures without degradation of its properties. These requirements are important parameters when choosing a filler for the creation of composite materials based on epoxy resin, and they can play a crucial role in achieving the desired technical characteristics and properties of the material [12]. These requirements are important parameters when choosing a filler for the creation of composite materials based on epoxy resin, and they can play a crucial role in achieving the desired technical characteristics and properties of the material.

In [13, 14], a method is proposed to improve the impact strength and adhesive strength of epoxy resins by including two different types of polyethyramines, as well as silica nanoparticles. In studies [15], the protective properties of coatings based on epoxy resin were increased by introducing TiO_2 nanoparticles as a filler.

Unique properties of microsilica: microsilica has unique properties that allow it to be used in various fields, such as the production of building mixes, refractory and heat-insulating materials, paving and facing tiles, building concrete, cement, as well as for anticorrosive protection of equipment and machinery parts [16].

Solving environmental protection problems: interest in the use of silica in building materials is caused by environmental protection problems. The introduction of microsilica as a filler can help reduce atmospheric pollution and energy consumption by replacing natural materials with industrial waste [17].

Improvement of physico-chemical and operational properties of materials and coatings: the use of microsilica as a filler can contribute to improving the physico-chemical and protective properties of materials and coatings. This can be an important factor to ensure durability and effective protection of surfaces [18].

In general, the presented research describes the relevance of the study of the use of silica as a filler in building materials and coatings. This is due to its unique properties, application in various industries, environmental protection problems and the need to improve the properties of materials and coatings.

Microsilica is a by-product in the production of silicon and ferrosilicon alloys. It is collected in bag filters, which makes it available for use [19].

Microsilica is an amorphous dust consisting of spherical particles with a size of about 150 nm and a specific surface area of about 20 m^2/g. These properties can be important when using microsilica in various applications [20].

There is no danger to health, microsilica does not pose a danger to human health and complies with international standards. It contains only insignificant amounts of heavy metal oxides and organic deposits that originate from natural raw materials. Thus, microsilica is an affordable and safe material that can be used in various fields without posing a health hazard [21].

The chemical composition of microsilica depends on the choice of raw materials and the parameters of the production process. According to international standards (for example, ASTM 1240-01, EN 13263-1), the silica content in silica smoke for use in concrete should be at least 85 %. Typical impurities are carbon, silicon, phosphorus, sulfur, silicon carbide, chloride and various metal oxides. The color of microsilica varies from dark black to almost white depending on the carbon content [22].

Since the beneficial effects of microsilica are based on its physicochemical properties, further research is the key to understanding this product and developing new applications. Previously, conducted studies on the effect of the addition of microsilica with different mass content as a filler in composite materials based on epoxy resin ED-20 on chemical resistance, abrasion resistance and resistance to variable temperatures [23].

Based on the review of the above studies, it was revealed that microsilica is mainly used as a mineral additive in the production of dry building mixes, concrete and cement, which allows not only to reduce the cost of the product, but also to improve the technical properties of the product. To improve the properties of the epoxy resin, various additives were introduced, such as: andesite flour, diabase powder, inorganic and organic nanoparticles, nanoscale resinous particles (thermoplastics), except microsilica.

In this regard, it is advisable to conduct research on the effect of microsilica as a filler in composite materials based on epoxy resin, in order to increase the physical and mechanical properties of the epoxy composition, and to reduce the cost of finished products and the negative impact of the filler on the environment.

3. The aim and objectives of the study

The aim of this study is identifying the influence of microsilicon on physical and mechanical properties of a composite material based on epoxy as a filler in ED-20 epoxy resin.

To achieve this aim, the following objectives are performed:

– to determine the adhesion;

– to determine the impact strength and tensile strength;

– to determine the modulus of elasticity of composite materials.

4. Materials and methods

The object of research is a composite material based on ED-20 epoxy resin with the addition of a filler – silica. The main hypothesis of the study is that the percentage of the introduced filler – microsilica in the composition of the epoxy resin changes the properties of the epoxy composite. The study assumes that the addition of 2 masses. % of microsilica in the composition of ED-20 epoxy resin increases the impact strength, adhesive and strength properties of the composite material.

