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RESEARCH ARTICLE

INFLUENCE OF WOOD WASTE ON THE STRUCTURE AND MECHANICAL PROPERTIES OF CERAMIC WALL MATERIALS

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Abstract. *The main goal of this work is to analyze the effect of wood waste on the physico-mechanical and microstructural properties of highly plastic and low admixture clay from the Astana deposit. Analysis of the primary components was carried out using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). It was found that the clay contains a significant amount of silicon and aluminum elements, which ensure the formation of a dense structure after firing, as well as a moderate amount of flux oxides (CaO, MgO, K_2O, Na_2O), which facilitate sintering at firing temperatures of 950–1000°C. Wood waste is characterized by a fibrous and porous structure. It contributes to the formation of a fine-pored microstructure during firing and a decrease in the density of products. It was found that the addition of wood waste has a complex effect on the physico-mechanical properties of ceramics. When replacing 20% of the total mass of clay with wood waste, the compressive strength decreased from 15 to 8.9 MPa due to increased porosity, but frost resistance increased to 38 cycles with the addition of 15% wood particles. The most optimal results were obtained with a sawdust content of 10–15%, which achieved a balance between strength (11–14 MPa) and frost resistance (up to 38 cycles), ensuring a balance between density, strength and operational durability of the products. The proposed composition can be recommended for industrial implementation in the production of lightweight and energy-efficient ceramic wall products. The results obtained confirm the possibility of recycling wood waste as a secondary raw material and prove that it contributes to the development of environmentally sustainable technologies for building ceramics.*

Keywords: *ceramic materials, wood waste, clay, SEM, EDS, chemical composition*

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ҒЫЛЫМИ МАҚАЛА

АҒАШ ҚАЛДЫҚТАРЫНЫҢ КЕРАМИКАЛЫҚ ҚАБЫРҒА МАТЕРИАЛДАРЫНЫҢ ҚҰРЫЛЫМЫ МЕН МЕХАНИКАЛЫҚ ҚАСИЕТТЕРІНЕ ӘСЕРІ

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Аңдатпа. *Бұл жұмыстың негізгі мақсаты - Астана кен орнынан алынған жоғары пластикалық және қоспалары аз керамикалық саздың физика-механикалық және микроқұрылымдық қасиеттеріне ағаш қалдықтарының әсерін талдау. Бастапқы компоненттерді талдау сканерлеуші электронды микроскопия (SEM) және энергияны дисперсиялық рентгендік спектроскопия (EDS) көмегімен жүргізілді. Саздың құрамында күйдіруден кейін тығыз құрылымның пайда болуын қамтамасыз ететін кремний мен алюминий элементтерінің айтарлықтай мөлшері, сондай-ақ 950–1000°C күйдіру температурасында күйдіруді жеңілдететін орташа мөлшердегі флюс оксидтері (CaO, MgO, K_2O, Na_2O) бар екені анықталды. Ағаш қалдықтары талшықты және кеуекті құрылыммен сипатталады. Ол күйдіру кезінде ұсақ кеуекті микроқұрылымның пайда болуына және өнімдердің тығыздығының төмендеуіне ықпал етеді. Ағаш қалдықтарын қосу керамиканың физика-механикалық қасиеттеріне кешенді әсер ететіні анықталды. Саздың жалпы массасының 20%-ын ағаш қалдықтарымен ауыстырған кезде, кеуектіліктің жоғарылауына байланысты қысу беріктігі 15-тен 8,9 МПа-ға дейін төмендеді, бірақ 15% ағаш бөлшектерін қосқанда аязға төзімділік 38 циклге дейін өсті. Ең оңтайлы нәтижелер 10-15% үгінді мөлшерімен алынды, бұл беріктік (11-14 МПа) мен аязға төзімділік (38 циклге дейін) арасындағы тепе-теңдікке қол жеткізді, бұл өнімдердің тығыздығы, беріктігі және пайдалану беріктігі арасындағы тепе-теңдікті қамтамасыз етті. Ұсынылған құрамды жеңіл және энергия үнемдейтін керамикалық қабырға бұйымдарын өндіруде өнеркәсіптік енгізу үшін ұсынуға болады. Алынған нәтижелер ағаш қалдықтарын екінші реттік шикізат ретінде қайта өңдеу мүмкіндігін растайды және оның құрылыс керамикасына арналған экологиялық тұрақты технологияларды дамытуға ықпал ететінін дәлелдейді.*

