

RECYCLING OF INDUSTRIAL WASTE TO CREATE NEW COMPOSITE MATERIALS

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ABSTRACT

This article investigates the possibility of producing new composite materials for construction applications using industrial and household waste. Brick rubble, microsilica, ash, and slaked lime were used as starting materials. The objective of the study is to develop a formulation for a recycled composite material and to evaluate its physical and mechanical properties. To achieve this objective, experimental formulations and a sample fabrication process were developed. The studies included determining compressive strength in accordance with GOST 10180-2012, water absorption in accordance with GOST 12730.3-2020, and examining the microstructure using scanning electron microscopy. It was found that samples containing brick rubble and slaked lime exhibited the highest compressive strengths, with compressive strengths of 9.1 and 8.28 MPa, respectively. It was shown that applying a protective coating reduces the water absorption of the studied materials to 2.5–12.5%, which contributes to an increase in their moisture resistance. Microstructural analysis confirmed the formation of a dense, homogeneous structure without pronounced defects in the samples with the highest strength characteristics. The results obtained confirm the potential of the integrated use of construction and industrial waste to produce composite materials with satisfactory performance properties intended for use in construction and foundry production, and also contribute to addressing the challenges of resource conservation and reducing environmental impact.

INTRODUCTION

The rational use of natural resources and the reduction of the negative environmental impact of waste are among the most important challenges facing modern society. As construction and industrial production continue to grow, the recycling and reuse of industrial waste as secondary raw materials for the production of construction materials are becoming particularly important.

A significant portion of construction waste consists of concrete and reinforced concrete rubble, broken bricks, waste from the production of construction products, and materials generated during the demolition of buildings and structures. Despite the large volume of such waste generated, only a small portion of it is recycled, while the bulk is transported to landfills or dumped in unauthorized dumping sites. At the same time, recycling construction debris yields recycled crushed stone, sand, and other materials, the use of which helps reduce the consumption



of natural raw materials and lower the cost of construction products (Tavares Gomes et al., 2026). Global experience shows that the use of recycled construction materials is highly effective. In a number of European countries, the recycling rate for construction waste reaches 90% or more. The use of recycled materials makes it possible to significantly reduce energy consumption, decrease the volume of waste sent to landfills, and lessen the environmental impact (Ulyeva et al., 2023).

According to various estimates, between 1,500 and 2,000 thousand metric tons of construction waste are generated each year in the construction sector. This includes construction debris from the demolition and dismantling of structures, defective and substandard products from reinforced concrete plants, and unused mortar and mixtures at construction sites. Of this total, 70,000–80,000 metric tons are recycled into secondary sand and crushed stone. The remainder is transported to construction waste landfills, conventional dumps, or dumped in the most unsuitable locations—such as forests, ravines, swamps, and other areas. There are approximately 80 billion metric tons of construction and industrial waste at disposal sites and landfills. About 10% of this volume enters the recycling stream for processing (Safeer et al., 2025).

Of particular interest is the use of broken brick, the volume of which increases annually as a result of the renovation and demolition of old buildings. Broken brick can be used as an aggregate for concrete, a material for constructing road bases, backfill for trenches and excavations, and to improve the thermal and sound insulation properties of building structures. The use of brick rubble helps reduce construction costs by partially replacing traditional aggregates and provides an effective solution to the problem of construction waste disposal (Zhang et al., 2025).

The problem of ash and slag waste disposal remains a pressing issue even after the industrial-scale implementation of new technologies for processing ash and slag. Every day, more than 350 metric tons of this waste are generated solely from the incineration of municipal solid waste in urban areas. Ash waste poses a particular environmental hazard due to its high dispersibility and increased toxicity. Furthermore, because of its low bulk density, the storage and disposal of ash require significant volumes and areas (Kumar & Shukla, 2023). Global practice demonstrates the high effectiveness of processing ash and slag waste. In a number of countries, the recycling rate reaches 70–100%. The use of ash and slag not only reduces the cost of construction materials but also decreases the volume of accumulated waste, thereby helping to address environmental problems in these regions (Tamanna et al., 2020; Zharmenov et al., 2022).