Simplifications adopted in the work are:

1) materials procurement in the form of ED-20 epoxy resin with PEPA hardener;

2) manufacture of composite materials based on ED-20 epoxy resin with different (2, 5, 10, 15 wt. %) the percentage of microsilica additives in the form of bars and double-sided blades;

3) application of layers of composite materials based on epoxy resin ED-20 with different (2, 5, 10, 15 wt. %) the percentage of microsilica additives on the prepared (cleaned) steel substrate;

4) laboratory testing;

5) data analysis.

The simplifications adopted in the work are as follows:

1) purchase of materials in the form of ED-20 epoxy resin with a PEP hardener;

2) production of composite materials based on ED-20 epoxy resin with various (2, 5, 10, 15 wt. %) the percentage of silica additives in the form of bars and double-sided blades;

3) application of layers of composite materials based on ED-20 epoxy resin with different (2, 5, 10, 15 wt. %) the percentage of silica additives on the steel substrate;

4) laboratory tests;

5) data analysis.

Microsilica was used as a filler in a composite material based on epoxy-diane resin ED-20 (GOST 10587-84). Microsilica is an ultrafine material consisting of spherical particles obtained in the process of gas purification of furnaces in the production of silicon-containing alloys (ferrosilicon) at the silicon plant of Tau-Ken Temir LLP (Karaganda). The main component of the material is silicon dioxide of amorphous modification. The synthesis of silicon metal alloys or ferrosilicon under the influence of high temperature forms a gas (silicon oxide). The gas reacts with oxygen and condenses into microsilica, taking the form of a gray powder consisting mainly of silicon dioxide.

The chemical and elemental composition of microsilica was determined using an X-ray fluorescence spectrometer manufactured by PANalytical, the Axios Max X-ray Spectrometer (XRF) model. The X-ray phase analysis was performed on an X-ray diffractometer manufactured by Rigaku (Rigaku Corporation, Japan), the smartLAB XRD model. The source of X-ray radiation is an X-ray tube Cu Ka-radiation (1.54059). The current and voltage of the tube are set to 50 mA and 40 kV, respectively. A one-dimensional detector (D/teX Ultra, Rigaku) with a Kß filter was used, and measurements were carried out by step-by-step scanning, provided the measurement angle range was 2θ=5–90°, the step width (δ2θ)=0.04° and the scanning speed=2°/min. PDXL software: INTEGRATED X-RAY POWDER DIFFRACTION SOFTWARE and the international database ICDD PDF-2 were used to identify phases and study the crystal structure.

Microsilica surface morphology was determined using a TM 3030 scanning electron microscope (Hitachi), and the size of microsilica particles was determined using a Mastersizer 3000 laser particle size analyzer with a Hydro MV prefix (120 ml) using water as a dispersion medium.

Samples of composite materials based on ED-20 epoxy resin with different (2, 5, 10, 15 weights were developed) the percentage of microsilica additives.

To obtain a composite material, a filler – microsilica in the amount of 2, 5, 10, 15 wt. % was added to the epoxy resin ED-20 and thoroughly mixed until a homogeneous mass was formed within 10 minutes. To cure the epoxy resin, a PEPA hardener was used in the resin: hardener ratio (1:10) and mixed for 2 minutes. To determine the adhesion and strength of the coating upon impact, the resulting material was applied to a prepared (cleaned) steel substrate (size 70×150 mm) in thin layers. The standard sample was made without the addition of filler. Then the coating was dried at a temperature of 18–20 °C for 24 hours. The thickness of the coating was 18 microns and it was determined according to ST RK GOST R 51694-2007, method 3A (micrometric).

To determine the impact strength and tensile testing of the composite material, samples were made by molding in the form of bars of the size 10±0.5×15±0.5×120±2 mm and double-sided blade size 4.0±0.2×20.0±0.2×170±0.2 mm. The test samples are shown in Fig. 1.

The impact strength of the composite material was determined by the Sharpie method according to GOST 4647-2015 on the KMM-M pendulum copra, shown in Fig. 2.

a

b

Fig. 1. Test samples in the form: *a* – a bar; *b* – a double-sided blade

Mechanical tensile tests of composite materials were determined according to GOST 11262-2017, and the modulus of elasticity under tension according to GOST 9550-81. The tests were carried out on a universal testing machine WDW-5E.