Түйін сөздер: *керамикалық материалдар, ағаш қалдықтар, саз, SEM, EDS, химиялық құрамы*

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НАУЧНАЯ СТАТЬЯ

ВЛИЯНИЕ ДРЕВЕСНЫХ ОТХОДОВ НА СТРУКТУРУ И МЕХАНИЧЕСКИЕ СВОЙСТВА КЕРАМИЧЕСКИХ СТЕНОВЫХ МАТЕРИАЛОВ

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Аннотация. *Целью данной работы является анализ влияния древесных отходов на физико-механические и микроструктурные свойства высокопластичной и малопримесной керамической глины месторождения Астана. Анализ основных компонентов проводился с помощью сканирующей электронной микроскопии (СЭМ) и энергодисперсионной рентгеновской спектроскопии (ЭДС). Установлено, что глина содержит значительное количество элементов кремния и алюминия, обеспечивающих формирование плотной структуры после обжига, а также умеренное количество оксидов-флюсов (CaO, MgO, K2O, Na2O), способствующих спеканию при температурах обжига 950–1000 °С. Древесные отходы характеризуются волокнисто-пористой структурой. Это способствует формированию мелкопористой микроструктуры при обжиге и снижению плотности изделий. Установлено, что добавление древесных отходов оказывает комплексное влияние на физико-механические свойства керамики. При замене 20% от общей массы глины древесными отходами предел прочности при сжатии снизился с 15 до 8,9 МПа за счет повышения пористости, но морозостойкость увеличилась до 38 циклов при добавлении 15% древесных частиц. Наиболее оптимальные результаты получены при содержании опилок 10–15%, что позволило достичь баланса между прочностью (11–14 МПа) и морозостойкостью (до 38 циклов), обеспечив баланс между плотностью, прочностью и эксплуатационной долговечностью изделий. Предложенный состав может быть рекомендован для промышленного внедрения в производство легких и энергоэффективных стеновых керамических изделий. Полученные результаты подтверждают возможность переработки древесных отходов в качестве вторичного сырья и доказывают, что это способствует развитию экологически устойчивых технологий производства строительной керамики.*

Ключевые слова: *керамические материалы, древесные отходы, глина, СЭМ, ЕДС, химический состав*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

The authors declare that no generative artificial intelligence technologies or AI-based tools were used in the preparation of this article.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

Авторлар мақаланы дайындау барысында генеративті жасанды интеллект технологиялары мен жасанды интеллектке негізделген технологияларды пайдаланбағанын мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

Авторы заявляют о том, что при подготовке статьи не использовались технологии генеративного искусственного интеллекта и технологии, основанные на искусственном интеллекте.

1 INTRODUCTION

The construction industry places high demands on energy efficiency, environmental safety and material economy. Traditional clay materials, despite their widespread use, consume a large amount of natural resources and require high energy costs during production. Therefore, special attention is paid to the development of new compositions based on local mineral raw materials and recycled resources **(Solonina, 2022).**

One of the developments in ceramic production technology is the use of wood waste (**Karasal et al., 2012**). The works of authors **(Cultrone et al., 2020; Takirova et al., 2025; Alabduljabbar et al., 2021; Phonphuak et al., 2020; Kizinievic et al., 2016; Santos et al., 2022; Seitkassymuly et al., 2025; Kultayeva, 2025)** have shown that the introduction of wood particles into clay mixtures can reduce the density of products and improve their thermal insulation properties. However, increasing the proportion of organic additives can negatively affect strength, so it is necessary to experimentally determine the optimal ratio of components. Despite some studies on the use of sawdust, ash and other biogenic waste, the effect of wood additives on the microstructure and physical and mechanical properties of ceramic materials has not yet been sufficiently **studied (Fadil-Djenabou et al., 2023).**

Research efforts are focused on the modification of clay bodies through the incorporation of industrial waste materials and functional modifiers into the raw material composition. These additives provide a multifunctional improvement in the forming behavior of the clay body, the drying performance of the green body, and the service properties of ceramic materials after firing **(Ibrambayeva et al., 2023).**

Of particular interest are clays from the Astana deposit, which are characterized by high plasticity and the balance of flux oxides (CaO, MgO, K_2O, Na_2O). However, the possibility of obtaining modified ceramic composites with organic additives from them has not been previously studied. Given that wood waste is an affordable and renewable resource, its use in clay mixtures will not only reduce the cost of production, but also help solve environmental problems associated with the use of biomass **(Cultrone et al., 2020)**.

