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Cement and Gypsum Concretes with Construction Aggregates and Industrial Wastes

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Abstract

Compositions of cement and gypsum concretes with aggregates from solid construction and industrial wastes have been developed. The most common building waste is shards of ceramics and inorganic glass.

Phosphogypsum is one of the many-tonnage industrial wastes of the chemical industry in the Tambov region. Complex studies of various compositions of concrete have been conducted. Optimum concentrations and sizes of aggregate grains have been found. Their main operational properties and the mechanism of deformation and fracture under load have been studied. A method for forecasting mechanical durability and deformation in operating conditions has been proposed. An example for enclosing hinged concrete slabs has been considered.

Keywords

Concrete; inorganic glass waste; asbestos-cement waste; expanded clay waste; phosphogypsum; climatic effects; mechanical durability; deformability.

Introduction

Utilization of industrial wastes is one of the main problems of modern building materials science. Located in dumps debris is often suitable for reuse as active or passive additives to new composite materials. Of all types of industrial waste the most used and studied are metallurgical slags and ash [1, 2].

Back in his days, V.I. Vernadsky wisely noted that human economic activities could lead to a global catastrophe. It seems that his prophetic statement is coming true. This is evidenced by the problem of waste as its amount grows 3–4 times faster than the population. Every year, each person consumes at least 20 tons of natural resources, while only 2 % is used for the production of goods. The remaining 98 % immediately goes to waste. After a while, these two percent also becomes waste. Clothes and shoes wear out. The equipment breaks down. Therefore, humanity does not produce anything except waste.

The issues of utilization of construction waste are in the center of attention, which is explained, first of all, by the shortage of raw materials and their rise in price [3]. At the same time, construction waste in its composition has components suitable for preparing building materials for various purposes. The most common construction waste is the shards of ceramics (brick, tiles, pipes), inorganic glass, expanded clay waste, asbestos-cement products (slate, pipes), cement-chipboards, chipboards, polymer products (paneling, sanitary-engineering parts), etc.

Especially urgent is the problem of utilization of asbestos-cement waste (**ACW**), waste of cement bonded particle board (**CBPB**) and pressed wood-fiber board (**PWFB**), thermosetting polymer materials, since with its solution the pollution of the environment will be reduced.

According to the data of the asbestos-cement industry, the amount of dry waste (faulty products and asbestos-cement shards, cuttings, chips from turning of pipes, dust from cutting and polishing sheets) is 2.6–4 % of the mass of products [3]. The volume of wet waste, which is the sewage sludge, in terms of dry matter reaches 1.5–2 % of the mass of the raw material. This means that it is necessary to reconsider the methods of waste management.

Phosphogypsum is one of the many-tonnage wastes of the chemical industry of the Tambov region. It results from the production of phosphoric acid from apatite or phosphorite concentrates (ores). The production of one ton of phosphoric acid results in 4.5–5.5 tons of phosphogypsum, and its utilization is negligible. Accumulated reserves of wastes in Russia exceeded 200 million tons, annually they increase by more than 10 million tons [4].

In the world, including in Russia, a great deal of studies of the properties of phosphogypsum, its processing technologies and possibilities of its use in the national economy has been carried out. The level of use of phosphogypsum in the past years has reached about 2.5 million tons per year, which is equal to more than 10 % of the annual output [4]. However, currently, because of the high cost of energy, transport, reduction in construction, consumption of phosphogypsum has decreased to almost 0.5 %. In the Tambov region, the phosphogypsum dumps of JSC "Uvarovo Chemical Plant" (Uvarovo) occupy an area of more than 7 km^2.

All these types of construction waste can be used as aggregates in cement and gypsum concretes.

In this paper, we proposed and investigated the compositions of cement concretes with glass, asbestos-cement and phosphogypsum wastes, and gypsum concretes with asbestos-cement and expanded clay waste.

Methods and materials

Samples for testing were prepared according to the following technology. As a binder we used Portland cement grade M400; building gypsum grade G-4; coarse-grained sand; water for mixing concrete mix according to GOST 23732–79; filler in the form of inorganic glass shards and waste of asbestos-cement sheets and pipes, expanded clay dust or crumbs. Crushed glass and asbestos-cement shards were separated into fractions on the screening machine using a standard set of screens (from 0.16 to 40 mm). Stacking and compacting of the concrete mix was carried out immediately after the mixing process was completed.

Samples were produced in three types:

– in the form of cubes with dimensions $100 \times 100 \times 100$ mm for testing for central compression;

– in the form of prisms with dimensions $40 \times 40 \times 160$ mm and $20 \times 20 \times 100$ mm for tests on transverse bending, and after their destruction they were cut into cubes with a rib size of 40 and 20 mm for testing for central compression.

Mechanical tests were carried out on multi-station laboratory stands [5] and on the IP-500 press. All the experimental data obtained were subjected to static processing in the "Excel 2007" program in accordance with GOST 14359–69.

Constant elevated temperatures were created using special attachable heat chambers [5].

The influence of the grain composition of aggregates from inorganic glass shards on the strength characteristics of cement-sand concrete was studied under various types of loading [6] (Fig. 1).

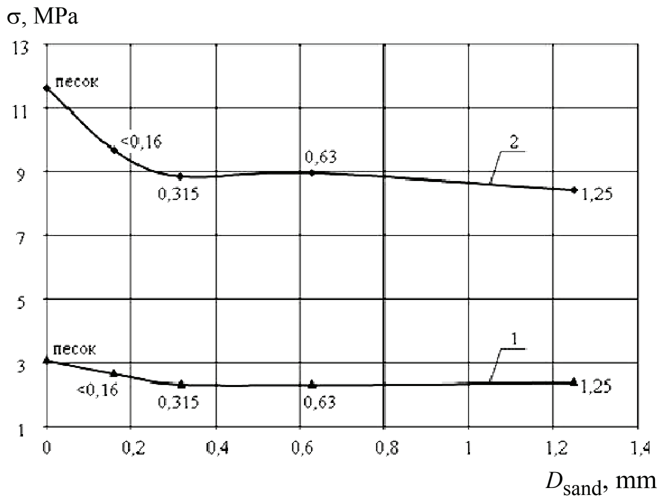

Fig. 1. The effect of the grain composition of crushed glass on the strength of concrete with water-cement ratio = 0.5, cement-sand ratio = 1:3.5:
1 – transverse bending; *2* – central compression

As can be seen from Fig. 1, the smaller the size of the aggregate is, the stronger the concrete is. Samples with sand were stronger than samples with glass. When the sand aggregate was completely replaced with crushed glass waste of various grain size, the strength characteristics of concrete were significantly reduced. However, when 33 and 67 % of crushed glass were added to the composition of concrete from the mass of aggregate with grain sizes < 0.16; 0.315; 0.63 and 1.25, the concrete became more durable than samples with the sand only (Fig. 2). This, apparently, was due to the physical interaction of the surface of grains of crushed glass and sand; another reason is the fact that the shape of the grains is very close to cubic, thus, causing a decrease in its voidness and a decrease in cement consumption [7, 8].

