Disperse reinforced concrete with polycarboxylate additive on a mechanically activated binder

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Abstract. The article discusses the properties of disperse reinforced claydite concrete on mechanically activated slag-portland cement with the addition of polycarboxylate superplasticizer Relaksol-Super PC. The idea of making a high-mobile claydite concrete mix with a settling of concrete cone 45 to 50 cm is substantiated. Particular attention is paid to the study of the effect of mechanical activation of the binder on the kinetics of the increasing in the strength of claydite concrete. The results of researches indicate that introduction of basalt fiber into slag-portland cement together with mechanical activation of binder allows to increase the impact strength of concrete by almost 1.7-1.9 times in comparison with the reference and to provide frost resistance of concrete at least than 350 cycles of alternating freezing and thawing.

1. Introduction
Due to the continuous rise in prices for energy resources, studies reflecting the influence of fine-disperse additives on the physical and mechanical characteristics of hardening and curing compositions based on Portland cement are of particular relevance. Among the many chemical additives to concrete mixtures, superplasticizers play an important role. In a number of modern water-reducing additives special place is a complex additive - superplasticizer Relaxol-Super PC.

Possibilities of improving the quality of concrete, more intensive accumulation of strength, especially in the early stages of curing, can be realized by purposefully changing the structure of cement stone, both by modifying their surface with surfactant additives [1, 2], and by activating the cement grains in conditions of intensive hydrodynamic influence on them. In the works of I. V. Barabash [3], S. I. Fedorkin [4] and others [5, 6] confirmed the positive role of mechanical activation of mineral binders on the quality of concrete, including the increase of its strength.

Dispersed reinforcement, in turn, provides for a uniform distribution of fiber by volume of material or product. This paper presents the results of investigation of concretes on a cement matrix reinforced with basalt fibers [7-9]. The introduction of fiber will allow the construction of complex structures, increase the endurance of concrete, reduce the overall weight of the structure, and significantly reduce the risk of deformation of cement dough in the early stage of curing, which will reduce the risk of shrinkage cracks [10, 11].
2. Purpose of research
The aim of the work was to obtain highly mobile concrete mixtures and claydite-concrete based on mechanically activated binder with improved physical and mechanical characteristics: strength of concrete in compression; impact strength and frost resistance.

To achieve this goal, the following research objectives were set:
- evaluate the effect of mechanical activation of slag Portland cement in the presence of Relaxol-Super PC and basalt fiber;
- to investigate the effect of basalt fiber on the impact strength of claydite-concrete on mechanically activated slag-portland cement;
- to find out the influence of prescription-technological factors on the frost resistance of claydite-concrete.

3. Research methods
The concrete mixture was prepared both by a separate method (with the use of mechanical activation of the binder in the triboactivator), and according to the traditional technology. In the preparation of concrete mixtures by the separate technology, the binder slurry, previously obtained by joint mixing of sequentially introduced high-speed tribo-mixer of water, Relaxol Super-PC additives, slag-portland cement and basalt fiber, was mixed with sand and expanded clay gravel in a slow-speed concrete mixer. Traditional technology involves the preparation of concrete mixtures of similar formulations in a slow-speed concrete mixer without pre-activation of the binder.

The flowability of concrete mixture was determined by the settling of the Abrams cone. The flowability of the concrete mixture in each line of the experiment plan (both by the separate and traditional technology) was assumed to be 50 cm. The strength of concrete in compression was determined by testing specimen cubes with a rib of 10 cm.

4. Research results
The effect of mechanical activation of a binder in the presence of a polycarboxylate superplasticizer of Super-PC and basalt fiber on the mechanical characteristics of a hardening concrete under normal conditions was investigated. Basalt fiber with a length of 12 mm, a diameter of 20 μm was used. To reduce water absorption, the basalt fiber was pre-treated with an organosilicon hydrophobizer GKZ-11. The consumption of basalt fiber ranged from 0 % to 1 % by weight of binder. The role of the small aggregate in the concrete mixture was assigned to quartz sand Mk=2.2. Clay gravel with fractions of 5-10 and 10-20 mm in a ratio of 1:1 by weight was used as a large aggregate.

The studies were performed on a standard three-factor plan containing 15 experimental points. Independent prescription-technological factors were adopted:
- \( X_1 \) - 450 ± 100 kg/m\(^3\) - binder consumption;
- \( X_2 \) - 1 ± 0.5 % - amount of Super-PC plasticizer;
- \( X_3 \) - 0.5 ± 0.5 % - amount of basalt fiber.