According to research findings, ash-slag waste can be used in the production of aerated concrete, silicate bricks, expanded clay concrete, artificial aggregates, and granular materials to replace crushed stone in concrete. The works (Gavrilin et al., 2002; Munkhtuvshin et al., 2017; Polyakov et al., 2000; Ulyeva, Tuyskhan, Akhmetova, & Aitbaev, 2023; Wang et al., 2022) propose a technological solution for the use of ash-slag waste: a raw material mixture for the manufacture of ash-ceramic blocks and bricks, containing a plasticizing additive based on an ash component and clay, characterized in that, as the ash component, the plasticizing additive contains ash from the incineration of industrial and municipal waste.

Microsilica, a dust-like byproduct of silicon and ferroalloy production, is also a promising man-made raw material. For every metric ton of silicon produced, hundreds of kilograms of silica dust are generated, which has a negative impact on the environment when stored. Due to its high silicon dioxide content, microsilica is widely regarded as an active mineral additive for composite building materials. Its use helps increase the strength, density, and durability of building products (Leonova, 2019).

Recent studies confirm the potential for the effective use of various industrial and construction wastes in the production of building ceramics, concrete, road materials, and other composite systems. Technologies are being developed for the comprehensive processing of silicon-containing wastes, enabling the production of useful products and significantly reducing

the environmental impact. The author addresses the problem of disposing of dust-like silicon waste by proposing a method for agglomerating dust from silicon production—containing an average of 86% SiO_2 —for use as an additional source of raw material in silicon production. This solution will reduce the environmental impact of the industrial region and improve working conditions for employees.

The integrated use of brick scrap, ash and slag waste, microsilica, and lime not only helps address environmental challenges related to waste disposal but also yields materials with improved performance characteristics. In this regard, a current focus of scientific research is the development of new recycled composite materials based on production and consumption waste. The use of inexpensive, readily available man-made raw materials helps reduce the consumption of natural resources, lower construction product costs, and improve the environmental safety of the construction industry. Research into the potential use of brick scrap, ash, microsilica, and lime to produce new composite materials is of both scientific and practical interest, as it contributes to resource conservation, waste utilization, and environmental protection.

The scientific novelty of this research lies in the proposal of a low-energy method for producing a composite heat-shielding material from recycled mineral raw materials. This method involves molding and subsequent low-temperature drying without a high-temperature firing stage.

Thus, the resulting low-temperature recycled composite material represents a promising approach to reducing energy consumption in production, facilitating resource conservation, waste recycling, and environmental protection.

MATERIALS AND METHODS

The purpose of this study is to investigate the physical and mechanical properties of new composite materials produced from industrial and household waste (broken bricks, ash, microsilica, and slaked lime) (Figure 1).

Each of the raw materials was sieved through a 1–2 mm sieve and weighed. The dry components were thoroughly mixed to ensure uniform distribution. After complete mixing, distilled water was gradually added in 3–7 g portions, and the mixture was stirred until a homogeneous consistency was achieved. Mixing and compaction were carried out manually.



Figure 1. Source Materials:

a) slaked lime; b) microsilica; c) fly ash; d) broken bricks

Note – compiled by the authors

The formulations of the samples obtained are presented in Table 1.

Table 1. Composition of the Components in the Samples Obtained

Material	Amount of material, g							
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Brick rubble	25	50	25	50	25	50	25	50
Ash	25	25	-	-	-	-	25	25
Microsilica	-	-	25	25	-	-	-	-
Slaked lime	-	-	-	-	25	25	25	25
<i>Note – compiled by the authors</i>								

The resulting mixture was compacted in molds and shaken to remove air. The samples took 14 days to dry. After drying, all samples were strong, virtually free of cracks and pores, and produced a metallic sound (Figure 2). The shape of the samples is round, 40 mm high.



Figure 2. Samples dried under natural conditions

Note – compiled by the authors

Determination of Compressive Strength (GOST 10180-2012).

