Effect of dispersed mineral additive on properties of mortar mixture and solution

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Abstract. The results of dispersed mineral (limestone) and plasticizing additives effect on the properties of the solution mixture and solution are presented in the articles. It is shown that the introduction of a dispersed mineral additive has a significant effect on water-retaining capacity of mortar mixture, mortar hardening and increasing its water resistance. The optimal amount of the additive, based on the maximum values of the investigated indicators, is 7 - 9%. The solution strength increases to 15%. It is shown that, when the limestone and hydrated lime are added, the water-retaining capacity of the solution mixture increases up to 90%. The introduction of 7% of the dispersed mineral additive makes it possible to obtain a water-resistant solution with 25% hydrated lime.

1. Introduction
One of the ways to increase the mechanical properties of cement materials is the micro additives use [1-9]. Dispersed mineral fillers can affect the hydrate formation process, as well as the structure formation during hardening of binders. The interaction of dispersed mineral additives’ particles with the forming cement stone occurs on the surface they are in contact. At the same time, the type of chemical bond in the substances, which form the mineral additive and the minerals of the cement clinker are of great importance [7-9]. In our opinion, the energy characteristics of the additive are rather important. These include enthalpy of compounds formation and their entropy. In the number of scientists’ opinions [7-10], limestone, diopside and wollastonite are the closest to clinker compounds among the additives that can be used to improve the cement stone properties and, consequently, all artificial portland cement-based conglomerates. So, in this case, we should expect a good energy compatibility of mineral additives and cement stone.

Since, alitic cement was used in the work; it is advisable to choose an additive in terms of thermodynamic characteristics approximate to alit or limestone. In addition, this additive has a chemical affinity for clinker minerals and their hydration products.

Thus, the purpose of this paper was to study the effect of a dispersed mineral additive (limestone) on the properties of the solution mixture and solution.

2. Materials and measurement procedures
As a binder, portland cement produced by Iskitim cement LLC (Novosibirsk Region) CEM II/A-SH 32,5 and hydrated lime were used. Mineralogical composition of clinker, % mass.: C₃S - 60, C₂S –
16, C₃A – 7,3, C₄AF – 14, CaO_free – 0,15; chemical composition, % mass.: SiO₂ -20,7; Al₂O₃ – 6,3; Fe₂O₃ – 4,6; CaO – 65,4; MgO – 1,3; SO₃ – 0,4; ignition loss was 0,5.

Hydrate lime of the third grade produced by Iskitim cement LLC (Novosibirsk Region), containing active oxides (CaO + MgO) 70 % was used as the second component of binder and plasticizing additive.

Dispersed limestone (Iskitim, Novosibirsk region), which is a mining industry waste was used in the work as a mineral additive. Dispersed limestone had a bulk density of 1400 kg / m³, a true density of 2800 kg / m³. Chemical composition of limestone: MgO – 0,45; Fe₂O₃ – 0,55; Al₂O₃ – 0,22; SiO₂ – 0,95; SO₃ – 0,27; ignition loss was 43,08.

Dispersion of the mineral additive was evaluated by the specific surface area, determined on the instrument by PXX-4 and by laser granulometry data. The specific surface area was 400 m² / kg. The average diameter of the limestone particle was 27 μm.

To evaluate the water-holding capacity of the mortar mixture, the strength and water resistance of the mortar, a mortar mixture of the following composition was prepared: binder - 313 kg, sand - 1400 kg. The amount of hydrated lime-louse varied from 0 to 30%.

The mortar mix was prepared as follows. First, portland cement was mixed with a mineral additive, then hydrated lime and sand were introduced. After that, the dry mixture was stirred. At the last stage, the necessary amount of water was added. Then, the solution mixture was thoroughly mixed.

The water retention capacity was determined by testing 12 mm thick mortar layer laid on the blotter paper.

The samples of a 70.7 X 70.7 X 70.7 mm cubes were molded from the solution for the compressive strength tests. Samples were formed in molds without a bottom; they were fixed on the suction base covered with moist paper. The seal was made by bayonet. The samples were hardened for 28 days at a plus (20-22) °C temperature and a relative humidity of 60%. Samples were tested both in a state of natural moisture and in a water-saturated one. For this purpose the samples were saturated with water to a constant mass.

3. Results of experiments

To study the effect of the mineral additive amount on the properties of the mortar mixture and solution was studied, which was made both without additives and with the dispersed limestone addition. Dispersed limestone was introduced in an amount of 2, 5, 7, 9 and 11% of the portland cement weight. The effect of the hydrated lime content in the cement-lime binder and the dispersed mineral additive amount on the water-retaining capacity of the mortar mixture are presented in Table 1 and in Figure 1; on the strength of the solution, depending on the duration of hardening is shown in Figure 2 and in Table 2.

