Effects of Bentonite Additives on Autoclaved Sand-Lime Product Properties

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Abstract. The paper presents the results of the research on modifications of sand-lime bricks with bentonite additives. The article presents correlations between physico-mechanical properties and a microstructure of traditional silicates and products modified with bentonite. Numerous images of scanning electron microscopy included in the article show the internal structure and phases occurring in both traditional and modified sand-lime products. The addition of bentonite results in a reduction of sand-lime products density and their compressive strength. The modified products achieve lower absorbability than conventional silicates by about 50%. The addition of bentonite changes the structure of pores and their distribution. The modified composition of a traditional silicate product contributed to changing the microstructure of the material (hydrogranates are formed).

1. Introduction
Autoclaved sand-lime products are one of the most common building materials used in residential construction. They are characterized by high compressive strength, good acoustic insulation and frost resistance, but some research is still being carried out to improve their properties.

The application of basalt aggregate [1], barium sulfate [2, 3] or lithium silicate [4-6] has improved properties of sand-lime products. A modified composition of silicate products with clay raw material in the form of metakaolin resulted in the formation of a new phase - hydrogranates, apart from C-S-H and tobermorite [7].

The paper presents the effects of the bentonite addition on the properties and the microstructure of sand-lime products.

2. Materials and methods
Traditional sand-lime products are produced from about 90% quartz sand, 7% lime and 3% water. The modified products were obtained from quartz sand (80,5%), unslaked lime (6,3%), water (2,7%) and bentonite (10,5%).

The raw material (consisting of quartz sand and lime) and bentonite were subjected to a particle size analysis in a HELOS H2746 laser diffractometer. The results of the granulometric analysis of the raw material and bentonite are shown in Figures 1 and 2.
Figure 1. Cumulative curve of particle size of mix quartz sand and lime.

The chemical composition of highly reactive lime is shown in Table 1.

Table 1. Chemical composition of quicklime.

| Components [%] | CaO | CaO<sub>active</sub> | MgO | CO<sub>2</sub> | SO<sub>3</sub> |
|----------------|-----|----------------------|-----|--------------|--------------|
|                | 94,72 | 91,22                | 0,97 | 1,47          | 0,18          |

Bentonite is a volcanic sedimentary rock containing at least 75% montmorillonite and illite, kaolinite, quartz and mica [8]. Montmorillonite, a member of the smectite group, is a 2:1 clay, i.e. it has two tetrahedral sheets of silica sandwiching a central octahedral sheet of alumina. Due to isomorphic substitutions Al<sup>3+</sup> by Mg<sup>2+</sup> or Fe<sup>3+</sup> in montmorillonite, there are usually electrically unbalanced structures. The resulting charge shortage may be partially compensated by interchangeable cations (mainly Na<sup>+</sup>, Ca<sup>2+</sup>, K<sup>+</sup>, H<sup>+</sup>) between the packages as well as their edges. They weaken the inter-package bond and cause a much easier water penetration, sometimes leading to a separation of individual packages [9, 10].

Figure 2. Cumulative curve of particle size of bentonite

The bentonite chemical composition is shown in Table 2.
In a silicate manufacturing plant, rectangular specimens (40x40x160 mm), which are typical and modified additive samples, were prepared. The procedure for a mass preparation and a sample preparation was carried out in an uniform and repetitive manner. After a lime slaking process, bentonite was added to the raw material containing sand, lime and water. After the ingredients were homogenised, the raw material was placed in moulds and pressed under 20 MPa. The samples cured in the autoclave for 8 hours at 203°C, at the pressure of 1,6 MPa. The tests were performed after the 21-day storage in dry air conditions.

Physical properties of the obtained products were determined according to the methods described in the standards for selected properties i.e. compressive strength [11], bulk density [12], water absorption [13] and coefficient of water absorption [14]. In a capillary action, liquid level rises in capillaries. Such a process can only occur in porous materials with pore diameters greater than $10^{-7}$ m (water is not able to penetrate smaller pores) and less than $10^{-4}$ m (in larger pores a capillary transport process does not take place). Compressive strength was determined using a Tecnotest KC 300 press. In addition, specific density of the samples was determined using a ULTRAPYC 1200e helical pycnometer.

The microstructure of the products was analysed by using scanning microscopy. A Quanta 250 FEG SEM-type scanning microscope with an EDS analyzer was used.

3. Results and discussion
Comparing the results of the sand-lime mix (Fig. 1) and bentonite (Fig. 2), we can see a significant difference in particle size. The sand-lime mix contains about 5% of dust fractions. Grains with diameters between 100 μm and 900 μm are prevalent in the mix composition. Contrary to the sand-lime mix, which consists mainly of sand fractions, bentonite consists of dust particles of 4 μm to 60 μm. The results of the granulometric analysis allow assessing the degree of material packing in both additive and non-additive samples. The bentonite sample obtains a tighter structure due to the addition of small size grains.

