СТРОИТЕЛЬСТВО И АРХИТЕКТУРА

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THE EFFECT OF THE HYDROTHERMAL TREATMENT METHOD ON OPERATIONAL CHARACTERISTICS OF SILICATE MATERIALS BASED ON CLAY AND VOLCANIC ASH

Abstract. *The research presents results on the use of Debub deposit loam and volcanic ash in the production of silicate materials under autoclaved and non-autoclaved conditions. For autoclaved conditions, an optimal mixture achieved a compressive strength of 22.75 MPa, an average density of 1955 kg/m^3, and water absorption of 6.31 % with a composition of 10 wt.% loam, 25 wt.% volcanic ash, and a mixture activity of 6%. The non-autoclaved method yielded a compressive strength of 20.14 MPa with 40 wt. % loam, 25 wt.% volcanic ash, and a mixture activity of 6%. The corresponding average density, water absorption, and softening coefficient for the non-autoclaved samples were 1926 kg/m^3, 8.58%, and 0.91, respectively. While the strength indicators for non-autoclaved samples are slightly lower than those produced by the autoclaved method, they remain within the recommended values for silicate products. It has been established that rock-forming loam minerals and volcanic ash actively interact with lime during hydrothermal treatment, both during autoclaving and steaming, forming fine- and coarse-crystalline new formations that provide high strength to silicate materials. In the State of Eritrea, where cost and environmental impact are paramount, autoclave and, especially, non-autoclave technology represents an optimal solution for the production of building materials.*

Keywords: *Debub loam deposit, volcanic ash, autoclave and non-autoclave technology, silicate materials.*

Introduction. Loam is an optimal raw material for construction purposes, characterized by a combination of silt, sand, and clay. It combines the most advantageous characteristics of each component, achieving an ideal balance that effectively supports foundation structures. Its color is noticeably darker, and its texture is soft, dry, and crumbly. The suitability of loam as a foundation is primarily due to its consistently balanced physical properties, particularly its ability to regulate moisture retention at an optimal level [1–5].

Loam is defined by a content of 10–30 wt.% clay particles with a size less than 0.005 mm. Loam with a high clay content is designated as heavy loam, and with a low clay content, as light loam. There is a classification of coarse-grained, fine-sandy, and silty loams based on the ratio of sand grains of the corresponding size and silt or aleurite particles.

Loam can contain organic matter. Loam is primarily formed from the decomposition of rock minerals – feldspar [6–8]. Loam is often used as the main raw material in the brick manufacturing process. The quality of the final brick product largely depends on the quality of the raw materials included in its composition. Clays and loams used in brick production, depending on their quality, are used in pure form or mixed with various additives to achieve the required operational properties and increase their effectiveness as a building material. Potential additives to ensure the best quality bricks at minimal production costs may include substances such as sand, volcanic ash, sawdust, peat, and other materials. The choice of raw materials also depends on the technological process in brick production [9–12].

One of the most important characteristics of clay, significantly affecting its suitability for brick production, is its plasticity [13–15]. The recommended plasticity for brick production ranges from 5% to 15%, depending on its granular (grain size) composition, meaning the presence of sand, dust, and the finest particles (less than 0.005 mm), which essentially constitute the clay substance. To obtain the highest quality bricks, it is crucial that the soil does not contain an excessive amount of clay. Therefore, the proportion of clay in the soil, defined as particles smaller than 2 µm, should be maintained within a range exceeding 5% but not exceeding 30%, thereby functioning as a binder. Additionally, coarse grains, particularly silt and sand, should have an average diameter of less than 5 mm, which contributes to the structural stability of the aggregate framework [14]. Clays with a high sand content (loams) are typically used in brick production without improvements.

Volcanic ash has been investigated as a potential raw material for various applications, depending on its mineralogical composition, chemical composition, and particle size distribution. It has been proposed for use as a partial cement replacement, as a filler in lightweight concretes and cellular blocks, and as a geopolymer [16–21]. Various studies confirm that the addition of volcanic ash to a clay mixture can improve the physical and mechanical characteristics of the final product, meeting the technical requirements established by design standards.

The purpose of this study is to investigate and compare the physico-mechanical properties of silicate materials obtained from local aluminosilicate materials under autoclave and non-autoclave hardening conditions (steam treatment at atmospheric pressure), as well as to determine the optimal component ratios to achieve desired mechanical properties in both hardening modes.

Materials and Methods. The loam and volcanic ash used in this study were sampled in the State of Eritrea, Debub region, near the village of Adi Golgol and the Alid mountains, respectively. The plasticity of the loam is Ip = 10. The rock color is light gray. The predominant oxides in the loam and volcanic ash are SiO_2, followed by Al_2O_3 and other important alkaline oxides (Table 1).

Table 1

Chemical composition of loam of the Dabub origin

Content of oxides, wt. %										
SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3	P_2O_5	Na_2O	K_2O	Σ
67,15	19,41	3,10	0,42	1,56	2,00	0,03	0,18	2,61	3,34	99,80

Quartz is the main mineral in clay, followed by feldspar. Volcanic ash is predominantly an amorphous rock, which also contains a significant amount of feldspar. This study used sand conforming to Industry Standard 21-1-80 "Sand for the production of silicate products of autoclave hardening," selected in the area of the Keikh-Kor village. The chemical and mineralogical composition of volcanic sand is given in work [22].

The investigated loam and volcanic ash were pre-dried in a drying oven at 105 °C until a constant mass was achieved and then ground in a laboratory vibratory mill to obtain the desired specific surface area. The lime was ground to a specific surface area of 400 m²/kg. The particle size distribution of the loam and volcanic ash was determined using a Fritsch ANALYSETTE 22 MicroTec plus particle size analyzer.

