Change in effective viscosity and level of synergism of cement-containing mechanoactivated suspension

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Abstract. The article considers the influence of prescription factors (ground chamot, superplasticizer C-3) on the change of the effective viscosity of mechanically activated cement-containing suspensions used in the technology of lightweight concrete mixtures. The synergistic effect of reducing the viscosity of cement-containing suspensions during their activation in high-speed mixers of turbulent type in the presence of C-3 was revealed. Optimized modes of mechanical activation of suspensions that provide the maximum reduction of their effective viscosity.

1. Introduction  
Lightweight concrete mixtures are increasingly used in the concreting of reinforced concrete structures, especially in frame-monolithic construction [1]. Prerequisites for obtaining lightweight concrete mixtures are the use of polyfraction fillers and additives, such as chamot. The need to obtain lightweight concrete mixtures based on Portland cement and ordinary granite rubble makes us look for new technological techniques. In particular, partial replacement of granite rubble with expanded clay gravel and the use of separate technology for preparing concrete mixes using high-speed mixers. This technology will allow to obtain high-tech cement-containing suspensions with low viscosity, which provide increased easy-to-place mixtures with lower consumption of water [2 - 6].

2. Analysis of recent research and publications  
Works [7, 8] found that the use of chamot as an additive to Portland cement, makes it possible to regulate both the easy-to-placing mixture and the processes of structure formation of cement stone and concrete based on it [8]. Strengthening the role of mineral and organic components is possible due to their mechanical activation in the suspension in high-speed mixers of the original design [2, 4]. The addition of surfactants to the suspension enhances the role of chamot in the formation of the structure of cement stone [9].

3. The purpose of the research  
The aim is to investigate the influence of mechanoactivation modes, chamot concentration, C-3 superplasticizer on the change of effective viscosity of binder suspensions. The task of research is to obtain a synergistic effect of reducing the viscosity of cement-containing suspensions with the addition of chamot with the joint action of high-speed mixing, superplasticizer C-3.
4. Research methods
It was of interest to elucidate the effect of high-speed mixing on the change in the effective viscosity of a cement-containing suspension. Ground chamot was used as a mineral additive to Portland cement (the content of chamot in the binder varied from 0 to 30% of the consumption of Portland cement). Ground chamot was milled to three type of specific surface - 250, 350 and 450 m²/kg. Superplasticizer C-3 was used as a reducing additive, the concentration of which varied from 0 to 1% of the binder mass. The effective viscosity of cement-containing suspensions was determined using a rotary viscometer with coaxial cylinders. The initial (control) composition of the suspension was accepted as follows: Portland cement - 500g; water - 145g. The effective viscosity of such a suspension was equal to 2950 cP.

Given in table. 1 experimental data on effective viscosity indicate that mechanical activation of a suspension leads to a sharp decrease in its effective viscosity. This is especially evident for suspensions, in the composition of which the superplasticizer C-3 was introduced in an amount of 1% by weight of the binder.

Table 1. Influence of the activation time of Portland cement on the effective viscosity of suspensions

| Portland cement, % | Chamot, % | Superplasticizer C-3, % | Specific surface area, m²/kg | The activation time, s |
|-------------------|-----------|-------------------------|-----------------------------|-----------------------|
|                   |           |                         | 0   | 30  | 60  | 90  | 120 | 150 | 180 |
| 100               | 0         | 0                       | 2950| 1980| 1920| 1936| 1943| 1961| 2215|
| 90                | 10        | 0                       | 2970| 2708| 2624| 2633| 2685| 2691| 2755|
| 80                | 20        | 0                       | 3100| 3024| 3020| 3062| 3081| 3094| 3181|
| 70                | 30        | 0                       | 3156| 3150| 2980| 2996| 3030| 3051| 3064|
| 100               | 0         | 450                     | 1820| 300 | 141 | 162 | 180 | 210 | 250 |
| 90                | 10        | 1                       | 2035| 450 | 255 | 275 | 299 | 310 | 364 |
| 80                | 20        | 1                       | 2375| 650 | 360 | 368 | 390 | 431 | 465 |
| 70                | 30        | 450                     | 2916| 860 | 510 | 516 | 542 | 572 | 600 |
| 100               | 0         | 250                     | 2950| 1980| 1920| 1936| 1943| 1961| 2215|
| 90                | 10        | 2                       | 2963| 2711| 2585| 2589| 2593| 2602| 2641|
| 80                | 20        | 0                       | 3002| 2981| 2783| 2810| 2826| 2851| 2916|
| 70                | 30        | 0                       | 3114| 3044| 2862| 2911| 2918| 2962| 3000|
| 100               | 0         | 2                       | 1820| 300 | 141 | 162 | 180 | 210 | 250 |
| 90                | 10        | 1                       | 1910| 320 | 290 | 300 | 310 | 320 | 470 |
| 80                | 20        | 2                       | 2030| 400 | 360 | 370 | 378 | 430 | 508 |
| 70                | 30        | 250                     | 2250| 514 | 444 | 446 | 453 | 494 | 660 |

Comparing the data on the minimum effective viscosity of suspensions without the addition of C-3 and with its addition in an amount of 1% of the binder weight, we see that high-speed mixing in the presence of the superplasticizer C-3 leads to a decrease in $\eta_{eff}$ in comparison with the control (the suspension was not subjected to activation; C-3 = 0%) from 2950 to 141 cP, that is, more than 20 times. The graphical dependences shown in Fig. 1 indicate that the time of mechanical activation of the cement suspension has a great influence on the decrease in the effective viscosity.