The adhesion of the coatings was determined in accordance with GOST 15140-78 by the method of parallel incisions. To determine the impact strength of coatings according to GOST 4765-730, a U-1 type device was used.

All tests were carried out at a temperature of (20±2) °C and relative humidity (65±5) %.

Fig. 2. KMM-M pendulum coper

5. Results of the study of the physical and mechanical properties of composite materials

5. 1. The determination of the adhesion of composite coatings to metal surfaces was carried out by the method of parallel incisions

The essence of the method consists in applying parallel incisions to the finished coating, in assessing the degree of adhesion of the paint film to the substrate by the number of detached film strips when detached from the substrate using adhesive tape. Adhesion by the method of parallel incisions is evaluated on a three-point scale. The results of the tests are shown in Table 1.

Table 1

Test results for determining the adhesion of composite coatings

No.	Coating composition	Description of the coating surface after applying parallel incisions and removing the adhesive tape	Number of samples, pieces	Average score value
1	ED-20 (without the addition of microsilica)	Slight peeling of coatings along the width of the strip and along the incisions (no more than 0.5 mm)	10	2
2	ED-20+2 % microsilica	The edges of the incisions are smooth	10	1
3	ED-20+5 % microsilica	Slight peeling of coatings along the width of the strip and along the incisions (no more than 0.5 mm)	10	2
4	ED-20+10 % microsilica	Slight peeling of coatings along the width of the strip and along the incisions (no more than 0.5 mm)	10	2
5	ED-20+15 % microsilica	Peeling of the coating with strips	10	3

Thus, it can be seen from Table 1 that the adhesion of the composite material with the addition of 2 masses. The % of microsilica with the protected metal is 1–2 points higher than the adhesion of regular and other composite materials with additives of microsilica 5, 10, 15 wt %.

5. 2. Determination of the impact strength and tensile strength of the composite material

According to the results of the conducted studies, the chemical composition of microsilica was determined, which is presented in Table 2. Microsilica consists mainly of SiO_2, Free K_2O, Fe_2O_3 and also contains small impurities of oxides MgO, Mn_2O_3.

Table 2

Chemical composition of microsilica

Element	O	Si	Ca	K	Fe	Mg	Mn
The content of the element, mass. %	57.512	39.677	0.857	0.294	0.126	0.035	0.021

The fractional composition of microsilica is characterized by a bimodal distribution and is represented by particles from 0.1 to 100 microns with average particle sizes of 2–6 microns and 7–14 microns (Fig. 3), which is also confirmed by scanning electron microscope (SEM) data (Fig. 4).

Fig. 4 shows that microsilica particles have a smooth surface and a spherical shape. The powder actually consists of loose silica agglomerates with a very low bulk density.

The data obtained on a laser diffraction particle size analyzer show that the volume fraction of microsilica particles smaller than 9 microns is 90 **%** (Table 3).

According to the RFA data, microsilica is represented by two main structures: Fe_2O_3 – 88 **%** and SiO_2 – 12 **%** (Fig. 5). X-ray diffraction analysis of the particles showed the orthorhombic structure of the crystal lattice [23].

Since composite materials are almost always under the influence of external and internal stresses during operation, therefore, to assess their quality and durability, it is mandatory to determine their physical and mechanical properties.

To assess the quality of a composite material based on ED-20 epoxy resin with a microsilica filler introduced into the composition in the amount of 2, 5, 10, 15 wt. %, the following laboratory tests were carried out.

