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# Study of the influence of fine fillers from technogenic waste and chemical additives on the properties of self-compacting concrete

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**Abstract**: The article is devoted to the researches considering the influence of various chemical additives and fine fillers (industrial wastes) available in the Republic of Kazakhstan on concrete mixes and concrete rheological and physical-technical properties. The article provides laboratory studies results of some of self-compacting concrete (SCC) mixtures properties. There were identified the most efficient type of fine-dispersed filler and the most optimal type of chemical additive to be able to get a high-quality SCC mix and a concrete with the class of B25 based on local raw materials. There were enlisted compositions of SCC with a high strength in early terms. The research results are of practical value in the forms of economic efficiency and quality improvement in the production of SCC mixes for manufacturers of ready-mixed concrete operating in the Republic of Kazakhstan.

**Keywords:** workability, conservability, concrete strength, chemical additives, self-compacting concrete, fine aggregate.

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## Introduction

Modern construction requires a variety of building materials with different property complexes. In this regard, high hopes are associated with the improvement of self-compacting concrete (SCC) technology, a material that will soon be widely used in the construction industry of the Republic of Kazakhstan [2]. In recent years, in construction practice abroad, during the production of new-generation concrete, the development of DMS compositions, which is a material that can be compacted under the influence of its own weight, filling the form even in densely reinforced structures, has become more and more inclined to [3]. This type of heavy concrete has a great future in monolithic construction, prefabricated concrete production, reinforcement of concrete and reinforced concrete structures for various purposes, as the use of this type of concrete allows you to abandon the traditional paving of concrete with the use of vibrocompaction, optimize labor costs and improve sanitary and hygienic working conditions [2]. SCC is the subject of research by scientists from all over the world. At the moment, there are studies that prove the possibility of creating a high performance SCC with high physical and technical characteristics, as well as the possibility of successful application of fibre reinforcement and application of various industrial wastes [4-6]. The use of SCC greatly reduces the impact of noise pollution on people and the environment during construction, allowing for concrete work in densely populated urban areas and even at night. However, such a sharp difference of the SCC from the traditional classical heavy concrete with the given physical and technical properties poses a number of serious problems to the researchers in the field of concrete science, which require a systematic and step-by-step approach to the prediction of the properties of the SCC, description of the rheological properties of cast concrete mixtures, the optimal distribution of fillers in the concrete matrix, as well as the establishment of dependencies that assess the impact of fine-graded fillers on the characteristics of self-compacting mixtures. Thus, a systematic approach is needed to predict and regulate its properties depending on the tasks set before the researchers [7]. During the construction process, there is a problem of easy paving of concrete mix, which affects the labor costs, timing and cost of construction. In this regard, it is necessary to use a new generation of chemical additives. Chemical additives provide an increase in the decidability of concrete mix, stability to stratification; increase the structural homogeneity of concrete and its strength at an early age of hardening. In addition, according to Professor V.I. Kalashnikov, one of the ways to solve the abovementioned problems is to provide high expansion[1] of coarse aggregate grains. It is impossible to solve this problem by additional application of chemical additives, as it will lead to separation of concrete mixture, and application of fine-dispersed filler gives positive result, especially as it does not lead to loss of durability of SDS in comparison with usual concrete [8]. The purpose of the conducted scientific researches was to study the influence of finely dispersed micro-fillers and various types of chemical additives on rheological and physical-technical properties of the SCC.

[1] Grain expansion coefficient is the ratio of the volume of the mortar part of the concrete mixture to the volume of voids between the coarse aggregate grains

## Research methods

This paper uses theoretical and empirical research methods. Theoretical research was carried out in order to get acquainted with the existing compositions of concrete mixtures of DMS, to determine the direction of work, to focus on the use of components that are industrial wastes. The empirical studies were aimed at experimental confirmation of theoretically developed composition and methods of SDS production.

The workability (mobility) and stability of concrete mixtures were determined according to [16]. According to this standard, the mobility of the concrete mixture is estimated by the sediment of cone (hereinafter – SC) molded from the concrete mixture. The standard Abrams cone is used. The SC of the concrete mixture is determined twice. The total test time from the beginning of filling the cone with the concrete mixture at the first determination to the moment of SC measurement at the second determination should not exceed 10 minutes. Moreover, the SC of the original sample concrete mixture shall be calculated with rounding to 1.0 cm as the arithmetic mean of the results of the two determinations, which differ from each other for not more than:

- 1 cm for cone draught up to and including 9 cm;
- 2 cm with a cone draft of 10 to 15 cm;
- 3 cm for cone draught of 16 cm or more.

