Strength and Deformability of Cement Composites of Various Types

I V Erofeeva¹, D V Emelyanov²*, D A Svetlov³, A A Matvievskiy⁴, I N Maksimova⁵ and N I Makridin⁶

¹Department of Engineering and Computer Graphics, National Research Ogarev Mordovia State University, 68 Bolshevistskaya St., Saransk 430005, Russia
²Department of Building Materials and Technologies, National Research Ogarev Mordovia State University, 68 Bolshevistskaya St., Saransk 430005, Russia
³Soft Protector LLC, 28 Himiko St., St. Petersburg 195030, Russia
⁴OJSC «MAKSMIR», 11 Novinsky Boulevard, Moscow 121099, Russia
⁵Department of Quality Management and Construction Production Technologies, Penza State University of Architecture and Construction, 28 German Titov St., Penza 440028, Russia
⁶Department of Technology of Building Materials and Woodworking, State University of Architecture and Construction, 28 German Titov St., Penza 440028, Russia

E-mail: emelyanoffdv@yandex.ru

Abstract. It is shown that the construction of buildings and structures requires concrete with universal characteristics, primarily with compressive strength in the range of 35-200 (MPa) with high tensile strength, crack resistance and durability. Strength and elastic-plastic and other properties of concretes and other cement composites are regulated by creating their various formulations. In this regard, it is important to conduct comprehensive studies of the properties of composites in relation to their compositions. Cement composites of various compounding compositions, including fillers, plasticizers, pigments, and biocidal preparations, are considered. Attention is also paid to the technological aspects of preparing mixtures and manufacturing products, namely, the influence of activated water on the properties of concretes of mixing and hardening conditions. Indicators of strength, modulus of elasticity, and brittleness were obtained for compositions that differed in the type of plasticizer ("Melflux 1641 F", "Melflux 5581 F", "Fortrace–strong", "Hidetal-P-5", "Hidetal GP-9" gamma "A"), a biocidal preparation (Teflex Antimould, Teflex Disinfectant, Teflex for Industrial sights), a pigment (iron oxide red, iron oxide yellow, green glauconito-vogo, meerkat iron). The influence on the properties of powder – activated concretes, rheologically active (rock flour), reactivity active (micro – silica), fillers, as well as quart sand fractions 0, 16 – 0.63 and 0.63-5.0 mm. The results of research showed an increase in the strength of concrete when using plasticizer "Melflux 1641F" and activated mixing water in the technology of their preparation. To increase the strength and modulus of elasticity led to the introduction of rock flour and silica. The introduction of plasticizers led to a decrease in the elastic modulus, and the use of activated closing water does not affect this indicator. From the examined compositions, compositions with the addition of pigments are characterized by increased fragility. The brittleness index of composites is mainly reduced when using the heat-and-water treatment mode compared to normal hardening modes.
1. Introduction
The production of building materials is one of the most important spheres of human deeds. In construction, one of the first places in terms of use among other materials is occupied by concrete and reinforced concrete. This is due to the advantages of reinforced concrete, such as relative cheapness, the ability to build structures of almost any shape, high strength, etc. [1-19].

The development of concrete is accompanied by the appearance of a large number of literature on the theory and practice of their production and application. It is very important to expand the use of new-generation concretes. Thus, high-strength and self-compacting concretes of a new generation have been developed to date. It is known that new-generation concretes, including powder-activated ones, have increased density and strength.

Powder-activated self-compacting sand concretes are formed with an increased content of dispersed and fine-grained components based on ground and fine-grained quartz Sands, which increase the content of water-dispersed water-dispersed-fine-grained suspension components [20-24]. Powder-activated concretes are a convenient matrix for producing various concretes, including fiber-reinforced concrete. They lack a large aggregate that “interferes” with the self-organized distribution and placement of fiber, as well as contributes to its accumulation between the grains of crushed stone [25-28]. Improvement in terms of improving the properties of powder-activated concrete is achieved in the works [29, 30] through the use of biocidal additives, plasticizers, pigments, etc.. In works [31, 32], the improvement of physical and technical properties of powder-activated concretes was found by using activated mixing water.