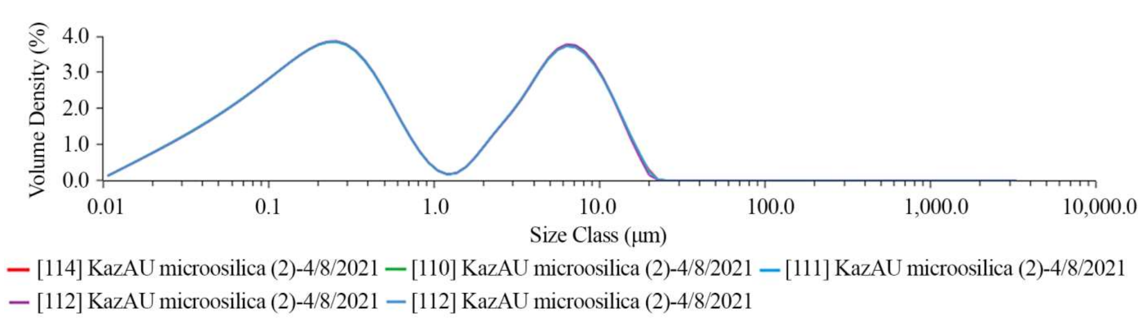

Fig. 3. Distribution of microsilica particle sizes

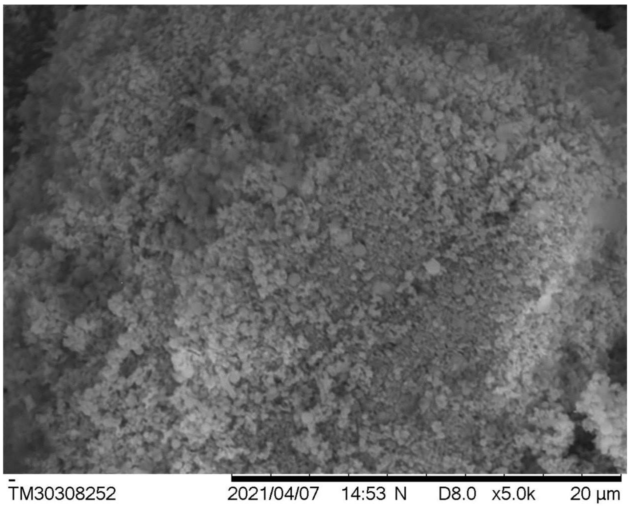

Fig. 4. Images of microsilica under a scanning electron microscope

Table 3

Distribution of microsilica particle sizes

Record number	Sample name	Dx (10) (µm)	Dx (50) (µm)	Dx (90) (µm)	Laser Obscuration (%)
128	Microsilica 1	0.0515	0.365	8.81	1.01
129	Microsilica 2	0.0520	0.368	8.84	1.00
130	Microsilica 3	0.0521	0.367	8.71	1.00
131	Microsilica 4	0.0520	0.367	8.80	1.00
132	Microsilica 5	0.0520	0.367	8.80	1.00
Mean		0.0519	0.367	8.79	1.00
1xStd Dev		0.000247	0.000756	0.0481	0.01
1xRSD (%)		0.476	0.206	0.547	0.42

Impact strength is the ability of a material to absorb mechanical energy in the process of deformation and destruction under the influence of shock load. The essence of the method for determining the impact strength of a material is a test in which a sample lying on two supports is struck by a pendulum at a constant speed (when struck "flat" or "in the rib"), and the impact line is located in the middle between the supports and directly opposite the incision of the incised samples. The blow is applied on the surface of the sample opposite to the incision.

The type of destruction is complete, the fracture surface is smooth. The arithmetic mean value of the test results of all samples, which are shown in Table 4, was taken as the test result, and according to which it is clear that the impact strength of samples with a content of 2, 5, 10, 15 masses. The % of microsilica varies in the range of 0.618–1.187 J/cm^2.

According to the test results, it can be seen that the impact strength of the composite material with the addition of 2 wt. The % of microsilica has a maximum value and is 1.187 J/cm^2, which is 1.4–1.9 times higher than the impact strength of standard and composite materials with additives of 5, 10, 15 wt. % of microsilica, respectively. The greater the impact strength, the better the material resists dynamic loading.

Table 4

Test results for determining the impact strength of a composite material

No.	Composition of the composite material	Number of samples, pieces	Impact energy, J	Impact strength, J/cm^2
1	ED-20 (without the addition of microsilica)	10	0.215	0.651
2	ED-20+2 % microsilica	10	0.380	1.187
3	ED-20+5 % microsilica	10	0.220	0.687
4	ED-20+ +10 % microsilica	10	0.265	0.827
5	ED-20+ +15 % microsilica	10	0.198	0.618

The test method is based on stretching the test sample along its main longitudinal axis at a constant speed, during the stretching process, the load sustained by the sample and the elongation of the sample are measured and the set parameters are determined. The essence of the method for determining the elastic modulus under tension is to determine the ratio of the stress increment to the corresponding elongation increment established by this standard. Tensile tests of the composite material were carried out on a universal testing machine WDW-5E.

