Selection and classification of various additives for monolithic concrete depending on the working conditions

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Abstract. The article presents the results of research on the choice of chemical additives for monolithic concrete depending on their types, main properties and applications. The working conditions are analyzed under which various monolithic concrete or monolithic reinforced concrete objects are constructed. The influence of additives on the properties of concrete and its performance characteristics is considered. The recommended calculation of the strength of concrete with additives is presented. It is shown that in the case of additives, the strength calculation should be performed using refined coefficients, mainly for the water-cement ratio. The calculation of the dosage of the additive in concrete, depending on the volume of the prepared mixture, is given. The results of an experiment with the addition of calcium nitrate to the concrete structure are presented, which confirmed an increase in the strength of the product by 20% compared to normal hardening conditions. An approximate method of selecting the most rational additives for concrete, depending on the working conditions, is given. The basis for classification of recommended additives is defined in order to ensure the required properties of concrete, taking into account the conditions of production and operation of objects using elements made of monolithic concrete.

1. Introduction
Monolithic reinforced concrete is widely used in the field of civil and industrial construction. This applies to civil and industrial buildings that, due to their orientation and urban planning position, cannot be built using precast concrete structures manufactured at the plant [1–4]. Also, monolithic structures are widely used in road construction (overpasses, road slabs), metro (tunnels, platforms), military facilities (bunkers, tunnels, facilities at weapons testing sites) and spaceports (bunkers, launch pads) [5–9].

The article considers the use of various chemical additives specifically for monolithic concrete (reinforced concrete) based on Portland cement. When manufacturing precast concrete and reinforced concrete structures in factories, questions of external (climatic) conditions are eliminated.
The relevance of the topic is due to the fact that currently the construction of objects made of monolithic concrete goes round for years, and certain external conditions can negatively affect the quality of structures being built. Most often, these external conditions mean certain climatic factors, when the concrete is affected by both low and high temperatures, when the humidity of the environment changes, etc. In such conditions, the introduction of various chemical additives in the concrete is necessary. Compliance with these measures helps to speed up the time and improve the quality of structures being built. Therefore, it is very important to choose the right supplement depending on external factors. And at the same time, the environmental situation should not have trend to deterioration [10–12].

2. Types of additives in concrete and their purpose
Additives in concrete are used to improve the quality of concrete, to obtain specific properties. These advantages speed up construction work, reduce the cost of the construction process. Concrete with special properties is used in the construction of roads, airfields, various hydraulic structures, swimming pools, berths, etc. Concrete with additives is used on most construction sites, as more and more requirements are imposed on concrete.

So, with modern technology of concrete preparation, additives-modifiers are a mandatory component of the concrete mix, they are included in it together with binders, aggregates and water.

Additives are an effective and simple method that improves the quality of the concrete mix. Additives in concrete allow solving various problems of creating concretes with the necessary properties. They are used to create concrete mixes with increased properties of strength, frost resistance, and durability.

Chemical additives are introduced into the concrete in a small amount about 0.1–2% of the weight of cement and change the properties of the concrete mixture, and fine-ground additives are introduced in an amount of 5–20% or more. The latter is used for the cement consumption, obtaining more dense structure of concrete, increase its durability. Chemical additives are a universal and affordable way to change the properties of a concrete mix and to regulate the properties of concrete. Additives should be checked before use [13–18]. This is due to the fact that their composition may change during storage and transportation. This often happens with various substances [16], [18–22]. Various non-contact methods, especially non-destructive testing, are used to assess the safety of additives and the properties of finished concrete with their application [13–16], [19], [22–24].

3. Methods
3.1. Calculation of the strength of concrete with additives
The strength of concrete is usually determined by the formula of I. Bolomey – B. G. Skramtayev, which generally looks like this:

\[ R_{\text{comp}} = A R_{ca} \left( C/W \pm 0.5 \right) \]  \hspace{1cm} (1)

If the activity of the binder is unknown, its brand is substituted in the formula; \( A \) and \( A_1 \) are coefficients that take into account the quality of fillers.

