Investigation of magnesian foam concrete properties

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Abstract. This paper presents a method for producing magnesium foam concrete of structural and heat-insulating purpose. It was assumed that the magnesium oxychloride cement will ensure the non-shrinkage and high-quality structure of the developed foam concrete due to the introduction of crystallization centers into it. Such kind of cement is based on dolomite wastes and obtained via firing at a temperature of 650 ° C. It has the ability to rapidly gain high strength under natural conditions that will eliminate the use of autoclave treatment. The possibility of obtaining foam concrete of non-autoclaved hardening on a magnesium oxychloride cement with the use of modern types of foaming agents is considered. The main technological features of the preparation of disperse systems, based on saponified resins, synthetic and organic foaming agents, as well as determination of their stability and physical properties are described. The effect of a crystal seed in the form of magnesium oxide of the grade of PFA of various concentrations on the properties of the foam and the strength characteristics of the resulting foam concrete are described.

1. Introduction

The construction industry is increasingly in need of obtaining more energy efficient, environmentally friendly and, most importantly, affordable building materials. Development of technology of resource-saving magnesium cellular concrete is a complex solution of the above-mentioned tasks. Due to the ability of magnesium oxychloride cement to quickly gain high strength in natural conditions in the production scheme of such foam concrete there is no autoclave treatment. Environmental-friendly is also justified by the disposal of unclaimed dolomite dumps, which are the main raw material for the production of magnesia astringent.

Known types of binders in the production of foam concrete by non-autoclave method have a long setting time, resulting in a gradual precipitation of the porous solution in the already molded product. Thus, excessive consolidation of the monolith occurs, the thermal insulation of the material decreases, the integrity of the structure of the finished product is compromised due to micro cracks caused by excessive shrinkage. Application of the autoclave method allows accelerating the setting time of the porous mixture, reducing the percentage of shrinkage of products, increasing their strength and retaining a low density. This method is quite energy-intensive and requires compliance with the increased requirements for work safety [1]. Binder that having the ability to quickly gain high strength in natural conditions can serve as a suitable alternative to autoclave treatment. Most of these binders, represented on the market of building materials, have a rather high cost, which reduces the economic efficiency of the technology to zero [2].
However, a number of recent studies on the possibility of obtaining magnesium cements based on low-grade magnesium-containing rocks showed that a high-strength and fast-hardening binder can be obtained by inexpensive processing of waste dumps of refractory industries [3, 4]. Dolomite magnesium cement is one of such binder. Investigation of the possibility of its use as raw material for the production of non-autoclave foam concrete is likely to yield a material with improved qualitative characteristics [5].

Based on the results of previous studies, it was found that the formation of the magnesium stone proceeds through complex chemical-physical processes, and the set of its strength and setting time largely depends on the order and rate of formation of oxyhydrochloride crystallites [6-15].

For non-autoclaved cellular concrete in particular, the shrinkage size of the product depends on the rate of setting time the porous mixture during hardening. To accelerate the setting time and, consequently, to reduce the shrinkage of the foam concrete, it is necessary to provide an increased rate of growth of new crystalline formations in the early hydration of the magnesium oxychloride cement.

In the course of preliminary research, it has been hypothesized that when an aqueous solution of magnesium oxide of the PFA brand is added to the foam, magnesium hydroxide compounds form on the surface of foam cells. With the introduction of such a foam into the dough of the magnesium oxychloride cement, the concentration of the magnesium chloride activator remains at the same level, which will favorably affect the strength of the finished foam concrete.

Thus, the main aim of this study is to produce a foam concrete based on a magnesium oxychloride cement using modern foamers.

To achieve this aim, the following tasks were set and solved.

1) Studying of the properties of foams obtained on the basis of modern types of foaming agents and their interaction with a magnesium oxychloride cement;
2) Determination the effect of the introduction of the MgO additive of the PFA brand as the crystalline seed for hardening of the magnesium cellular concrete;
3) Evaluation the properties of foam concrete obtained on a foam modified with aqueous solution of magnesium oxide.