Aggregates from wastes of asbestos-cement materials with continuous grain composition were added to concrete cement with a different percentage of the following fractions:

– Fraction 1 – shards of corrugated asbestos-cement sheets, grain size ≤ 5 mm;

– Fraction 2 – shards of corrugated asbestos-cement sheets, grain size 10–20 mm;

– Fraction 3 – shards of corrugated asbestos-cement sheets, grain size 20–40 mm;

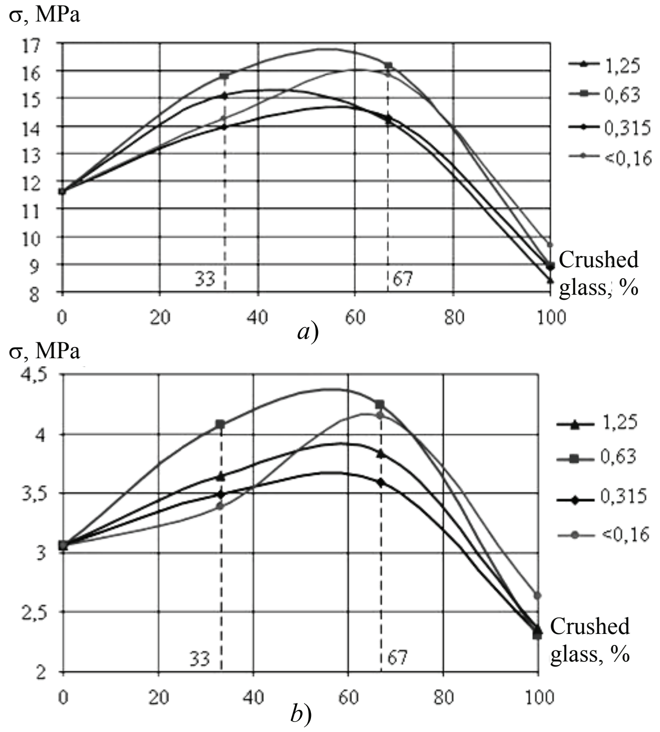

Fig. 2. The dependence of strength on the % of glass content in concrete with water-cement ratio = 0.5, cement-sand ratio = 1:3.5:
a – central compression; *b* – transverse bending

– Fraction 4 – fragments of asbestos-cement pipes, grain size 20–40 m.

Fig. 3 shows the dependence of the strength of concrete in transverse bending on the time of hardening. Fig. 4 shows the dependence of the strength of concrete upon compression on the amount of aggregates in it. In concrete M100, as in the case with crushed glass aggregates, the sand was partially replaced with ground dry asbestos cement waste (**DACW**). To construct the dependence, samples of fraction 1 were tested with the content of DACW of 0, 33, 66, 100 % by weight; fractions 2–4 were tested with the content of DACW of 0, 20, 40, 60 %. The compressive strength reached a maximum value by adding 30–40 % of the filler. After exceeding this value, the strength dropped sharply because the cement binder ceased to provide a complete cohesion of the aggregate grains [9].

As can be seen from Fig. 4, the strength of concrete increased by 1.5 times with the addition of various fractions to it. The strength in transverse bending increased with decreasing size of the filler particles.

To increase the concrete strength, liquid active additives – polyvinyl acetate and sodium silicate in an amount of 10% by weight were added to the concrete. Grain composition of the asbestos-cement aggregate with the size modulus was 4.11.

Fig. 5 shows the dependences of strength in compression and transverse bending of samples with 33 % percentage of DACW and 10 % of PVAC content and liquid glass. As can be seen from Fig. 5, adding of 10 % polyvinyl acetate substantially increased the mechanical characteristics of the concrete. The material became more "plastic", the compressive strength and the deflection from the transverse load increased. The introduction of sodium silicate, on the contrary, had a negative effect on the physical-mechanical characteristics of the composite. This was because the required amount of water for the concrete mix significantly increased. As a result, the porosity and heterogeneity of the material increased.

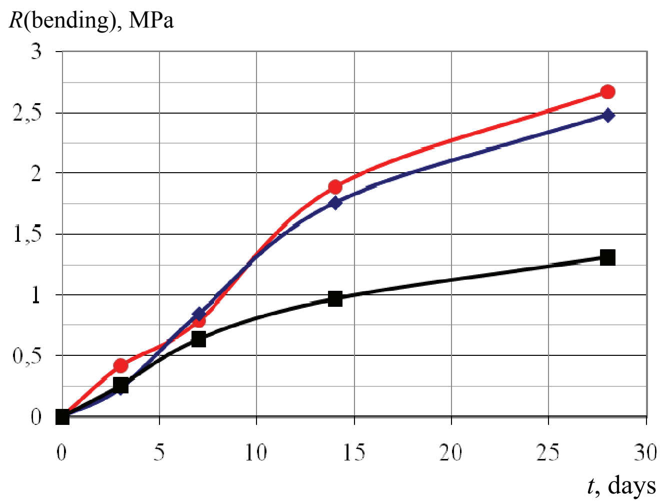

Fig. 3. Dependence of the concrete strength in transverse bending on the time of hardening of samples:
– Fraction 1; – Fraction 2;
– Cement/Sand

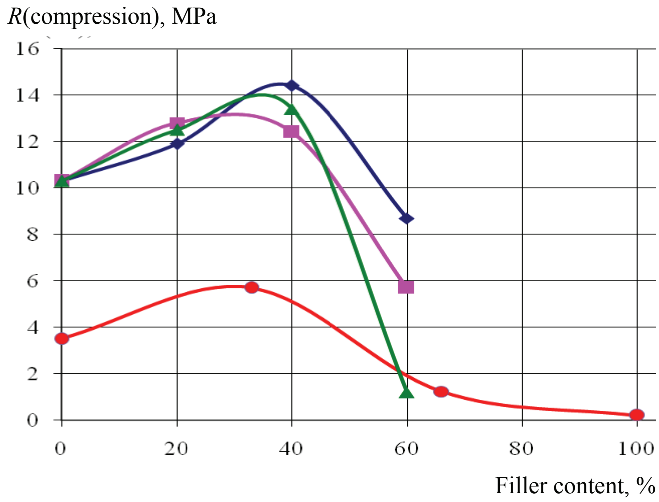

Fig. 4. Dependence of strength of concrete on the DACW content:
– Fraction 1; – Fraction 2;
– Fraction 3; – Fraction 4