World construction experience shows that modern buildings and structures require concrete with universal characteristics, primarily with a compressive strength of 35-200 (MPa), with high tensile strength, bending, crack resistance, impact strength and long-term durability, especially in difficult operating conditions. Concretes and other cement composites have different indicators of ultimate deformability and therefore have different brittleness. Increased brittleness often leads to faster cracking and splitting. There are various methods for evaluating the fragility of concrete [33-38]. In our research, the brittleness of materials was evaluated as the ratio of the tensile strength at bending to the compressive strength.

To ensure the transfer strength of concrete at the age of 10-12 hours, the issue of achieving its high early strength is extremely relevant. It is known that the following methods of influence on the cement system contribute to increasing the strength of cement stone at an early stage of hardening: reducing the water-cement ratio due to water-reducing additives, introducing hardening accelerators and fine mineral fillers, and conducting heat-and-water treatment [39-43]. At the same time, it is also known that certain types of pigments affect the hardening time in an inhibitory way [1]. In this regard, this issue is also considered in the work.

2. Purpose
The purpose of the work was to study the strength and deformability of cement composites of various types.

The research objectives were:
1. Determination of the strength and modulus of elasticity of cement composites composed with the use of various fillers, pigments, plasticizers and biocidal preparations.
2. Determine the effect of the hardening conditions on the physical and mechanical properties of composites.
3. Determine the effect of prescription factors on the fragility of cement composites.

3. Materials and methods
The binding material used was Portland cement 500D0 (GOST 10178-85) produced by LLC "Ul'yansovstsement" with the following chemical composition, %: CaO – 62.24; SiO2 – 19.57; Al2O3 – 5.24; Fe2O3 – 2.41; SO3 – 3.09; MgO – 5.41; K2O – 0.389; Na2O – 0.334; TiO2 – 0.601; P2O5 – 0.040; SrO – 0.065; MnO – 0.341; ZnO – 0.177; Cr2O3 – 0.019. The mineralogical composition
includes, %: 3CaO•SiO$_2$ – 62,4; 2CaO•SiO$_2$-β – 13,3; 3CaO•Al$_2$O$_3$ (cub.) – 4,1; 3CaO•Al$_2$O$_3$ (ort.) – 2,5; 4CaO•Al$_2$O$_3$•Fe$_2$O$_3$ – 11,6; CaSO$_4$•0,5H$_2$O – 2,4; MgO – 3,7.

The following plasticizing additives were used.

Hyperplasticizer (HP) series "Melflux" – "Melflux 1641F" based on polycarboxylate esters (manufacturer-Degussa Constraction Polymers, SKW Trostberg, Germany), structure – grafted copolymers. They differ in that dispersion (deflocculation, destruction of agglomerates, plasticization) occurs according to the electrosteric principle.

Hyperplasticizer (HP) of the "Melflux" series – "Melflux 5581 F" based on polycarboxylate esters (Degussa Constraction Polymers, SKW Trostberg, Germany) by structure-grafted copolymers. They differ in that dispersion (deflocculation, destruction of agglomerates, plasticization) occurs according to the electrosteric principle (electrostatic repulsion + steric obstacle to the convergence of small particles). “Fortrais-Strong” superplasticizer (SP) is a superplasticizer (cone sediment from P1 to P5) and water – reducing additive for concrete and construction solutions. It is a modified naphthalene sulfonates.

Complex additive "Khidetal-P-5" – accelerator-superplasticizer-inhibitor, which is a mixture of inorganic salts of sodium and potassium, plasticizer and inhibitor. The additive has a plasticizing effect, accelerates hardening, and increases strength.

Complex additive-hyperplasticizer "Khidetal GP-9 "gamma" A "(manufacturer-LLC "UK GP SKT-Standard", Kolomna). A plasticizing additive of the latest generation of polycarboxylate compound. An important property of it in concrete is the long-term stability of the mobility of the concrete mix, which is especially important when transporting it in large cities and over long distances.

