Identification of principles for calculating composition of heavy magnesia concrete

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Abstract. The article suggests a method for obtaining heavy magnesium concrete on alternative materials, which are magnesium wastes of the mining and refractory industries. The advantages of using a magnesium oxychloride cement as a binder component of a concrete mixture are described. The suitability of the existing methodology for calculating the composition of heavy magnesium concrete has been analyzed and the need for its deep processing has been established. It is established that on the basis of magnesium oxychloride cement and aggregates from dolomite it is possible to obtain heavy concrete in terms of density and strength corresponding to the requirements of the current technical regulations. The need to correct a known method for calculating the composition of heavy concrete, namely the introduction of special correction factors, taking into account the specific features of the materials used, was identified. Based on the calculated formulation, a concrete mixture was obtained and its characteristics were studied.

1. Introduction

The composition of the concrete mixture is selected in order to obtain a concrete mixture and concrete with the desired properties. It must providing the necessary strength of concrete in the required time with the minimum possible flow of cement. The composition is selected taking into account the modes of preparation, compaction of the mixture during molding and the conditions for hardening the molded products, the properties of materials, concrete and concrete mix. The simplest and most convenient method for determining the composition of heavy concrete is the absolute volume calculation method, developed by Professor B.G. Scrumtayev [1].

In a concrete mix of the optimal composition, the components are in an "absolutely dense state". The voids of a coarse aggregate are filled with a fine aggregate, and the voids of a fine aggregate are filled with a cement test. With a high-quality compaction of concrete mix, concrete will be dense, strong and durable.

Calculation and selection the composition of concrete after the testing of raw materials lead in the following sequence.

1. Determination of the optimal water content, which provides the required indices of workability of the mixture, and the cement-water ratio;
2. Establishment of cement consumption per 1 m3 of the mixture, providing the required concrete strength at a given time under certain compaction and hardening conditions;
3. Determination of aggregate consumption per 1 m3 of packed and compacted mixture, choice of the relationships between them;
4. Refinement of the experimental composition of the mixture and calculation of the production composition.

The possibility of using a magnesium oxychloride cement as the main component of a concrete mixture in place of the traditionally used Portland cement was considered by a number of researchers [2-4]. Advantages of using this type of cement are its unique properties, such as the ability to quickly gain high strength, high wear resistance, resistance to bio corrosion and organic environments [5-12]. As aggregates for heavy concrete on its basis, it is proposed to use waste from the mining industry in the form of dolomite fractions 5…70 and 0.16…5 mm.

For the selection of the composition of a concrete mixture based on a magnesium oxychloride cement, the standard method is not suitable, since it is based on the relationships between the properties of raw materials and the required properties of Portland cement concrete [11].

The purpose of this study is to identify the principles for calculating the composition of heavy magnesium concrete and the relationship between the properties of raw materials and the characteristics of the resulting concrete.

To achieve this aim, the following tasks were set:
1. Calculate the initial composition of a concrete mixture based on a specific raw material on the basis of the existing methodology for calculating the composition of heavy Portland cement concrete. Determine its characteristics.
2. Introduce correction factors by analogy with the existing amendments for Portland cement heavy concrete.
3. Determine the characteristics of concrete obtained by the developed composition. Suggest options for adjusting the composition.

To calculate the initial composition of heavy magnesium concrete, a corrected absolute volume method was adopted.

As the initial data for calculating the composition of heavy magnesium concrete, it is proposed to accept the following characteristics of the raw material: for cement – density, activity (strength class); for cement mix – B/MOC (ratio of bischofite to magnesium oxychloride cement by weight); for coarse aggregate – density, the largest size, density of grains, bulk density, humidity; for fine aggregate – density of grains, bulk density, fineness modulus, humidity.

1. Calculation of the aggregates void ratio. Calculation of the void ratio is necessary for further calculations of the volumes of unoccupied by aggregates. Void ratio is the proportion of intergranular voids in a bulk material. It is determined only for bulk materials (sand, gravel, etc.).

\[ P = (1 - \frac{\rho_b}{\rho_t} \times 100) \]  \hspace{1cm} (1)

where \( \rho_b \) is the bulk density of the material, g/cm\(^3\), \( \rho_t \) is the true density of the material, g/cm\(^3\) (Table 1).

2. Calculation of the mass of fine and coarse aggregates.

\[ m_{ca} = \frac{\rho_{ca} \times 1000}{k_{id}} \]  \hspace{1cm} (2)

where \( \rho_{ca} \) is the bulk density of coarse aggregates, g/cm\(^3\), \( k_{id} \) - coefficient for increase of distance between grains (Table 1).

With the densest packing of a coarse aggregate, the amount of cement mixture will not be sufficient to form a continuous matrix. For this, it is necessary to take into account the coefficient for increase of distance between grains.

\[ \Pi = \frac{\rho_{ca} \times 1000 \times \rho_{ca}}{100} \]  \hspace{1cm} (3)
where $\Pi_a$ - void ratio of coarse aggregates, %; $\rho_{fa}$ - bulk density of fine aggregates, g/cm³.