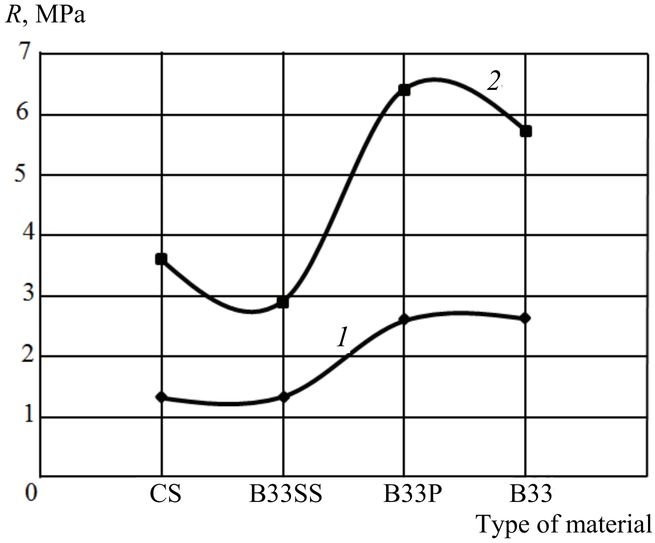

Fig. 5. Dependence of strength in bending (*1*) and compression (*2*) on the type of additive, where CS is samples of cement-sand mortar 1: 4; B33 – concretes with 33 % of DACW; B33SS - concretes with 33 % of DACW and 10 % of sodium silicate; B33P – concretes with 33 % of DACW and 10 % of PVAC

In samples of gypsum concrete using asbestos-cement waste materials, slate shards with the size of the fraction 5–10 mm were added.

Based on the results of tests for compression and transverse bending, the strength dependences on the DACW content were constructed (Fig. 6).

As can be seen from Fig. 6, the dependence of strength on the content of DACW is extreme. Its maximum was reached by adding 20 % of DACW by weight.

To study the effect of expanded clay waste on the strength characteristics of gypsum concrete, expanded clay crumb of particle sizes from 0.63 to 10 mm in the amount of 25, 50 and 75 % by weight of DACW was added to the initial mixture with 20 % of DACW.

Fig. 7 shows the experimental results. As can be seen from Fig. 7, the introduction of expanded clay granules of 0.63 mm fraction leads to an increase in strength with a maximum content of 75 % of the weight of DACW. Fraction of 2.5 mm leads to an increase in strength with a content of 50 and 75 %. Fraction of 5 mm increases the strength of concrete at a content of 25 and 50 %. With a content of 25 % and 50 % of the 10 mm fraction, the strength also increases. The content of 70 % of 10 mm and 5mm fractions, as well as 25 % of fractions of 0.63 and 2.5 mm, leads to a decrease in strength.

Thus, the increase in strength with the introduction of fine fractions occurs at their maximum content. For large fractions, the strength increases with the introduction of a minimum number of them. This is due to the fact that the introduction of a large amount of expanded clay granulate fraction of 5mm and 10mm causes lack of binder to coat the aggregate [10]. With a content of 75 % of the fraction of 0.63 mm, the expanded clay fills the spaces between the larger aggregate – DACW, which leads to an increase in strength because of a good contact of the aggregate with the binder and a large surface of expanded clay.

To study the effect of phosphogypsum on the strength of fine-grained concrete, several compositions with different percentages of components by mass were studied: Cement (C): Sand (S): Phosphogypsum (PG). Since the task of ongoing research is the utilization of phosphogypsum, it is necessary that the mixture contain at least 50 % of it [11].

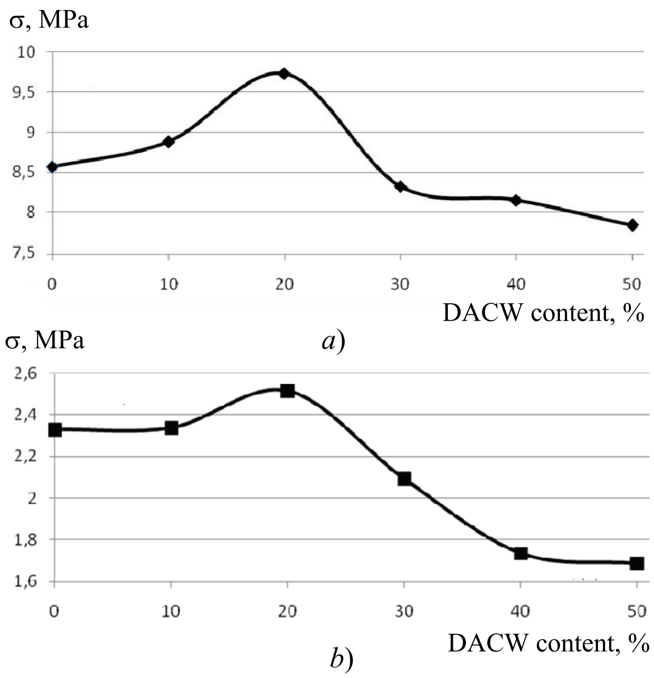

Fig. 6. Dependence of gypsum concrete strength on the DACW content under compression (*a*), transverse bending (*b*)

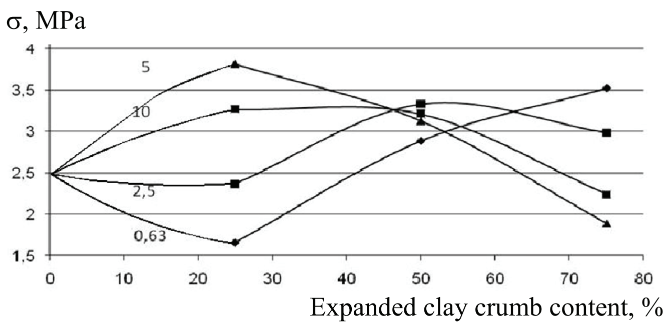

Fig. 7. Dependence of the strength at transverse bending of gypsum concrete on the percentage of expanded clay for various fractions