Preparation of the raw materials included precise mixing of the dry ingredients in the required ratio, and moistening with water. After this, the mixture was stored in a sealed container until the lime was completely slaked.

Cylindrical samples, each with a diameter and height of 25 mm, were fabricated using a hydraulic press at a pressing pressure of 20 MPa. The samples underwent two different hardening processes. Autoclaved samples were exposed to saturated steam at a pressure of 1 MPa for 6 hours. In contrast, non-autoclaved samples underwent controlled heat and humidity treatment, maintaining a steam temperature of 95 °C for 12 hours. Morphological and microstructural characterization of the prepared samples was performed using a TESCAN MIRA 3 LMU scanning electron microscope.

An orthogonal central composite design was used in the experiment to investigate the influence of three material components: loam (x_1), volcanic ash (x_2), and active CaO (x_3). Each of these variables was systematically varied at three different levels: a central level (0), a lower level (-1), and an upper level (+1), with each level separated from the central point by a specific differential value (Δx_i) (Table 2). The primary data obtained from these experiments were subjected to detailed analytical calculation to determine the coefficients of the regression equation, which, in turn, would characterize the physical and mechanical properties of the material.

Table 2

Experimental planning conditions

Factors	Levels of variation			The range of variation
	–1	0	+1	
Content of loam, wt. % (x_1)	10	25	40	15
Content of volcanic ash, wt. %(x_2)	5	15	25	10
Content of $CaO_{act.}$ (x_3)	6	8	10	2

The study investigated the relationship between the composition of synthesized samples and their resulting mechanical properties, specifically compressive strength (R_C), average density (ρ), water absorption (ω), and softening coefficient (K_S). Statistical software was used to process the data, create a data matrix, and construct graphs illustrating the correlations between composition and properties for both autoclave and non-autoclave hardening methods.

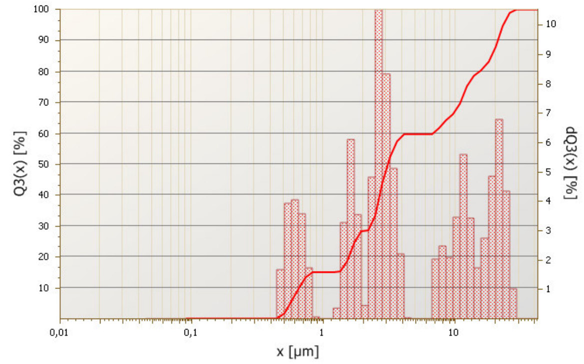
Results and discussion. Loam exhibits a particle size range of 0.5 to 45 microns, indicating a relatively broad particle size distribution (Fig. 1). The presence of five distinct peaks suggests a heterogeneous composition, likely including various mineral phases or different degrees of aggregation. The most significant absorption intensity in the 2 to 3 micron range indicates a predominant fraction within this size range. This intermediate particle size can provide a good balance between reactivity (due to sufficient surface area) and ease of handling. The next significant peaks at 0.6 microns and in the 0.4 to 0.6 micron range indicate the presence of finer fractions. These very fine particles possess a large specific surface area, which is extremely favorable for hydrothermal reactions, as it provides more sites for dissolution and subsequent precipitation of new phases.

Volcanic ash with a particle size range of 0.1 to 45 microns also exhibits a broad distribution but with six distinct peaks, suggesting an even more complex or diverse particle population compared to loam. The highest peak intensity observed in the 0.4 to 0.6 micron range indicates a significant proportion of very fine particles. This is a critical characteristic of volcanic ash in hydrothermal synthesis, as fine volcanic ash particles are known to be highly reactive due to their amorphous or weakly crystalline nature and large surface area. The next significant peak at 4 microns represents a larger fraction that can contribute to the long-term development of the silicate structure.

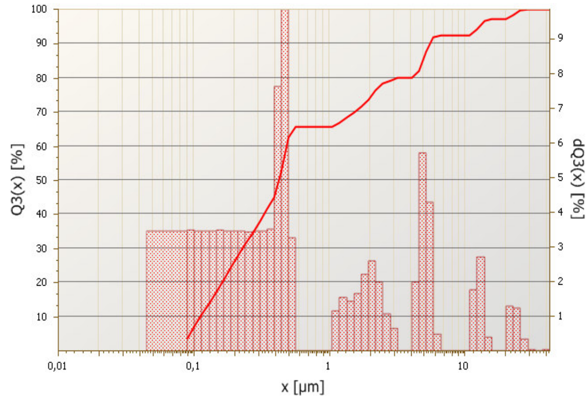
Different, yet complementary, particle size distributions of loam and volcanic ash indicate significant synergistic potential in the production of hydrothermal silicate materials. The combination of very fine, reactive particles with somewhat coarser fractions can lead to improved dissolution kinetics, controlled nucleation and growth, increased packing density, and ultimately, the formation of promising silicate materials with tailored properties

Materials obtained under autoclave conditions were studied. The average density of the material initially increased with increasing loam content, reaching a peak at 20 wt.% loam with a density of 1922 kg/m³. After this value, the density begins to decrease, suggesting that higher loam content may lead to a less compact structure or different hydration products under hydrothermal conditions (Table 3).

Compressive strength demonstrates a similar trend to density, initially increasing and then decreasing. The maximum compressive strength of 25.86 MPa is achieved at a loam content of 30 wt.% (Fig. 2). This indicates that a moderate amount of loam positively affects the material's bearing capacity. The decrease after 30 wt.% may be due to an excess of loam hindering the formation of strong calcium hydrosilicate (CSH) phases, which are crucial for the strength of autoclaved silicate materials.