“Teflex” preparations were used as biocides. “Teflex” are preparations based on guanidine compounds. Used preparations for industrial use: "Teflex Antimould" (TC 23-86-003-23170704-99);" Teflex Disinfectant "(TC 9392-006-23170704-2004);" Teflex for industrial sights" (TC 23-86-003-23170704-99).

As pigments in the compositions used: "iron Oxide red", "iron Oxide yellow", "Green glauconite", "iron Meerkat".

Stone flour prepared during grinding in a laboratory ball mill was used as a rheologically active dispersed filler. For the preparation of stone flour, a microquart of the Lipetsk mining and processing plant (LMPP) was used, $S_{sp} = 3400$ cm$^2$/g.

As a reaction additive, condensed silica powdered Lipetsk with a specific surface area of 5500 m$^2$/g and a bulk density of 175 kg/m$^3$ was used.

As fine-grained fillers and sand-filler, quartz crushing screenings were used, dispersed into fractions of 0.16–0.63, 0.63–2.5 or 0.63–5.0 mm. The study used the Sands of the Smolny, quarry of the Ichalkovsky district of the RM and the Khramtsovsky quarry of the Ivanovo region.

Water activation was performed using the UPOVS2–5.0 «Maksmir» water system anti-boiling treatment unit [44]. Experimental studies were carried out according to the established modes of operation of the device. In total, three modes were used, the cipher of which is composed of alphanumeric notation. The modes used and their parameters are shown in table 1.

| Activation mode | Current density $j_{max}$, A / m$^2$ | Electro-magnetic field strength $H_{max}$, kA / m |
|----------------|----------------------------------|----------------------------------|
| M1            | 5,65                             | 24                               |
| M3            | 22,58                            | 75                               |
| M6            | 43,55                            | 135                              |

As a control, we used a composition based on non-activated closing water (M0).
On the basis of the above-mentioned composites, samples were made, the compositions of which are shown in Table 2-4.

### Table 2. Basic composite compositions.

| Components                              | Content of components, in mass parts for the composition |
|-----------------------------------------|--------------------------------------------------------|
|                                        | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Ulyanovsk’s Cement PC 500 D0            | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  |
| Water                                   | 0.267 | 0.35 | 0.171 | 0.6 | 0.475 | 0.525 | 0.56 | 0.56 | 0.261 | 0.289 |
| HP «Melflux 1641F»                      | – | – | 0.009 | 0.009 | 0.009 | 0.009 | – | – | – | – |
| SP «Fortrais-Strong»                     | – | – | – | – | – | – | – | – | 0.015 | – |
| HP «Khidetal 9γ»                         | – | – | – | – | – | – | – | – | 0.012 | – |
| SP «Khidetal-P-5»                        | – | – | – | – | – | – | – | – | – | – |
| Lipetsk’s micro-silica                  | – | – | – | 0.1 | – | – | – | – | – | – |
| Microquartz                             | – | – | – | 1.1 | 0.75 | – | – | 0.825 | – | – |
| Fractionation’s quartz sand 0-0.63 mm   | – | – | – | 2.753 | 1.775 | 2.065 | 2.51 | 2.065 | – | – |
| Fractionation’s quartz sand 0.63–2.5 мм | – | – | – | 2.347 | 1.975 | 1.76 | 2.14 | 1.76 | – | – |