2. Materials and methods of research

The magnesium oxychloride cement, obtained by roasting at 650 °C of the dolomite rock by Satka deposit was used in the work. Roasting process was modified by the addition of potassium chloride in an amount of 4% from the weight of raw. As an activator for hydration the magnesium chloride (bischofite technical by Volgograd) was used.

Three types of foaming agents (FA) were used to form disperse systems: synthetic and organic (saponified resin and protein FA). To obtain foam on saponified resins, it is mandatory to use a stabilizer in the form of 10% aqueous solution of magnesium oxide, which is introduced into the solution of the foaming agent with water in a ratio of 1:1, because without the use of this stabilizer, due to the difference in pH, foaming of the foam concrete mixture without this component does not occur.

The last component for the production of magnesium foam concrete is the addition of magnesium oxide, introduced as an aqueous solution of 10, 20, 30 and 40% concentration. In the research work this additive is used as:
1) experimental stabilizer for foams;
2) crystalline seed (crystallization centers).

For the foams examined the following properties: stability, density, dispersion, wall thickness between air bubbles. For the finished samples of foam concrete studied: compressive strength, thermal conductivity.

Compressive strength was studied on samples-cubes with edge of 10 cm. Thermal conductivity was tested on an ITS-1 instrument.
3. The research part

In the course of the research, in particular at the stage of foams research, the results of foam density and their stability were obtained. The regularity of increasing the stability of foam systems modified by crystalline seeds is clearly traced. As the crystalline seed concentration increases, the stability of the foams increases (Table 1). It was found that the most stable foams could be obtained on organic blowing agents.

Microscopic examination of foams samples modified by the addition of magnesium oxide magnesium of different concentrations showed a proportional dependence of the wall thickness on the concentration of the seed used. Thus, the thinnest of interfacial film are observed in samples of foams not modified with crystalline seeds. The thickest walls have foam samples modified with an additive of 40% concentration (Table 1).

| Foamer on saponified resins                       | Foamer solution (g) | Crystalline seed solution (g) | \( \rho \) (кг/м\(^3\)) | Stability by sinking of foam (mm/h) | Cell wall thickness (μm) |
|--------------------------------------------------|---------------------|-------------------------------|--------------------------|-----------------------------------|--------------------------|
| Water Foamer MgO Water                              | 60 5 6,5 58,5 0       | 0                              | 65                       | 2,3                               | 28                       |
| Water Foamer MgO Water                              | 60 5 6,5 58,5 117 13  | 68                             | 2,2                      | 28                               | 33                       |
| Water Foamer MgO Water                              | 60 5 6,5 58,5 104 26  | 75                             | 2,2                      | 33                               | 33                       |
| Water Foamer MgO Water                              | 60 5 6,5 58,5 91 39   | 83                             | 2                        | 33                               | 33                       |
| Water Foamer MgO Water                              | 60 5 6,5 58,5 78 52   | 85                             | 1                        | 46                               | 46                       |

**Table 1. Summary table of characteristics of foams**

| Protein Foamer | Foamer solution (g) | Crystalline seed solution (g) | \( \rho \) (кг/м\(^3\)) | Stability by sinking of foam (mm/h) | Cell wall thickness (μm) |
|----------------|---------------------|-------------------------------|--------------------------|-----------------------------------|--------------------------|
| Water Foamer   | 127,4 2,6          | 0                              | 70                       | 2,2                               | 34                       |
| Water MgO      | 127,4 2,6          | 117                            | 76                       | 2                                 | 34,5                     |
| Water MgO      | 127,4 2,6          | 104                            | 80                       | 2                                 | 35                       |
| Water MgO      | 127,4 2,6          | 91                             | 91                       | 2                                 | 36                       |
| Water MgO      | 127,4 2,6          | 78                             | 93                       | 1                                 | 40                       |

| Synthetic foamer | Foamer solution (g) | Crystalline seed solution (g) | \( \rho \) (кг/м\(^3\)) | Stability by sinking of foam (mm/h) | Cell wall thickness (μm) |
|------------------|---------------------|-------------------------------|--------------------------|-----------------------------------|--------------------------|
| Water MgO        | 126 4               | 0                              | 12                       | 105                               | 12                       |
| Water MgO        | 126 4               | 117                            | 18                       | 82                                | 16                       |
| Water MgO        | 126 4               | 104                            | 21                       | 63                                | 18                       |
| Water MgO        | 126 4               | 91                             | 27                       | 46                                | 20                       |
| Water MgO        | 126 4               | 78                             | 32                       | 28                                | 22                       |

Thus, with increasing crystalline seed concentration, the thickness of the foam walls increases, and, consequently, their stability is also increasing.

