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Energy Efficient Compositions of Dry Concrete Mixes Based on Gypsum-Bearing Systems

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Abstract

The work focuses on the profound research results aimed at developing new energy efficient compositions of gypsum-based dry concrete mixes with improved building and technical properties. The article analyzes the geological survey of local raw materials for further rational use of fine-dispersion mineral fillers in gypsum-bearing systems. The researchers have conducted the comparative tests of compositions, determined optimum dosage and found the most rational new uses. The planned modification of the mineral part was performed with present-day construction chemicals using the two-factor and three-factor plans of the experiment that made it possible to get dry mixes. The dry mixes are equal in quality to the mixes made by well-known producers but cost much less.

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Keywords: gypsum, filler, properties, dry mixes, isosurface, composition

1. Introduction

The present-day architecture of buildings and structures is characterized by original and creative shapes and solutions that are impossible without using decorative and effective building materials. Various gypsum-based compositions were widely used even in IV century B.C. in ancient Egypt [1]. Nowadays most gypsum binders are used in the production of dry building mixes. Gypsum finishes account over 40% of the total amount of materials produced in Russia.

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2. Research

Aesthetics, ecology, great comfort and low labor costs promote the use of gypsum materials. Taking into account the increasing construction scale, the growing number of slum dwellings and the data presented in the document ‘Development Strategy of Orenburg Region up to 2030’, thousands of tons of the above mentioned materials will be consumed. Thus the development of gypsum-bearing systems and dry building mixes with the maximum use of local raw materials seems to be quite topical research direction [2-10]. The concurrent task of the research is to get the cost advantage as the result of falling costs and the increase of the operating life.

To get good water-resistant properties is rather complicated when gypsum-bearing systems contact water. However it is possible to avoid rapid deterioration of stones caused by moisture absorption from air by improving its inner and surface structure with the use of various fillers [11-13]. Their application in the composition of the gypsum binder results in the changed rheological, physical, mechanical and structural indexes of the whole system. Thus, the main research goal was to develop up-to-date effective gypsum-filled dry building mixes using local raw materials and regional dispersion mineral waste with the improved water-repellent properties.

Testing of the investigated samples was performed in accordance with State Standard 31376-2008 ‘Dry building mixes with gypsum binders. Test methods’.

Statistical and mathematical methods were used for processing the research results. The structure was studied with the help of normative techniques, optical and electron-microscopic analysis. Geological survey of Orenburg Region deposits and statistical analyses of regional waste disposal and utilization are used in the research paper [14-16]. The following materials were used as the starting components: local raw materials, industrial wastes- chalk, limestone, magnesite, burnt clay, serpentinite, water softening sludge of CHP, glass reinforced epoxy slag, sand, marshallit and modifying additives of different applications. The research was carried out on the equipment provided by Scientific-Research Institute ‘Construction Materials’, Testing Centre ‘Orenburgstroyispytaniya ‘ and Institute of Micro and Nanotechnology at Orenburg State University.

At the first stage there was found the dependence of rheological properties of mineral system on the amount of filler added, see Fig.1.

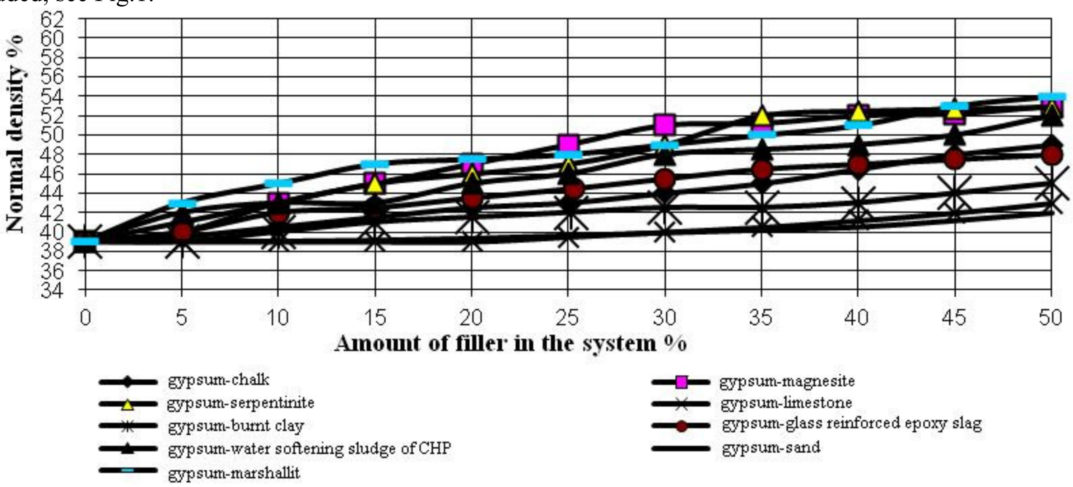
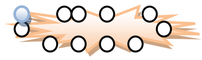
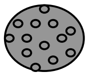
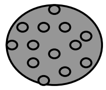
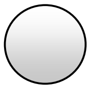
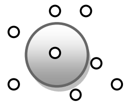
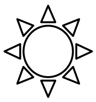
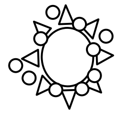
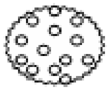
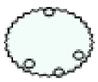
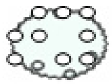
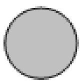
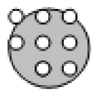
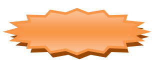
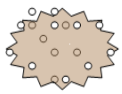
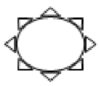
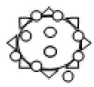