Loam



Volcanic ash

Fig. 1. Particle size distribution for loam and volcanic ash

Water absorption generally decreases with increasing loam content up to a certain level, indicating improved resistance to water penetration. The lowest water absorption, 8.02%, is observed at a loam content of 20 wt.%. However, at loam contents exceeding 30 wt.%, water absorption begins to increase again, possibly due to the formation of more hydrophilic clay-rich phases or an increase in overall porosity.

Table 3

Dependence of the physico-mechanical properties on loam content (control)

Loam content, mass %	Density, kg/m³	Compressive strength, MPa	Water absorption, %	Coefficient of softening
0	1812	17,65	11,70	0,79
5	1831	17,07	12,09	0,82
10	1881	20,52	10,37	0,78
20	1922	25,34	8,02	0,86
30	1913	25,86	8,72	0,92
40	1850	22,50	11,92	0,85
50	1780	16,29	14,87	0,9

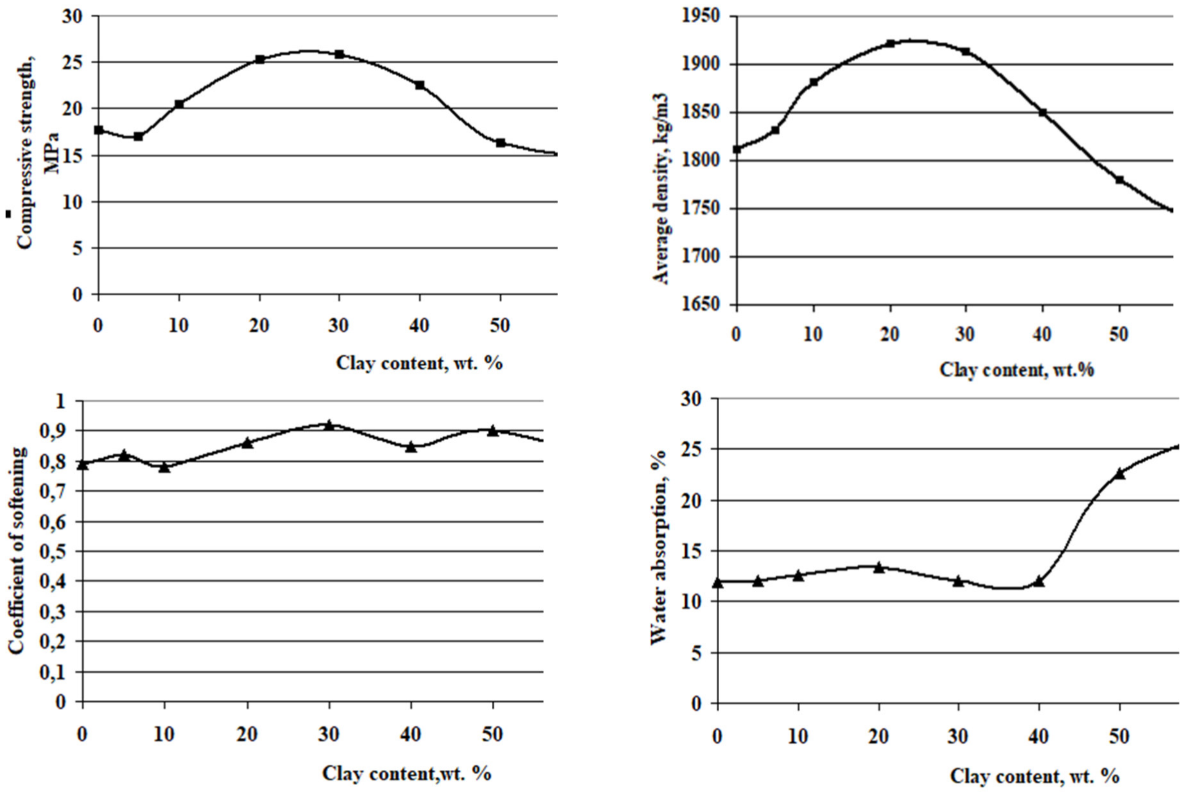


Fig. 2. Dependence of compressive strength, average density, water absorption and coefficient of softening on loam content (control)

The softening coefficient, which indicates a material's ability to retain strength when saturated with water, generally improves with increasing loam content. The highest water resistance coefficient, equal to 0.92, is achieved at a loam content of 30 wt.%. This suggests that loam, up to a certain percentage, can increase the durability of the material in a wet environment. A slight decrease at 40 wt.% and 50 wt.% loam content, despite still being relatively high, may indicate a change in the material's microstructure or the nature of hydration products that are less stable in water.

The optimal range for loam content in autoclaved silicate materials, considering a balance of density, high compressive strength, low water absorption, and excellent water resistance, is 20 to 30 wt. %. Specifically, a loam content of 30 wt. % yields the highest compressive strength and water resistance coefficient. This range is crucial for achieving desired material properties in construction and other applications where durability and performance under various environmental conditions are paramount. The inclusion of loam in this proportion contributes to the formation of stable silicate structures during the autoclaving process, enhancing the overall mechanical and physical characteristics of the final product

The compressive strength (R_C) of silicate materials obtained by two different methods—autoclave and non-autoclave—is represented by two different regression equations. Each equation includes three key parameters: content of loam (x_1), content of volcanic ash (x_2), and content of CaO (x_3).

