Aerated concrete, obtained by joint grinding of components

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Abstract. The effect of joint grinding Portland cement clinker, silica component and mineral additives (diopside, wollastonite) to a specific surface of 280-300 m² / kg on non-autoclaved aerated concrete properties (strength, average density and thermal conductivity), and also the joint grinding influence on porosity of hardened cement paste made from portland cement clinker with mineral admixtures were investigated in the work. It was found that these factors ensure the production of non-autoclaved aerated concrete with an average density of 580 kg/m³, a compressive strength of 3.3 MPa and a thermal conductivity of 0.131 W / m • °C.

1. Introduction
The heat-insulating products and the constructively heat-insulating products, made of the aerated concrete, are one of the most promising and competitive goods on the construction market. The aerated concrete is one of the effective materials for walling and is used both in the form of panels, and in the form of small wall blocks, as well as in monolithic building. The aerated concrete with not autoclave curing have the low coefficient of heat conductivity and it is made from available raw materials.

However, despite all the advantages, the aerated concrete refers to energy-intensive construction materials. At the same time, the most expensive component of the aerated concrete is cement. Autoclave processing of the silica component products and grinding are the most power-intensive operations in the aerated concrete production technology.

To ensure the production of aerated concrete with an average density of 400-500 kg / m³, it is necessary to use the silica component with a specific surface of 250-300 m² / kg [1, 2]. It was found that the one ton of the silica component grinding consumes electricity up to 25 kW·h or per 1 m³ of aerated concrete, taking into account the sand consumption (0.18-0.28) tons – 4.5-7 kW·h [3]. At the same time, a literary analysis showed that the joint grinding question of clinker and silica component is studied a little.

In order to increase the strength of materials based on portland cement, the introduction of mineral additives, for example, micro silica dioxide, fly ash, diopside, etc., is used [4 – 10]. Their application allows realizing potential opportunities of portland cement. The introduction of additives reduces the expensive binders’ consumption. The effectiveness of mineral additives used by authors (diopside, wollastonite) is determined by similarity in composition, type of chemical bonds, physicochemical characteristics (specific enthalpy of formation, specific entropy) to the original binders and the products of their hydration [4].

Thus, we studied the joint grinding effect of Portland cement clinker with silica and carbonate components to a specific surface of 280-300 m² / kg. We investigated the dispersed mineral additives
effect on properties of non-autoclaved aerated concrete (strength, average density and thermal conductivity) as well as the porosity of hardened cement paste made from Portland cement clinker with mineral additives.

2. Studied materials and method for measuring properties of mineral powders and aerated concrete

Portland cement produced by LLC “Iskitimcement” (Novosibirsk Region), with strength class 32.5 (CEM II/A-Sch. 32.5) was used as a binder. The mineral composition of the cement was $C_3S$ – 60-62, $C_2S$ – 15-17, $C_3A$ – 5-7, $C_4AF$ – 14 % of weight. Clinker was stored for 7 days in the form of granules with a size of 5-20 mm at a temperature of 20 ± 2 °C and a humidity not more than 60%.

Quartz sand of “Kamnerechensky Kamenni Karier” (Novosibirsk Region) was used as a silica component. The mineral composition of sand was: quartz 80 - 90, feldspar 10 - 20 % of weight. The true density of sand grains was 2650 kg / m$^3$, sand bulk density – 1420 kg/m$^3$. Loss on ignition – 0.45%, content of clay and silt impurities – 0.5%, clay lumps were absent.

As a carbonate component, the lump lime of LLC “Iskitimizvest” (Novosibirsk region) was used. The content of active CaO + MgO was at least 80 % of weight, non-slaked grains – less than 14%.

