Comparative tests of cements in concrete mixtures of high mobility

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Abstract. The paper presents the results of comparative tests of imported and local cements in highly mobile concrete mixtures of various classes and brands. It is proved that on the basis of local cement it is possible to obtain concrete of any grades in terms of workability and grades in compressive strength up to B45. Various factors affecting the stability of the composition and properties of the concrete mixture are considered. Recommendations on their use in high strength concrete are proposed.

1. Introduction

In recent decades, as you know, high-rise construction is widely developed, where monolithic concrete mixtures of various grades and classes are used [1, 2]. With the intensification of the construction process, the requirements for concrete mixes and concrete have noticeably increased [3]. Instead of the usual concrete mixes of grades of workability from P1 to P3, highly mobile concrete mixtures of grades P4, P5 (for draft of cone) or P4, P5, P6 (i.e. grade of mix for spread of cone) have been increasingly used recently. Undoubtedly, such high-quality, highly mobile (cast) concrete mixes require special approaches in their preparation, dosing of raw materials, mixing and compaction [5, 17].

The strength of the future composite on clean, high-quality aggregates that meet the requirements of the relevant standards, and proper compaction will also depend on the activity and normal density of the binder, W/C concrete mix, i.e. from the qualitative indicators of the latter [6, 18].

As you know, the workability of concrete mixtures is influenced by a number of factors [7–11]:

- the ratio between binder and aggregates;
- the ratio between small and large aggregates;
- water demand and quality, astringent;
- water-cement ratio of concrete mix, etc.
In addition to the factors listed above, the workability of the mixture is affected by the nature and shape of the aggregate grains, the presence of fine aggregate, mineral filler, chemical modifiers, etc. [12–16, 20–22].

At construction sites in the Chechen Republic, such as the Grozny Mall Shopping and Entertainment Center, the Akhmat Tower multifunctional high-rise complex, the Grozny TPP, etc., high-quality highly mobile concrete mixes and high-strength concrete based on them are regularly used [19, 23, 24].

To develop technological maps for the selection of optimal recipes for high-quality concrete mixtures of various grades and classes, we conducted comparative studies of local and imported binders and aggregates to increase the efficiency of use of local resources.

2. Methods and materials

The technological properties of concrete mixtures were studied, namely, water holding capacity (water separation), sedimentation (separation), uniformity (uniform distribution of aggregate grains throughout the volume) of concrete mixtures.

In the experimental and control compositions, Portland cement of different manufacturers was used – the imported PC M500 D0 Novoroscement and the local PC M500 D0 GUP Chechencement.

PC M500 D0 Novoroscement is characterized by the following indicators: normal density (ND) is 26.2 %, specific surface area of particles is 3132 cm$^2$/g, water separation of cement paste is not more than 16 %, setting time: start – 2 hours. 25 minutes, and the end – 3 hours. 45 minutes.

The characteristics of the M500 D0 PC of the Chechencement State Unitary Enterprise are close to the M500 D0 Novoroscement PC, but there are differences in the following indicators: ND = 25.5 %, specific surface 3260 cm$^2$/g, water separation – more than 18 %, setting time – 2 hours. 15 minutes. (beginning) and 3 hours. 40 min (end).

The local crushed stone of the Argun deposit of ordinary quality was used as a large aggregate: the crushability mark in the cylinder was 800; bulk density – 1372 kg/m$^3$; true density – 2627 kg/m$^3$; the content of dusty and clay particles is 0.5–0.9 %; the content of crushed grains is more than 83 %; voidness – 41.5 %.

Fine aggregate – the local natural sand of the Chervlenskoye field, despite the fineness of its grains, is most common in the region due to the lack of higher quality sand deposits. The nature of the shape of the grains of Chervlensky sand is rough, irregular in shape, mostly monofractional: the particle size modulus is not more than 1.6-1.9, which classifies it as fine sand; the content of dusty and clay particles is 1.5–1.95 %; bulk density – 1528 kg/m$^3$; true density – 2623 kg/m$^3$; voidness – 43.4 %.