Autoclave method:

$$R_C = 12{,}043 + 0{,}555x_1 + 2{,}586x_2 + 0{,}541x_3 + 2{,}768x_1^2 + 2{,}113x_2^2 + 1{,}518x_3^2 - 1{,}863x_1x_2 + 0{,}215x_1x_3 - 0{,}775x_2x_3$$

Non-autoclave method:

$$R_C = 13{,}242 + 1{,}659x_1 + 4{,}176x_2 - 0{,}083x_3 + 0.793x_1^2 + 0{,}138x_2^2 - 0{,}457x_3^2 - 0{,}143x_1x_2 - 0{,}265x_1x_3 - 0{,}672x_2x_3$$

Volcanic ash significantly increased compressive strength in both methods, with a positive coefficient (+4.17) being higher in the non-autoclaved method compared to the autoclaved method. Lime content has less influence on compressive strength compared to loam and volcanic ash in both methods, with a negative effect observed in the non-autoclaved method. Interaction terms between components indicate that their combined effect can either increase or decrease compressive strength. In the autoclaved method, negative interaction terms (−1.863) between loam and volcanic ash suggest that, although both components individually have a positive effect on strength, their combination may not yield optimal results.

In the autoclave method, an increase in loam content positively affects compressive strength, but this effect is mitigated by interaction with other components, especially volcanic ash (negative interaction term). In contrast, the non-autoclave method favors a combination of high loam content and high volcanic ash content.

The compressive strength under autoclaved conditions with 10 wt. % loam and 25 wt. % volcanic ash content is 22.78 MPa, 20.79 MPa, and 21.87 MPa for 6, 8, and 10 wt. % CaO, respectively (Fig. 3,a). For the non-autoclaving method, the best results were obtained with 40 wt. % loam and 25 wt. % volcanic ash content, where the compressive strength is 20.43 MPa, 19.87 MPa, and 18.39 MPa for 6, 8, and 10 wt. % CaO, respectively (Fig. 3,b). This method benefits from a synergistic effect between high loam content and high volcanic ash content, which allows for the creation of a stronger matrix under atmospheric pressure conditions.

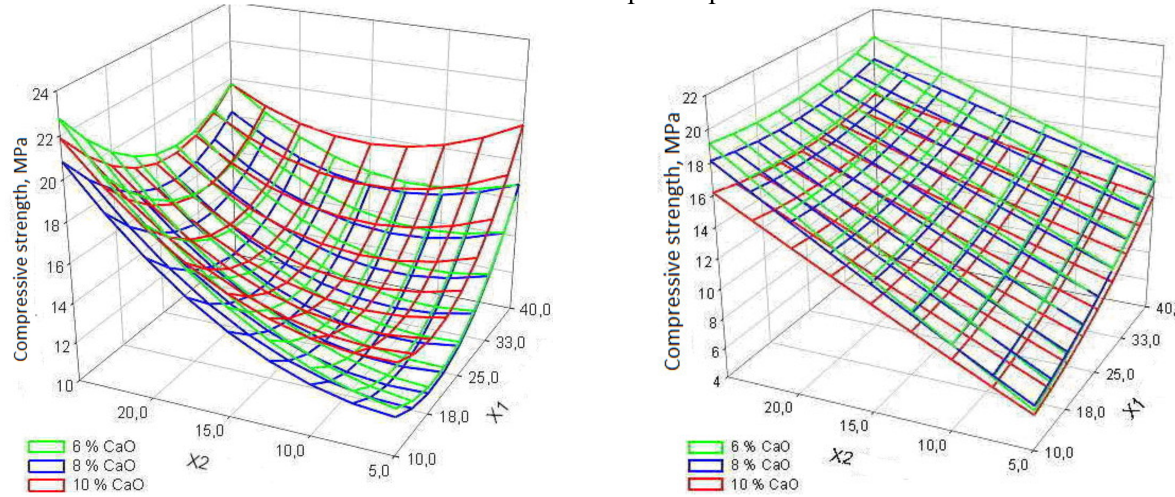


Fig. 3. Dependence of compressive strength on loam, volcanic ash and active CaO contents for autoclave (a) and non-autoclave (b) methods, respectively

Although both methods use similar raw materials, their optimal composition for achieving maximum compressive strength differs significantly due to processing conditions (high pressure versus atmospheric pressure). Achieving maximum compressive strength requires a high volcanic ash content combined with a low loam content. In the absence of an autoclave, a significant proportion of loam and volcanic ash is necessary to ensure structural integrity, as silica (sand) is practically unreactive at atmospheric pressure and a low temperature of 95 °C. This condition contrasts with autoclaving, where elevated temperatures and pressures promote the dissolution and reaction of silica, contributing to structure formation. The limited reactivity of sand under the given conditions means that alternative, more reactive pozzolanic materials such as loam and volcanic ash are crucial for developing desired mechanical properties and a binding matrix.

The two regression equations obtained for the average density were as follows:

For the autoclave method:

$$\rho = 1870{,}711 - 41{,}1x_1 - 29{,}8x_2 - 24{,}1x_3 + 6{,}680x_1^2 + 25{,}18x_2^2 + 2{,}68x_3^2 - 26{,}75x_1x_2 - 8{,}25x_1x_3 - 10x_2x_3$$

For non-autoclave method:

$$\rho = 1876{,}586 - 38{,}1x_1 - 26{,}4x_2 - 36{,}1x_3 - 4{,}649x_1^2 + 13{,}851x_2^2 - 8{,}649x_3^2 - 24{,}25x_1x_2 - 10{,}5x_1x_3 - 16{,}75x_2x_3$$

Under non-autoclaved conditions, the initial material density is slightly higher (1876 kg/m^3) compared to conditions after autoclaving (1871 kg/m^3). This initial difference suggests that the curing method itself affects the initial material density before accounting for changes in components.