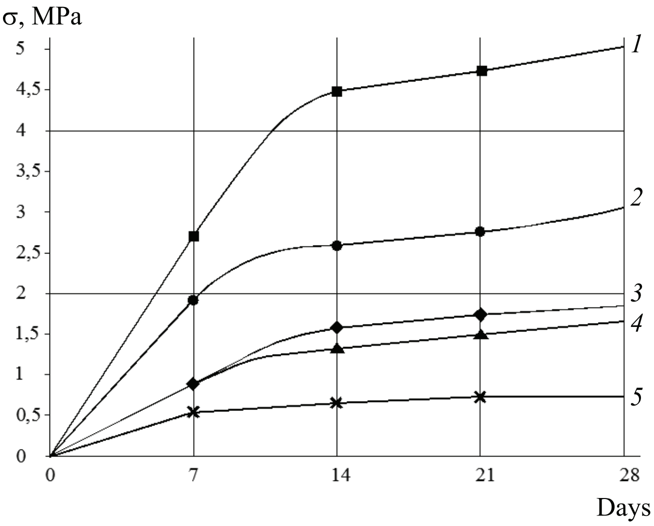

Fig. 8. Dependence of the strength in transverse bending on the time of hardening of fine-grained concrete with aggregates of phosphogypsum and sand:
1 – C50-S50; *2* – C50-PG50; *3* – C25-S-25-PG50; *4* – C25-S75; *5* – C9-PG91

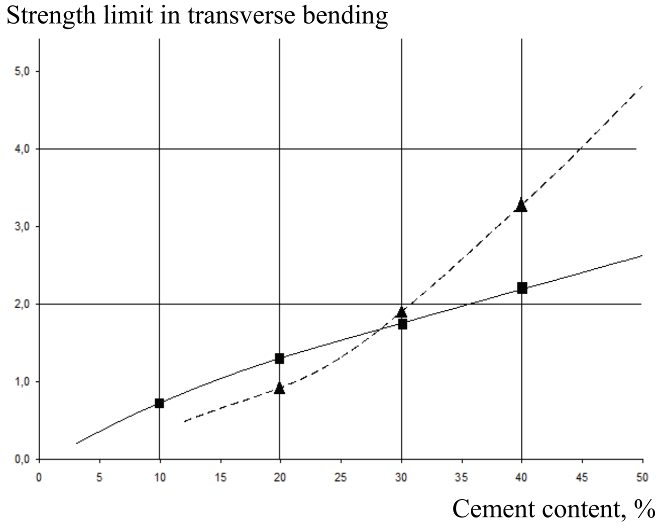

Fig. 9. Dependence of strength in transverse bending of concrete samples with aggregates of phosphogypsum and sand from the cement content (% by mass) at the age of 14 days:
——— – Cement-Phosphogypsum;
- - - – Cement-Sand

The tests were carried out on the 7th, 14th, 21th, and 28th day of hardening the samples. The value of the tensile strength was taken from the average test result of three or five samples. Portland cement M400 was used as a binder.

It was found that introduction of up to 3 % of cement into the system did not improve the strength of the samples. The presence of more than 3 % of cement led to hardening of the system, in which phosphogypsum plays the role of aggregate. Fig. 8 shows the dependence of the strength in transverse bending on the time of hardening of various compositions of fine-grained concretes with aggregates of phosphogypsum and sand.

According to the test results, it was found that when the cement content in the system was up to 25–32 %, the strength of the samples with phosphogypsum aggregate was higher than that with the aggregate from sand of the same grain composition (Fig. 9).

Since phosphogypsum consists of fine particles of less than 0.016 mm in size, the aggregate for fine-grained concrete can be composed of particles of phosphogypsum and larger particles of sand, that is, the fine sand fractions can be replaced with phosphogypsum.

According to the results of short-term mechanical tests, it can be concluded that phosphogypsum in combination with sand can be used as an aggregate for fine-grained concretes, with a content of up to 30 % more optimal in this case.

In operation concrete is under sustained action of climatic factors. Therefore, the greatest interest is the study of their effect on the operational properties of concrete. For this, the samples were subjected to repeated freezing-thawing [12]. The dependence of the strength on the number of freeze-thaw cycles was found (Fig. 10).

As can be seen from Fig. 10 the strength of concrete after 200 freeze-thaw cycles fell by 15–20 %, which corresponded to 10 years of operation under direct atmospheric influence for the central black-earth region of Russia.

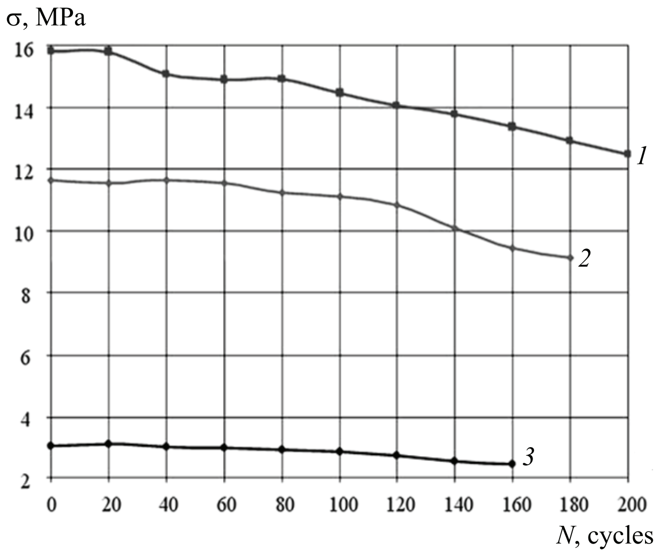

Fig. 10. Dependence of the strength of cement concrete on the number of "freeze-thaw" cycles:
1 – *W*/*C*=0.5, *C*/*S*=1:3.5; 33 % of crushed glass with particle size of 0.63 mm (central compression);
2 – *W*/*C*=0.5; *C*/*S*=1:3.5 (central compression);
3 – *W*/*C*=0.5; *C*/*S*=1:3.5 (transverse bending)

Results and discussion

When exposed to elevated temperatures, the concrete dimensions changed, causing significant thermal stresses in the material. In this connection, it becomes necessary to study the behavior of the material in the free state when heated at a given rate.

The investigations were carried out in a linear dilatometer on concrete samples at a given constant heating rate of 2.8 °C/min [5]. The results are shown in Fig. 11. Dependencies are exponential.

From the obtained curves, the coefficients of linear thermal expansion were found

$$\alpha = \frac{1}{l_0}\frac{\Delta l}{\Delta T}, \qquad (1)$$

where α is coefficient of linear thermal expansion, 1 °C; l_0 is initial length of the sample, mm; Δl is elongation of the sample (mm) with a change in temperature by ΔT, °C.