To stabilize the structure, grinded gypsum stone manufactured according to TU - 5743-001-05297513-2002 by LLC "Yergach" (settlement Ergach, Perm Territory) was used. In accordance with the quality certificate, it had the following characteristics: the content of $CaSO_4\cdot 2H_2O$: (conditional) – 80.6%, mass fraction of moisture – 0.82%, the total residue on 1 mm sieve – 0.24%, the total residue on 0.2 mm sieve – 14.06%; chemical composition: CaO – 47%, MgO – 2.0%, SO3 – 42.0%, others – 0.1%.

Aluminum powder grade PAP-1 (GOST 5494) was used as a blowing agent. The active aluminum content was 91.1 - 93.9%, the active gas evaporation time was 3 - 4 min from the beginning of mixing components of aerated concrete.

Rocks: wollastonite (deposit Sinyuhinskoe, mine "Vesjolij", Altai Republic), diopside (Bugotaksky deposit, Irkutsk Region), which are waste products of phlogopite ore, were used as a mineral additives. The true density of these additives was 2915 kg / m$^3$ for wollastonite, 3300 kg / m$^3$ for diopside. Their chemical compositions are given in Table 1.

| Name of additive | SiO$_2$ | CaO | MgO | Al$_2$O$_3$ | Fe$_2$O$_3$ | Na$_2$O | K$_2$O | TiO$_2$ | Loss on ignition |
|------------------|---------|-----|-----|-------------|-------------|--------|--------|--------|----------------|
| Wollastonite     | 53.4    | 34.7| 0.3 | 3.1         | 2.4         | -      | -      | -      | 6.1            |
| Diopside         | 56.1    | 25.4| 15.8| 1.0         | 0.7         | 0.1    | 0.1    | 0.1    | 0.6            |

Mineral additives were crushed in a planetary mill AGO-3 during 30 - 120 seconds for diopside and 15 - 60 – for wollastonite. Technical characteristics of mill are given in Table 2.

To control the particles size of diopside and wollastonite mineral powders, we used a PRO-7000 laser dispersion analyzer from Seishin Enterprice Co., LTD, Tokyo. It provides the determination of the particles size in the range from 1 to 192 microns in 16 intervals of values.

The resulting data are the result of no less than 320 continuously performed measurements that were carried out by photo detectors within 30 s, which provides high precision and reproducibility of measurements. The device gives information on the granulometric composition of the powder in the digits form, distribution curves and histograms for each interval of particle values. The laser dispersion analyzer shows the particles distribution in occupied volume, the corresponding mean value, the percentage content of each fraction particles, and the specific surface area (cm$^2$ / cm$^3$). The results are given in Table 3.
Table 2. Technical characteristics of AGO-3 mill.

| Index name                          | Index value |
|------------------------------------|-------------|
| Input size, mm                     | 5           |
| Discharge size, micron             | 0.5 - 3     |
| Quantity and volume of cylindrical rotors, ml | 3*2000      |
| Milling bodies                     | Balls       |
| Diameter of milling bodies, mm     | 6 - 10      |
| Cooling liquid                     | Water       |
| Centrifugal acceleration developed by milling bodies, m / s² | 400 - 800   |
| Method of milling                  | Wet, dry    |
| Weight, kg                         | 350         |
| Operating mode                     | Discrete    |

Table 3. Results of diopside and wollastonite powders granulometric analysis.

| Grinding time, sec | Average volume of particles, micron | Specific surface area | Volume fraction of particles with the size |
|--------------------|-------------------------------------|-----------------------|-------------------------------------------|
|                    |                                     | cm² / cm³ | m² / kg | ≤ 4 microns | ≤ 12 microns |
| 30                 | 27.0                                | 12670      | 393     | 19.5        | 31.9         |
| 60                 | 12.8                                | 20440      | 635     | 32.2        | 48.4         |
| 90                 | 4.3                                 | 31530      | 979     | 49.2        | 66.6         |
| 120                | 2.9                                 | 37240      | 1157    | 58.2        | 74.7         |
| 15 Diopside        | 28.6                                | 8980       | 309     | 13.3        | 27.9         |
| 30 Wollastonite    | 9.0                                 | 21710      | 746     | 36.4        | 57.6         |
| 45                 | 5.9                                 | 25840      | 888     | 43.6        | 65.1         |
| 60                 | 4.3                                 | 28590      | 982     | 49.0        | 68.6         |

