Rheological Behavior of Model Systems of Resource Matrix Efficient Self-Compacting Concrete

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ABSTRACT

This paper considers the problem of resource-intensive production of self-compacting concrete. The possibility of using the by-product of the production of nitrogen phosphorus potash (NPK) in the OJSC “Mineral fertilizers” of the city of Rossosh as a component of self-compacting concrete is assessed. Thus, the article solves the problem associated with resource saving, namely, it proposes an alternative to natural filler in the form of technogenic calcium carbonate, dumps of which occupy a huge area and bring incontestable harm to the environment. The results of experimental studies of water systems “limestone flour + water”, as well as “technogenic calcium carbonate + water” are given. The dependence of the water-solid ratio on the amount of the dosage of various additives at a constant viscosity of the systems is established.

INTRODUCTION

The problem of the widespread introduction of self-compacting concrete mixtures is their high cost due to the use of natural mineral fillers, the use of expensive superplasticizers and hyperplasticizers, fractionated aggregates [1-6]. The economic efficiency of widespread use in the construction of self-compacting concrete mixtures (especially concrete with ordinary strength) is largely leveled by an increase in the cost of concrete in comparison with traditional concrete [7-13]. These circumstances limit the widespread use of self-compacting concrete in construction.

In this regard, relevant research aimed at reducing their cost.

There are several ways to solve this problem:

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- reduction of cement consumption, as an expensive component;
- the choice of a rational chemical additive, based on the properties of the mixture;
- replacement of expensive filler for cheaper.

This question should be considered in context with the classification of self-compacting concretes [14-15]:

1) type 1: concrete mixes with a high content of dispersed materials, mainly mineral filler;
2) type 2: concretes with low filler content or without it at all, in this case, the necessary rheological characteristics of the concrete mixture are achieved through the use of special chemical additives—viscosity modifiers;
3) type 3: combined type: in fact, it is type 1 concrete with the use of viscosity modifiers.

Each of these types has its advantages and disadvantages. Type 1 in this sense has advantages since along with the improvement of the rheological properties of concrete mixes, they provide an increase in the physical, mechanical and operational characteristics of concrete. In addition, it has the greatest potential for resource saving, due to large dosages of mineral filler.

Therefore, one of the ways to save natural resources (resource saving), as well as reduce the cost of production of concrete mixes is to replace natural filler with industrial waste [15].

In connection with the above, the article discusses the possible replacement of natural raw materials - limestone flour with mineral filler (powder type) conversion chalk—waste production of chemical fertilizers of JSC “Mineral fertilizers”, Rossosh city (annual accumulation of waste is up to 300,000 tons).

Conversion of calcium carbonate is formed in the technology of nitrogen phosphorus potash (NPK) production in the form of fine powder containing mainly calcium carbonate (the total content of carbonates, in terms of calcium carbonate, is about 95%). And also up to ~ 3% ammonium compounds (in terms of ammonium nitrate), as well as compounds Sr (1.38%), P2O5 (0.58%) and SiO2 (0.49%), SO4 (<0.1%).

This article discusses a part of the problem of obtaining new compositions of the self-compacting concrete, which is associated with the rheology of water systems based on technogenic calcium carbonate and limestone flour.

MATERIALS AND METHODS

When conducting experiments for the preparation of pastes, technogenic calcium carbonate, waste from the production of chemical fertilizers by JSC Mineral Fertilizers, Rossosh, and limestone powder produced by <<VZMP>> LLC, Voronezh, were used as mineral fillers.

So, these two types of raw materials differ in the method of production, namely, the first is the result of exchange reactions, recrystallization processes in the
production of mineral fertilizers such as nitrogen phosphorus potash (NPK), the second is a product of mechanical transformations of natural raw materials (various kinds of limestone).

The main chemical components of limestone flour are carbonates, so the total mass fraction of CaCO₃ + MgCO₃ in terms of dry matter is equal to 95.17% (including the proportion of Ca - 37.27%).

As an alternative to limestone flour, technogenic calcium carbonate was considered, the chemical composition and properties of which are presented below. The product corresponds to technical conditions 2144-028-00206486-2008.

Obtaining self-compacting concrete mixtures is impossible without the use of modern additives, which are based on various kinds of polymeric compounds, such as polyaryls, polycarboxylates [16-18].

The work investigated the effect of various kinds of additives on the rheology of flooded systems.

Additives that have been reviewed cover the full range of these products on the market. The remaining uncovered names are just a combination of them.

Types of additives used:
- Polyaryls (Polyheed 4030, manufactured by BASF);
- Polycarboxylates (Glenium 430, manufactured by BASF);
- Lignosulfonates (Centrament P 40, manufactured by MC Bauchemie);
- Naphthalene sulfonates (Muraplast FK 48, manufactured by MC Bauchemie).

According to the above, it is advisable to make a study of the rheological characteristics of water systems of technogenic calcium carbonate and limestone flour, as well as the effect of various additives on the characteristics of this system.