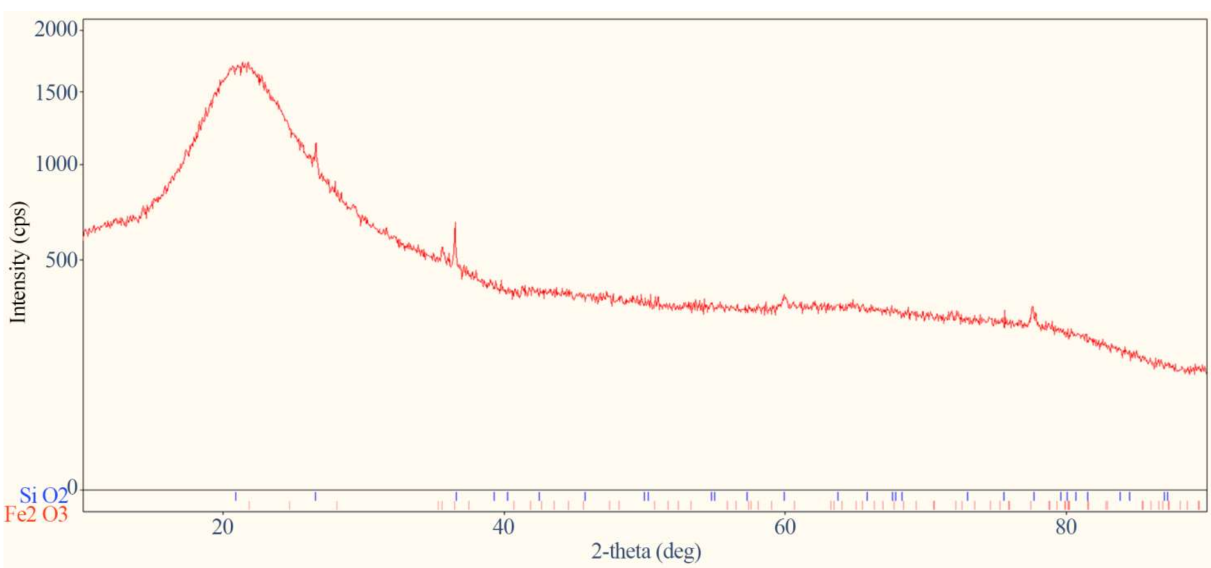

Fig. 5. Diffractogram (XRD) of microsilica

The arithmetic mean of the test results of all samples, which are shown in Table 5, was taken as the test result.

Table 5

Results of tensile tests of composite material

No.	Composition of the composite material	Number of samples, pieces	Tensile strength, MPa	Tensile modulus of elasticity, MPa
1	ED-20 (without the addition of microsilica)	10	22	1611
2	ED-20+2 % microsilica	10	28	1696
3	ED-20+5 % microsilica	10	19	1336
4	ED-20+10 % microsilica	10	14	1330
5	ED-20+15 % microsilica	10	13	1011

Table 3 shows graphs of the dependence of the strength and elastic modulus of a composite material under tension on the mass content of microsilica in the epoxy resin. It can be seen from the graphs that the peak with the maximum values of the strength and elastic modulus of the composite material under tension are observed at a content of 2 masses. % of microsilica in ED-20, and with a further increase in the content of microsilica in ED-20 over 2 wt. % strength indicators are decreasing.

The results obtained indicate that the most rational content as an additive is 2 wt. % of microsilica, since with such a content, the strength increases by 21 % and the modulus of elasticity increases by 5 % when stretched by a composite material compared to the standard material.

5. 3. Determination of the strength of composite coatings on impact

To determine the strength of composite coatings on impact, a method was used based on determining the maximum height, when falling from which a load of a certain mass does not cause visible mechanical damage (cracks, peeling) on the surface of the plate with the composite material.

If there are no defects, then the test is repeated, increasing the height of dropping the load each time by 5–10 cm until the first damage to the coating is detected on impact. Repeated tests are carried out each time on a new section of the plate. For each height, the definition is repeated at least three times. The value of the maximum height at which three positive test definitions are obtained is taken as the result.