Fig1. Dependence of mixture’s normal density on the percentage of filler’s adding

Fig.1 shows that the tested fillers have different effect on the mixture’s rheology due to various structural characteristics of materials, see Table 1 [17].

The most intensive increase of hydrophilic properties is observed by adding magnesite, marshallit, serpentinite, chalk and sludge correlating with porous structure of their grains. Components with greater density such as sand, clay and limestone have practically no effect on the above mentioned characteristic.

Table 1. Structural characteristics of component grains with different mineral basics

Item	Grain shape	Interaction with water
Sand		 Good hydrophilic properties
Water softening sludge of CHP		 Absorbs water increasing the size
Glass reinforced epoxy slag		 Hydrophobic properties
Limestone		 Good hydrophilic properties
Chalk		 Satisfactory hydrophilic properties with softening surface
Serpentinite		 Satisfactory hydrophilic properties, a little absorption
Magnesite		 Satisfactory hydrophilic properties
Burnt clay		 Good hydrophilic prrtieopes, expands
Marshallit		 Satisfactory hydrophilic properties

The next testing stage was aimed at recording the setting time of ‘gypsum- filler’ compositions. The system ‘gypsum-electric-furnace steelmaking slag’ has the most rapid setting time (from the 6th to the 8th minute after filler’s adding) whereas the system ‘gypsum-magnesite’ has the longest setting time (from the 9th to the 19th minute). Limestone, chalk, marshals, serpentine, clay, sand, sludge have similar starting and ending points of setting time (from the 8th to the 14th and from the 19th to the 20th minute). Moreover, the more filler is added the longer the setting time.

Adding dispersive components to the gypsum binder affected its strength values. Strength values were registered twice, i.e. 2 hours and 7 days after starting the experiment, see Fig. 2-5. Filling the binder with inert components decreases the strength characteristics. The strength loss rate is different depending upon the kind of the filler, its structure and water requirement.

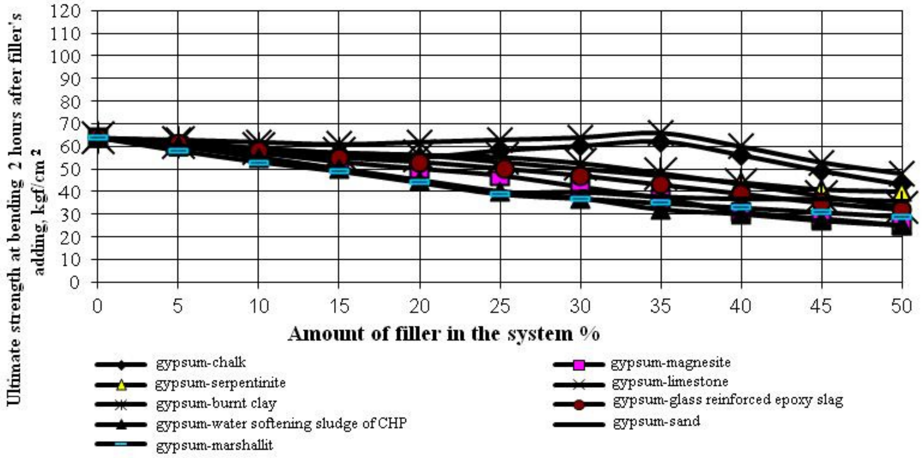


Fig.2 Gypsum rock strength at bending depending upon the filler's components 2 hours after filler's adding