The compressive strength is one of the key parameters used to characterize the mechanical properties of materials. It defines the maximum stress a material can withstand before failure or deformation occurs.

To determine the compressive strength, a method is used that involves gradually increasing the uniformly distributed load on the specimen until it fails.

When preparing specimens for compression testing, their surfaces—which are perpendicular to the direction of the compressive load—are leveled. This ensures an even distribution of the load across the specimen during testing, which yields more accurate results.

Next, the diameter of the specimens (d) is measured, and the cross-sectional area of the specimen (A) is calculated using the following formula:

$$A = \pi * R^2 \quad (1)$$

where π – is a mathematical constant equal to 3.14;

R – is the radius of the sample.

The specimens were then placed one at a time between the support plates of the MI-40KU testing machine.

The compressive strength was determined using the following formula:

$$\sigma_{сж} = \frac{F}{S} \text{ (MPa)} \quad (2)$$

where F – is the load applied to the specimen, N;

S – is the cross-sectional area of the specimen, cm^2 .

The behavior of the specimens during the compression test is shown in Figure 3.

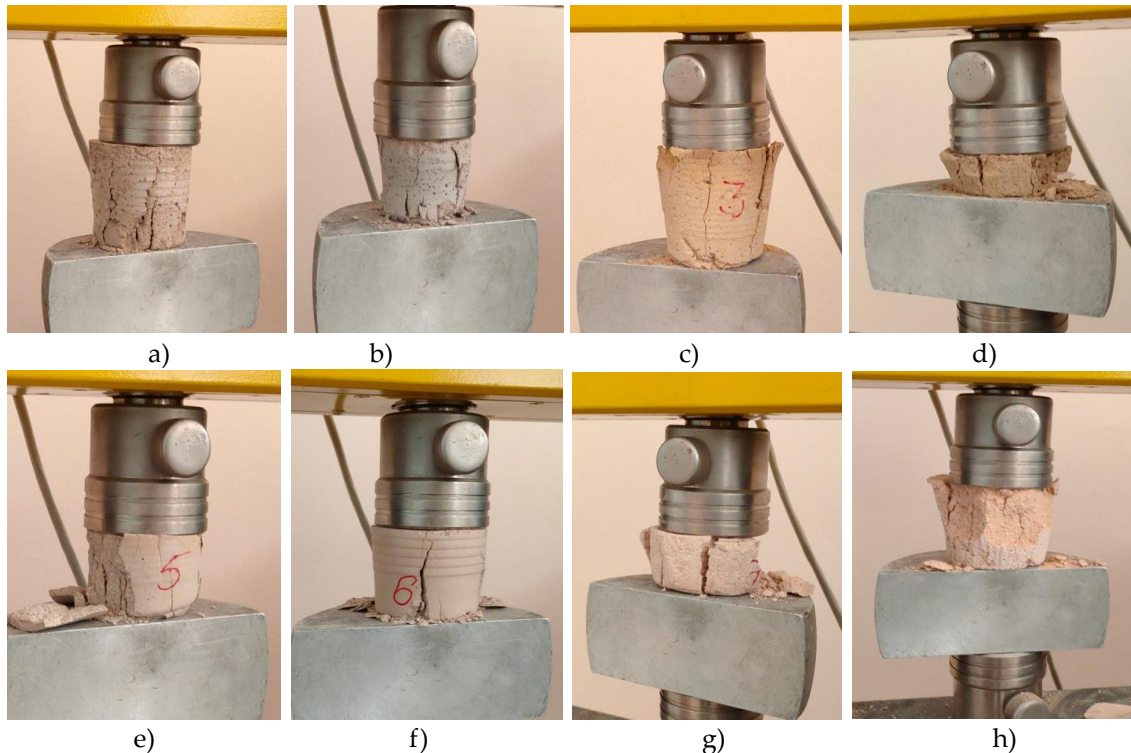


Figure 3. Condition of the samples after testing:

a – Sample No.1; b – Sample No.2; c – Sample No.3; d – Sample No.4;
e – Sample No.5; f – Sample No.6; g – Sample No.7; h – Sample No.8

Note – compiled by the authors

Determination of Water Absorption (GOST 12730.3-2020). The determination of water absorption in materials is based on measuring their ability to absorb moisture. This is achieved by immersing a sample in water. After a specified exposure time, the change in the sample's mass is measured.