Quartz sand consumption ranged from 727 to 812 kg/m\(^3\), expanded clay gravel from 630 to 715 l/m\(^3\). The increased consumption of quartz sand (compared to regular concrete compositions of its consumption increased by 10-20 %) is effect of need to obtain a high-mobility self-flowing concrete mixture with little mechanical impact on it.

Concrete aged 28 days of normal curing was subjected to compression, impact strength and frost resistance tests. The molding of the samples was carried out by pouring the concrete mixture into triangular shapes with an edge size of 10 sm.

The influence of prescription factors on the strength of claydite concrete at the age of 3, 7 and 28 days (index 3, 7 and 28, respectively) for the technologies prepared for separate (index "s") and traditional (index "t") the experimental models below are as follows:
Model analysis shows that the strength of concretes prepared by separate technology is higher than the strength of concretes prepared by traditional technology during the entire studied curing period by 10-30\%. It was found experimentally that the strength of concrete, the mixture of which was prepared by separate technology, on the 3rd day of curing is 1.5 times higher than that of the reference samples (binder was not subjected to mechanical activation).

Further, the rate of strength of claydite concrete on mechanically activated binder slows down and up to 28 days of age, the strength gain compared to the control does not exceed 10-15\% (Figure 1).

**Figure 1.** Influence of curing time on the strength of claydite concrete composition:
- slag-Portland cement – 550 kg/m³;
- sand – 727 kg/m³;
- expanded clay gravel _s_{10} – 385 kg/m³;
- expanded clay gravel _s_{20} – 245 kg/m³;
- Relaxol-Super PC - 1.5\%;
- fiber – 1\%.

\( f_{ckcubes} \) - is traditional technology;
\( f_{ckcube_s} \) - is a separate technology.
Graphic dependence analysis indicates a significant effect of binder consumption on concrete strength. As the binder content increases from 350 to 550 kg/m³, the concrete strength increases from 17.8 to 29.5 MPa, i.e. more than 1.5 times.

The effect on the concrete strength of the amount of plasticizer introduced by Relaxol-Super PC should be noted. Thus, increasing its concentration from 0.5 to 1.5 % leads to an increase in strength from 24.2 to 27.5 MPa, i.e. by almost 13 %.

Joint effect on slag-portland cement of mechanical activation, Relaxol-Super PC additives and basalt fiber leads to increased strength in the 28th day of concrete compared to control (concrete on non-mechanically activated portland cement, Relaxol-Super PC and basalt fiber are absent) from 11.3 to 29.5 MPa, i.e. more than 2.5 times.

Frost resistance is a very important indicator of quality for concrete. ES models reflecting the effect of varying composition factors on the frost resistance of claydite concrete (activated and control respectively) are given below:

$$F_t(\text{cycles}) = 291.1 + 55.0 X_1 - 13.9 X_1^2 + 25.0 X_2 - 13.8 X_2^2 - 13.8 X_3$$  \hspace{1cm} (7)

$$F_s(\text{cycles}) = 336.7 + 40.0 X_1 - 33.3 X_1^2 - 12.5 X_1 X_2 + 15.0 X_2 - 8.3 X_2^2 + 25.0 X_3 - 8.3 X_3^2$$  \hspace{1cm} (8)

It should be noted that since the test methods and standards, therefore, provide only discrete marks on the frost resistance of the material in increments of 25 cycles, the accuracy of estimating the influence of varying composition factors on the value of $F$ is largely due to such discretion. In other words, it is impossible to smoothly change the concrete frost resistance evaluated in the experiment by varying its composition.

This should be taken into account in the analysis of both $F$ and EC models based on the results of the determination of this indicator for individual concretes made during the experiment. Graphical interpretation of models (7) and (8) describing the effect of recipe factors on the frost resistance of claydite concrete prepared by the separate and traditional technology are shown in Figure 2.

**Figure 2.** Influence of recipe factors of composition on the frost resistance of expanded clay concrete prepared by separate and traditional technologies: (a) - control (no mechanical activation of the binder); (b) - concrete on mechanically activated binder.
The analysis of graphical dependences shows that the varying factors of the formulations have a similar effect on the frost resistance of concretes prepared by both separate and traditional technologies.