To accomplish the tasks set in the work, it is necessary to carry out a dispersion analysis, which will allow a more thorough analysis of the particle size distribution of the used powder type fillers. And also you need to choose the optimal dosage and type of additives used.

Experimental studies were performed using standard and special methods.

The ANALZSETTE 22 Nano Tec laser analyzer was used to determine the dispersed parameters (particle size and particle size distribution functions), particle size distribution and analysis of the shape of technogenic calcium carbonate and limestone flour.

The study of the rheological characteristics of flooded systems (ultimate shear stress and the value of "effective" viscosity) was carried out using a rotational-type viscometer RV-8.

To obtain each of the systems 100 grams of conversion calcium carbonate (or limestone flour) were weighed and placed into a bowl, previously rubbed with a damp cloth. Then a recess was made in the powder, in which water was poured into one intake in an amount calculated on the basis of the specified water-hard ratio. Then 30 seconds after the addition of water, they were stirred until a homogeneous mass was obtained. The additive was introduced with the mixing water. The dosage of the additive was increased until the water-solid ratio ceased to depend on its
quantity, only after that the experiment was stopped. In the study, the fundamental point was to maintain a constant "effective" viscosity when changing the dosage of additives.

RESULTS OF EXPERIMENTAL STUDIES

Disperse analysis of technogenic calcium carbonate and limestone flour was carried out (the studies were carried out at the Center for Collective Use named after Professor YM Borisov of the VSTU (http://ckp-vrn.ru).

From the data of the histogram (Figure 1), it can be seen that the distribution of particles is normal. At the same time, the distribution region for technogenic calcium carbonate can be seen as the interval from 10 nm to 100 nm, while for limestone flour is from 0.5 nm to 50 nm.

Particles of technogenic calcium carbonate are presented in the form of compositions close to spherical shape, which is probably the result of the free growth of CaCO3 crystals during its synthesis during the technological process.

It was established that the conversion of calcium carbonate is represented by a fine powder with an average grain size of ~ 60 μm, for limestone flour this indicator is ~ 10 μm.

![Integral histograms of the particle size distribution of the studied powders](image)

Figure 1. Integral histograms of the particle size distribution of the studied powders: a) technogenic calcium carbonate; b) limestone flour.

Taking into account the specificity of the particle size of technogenic calcium carbonate, determined by dispersion analysis, as well as its close to monomineral composition, corresponding to natural raw materials, it was suggested that it can be used as a mineral filler in self-compacting concrete mixtures.

Due to the experiment, the following relationships were obtained for the two systems under study (Figure 2 and Figure 3).
Considering the distinctive relationships obtained for this system, we can conclude that all the considered additives can reduce the water-hard ratio while maintaining a constant value of the "effective viscosity".

It is established that for the system relationships are described by polynomials of the 4th order.

So the additive based on lignosulfonates (Centrament P 40), at a dosage of 1.2% by weight of solids, reduces W/S to a value of 0.316; the naphthalene formaldehyde sulfonic acid condensation product (Muraplast FK 48) reduces W/S to 0.292 in the same dosage; polycarboxylates (Glenium 430) reduce W/S to 0.28; polyaryls (Polyheed 4030) reduce W/S to 0.268.

Thus, a maximum reduction in W/S can be achieved using a polyaryl-based plasticizer. In this case, polycarboxylates are less effective.

Based on the relationships obtained, the optimal dosage is 0.4% by weight of the solid.

In the system of “limestone flour and water,” it is also possible to observe a decrease in the water-solid ratio with the introduction of various kinds of additives into the system.

Figure 2. Dependencies of water-solid relationship in the system of calcium carbonate conversion + water.
However, unlike the first system, with the introduction of small dosages of additives such as Polyheed 4030 (polyaryls) and Glenium 430 (polycarboxylates), an increase in the water-solid ratio occurs, perhaps due to the fact that limestone flour has a higher dispersion.

It was also found that relationships that can be described by fourth-order polynomials are characteristic of this system.

Additives based on polyaryls and polycarboxylates are more effective in the “limestone flour + water” system since their use allows a lower water-solid ratio to be obtained because the former reduce \( W/S \) to 0.182 and the latter to 0.175. The condensation product of naphthalene formaldehyde sulphonic acid (Muraplast FK 48) reduces \( W/S \) to 0.21. Additive based on lignosulfonates (Centrament P 40) - up to 0.25.

In this system, based on the obtained relationships, it is optimal to use an additive based on polycarboxylates at a dosage of 1% by weight of solid matter.

**CONCLUSIONS**

The obtained data on the dispersed composition of limestone flour and technogenic calcium carbonate in the future will allow the selection of the optimal composition of the concrete mix on the latter, which will make it possible to abandon the expensive natural filler.
Mathematical models describing the relationship of the water-solid ratio on the mass fraction of the additive, which can be described by fourth-order polynomials, have the following form:

\[
\frac{W}{S} = a \times d^4 + b \times d^3 + c \times d^2 + f \times d + k
\] (1)

This model allows one to choose the optimal dosage of the additive for various systems.

The optimal dosages of the studied additives were found, which will be used in the future for the selection of concrete mixtures.

REFERENCES