Magnesia compositions with technogenic fillers

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Abstract. The paper presents the results of researching magnesia compositions, which contain caustic magnesite and porous technogenic fillers. The research is aimed at creating resource-saving magnesia materials with the density less than 1000 kg/m³. The dependence of the magnesia composition’s density and strength on the size of arboreal particles is exposed. The increase of the particles’ size lowers the density of materials, but worsens the moulding characteristics. The influence of ash microsphere on the structural and mechanical properties of magnesia materials is found out. The content of hollow particles in the magnesia mixture is restricted due to the decrease of the raw materials’ mass plasticity. The mathematical models, presenting the dependences of moulding mass’ properties and composition density on the filler’s composition, are obtained. The compositions of raw materials’ mixtures for getting materials with a reduced density are determined. Moulding masses, which contain the integral filler (20-50% of arboreal particles with the size 0.63-2.5 mm and 50-80% of the ash microsphere), are preferable. The combination of fibrous and spherical hollow particles provides mouldability of the raw materials’ mixture as well as a reduced density of magnesia compositions. The electronic microscopy is used to research the materials’ structure.

1. Introduction

The energy effectiveness of the construction to a considerable degree is provided by the materials, having heat-shielding properties. This determines the availability of porous composite materials, for instance, of porous concretes and light-weight concretes based on porous fillers. Porous concretes are favourably distinguished by a vast source of raw materials, by the variety of product, by the economy of maintenance [1, 2]. However, a low strength and the inclination to the shrink deformations restrict the sphere of porous concretes’ use.

The development of effective light-weigh concretes’ technology depends on the quality of porous fillers. The researches, aimed at the decrease of density and the increase of the fillers’ strength, as well as at the lowering of manufacture’s energy intensity are relevant [3–9].

The use of new raw materials and the technology’s improvement allowed obtaining effective porous granular and composite materials on the basis of liquid glass [10, 11]; and high-strength light-weight concretes on the basis of nanomodification and microdispersed reinforcement [12].

Frequently, the technologies of porous materials are based on the power-intensive processes which provide thermoplastic bulging of the raw materials’ mass [3, 11], and hardening under the influence of raised temperatures and pressure [1,2].

The technologies of roasting free granular fillers, in which the filler’s particles are cemented, are being developed. The use of cement determines the technological complexities of moulding and high values of granular fillers’ density.
Magnesia binding is an effective variety of low power-intensive materials, and is distinguished by an intensive hardening and high strengthening characteristics. The adhesion to mineral and organic materials provides the compatibility of magnesia binding with different fillers. This is the basis for the technology of famous materials based on an arboreal filler: xylolite, fibrolite and cement wood, the production of which often requires intensive compaction methods. A high activating capability of caustic magnesite allows obtaining combined binding substances with improved properties [13–21]. Unique properties of magnesia bindings are insufficiently used, especially while creating materials of a porous structure.

The aim of the study is the developing of resource-saving magnesia compositional material with a lower density.

To achieve the set goal the following tasks have to be done: to study the influence of porous technogenic particles on the materials’ structure; to design the moulding mixture composition, providing the getting of the composition with the density not more than 1000 kg/m³.

2. Materials and methods
Caustic magnesite with 85% of active MgO content was used in the experiments; the technogenic fillers of a porous structure were sawdust and the ash microsphere.

Sawdust is a friable mass obtained in the result of crushing and fractionating the woodworking waste. Sawdust of different fractures was used.

The ash microsphere is a dry material consisting of hollow particles of a spherical shape with the diameter 100 – 350 μm; it is the waste of heat and power engineering which is obtained as a light ash fraction in the process of solid fuel burning. The apparent density is 400 kg/m³. The chemical composition, %, is SiO₂ 65 – 70; Al₂O₃ 1 – 2; Fe₂O₃ 2 – 4; CaO up to 10.

Raw material’s mixtures were prepared by the introduction of the filler into the suspension, which was obtained by tempering of the caustic magnesite with the magnesium chloride solution with the density of 1230 kg/m³.

The moulding properties of the raw material’s mixture were determined by the cone’s flow. Magnesia compositions hardened at the temperature of 50°C. The models with the sizes of 40x40x160 mm were tested for strength. The microstructure of the materials was researched by the method of electronic microscopy.

3. Results and discussions
Magnesia composites were prepared with the ratio “caustic magnesite: arboreal filler – 1:0.5”. Factionated particles were used as a filler (Figures 1, 2). A comparative analysis of the compositions, containing different fractions of the filler, showed that with the decrease of the particles’ size the characteristics of the materials’ density and strength increase (Figures 1, 2). The substitution of small arboreal particles (size 0.14 – 0.63 mm) with large particles (size 2.5 – 5.00 mm) is accompanied by the porosity increase and, correspondingly, by the density decrease by 30 %. The porosity of the materials is mainly concentrated in the arboreal particles (Figure 3). An additional amount of pores is generated due to the high content of the tempering solution, i.e. the solution of magnesium chloride. The maximum strength of the materials is reached while using the fractions with the sizes of 0.63 – 1.25 mm. With the further decrease of the particles’ size the strength of the materials decreases as a result of the fibrous filler’s reinforced role diminishing.
Figure 1. The influence of the size of the arboreal filler’s particles on the materials’ density.

