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Autoclaved Sand-Lime Products with a Polypropylene Mesh

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Abstract. The paper presents the results of the research on modifications of silicate bricks with a polypropylene mesh and their influence on physical, mechanical and microstructural properties of such bricks. The main goal of the paper was to determine effects of the polypropylene mesh on sand-lime product parameters. The analysis has focused on compressive strength, water absorption, bulk density and structural features of the material. The obtained product is characterized by improved basic performance characteristics compared to traditional silicate products. Using the polypropylene mesh increased compressive strength by 25% while decreasing the product density. The modified products retain their form and do not disintegrate after losing their bearing capacity.

1. Introduction

Statistics on production and application of building materials in Poland, and in the world, show that consumption and demand for silicate materials have increased since the turn of the 21st century. They are not only used in Eastern and Central Europe, but also in Germany, Portugal, and the Middle East and Asian countries [1]. Such autoclaved bricks have the strength of 15-25 MPa, and are designed for constructing structural and partition walls (depending on a type), including up to 5 storeys, and in justified cases more. Civilization and technological advances force modifications in all industries, including a construction industry. By studying each type of material, its properties i.e. strength, density, water absorption and thermal properties are a priority. Such performance characteristics are due to bonds and reactions resulting from a hydration process between a binder and water. Autoclaving (hydrothermal treatment), in the case of silicate bricks, accelerates material maturation, the result of which is an artificial stone (mortar) as the end product.

Crystalline phases produced in a sand-lime product depend on the whole brick production process, including mainly autoclave conditions, temperature, steam pressure, quality and proportion of constituents used, aggregate fractions and others [2, 3].

A modification of sand-lime product composition is a decisive factor in the technology development and leads to structural changes and performance of a product. Using basalt aggregate [4], barium sulphate [5, 6], lithium silicate [7] or leachate from a landfill [8] has improved properties of sand-lime products. Efforts were also made to reduce bulk density of silicates and improve their thermal insulation properties by using a light additive in the form of expanded glass granules [9, 10].

In the era of sustainable development, attempts have been made to dispose of waste materials by using them as a filler in silicate products. Modifying sand-lime bricks with plastics (high impact polystyrene HIPS, and polypropylene and polyethylene PP) in the form of regranulates has improved strength, while lowering absorbability and density of finished products [11, 12]. Using granular
materials may result in their uneven distribution in the product giving rise to a local deterioration in finished products.

Sand-lime products are characterized by high compression strength, but they are brittle. Like in autoclaved cellular concrete, there are cracks and fissures occurring during production, transport or assembly. The problem can be eliminated by reinforcing a skeleton structure of a material. Reinforcement of cellular concrete with organic fibers (terephthalate, capron, polypropylene, polyethylene) has been explored in detail in contemporary construction, but there is no similar information on autoclaved lime sand. A positive effect of polypropylene and polyester granulates on sand-lime brick properties encourages reinforcement with a plastic spatial mesh. In addition, one of the advantages of such a solution will be an even material distribution in raw mass.

2. Materials and methods

Fine quartz sand is mainly used in production of autoclaved materials such as silicate bricks. The best quality sand is characterized by a high silica content, good compaction and a high degree of rolling and a low content of foreign substances. Minimum 65% of sand grains should be between 0.05-0.5 mm, and the remainder is sand with a grain size of less than 2 mm, although 2 mm grains are rare [13]. Sand used for autoclaved silicate materials is rich in quartz and calcite with a small amount of aragonite or rutil.

The graph below shows the sand grading curve for quartz sand.

![Figure 1. Cumulative curve of particle size of quartz sand](image)

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

| Components [%] | CaO | CaO$\text{active}$ | MgO | CO$_2$ | SO$_3$
|----------------|-----|-------------------|-----|-------|-------|
|                | 94.72 | 91.22 | 0.97 | 1.47 | 0.18 |

The additive used in the tests is a polypropylene mesh. Polypropylene is obtained by polymerizing propylene in the presence of metallographic catalysts. The reaction takes place at about 100 °C in
aqueous aliphatic hydrocarbons. Depending on a type of catalyst and polymerization conditions, polymers of different spatial structures are obtained [14]. Polypropylene is one of the lightest plastics ($d=0.92 \text{ g/cm}^3$). In its natural form, the material is safe for the environment and humans, and is highly chemically resistant (especially at an ambient temperature). Due to a rise in temperature, it is possible to introduce PP into a highly flexible state (due to its composition and structure) without changing the material structure. Mechanical and thermal properties of polypropylene depend on a degree of polymer crystallinity. Due to good polypropylene properties, it is widely used in industrial plastics (for machine elements, casings and covers). Good electrical properties combined with other properties make polypropylene widely applicable in electrical [15] and medical industries [16].

Due to polypropylene durability, attempts have been made to modify a silicate product using a polypropylene mesh. Rectangular laboratory samples (40x40x160 mm) were prepared. A traditional raw material mix consists of quicklime (about 7% by weight), quartz sand (about 90% by weight) and water (about 3% by weight). Samples with a traditional composition and the ones modified with polypropylene were prepared.

