Aerated concrete with mineral dispersed reinforcing additives

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Abstract. To guarantee the production of aerated concrete with the lowest average density while ensuring the required strength it is necessary to use a silica component with a surface area of 250-300 m²/kg. The article presents experimental data on grinding the silica component together with clinker to the optimum dispersion. This allows increasing the strength of non-autoclaved aerated concrete up to 33%. Furthermore, the addition to aerated concrete the mixture of dispersed reinforcing agents (wollastonite, diopside) and electrolytes with multiply charged cations and anions (1% Fe₂(SO₄)₃; Al₂(SO₄)₃) provides the growth of aerated concrete strength at 30 - 75%. As a cohesive the clinker, crushed together with silica and mineral supplements should be used. This increases the strength of aerated concrete at 65% in comparing with Portland cement.

1. Introduction
Cellular concrete is an effective material for the frame structures and is used both in the form of panels and in the form of small building blocks, as well as in monolithic construction [1-4]. Despite the undoubted merits, cellular concrete is energy consuming building material. Cement is the most expensive concrete component and the silica component crushing and autoclaving are the most energy-intensive operations in cellular concrete technology.

The mass reduction after 2.0 - 2.5 hours on 6.5-4.5% is a characteristic of the aerated concrete mixture based of natural sand with the specific surface 9.4 m²/kg structure formation. The average density of aerated concrete based on the natural sand is 1140-1170 kg/m³ and decreases with increasing the sand specific surface [5]. To ensure production of aerated concrete with average density 400-500 kg/m³ the use of quartz sand with specific surface 250-300 m²/kg (specific surface of no crushed sand is 3-19 m²/kg) is required.

However, the clinker and the sand combining crushing have not been studied enough. To increase the hardness of materials based on Portland cement by introduction of mineral additives such as micro silica, fly ash, diopside etc. is widely used, helping realize the potential of Portland cement.

This work studied the effect of dispersed mineral additives and electrolytes on aerated concrete strength and density, and the effects of combing crushing the Portland cement clinker, sand and mineral additives to specific surface 280-300 m²/kg.
2. Materials and methods
The cohesive has been the Portland clinker manufactured by "Iskitimcement", Ltd. company (Novosibirsk region), used in the production of Portland cement grade PC 400 d-20. It has the mineralogical composition, % mass: C\textsubscript{3}S – 60-62, C\textsubscript{2}S– 15-17, C\textsubscript{3}A– 5-7, C\textsubscript{4}AF– 14. Clinker was kept in the form of granules with size 5 - 20 mm for 7 days under standard conditions (temperature of 20 ± 2°С, humidity no more than 60 %) and 12 months in moist conditions (humidity 80-85 %).

As a mineral additives the next crushed rocks were used: wollastonite (Sinyukhinskoye deposit, mine "Veselyi", the Republic of Altai), diopside (Bugotakskoe deposit, Irkutsk region) that represent a production waste. Chemical compositions of wollastonite and diopside are shown in Table 1.

Wollastonite additive was admixed in 7%, diopside – 5% from the mass of clinker. Such content, as shown by previous experiments, is close to the optimal value [6]. The added electrolytes were salts with multiply-charged cations anions – Fe\textsubscript{2}(SO\textsubscript{4})\textsubscript{3} or Al\textsubscript{2}(SO\textsubscript{4})\textsubscript{3}. The salts were mixed into the water in amount of 1% from clinker mass which corresponds to its optimal concentration to increase the cement stone strength [7].

| Additive  | SiO\textsubscript{2} | CaO  | MgO  | Al\textsubscript{2}O\textsubscript{3} | Fe\textsubscript{2}O\textsubscript{3} | Na\textsubscript{2}O | K\textsubscript{2}O | TiO\textsubscript{2} | LOI |
|-----------|-------------------|------|------|-----------------|-----------------|------|-------|-------|-----|
| Wollastonite | 53,4              | 34,7 | 0,3  | 3,1             | 2,4             | -    | 0,1   | 0,1   | 6,1 |
| Diopside  | 56,1              | 25,4 | 15,8 | 1,0             | 0,7             | 0,1  | 0,1   | 0,6   |     |

As a small filler the quartz sand from "Kammerechenskij stone quarry", JSC,"NerudZapsib", CJSC (Novosibirsk region) was used. The mineral composition of the sand,% mass: quartz – 80-90, feldspar – 10-20. True density of sand grains was 2650 kg/m\textsuperscript{3}. The pour density of the sand was 1420 kg/m\textsuperscript{3}. Mass loss on roasting was 0.45%, contents of clay and silt particles – 0.5%.