![Figure 1](image-url)

**Figure 1.** Influence of the hydrated lime content in the cement-lime binder and the dispersed mineral additive amount on the water-retaining capacity of the mortar mixture: 1. 0-90 water retention capacity; 2. 0-30 content of hydrated lime%; 3. 0-11 amount of additive%.
Table 1. The effect of the hydrated lime content in the cement-lime binder and the amount of dispersed mineral additive on the water-retaining capacity of the solution mixture.

| The hydrated cement content in a cement-lime binder, % of the Portland cement mass | Water-retaining capacity of the mortar mixture, %, depending on the dispersed mineral additive amount, % of the Portland mass cement |
|---|---|
| | 0 | 2 | 5 | 7 | 9 | 11 |
| 0 | 65 | 65 | 66 | 68 | 69 | 65 |
| 15 | 79 | 80 | 81 | 83 | 84 | 80 |
| 20 | 81 | 82 | 83 | 85 | 87 | 82 |
| 25 | 83 | 84 | 85 | 86 | 88 | 82 |
| 30 | 84 | 85 | 86 | 88 | 90 | 84 |

Figure 2. Influence of the hydrated lime content in the cement-lime binder and the dispersed mineral additive amount on the strength of the solution that solidified within 3 days (a), 7 days (b), and 28 days (c): 1. 0–400 strength of solution kgf/sm²; 2. 0–30 content of hydrated lime%; 3. 0–11 amount of additive%.

Table 2. Influence of the hydrated lime content in the cement-lime binder and the amount of the dispersed mineral additive on the solution strength.

| The content of hydrated lime in a cement-lime binder, % of the portlander weight | The strength of the solution, kgf/sm², depending on the dispersed mineral additive amount, % of the portlander weight |
|---|---|
| | 0 | 2 | 5 | 7 | 9 | 11 |
| 0 | 160.6 | 167.4 | 177.0 | 184.7 | 170.7 | 162.6 |
| 15 | 71.1 | 73.2 | 75.4 | 81.1 | 74.4 | 70.0 |
| 20 | 34.0 | 35.0 | 36.7 | 38.1 | 35.2 | 33.4 |
| 25 | 24.4 | 25.1 | 26.0 | 27.3 | 25.7 | 22.0 |
| 30 | 16.1 | 16.6 | 17.5 | 18.4 | 17.0 | 16.6 |
| 0 | 304.3 | 318.9 | 335.2 | 349.9 | 330.7 | 310.0 |
| 15 | 157.7 | 164.1 | 172.6 | 179.8 | 170.6 | 160.4 |
| 20 | 84.9 | 88.7 | 93.1 | 96.0 | 91.8 | 86.5 |
| 25 | 69.8 | 72.0 | 75.5 | 78.2 | 74.2 | 70.7 |
| 30 | 53.6 | 55.0 | 57.3 | 59.5 | 56.3 | 54.8 |
| 0 | 431.9 | 452.5 | 478.1 | 496.6 | 470.0 | 435.6 |
| 15 | 225.4 | 235.8 | 247.1 | 259.0 | 240.6 | 222.9 |
| 20 | 130.6 | 135.9 | 141.3 | 147.5 | 140.5 | 132.3 |
| 25 | 116.5 | 121.1 | 126.4 | 130.5 | 125.4 | 118.2 |
| 30 | 97.4 | 98.9 | 103.6 | 107.1 | 102.8 | 101.0 |
The influence of the hydrated lime amount in the cement-lime binder and the amount of the dispersed mineral additive on the water resistance of the solution are shown in Figure 3 and in Table 3.

Table 3. Influence of the hydrated lime content in the cement-lime binder and the amount of the dispersed mineral additive on the water resistance of the solution.