**Table 1.** Coefficient for increase of distance between grains.

| B/MOC | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|-------|-----|-----|-----|-----|-----|
| Coefficient | 1.32 | 1.38 | 1.44 | 1.52 | 1.56 |

3. Correction of the proportion of aggregates, depending on the largest coarse aggregate.

Depending on the largest size of the coarse aggregate and the fineness modulus of the fine aggregate, its proportion in the aggregate mixture must be adjusted. The proportion of fine aggregate in the mixture of aggregates in absolute volume ($r$) is selected depending on the largest crushed stone in accordance with Table 2.

**Table 2.** Share of fine aggregate in the aggregate mixture.

| The value of $r$ at the largest coarse aggregate, mm | 10 | 20 | 40 |
|---------------------------------------------------|----|----|----|
| $r$                                               | 0.42 | 0.39 | 0.36 |

Notes:
1. The table is made for sand with fineness modulus = 2, with increasing (decreasing) fineness modulus by 0.5, the proportion of fine aggregates increases (decreases) by 0.03.
2. When using gravel, the proportion of fine aggregates decreases by 0.05.
3. For hard concrete mixtures with hardness > 20 seconds, the proportion of fine aggregates decreases by 0.04. For high-flow concrete mix with cone slump of at least 10 cm, the proportion of fine aggregates increases by 0.04.

\[
m_{ca2} = (m_{ca1} + m_{fa1}) \times (1 - r)
\]

(4)

where $m_{ca2}$ is the corrected mass of coarse aggregates, kg; $m_{ca1}$ - the initial mass of coarse aggregates, kg; $m_{fa1}$ - initial mass of fine aggregates, kg; $r$ is the proportion of fine aggregates in the mixture of aggregates (Table 2).

\[
m_{fa2} = (m_{ca1} + m_{fa1}) \times r
\]

(5)

where $m_{fa2}$ is the corrected mass of fine aggregates, kg; $m_{ca1}$ — the initial mass of coarse aggregates, kg; $m_{fa1}$ — initial mass of fine aggregates, kg; $r$ is the proportion of fine aggregates in the mixture of aggregates (Table 2).

4. Calculation of the volume occupied by the cement mix.

The void remaining between the grains will be filled with the cement mix. It is calculated according to the following formula:

\[
V_{mix} = \left(\frac{P_{ca} \times 1000}{\rho_{ca}}\right) - \left(\frac{m_{fa2}}{\rho_{fa}}\right) - \left(\frac{P_{fa} \times 1000}{\rho_{fa}}\right) + \left(\frac{1000 - m_{ca2}}{\rho_{ca}}\right)
\]

(6)

5. Calculation of the mass of cement and activator of hydration.

To calculate the mass of the cement and activator of hydration, it is necessary to calculate the mass of the cement mix.

\[
m_{mix} = V_{mix} \times \rho_{mix}
\]

(7)

where $m_{mix}$ is the mass of the cement mix, kg; $V_{mix}$ - the volume of the cement mix, l; $\rho_{mix}$ - the density of the cement mix, kg/cm³;

Using the ratio B/MOC, calculate the amount of magnesium binder and bischofite solution.
\[ m_b = \frac{m_{\text{mix}}}{S} \times P_b \]  

where \( m_b \) is the mass of bischofite solution, \( l \); \( S, P_b \) – constants of the calculation of proportions (Table 3).

\[ m_{\text{MOC}} = \frac{m_{\text{mix}}}{S} \times P_m \]  

where \( m_{\text{MOC}} \) is the mass of the magnesium oxychloride cement \( l \); \( S, P_m \) - constants of the calculation of proportions (Table 3).

| Table 3. Proportional ratio for a certain B/MOC. |
|-----------------------------------------------|
| B/MOC | 0,50 | 0,60 | 0,70 | 0,75 | 0,80 | 1,00 | 1,10 |
| Parts of bischofite (Pb) | 1,00 | 3,00 | 7,00 | 7,50 | 4,00 | 1,00 | 1,10 |
| Parts of the MOC (Pm) | 2,00 | 5,00 | 10,00 | 10,00 | 5,00 | 1,00 | 1,00 |
| Sum of parts (S) | 3,00 | 8,00 | 17,00 | 17,50 | 9,00 | 2,00 | 2,10 |

2. Materials and methods of research

Crystalline dolomite from the Satka deposit with grain size 0 ... 70 mm of unregulated mineralogical composition was accepted for the study.

Magnesium oxychloride cement

To produce the magnesium cement, a fraction of the feedstock passed through a 0.16 mm sieve was used. Fractions \( f > 40 \) mm were also used, after the grinding. Roasting of raw was carried out at a temperature of 650 °C. After roasting, magnesium cement was ground to a residue on the 008 sieve no more than 15%.