The samples were first weighed to determine their initial mass and then immersed in a container of water for 10 minutes, after which they were weighed again upon removal from the water.

The samples are then dried in a SNOL 3.5/3-IZ oven at a temperature of 120–250 °C until a stable weight is reached.

Stage II of the water absorption test was conducted to reduce the percentage of water absorption. This experiment consisted of:

- cleaning the surface of the samples of dust, dirt, and traces of lubricant using a small brush;
- coating the samples with a protective varnish to reduce microporosity and prevent them from becoming saturated with water.

The samples are then placed in a container of water so that the water level exceeds the top of the samples by approximately 50 mm. The samples are then left in this container for 24 hours for subsequent measurements and analysis. The water temperature in the container must be (20 ± 2) °C.

The samples are then removed from the water, weighed, and allowed to dry for 24 hours under natural conditions.

The samples are weighed every 24 hours during the weight measurement process using standard electronic scales with an accuracy of no more than 0.1%. Samples removed from the water are first wiped with a wrung-out damp cloth.

The test continues until the results of two consecutive weighings differ by more than 0.1%.

RESULTS AND DISCUSSION

This section should present the main findings obtained in the course of the study. The data should be clearly structured and, if necessary, supplemented with tables, graphs, or figures. Excessive descriptions should be avoided – focus on interpreting key observations, measurements, or calculations. If needed, the results can be divided into subsections or thematic blocks.

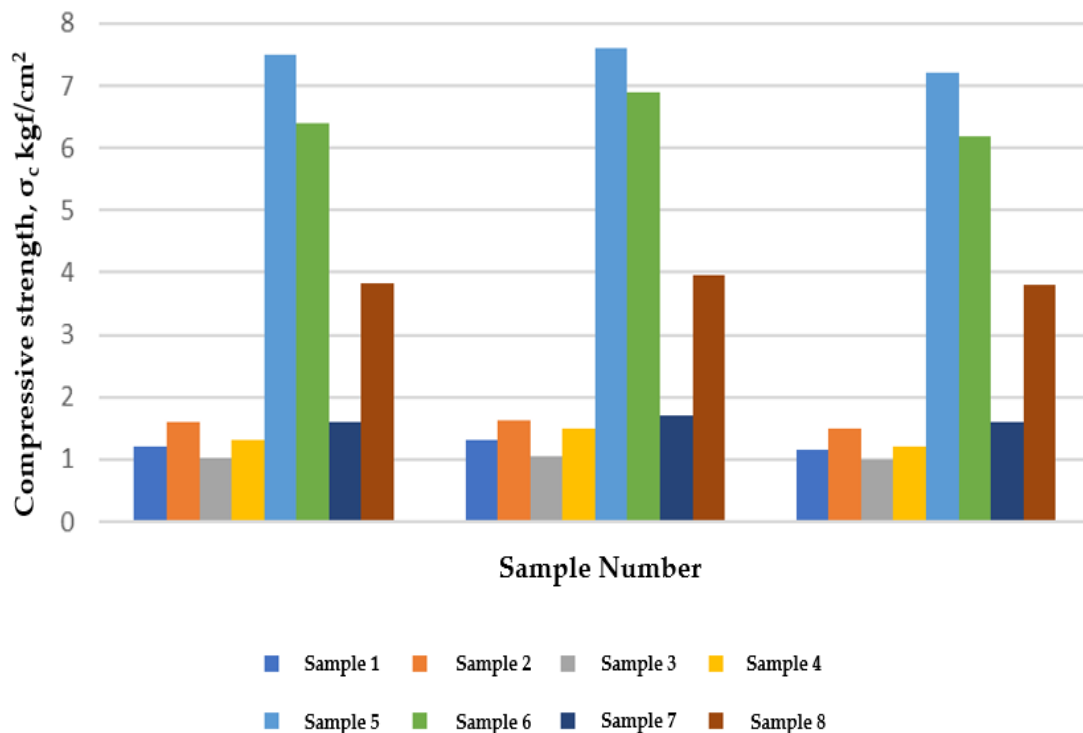


Figure 4. Graph showing the behavior of the specimens during the compression test
Note – compiled by the authors