The porosity was studied on samples of hardened cement paste made from portland cement clinker with mineral additives, which was hydrated for 28 days under normal conditions (the first day – over water in a bath with a hydraulic seal and the subsequent 27 days – in a water at a temperature of 20 °C). The study of porosity was carried out on an automatic mercury porometer AutoPore IV 9520 Micromeritics (USA), controlled by a personal computer. The measurements were performed at G.K. Boreskov Institute of Catalysis in Siberian Branch of Sciences Russian Academy. The measurement error did not exceed ± 2%. The measurement technique conformed to the international ASTM D4284-03 and ASTM D4404-84 (2004) standards. The pressure of mercury varied from 0.03 to 414 MPa, which made it possible to measure pore sizes up to 1.8 nm in diameter.

The compressive strength of aerated concrete, its average density and the thermal conductivity were determined on samples in the form of cubes with an edge of 100 mm made of aerated concrete mixture. Its composition was: Portland cement clinker – 27.0 - 28.5, silica component – 31.5, carbonate component – 4.0 - 5.0, water – 31.0 - 32.0, dehydrated gypsum stone – 2.27, the gas-forming component – 0.07-0.09% of mass. After accumulation of the initial structural strength, the samples were hardened under conditions of heat and moisture treatment, it was carried out according to the regime: within 3 hours the temperature rose to 90 °C, then for 8 hours – isothermal aging at 90 °C, and for 3 hours the temperature reduced to 20 °C.
In order to determine the strength limit of aerated concrete, the compression press with a maximum load of 500 kN was used, it ensured the loading of samples in the pure compression mode. The load increased on average by \((2.0 \pm 0.5)\) MPa/s during the test.

In order to compensate the spatial deviation due to nonparallel support surfaces of the sample, the press had a movable ball joint and was equipped with a device for setting centered push plates. Push plates transmitted the load on the sample.

Measurements of the thermal conductivity were carried out on samples of \(100 \times 100 \times 20\) mm by the method of Russian National Standard GOST 7076 on electronic thermal conductivity measuring instrument ITP-MG-4 in Research and Production Center "SibstrinStroyMaterials and Technologies". The error in determining the thermal conductivity was \(\pm 5\%\).

3. Experimental part

At the first stage, it was necessary to find out the joint influence and separate grinding of portland cement clinker and the silica component on the properties of non-autoclaved aerated concrete.

3.1. Influence the type of binder on aerated concrete properties

In order to assess the influence of the binder type on aerated concrete properties, the influence of three binders was studied: Portland cement, grinded Portland cement clinker and the silica-cement binder. The last was obtained by joint grinding of Portland cement clinker with a silica component. The quantity of silica component, grinded together with Portland cement clinker was 50% of required quantity for aerated concrete production. The specific surface of researched binders was \(280-300\) \(m^2/kg\). The carbonate component was milled separately to the same specific surface and then it was admixed into the binder. The dependence of non-autoclaved aerated concrete properties on the binder type is given in Table 4.

| Type of binder                  | Average density, kg/m³ | Compressive strength, MPa |
|---------------------------------|------------------------|----------------------------|
| Portland cement                 | 630                    | 1.7                        |
| Grinded Portland cement clinker | 628                    | 2.1                        |
| Silica-cement binder            | 610                    | 2.8                        |

The use of grinded clinker increased the strength of aerated concrete by 30% compared with the use of Portland cement. An even higher strength was achieved by grinding clinker together with 50% of silica component. At the same time, the density of aerated concrete remained practically unchanged, and the compressive strength increased by 65%.