Since the dependencies are not rectilinear, they are divided into linear sections [5]. For each section a coefficient of linear thermal expansion is found. Then a_{mid} is determined by the formula:

$$\alpha_{\text{mid}} = \frac{\alpha_1 \Delta T_1 + \cdots + \alpha_n \Delta T_n}{\Delta T_1 + \cdots + \Delta T_n}. \qquad (2)$$

Table 1 shows the coefficients of thermal expansion for concrete of various compositions.

Studies of water absorption of DACW by weight W_m have been carried out (Fig. 12).

As can be seen from Fig. 12 the maximum water absorption is observed in the material B33S (33 % DACW + 10 % sodium silicate). This confirms the high porosity of this material. In contrast, materials with a high surface density and, accordingly, less porosity, have a minimum water absorption (B33P, PG2).

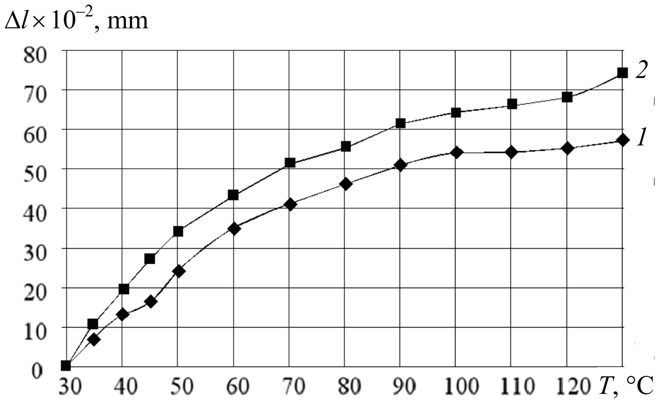

Fig. 11. Dilatometric curves of concrete at a heating rate of 2.8 °C/min:
1 – $W/C = 0.5$; $C/S = 1:3.5$; *2* – $W/C = 0.5$; $C/S = 1:3.5$; 33 % of crushed glass with a particle size of 0.63 mm

Table 1

The values of thermal expansion coefficient for concrete of various composition

Concrete composition	$\alpha \cdot 10^{-4}$, °C^{-1}
$W/C = 0.5$; $C/S = 1:3.5$	14.3
$W/C = 0.5$; $C/S = 1:3.5$; 33 % of crushed glass with a particle size of 0.63 mm	18.5

Concretes with dry asbestos-cement aggregate compositions B33, B33SS, B33P, CS and PG2 (fraction of 10–20 mm) were subjected to 40 freeze-thaw cycles. The results of measuring the compressive strength are summarized in Table 2.

Frost resistance of the material is directly related to its water absorption, thus the materials with the highest water absorption withstood the least number of “freeze-thaw” cycles. The greatest degree of frost resistance was shown in materials B33 and B33P, therefore further studies were carried out with these materials. B33SS was not studied due to the irrationality of additional studies.

The results of the study of the effect of UV irradiation on the strength parameters of gypsum concrete with the addition of DACW are shown in Fig. 13.

As can be seen from Fig. 13, the dependence was extreme and reached its peak at 120 hours of ultraviolet exposure. Then there was a slight decrease in strength. The influence of ultraviolet rays, obviously, served as a catalyst for processes leading to an increase in strength. However, at the same time, the aging process was taking place. Accumulation of irreversible changes above a certain concentration led to a decrease in strength [13].

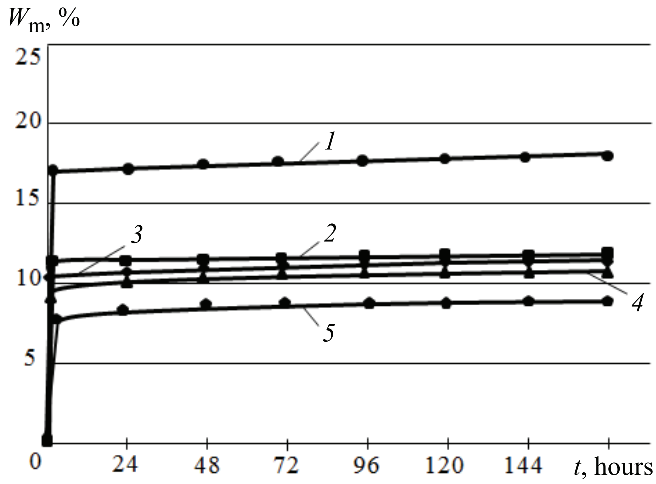

Fig. 12. Dependence of water absorption of the material by weight on the time of soaking of concrete:
1 – CS, *2* – B33, *3* – B33P; *4* – Б33SS; *5* – PG 2

Table 2

Frost resistance results

Name of material	The number of "freeze-thaw" cycles	Reduction in compressive strength, %	Decrease in mass of material, %	Frost resistance brand by GOST 10060.0–95
Fraction 2	25	19.8	4.21	F25
CS	25	19.4	2.56	F20
B33	30	20	3.12	F30
B33P	40	22.3	2.75	F40
B33SS	15	22.4	3.15	F15

With thermal aging, irreversible changes in the gypsum matrix lead to a decrease in strength [13]. A noticeable decrease in strength begins after 80 hours of aging.

To study the mechanical durability of the composites under consideration, a thermofluctuation concept of fracture and deformation was used [14].

The patterns of fracture and deformation of fine-grained concretes were investigated under different types of loading (transverse bending, compression) in a wide range of constant stresses and temperatures.

The experimental results were processed in the coordinates of the time to failure τ from the stresses σ (lgτ – σ) at specified constant temperatures T.

The obtained dependences for all the studied concrete are families of fan-shaped straight lines (an example is shown in Fig. 15) and described by equation:

$$\tau = \tau_m \exp\left[\frac{U_0 - \gamma\sigma}{R}\left(T^{-1} - T_m^{-1}\right)\right], \quad (3)$$

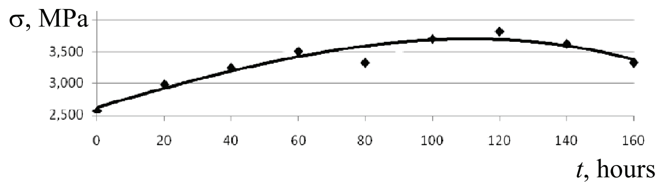

Fig. 13. Dependence of gypsum concrete strength on the time of exposure to UV irradiation

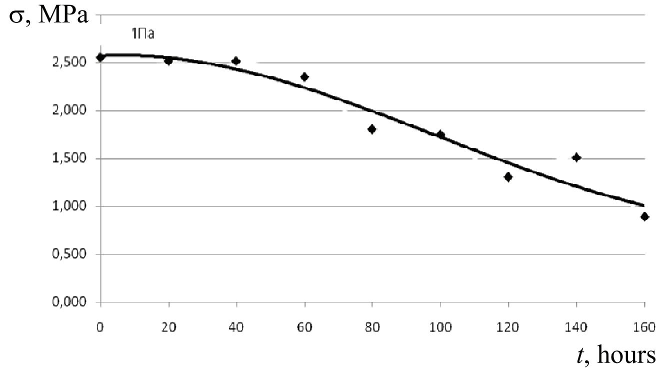

Fig. 14. Dependence of strength of gypsum concrete on the time of exposure to elevated temperatures

where τ_m, U_0, γ, T_m are physical constants: τ_m is minimum durability; U_0 is maximum activation energy of destruction; γ is structural-mechanical constant; T_m is Limiting temperature of the existence of a solid body; R is universal gas constant.