If the difference is higher than the aforementioned, the test is repeated on a new batch of concrete of the same composition.The stability of the concrete mixture is determined by the establishment of mobility at certain intervals from the time of preparation of the mixture [16].

The standard Abrams cone is used to determine the cone melt of the self-compacting concrete. The cone and the metal sheet are wetted, and then the cone is placed on the metal sheet with a smaller base to the sheet surface. The concrete mixture is poured until the cone is completely filled in one step. The cone is lifted within 5-7 seconds, and after the mixture has stopped completely, the two largest melt diameters are measured. The arithmetic mean of the two largest melt diameters is the result of a test.

This study was conducted in four stages, each of which was aimed at solving a specific problem (Fig. 1).

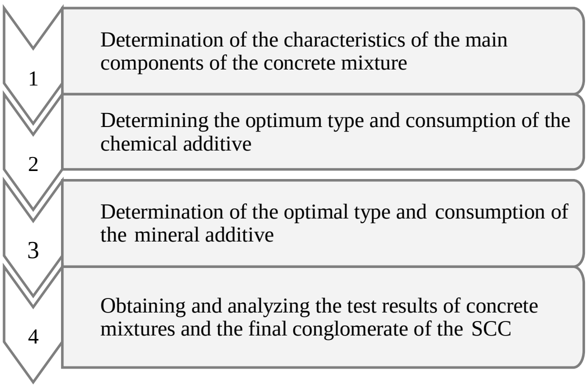


**Figure 1** Stages of work

The research methodology is aimed at comparing the rheological and physical-technical characteristics of the concrete mixture obtained as a result of mathematical planning of the experiment by varying the components of the DBMS. All researches and tests were carried out according to the normative documentation operating in the territory of the Republic of Kazakhstan.

## Input materials

Local raw materials were used in the work, as well as fine-graded fillers made of waste from the Kazakhstan industry, and a number of chemical additives proposed by Ariranggroup were studied as hyperplasticizers.

M400D20 cement produced by Semey Cement Plant LLP (Semey, Kazakhstan) was used as a binder for the concrete mixtures under study. To confirm the compliance of the selected binder with the norms and requirements [9] a number of tests were conducted. The methods specified in these standards allow to define the following parameters of the building material:

1) Grinding fineness:

The binder under study showed a grinding fineness of 94.4%.

2) Normal density and setting time of cement dough:

The binder under test showed a normal density of 27.30 %. The cure started after 2 hours and 11 minutes, and the cure ended after 4 hours and 10 minutes of cure. These values are included in the normalized area.

3) Compressive and bending strength (at the age of 28 days):

In determining the strength characteristics of the investigated binder showed the result at the age of 28 days: bending - 5.6 MPa; compression - 42.4 MPa. These parameters are included in the normalized area.

For carrying out of tests the sand of the manufacturer "Mark" LLP (Almaty region, Kazakhstan), corresponding to the standard document [10] was used. According to this standard, sands with a maximum amount of dusty and clayey inclusions for groups of increased size, large and medium in size of 3%, can be used as fine aggregate for heavy concrete, under the definition of which the SCC will fall under, [10]. However, according to the results of laboratory and production tests [11], in order to obtain satisfactory characteristics of the concrete mixture and the final conglomerate of the DLS it is necessary to use sand, the amount of dusty inclusions in which does not exceed 1.5% [11]. Testing to determine the amount of dusty and clayey inclusions of the sand under consideration was carried out by the method of soaking according to [12]. According to the test results, the content of dusty and clayey inclusions in the sand under study was 1.08%. Also, according to [12] by sieving and determining the grain composition of the aggregate, was determined by a modulus of grain size of the sand under study, which was 2.6. These parameters are acceptable for the use of the investigated aggregate both in heavy concretes and in the DBMS in particular.

As a coarse aggregate, 5-10 mm and 10-20 mm crushed stone produced by KENTAS LLP (Almaty region, Kazakhstan) with known physical and technical characteristics was accepted. This aggregate meets the requirements of the regulatory document [13], which defines the basic requirements for crushed rock from dense rocks, used as a filler for heavy concrete, including the SCC.

The following chapters discuss the steps for determining the types and costs of chemical and mineralogical additives for SDR based on laboratory testing. The effectiveness of the chemical and mineralogical additives is based on the data obtained from the testing of concrete mixtures and the final conglomerate.