Both processes show an overall decrease in density as the concentration of loam, volcanic ash, and lime increases (indicated by negative linear coefficients). Interaction terms are predominantly negative, implying that the combination of these components often leads to a further reduction in density. The negative interaction terms, especially for x_1x_3 and x_2x_3, tend to be stronger (more negative) in the non-autoclaved process. This suggests that the combined effect of these components on density reduction is more pronounced without autoclaving.

In the autoclaving process, a positive quadratic effect is observed for loam, which suggests a potential reversal or slowing down of the density decrease at higher loam levels. Conversely, in the non-autoclaving process, a negative quadratic effect is observed, indicating that density continues to decrease, possibly at an accelerating rate, with increasing loam content. In the autoclaving process, a positive quadratic effect is observed for lime, whereas in the non-autoclaving process, a negative quadratic effect is observed. This is a significant difference, implying that the behavior of lime at higher concentrations varies significantly between the two curing methods. The presence of quadratic and interaction terms underscores the non-linear nature of these relationships. Simple linear models would be insufficient to describe the full behavior. Orthogonal central composite design is effective for investigating such complex response surfaces.

During the autoclaving process, the maximum density was 1955 kg/m^3, which was observed at the lowest concentrations of all three components: 10 wt.% loam, 5 wt.% volcanic ash, and 6% lime (Fig. 4, a). In contrast, the minimum density during autoclaving was 1765 kg/m^3, which was recorded at the highest concentrations of the components: 40 wt.% loam, 25 wt.% volcanic ash, and 10% lime. During the steaming process, the maximum density achieved was 1926 kg/m^3, which was also observed at the lowest concentrations of all three components (Fig. 4, b). The minimum density during the steaming process was 1720 kg/m^3, which was observed at the highest concentrations of all three components.

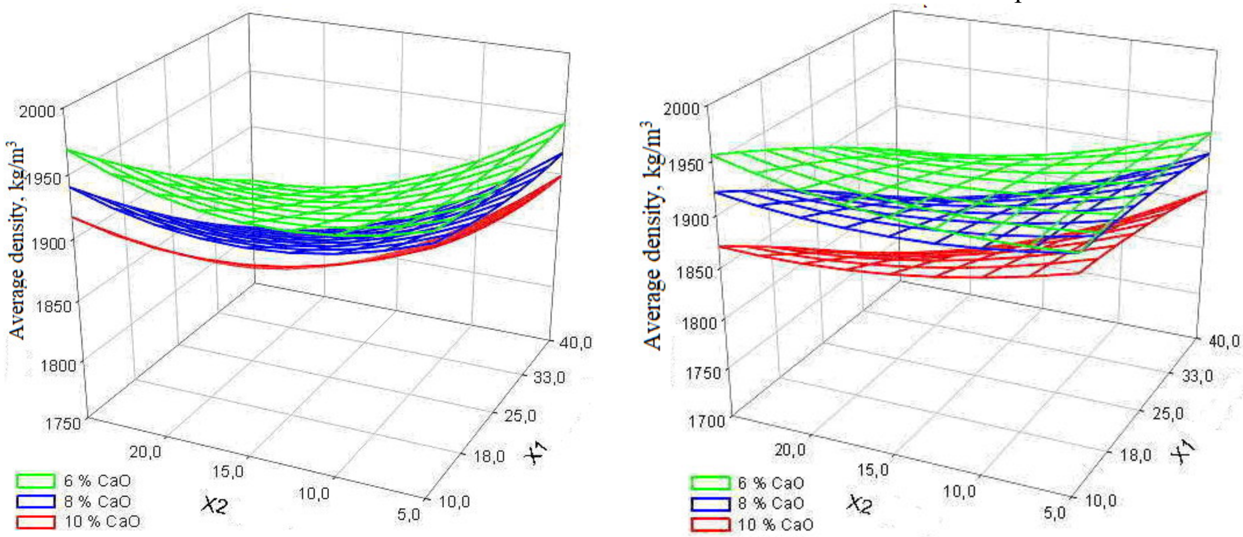


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Fig. 4. Dependence average density on loam, volcanic ash and active CaO contents

The regression equations of water absorption for autoclave (a) and non-autoclave (b) methods, respectively.

The most significant difference between the two methods lies in the effect of volcanic ash (x_2) and the interaction between loam and active CaO (x_1x_3). In the autoclaved method, volcanic ash initially reduces water absorption, whereas in the non-autoclaved method, it has a more negative effect. Furthermore, the interaction between loam and active CaO is antagonistic in the autoclaved method but synergistic in the non-autoclaved method. These differences highlight that curing conditions (autoclaved versus non-autoclaved) significantly alter material hydration and porous structure development, thereby influencing water absorption characteristics as follows:

$$\omega = 9{,}01 + 1{,}14x_1 - 0{,}611x_2 + 0{,}276x_3 + 0{,}652x_1^2 + 0{,}317x_2^2 - 0{,}158x_3^2 + 0{,}758x_1x_2 - 0{,}29x_1x_3 + 0{,}432x_2x_3$$

$$\omega = 8{,}865 + 0{,}882x_1 - 1{,}511x_2 + 0{,}876x_3 + 0{,}768x_1^2 + 0{,}433x_2^2 - 0{,}042x_3^2 + 0{,}887x_1x_2 + 0{,}48x_1x_3 + 0{,}345x_2x_3.$$

The minimum water absorption coefficient for the autoclaved method is 6.31%, which is achieved with a composition including 10 wt.% loam, 25 wt.% volcanic ash, and 6% active CaO (Fig. 5). The maximum water absorption coefficient for the autoclaved method is 11.53%, which is achieved with a composition including 40 wt.% loam, 25 wt.% volcanic ash, and 10% active CaO. For the non-autoclaved method, the minimum water absorption coefficient is 6.00%, observed with a composition including 10 wt.% loam, 25 wt.% volcanic ash, and 6% active CaO. The maximum water absorption coefficient for the non-autoclaved method is 12.53%, which is achieved with a composition including 40 wt.% loam, 5 wt.% volcanic ash, and 10% active CaO. These water absorption values (from 6% to 13%) are within the permissible range for building bricks.