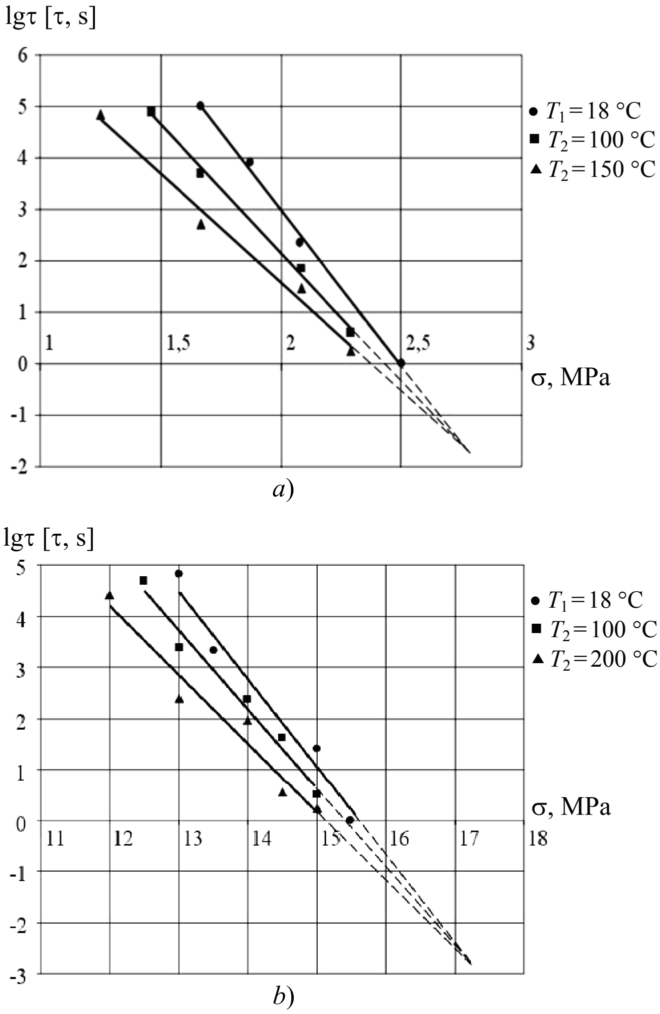

Fig. 15. Dependence of time to failure on the stress of fine-grained concrete:
a – transverse bending, *W*/*C*=0.5, C:S = 1:3.5;
b – central compression, *W*/*C* = 0.5, *C*:*S* = 1:3.5, 33 % of crushed glass with particle size of 0.63 mm

The obtained dependences were reconstructed into coordinates $\lg\tau - 10^3/T$. Graphical-analytical method for the Konstanta program was used to find the physical constants for all concretes. The values of physical constants are in Table 3.

By substituting the constants in formula (3), we can calculate the durability of concrete during compression and transverse bending in a wide range of basic operational parameters – temperatures and loads [15].

Boards from DACW can be used as facing panels on a metal frame, attached to the exterior walls of buildings. Approximate geometric dimensions of these panels can be taken as $600 \times 600 \times 20$ mm. The main effect in forming a transverse bend from the plane of the panel is the wind load.

The normative value of the average component of the wind load w_m at a height z above the ground surface can be found by the formula

$$w_m = w_0 kc, \quad (4)$$

where w_0 is the normative value of wind pressure, for the II wind area equal to 0.3 kPa; k is coefficient reflecting the change in pressure adjustment to terrain type "A" at 10-meter height equal to 1.0; c is aerodynamic coefficient, for the windward side equal to $+0.8$.

Hence, the wind load on the panel is

$$w_m = 0.3 \cdot 1 \cdot 0.8 = 0.24 \text{ kPa}.$$

We find the stress acting in the plate by the formula:

$$\sigma = \frac{3}{2}\frac{w_m l^2}{t^2} = \frac{3}{2}\frac{0.24 \cdot 0.6^2}{0.02^2} = 0.324 \text{ MPa}.$$

With this load and a temperature of $+5$ °C, which corresponds to the annual average for Tambov, the operation time is:

– for B33 – 5.8 years;
– for B33P – 62.5 years.

Products from concrete are subject to deformation. Therefore, there is a need to study the mechanism of concrete deformation during prolonged compression.

Samples were made in the form of cubes with dimensions of $20 \times 20 \times 20$ mm. The tests were carried out in the regime of preset constant stresses and temperatures (in the range from 18 to 200 °C) according to the following procedure. Samples were matured on a test bench at a given temperature in a surface-mounted thermal chamber for an hour (thermostated) and then loaded to a certain value. To perform experiments at elevated temperatures, a ring furnace was used and its voltage was regulated by a laboratory transformer with an accuracy of ± 10 °C. The strain of the sample in time was measured with a dial gauge (IC 10) with an accuracy of 0.01 mm. In the same conditions, 5–6 samples were tested to obtain a single point. The final result was taken as their arithmetic mean.

With prolonged compression at certain intervals of time, the deformation of the sample was recorded. The tests were carried out at constant temperatures and loads. By results, the kinetic curves (Fig. 16) were constructed, which are described by an equation of the Arrhenius type [16]:

$$V = V_{m(d)} \exp\left[-\frac{U_{0(d)} - \gamma_{(d)}\sigma}{RT}\left(1 - \frac{T}{T_{m(d)}}\right)\right], \quad (5)$$

where V is deformation rate, %/sec; $V_{m(d)}$ is ultimate material deformation rate; $U_{0(d)}$ is initial apparent activation energy; $\gamma_{(d)}$ is structural-mechanical factor; $T_{m(d)}$ is limiting temperature of material existence, σ is load on the sample, MPa; R is universal gas constant, kJ/(mol×K); T is temperature, K.