Therefore, the aim of this study was to assess the influence of wood waste on the microstructural and physico-mechanical properties of ceramic materials. The following tasks were solved:

1. Study of the surface morphology and structural changes caused by the addition of wood particles by SEM investigation.
2. Determination of the chemical and elemental composition of clay and wood waste by EDS analysis.
3. Determination of the optimal composition of wood waste (10–20%) and understanding their influence on material microstructure and properties, such as the compressive strength and frost resistance of products.
4. Assessment of the possibility of applying the new composites in industry and development of recommendations for the further implementation of this technology.

Taking into consideration the preliminary literature research, the following hypothesis was formulated: the introduction of a limited amount of wood waste (up to 15%) contributes to the formation of a porous microstructure, improves thermal insulation properties of products without significantly reducing their strength **(Zhalykova et al., 2023)**.

The results of the study are aimed at providing a scientific justification for the rational use of wood waste in the production of ceramic materials, which will increase the efficiency of using local natural resources.

The growing interest in energy-efficient building materials has led to the need to study the possibility of reusing woodworking industry waste. One of the directions of such utilization is the introduction of sawdust into the composition of the ceramic mass **(Karasal et al., 2012)**. Using wood waste in ceramic production allows you to change the structure of ceramic products, improve their thermal insulation properties and reduce the mass of the product **(Takirova et al., 2025)**. Similar results were obtained in the work of **(Rahman et al., 2019)**, that is, the use of wood ash as an additive allowed to reduce the density and increase the porosity of clay bricks without significantly losing strength.

The authors' work **(Alabduljabbar et al., 2021)** studies the effect of adding wood sawdust to the clay mass on the firing process, physical and mechanical characteristics and structure of ceramic bricks. The authors added sawdust in an amount of 5-20% and fired at a temperature of 800-1000 ° C. As a result, the porosity of the material increases, and the bulk density of the brick decreases. Optimal strength and thermal conductivity are achieved by adding 5% sawdust, while adding 10–20% significantly reduces the strength, but improves thermal insulation properties.

According to the work of **(Phonphuak et al., 2020)**, it was found that the introduction of wood waste into the raw material mass at a rate of up to 10% and firing in the range of 900–1100 °C leads to the formation of a porous structure. The total porosity of the brick increased by more than 15–20% compared to the control samples, which was accompanied by a decrease in its bulk density (average values decreased from 1.9 g/cm3 to 1.5 g/cm3) and a decrease in the thermal conductivity coefficient (from 0.65 W/m·K to 0.35–0.40 W/m·K). The results showed that such products can be classified as energy-efficient lightweight ceramic bricks. **(Srisuwan et al., 2020)** also noted an increase in thermal insulation properties and a decrease in thermal conductivity with a moderate amount of wood particles.

One of the studies, **(Kizinievic et al., 2016)**, showed that the addition of sawdust contributes to a decrease in bulk density, an increase in total porosity, and a decrease in the thermal conductivity coefficient of the brick, which makes it an energy-efficient and environmentally friendly building material. The article showed that the content of sawdust more than 4% of the total composition, the products can be classified as lightweight bricks, and this has a positive effect on reducing the load on building structures and facilitating transportation.

In the work of **(Santos et al., 2022)**, it was proven that the introduction of wood sawdust up to 10% leads to a significant increase in the porosity of the brick (from 38% to 60%), a decrease in density and mass. The decrease in the acid resistance of the brick, the appearance of large pores made the products unsuitable for widespread use. **(Al-Qodah et al., 2025)** substantiated the potential of using wood waste and agricultural bioproducts in building ceramic technology, where it was noted that it would increase the energy efficiency of the product and its compliance with environmental safety requirements. According to the author's work **(Benjeddou, 2025)**, the introduction of wood chips into the clay mass structure not only in a certain amount, but also in what size plays an important role. Using small fractions (<0.4 mm), a uniform and finely porous structure is formed, which allows maintaining the strength at the level of 10-11 MPa. However, the introduction of large particles (0.8–1.2 mm) leads to the appearance of defects and large pores, which reduces the strength to 7–8 MPa, but also significantly reduces thermal conductivity. Thus, the results obtained in our work confirm and supplement existing studies, which show that the introduction of 10-15% wood waste is optimal regardless of the type of clay raw material used, however, due to the high content of the clay aluminosilicate phase in the Astana deposit, a dense structure and stable physical and mechanical properties are achieved.