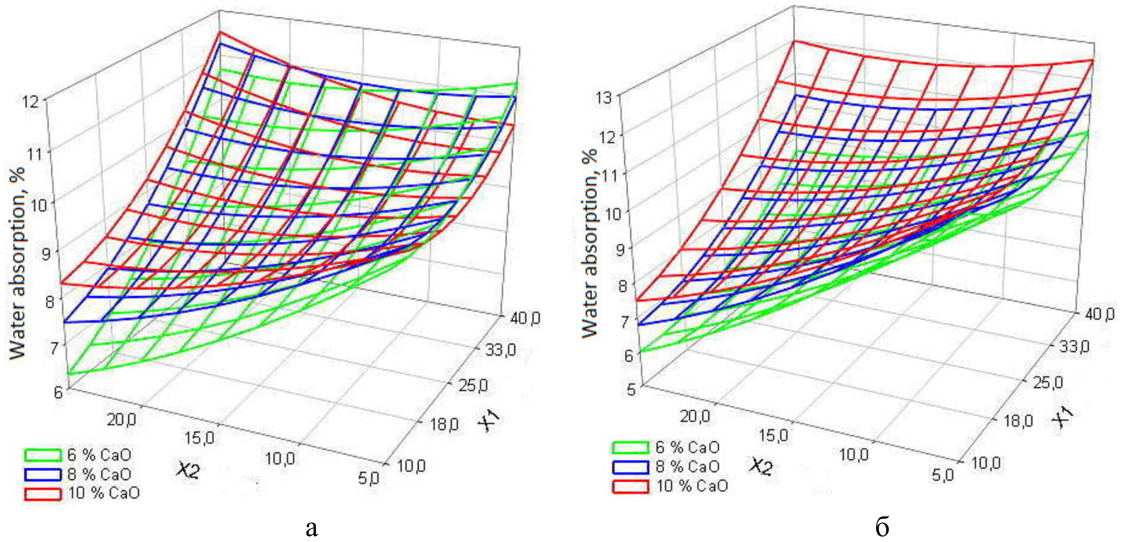

Fig. 5. Dependence of water absorption on loam, volcanic ash and active CaO contents for autoclave (a) and non-autoclave (b) methods, respectively

The softening coefficient for the autoclave method is:

$$K_S = 0{,}8354 - 0{,}0036x_1 + 0{,}0289x_2 + 0{,}0058x_3 - 0{,}0163x_1^2 + 0{,}0558x_2^2 + 0{,}0138x_3^2 + 0{,}0046x_1x_2 - 0{,}0044x_1x_3 - 0{,}0134x_2x_3$$

The softening coefficient for the non-autoclave method is:

$$K_S = 0{,}8433 - 0{,}026x_1 + 0{,}0160x_2 - 0{,}003x_3 - 0{,}0304x_1^2 - 0{,}3958x_2^2 + 0{,}0146x_3^2 - 0{,}0125x_1x_2 + 0{,}01x_1x_3 - 0{,}0675x_2x_3$$

In autoclaving conditions, the most significant quadratic effects are those of volcanic ash (0.0558) and active CaO (0.0138), both of which are positive, indicating that moderate to high levels of volcanic ash and active CaO generally improve water resistance under autoclaving. The negative quadratic term for loam ($-0.0163x_1^2$) suggests that extreme levels of loam content, both very low and very high, may reduce water resistance, with an optimal range likely around the central level. Interaction terms are relatively small, but the negative coefficient (−0.0134) implies that high levels of both volcanic ash and active CaO simultaneously might have a slight negative impact on water resistance, possibly due to competing reactions or microstructural changes.

In steaming conditions, the most prominent effects are the highly negative quadratic effect of volcanic ash (-0.3958) and the negative linear effect of loam (-0.026). This indicates that high levels of volcanic ash content significantly reduce non-autoclaved water resistance, and an increase in loam content generally lowers water resistance in this curing environment. The positive linear term for volcanic ash (0.016) suggests a complex relationship where an initial increase in volcanic ash might be beneficial, but at higher contents, the strong negative quadratic term predominates. The negative interaction term (-0.0675) is also significant, implying that the combination of higher volcanic ash content and active CaO is particularly detrimental to non-autoclaved water resistance, possibly due to insufficient activation of the pozzolanic reaction or unfavorable phase formation.

For samples subjected to autoclaving, water resistance ranged from 0.798 (with 40 wt% loam, 5 wt% volcanic ash, and 10% lime) to 0.901 (with 10 wt% loam, 25 wt% volcanic ash, and 8% lime) (Fig. 6). In contrast, for non-autoclaved samples, water resistance showed a wider range, from 0.375 (with 10 wt% loam, 5 wt% volcanic ash, and 6% lime) to 0.857 (with 25 wt% loam, 15 wt% volcanic ash, and 8% lime). These results highlight the significant impact of curing conditions and material composition on the water resistance of the investigated materials.

