The Impact of Glass Components on the Quality and Strength of Silicate Autoclaved Materials

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Abstract. Compressive strength is the starting point, which is important in the process of researching new or modified building materials. The article contains the characteristics of traditional material (sand-SiO2, lime-CaO, H2O-water) and the results of research on modifications of composite silicate materials and the same products with using glass fiber. The paper contains information on modification of this kind of materials using glass fiber, because it is a lightweight and durable component made of boroglinosilicate glass containing less than 1% alkali. This type of fibers are characterized by a good degree of gluing the bundle, and so-called "strand integrity". Glass fiber (WS) cut strips are mainly intended for reinforcing thermoplastics and this fiber can have a good application in silicate composite materials, which arise under hydrothermal conditions (around 200°C). This paper also presents the results of the conducted compression tests, which were focused on: microstructure, compressive strength, water absorption, and bulk density. The Scanning Electron Microscope with spectrum EDS analysis helped to define the microstructural changes of modified materials. The interpretation of the materials structure revealed the existence of diversified phases i.e. tobermorite and C-S-H phase. CaO-SiO2-H2O system is the object of intensive research due to its meaning in chemistry and technologies of mineral binding materials. The dimensions and precision of the modified material were also analyzed. Silicate products are known for their almost perfect proportions and exact dimensions (+/- 1mm.) Obtained during production. Glass due to its amorphousness in hydrothermal conditions affects the behaviour of the mass in the mould during the autoclaving of the modified material, and glass fibers spread unevenly in the mass, and this factor should be taken into account especially.

1. Introduction
Compressive strength is the starting point, which is important in the process of researching new or modified building materials. A lot of modifications are applied in the building and cement industry [1-6,9]. The paper contains information on modification of the materials with glass fiber, because it is a lightweight and durable component made of boroglinosilicate glass containing less than 1% alkali. This type of fibers are characterized by a good degree of gluing the bundle [20, 21]. Glass fiber (WS) cut strips are mainly intended for reinforcing thermoplastics and this fiber can have a good application in silicate composite materials, which arise under hydrothermal conditions (around 200°C). This paper also presents the results of the conducted compression tests, which were focused on: microstructure, compressive strength, water absorption, and bulk density. The Scanning Electron Microscope with spectrum EDS analysis helped to define the microstructural changes of modified materials.
materials. The interpretation of the materials structure revealed the existence of diversified phases i.e. tobermorite and C-S-H phase. CaO-SiO2-H2O system is the object of intensive research due to its meaning in chemistry and technologies of mineral binding materials. Because the blocks are the autoclaving materials, the temperature of hydrothermal treatment of the products is around 200°C, the pressure 1,6-1,8 MPa and the autoclaving time is around 8 hours. The microstructure of the silica materials consists mostly of calcium silicates hydrated with a different level of structural arrangement [12,11,20]. Thinking about these components that may be used in the process of modification of this kind of materials/bricks, one should pay attention to their safety and lack of harmfulness to environment, economy and human protection [7,8]. The article aims at introducing to the question how glass fiber (WS) influence the autoclaved silica materials. An important point of these tests are compressive strength and microscope examination in the approach of grinding composition, problem of hydration these kind of products, ratio of lime and silica, which are created in concrete and autoclaved materials and connection of mechanical properties and their microstructural structure. Composite materials are currently the largest material base on the construction market. Glass fiber reinforced plastics are often regarded as priority construction materials that are widely used in the aerospace, shipbuilding, automotive and electrotechnical industries, and further in the sports and recreation industry [21]. The composite material is also called sand-lime products (so-called white brick). The article describes a method of modifying a silicate composite with chopped glass fibers. Glass is an amorphous material (not crystallized) formed in the first phase in the melting process at 1300-1500°C, followed by cooling of its two main components, i.e. quartz and sodium sand. The glass fiber in the form of cut strands is produced from boroglinosilicate glass containing less than 1% alkali. Such fibers are characterized by a good degree of gluing the bundle. Glass fiber (WS) cut strips are mainly intended for reinforcing thermoplastics. Glass fiber products of various types are formed in the process of stretching the alloy of a given glass and occur in the form of fibers with long strands or cut and staple small elements. Research shows that glass fiber reinforced plastics are resistant to aging processes, weather conditions, chemical substances and are non-flammable. They are characterized by a high modulus of elasticity [21]. This modification has been proposed because of the possibility of utilizing glass components in the form of fibers in other composite materials, as well as attempts to determine the effect of this type of filler on the 'white brick' properties, including the fire resistance of these type of material. Cut fibers with a length of up to 0.5 mm were used, packed from a polyethylene bag with a capacity of 10 kg.