2 MATERIALS AND METHODS

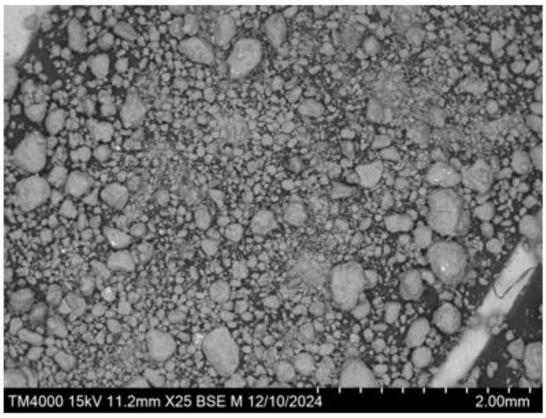
The work was carried out using highly plastic and low-admixture clay from the Astana deposit. Wood waste (sawdust) obtained from mechanical processing was used as an organic additive.

The microstructural properties of the ceramic material were studied using Hitachi scanning electron microscopy (TM4000Plus model) SEM analysis. Chemical analysis of wood waste and clay was carried out using an EDS X-ray spectrometer.

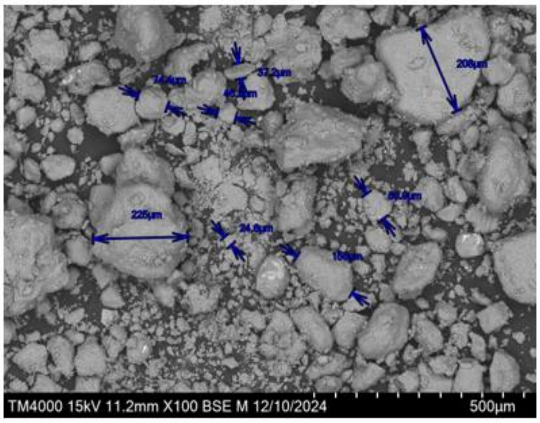
The additives were added in amounts of 0, 5, 10, 15 and 20% of the total clay mass. Before use, the wood waste was pre-dried to a moisture content of not more than 7%. The samples were formed by semi-dry pressing at an optimum moisture content of 20%. Ceramic samples were molded into cylindrical shapes with a diameter of 5 cm and a height of 10 cm. After molding, the products were dried at a temperature of 100 ° C to constant weight. Firing was carried out in a muffle furnace at a temperature of 950–1000 °C. To determine the compressive strength, Controls pressing equipment was used. Frost resistance was determined by the standard method of cyclic freezing and thawing until visible signs of damage appeared.

3 RESULTS AND DISCUSSION

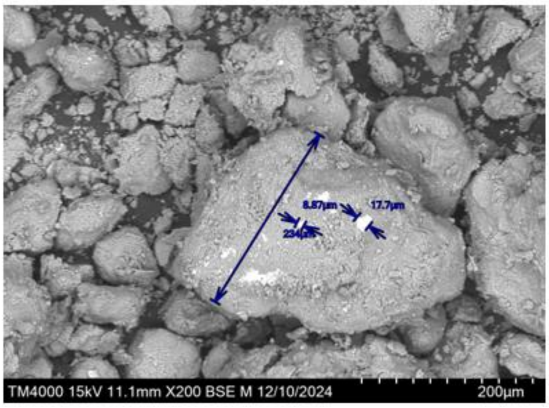
Figure 1 shows scanning electron microscopy (SEM) micrographs of the initial clay at various magnifications of ×25, ×50, ×100, and ×200. The study was conducted to determine the morphological features and distribution of the particles before incorporation into the ceramic mass.