The test results are presented in Table 2.

As shown in Table 2, samples Nos. 1, 3, and 4 have the lowest compressive strength values. This is most likely due to the influence of microsilica and fly ash, which inherently possess lower strength properties.

Samples Nos. 5 and 6 (9.1 and 8.28 MPa, respectively), which contain brick rubble and lime, have the highest compressive strength values. Samples Nos. 2, 7, and 8 have average compressive strength values and contain, in addition to brick rubble, ash and microsilica. It turns out that microsilica and ash reduce the material's strength. At the same time, the behavior and failure of the specimens complied with GOST 10180-2012, except for specimen No. 2, which failed diagonally.

Table 2. Results of the Compressive Strength Test

Sample Number	F, H	$\sigma_{сж}$, MPa	Cross-sectional area of the specimen, A, mm ²	Behavior of the specimen after loading
1	1120	1,24	9156	cracked along the edge, broken
2	1600	2,25	7234	cracked along the edge, broken diagonally
3	1030	1,1	9498	cracked on the sides, slightly broken
4	1270	1,52	8490	broken along the edge
5	7580	9,1	8490	cracked along the edge, broken
6	6900	8,28	8490	cracked along the edge, broken
7	1600	1,54	10562	cracked along the edge, broken
8	3950	2,85	14095	cracked along the edge and in the center, broken
<i>Note – compiled by the authors</i>				

Table 3 presents an analysis of the samples for water absorption.

Table 3. Analysis of Samples for Water Absorption

Sample Number	Water Absorption, % (Stage 1)	Water Absorption, % (Stage 2)
1	39,50	4,95
2	18,43	12,5
3	17,08	2,50
4	9,64	3,85
5	29,85	7,32
6	22,92	7,04
7	29,91	3,08
8	31,58	4,81
<i>Note – compiled by the authors</i>		

Table 3 shows that Stage I samples with a high water absorption percentage—such as No. 1 and Nos. 5–8—contain ash or slaked lime, which can lead to increased water absorption due to their ability to retain moisture. For example, ash often contains mineral components capable of reacting with water to form hydrates, thereby increasing the material's mass. Slaked lime can also form calcium hydroxide upon contact with water, leading to an increase in the sample's volume and mass. Samples Nos. 2–4 exhibit a satisfactory water absorption percentage. A structural feature of brick rubble is that its fine particles are closely packed together, providing a dense matrix. This creates an effective barrier against moisture, and the addition of microsilica reduces the percentage of water absorption due to the compaction of the material structure.

Therefore, Sample No. 4, consisting of 50 g of brick rubble and 25 g of microsilica, exhibited the lowest water absorption percentage among all the samples tested, at just 9.64%, thanks to the synergy between the increased amounts of brick rubble and microsilica.

The results of the water absorption test (Stage II) are presented in Table 3.

The results of Stage II testing show that applying a protective coating (varnish) improves the water absorption percentage for all tested samples.

The fracture surfaces of samples Nos. 1, 5, and 6, which exhibited low and high values of water absorption and compressive strength, were examined using an EVO18 scanning electron microscope (Qarmet, JSC) (Figures 5–7).

The structure of sample No. 1, which has a high water absorption value, is characterized by the presence of pores and cracks, as well as fragments of brick and lime, which are unevenly distributed throughout the volume and irregular in shape (Figure 5). The structure of the sample is loose, and the material is brittle.