The introduction of volcanic ash in combination with autoclaving presents an alternative to the clay-sand mixture. While the latter provides the highest compressive strength, the autoclaved method using volcanic ash offers a better balance of properties, particularly excelling in density and water absorption, which are crucial for durability and performance. The lower water absorption of the autoclaved volcanic ash mixture is a significant advantage, indicating increased resistance to environmental exposure. The use of steam curing, although potentially more cost-effective due to lower energy consumption, results in lower compressive strength and higher water absorption. The optimal composition for the autoclave method (10 wt.% clay, 25 wt.% volcanic ash, 6% lime) also uses less loam than loam-only samples (30 wt.%), which may have environmental and economic advantages if volcanic ash is a more accessible or sustainable resource.

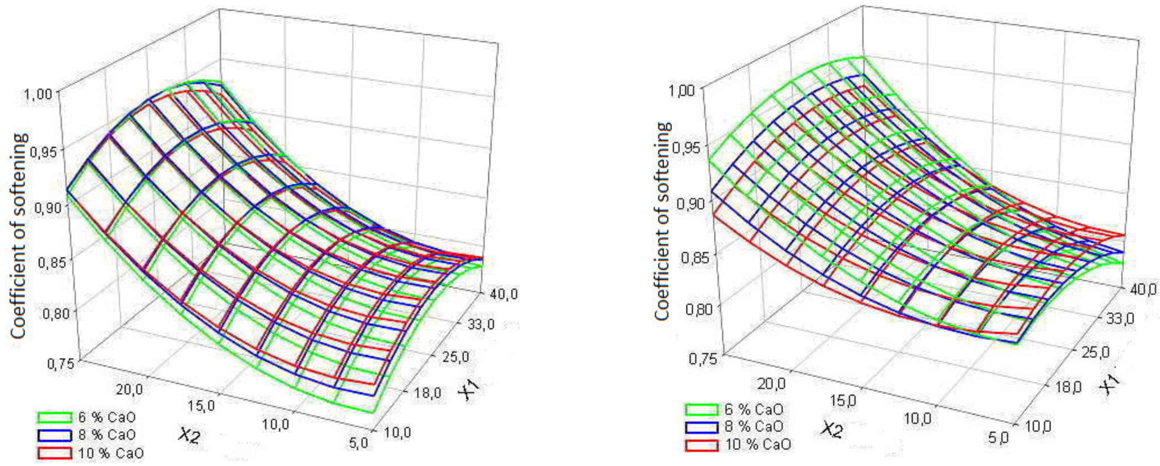

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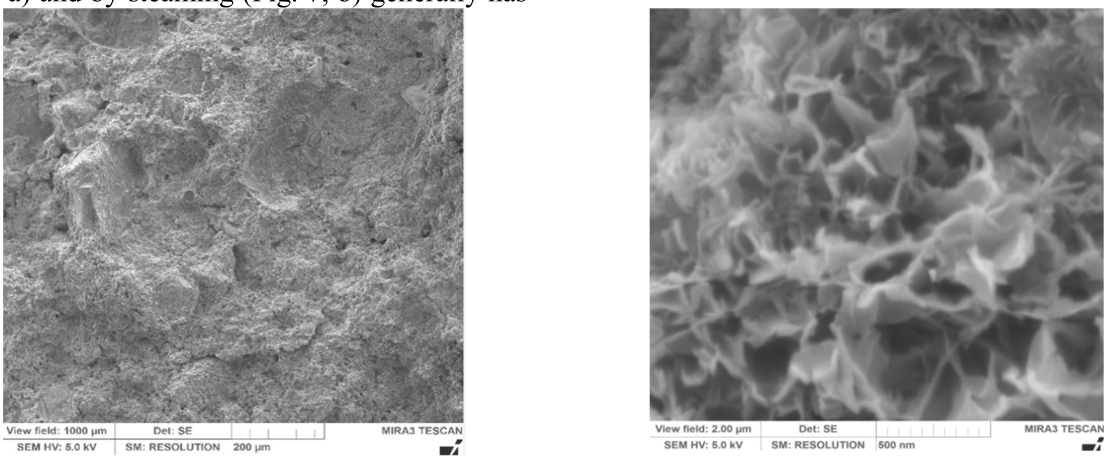
Fig. 6. Dependence of coefficient of softening on loam, volcanic ash and active CaO contents for autoclave (a) and non-autoclave (b) methods, respectively

Calcium silicate hydrate (CSH) gel is the most important product of binder hydration. During the hydration process, CSH gel can have a fibrillar or acicular, tubular, foil-like, and lace-like shape, varying depending on influencing factors, mainly the calcium-to-silica ratio. CSH synthesized in an autoclave (Fig. 7, a) and by steaming (Fig. 7, b) generally has a spherical or lamellar shape. The synthesized CSH gel has a porous network structure formed by the layered arrangement of fibrous compounds, which is created at a calcium-to-silica ratio of 1.5 to 2 and is designated as CSH(B). Scanning electron microscopy images show that the samples are compact.



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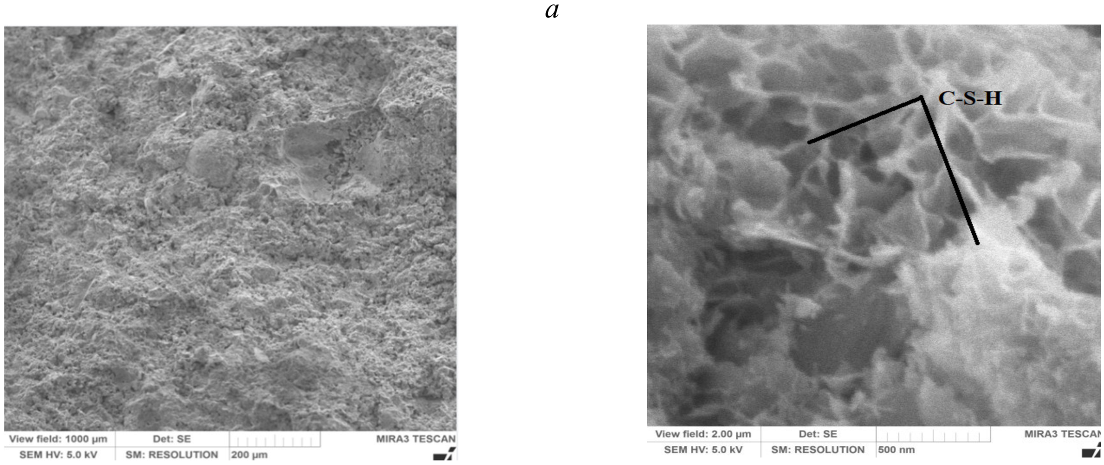