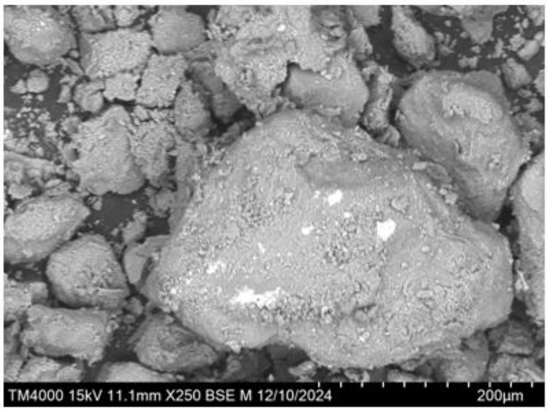
a) Magnification of 25x



b) Magnification of 100x



c)Magnification of 200x



d) Magnification of 250x

Figure 1 – Micrographs of clay surface at different magnifications (author's material)

Figure 1 shows a loose, heterogeneous structure with a uniform particle distribution at 25x magnification. There are tiny pores and intergranular gaps observable between the particle size of 1.5 and 2.0 mm. The microstructure is clearly visible at 100x magnification, with the size and degree of compaction allowing for particle differentiation. Each grain has a diameter between 400 and 800 µm. The picture at 200x magnification demonstrates the intersection of variously shaped particles; the finely distributed clay mass includes large agglomerates. Dense particles range in size from 200 to 400 µm. It is possible to see spherical structures at a maximum magnification of 250x. These structures range in size from 150 to 250 µm.

Table 1
Elemental composition of clay, %

Elements	O	Si	Al	Ca	Fe	Mg	K	Na
%	41.69	23.19	10.84	6.71	6.39	2.53	2.37	0.76

As shown in **Table 1**, the clay material is characterized by a high content of silicon and aluminum, which determines the silicate-clay basis, and a moderate amount of flux elements (Ca, Mg, K, Na), which facilitate optimal sintering at temperatures of 900–1050°C. This composition ensures the formation of a dense, strong microstructure and reduced water absorption after firing, which makes it a promising raw material for the production of ceramic wall materials. Increasing the nano-SiC content and sintering temperature enhanced the partial compaction of the framework due to silica binding **(Kultayeva, 2025).**

Table 2
Oxide content of clay, %

Oxides	SiO_2	Al_2O_3	CaO	FeO	MgO	K_2O	Na_2O
%	49.61	18.88	9.34	7.58	3.08	2.26	0.94

Table 2 shows that the main components are silicon oxide (SiO_2) and aluminum oxide (Al_2O_3), which determine the clay mineral composition of the material. According to the analysis results, the content of SiO_2 is 49.61%, the content of Al_2O_3 is 18.88%, which indicates the predominance of kaolinite and montmorillonite phases in the clay structure. They are components that determine the heat resistance and chemical inertness of the material. Increasing its content contributes to the formation of a dense structure during firing and increases the strength of the products (9). CaO, MgO, K_2O, Na_2O are fluxing components that reduce the melting point, contribute to the agglomeration of particles and the formation of a glassy phase.

The chemical composition of the clay by element is shown in spectral form in **Figure 2**.