Figure 2. The influence of the size of the arboreal filler’s particles on the materials’ strength.

Figure 3. The influence of the size of the arboreal filler’s particles on the materials’ strength.

The use of long-staple particles hampers preparing the moulding mixtures. The material on the basis of polyfractional particles with the size 0.63 – 1.25 mm does not demonstrate the sufficient changes in the density in comparison with the composition from the particles with the size 0.63 – 1.25 mm. However, the polyfractional material strength is by 20% less.

Magnesia compositions with different content of the ash microsphere are researched (Figure 4). The introduction of 5 % additive lowers the density of the magnesia composition by 130 kg/m³; along
with this, the strength of the material does not practically decrease. The structure of hollow particles is characterized by the presence of small cells in the microsphere membranes (Figure 5). That is why at the content of 30 % of the ash microsphere in the composition the composition’s density lowers by 500 kg/m³. The density of such material is 32 % lower than the density of a magnesia stone without additives. The increase of the ash microsphere part by more than 30 % is unreasonable due to the worsening of moulding and strength properties of the magnesia composition.

Figure 4. The influence of the size of the arboreal filler’s particles on the materials’ strength.

Figure 5. The influence of the size of the arboreal filler’s particles on the materials’ strength.

The analysis of the properties of the compositions on the basis of different origin porous particles allowed assuming the reasonability of the combination of arboreal fraction’s particles 0.63 – 2.5 mm with the ash microsphere. To design compositions of a complex structure the method of the experiment’s mathematical planning was used (Tables 1, 2). The results of testing the materials of different structure are presented in Table 3.

As a result of the experimental data processing the dependence of liquid-solid ratio on the researched factors was presented as the regression equation of the complete quadric model:

$$Y_1 = 0.531 + 0.0015x_1 - 0.022x_2 + 0.0045x_1^2 - 0.067x_2^2 - 0.021x_1x_2.$$  \hspace{1cm} (1)

| Factors | Variation levels |
|---------|------------------|
| Natural kind | Encoded kind | -1 | 0 | +1 |
| Binding: filler | $x_1$ | 3 | 4 | 5 |
| The part of the ash microsphere in the filler | $x_2$ | 20 | 50 | 80 |
Table 2. Matrix of the experiment’s mathematical planning.

| No. | The researched factors | Binding : filler | The part of the ash microsphere in the filler, % |
|-----|------------------------|-----------------|-----------------------------------------------|
| 1   | 1                      | 1               | 5                                             |
| 2   | 0                      | 1               | 4                                             |
| 3   | −1                     | 1               | 3                                             |
| 4   | 1                      | 0               | 5                                             |
| 5   | 0                      | 0               | 4                                             |
| 6   | −1                     | 0               | 3                                             |
| 7   | 1                      | −1              | 5                                             |
| 8   | 0                      | −1              | 4                                             |
| 9   | −1                     | −1              | 3                                             |

Table 3. The results of magnesia materials’ test.

| No. | Binding : filler | The part of the ash microsphere in the filler, % | Liquid : Solid | Density, kg/m³ |
|-----|------------------|-----------------------------------------------|----------------|----------------|
| 1   | 5                | 80                                            | 0.417          | 1068           |
| 2   | 4                | 80                                            | 0.450          | 1358           |
| 3   | 3                | 80                                            | 0.500          | 1173           |
| 4   | 5                | 50                                            | 0.542          | 1313           |
| 5   | 4                | 50                                            | 0.550          | 1184           |
| 6   | 3                | 50                                            | 0.450          | 990            |
| 7   | 5                | 20                                            | 0.500          | 1444           |
| 8   | 4                | 20                                            | 0.500          | 1301           |
| 9   | 3                | 20                                            | 0.500          | 1218           |

The geometric image, corresponding to the function, is presented in Figure 6.

The regression equation for the dependence of the composition’s density on the substantial structure of the filler is as follows:

\[ Y_2 = 1228 + 74x_1 - 60.667x_2 + 222x_1^2 - 182x_2^2 - 82.75x_1x_2. \] (2)

The geometric interpretation of the density’s dependence on the substantial structure of the filler is presented in Figure 7.

The lowering of the magnesia compositions’ density is provided in case of restricting the binding in the composition of the moulding mixture. However, the substantial structure of the filler influences mostly the materials’ density. The compositions, obtained with the use of the combined filler, in which the ash microsphere is not less than 50%, are preferable. The introduction of the salt solution in the ratio liquid : solid 0.45 – 0.50 provides the mouldability of the raw materials’ mixtures.

Magnesia compositions with the density of 950 – 1000 kg/m³ are characterized by the strength under the pressure of 17.5 – 21.4 MPa.
Figure 6. The surfaces of the response of the liquid-solid ratio’s dependence on the filler’s structure.

Figure 7. The surfaces of the response of the compositions density’s dependence on the filler’s structure.

4. Summary
Magnesia compositions on the basis of porous technogenic fillers are offered. The effectiveness of the fillers, containing arboreal particles and ash microsphere, is determined in order to create magnesia materials with a reduced density.

Combination of fibrous and hollow spherical particles improves moulding properties of the raw materials’ mixture, and provides the formation of a combined porosity.

The resource-saving of the developed compositions is provided by the use of technogenic materials of different origin, and by low power-intensity of magnesia products’ technology.

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