To determine the constants in equation (5) graphoanalytical differentiation was used [17]. From the kinetic curves, the dependence of the deformation

Table 3

The values of the physical constants of equation (3) for fine-grained concrete of various composition

Composition	Type of loading	U_0, KJ/mol	T_m, K	$\lg\tau_m$ [τ, s]	γ, KJ/(mol×MPa)
$W/C = 0.3$; $C/S = 1:3.5$	Central compression	53.2	3200	$10^{-0,2}$	6.01
$W/C = 0.5$; $C/S = 1:3.5$	Central compression	64.5	∞	$10^{-1,8}$	4.83
	Transverse bending	85.0	∞	$10^{-1,55}$	30
$W/C = 0,5$; $C/S = 1:3.5$; 33 % of crushed glass with particle size of 0.63 mm	Central compression	98.1	∞	$10^{-2,54}$	5.77

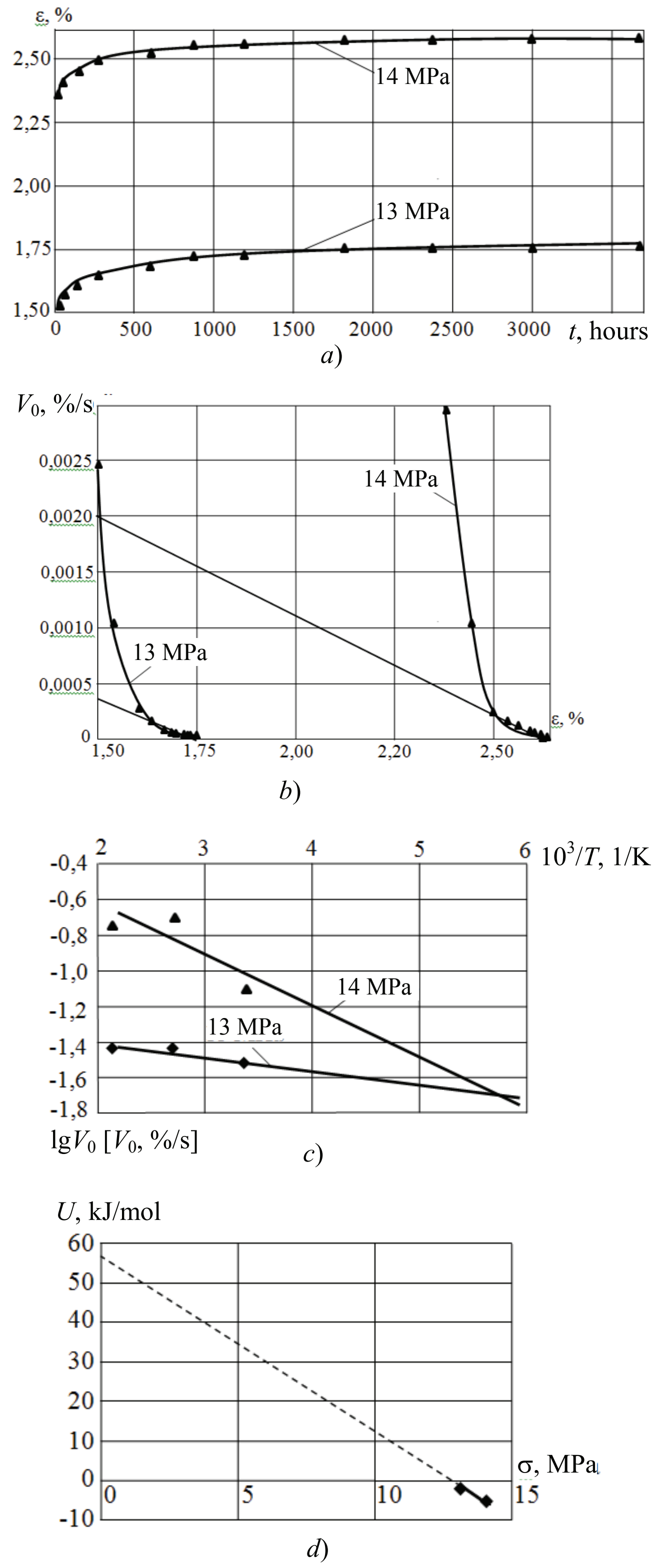

Fig. 16. Dependences:
a – relative deformation on the load action time at 100 C^o;
b – deformation rate on the relative deformation at 100 C^o;
c – logarithm of the deformation rate on the reciprocal temperature;
d – apparent activation energy of deformation from stresses;
– concrete under central compression
(W/C = 0.5, W/S = 1 : 3.5 and 33 % of crushed
glass with particle sizes of 0.63 mm)

Table 4

The values of empirical constants under central compression for fine-grained concrete

Composition	U_0, kJ/mol	T_m, K	lgV_m, %/c	γ, kJ/(mol×MPa)
W/C = 0.3; C/S = 1 : 3.5	−89.2	520.8	−2.70	−16.7
W/C = 0.3; C/S = 1 : 3.5	−60.0	266.7	−0.89	−5.9
W/C = 0.3; C/S = 1 : 3.5; 33 % of crushed glass with particle size of 0.63 mm	56.3	178.6	−1.65	−4.4

rate on the value of deformation was constructed (Fig. 16 *b*).

Further, by extrapolating the linear sections of the deformation rate curves to the ordinate axis, the initial apparent velocities V_0 were determined, the values of which were used to plot the logarithm of the initial velocity versus the inverse absolute temperature (Fig. 16 *c*).

The value of the apparent activation energy (Fig. 16 *c*) was determined by the formula

$$U = 2.3R\frac{\Delta\left(\lg v_0\right)}{\Delta\left(10^3/T\right)} \qquad (6)$$

and the dependence was plotted in coordinates $U-\sigma$ (Fig. 16 *d*), the extrapolation of which was used to determine U_0 on the ordinate axis, and by the tangent of the slope angle of this straight line the value γ was found.

To process the experimental results, the Graffdiffer program was also used.

The values of the empirical constants are given in Table 4.

Substituting their values in equation (5), we can calculate the rate of deformation of concrete.

Conclusions

The effect of glass waste on the mechanical properties of concrete has been studied. It is shown that the optimal composition is granules with a diameter of 0.63 mm, a concentration of 33 %.

Composite materials with the use of dry asbestos-cement waste as aggregates have been developed. The dependence of strength on the amount of aggregate has been studied. It has been revealed that compositions with a content of 20 % dry asbestos-cement waste by weight are optimal.

The effects of climatic factors (cycles of "freezing-thawing" and "soaking-drying") on the strength properties of concrete have been investigated. It is found that the strength of gypsum concrete is reduced by 20 % with 15 freeze-thaw cycles.