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Fig. 7. Images of SE with a loam content of – 40%, volcanic ash – 25%, CaO – 10%, (a) in an autoclave; (b) in non-autoclave

The comparable compressive strength when using both autoclaved and non-autoclaved methods is explained by the fact that, while the autoclaved method causes rapid and crystalline hydration, the non-autoclaved method, thanks to reactive mineral components such as clays and volcanic ash, forms a strong amorphous binding network over time. This optimized reaction in the non-autoclaved process compensates for the typical strength increase expected from high-pressure hardening. Essentially, the specific interactions of the mixtures and the inherent pozzolanic or geopolymer reactivity of the raw materials help both methods achieve similar compressive strength.

Silicate materials with volcanic ash, produced using steam curing, stand out for their environmental friendliness due to the exclusion of the energy-intensive autoclaving process, despite lower compressive strength. The planned autoclave mixture provides a good balance of strength and durability, while utilizing environmentally friendly raw materials. The final choice depends on the specific performance requirements and environmental priorities of the construction project.

The autoclave method typically requires significant investment in equipment and energy costs associated with high-pressure steam processing. The non-autoclave method, being less technologically complex and effectively utilizing local resources, can provide a lower overall cost structure. Given Eritrea's current economic situation and technological capabilities, it is likely that the non-autoclave method would be more appropriate due to lower initial investment and operating costs.

Conclusions. This study investigated the feasibility of incorporating loams and volcanic ash into the production of silicate materials, under both autoclaved and non-autoclaved conditions. The results showed that both autoclaved and non-autoclaved methods are viable for producing silicate materials using these readily available raw materials. The properties of the resulting silicate materials largely conform to the recommended limits for such building products, indicating their potential for developing cost-effective and durable construction solutions. This research highlights the environmental and economic benefits of utilizing natural resources.

The developed materials have been shown to possess high strength and water resistance, which is a crucial property for various applications. Specifically, samples treated under autoclaved conditions achieved a compressive strength of up to 23 MPa, while samples treated without autoclaving still reached a significant strength of 20 MPa. The results demonstrated that non-autoclave technology, utilizing these readily available materials, can provide acceptable compressive strength and water resistance, making it a technically and economically feasible solution for the construction of residential and public buildings, even in humid climates.

It has been established that loam and volcanic ash actively interact with lime during hydrothermal treatment, both in autoclave and non-autoclave conditions, forming poorly crystallized calcium hydrosilicates (CSH(B)). Future research can focus on optimizing mixture compositions for specific applications, conducting long-term durability assessments, and studying the scalability of these production methods for industrial implementation.

In Eritrea, where cost and environmental impact are paramount, non-autoclaved technology presents an attractive solution. Its lower production cost, good water resistance, and significantly reduced environmental footprint make it a highly viable and sustainable option, despite slightly lower strength. Further research could focus on optimizing the non-autoclaved mix to enhance its strength without substantially increasing cost or environmental impact.

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ВЛИЯНИЕ СПОСОБА ГИДРОТЕРМАЛЬНОЙ ОБРАБОТКИ НА ЭКСПЛУАТАЦИОННЫЕ ХАРАКТЕРИСТИКИ СИЛИКАТНЫХ МАТЕРИАЛОВ НА ОСНОВЕ ГЛИНЫ И ВУЛКАНИЧЕСКОГО ПЕПЛА

***Аннотация**. Представлены результаты исследований по использованию глины месторождения Дэбуб и вулканического пепла в производстве силикатных материалов в автоклавных и безавтоклавных условиях. Рациональная смесь в автоклавных условиях обеспечивает прочность на сжатие 22,75 МПа, среднюю плотность 1955 кг/м^3 и водопоглощение 6,31 % при содержании 10 мас. % суглинка, 25 мас. % вулканического пепла и активности смеси 6 %. Неавтоклавный метод обеспечил прочность на сжатие 20,14 МПа при 40 мас. % суглинка, 25 мас. % вулканического пепла и активности смеси 6 %. Соответствующие средняя плотность, водопоглощение и коэффициент размягчения составили 1926 кг/м^3, 8,58 % и 0,91 соответственно. Прочностные показатели неавтоклавных образцов несколько ниже, чем у автоклавного способа производства, однако находятся в пределах рекомендуемых значений для силикатных изделий. Установлено, что породообразующие минералы глины и вулканический пепел активно взаимодействуют с известью во время гидротермической обработки как при автоклавировании, так и при пропарке, образуя мелко- и крупнокристаллические новообразования, обеспечивающие высокую прочность силикатным материалам. В Государстве Эритрея, где стоимость и воздействие на окружающую среду имеют первостепенное значение, автоклавная и, особенно, неавтоклавная технология представляет собой оптимальное решение при производстве строительных материалов.*

***Ключевые слова**: суглинок месторождения Дэбуб, вулканический пепел, автоклавная и неавтоклавная технология, силикатные материалы.*

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