For concrete with a water-cement ratio \( W/C \geq 4 \) \( (C/W \leq 2.5) \) this formula has the following kind:

\[ R_{\text{comp}} = A R_{ca} \left( C/W \right) \]  \hspace{1cm} (2)

For concretes with a water-cement ratio \( W/C < 0.4 \) \( (C/W > 2.5) \) the following formula is used:

\[ R_{\text{comp}} = A_1 R_{ca} \left( C/W + 0.5 \right) \]  \hspace{1cm} (3)
where: $R_{\text{comp}}$ is compressive strength of concrete at the age of 28 days of normal hardening (kg/cm$^2$); $R_a$ is the activity of the cement or mixed binder (kg/cm$^2$). If the activity of the binder is unknown, its brand is substituted in the formula; $A$ и $A_1$ are the coefficients that take into account the quality of placeholders, $C$ is the weight of cement, $W$ is the weight of cement.

Coefficients $A$ и $A_1$ are selected based on the concrete application and the required quality of materials. There are high-quality fillers ($A=0.65$ и $A_1=0.45$), ordinary fillers ($A=0.60$ и $A_1=0.40$), low quality fillers ($A=0.55$ и $A_1=0.37$).

High-quality fillers are considered to be crushed stone of dense and durable rocks, sand of optimal size, as well as clean fillers, fractionated fillers, and fillers with an optimal grain composition. The common ones include fillers (including gravel) that meet the requirements of the standard. Fillers of low quality are low-grade crushed stone and gravel, fine sands [6–9].

3.2. Calculation of the dosage of additives in concrete depending on the volume of the prepared mixture

As a rule, the calculation of the amount of admixture in concrete is based on the following example.

Let's assume that the dosage of the additive in the concrete mix is 0.5% by weight of cement. The consumption of the additive per 100 kg of cement is calculated according to the proportion:

$$\frac{100 \text{ kg}}{100\%} = \frac{X \text{ kg}}{0.5\%} \quad X = 100 \text{ kg} \times \frac{0.5\%}{100\%} = 0.5 \text{ kg of absolutely dry additive;}$$

The additive is introduced as a working solution of 35 % concentration, i.e.:

$$\frac{0.5 \text{ kg}}{35\%} = \frac{X \text{ kg}}{100\%} \quad X = 0.5 \text{ kg} \times \frac{100\%}{35\%} = \frac{1,429 \text{ kg of solution by concentration 35%}}{100 \text{ kg of cement}}.$$

If the dosage of the additive solution is carried out in liters (L), then:

$$V = \frac{m}{d} \quad (4)$$

where: $m$ is a mass of working solution of the additive, kg; $d$ is a density of 35% solution of the additive, g/cm$^3$. $V=1.429/1.19=1.2$ L of the additive per 100 kg of cement.

The calculation principles are common to all additives, but for each specific additive, its individual properties must be taken into account. As a rule, the dosage of the additive in concrete is given in its description (in the technical specifications). With the use of additives, the characteristics of concrete change, and, therefore, the strength calculation should be made using refined coefficients. The main change is the coefficient $A$, which depends on $W/C$. By changing $W/C$, formulas (2) and (3) will change the $C/W$ indicators and the coefficient $A$, and therefore, depending on the function of a particular additive, the concrete will gain or not gain strength.

3.3. Experiment with the addition of calcium nitrate (CN).

The chemical additive calcium nitrate (CN) was selected for the experiment. This additive is an accelerator for concrete hardening. Its chemical formula is Ca(NO$_3$)$_2$.

The experiment was conducted for 28 days using a mechanical concrete strength meter (sclerometer) shown in figure 1.
3.4. The method of selection of the most efficient additives
When choosing the most rational additives from a certain classification, which they belong to, it is necessary to analyze their descriptions and properties on the basis of available text, digital, tabular, graphical and other data.

4. Results and Discussion
A number of additives have been studied for their properties, including the experimental and analytical data obtained.

Figure 2 shows the dependence of concrete strength when using various fillers. If the values of coefficients $A$ and $A_1$ are unknown, then $C/W$ is found from the graphs (figure 3).