The influence of thermal and ultraviolet aging on the strength properties of concrete has been studied. It is found that UV exposure of gypsum-concrete causes processes leading to an increase in strength. The maximum effect is achieved with 120 hours of irradiation.

The influence of expanded clay and phosphogypsum on the strength characteristics of the material has been studied. The optimum compositions are 75 % expanded clay crumb of 0.63 mm fraction and 30 % phosphogypsum from the weight of DACW.

The regularities of destruction and deformation of concrete with various aggregates in a wide range of specified constant stresses and temperatures from the perspective of the kinetic (thermal fluctuation) concept of strength have been studied. Analytical dependencies related to the main parameters of working capacity – operating time, stress, temperature, and deformation rate have been found. The values of the physical and empirical constants of materials used in these dependences and determining these parameters have been obtained.

The possibility of predicting the performance of cement and gypsum concretes is shown using the main provisions of the thermal fluctuation concept of mechanical behavior of solids.

References

1. Bazhenov Ju.M., Shubekin P.F., Dvorkin L.I. *Primenenie promyshlennyh othodov v proizvodstve stroitel'nyh materialov* [Application of industrial waste in the production of building materials]. M.: Strojizdat, 1986

2. Pavlenko S.I. *Melkozernistye betony iz othodov promyshlennosti* [Fine-grained concrete from industrial wastes]. M.: izd-vo ASV, 1997, 176 p.

3. Dolgorev A.V., Koshman N.P., Dolgorev V.A. Tehnogennye othody – jenergeticheskie «zapasniki» kak osnovnoe kachestvennoe i dostupnoe syr'e dlja promyshlennosti stroitel'nyh materialov [Technogenic waste – energy "storage" as high-quality and affordable raw materials for building materials]. *Materialy III Vserossijskogo seminara s mezhdunar. uchastiem "Povyshenie jeffektivnosti proizvodstva i primenenija gipsovyh materialov i izdelij"* (edited by Ferronskaya A.V.). M.: Izdatel'stvo Alvian, 2006, pp. 263-268.

4. Tarasov A.S., Chistov Ju.D. Fosfogipsovaja kompozicija i betony na jojo osnove [Phosphogypsum composition and concretes based on it.] *Ctroitel'nye materialy, oborudovanie, tehnologii HHI veka* [Building materials, equipment, technologies of the XXI century]. Vol. 5, 2004, p. 68.

5. Yartsev V.P. *Prognozirovanie rabotosposobnosti polimernyh materialov v detaljah i konstrukcijah zdanij i sooruzhenij. Uchebnoe posobie* [Forecasting the efficiency of polymer materials in the details and structures of buildings and structures. Tutorial]. Tambov: izd-vo Tamb. gos. tehn. un-ta, Rekomendovano UMO RF, 2001, 149 p.

6. Il'in V.O., Yartsev V.P. Vlijanie stekljannogo napolnitelja na prochnost' i dolgovechnost' melkozernistogo betona [Effect of glass filler on the strength and durability of fine-grained concrete]. *V–aja Mezhdunarodnaja nauch.-prakt. Internet-konferencija "Sostojanie sovremennoj stroitel'noj nauki – 2007"* [5th International Scientific-Practical Internet conference "The state of modern building science – 2007"]. Poltava, 2007. Available from: www.ipl.poltava.ua.

7. Ryb'ev I.A. *Stroitel'noe materialovedenie* [Building Material Science]. M.: Vyssh. shk., 2003, 701 p.

8. Volzhenskij A.V., Burov Ju.S., Kolokol'nikov V.S. *Mineral'nye vjazhushhie veshhestva* [Mineral binders]. M.: Strojizdat, 1979, 476 p.

9. Volokitin G.G. et al. *Fiziko-himicheskie osnovy stroitel'nogo materialovedenija: Uchebnoe posobie* [Physical and chemical basis of building materials science: Textbook]. M.: Izdatel'stvo ASV, 2004, 192 p.

10. Mikul'skij V.G. et al *Stroitel'nye materialy* [Construction Materials]. M.: Izd-vo ASV, 1996, 488 p.

11. Sanickij M.A. et al. Modificirovannye kompozicionnye gipsovye vjazhushhie na osnove fosfogipsa [Modified compositional gypsum binders based on phosphogypsum]. *Materialy III Vserossijskogo seminara s mezhdunar. uchastiem "Povyshenie jeffektivnosti proizvodstva i primenenija gipsovyh materialov i izdelij".* [Proceedings of the 3rd All-Russian Seminar with Intern. participation "Increase in production efficiency and application of gypsum materials and products"]. (edited by Feronskaya A.V.). M.: Izdatel'stvo Alvian, 2006, pp. 139-144.

12. GOST 10060.0–95. Betony. Metody opredeleniya morozostoikosti. Obshchie trebovaniya [GOST 10060.0–95. Concretes. Methods for determining frost resistance. General requirements].

13. Ferronskaya A.V. Gipsovye materialy i izdelija (proizvodstvo i primenenie). Spravochnik [Gypsum materials and products (production and use). Reference book]. M.: Izdatel'stvo ASV, 2004, 488 p.

14. Ratner S.B. Yartsev V.P. *Fizicheskaja mehanika plastmass. Kak prognozirujut rabotosposobnost'?* [Physical mechanics of plastics. How to predict the performance?] M.: Himija, 1992, 320 p.

15. Il'in V.O., Yartsev V.P. Opredelenie dolgovechnosti melkozernistyh betonov pri central'nom szhatii [Determination of the durability of fine-grained concretes under central compression]. *Sb. materialov.VII Mezhdunar. nauch.–tehnich. konferencii "Aktual'nye problemy stroitel'stva i stroitel'noj industrii"* [Proceedings of 7th Intern. scientific-technical conference "Relevant problems of construction and construction industry Tula", 2006, pp. 53-54.

16. Madorskij S. Termicheskoe razlozhenie organicheskih polimerov [Thermal decomposition of organic polymers]. M.: Mir, 1967, 340 p.

17. Yartsev V.P., Sannikov D.A. Primenenie metoda grafoanaliticheskogo differencirovanija dlja opredelenija kojefficientov Arreniusa [The application of the method of graph-analytic differentiation for determining the Arrhenius coefficients]. *Trudy TGTU: Sbornik nauchnyh statej molodyh uchenyh i studentov* [Proceedings of TSTU: Collection of scientific articles of young scientists and students]. Tambov: Izd-vo Tamb. gos. tehn. un-ta, 2003, Issue 14, pp.22-25.