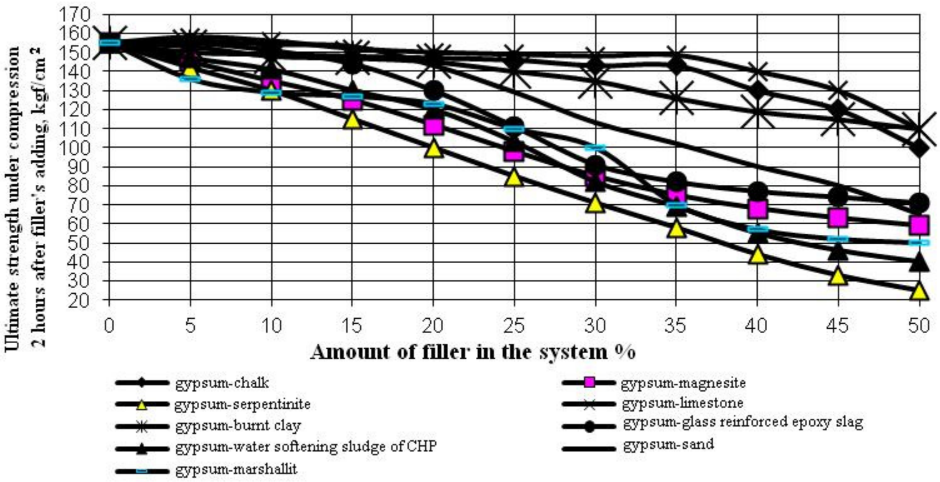


Fig.3 Gypsum rock strength under compression depending upon the filler's components 2 hours after filler's adding

Having analyzed the dependence of strength on the amount of filler in the system we can confidently say that by increasing the amount of filler at bending as well as under compression the system's strength values decrease. The most rapid strength loss is observed in the systems 'gypsum-serpentine' and 'gypsum-sludge'. It should be noted that the behavior of chalk and limestone differs a lot from the behavior of the other fillers. Thus, while increasing the amount of limestone up to 35 % the strength value decreases to 64kgf/cm^2 at bending and to149kgf/cm2 under compression. The addition of more than 35 % of filler is characterized by the decrease of the above mentioned characteristics that is because the inner structure of the gypsum rock becomes more defective. The strength value changes in the same way while adding chalk. However, when the amount of filler is 35%, the strength value under compression is142kgf/cm^2 and the strength value at bending is 59kgf/cm^2. The change in the samples' strength characteristics after 7 days seems to have the same tendency as after 2 hours. Chalk and limestone fillers in the amount of up to 35% have the positive effect on the gypsum-binder. Chalk and limestone were taken by us as mineral basics in order to change properties by using the products of construction chemistry.

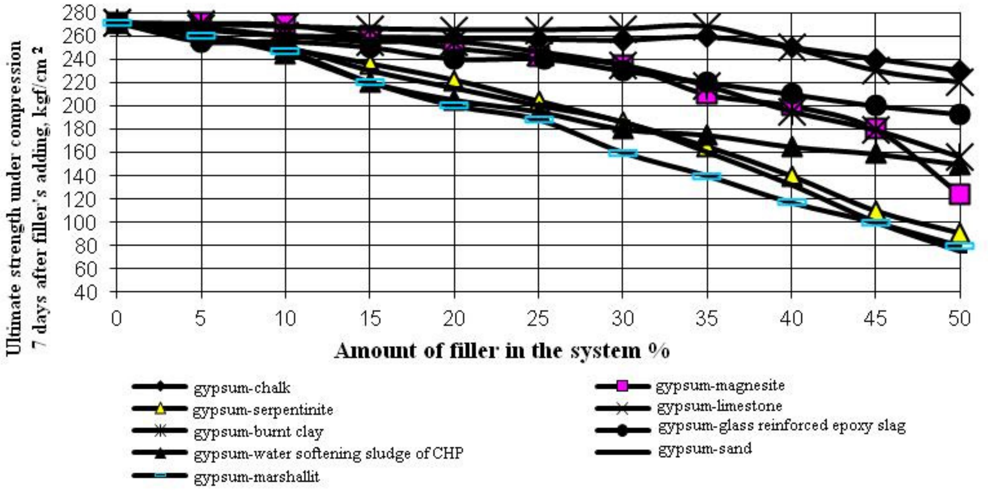


Fig. 4 Ultimate gypsum rock strength under compression 7days after filler's adding