Sample No. 5, which has the lowest moisture absorption value, produces a corresponding sound and is a durable material. The fracture surface is dense, with no cracks observed. No micropores are observed in the microstructure (Figure 6).

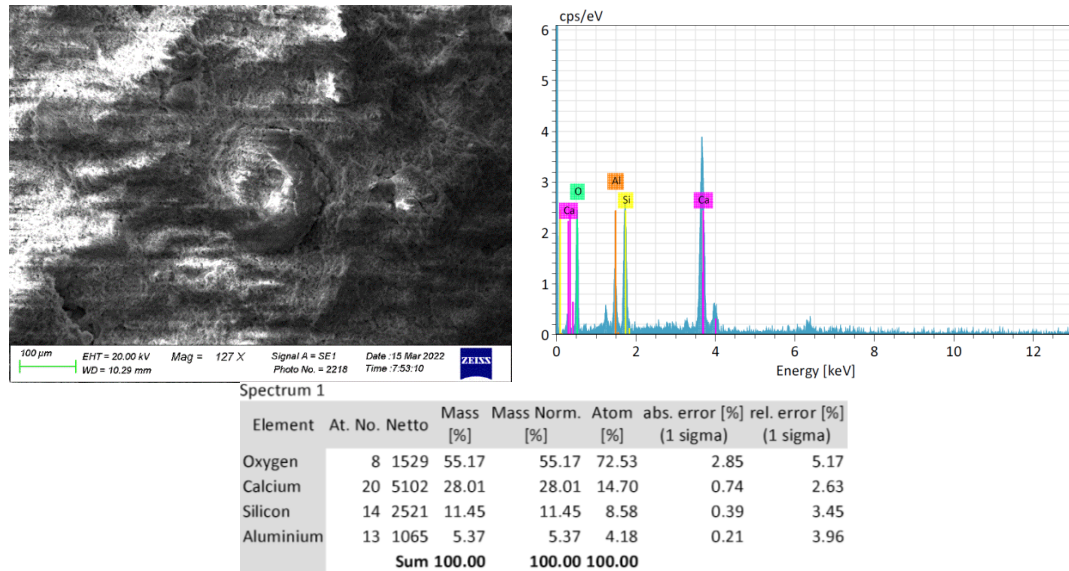


Figure 5. Microstructure, elemental distribution, and spectrum of Sample No. 1
Note – compiled by the authors