Within the limits of the given research laboratory tests of a concrete mix with application of the following additives-hyperplasticizers of manufacture of factory of "Ariranggroup" (Nur-Sultan, Kazakhstan) on conformity to requirements [14] are carried out:

1. Polycarboxylate ether (hereinafter – PCE);
2. Polycarboxylate ether + Lignosulphonate (hereinafter – PCE+Lig);
3. Naphthalene sulfonate (hereinafter – SNF);
4. Naftalin sulfonate + Lignosulphonate (hereinafter – SNF+Lig);
5. Lignosulphonate (hereinafter – Lig).

## Experiemental studies

Determining the optimum type and consumption of the chemical additive.

The primary task was to determine the effectiveness of each of the presented chemical additives in terms of the parameters of paving properties and the stability of the concrete mixture. To carry out the tests it was necessary to determine the basic composition, taking the following corrections [15]: the amount of water in all compositions to take equal to 135 kg/m3, mark on the paving of concrete mixtures - P4-P5, the consumption of additives - 1% of the mass of cement. The composition presented in Table 1 below was accepted as a base one:

**Table 1** Basic composition [15]

| Cement, kg/m3 | Sand, kg/m3 | Crushed stone, kg/m3 | Water, kg/m3 |
|---|---|---|---|
| 350 | 850 | 1065 | 135 |

**Table 2** Test results to determine the suitability and stability of the studied compositions

| Type of additive | W/C | Cement, kg/m$^3$ | Sand, kg/m$^3$ | Crushed stone, kg/m$^3$ | Additive, kg/m$^3$ | Water, kg/m$^3$ | SC, cm | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | After the production | After 30 minutes | After 60 minutes | After 120 minutes |
| PCE | 0,39 | 350 | 850 | 1065 | 3,5 | 135 | 22 | 22 | 21,5 | 21 |
| PCE+Lig | 0,39 | 350 | 850 | 1065 | 3,5 | 135 | 21 | 21 | 19 | 14 |
| SNF | 0,39 | 350 | 850 | 1065 | 3,5 | 135 | 17 | 16 | 14 | 11 |
| SNF+Lig | 0,39 | 350 | 850 | 1065 | 3,5 | 135 | 19 | 18 | 16 | 12 |
| Lig | 0,39 | 350 | 850 | 1065 | 3,5 | 135 | 20 | 19 | 17 | 13 |

The results of the conducted tests, reflected in Table 2, show that the concrete mixture with the use of PCE chemical admixture has acquired the largest amount of OK, which indicates its best water-reducing capacity in comparison with other admixtures. It is also worth noting that this mixture also has the best retention rate.

In order to determine the effect of the type of chemical additive used on the paving properties of the self-compacting concrete mixture, a number of experiments had to be carried out.

The aim of the experiment was to obtain a concrete mixture of SCC with the same cone melt according to [18] and to obtain data on the compressive strength of the studied compositions at the age of 1, 3, 7, 28 days. The experiment was carried out on the previously selected composition of SCC within the framework of the research conducted in 2016-2017 by the Scientific Research Institute of Building Materials and Design of NIISTROMPROEKT LLP in order to select the composition of SCC of M350 class B25 for monolithic construction [18].

**Table 3** CompositYion of SSC

| W/C | Cement, kg/m$^3$ | Sand, kg/m$^3$ | Cr. stone, 5-10 mm, kg/m$^3$ | Cr. stone, 10-20 mm, kg/m$^3$ | Additive, kg/m$^3$ | Silica, kg/m$^3$ |
|---|---|---|---|---|---|---|
| 0,3-0,4 | 500 | 999 | 468 | 252 | 10,45 | 50 |

According to [19], the SCC is classified into three classes of fitability (Table 4).

**Table 4** Classification of the SCC according to suitability

| Class | The cone's floating, mm |
|---|---|
| SF 1 | 550-650 |
| SF 2 | 660-750 |
| SF 3 | 760-850 |

In order to use the SCC in large-size and reinforced structures in order to obtain the required surface quality, the mixture should correspond to SF class 2 in terms of its suitability for laying, and the optimum is the melting of the cone of 68-75 cm. Therefore, [21] achieved a composition with 75 cm melt cone, adhering to the experience of previous studies.

However, in order to obtain results that reflect the effect of the chemical additive only on the properties of the self-compacting concrete and the mixture, adjustments have been made to the composition shown in Table 3: the fine aggregate is excluded, the additive is reduced to 1%.