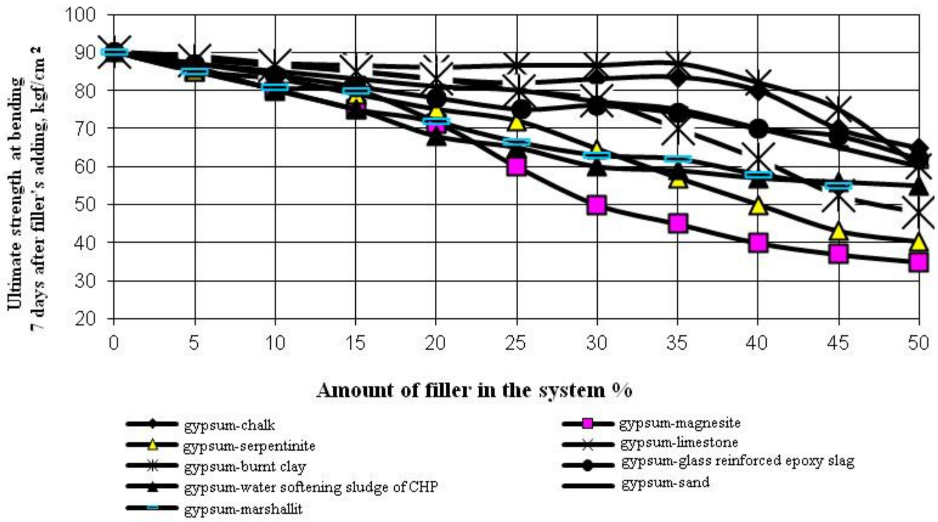


Fig. 5 Ultimate gypsum rock strength at bending7days after filler's adding

Then we studied the effect of powder modifiers (setting regulator and water-repellent agent) and reinforcing fibers on building-technical properties of the system by using three-factor plan of the experiment [15, 16].

Table 2. Experiment matrix

Code	-1	1
X_1	0	1
X_2	0	0.5
X_3	0	0.5

Modified factors are: X_1 – water-repellent agent (zinc stearate), X_2 – reinforcing fiber (hard fiber Technocel 500-1), X_3 – setting regulator (citric acid). For illustrative purposes there were built isosurfaces of the systems' mechanical-and-physical characteristics, Fig. 6 – 8.

Strength seems to be important characteristic of any compositional system used in finishing works. At the first stage we analyzed the effect of complex modification on the ultimate strength under compression, Fig.6. As shown on the isosurfaces in Fig.6, factors X_1 and X_3 that are responsible for the existence of setting regulator and water-repellent agent have the greatest effect on the strength loss. When there is maximum amount of the compound in the system, it loses its strength values that fall to less than 2MPa. The presence of reinforcing fibers has practically no effect on strength change. Moreover by introducing the fibers we wanted to improve crack-resistant properties. When the amount of water-repellent agent and setting regulator is minimum the strength of the system reaches its maximum values of more than 10mPa. However in this situation we observe low technological effectiveness of the mix. 0.25 % of the setting regulator (citric acid) is considered to be optimal in the gypsum-chalk system. In this case system's setting time is 47 minutes.

As far as the gypsum-limestone system is concerned, from Fig.6b it is seen that the more significant factor X_1 has the least effect on the property X_3. In the given case the reinforcing fiber is also inert as there are no after-effects of its use observed.