Thus, the arithmetic mean of the test results of all samples, which are shown in Table 6 was taken as the test result.

So, according to the test results obtained, it can be seen that the impact strength of the composite coating with the addition of 2 wt. The % of microsilica has a maximum value and is 125 kg/cm, which is 32 % more impact strength of the standard coating.

Thus, the data of the conducted tests indicate that the highest indicators for the physico-mechanical properties of the composite material were obtained when introducing microsilica in the amount of 2 wt. % into ED-20 as a filler.

6. Discussion of results of the study of the physical and mechanical properties of composite materials

The conducted studies show that with the introduction of microsilica filler into the composition of the ED–20 epoxy resin, the physical and mechanical properties of the composite material increase. According to the test results, it can be seen that in comparison with the material without the addition of filler, the following indicators of the composite material with the addition of 2 masses are improved % of microsilica:

– the impact strength, determined by the Sharpie method on the KMM-M pendulum copra (Fig. 2), has a maximum value and increases by 1.9 times, as shown in Table 2;

– tensile strength and modulus of elasticity increased by 21 % and 5 %, respectively, as shown in Table 3. Tensile tests of composite materials were carried out on a universal testing machine WDW-5E (Fig. 3);

– adhesion increased by 1 point (Table 4);

– impact strength increased by 32 %, as shown in Table 6 and was determined using the U-1 type device shown in Fig. 4.

In this work, microsilica is used as a filler, which, in addition to increasing the toughness, adhesion and impact strength of the epoxy resin-based material, which is also improved by the results of works [13, 14] in which fillers – polyethyramines and silica nanoparticles were used, increases the strength and modulus of elasticity under tension. The works of scientists [24, 25] present studies on the effect of additives of elastomers-rubbers and filamentous crystals of potassium polytitanate in epoxy resin on the strength properties of the resin. The introduction of these additives into the epoxy resin leads to an increase in compressive strength by 25 %, tensile strength by 20 %, impact strength by 33 %, elongation by 28 % and hardness by 43 %, as well as to an increase in the resistance of the epoxy composite to shock loads by 27 %. In addition, microsilica is traditionally used as a filler as a highly active mineral additive to concrete and cement [17, 19], and in our case it is used as an additive for hardening epoxy resin.

Thus, in comparison with other fillers, let's propose the optimal composition of a composite material based on ED-20 epoxy resin with the addition of a filler – microsilica and determined its optimal content, which is 2 % of the mass of ED-20 epoxy resin. With this filler content, the strength properties of the epoxy resin give the best performance.

Currently, one of the most promising areas for the use of industrial waste is to involve them in secondary circulation as secondary material or energy resources. Within the framework of this study, the issue related to the involvement of industrial waste by the activation of microsilica, which is a waste of ferroalloy production, and its use as an affordable and inexpensive filler to improve the physical and mechanical properties of the composite material is considered.

Table 6

Test results for determining the strength of composite coatings on impact

No.	Coating composition	Coating thickness, microns	Cargo weight, kg	Number of samples, pcs	Load drop height, cm	Impact strength of the coating, kg·cm
1	ED-20 (without the addition of microsilica)	18	1	8	85	85
2	ED-20+2 % microsilica	18	1	8	125	125
3	ED-20+5 % microsilica	18	1	8	115	115
4	ED-20+10 % microsilica	18	1	8	100	100
5	ED-20+15 % microsilica	18	1	8	90	90

The main limitation of the conducted research is to determine the effect of the addition of microsilica on the physical and mechanical properties of the composite material, such as toughness, tensile strength and modulus of elasticity, adhesion and impact strength. In the future, it is advisable to investigate the microstructure of the material with various additives. Therefore, it is necessary to conduct a thorough and in-depth study in this direction.

In addition, for a complete study of the physico-mechanical properties of a composite material based on epoxy resin with the addition of microsilica, it is necessary to investigate additional characteristics, including tests to determine the thermophysical properties of the composite material. In this regard, further research will be continued to determine the wear resistance, heat resistance, compressive strength and microhardness of composite material with microsilica additives.