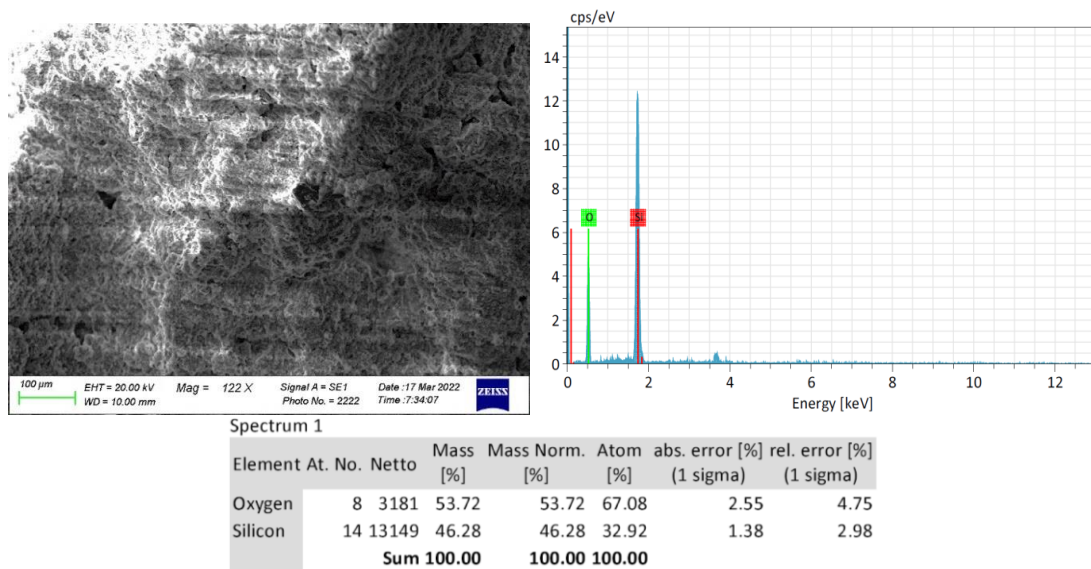


Figure 6. Brick particles (sample No. 5)
Note – compiled by the authors

Sample No. 6, which exhibits high compressive strength values similar to those of Sample No. 5, has a dense, homogeneous structure. No macro- or microdefects are observed (Figure 7).

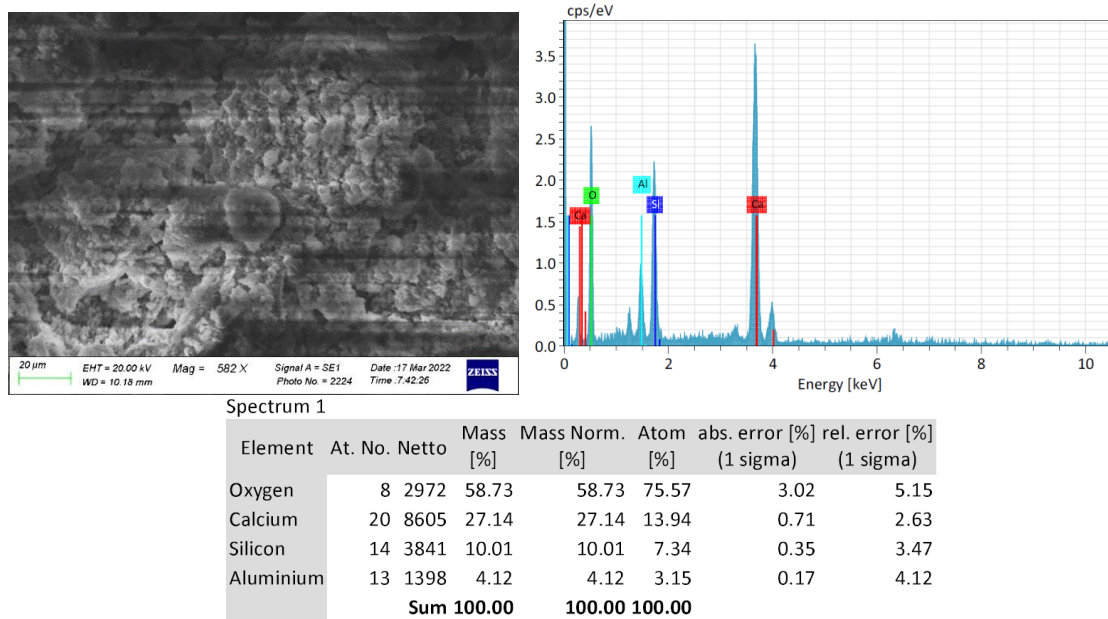


Figure 7. Microstructure of the resulting material (sample No. 6)

Note – compiled by the authors

Thus, the new composite materials obtained, which have high water absorption percentages and high compressive strength, can be used as interior cladding materials. When coated with a protective layer, these materials can serve as cladding materials for exterior finishes.

Samples with low compressive strength can also be used in foundries as inexpensive, single-use molds for non-critical applications.

CONCLUSIONS

Thus, a formulation of novel composite materials based on industrial and household waste was developed. Furthermore, a non-fired manufacturing technology was developed for producing secondary composite materials with a targeted set of physicomaterial properties.

The obtained data are preliminary in nature; however, they highlight the existing problem and demonstrate the need for comprehensive research, including further theoretical investigation and more in-depth technological development aimed at the recycling of industrial waste.

The production of secondary materials is expected to reduce production costs, mitigate the environmental burden on the region, expand the country's raw material base, and thereby enhance the competitiveness of Kazakhstan.

Research in this field is ongoing.

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