The experimental and control compositions of concrete mixtures of different grades in terms of workability, obtained by calculation and theoretical methods and corrected by trial mixtures, are presented in table 1.

Experimental studies were carried out in the accredited testing laboratory of the scientific and technical center for collective use "Modern building materials and technologies" of the Grozny state oil technical university named after academician M.D. Millionschikova.

Also, in the studied compositions of concrete mixtures, a chemical additive was used – the Linamix PK superplasticizer in the amount of 1.1 % by weight of cement. The quality indicators of the Linamix PK additive are as follows: liquid (brown) with a solution density of 1.03–1.08 g/cm$^3$; pH value – not less than 8.0 ± 1; the recommended dosage is 0.3–2.5 % by weight of cement.

The mineral filler from concrete scrap and brick fight was not specifically used to make it easier to identify signs of water separation of concrete mixtures.

3. Results

The results of comparative tests, binders in highly mobile concrete mixtures obtained using the above raw materials are presented in tables 1 and 2.
Table 1. Compositions of high-movable concrete mixes for comparative tests of binders

| Composition number | W/C | Consumption of materials per 1 m³ of concrete, kg |
|--------------------|-----|-----------------------------------------------|
|                    |     | SC | S | C | A | W |
| 1                  | 0.41| 1200 | 620 | 400* | 4.4 | 163 |
| 2                  | 0.44| 1190 | 613 | 175 |     | 175 |
| 3                  | 0.47| 1180 | 608 |   |     | 188 |
| 4                  | 0.42| 1200 | 620 | 400** | 4.4 | 166 |
| 5                  | 0.45| 1187 | 614 |   |     | 180 |
| 6                  | 0.49| 1180 | 610 |   |     | 195 |

Note to table 1: * – Portland cement grade PC M500 D0 GUP "Chechencement"; ** – Portland cement of the brand PC M500 D0 Novoroscement; W/C – water-cement ratio; SC – crushed stone consumption; S – sand; C – cement; A – additive; W – water.

Table 2. Results of comparative tests of binders in highly movable concrete mixtures

| Composition number from the table 1 | Mark on the draft of the cone, cm | The density of the mixture, kg/cm³ | Water separation, % by weight | Solution separation, % by weight |
|--------------------------------------|----------------------------------|-----------------------------------|-----------------------------|---------------------------------|
| 1                                    | P3                               | 2387                              | 0,3                         | 2                               |
| 2                                    | P4                               | 2383                              | 0,4                         | 2                               |
| 3                                    | P5                               | 2378                              | 0,6                         | 4                               |
| 4                                    | P3                               | 2392                              | 0,1                         | 1                               |
| 5                                    | P4                               | 2385                              | 0,2                         | 1                               |
| 6                                    | P5                               | 2380                              | 0,3                         | 2                               |

Indices of uniformity and stability of concrete mixes must meet the requirements presented in GOST 7473-2010 “Concrete mixtures. Technical conditions ”[8] (table 2).

Table 3. Requirements for breadability of concrete mix [8]

| The mobility or stiffness of the mixture | Separation of concrete mix, %, no more | Separation of concrete mix, %, no more |
|----------------------------------------|----------------------------------------|----------------------------------------|
| Z1 – Z5                                | 0,2                                    | 3                                      |
| P1 – P2                                | 0,4                                    | 3                                      |
| P3 – P5 и P1 – P6                      | 0,8                                    | 4                                      |

Since the delamination of concrete mixtures characterizes the quality of the latter, in addition to the density of the concrete mix and the grade of the sediment cone, we mainly studied the indicators of solution separation and water separation, which, as a rule, evaluate the delamination of the mixture.

The solution separation of the concrete mix with coarse aggregate, characterizing its delamination under dynamic action, was determined by comparing the content of the mortar component in the lower and upper parts of the concrete mix, compacted in a measuring vessel or mold.