Based on the results of the tests performed, the results were obtained as shown in Table 5.

**Table 5** – Test results of B25 (M350) concrete mixtures to determine the workability of the concrete mixtures

| Hyperplasticizer | W/C | Cement kg/m$^3$ | Sand kg/m$^3$ | Cr. stone, 5-10 mm, kg/m$^3$ | Crushed stone, 10-20 mm, g/m$^3$ | Additive, kg/m$^3$ | Water, kg/m$^3$ | Cone's floating, cm |
|---|---|---|---|---|---|---|---|---|
| PCE | 0,31 | 550 | 999 | 468 | 252 | 5,4 | 170 | 75 |
| SNF+Lig | 0,35 | 550 | 999 | 468 | 252 | 5,4 | 195 | 75 |
| SNF | 0,36 | 550 | 999 | 468 | 252 | 5,4 | 200 | 75 |
| PCE+Lig | 0,33 | 550 | 999 | 468 | 252 | 5,4 | 180 | 75 |
| Lig | 0,34 | 550 | 999 | 468 | 252 | 5,4 | 190 | 75 |

Table 5 shows that:

- when introducing PCE into the concrete mixture of the SCC, the desired characteristics of 75 cm cone melting can be obtained with the lowest water consumption for mixing the mixture;

- Concrete mixture with SNF has the highest water-cement ratio at 75 cm cone floating.

To obtain a complete picture of the influence of the additives under study on the characteristics of the final conglomerate of the SCC, tests were carried out in this paper to determine the compressive strength of the concrete compositions examined in Table 5. The results are shown graphically in Figure 2 below.

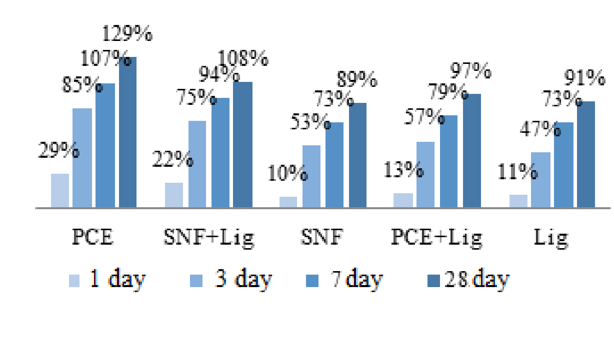


**Figure 2** Influence of chemical additives on the strength of concrete mix

If we consider the results of these studies in relation to the production of construction works, then, according to generally accepted methods [22], further loading of reinforced concrete structures can be made at the acquisition of strength of concrete at the rate of 70% of grade strength. Based on the results obtained, it is possible to give a high estimation of the effect of the RSE hyperplasticizer in the SCC. Thus, at the age of 3 days, this composition is gaining strength in the amount of 85% of the grade strength of concrete (B25), which will accelerate the pace of construction work. The highest index of strength at the age of 7 days (107%) and 28 days (128%) is also observed in the composition with the use of RFE. This effect is expected, as the application of RCE has caused the lowest water-cement ratio in the mixture. From which it can be assumed that the basic law [23] of concrete strength (the relationship between strength and water-cement ratio) in this case is not broken and works similarly in the SCC.

**Determination of the optimal type and consumption of the mineral additive.** The influence of fine aggregate on the properties of concrete was studied by many foreign scientists, the results of which can be used to conclude that micro-fillers affect the hydration of cement, and therefore the properties of self-compacting concrete mixture as a whole [21].

In order to determine the efficiency of application of fine mineral additives made of technogenic waste, similar to the previous tests were carried out in order to obtain concrete mixtures with the same spraying of cone (75 cm) and to determine the strength characteristics of concrete in different curing terms (3, 7 and 28 days).

As a fine-graded filler in this paper we considered:

- Microsilica of Tau-Ken Temir LLP (Karaganda, Kazakhstan);

- Slag of refined ferrochrome (hereinafter - Slag RFH) of JSC "Aktobe Ferroalloy Plant" (Aktobe, Kazakhstan);

- Fly ash from Almaty CHPP-1 (Almaty, Kazakhstan).

In addition to strength characteristics, the influence of the type and quantity of the mineral additive on the stability of the concrete mixture of the SCC with the use of hyperplasticizer PCE was considered.

In order to analyze the efficiency of mineral additives based on production wastes, the compositions of mixtures have been developed in order to obtain 75 cm cone melt. The compositions are presented in Table 6 below.