Coarse aggregate

For a coarse aggregate, fractions from 5 to 70 mm were taken from the rocks of the dolomite dumps of the Satka deposit.

Fine aggregate

As a fine aggregate, fractions from 0.16 to 5 mm of the rock of the dolomite dumps of the Satka deposit were accepted.

Magnesium chloride hexaqua technical (bischofite)

Technical magnesium chloride (bischofite MgCl2 · 6H2O) was used as an activator of hydration for mixture based on a magnesium oxychloride cement.

Physical-mechanical methods of test

To determine the physicomechanical properties of the materials, the standard methods [14-20].

Physicochemical methods of research

The raw materials were subjected to a complex study using derivatography, X-ray phase analysis and standard methods. Thermal analysis of the minerals was carried out on the "Luxx STA 409" Derivatograph system of the German company "Netsch". The rate of temperature rise in the furnace is 10 °C/min, the maximum heating temperature is 1000 °C. Platinum crucibles were used for the test, heated in a nitrogen atmosphere. X-ray phase analysis was carried out on a DRON-3M device upgraded with a PDWin attachment, at a voltage of 30 kV, a current strength of 10 mA, and a width of the output slit of 1 mm. The surveys were conducted in the angular interval 6-70 °.

3. The research part

The results of the study are presented in the summary table necessary for calculating the composition of heavy magnesia concrete (Table 4).
Table 4. Baseline data.

| Characteristics          | The name of indicators | Notation | Unit of measurement | Value |
|--------------------------|------------------------|----------|---------------------|-------|
| Cement                   | Density                | ρ_moc   | g/cm³               | 2,9   |
|                          | Activity (strength class) | R_a   | MPa                 | 85    |
| Cement mix              | B/MOC (ratio of bischofite to magnesium oxychloride cement by weight) | B/MOC | -                  | 0,5   |
|                          | Density                | ρ_mix   | g/cm³               | 2,1   |
| Coarse aggregate        | The largest size       | LS      | -                   | 20    |
|                          | Density of grains      | ρ_t     | g/cm³               | 2,9   |
|                          | Bulk density           | ρ_ca    | g/cm³               | 1,52  |
|                          | Humidity               | W       | %                   | 0     |
| Fine aggregate          | Density of grains      | ρ_t     | g/cm³               | 2,98  |
|                          | Bulk density           | ρ_mix   | g/cm³               | 1,58  |
|                          | Fineness modulus       | FM      | -                   | 2,894 |
|                          | Humidity               | W       | %                   | 0     |

Taking into account the received characteristics, the composition of the magnesian concrete mixture was calculated:

\[ m_{ca2} = 987.3 \text{ kg/m}^3; m_{fa2} = 796.2 \text{ kg/m}^3; m_{b2} = 225 \text{ kg/m}^3; m_{moc2} = 453.5 \text{ kg/m}^3 \]

A concrete mixture with the properties shown in Table 5 was obtained.

Table 5. Properties of the resulting concrete mixture.

| The name of indicators | Unit of measurement | Value |
|------------------------|---------------------|-------|
| Flowability            | P2                  |       |
| Density                | g/cm³               | 2,48  |
| conservation of concrete | h                  | 1     |
| Separability           | Water separation    | %     | 0,1               |
|                        | Mortar separation   | %     | 1                 |

The strength of the concrete samples obtained on the basis of the given composition is presented in Table 8.

Table 6. Strength of concrete samples.

| Age of samples | Average value, MPa |
|----------------|--------------------|
| 1 day          | 37,55              |
| 3 day          | 46,5               |
| 7 day          | 53,5               |
| 28 day         | 55,9               |

The value of the STDEV (for samples aged 28 days t (p, f) = 5.19. Table value of the required STDEV for three samples t (p, f) = 4,3. Due to the fact that the actual STDEV is greater than the required number of samples, n = 3 is sufficient for an experiment with a confidence level of P = 95% and an error error of ee = 3%. The value of the coefficient of variation for samples aged 28 days V = 0.99%. The value of the required strength coefficient Km for the coefficient of variation V = 0.99% and the number of samples n = 3 in accordance with the technical regulations is Km = 1.07. The concrete class with an average strength Rc = 55.9 and Kt = 1.07 is equal to B40.
Thus, samples of heavy concrete with a strength of B40, with an average density of 2462 kg/m³ were obtained.

4. Conclusions
On the basis of magnesium oxychloride cement and aggregates from dolomite it is possible to obtain heavy concrete in density and strength corresponding to the requirements of GOST 26633-2015 «Heavy and fine-grained concrete».

To develop a full-fledged methodology for calculating the composition of heavy concrete, it is necessary to derive a number of correction factors that take into account the specific features of the materials used.

Concrete mixture obtained by the composition calculated on the principle of absolute volumes on the raw materials under study has flowability on cone slump P2 and a density of 2483 kg/m³. Concrete prepared on the basis of this mixture has a strength class of B40 and a density of 2462 kg/m³.

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