2. Materials, methods and laboratory tests

Laboratory tests were carried out. The samples were produced in steel forms size 40x40x160 mm (Figures 1, 2). In every cycle of modifications applied, a reference sample, then a sample modified with glass fiber (WS). The research was carried with the cooperation with silicate production company in Ludynia (Kielce, Poland) belonging to the Sand-Lime Group Corporation. Silicate mass prepared in these company was used in modifications too. These mass consisted of quartz sand SiO2, hydrated lime CaO (7-10% of the product mass) and water. Quartz sand used in technological process stands out with its graining of 0-2 mm (90% of the mass product, when 50-60% out of 90% is the sand with graining of 0-0,5 mm, whereas the remaining 30-40% out of 90% of quartz sand is the sand with graining of 0,5-2 mm). Water in the amount of 7-9% of the mass supplements the mixture (for 250 kg sand-lime mass one expects about 18-20 l of water, which is 7.2-8% of the product mass). The mass is then placed in steel reactor tanks, where it is left for around 4 hours. Here the process of slaking takes place, accompanied by an increase in temperature up to 70°C. At this stage silica loses its crystalline structure, which in turn facilitates the subsequent formation of products. Next, the silicate mix is directed to the press, in which it is compressed at a maximum pressure of 15-20 MPa, and formed into blocks of suitable size. In the final phase the compressed elements are placed in autoclaves (the temperature 203°C and pressure around 16 bar (1.6 MPa)) [2,3,4,5,10,14,19].
Table 1. Percentage of modifier in relation to mass product [%]

| No | Name | Glass fiber (WS) | Water [%] | Mass [g] |
|----|------|------------------|-----------|---------|
| 1  | N    | -                | 5% - 90g  | 1800g   |
| 1  | WS10 | 10%              | 5         | 1800g   |
| 3  | WS30 | 30%              | 5         | 1800g   |
| 2  | WS50 | 50%              | 5         | 1800g   |

As a result of modification of 30% and 50% glass fibers, it was necessary to add more water by 3% (after preliminary mixing).

Examination of compressive resistance, determining volume density were carried out with respect to polish standards and norms [14-19]. When sand-lime products were produced, the samples were placed centrally on the plate of compression resistance machine. Laboratory samples were examined using Tecnotest KC300 press.

3. Research and the results of the analysis
The main tests were carried out, such as: compressive strength, volume density, water absorption, and further research using a microscope (SEM microscope for this modification (Figures 4, 9-15)). Traditional silicate autoclaved materials have compressive strength at the level of around 20 MPa. This feature depends on the quality of components, technology, and the accuracy of technological processes, purpose and class of a silicate blocks. Bulk density of a reference material stays at the level of around 1,7 kg/dm3, whereas its absorbability at the level of 16% (in relation to the mass product [12,14-19] New samples with high glass fiber content were brittle, dry and irregular. The content of glass fibers is up to a maximum of 10% due to their properties.
### Table 2. The compressive strength test.

| Sample | Serie A     | Serie B     | Average   |
|--------|-------------|-------------|-----------|
|        | kN N/mm²    | kN N/mm²    | N/mm²     |
| N      | 58.40       | 23.360      | 21.060    |
| WS10   | 35.90       | 14.360      | 14.860    |
| WS30   | 10.70       | 4.280       | 4.200     |
| WS50   | 4.50        | 1.800       | 1.800     |

The sample with 50% glass fiber (WS) content cracked along its length during the first strength test and fell apart, making the second measurement impossible (Tables 1, 2, Figure 1,3).