**Table 6** Compositions of concrete mixtures of SCC

| Component name | Quantity | Composition number | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Cement | kg/m$^3$ | 385 | 385 | 495 | 459 | 477 |
| Microsilica | | 0 | 0 | 55 | 51 | 53 |
| Fly ash | | 0 | 165 | 0 | 0 | 0 |
| Slag | | 165 | 0 | 0 | 0 | 0 |
| Water | | 160 | 180 | 165 | 160 | 160 |
| Sand | | 960 | 800 | 999 | 943 | 900 |
| Crushed stone 5-10 | | 438 | 550 | 468 | 472 | 489 |
| Crushed stone 10-15 | | 292 | 315 | 252 | 328 | 326 |
| Additive PCE | | 16,5 | 16,5 | 16,5 | 15,3 | 15,9 |

The previously described methods [16, 19] have determined the characteristics of the cone melting stability of the concrete mixtures under study. Test results are shown in Fig. 3.

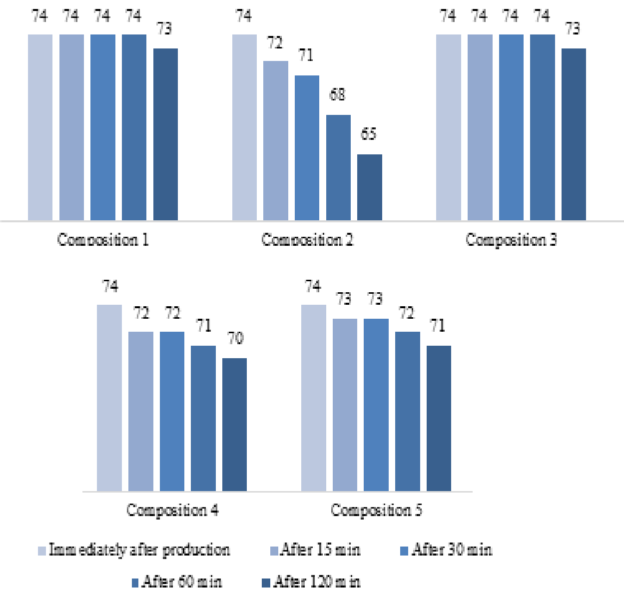


**Figure 3** Cone floating and persistence of concrete mixtures of different compositions, see

After the above characteristics were determined, cube samples with a rib length of 150 mm were formed (Fig. 4). Further, the test for determining the compressive strength of cubes at the age of 3, 7 and 28 days of hardening under normal conditions was carried out. The results are shown in Fig. 5.

**Figure 4** Concrete cube samples

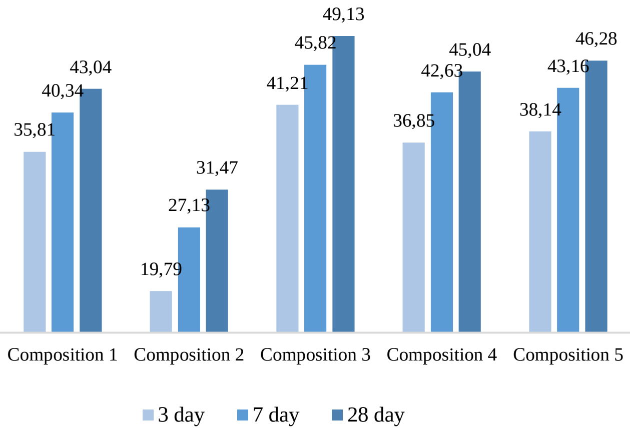


**Figure 5** Strength characteristics of the studied compositions, MPa

## Discussion of research results

Based on the results of the tests performed, the following can be assumed:

- the mixture with the inclusion of fly ash has the highest water requirement, which affects the strength characteristics of the final conglomerate (the lowest strength of the presented compositions) and the reduction of the mixture persistence;

- the highest strength index shows composition 3 with inclusion of microsilica and the highest cement content, however, this consumption has no effect on the stability of the mixture.

Thus, slag and microsilica are considered acceptable for use. However, it is the microsilica that should be used to obtain the high strength characteristics of the SCC.

### Conclusion

Studies have shown that the use of hyperplasticizers based on PCE polycarboxylate esters gives the following effect:

– maintaining the mobility (workability) of the concrete mixture for 2 hours from the time of manufacture.