3.2. Influence the type of mineral additive on aerated concrete properties

At the second stage, the effect of mineral additives on the properties of non-autoclaved aerated concrete was investigated. Pre-crushed wollastonite was admixed in an amount of 7%, diopside – 5% of the cement weight. Previous experiments showed that such an amount of additives maximizes the strength of hardened cement paste [111]. The mineral additive was mixed with silica cement binder, gypsum stone and the remaining 50% of silica component. The results are shown in Table 5.

Analysis of experimental data showed that mineral admixtures introducing into the aerated concrete mix leads to a slight decrease in the density of aerated concrete. The compressive strength increased by 11% while wollastonite was admixed and by 18% when diopside was admixed. The thermal conductivity varied from \(0.138\ W/(m\ °C)\) in the case of aerated concrete with no additives up to \(0.131\ W/(m\ °C)\) after introduction 5% of diopside. As far as the best characteristics of aerated concrete (average density, thermal conductivity and compressive strength) were obtained with the introduction of diopside, this admixture was chosen for further experiments.
Table 5. Properties of aerated concrete with mineral additives.

| Type and amount of additives, % by weight of Portland cement clinker | Average density of aerated concrete, kg / cm³ | Compressive strength of aerated concrete, MPa | Thermal conductivity, W / (m ° C) |
|---------------------------------------------------------------|---------------------------------------------|---------------------------------------------|---------------------------------|
| No additives                                                  | 610                                         | 2.8                                         | 0.138                           |
| Wollastonite, 7 %                                             | 600                                         | 3.1                                         | 0.135                           |
| Diopside, 5 %                                                 | 580                                         | 3.3                                         | 0.131                           |

3.3. Influence the type of mineral additive on porosity of hardened cement paste

At the third stage, the effect of mineral additive (diopside) on the porosity of hardened cement paste was investigated. The results of study for hardened cement paste made from Portland cement clinker with mineral admixtures are given in Table 6.

Table 6. Characteristics of hardened cement paste porosity by results of mercury porosimetry.

| Characteristics                              | Binder composition                        |
|---------------------------------------------|-------------------------------------------|
|                                             | Grinded Portland cement clinker          | Grinded Portland cement clinker with 7 % of diopside |
| Total pore volume, ml / g                   | 0.2730                                    | 0.3380                                      |
| Total area of pores, m² / g                 | 28.886                                    | 27.707                                      |
| Volume of pores with diameter less than 1.2 microns, ml / g | 0.1543                                    | 0.1854                                      |
| Average diameter of pores, microns          | 0.0484                                    | 0.0406                                      |
| Characteristic length of pores, microns     | 1.680                                     | 7.672                                       |
| Pores tortuosity, relative units            | 183.27                                    | 28.279                                      |

An analysis of mercury intrusion porosimetry showed that when 7% of diopside was admixed, the characteristic length of pores significantly increased comparing with Portland cement clinker with no admixtures. At the same time, the tortuosity of pores decreased substantially. This provides convenient conditions for moving part of water to neighboring air inclusions. The presence of pores (capillaries) large number with small diameter (less than 1.2 microns) increases the frost resistance of concrete, since water in pores will be in the film state mainly.

4. Conclusion

Thus, the joint grinding of Portland cement clinker with silica and carbonate components increases the strength of non-autoclaved aerated concrete and reduces its average density and thermal conductivity. The joint grinding of Portland cement clinker with additives improves properties of aerated concrete, and allows to reduce the energy consumption for a separate grinding of each component.

The mineral additive (diopside) behaves like a micro armature [11], being located in partitions between pores of aerated concrete [11]. Diopside with a very developed surface, acts as a barrier in the path of cracks and interconnected pores propagation. Admixing of diopside effects on hardened cement’s paste structure formation [11] and the average pore diameter decreases.

The use of these two approaches made it possible to increase the compressive strength of non-autoclaved aerated concrete by almost twice, to reduce its average density by 8% and the thermal conductivity by 7%. As a result, the non-autoclaved aerated concrete with an average density of 580 kg / m³, a compressive strength of 3.3 MPa and a thermal conductivity of 0.131 W / m • ° C was obtained.
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