### Table 3. Compositions of composites with pigments and on activated water of mixing.

| Composition code | Ulyanovsk’s Cement PC 500 D0 | Water | Water activated according to the mode E+M (1-1) | Water activated according to the mode E+M (3-3) | Water activated according to the mode E+M (6-6) | «Iron Oxide red» pigment | «Iron Oxide yellow» pigment | «Green glauconite» pigment | «Meerkat iron» pigment |
|------------------|-------------------------------|-------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|--------------------------|----------------------------|---------------------------|------------------------|
| M0               | 1                             | 0.267 | –                                                | –                                                | –                                                | –                        | –                          | –                         | –                      |
| M1               | 1                             | –     | 0.264                                           | –                                                | –                                                | –                        | –                          | –                         | –                      |
| M3               | 1                             | –     | –                                                | 0.26                                             | –                                                | –                        | –                          | –                         | –                      |
| M6               | 1                             | –     | –                                                | –                                                | 0.264                                            | –                        | –                          | –                         | –                      |
| P1               | 1                             | 0.292 | –                                                | –                                                | –                                                | 0.033                    | –                          | –                         | –                      |
| P3               | 1                             | 0.331 | –                                                | –                                                | –                                                | –                        | 0.057                      | –                         | –                      |
| P6               | 1                             | 0.306 | –                                                | –                                                | –                                                | –                        | 0.129                      | –                         | –                      |
| P7               | 1                             | 0.317 | –                                                | –                                                | –                                                | –                        | –                          | 0.049                     | –                      |

Samples based on cement pastes were prepared manually. Before preparing the mixtures, the fillers were dried. Weighing of cement and fillers was carried out on electronic scales with an accuracy of 0.01 g. When preparing mixtures, a dry mixture of cement and fillers was first prepared, then it was inserted into water. In compositions with superplasticizers, the amount of water was taken in such a way as to ensure that the test obtained a normal density. Samples were made in metal molds, which were pre-lubricated with paraffin. The samples were hardened under 2 conditions: under normal temperature and humidity conditions and under heat and humidity treatment. The samples were subjected to heat and humidity treatment after they had been solidified in molds in a bathtub with a hydraulic shutter for one day.
During the research, along with conventional tap drinking water, the technology of preparing samples on activated water of the closure was used. The water was activated using an electromagnetic activation device according to the technology described in [31-32]. To study the strength, we used samples-prisms with a size of 1×1×3 cm, cured at different times under normal temperature and humidity conditions or after heat and humidity treatment, in accordance with GOST 10180-2012 «Concretes. Methods for determining the strength of control samples».

Table 4. Compositions with biocidal additives based on guanidine compounds and compositions including a biocidal additive and a hyperplasticizer.

| № compound | Cement | Water  | Teflex «Desinfectant» | Teflex «universal» | Ultra-dez-BIO | HP «Melflux 5581» | Micro-silica | Micro-quartz | Sand FR 0.63-2.5 mm |
|------------|--------|--------|-----------------------|-------------------|---------------|------------------|--------------|--------------|---------------------|
| T1         | 1,000  | 0.267  | –                     | –                 | –             | –                | –            | –            | –                   |
| T2         | 1,000  | 0.267  | 0.030                 | –                 | –             | –                | –            | –            | –                   |
| T3         | 1,000  | 0.267  | – 0.030               | –                 | –             | –                | –            | –            | –                   |
| T4         | 1,000  | 0.267  | – – 0.030             | –                 | –             | –                | –            | –            | –                   |
| T5         | 1,000  | 0.35   | – – –                 | –                 | –             | –                | –            | –            | –                   |
| T6         | 1,000  | 0.35   | 0.030                 | –                 | –             | –                | –            | –            | –                   |
| T7         | 1,000  | 0.35   | – 0.030               | –                 | –             | –                | –            | –            | –                   |
| T8         | 1,000  | 0.35   | – – 0.030             | –                 | –             | –                | –            | –            | –                   |
| T9         | 1,000  | 0.195  | – – –                 | –                 | –             | –                | 0.009        | –            | –                   |
| T12        | 1,000  | 0.195  | – – –                 | –                 | 0.009         | –                | –            | –            | –                   |
| T13        | 1,000  | 0.589  | – – –                 | –                 | 0.009         | 0.100           | 0.750        | 3.75         | –                   |
| T14        | 1,000  | 0.537  | 0.030                 | –                 | 0.009         | 0.100           | 0.750        | 3.75         | –                   |
| T17        | 1,000  | 0.267  | 0.030                 | –                 | 0.009         | –                | –            | –            | –                   |
| T18        | 1,000  | 0.35   | 0.030                 | –                 | 0.009         | –                | –            | –            | –                   |
| T19        | 1,000  | 0.195  | 0.030                 | –                 | 0.009         | –                | –            | –            | –                   |