For this, the concrete mixture was laid out in a measuring vessel (mold) and compacted in accordance with GOST 10180-2012. The compacted concrete mixture was additionally vibrated on a laboratory vibratory platform for 10 seconds.

After additional vibration, the upper layer of the concrete mixture with a height of about half the height of the measuring vessel (mold) was selected on a previously weighed baking sheet, and the mixture remaining in the lower part of the measuring vessel (mold) was vibrated until the surface of the mixture was leveled. Then, the height of the layer of the HH mixture remaining in the lower part of the measuring vessel (shape) was measured with an error of up to 5 mm, and the height of the selected layer of the mixture of HB was calculated. The remaining mixture was laid out on a second weighed baking sheet.

Divided into two samples, the concrete mixture from the upper and lower parts of the measuring vessel (mold) was weighed and wet sifted on a sieve with holes with a diameter of 5 mm. During wet sieving, each sample of the mixture laid out on a sieve was washed with a stream of clean water until the cement-sand mortar was completely removed from the surface of the coarse aggregate grains.
The washed coarse aggregate from each sample of the concrete mixture was transferred onto a clean baking sheet, dried to constant weight at a temperature of $(105 \pm 5)^\circ C$ and weighed.

The mass of the solution component in the samples of the upper and lower parts of the measuring vessel (form), considering the volume of the sample taken, was determined by the formulas:

$$m_{R,U} = \frac{(m_{CM,U} - m_{C,U}) \cdot 0.5H}{H_U}$$  \hspace{1cm} (1)

$$m_{R,D} = \frac{(m_{CM,D} - m_{C,D}) \cdot 0.5H}{H_D}$$  \hspace{1cm} (2)

where $m_{R,U}, m_{R,D}$ – the mass of the mortar component of the mixture located in the upper and lower parts of the measuring vessel (form), g;

$m_{CM,U}, m_{CM,D}$ – mass of concrete mixture selected from the upper and lower parts of the measuring vessel (form), g;

$m_{C,U}, m_{C,D}$ – mass of dried coarse aggregate contained in samples from the upper and lower parts of the measuring vessel (form), g;

$H$ – height of a measuring vessel (form), mm;

$H_U, H_D$ – the actual height of the upper and lower layers of the mixture.

Mortar separation of concrete mix $\Pi_R$, %, was determined by the formula:

$$\Pi_R = \frac{m_{R,U} - m_{R,D}}{m_{R,U} + m_{R,D}} \cdot 100$$  \hspace{1cm} (3)

The solution separation of each concrete mixture sample was determined twice and calculated with rounding to 1 % as the arithmetic mean of the results of two determinations that differ by no more than 20 % of the average value. With a larger discrepancy between the results, the test was repeated on a new sample of concrete mix.

The test results of concrete mixtures for solution separation are presented in table 2.

The water separation of the concrete mixture was determined after it was settled in a measuring vessel or mold for a certain period of time.

For this, the concrete mixture was placed in a measuring vessel (mold) and compacted on a vibrating platform for 10 seconds. The level of the concrete mixture was $(10 \pm 5)$ mm below the upper edge of the measuring vessel (mold). After that, the mold (vessel) was covered with a sheet of vapor-tight material (glass) and left alone for 2 hours.

The separated water was taken with a pipette every 15 min, collecting it in a glass with a lid and weighing it at the end of the test.

The water separation of the concrete mixture $\Pi_U$, in %, characterizing the volume of water released from the concrete mixture in 2 hours, referred to the volume of concrete mixture in a measuring vessel (form), and was calculated by the formula:

$$\Pi_U = \frac{m_U}{\rho_U \cdot V_{CM}} \cdot 100$$  \hspace{1cm} (4)

where $m_U$ – mass of separated water, g;

$\rho_U$ – the density of water, taken equal to 1 g/cm$^3$;

$V_{CM}$ – the volume of concentrated concrete mixture, cm$^3$.

Water separation was determined twice for each concrete mixture sample and was calculated with rounding to 1 %, as the arithmetic mean of the results of two determinations that differ from each other by no more than 20 % of the average value. With a larger discrepancy between the results, the test was repeated on a new sample of concrete mix.