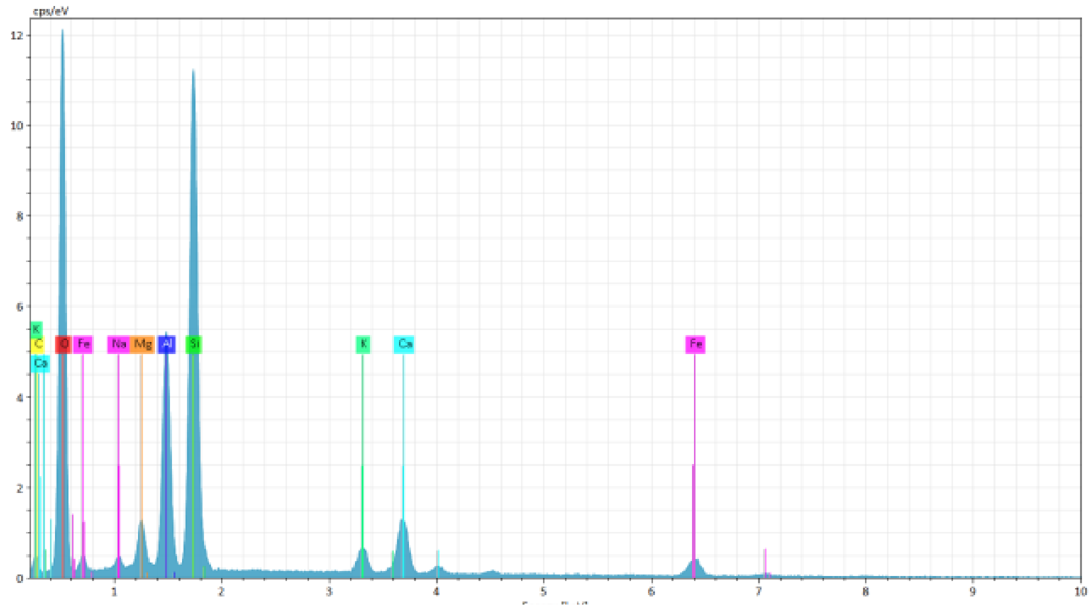
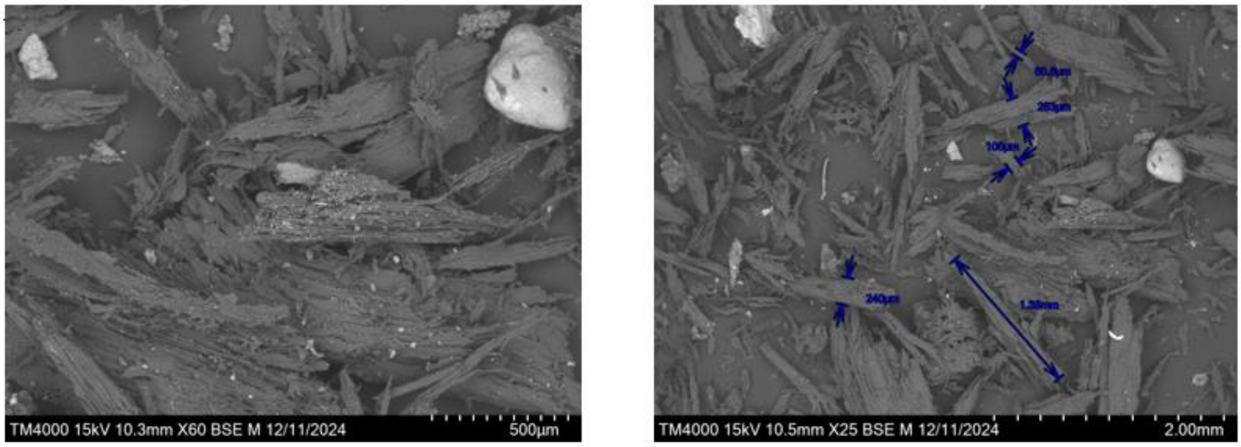


Figure 2 – Energy dispersive spectrum (EDS) of clay by element
(author's material)

Figure 3 shows micrographs of wood material at different magnifications, which were analyzed by SEM.

The structure of the material is characterized by a fibrous and porous structure typical of cellulose-lignin organic materials. Long longitudinal fibers and cell wall fragments are visible, which are intersected by capillary pores of various shapes and sizes. This microstructure provides the material with high porosity and low density, which explains its light weight and thermal insulation properties. The fiber sizes range from 40 μm to 240 μm.



a)Magnification 60x *b)Magnification 25x*

Figure 3 – Micrographs of wood surface at magnifications ×25 and ×60 (author's material)

According to the energy-dispersive X-ray analysis (EDS) data presented in **Tables 3 and 4**, the studied raw material sample consists mainly of oxygen and aluminum.

Table 3
Elemental composition of wood, %

Elements	C	O	N	S	Mg	K	Ca
%	46.5	41.68	0.7	0.3	1.91	1.44	1.47

Table 4
Oxide composition of wood ash, %

Oxides	CaO	K_2O	SiO_2	P_2O_5	MgO	Na_2O	Al_2O_3	Fe_2O_3	MnO
%	34.8	18.2	14.7	7.08	6.3	1.73	3	2	0.5

The high carbon content (46.5%) confirms the organic nature of the wood ash. Carbon burns out during heat treatment, contributing to the formation of the material's porous structure. Oxygen (41.68%) is part of the organic compounds and is associated with oxidation processes **(Santos et al., 2022).** Hydrogen (6%) is also part of the organic compounds of wood and is removed as water vapor during heating. Nitrogen (0.7%) and sulfur (0.3%) are present in trace amounts and transform into a gaseous phase during firing, having virtually no effect on the mineral structure of the ceramic. The elements magnesium (1.91%), potassium (1.44%), and calcium (1.47%) form an oxide phase after the organics burn out and influence the sintering process **(Kizinievic et al., 2016).**