The samples were tested for bending as a beam on two supports with a single force applied in the middle of the span. The compressive strength was determined on the halves of the samples-beams having a cross-sectional area of 1.4 cm², using a specially manufactured device that provides the application of the load through the pressure plates. The strength was determined based on the test results of at least five samples in the series. Conversion of indicators to prisms of the base size can be performed using the transition coefficient K according to the formula obtained by V. I. Kalashnikov [45]:

\[
K = \left( \frac{m}{M} \right)^{2/3},
\]

where m and M are modules of the surface of small and large prisms, determined from the ratio \( S/V \) (\( S \) is the surface of the figure, cm²; \( V \) is the volume of the figure, cm³).

The value of the compressive strength was determined by the formula:
\[ R = \alpha F K_w (A)^{-1}, \tag{2} \]

where \( \alpha = 0.85 \) – scale coefficient; \( K_w = 1.0 \) is the correction coefficient.; \( K_r = 1.0 \) – correction coefficient.

The calculation of the bending strength was calculated using the formula

\[ \sigma_p = \frac{3P l}{2bh^2}, \tag{3} \]

where \( P \) is the bending load, N; \( b \) – sample width, mm; \( h \) – height of the sample, mm; \( l \) – base, mm.

The modulus of elasticity was calculated using the formula

\[ E = \frac{Pl_0}{\Delta l F}, \tag{4} \]

where \( P \) – breaking load, N; \( l_0 \) – initial length of the sample, mm; \( \Delta l \) – value of the absolute longitudinal strain.

4. Results and discussion

The strength and deformability of structural materials are one of the main parameters in engineering that characterize their resistance to destruction and determine the integrity and performance of structures. The ratio of Flexural tensile strength to compressive strength characterizes the brittleness of concrete. Short-term tests were performed to obtain the main physical and mechanical characteristics (cubic strength, Flexural tensile strength, and modulus of elasticity). They consisted of compression tests on cubic and prismatic samples.

The research was carried out in two stages. At the first stage, complex studies were carried out to establish quantitative dependencies of the properties of materials of old, transitional and new generations, followed by a comparison of strength indicators and elastic modulus. Experiments at the second stage were aimed at establishing the properties and optimizing the compositions, taking into account their modification by additives, activation of the closing water, contributing to the improvement of their decorative properties, biological and climatic resistance and force resistance, and cost reduction. These additives include inorganic pigments, biocidal preparations, new-generation superplasticizers, as well as local and non-deficient fillers of various sizes. Activation of the closing water was performed by electrochemical method.

Taking into account that the issue of moisture content of cement composites is important, during their tests for biostability and climate resistance, the strength and stiffness of materials were determined on samples that hardened under normal temperature and humidity conditions and under temperature and humidity treatment.

Figures 1-4 show changes in the properties of the compounds in relation to the composition based on the normal density test.