Compressive strength and average density were determined on samples of size 100х100х100 mm, made of aerated concrete mixture, % mass: the Portland clinker– 27.23-28.36, silica component– 31.5, calx– 4.5, aluminum powder– 0.08, sulfanol– 0.001, water– 31.56, two-water gypsum stone– 2.27, diopside– 1.42-2.55, electrolyte Fe\textsubscript{2}(SO\textsubscript{4})\textsubscript{3} or Al\textsubscript{2}(SO\textsubscript{4})\textsubscript{3}– 0.28. The samples hardened in conditions of heat and humidity processing with the regime: 3 hours the temperature rise up to 90°С, 8 hours isothermal aging at a given temperature and 3 hours reducing the temperature to 20°С.

3. Results and discussion
Consider the dependence of aerated concrete properties from a cohesive type. The strength and density of aerated concrete produced using Portland cement, crushed clinker, as well as clinker, crushed together with 50% sand have been defined (Table 2).

| Cohesive type                          | Density, kg/m\textsuperscript{3} | Compressive strength, MPa |
|----------------------------------------|----------------------------------|---------------------------|
| Cement                                 | 630                              | 1.7                       |
| Clinker, crushed apart from sand       | 628                              | 2.1                       |
| Clinker, crushed together with 50% sand| 610                              | 2.8                       |

The clinker strength increased by 30% when crushed concrete was used comparing the Portland cement was applied. Even higher results were achieved when the clinker crushed together with 50% sand was used. While the aerated concrete density reduced from 630 to 610 kg/m\textsuperscript{3}, the compressive strength increased on 65%.

Later the joint crushing clinker with sand, mineral additives and carbonate component was applied. Water for dilution containing electrolytes was used to stir the dry aerated concrete mixture. The concrete test results are presented in Table 3.
Integration of 7% wollastonite or 5% diopside to aerated concrete mixture reduces the concrete density. The compressive strength increased by 11% with wollastonite and 18% with diopside additions. Strength increase may be explained by reinforcing effects of used additives.

A much greater increase in aerated concrete strength is seen while at the same time with wollastonite and diopside additives 1% electrolytes with multiply-charged cations and anions Fe\(_2\)(SO\(_4\))\(_3\) and Al\(_2\)(SO\(_4\))\(_3\) are used. Especially effective is the influence of the last salt. The growth in compressive strength is 57% if one uses wollastonite and 75% in the case of diopside.

| The type and quantity of additives | Density, kg/m\(^3\) | Compressive strength, MPa | The strength increase, % |
|-----------------------------------|----------------------|---------------------------|--------------------------|
| Clinker, stored 7 days under normal conditions | | | |
| Noadditives | 610 | 2,8 | - |
| Wollastonite7 % | 600 | 3,1 | 11 |
| Wollastonite7 % + 1 % Fe\(_2\)(SO\(_4\))\(_3\) | 615 | 3,9 | 25 |
| Wollastonite7 % + 1 % Al\(_2\)(SO\(_4\))\(_3\) | 625 | 4,4 | 57 |
| Diopside5 % | 580 | 3,3 | 18 |
| Diopside5 % + 1 % Fe\(_2\)(SO\(_4\))\(_3\) | 600 | 4,4 | 57 |
| Diopside5 % + 1 % Al\(_2\)(SO\(_4\))\(_3\) | 610 | 4,9 | 75 |
| Clinker, stored 12 months under damp conditions | | | |
| Noadditives | 610 | 2,1 | - |
| Wollastonite7 % | 605 | 2,3 | 8,7 |
| Wollastonite7 % + 1 % Fe\(_2\)(SO\(_4\))\(_3\) | 613 | 3,1 | 48,0 |
| Wollastonite7 % + 1 % Al\(_2\)(SO\(_4\))\(_3\) | 620 | 3,4 | 62,0 |
| Diopside5 % | 590 | 2,4 | 14,3 |
| Diopside5 % + 1 % Fe\(_2\)(SO\(_4\))\(_3\) | 603 | 3,4 | 62,0 |
| Diopside5 % + 1 % Al\(_2\)(SO\(_4\))\(_3\) | 615 | 3,8 | 81,0 |

Effect of electrolytes containing ions of Fe\(^{3+}\) and Al\(^{3+}\) may be due to their intense exchange with clinker Ca\(^{2+}\) ion resulting in accelerated hydration alite and belite–silicate clinker minerals.

Sometimes, when the aerated concrete production is located in regions where there are no cement plants (Far North, Far East) the Portland clinker can be stored for a long time because the delivery is carried out during the short summer season. When using long-stored clinker aerated concrete strength significantly reduces (by 25%). Adding dispersed minerals and electrolytes leads to increased strength as if clinker was stored 7 days under normal conditions (Table 3).

4. Conclusions
The strength of aerated concrete with additives of dispersed minerals and electrolytes that produced using long-stored clinker exceeds the strength of aerated concrete with no additives, produced using clinker stored 7 days under normal conditions. The hardness of aerated concrete manufactured from clinker crushed together with sand and mineral additives and stirred with salt solution increases in 2.9 times comparing with the hardness of aerated concrete produced from Portland cement without additives. In addition there is a decrease in the average density of aerated concrete with 630-615kg/m\(^3\).

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