7. Conclusions

1. The adhesion of the composite material with the addition of 2 wt. % of microsilica with protected metal showed the best score. Further increase in the amount of the additive (more than 2 wt. %) leads to a decrease in the physical and mechanical properties of the composite material.

2. The maximum value of the impact strength of a composite material with the addition of 2 wt. % filler is 1,187 J/cm^2. The tensile strength of the composite material increases from 22 MPa to 28 MPa, i. e. by 21 %, with the addition of 2 wt. % of the filler is microsilica.

3. At the same time, the tensile modulus of elasticity increases from 1611 MPa to 1696 MPa, i. e. by 5 %. Impact strength of the composite coating with the addition of 2 wt. The % of microsilica has a maximum value and is 125 kg/cm, which is 32 % more than the impact strength of the epoxy coating without filler.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, au-thorship or otherwise, that could affect the research and its results presented in this paper.

Financing

This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant no. AP09058166).

Data availability

Manuscript has associated data in a data repository.

Acknowledgments

This study was conducted within the framework of a funded scientific project by the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant No. AP09058166). The study was conducted in the laboratory of the Kazakh Agrotechnical Research University.

References

1. Sun, W., Xu, X., Lv, Z., Mao, H., Wu, J. (2019). Environmental impact assessment of wastewater discharge with multi-pollutants from iron and steel industry. Journal of Environmental Management, 245, 210–215. doi: https://doi.org/10.1016/j.jenvman.2019.05.081
2. Doifode, S., Matani, A. G. (2015). Effective industrial waste utilization technologies towards cleaner environment. International Journal of Chemical and Physical Sciences, 4, 536–540.
3. Andrzejuk, W., Barnat-Hunek, D., Góra, J. (2019). Physical Properties of Mineral and Recycled Aggregates Used to Mineral-Asphalt Mixtures. Materials, 12 (20), 3437. doi: https://doi.org/10.3390/ma12203437
4. Gil, D. M., Golewski, G. L. (2018). Potential of siliceous fly ash and silica fume as a substitute for binder in cementitious concretes. E3S Web of Conferences, 49, 00030. doi: https://doi.org/10.1051/e3sconf/20184900030
5. Wan, J., Li, C., Bu, Z.-Y., Xu, C.-J., Li, B.-G., Fan, H. (2012). A comparative study of epoxy resin cured with a linear diamine and a branched polyamine. Chemical Engineering Journal, 188, 160–172. doi: https://doi.org/10.1016/j.cej.2012.01.134
6. Gómez-del Río, T., Rodríguez, J., Pearson, R. A. (2014). Compressive properties of nanoparticle modified epoxy resin at different strain rates. Composites Part B: Engineering, 57, 173–179. doi: https://doi.org/10.1016/j.compositesb.2013.10.002
7. Sukanto, H., Raharjo, W. W., Ariawan, D., Triyono, J., Kaavesina, M. (2021). Epoxy resins thermosetting for mechanical engineering. Open Engineering, 11 (1), 797–814. https://doi.org/10.1515/eng-2021-0078
8. Unnikrishnan, K. P., Thachil, E. T. (2006). Toughening of epoxy resins. Designed Monomers and Polymers, 9 (2), 129–152. doi: https://doi.org/10.1163/156855506776382664
9. Lou, C., Liu, X. (2018). Functional dendritic curing agent for epoxy resin: Processing, mechanical performance and curing/toughening mechanism. Composites Part B: Engineering, 136, 20–27. doi: https://doi.org/10.1016/j.compositesb.2017.09.073
10. Sun, Z., Xu, L., Chen, Z., Wang, Y., Tusiime, R., Cheng, C. et al. (2019). Enhancing the Mechanical and Thermal Properties of Epoxy Resin via Blending with Thermoplastic Polysulfone. Polymers, 11 (3), 461. doi: https://doi.org/10.3390/polym11030461
11. Fernández Zapico, G., Ohtake, N., Akasaka, H., Munoz-Guijosa, J. M. (2019). Epoxy toughening through high pressure and shear rate preprocessing. Scientific Reports, 9 (1). doi: https://doi.org/10.1038/s41598-019-53881-0
12. Farooq, U., Teuwen, J., Dransfeld, C. (2020). Toughening of Epoxy Systems with Interpenetrating Polymer Network (IPN): A Review. Polymers, 12 (9), 1908. doi: https://doi.org/10.3390/polym12091908