In the first stage of the production process, sand was mixed with lime and water in the ratio 9:1, and placed in reactors, where a lime slaking process took place. The PP mesh was placed in trigeminal moulds, filled with raw material and pressed under 20 MPa. The samples were then left in autoclaves for 8 hours at 203°C and under the pressure of 1.6 MPa. Physical characteristics of the material were determined according to the scope and methods described in the standards relating to the selected characteristics, in particular to compressive strength [18], bulk density [19] and absorbability [20]. A capillary uptake is also indicated. Compressive strength was determined using a Tecnostest KC 300 press. A product microstructure was analysed by using scanning microscopy. A Quanta 250 FEG SEM-type scanning microscope with an EDS analyser was used.

### 3. Results and discussions

The results of physico-mechanical properties of sand-lime products with the addition of polypropylene and the reference samples are presented in Table 2. The results presented below are mean values. A single series consists of 6 samples. A sample labelled "N" refers to a traditional product, while "PP" to a polypropylene product.

|          | Compressive strength [MPa] | Bulk density [kg/m³] | Water absorption [%] |
|----------|----------------------------|----------------------|----------------------|
| N        | 10.84                      | 1698                 | 14.8                 |
| PP       | 13.56                      | 1499                 | 18.6                 |
3.1. Compressive strength
During the autoclaving process, the plastic reinforcement mesh lost its properties, became more fragile and brittle. Compressive strength of the traditional sand-lime products is 25% lower than their modified counterparts. Lower strength coefficient may indicate that there are fewer bondings typical of silica bricks (C-S-H phase, tobermorite) in the contact zone: aggregate-phase. The presence of certain chemicals, especially heavy metals, often interferes with the formation and the synthesis of individual phases. Despite the reduced compressive strength, the modified material was more durable during decay (sample damage).

![Figure 3. Beams with polypropylene filler after compression testing](image3.jpg)

![Figure 4. Traditional beams after compression testing](image4.jpg)

3.2. Bulk density
The product with the polypropylene additive has about 12% lower bulk density than traditional silica. Lower volumetric density results from the use of a lightweight filler. The insertion of the polypropylene mesh into sand-lime bricks affected the microstructure of the material being examined. The PP mesh and bulk material form a heterogeneous material that is enriched with additional pores, which promotes density reduction, but at the same time it can result in a better thermal insulation of the material.
3.3. Water absorption

The polypropylene mesh filler samples have greater absorbability than the reference samples. The insertion of the rigid polypropylene mesh affected pore sizes, their type and quantity, which is related to the reduction in bulk density and the increase in absorbability.

4. Microstructure of sand-lime products

Silicate materials are products of hydrothermal processes that take place between sand, lime and water. In a traditional silicate production, an amorphous phase C-S-H and crystalline tobermorite (C₅S₆H₅) [21] are common effects of synthesis. The C-S-H phase, by many researchers, was referred as tobermorite-like, currently considered to be a distinct group of varying morphology and a variable phase composition. It is divided into C-S-H (I) and C-S-H (II) [22]. Tobermorite is a bonding phase, stable at the Ca / Si ratio of 0.8:1. There is a direct proportional relationship between the total content of the
above mentioned mineral phases and the strength of the autoclaved material [23]. The quality of the phases and the frequency of their occurrence are influenced by elements and compounds introduced into a silicate mass at different stages of production.

Some characteristic microstructure images of the analyzed sample fracture surfaces observed under the scanning microscope are shown in Figures 7-9.

Figure 7. Microstructure of a traditional silicate product sample

In the photo (Fig. 7), the reference sample is partially covered with an amorphous C-S-H phase, which, when heated, changes its surface to form a crystalline tobermorite phase. The tobermorite phase is usually predominant in the investigated products. Aluminum Al is mainly used for tobermorite stabilization especially in autoclaved concrete production. Aluminum is also preferable in calcium silicate production, as sand rich in aluminum helps to limit using CaO calcium, which is economically important, and thus also affects tobermorite synthesis and stabilization.

Figure 8. Microstructure of the modified sample

In both modified and traditional products, the C-S-H and tobermorite phases were created. High temperatures during the tempering process caused the plastic mesh to overlap. Figure 8a shows a part
of the polypropylene grid with aggregate grains. In addition, there is a contact zone line between the mesh and the raw material Figure 8b.

There was no reaction between plastics and the raw material, no new phases were formed at the contact zone between aggregate and the filling compound. Figure 8b shows a part of the polypropylene mesh (dark color) and the phases formed between aggregate and calcium. The C-S-H and tobermorite phases settle at the boundaries of the polypropylene mesh.

Due to the fact that silicate products are rich in SiO2 and Ca content, the SEM analysis in the test portion of the sample revealed a significant concentration of quartz, calcium and silicon, which may indicate the presence of the alkaline-calcium silicate phase. The EDS analysis of the piece of polypropylene showed the predominant carbon content and silicon and calcium traces.

5. Conclusions
The research has shown the benefits of using the PP mesh in silicate mass. The following conclusions can be drawn:

- The filler in the form of the polypropylene mesh reduced density of sand-lime products and increased absorbability of the tested samples.
- The modified products retain their form and do not disintegrate after losing their bearing capacity.

In order to draw more detailed conclusions, a further research on microstructure, fire resistance and heat transfer coefficient of the modified material should be carried out.

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