The results of analyzing physico-mechanical properties of the sand-lime products with the addition of bentonite and the reference samples are presented in Table 3. The results presented below are average values. The sample marked with the "T" symbol refers to the traditional product and "B" for the bentonite additive.

| Table 2. Chemical composition of bentonite. |
|--------------------------------------------|
| Components [%]                             |
| SiO$_2$ | Al$_2$O$_3$ | CaO | Fe$_2$O$_3$ | MgO | Na$_2$O | H$_2$O | Other |
| 60      | 20          | 1   | 5           | 3   | 3       | 6      | 2     |

The properties of the tested samples met the standard requirements for silicate products [15]. The product with the bentonite addition has by 1% lower density than traditional silica. Porosity of the modified and reference samples was determined, which was based on density and bulk density. The amount of pores in the traditional sample constitutes about 34% and in the modified one 35%.

The bentonite sample reveals a reduction in compressive strength by 31% compared to the reference sample. The bentonite modified product also obtained roughly a half lower absorbability. The difference in absorbency of the sample with and without the bentonite additive is related to a better component
packing in the modified product. Despite a slight difference in the total pore volume in the samples, applying bentonite changed the structure and pore sizes. It is assumed that a fine-grained additive caused the formation of tighter pores.

![Graph](image)

**Figure 3.** Coefficient of water absorption

Figure 3 shows changes in absorption per unit area over time. Within the first minutes of the material immersion in water, an increased liquid uptake may be observed. Over time, both in the reference sample and with the bentonite additive, water is absorbed more slowly and in smaller amounts. The coefficient of water absorption, which resulted from a capillary pull in time, is a half smaller for the products with bentonite additions.

Some characteristic microstructure images of the analyzed fracture sample surfaces observed under the scanning microscope are shown in Figures 4 and 5.

![Microstructure Images](image)

**Figure 4.** The microstructure of the traditional silicate product.

In the reference sample (Figure 4), a piece of aggregate is partially covered with a spongy C-S-H phase and tobermorite (occurring as needles). In the sample presented below, as well as in other analyses, the phases are predominant.
Figure 5. The microstructure of the bentonite modified sample.

The modified samples also show the C-S-H phase in the contact zone with aggregate and tobermorite crystals. The frequency of occurrence of both phases is smaller than for the reference sample. A smaller amount of manufactured tobermorite crystals results from the presence of aluminum. At the initial stage of the autoclave process, aluminum has an influence on silica solubility. It results in the direct C-S-H phase formation and then the tobermorite formation in the final stage [16]. The picture (Figure 5a) shows the C-S-H phase and smaller amounts of tobermorite crystals.

In a traditional production of autoclaved silicate products, amorphous C-S-H and crystal tobermorite (C5S6H5) are usually synthesis products [17-20]. According to the literature data, the strength of autoclaved materials depends on the total content of the two mineral phases [21, 22]. It means that an improvement of strength properties can be achieved by providing optimum conditions for a synthesis reaction, resulting in larger amounts of C-S-H and tobermorite. Such results can be obtained by an appropriate chemical or physical activation of reacting components [23].

The result of the reaction in the modified bentonite sample is the formation of a new phase - hydrographs, as shown in Figure 5b. Additives containing significant amounts of Al<sup>3+</sup> ions (e.g., high-flux fly ash or metakaolin) can cause the formation of hydrogranates [24]. The reaction of metakaolin and calcium oxide results in the formation of hydrated calcium silicates (C-S-H), stratlingite (C<sub>2</sub>ASH<sub>8</sub>) and hydrated calcium aluminate (C<sub>4</sub>AH<sub>13</sub>) [25].

The presence of hydrogranates is conditioned by the autoclaving time as well as the initial content of Al<sub>2</sub>O<sub>3</sub> in the raw material composition. Hydrogranates appear in the early stages of autoclaving prior to the 11 Å tobermorite. The longer the reaction time is, the smaller amount of hydrogranates appears, therefore they can also completely disappear [26].

In the sample with bentonite, compressive strength is lower than in the sample without the additive. The content of bentonite, about 10%, in sand-lime products causes the formation of large quantities of hydrogranates, which can lead to a loss of material strength.

4. Summary and conclusions
The study shows the effects of bentonite additions on specific properties of sand-lime products. The following conclusions can be drawn:

1. The addition of bentonite reduces density and compressive strength of the product.
2. The addition of bentonite contributed to changes in the structure and the size of pores. It is assumed that the fine-grained additive caused the formation of tighter pores, therefore the modified products have less absorbency.
3. Modifications of the composition of a traditional silicate product contributed to the change in the material microstructure - the formation of hydrographs. Their presence lowers the strength of the material.

A further research employing a different percentage of a bentonite additive will allow determining an optimum content of the additive, taking into account product characteristics.

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