The test results of concrete mixtures for water separation are also presented in table 2.

The analysis of tables 1 and 2 showed that with the transition to higher grades according to the cone sediment (from P3 to P5), the delamination parameters (water and solution separation) of concrete mixtures at the M500 D0 PC of the Chechencement state enterprise in comparison with concrete mixtures at the M500 PC D0 Novoroscement is much closer to the limit of permissible values.
according to GOST 7374-2010 [8], according to which the water separation should not be more than 0.8 % by mass, and solution separation should not exceed 4 %.

These indicators of the control compositions of concrete mixtures at the imported processing center M500 D0 Novoroscement are noticeably stable. This can be explained by the fact that this Portland cement initially has a lower water separation (no more than 16 %), when the same indicator at the M500 D0 Chechencement is more than 18 %.

Figure 1. Comparison of concrete mixtures: a – high-quality mixture at the PC M500 D0 Novoroscement; b – with signs of water separation and stratification at the human processing center M500 D0 of the State Unitary Enterprise “Chechencement”

Naturally, the control and experimental compositions presented in Table 1 meet the requirements of GOST 7374-2010 and had a compressive strength class of B22.5. However, as additional studies of similar compositions with a higher specified strength (concrete classes B50-B60) and mobility over a cone melt of 56–62 cm (P5) and more than 62 cm (P6), in which the consumption of cement and water are much higher than in low-grade concretes, in highly mobile concrete mixtures at the M500 D0 Processing Center of the Chechencement State Unitary Enterprise, signs of water separation and delamination could be seen (Figure 1). Although there was no apparent water and solution separation.

In highly mobile concrete mixtures of low grade B25-B40 concrete at the local PC M500 D0 of the Chechencement state unitary enterprise, signs of water separation and separation are not observed. This phenomenon can be found in highly mobile concrete mixtures of higher classes of concrete (B50 and above), for which the value of the coefficient r, which characterizes the ratio of sand consumption to crushed stone consumption and determined by formula (1), decreases markedly.

\[ r = \frac{\Pi}{C} \] (5)

where \( \Pi \) – is the consumption of sand in the concrete mixture, kg; \( C \) – crushed stone consumption in concrete mix, kg.

For concrete of not high classes (B40 and lower), the index r, as a rule, is in the range of 0.48–0.6. r noticeably decreases (to 0.3–0.4) when switching to high-grade concrete (B60-B80 and higher), in concrete mixtures of which the binder consumption increases with an equal replacement of a fraction of a fine aggregate with a higher water retention capacity than grains of large aggregate (crushed stone). And the attempt to switch to high classes of concrete, while maintaining the r value by simultaneously reducing the fraction of crushed stone and sand, contributes to the violation of the high-density packing of coarse aggregate grains, the “rigid skeleton” of which forms the basis for the high strength of the future concrete composite.
4. Conclusion
Thus, on the basis of the comparative studies, it can be concluded that one of the most rational solutions to the problem of using locally produced cement in high-quality concrete mixes and concretes is its use either for middle-class concrete in compressive strength (B25-B45), or to obtain it is based on filled binders with a mineral filler of various nature with a higher water retention capacity (for example, filler from concrete scrap and brick fight), characterizing Xia high stability and rheology, which are suitable for both low and medium concrete classes, and for the high-active and high-strength concretes (B50 and above).

Acknowledgment
This work was carried out as part of research on the implementation of scientific project No. 05.607.21.0320. “Development of technology for new building composites on clinkerless alkaline binders using substandard natural and secondary raw materials” that received support from the federal target program “Research and Development in Priority Directions for the Development of the Russian Science and Technology Complex for 2014–2020”. Unique Agreement Identifier RFMTF60719X0320. This work was carried out as part of research on the implementation of scientific project No. 18-48-200001 “High-quality concrete with enhanced performance properties based on local natural and technogenic raw materials,” which received support from the Russian Foundation for Basic Research (RFBR).

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