The oxide composition of wood ash is characterized by a high content of CaO and K_2O. These act as fluxes and help lower the melting point. SiO_2 increases the chemical resistance of the material. P_2O_5 affects the microstructure of the sintered material. MgO improves thermal stability and promotes structural stabilization **(Seitkassymuly et al., 2016).**

Figures 4 shows the chemical composition of wood waste by elements in the form of a map and a graph. The EDS mapping shows that the carbon which is indicated in green color forms the basis of the wood structure. Oxygen, indicated in red, is distributed almost uniformly, which is typical of cellulose fibers. Aluminum, indicated in blue, is found in scattered patterns, indicating inorganic contaminants.

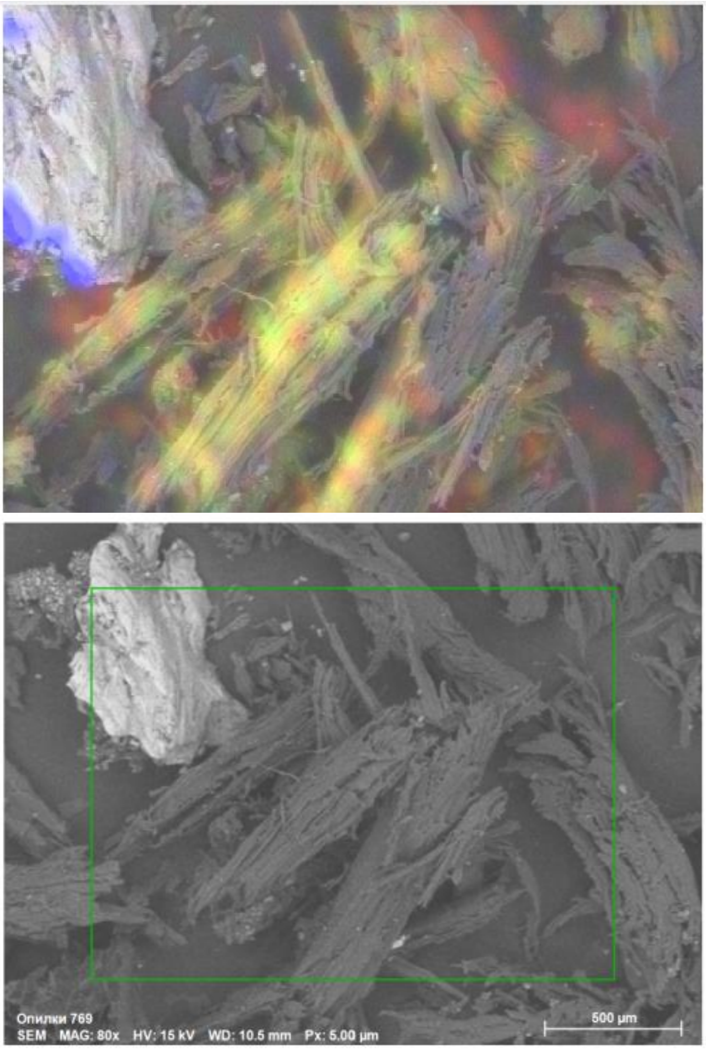


Figure 4 – Distribution map of dominant elements in wood (EDS)
(author's material)

Table 5 shows the proportions of clay and wood chips for obtaining ceramic materials, with results of compressive strength for wood waste additions of 10-20%.

Table 5
Properties of ceramic material based on wood waste

№	Wood waste content, %	Clay, g	Waste, g	Water, g	Compressive strength, MPa	Frost resistance, cycles
1	0	680	-	136	15	25
2	10	612	68	136	13.8	35
3	15	578	102	136	11.5	38
4	20	544	136	136	8.9	28

Figure 5 shows a ceramic material based on wood waste and testing its compressive strength.

The results of the study show that the addition of wood waste to the composition of ceramic bricks negatively affects their physical and mechanical properties, including compressive strength. With an increase in the amount of sawdust, the compressive strength decreases from 15 MPa (0% wood waste) to 8.9 MPa (sawdust content of 20%). Frost resistance (freeze-thaw cycles) increases to an optimal value at 15% sawdust (38 cycles), which is explained by an increase in porosity, which allows to compensate for the volumetric expansion of water during freezing (**Solonina, 2022**). With a further increase in the sawdust content (20%), frost resistance decreases again to 28 cycles due to excessive porosity and structural degradation.