| Hydrated lime content in a cement-lime binder, % of the portland cement mass | The strength of the solution, kgf / sm², depending on the dispersed mineral additive amount, % of the portland cement mass |
|---|---|
| | 0 | 2 | 5 | 7 | 9 | 11 |
| solution in a natural humidity state | | | | | | |
| 0 | 431,9 | 452,5 | 478,1 | 496,6 | 470,0 | 435,6 |
| 15 | 225,4 | 235,8 | 247,1 | 259,0 | 240,6 | 222,9 |
| 20 | 130,6 | 135,9 | 141,3 | 147,5 | 140,5 | 132,3 |
| 25 | 116,5 | 121,1 | 126,4 | 130,5 | 125,4 | 118,2 |
| 30 | 97,4 | 98,9 | 103,6 | 107,1 | 102,8 | 101,0 |
| solution in a saturated water state | | | | | | |
| 0 | 431,9 | 453,0 | 478,4 | 497,0 | 470,2 | 435,9 |
| 15 | 184,8 | 198,1 | 212,5 | 233,1 | 223,8 | 216,2 |
| 20 | 98,0 | 104,6 | 114,5 | 125,4 | 123,6 | 121,7 |
| 25 | 78,1 | 86,0 | 96,1 | 104,4 | 102,8 | 85,8 |
| 30 | 53,6 | 58,4 | 67,3 | 76,0 | 75,0 | 75,7 |
| softening factor | | | | | | |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 15 | 0,82 | 0,84 | 0,86 | 0,90 | 0,93 | 0,97 |
| 20 | 0,75 | 0,77 | 0,81 | 0,85 | 0,88 | 0,92 |
| 25 | 0,67 | 0,71 | 0,76 | 0,80 | 0,82 | 0,85 |
| 30 | 0,55 | 0,59 | 0,65 | 0,71 | 0,73 | 0,75 |

Figure 3. Influence of the hydrated lime content in cement-lime binder and the amount of dispersed mineral additive to the water resistance of the solution.

4. Analysis of experimental data

Analysis of the experimental data showed that the greatest water-retaining capacity of the solution mixture was achieved in a case of 9% of the dispersed limestone was introduced. 30% hydrated lime solution and 9% dispersed limestone have a high water-holding capacity. The water-retaining mixture capacity is 90%. The favorable effect of carbonate additives on the water separation reduction in portland cement is likely to be explained by the formation in the initial period of hydrated products increased amount are in a colloidal state and possess a high water retention capacity.

The introduction of a dispersed mineral additive increases the solution compressive strength. The greatest increase in strength was achieved with 7% limestone introduction. In this case, the strength increases with the content of hydrated lime in the amount:
• 15% - strength increased by 15%;
• 20% - strength increased by 13%;
• 25% - strength increases by 12%;
• 30% - strength increases by 10%.

Water resistance obtained data showed that the introduction of a dispersed mineral additive increases the solution water resistance. The addition of 7% limestone makes it possible to obtain a water-resistant solution containing 25% hydrated lime.

The activity of mineral additives introduced into portland cement and involved in acid-base interaction is estimated, mainly by their ability to bind calcium hydroxide from its saturated solution [11].

According to the opinions of V.K. Kozlova, A.M. Manoha, A.A. Likhosherstova, E.V. Manuilova, E.Yu. Malovoi [12] the interaction of limestone with water is the hydrolytic decomposition process of salts formed by a strong base and a weak acid, resulting in the formation of calcium hydrogen carbonate \( \text{Ca(HCO}_3\text{)}_2 \), capable of interacting with calcium hydroxide by reaction:

\[
\text{Ca(HCO}_3\text{)}_2 + \text{Ca(OH)}_2 \rightarrow 2\text{CaCO}_3 + 2\text{H}_2\text{O}
\]

In addition to these compounds, \( \text{Ca(OH)}_2 \) possible formation of a new phase in the compound form is \( \text{Ca(OH)}_2 \cdot \text{CaCO}_3 \cdot n\text{H}_2\text{O} \) – mineral defernite.

According to the literature data on the active interaction of carbonate rocks with calcium hydroxide, with alkali metal hydroxides and carbonates [11,12], the carbonate additives can bind a significant part of the calcium hydroxide liberated during the hydrolysis of silicate minerals in hardening cement. A significant part of the resulting calcium bicarbonate can interact with calcium hydrosilicates with the formation of calcium hydrobicarboxylates and calcium hydroaluminates with the calcium hydrogen carbonate formation.

Thus, the effectiveness of limestone is due to its chemical interaction with clinker minerals and their hydration products and hydrated lime and the limestone influence on the contact zone of the system.

5. Conclusion

As the investigation result of the dispersed limestone influence on the properties of mortar mixture and solution, it was found that, when the limestone is introduced, the water-retaining capacity of the mortar mixture, the strength and water resistance of the solution significantly increase. These facts are explained by the chemical affinity of limestone with clinker minerals, their hydration products and hydrated lime. The optimum dosage of dispersed limestone in terms of ensuring the artificial stone maximum strength is 7% by weight, which is determined by its effect on the process of cement hydration and the formation of a contact zone between limestone particles and cement stone.

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