It should be noted that the greatest influence on the frost resistance of expanded clay concrete has the consumption of binder. Thus, increasing the binder content from 350 to 450 kg/m$^3$ leads to an increase in the frost resistance of claydite concrete for 75 cycles (regardless of the conditions of preparation of the concrete mix). Further increase in binder consumption up to 550 kg/m$^3$ increases the $F$ level by approximately 25-50 cycles.

It was interesting to find out the effect of recipe factors on the impact strength of claydite concrete. The values of impact resistance (J/cm$^3$) for fifteen investigated formulations of claydite concrete were experimentally established in the process of testing on laboratory impactor. The influence of varying composition factors on impact-resistance $a$ of claydite concretes is described by the following relevant ES-models:

\[
a_t = 51.6 + 4.9X_1 - 1.1X_1^2 - 0.2X_1X_2 + 2.5X_2 - 0.6X_2^2 + 13.9X_3 - 3X_3^2
\]

\[
a_s = 58.6 + 5.1X_1 - 1.2X_1^2 - 0.3X_1X_2 + 2.4X_2 - 1.1X_2^2 + 14.1X_3 - 3.1X_3^2
\]

A graphical interpretation of the models (9), (10) describing the effect of recipe factors on the impact strength of concrete prepared by separate and traditional technologies is presented in figure 3.

![Figure 3](image_url)

**Figure 3.** Influence of recipe factors on the impact strength of concrete (J/cm$^3$) prepared by separate and traditional technologies: (a) - control (non-mechanical activation of binder); (b) - concrete on mechanically activated binder.

The amount of Super-PCs has little effect on the increase in impact strength. Thus, with the introduction of superplasticizer from 0.5 to 1.5 % (basalt fiber 1 %, binder consumption 550 kg/m$^3$), the value of impact strength increases from 63.5 to 68.1 J/cm$^3$, i.e. not more than 8 %.

Mechanical activation of the binder increases the impact strength of concrete by an average of 10-14 % throughout the range of content of basalt fiber in slag-portland cement.
5. Conclusions
It has been found that the mechanical activation of the binder leads to an increase in the strength of concrete at 3 days of age from 11.4 to 16.2 MPa, i.e. more than 40% compared to the control. The introduction of basalt fiber in the amount of 1% by weight of mechanically activated binder provides a further increase in the strength of concrete by 10-15%.

Claydite concrete on mechanically activated slag-Portland cement with the addition of basalt fiber and superplasticizer Relaxol-Super PC is characterized by frost resistance at least than 350 cycles of freezing and thawing. The presence of basalt fiber in the mixture increases the impact strength of concrete from 47 to 75 J/cm².

References
[1] Ramakrishnan V, Coyle W V and Pande S S 1980 Workability and strength of superplasticized concrete The Indian Concrete J. 54 (1) 23-27
[2] Constitutive modeling of high strength/high performance concrete (State-of-art report) 2008 (Stuttgart: Sprint-Digital-Druck) FIB Bulletin 42 130
[3] Barabash I V 2002 Mechanochemical Activation of Mineral Weavers: Training manual (Odesa: Astroprint)
[4] Fedorkin S 11997 Mechanisation of production of building materials (Simferopol: Tavria)
[5] Ksonshkevych L 2013 High-strength concrete on the mechanically activated binder: Dis. cand. tech. sc. (Odesa: OSACEA)
[6] Ksonshkevych L, Krantovska O, Petrov M, Synii S and Uhl A 2018 Investigation of the structure of cement stone, obtaining and optimization of high-strength concrete on mechanically activated binder MATEC Web Conf. 230 03010
[7] Novitskiy A G 2003 Chemical resistance of basalt fibers for concrete reinforcement Chemical industry of Ukraine 3 16-19
[8] Rabinovich F N 2004 Composites based on dispersed-reinforced concrete. Questions of theory and design, technology, constructions: a monograph (Moscow: ACB)
[9] Pukharenko Yu V 2005 Scientific and practical bases of formation of structure and properties of fiber concrete: avtoref. diss. dok. tekhn. nauk (St. Petersburg)
[10] Babych E M and Andriichuk O V 2017 Strength of Elements with Annular Cross Sections Made of Steel-fiber-Reinforced Concrete Under One-Time Materials Science (New York) 52 (4) 509-513
[11] Andriichuk O, Babich V, Yasyuk I and Uzhehov S 2017 The influence of repeated loading on work of the steel fiber concrete drainage trays and pipes on the roads MATEC Web Conf. 116 02001