28-days long experiment using mechanical concrete strength meter allowed to get some important results. The experiment was conducted on a construction site at an average monthly temperature of 5°C, so from figure 2 we took one graph of the strength gain of concrete on Portland cement at this temperature to compare it with the graph that obtained experimentally – by adding an additive to the concrete at the same temperature.

After pouring concrete into the foundation and adding CN (1% by weight of cement), the following 4 readings of sclerometer were obtained every 7 days: concerning compressive strength of concrete $R_{comp}$ in different periods: after 7 days $R_{comp} = 196$ MPa (50%); after 14 days $R_{comp} = 277$ MPa (70%); after 21 days $R_{comp} = 326$ MPa (82%); after 28 days $R_{comp} = 373$ MPa (93%). These 4 values were used to plot the strength gain of concrete with CN addition at 5°C (figure 4).

To determine the rate of strength gain of two similar additives-concrete hardening accelerators "Lignopan B-1" and "Lignopan B-3", their strength gain graphs are considered (figure 5).

Analyzing the graphs, it becomes obvious that "Lignopan B-3" allows concrete to gain strength 2 times more than its analogue "Lignopan B-1". Therefore, the choice is inclined to the additive-accelerator of concrete setting "Lignopan B-3".
Figure 2. Graphs of the dependence of concrete tensile and compressive strength when using various fillers: \( N \) – without fillers; \( 1 \) – with high-quality fillers; \( 2 \) – with ordinary fillers; \( 3 \) – with low-quality fillers.

Figure 3. Graphs for finding \( C/W \) depending on the required compressive strength of concrete \( R_{\text{comp}} \) and the activity of cement \( R_{\text{ca}} \).

Figure 4. Graphs of strength gain by concrete at 5°C without additives and with the addition of CN.

Figure 5. Graphs of strength gain by concrete with additives "Lignopan B-1" and "Lignopan B-3".

After analyzing the graphs, we can conclude that with the use of the CN additive, in this case, on the 28th day, the strength of concrete will be almost 20% greater than without its use. Thus, the feasibility of using an additive was confirmed experimentally, where it was required to obtain concrete with the strength mark M400 in a period of 28 days.

When choosing the most rational concrete hardening moderator between technical lignosulfonate "TLS" and "Superplasticizer C-3" with their equal effectiveness in influencing concrete, their economic indicators were compared according to the diagram (figure 6).
Based on the analysis of diagram, it can be concluded that the "LST" additive is the most cost-effective compared to the "Superplasticizer C-3". Therefore, between these two additives, the choice falls on the "LST".

When choosing the most effective modifier for concrete between the additives "Lignopan B-1", "Superplasticizer C-3" and polyfunctional concrete modifier "PFM-NLK", their diagram of frost resistance were compared (figure 7). The diagram shows that the "PFM-NLK" modifier shows higher frost resistance characteristics compared to other additives. Therefore, of these three additives, "PFM-NLK" is the most effective in construction regions with a more severe climate.

The applied computational and analytical methods allowed us to obtain reliable results, examples of which are given above. Based on them, specific recommendations can be set for the further use of additives for concrete in various areas of construction.

On the data obtained during the research, additives are classified according to the following criteria. 1. The kind of an additive. 2. The name of the additive. 3. The composition of the additive, its chemical formula and appearance (liquid, powder). 4. GOST, Technical Conditions. 5. Temperature range of application, °C. 6. Dosage of the additive (% by weight of cement). 7. Time of action on the working process (minutes). 8. Main impact on concrete. 9. Additional properties. 10. Saving cement (%). 11. Impact on the life safety. 12. Economic effect (at the price at this time). 13. The type of construction in which it is used. 14. Interaction with other additives. 15. Influence on rebar. 16. Features of application taking into account properties.

The general classification is made for various types of additives, which includes 20 names, and further expansion of the classification is planned.

5. Conclusions
Considered additives are used in various areas of concrete construction: civil, industrial, transport, road, hydraulic, bridge, airfield, etc. But for each additive, there is the most preferred field of construction in which it is better to use it. The convenience of the proposed classification is that it allows optimal consideration of specific requirements for places, areas, and construction objects.

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