13. Panthakkal Abdul Muthalif, M., Choe, Y. (2022). Adhesive and Impact-Peel Strength Improvement of Epoxy Resins Modified with Mono and Diamine Functionalized Elastomers. Advances in Polymer Technology, 2022, 1–9. doi: https://doi.org/10.1155/2022/2309235
14. Sprenger, S. (2013). Epoxy resins modified with elastomers and surface-modified silica nanoparticles. Polymer, 54 (18), 4790–4797. doi: https://doi.org/10.1016/j.polymer.2013.06.011
15. Shafaamri, A., Cheng, C. H., Wonnie Ma, I. A., Baig, S. B., Kasi, R., Subramaniam, R., Balakrishnan, V. (2020). Effects of TiO_2 Nanoparticles on the Overall Performance and Corrosion Protection Ability of Neat Epoxy and PDMS Modified Epoxy Coating Systems. Frontiers in Materials, 6. doi: https://doi.org/10.3389/fmats.2019.00336
16. Majeed, A. H. (2018). Enforcement of Epoxy with Silica Fume and Carbon Fiber. Tikrit Journal of Engineering Sciences, 25 (1), 74–77. doi: https://doi.org/10.25130/tjes.25.1.11
17. Tkach, E. V., Temirkanov, R. I., Tkach, S. A. (2021). A comprehensive study of modified concrete based on activated silica in conjunction with micro-reinforcing fiber to improve performance. Izvestiya Tomsk Polytechnic University. Georesource engineering, 332 (5), 215–226.
18. Szewczak, A., Szeląg, M. (2020). Physico-Mechanical and Rheological Properties of Epoxy Adhesives Modified by Microsilica and Sonication Process. Materials, 13 (23), 5310. doi: https://doi.org/10.3390/ma13235310
19. Massana, J., Reyes, E., Bernal, J., León, N., Sánchez-Espinosa, E. (2018). Influence of nano- and micro-silica additions on the durability of a high-performance self-compacting concrete. Construction and Building Materials, 165, 93–103. doi: https://doi.org/10.1016/j.conbuildmat.2017.12.100
20. Kononova, O. V., Smirnov, A. O. (2017). Investigation of the features of the formation of the strength of quasi-self-compacting concrete with silica. Fundamental Research, 7, 327–331.
21. Mohammad Nejad, S., Srivastava, R., Bellussi, F. M., Chávez Thielemann, H., Asinari, P., Fasano, M. (2021). Nanoscale thermal properties of carbon nanotubes/epoxy composites by atomistic simulations. International Journal of Thermal Sciences, 159, 106588. doi: https://doi.org/10.1016/j.ijthermalsci.2020.106588
22. Wu, S., Peng, S., Wang, C. (2018). Multifunctional Polymer Nanocomposites Reinforced by Aligned Carbon Nanomaterials. Polymers, 10 (5), 542. doi: https://doi.org/10.3390/polym10050542
23. Serekpayeva, M. A., Kokayeva, G. A., Niyazbekova, R. K., Kardybai, S. (2021). Investigation of the properties of composite materials based on epoxy resins with microsilica additives. Kompleksnoe Ispol′zovanie Mineral′nogo Syr′â/Complex Use of Mineral Resources/Mineraldik Shikisattardy Keshendi Paidalanu, 318 (3), 63–70. doi: https://doi.org/10.31643/2021/6445.29
24. Meiirbekov, M. N., Ismailov, M. B. (2020). The effect of rubber on the mechanical properties of epoxy and carbon fiber (Review). Kompleksnoe Ispol′zovanie Mineral′nogo Syr′â/Complex Use of Mineral Resources/Mineraldik Shikisattardy Keshendi Paidalanu, 312 (1), 11–21. doi: https://doi.org/10.31643/2020/6445.02
25. Mostovoy, A. S., Kadykova, Y. A., Bekeshev, A. Z., Tastanova, L. K. (2018). Epoxy composites modified with microfibers of potassium polytitanates. Journal of Applied Polymer Science, 135 (35), 46651. doi: https://doi.org/10.1002/app.46651