Figure 5 – ceramic material based on wood waste and testing its compressive strength (author's material)

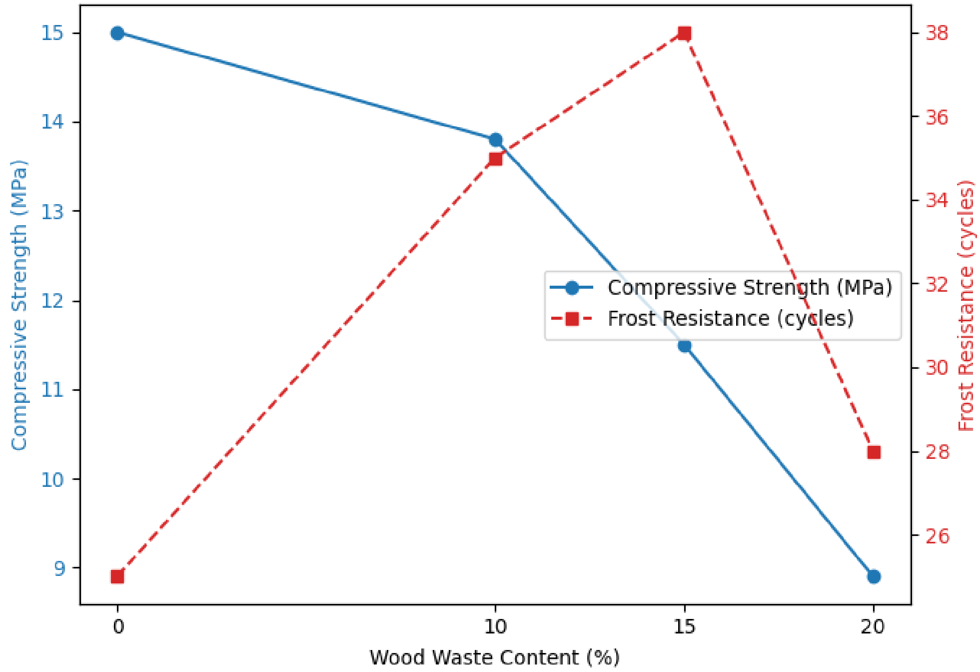


Figure 6 – Effect of wood waste content on compressive strength and frost resistance of ceramic materials (author's material)

The graph demonstrates the relationship between wood waste content, compressive strength, and frost resistance of ceramic materials. As the wood waste content increases, strength decreases due to increased porosity, which reduces the material's density and compressive strength. At the same time, moderate wood waste content (10–15%) promotes the formation of compensating pores, which reduce internal stresses during freezing, increasing frost resistance. With further increases in wood waste content, the material structure becomes excessively loose, with large, interconnected pores, leading to decreased frost resistance.

5 CONCLUSIONS

This study investigated the effect of wood waste to produce ceramic materials. SEM and EDS analysis were used to study microstructure and elemental composition. Strength testing and frost-resistance tests were carried out to determine the physical and mechanical properties of the material.

Based on the experimental results, the following conclusions can be drawn:

1. The incorporation of wood waste (0–20%) into ceramic compositions increases porosity, as confirmed by SEM analysis, leading to a reduction in compressive strength from 15 MPa (0%) to 8.9 MPa (20%).
2. A moderate wood waste content (10–15%) improves frost resistance from 25 cycles (0%) to 38 cycles (15%), due to the formation of compensating pores that reduce internal stresses during water freezing.
3. An excessive wood waste content (20%) results in structural degradation and a decrease in frost resistance to 28 cycles.
4. The optimal wood waste content for producing ceramic materials with balanced mechanical strength and enhanced frost resistance is 10–15%.
5. The developed composition can be recommended for the production of lightweight wall ceramic materials.
6. The partial replacement of clay with wood waste contributes to the conservation of natural raw materials and promotes sustainable waste recycling.
7. The proposed composition can be implemented in conventional ceramic manufacturing without modification of the firing temperature (950–1000 °C).
8. Further research should focus on long-term durability under real operating conditions and on the influence of wood waste particle size on microstructure and performance characteristics.

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