– the strength of concrete is 107% for 7 days.

When using RFC slag as a micropolluting agent, it is possible to obtain the required shrinkage capacity at W/C=0.41, with satisfactory retention and high strength at early curing times.

When using fly ash, the test results are comparatively worse - a decrease in the cone melt in time is observed. Despite the high water-cement ratio of 0.47, the conglomerate strength in the early curing time is much lower than that of other studied compositions.

At introduction in structures of the various maintenance of microsilica, the concrete mix and concrete with the expense of cement 495 kg and microsilica in quantity of 55 kg/m$^3$ possesses the best characteristics. This composition has the highest strength characteristics at the age of 3 days, as well as a satisfactory preservation of the mixture at a water-cement ratio of 0.33.

Concretes with the use of hyperplasticizers based on PCE polycarboxylates and fine fillers based on microsilica and RFC slag can be classified as "highly-productive" [24], which have high transportability and patchability at the stage of freshly prepared mixture, and in the hardened form – a fast set of strength.

From the received data it is possible to draw a conclusion that for reception of a set of durability of SUB in early terms (for example, 2 days), builders should resort along with increase in the expense of cement to following technological receptions, such as introduction in structure of concrete of fine-dispersed fillers (microsilica and slag RFH), and also decrease in a water-cement parity by introduction of high enough quantity of the chemical additive on the basis of polycarboxylates PCE. If it is necessary to reduce the consumption of astringent introduction of microsilica or similar mineral additives allows to preserve the physical and technical characteristics of conglomerate [25, 26].

As a whole, it is necessary to note that the purpose of work and the set tasks have been successfully realized, the necessary results for successful practical application have been received.

## Source of research funding

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## Өндірістік қалдықтар мен химиялық қоспалардан бөлінген толтырғыштардың өздігінен тығыздалатын бетонның қасиетіне әсерін зерттеу

**Е.Б. Утепов, Д.А. Ахметов, И.Т. Ахматшаева, Е. Н. Роот**

**Түйіндеме.** Мақала Қазақстан Республикасында қол жетімді әр түрлі химиялық қоспалар мен майда бөлінген толтырғыштардың (өндірістік қалдықтардың) бетон қоспалары мен бетонның реологиялық және физикалық-техникалық қасиеттеріне әсерін зерттеуге арналған. Мақалада өздігінен тығыздалатын бетон қоспаларының (ӨТБ) кейбір қасиеттерін зертханалық зерттеу нәтижелері келтірілген. Жергілікті шикізаттан В25 класының жоғары сапалы өздігінен тығыздалатын және бетон қоспасын алуға арналған тиімді бөлінген толтырғыштың және химиялық қоспаның оңтайлы түрі анықталды. Беріктендірудің алғашқы кезеңдерінде жоғары беріктігі бар өздігінен тығыздалатын бетонның композициясы келтірілген. Жұмыстың нәтижелерінің Қазақстан Республикасының аумағында жұмыс істейтін дайын бетон өндірушілер үшін практикалық маңызы бар.

**Түйінді сөздер:** жұмыс қабілеттілігі, қасиеттердің сақталуы, бетонның беріктігі, химиялық қоспалар, өздігінен тығыздалатын бетон қоспасы, ұсақ дисперсті толтырғыш.

# Исследование влияния мелкодисперсных наполнителей из техногенных отходов и химических добавок на свойства самоуплотняющихся бетонов

**Е.Б. Утепов, Д.А. Ахметов, И.Т. Ахматшаева, Е. Н. Роот**

**Аннотация:** Статья посвящена исследованиям, рассматривающим влияние различных типов химических добавок и мелкодисперсных наполнителей (техногенных отходов), имеющихся в Республике Казахстан, на реологические и физико-технические свойства бетонных смесей и бетона. В статье приводятся результаты лабораторных исследований некоторых свойств самоуплотняющихся бетонных смесей (СУБ). Выявлен наиболее эффективный вид мелкодисперсного наполнителя и оптимальный тип химической добавки для получения высококачественной смеси СУБ и бетона класса В25 на местных сырьевых материалах. Приведены составы СУБ с высоким набором прочности в ранние сроки твердения. Результаты проведенных работ представляют практическую ценность для заводов-изготовителей товарного бетона, действующих на территории Республики Казахстан.

**Ключевые слова:** Удобоукладываемость, сохраняемость, прочность бетона, химические добавки, самоуплотняющаяся бетонная смесь, мелкодисперсный наполнитель.

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