$\eta_{eff}$, cP
The greatest decrease in viscosity is observed in the first 30 seconds of high-speed mixing of the suspension. Having reached the minimum value, the effective viscosity of the suspension begins to increase, reaching a maximum after 180 seconds of activation. In our opinion, this can be explained by the fact that in the process of intense hydrodynamic effects on cement-water systems in them, along with the destruction of spatial aggregates and the weakening of bonds between particles, the reverse process also occurs - thixotropic restoration of the structure, i.e., the formation of new aggregates and bonds.

The introduction of ground chamot into Portland cement leads to an increase in the minimum effective viscosity of the suspension achieved after 60 seconds of activation. So, at a 10% content of ground chamot in Portland cement, the minimum effective viscosity increases from 141 to 255 cP.

The introduction of 30% ground chamot causes a further increase in the effective viscosity of the suspension up to 510 cP. It has been experimentally established that the specific surface area of ground chamot also affects the change in the effective viscosity of the suspension. Comparing the values of its effective viscosity after 60 seconds of activation, we see that as the specific surface of the chamot increases, η_{eff} increases. So, if η_{eff} for Portland cement with the addition of 30% ground chamot with $S = 250 \text{ m}^2 / \text{kg}$ is characterized by an effective viscosity of 444 cP, then the introduction of the same amount of chamot into Portland cement with $S_p = 450 \text{ m}^2 / \text{kg}$ causes an increase in the effective viscosity to 510 cP. Thus, it can be stated that the introduction of ground chamot into Portland cement increases the effective viscosity of the suspension both on a mechanically activated binder and on a binder that has not been mechanically activated. An increase in the specific surface area of chamot leads to an increase in effective viscosity by an average of 20%.

To assess the effect of high-speed mixing in the presence of C-3 superplasticizer on the cement-containing suspension, a dimensionless coefficient ($K$) was chosen, which was defined as the ratio of the viscosity of a practically intact (η₀) structure to the minimum possible viscosity that the suspension acquires as a result of the application of mechanical activation ($\eta_{ma}$), the introduction superplasticizer C-3 ($\eta_{C-3}$), or their combined effect ($\eta_{mix}$):

$$K_{ma} = \frac{\eta_0}{\eta_{ma}}$$

\textbf{Figure 1.} Influence of the activation time of cement-containing suspensions on the change in its effective viscosity. Specific surface area chamot = 250 m²/ kg 1,2,3,4 content of ground chamot, respectively 0%,10%, 20% and 30% activation, we see that as the specific surface of the chamot increases, η_{eff} increases. So, if η_{eff} for Portland cement with the addition of 30% ground chamot with $S = 250 \text{ m}^2 / \text{kg}$ is characterized by an effective viscosity of 444 cP, then the introduction of the same amount of chamot into Portland cement with $S_p = 450 \text{ m}^2 / \text{kg}$ causes an increase in the effective viscosity to 510 cP. Thus, it can be stated that the introduction of ground chamot into Portland cement increases the effective viscosity of the suspension both on a mechanically activated binder and on a binder that has not been mechanically activated. An increase in the specific surface area of chamot leads to an increase in effective viscosity by an average of 20%.

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\[ K_{ma} = \frac{\eta_0}{\eta_{ma}} \]
The calculated coefficient of effective viscosity reduction under the combined action of high-speed mixing and superplasticizer C-3 ($K^c_{C-3}$) on the suspension is a function that depends on the effectiveness of each of these factors separately:

$$
\eta_{\Sigma}^e = \eta_0 \frac{\eta_{ma} \cdot \eta_{C-3}}{\eta_0}
$$

or

$$
K^e_{\Sigma} = \frac{\eta_0}{\eta_\Sigma} = K_{ma} \cdot K_{C-3}
$$

The level of synergy ($Y_s$) was determined as the ratio of the actual coefficient of viscosity decrease ($K^e_{\Sigma}$) obtained experimentally to its calculated value:

$$
Y_s = \frac{K^e_{\Sigma}}{K^c_{\Sigma}}
$$

The obtained results of experimental studies are presented in table 2.

| Chamot, % | Superplasticizer C-3, % | $Y_s$ |
|-----------|--------------------------|-------|
|           |                          |       |
|           | 1                        |       |
| 0         |                          |       |
| 10        |                          |       |
| 20        |                          |       |
| 30        |                          |       |
| 0         | 0.5                      |       |
| 10        |                          |       |
| 20        |                          |       |
| 30        |                          |       |

It was found that the level of synergy depends on the concentration of C-3, as well as the concentration and specific surface area of ground chamot.

The greatest influence on the level of synergism is exerted by the concentration of the reducing additive C-3. The level of synergism with simultaneous action on the suspension of high-speed mixing and the addition of C-3 in an amount of 0.5% increases, as compared to the level of synergism of the suspension with the addition of C-3 = 1% from 3.8 to 4.94, i.e. 23% higher.

When 10% ground chamot is added to Portland cement, the level of synergism increases to a value of 6.44. A further increase in the content of chamot in Portland cement slows down the growth of the level of synergy, and at a 20% content of chamot in the binder, its value is 6.57.

A further increase in the content of ground chamot in Portland cement leads to a decrease in the level of synergy at 30% of its content in Portland cement, the value of $Y_s$ is 4.85. It should be noted the effect of the specific surface area of chamot on $Y_s$ - with an increase in $S_{sp}$ from 250 to 450 m$^2$/kg, the level of synergy increases from 4.36 to 4.68, that is, by 7%.
5. Conclusions
Activation of a cement suspension in a high-speed tribomixer and in the presence of C-3 superplasticizer leads to a sharp decrease (20 times) in its effective viscosity in comparison with the control.

The introduction of ground chamot into the binder leads to an increase in the minimum possible effective viscosity of the cement slurry from 141 cP (the content of ground chamot in Portland cement is 0%) to 444 cP (the content of ground chamot in Portland cement is 30%).

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