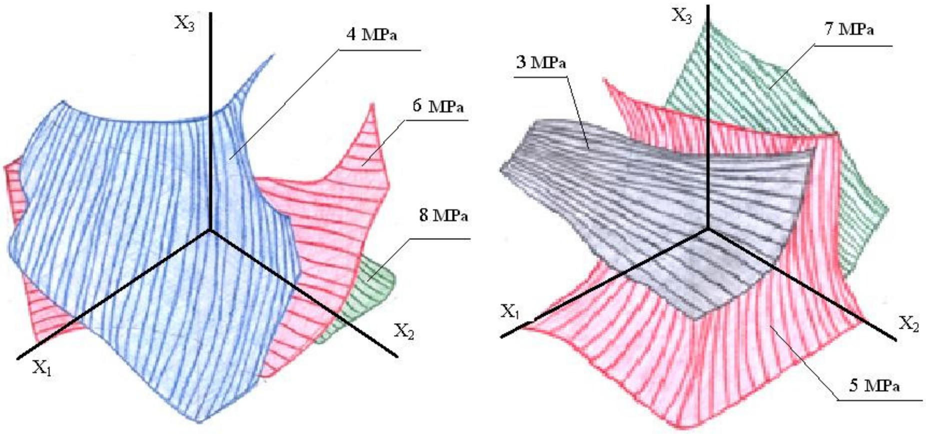


Fig. 6 Isosurfaces of ultimate strength under compression
a –gypsum-chalk system; b – gypsum-limestone system

When the content of setting regulator and water-repellent agent is max the strength reaches its min values, less than 2MPa. When the content of the additives is minimum (a little less than in the gypsum-chalk system) the strength is more than 8MPa. Optimal content of citric acid is 0.5 %.

One of the urgent problems in construction is the appearing of wet stains on finishing materials that is caused by moisture movement as the result of its capillary inflow. The addition of powder water-repellent agents (fatty acid salts) is the most progressive method to minimize them. From the analysis made we chose zinc stearate. Water saturation at capillary inflow was performed by normative technique and was calculated by the formula:

$$W\kappa n = Kw \cdot \frac{m_2 - m_1}{S} \quad (1)$$

Where

m_1 – mass of the dry sample, kg;

m_2 – sample's mass after water saturation, kg;

S – square of the wetted edge of the sample, m^2;

K_w – coefficient taking into account the time of the sample's water saturation and equal to $1/\sqrt{24}$, $h^{-0.5}$.

Isosurfaces of capillary inflow of moisture along with complex modification are shown in Fig.7. The gypsum-chalk system is characterized by greater values of capillary inflow of moisture in comparison with the gypsum-limestone system. This is due to inner structural features of chalk and limestone. While adding 1% of zinc stearate we observe minimum value of the studied characteristic which accounts less than 0.3 $kg/m^2 \cdot h^{0.5}$ for the gypsum-limestone system and less than 2 $kg/m^2 \cdot h^{0.5}$ for the gypsum-chalk system. In the gypsum-limestone system the capillary inflow of moisture decreases most when zinc stearate is added in the amount of up to 0.5 %. If the amount of the water-repellent agent in the gypsum-chalk system is max the water-repellent agent works most active.

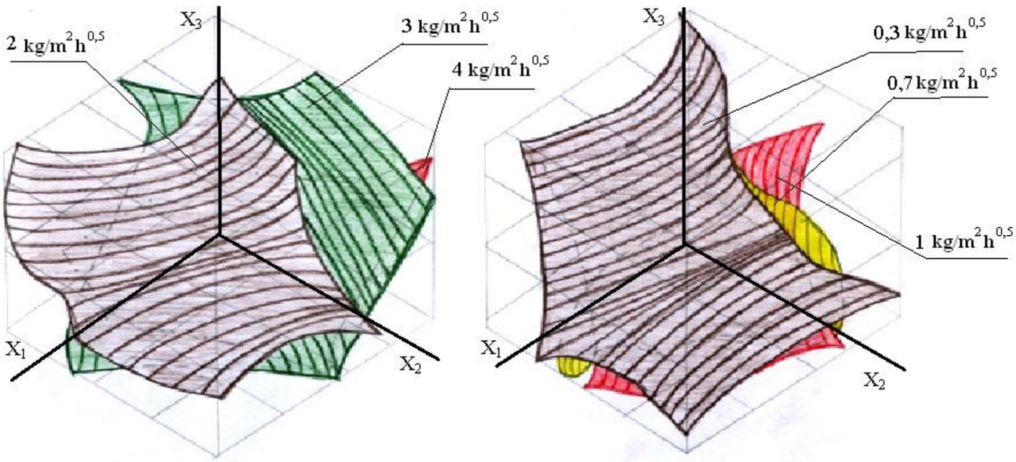


Fig. 7. Isosurfaces of capillary inflow of moisture
a –gypsum-chalk system; b – gypsum-limestone system

Optimum content of the complex additive according to the value of the capillary inflow of moisture is 1% for the gypsum-chalk mix and 0.5% for the gypsum-limestone mix.