![Figure 5](image_url)  
**Figure 5.** Chart of compressive strength [MPa].

Glass fiber content decreased the compressive strength of the final product. These type of fibers acted as a filler not as a modifier (Figure 5).

### Table 3. Bulk density test.

| No  | dimensions | Length [cm] | Width [cm] | Length [cm] |
|-----|------------|-------------|------------|-------------|
| N   | 4.414      | 4.360       | 4.013      | 3.961       | 3.964       | 16.200     |
| WS10| 4.672      | 4.444       | 3.983      | 3.974       | 3.976       | 16.000     |
| WS30| 4.883      | 5.035       | 4.066      | 4.127       | 4.063       | 16.100     |
| WS50| 4.314      | 4.443       | 4.001      | 3.987       | 3.987       | 16.000     |

The bulk density was the lower (Figure 6), the more glass fibers (WS) were used. Everything because of the lower weight of these kind of fibers. However, the mass with fiber (WS) was more dry and heterogeneous.
The samples with the WS had a lower density, but they absorbed slightly more water (Figure 6, 7, Tables 3-5).

Table 4. Water absorption research.

| No | Dry sample g | Sample after 10 min g | After 30 min g | After 90 min g |
|----|--------------|------------------------|----------------|----------------|
| N  | 481.60, 0,0  | 493.81, 2.2            | 502.42, 4.8    | 511.00, 6.5    |
| WS10 | 443.23, 0,0  | 467.24, 3.0            | 479.51, 5.8    | 490.69, 8.5    |
| WS30 | 402.98, 0,0  | 443.17, 6.0            | 450.73, 9.4    | 464.87, 12.0   |
| WS50 | 274.85, 0,0  | 319.76, 3.9            | 324.33, 13.5   | 342.81, 16.0   |

The absorbability of the material increased due to the heterogeneity of the mass and a slightly higher proportion of pores in the laboratory sample. However, the elements were lighter, which may indicate a higher thermal material. In these tests, the lack of mechanization of the technological production process should be taken into account.

Figure 6. Bulk density graph.

Figure 7. The graph of water absorption of the sample reference (N) and modified by glass fiber (WS10, WS30, WS50 [%]) in different time (min).
4. Microstructure of modified autoclaved materials
Interpretation of the microstructure was applied with the use of SEM using the scanning microscope cooperating with the EDS analyzer (Figures 8-15). These type of silicate materials formed in hydrothermal conditions with the participation of high pressure are characterized by the presence of calcium silicates hydrated (S-H C phase and tobermorite usually). Tests have shown a greater heterogeneity of these type of material and as a result of minor production errors (laboratory tests). The glass fibers have unevenly formed in the material. The share of fibers in the amount exceeding 10% (also due to technical parameters and material dimensions) adversely affects the material.

| weight of wet sample | After 10 min [g] | 30 min [g] | 90 min [g] |
|----------------------|------------------|------------|------------|
| N                    | 12,21            | 20,82      | 29,40      |
| WS10                 | 24,01            | 36,28      | 47,46      |
| WS30                 | 40,19            | 47,75      | 61,89      |
| WS50                 | 44,91            | 49,48      | 67,96      |

Table 5. The weight of wet sample in a different time [g].
5. Summary and discussion
The use of glass fiber changed the most of the parameters of the autoclaved silicate materials. Compressive resistance was stated to have been on the level of 21 MPa (material without WS). Too much of glass fiber leads to lack of suitable correlation and bonds between sand and lime with water. The mixture becomes porous and fragile (fibers are flat, smooth and cut). In reference products, as a result of hydration certain bonds are created because of which the final material in the form of a blocks achieves the expanded value. In these case of using too much glass fiber (WS) then we lose the compressive strength and other parameters, because of the lack of bonds (contact surface between sand and fiber). In this case, it is advised to take other technology (perhaps the method of compacting the mix should be changed in order to obtain better strength parameters). In order to gain additional results on the subject of strength and texture of these materials, we need to take other research into consideration - on flexibility module and surface firmness using, maybe calibrated Berkovich indenter will be good in this case. So far, this type of research has only been carried out when measuring resin coating and surface layers of steel [13].

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