Depending on the composition of the compositions, thermal-water treatment contributed to both an increase and a decrease in strength indicators and deformability within insignificant limits. Consider materials cured under temperature and humidity conditions. From the analysis of the results it follows: comparison of compositions № 1 and № 2, which differ in water content, shows that an increase in the amount of sealing water in the cement stone leads to a decrease in the strength of both compression and bending. The graphs show that the use of the "Melflux1641F" hyperplasticizer in composition № 3 resulted in a significant increase in the cement-water ratio from 1.56 (composition № 1) to 2.04 (composition № 2) times The introduction of the plasticizer "Melflux1641F" contributed to a sharp increase in compressive strength compared to the prototype without the presence of a plasticizer from 1.2 to 1.72 times. A more significant change is observed for the bending strength, which increases by 2.91 times in comparison with composition № 2, which correlates with the previously established influence of the water-cement ratio. The introduction of the plasticizer brand "Khidetal GP-9 "gamma" A" lowered the strength indicators.
A significant effect on the strength index was revealed when using activated water for the preparation of composites. Activation of water in the M1 and M3 modes contributed to a 10% increase in strength during bending and compression tests.
At the same time, the test results show that the use of activated water does not significantly affect the modulus of elasticity. The introduction of microquartz, PE fractions of 0.14-0.63 mm and 0.63-2.5 mm allowed to obtain powdered concrete with a strength close to that of cement stone based on a test of normal density. Here the essential role of microquartz is visible – compositions without this filler showed lower strength. It follows from the graphs that the use of fine quartz in sand concrete compositions leads to an increase in strength indicators from 1.62 to 2.55 times, which is explained by an increase in the density of quartz aggregate packaging and is confirmed by an increase in the density of such samples by 9.5%. At the same time, a 1.3% decrease in the density of composition № 5 in relation to composition № 4 not only did not reduce the strength indicators, but led to an increase in compressive strength by 9.1%, bending strength by 20.6%, which is explained by the use of a silica filler – microsilicon with a more active surface than that of microquartz, which, as is known, affects the increase in $R_{th}$, and especially $R_{bb}$. It should be noted that filled compositions without microquartz also showed a decrease in the modulus of elasticity in comparison with cement stone based on a test of normal density, and with the introduction of a micro-silica additive, the modulus of elasticity increases. Also, both types of plasticizer have a favorable effect on increasing the elastic modulus, which is due to a decrease in water-cement ratio and an increase in strength.

Research on the influence of biocidal preparations, pigments and activated water on the elastic-strength properties of cement composites is of considerable interest. It follows from the graphs that the cement stone based on the test of normal density with additives "Teflex Universal", "Ultradez Bio" and "Teflex Disinfectant" have a lower strength than additive-free compositions. Apparently, the processes of hydration in this case are somewhat worse. This follows from the comparative results obtained by testing the above compositions with materials in which biocidal additives were additional components to the test of normal density. However, a greater increase in the strength properties of both bending and compression is achieved by simultaneously adding a plasticizer and a biocide preparation with different water-cement ratio to the compositions.
It is noteworthy that the use of pigments in samples that have undergone heat-and-humidity treatment, contributed to an increase in the strength of the bending and compression test compared to materials that hardened under normal temperature and humidity conditions. Perhaps the higher temperature contributed to the increased interaction of the cement components with the Ca(OH)$_2$.

According to the study presented in figure 4, it follows that the brittleness index of cement composites with the exception of compositions 9, 10, T18 and M6 decreases with the use of heat-and-water treatment mode compared to the normal hardening mode. From all of them, the best indicators are compositions 5, 6 and 11 among concretes of old, transitional and new generations; T3, T7 and T12 among compositions with biocidal preparations; P3 among compositions with pigments; M3 among compositions with the use of activated mixing water.

5. Summary
1. The results of research of strength and elastic-plastic properties of cement composites of various compounding compositions made by technologies of hardening under normal conditions and heat-moisture treatment and including fillers, small fillers, pigments, superplasticizers and biocidal preparations are presented.
2. For cement materials, quantitative indicators of compressive strength, Flexural tensile strength, elastic modulus and brittleness depending on the water – cement ratio, the type of activation of the closing water, the type of polycarboxylate plasticizer, the complex application of real and reactive fillers, the type of inorganic pigments and small fillers of a rational granulometric composition were obtained.
3. It was found that powder – activated concretes, which include a new – generation superplasticizer "Melflux 1641 F", stone flour, micro-silica and a fine quartz aggregate of 2 fractions with a size of 0.16 – 0.63 and 0.63 – 5.0 mm, have improved physical and mechanical properties.
4. For biostable concretes, the influence of biocidal preparations on physical and mechanical properties has been established. The positive role of the preparation Teflex "Universal" has been established, which contributes to increasing the strength and improving the elastic-plastic properties.
5. The positive role of the "Iron oxide yellow" pigment on physical and mechanical properties was revealed for painted concrete mixtures.

6. Rational hardening conditions, namely normal or heat-humidity conditions, for concretes and other cement composites, including those with special properties, have been identified.

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