The other hydro-physical characteristic that is important for finishing coverings is the saturation at moisture adsorption [19-21]. This value was estimated by changing the mass of samples kept in the desiccant over water. Isosurfaces of saturation at moisture adsorption are shown in Fig.8. As with the capillary inflow the gypsum-chalk system has better hydroscopic property than the system gypsum-limestone. Factor X_1 affects the water adsorption value. When the gypsum-chalk system contains max 1% of Factor X_1, the moisture adsorption value decreases to 0.5%. For the gypsum-limestone system the amount of zinc stearate enough for providing the decrease in hydroscopic property is 0.5 %.

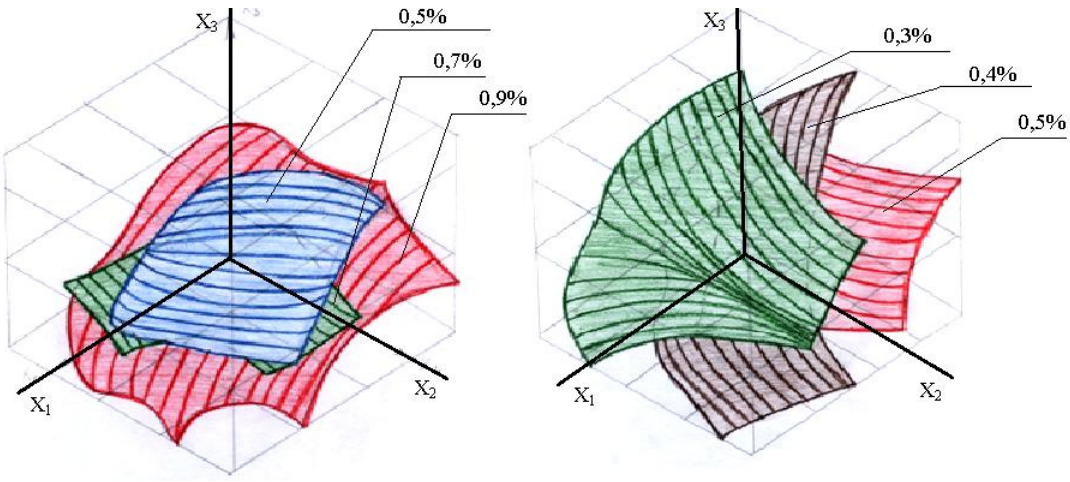


Fig. 8. Isosurfaces of saturation at moisture adsorption
a –gypsum-chalk system; b – gypsum-limestone system

Thus, the result values of saturation at moisture adsorption and the result values at capillary inflow correlate. So in order to achieve an optimum it is necessary to add 1% of the water-repellent agent in the gypsum-chalk system and 0.5 % of the water-repellent agent in the gypsum-limestone system.

The crack-resistant properties were examined with the techniques of «Clariant» company using 'needle-test'. The results showed that optimum amount of fibers in both systems is 0.1%. The recommended thickness of the covering is 2-6 mm. Within this interval there are no visible cracks.

Taking into consideration the made research, optimum proportions of the mineral components were found. The proportions of effective construction chemicals were estimated. Two compositions of dry gypsum- based construction mixes are advised to be used, see Table 3.

Table 3. Composition of the developed dry gypsum- based construction mixes

Component content, %					
Gypsum	Chalk	Limestone	Water-repellent agent	Setting regulator	Fiber
64	34.65	-	1.0	0.25	0.1
64	-	34.9	0.5	0.5	0.1

3. Conclusion

1. The research was made on the compositions of dry gypsum- bearing construction mixes with mineral additives (fillers) and modifying additives of different functional purpose. Local raw materials (chalk, limestone, magnesite, burnt clay, serpentinite, sand, marshallit) and industrial wastes (water softening sludge of CHP, glass reinforced epoxy slag) were used as mineral additives.
2. The effect of different fillers on rheological, physical, mechanical and structural indexes, the effect of setting regulator (citric acid), water-repellent agent (zinc stearate) and reinforcing fiber (hard fiber Technocel 500-1) on the technical construction properties of the system were estimated.
3. There have been developed gypsum-filled compositions of dry construction mixes with better water-repellent properties based on local raw materials. The use of such compositions will have economic benefits as some part of gypsum can be substituted for local mineral filler and the operating life can be longer because of structure's optimization.

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