At maximum crystalline seed concentrations (30-40%), samples of foams from the synthetic foaming agent are not stable in time and in volume. Because of the high expansion ratio of the foam, a large amount of air is involved, which contributes to the formation of large air bubbles and thinning of interfacial film up to 12 μm. Which leads to the precipitation of the resulting foam concrete mixture because of the destruction of the partitions under the action of heavy binder particles. So it was decided to abandon the synthetic foamer.
In the further work, the results of the strength of foam concrete on a protein foaming agent and on saponified resins with different concentrations of a crystalline seed of magnesium oxide were obtained. The results of the study are shown in the form of graphs (Figure 1a, 1b).

![Figure 1. Strength of samples at 7-day age a) foamed on a protein foaming agent; b) foamed on saponified resins.](image)

The highest values were obtained at average concentrations of aqueous solution of magnesium oxide (10-20%) on both types of foaming agents.

Based on the results of the experiment, it can be seen that the introduction of a crystalline seeds in the aqueous solution form of magnesium oxide of various concentrations (0-40%) affects the strength of the obtained samples. Namely, a concentration of 20% gives the greatest increase in strength. Onward due to increasing of the concentration of aqueous solution of magnesium oxide increases, the strength of foam concrete samples gradually decreases. This indicates that an increase in the strength of the samples is not associated with an increase in the content of magnesium oxide in the system.

To confirm this theory, an analysis was made of the quantitative content of the magnesium hydroxide phase in the samples at the first stages of hardening. In total, during the experiment, 3 derivatograms were obtained and processed on 3 different compositions. Samples were selected at the age of 2 hours after the introduction of foam into the binder solution. Peak compositions with the largest (40%), the smallest (0%) and the optimal (20%) concentration of aqueous solution of the magnesium oxide additive on the protein foaming agent were chosen as the control samples.

This derivatograms has endo-effects that correspond to the decomposition of the components of the foam concrete samples. For study of mass losses for the decomposition of the sought minerals under heating, an analytical calculation of the magnesium hydroxide content via stoichiometric equations was made. The results of the calculation are shown in Table 2.

| The content of MgO in the composition, % | The content of Mg(OH)₂ in the sample, % |
|----------------------------------------|----------------------------------------|
| 0                                      | 16%                                    |
| 20                                     | 20%                                    |
| 40                                     | 26%                                    |

Table 2. The content of magnesium hydroxide
Thus, it can be seen from the data obtained that the magnesium hydroxide content increases with increasing concentration of the magnesium oxide solution.

It is obvious that the introduction of magnesium oxide over 20% entails the reducing of the strength of the material, since the magnesium hydroxide content in the system is substantially increased. It does not fully react with the activator, and partially remains as free connections. At the same time, it is known from early studies that Mg (OH)₂ has low strength and high adsorption capacity.

4. Conclusions

Based on the results of studies of the physical characteristics of foams, the most effective foaming agents, protein and saponified resins, were identified. These blowing agents contribute to the formation of a stable structure of cellular foam concrete.

When an aqueous solution of magnesium oxide is added to the foam as a foam stabilizer, the thickness of the interfacial film between the air cells is markedly increased. With an increase in the concentration of magnesium oxide solution, the thickness of interfacial film also increases. In this case, the stability of the foams increases with increasing concentration of magnesium oxide introduced into the system.

When magnesium oxide additive concentrations were from 10 to 20% as crystalline seeds, samples of magnesium foam concrete showed the highest strength - 5.8 MPa. In addition, thermal analysis showed that the presence of a crystalline seed in the form of aqueous solution of magnesium oxide promotes the formation of primary hydration phases - magnesium hydroxide in an amount of up to 20%, which form the structure and strength of the magnesian stone.

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