

# On use of blast-furnace granulated ground slag in construction

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**Abstract.** The paper presents the results of studies on the replacement of a cement binder in a concrete mixture with fine blast-furnace granulated ground slag. This material has found its application in construction as an active mineral additive, improving the structure of concrete, and it also allows reducing the cost of concrete production. The results of the matching composition of concrete class B25 with a cement binder, as well as with the use of ground slag, are demonstrated. The information on the physico-mechanical characteristics recorded during the preparation of the concrete mix is also given. As a result of the control samples testing, it was revealed that the replacement of cement with slag in the range of up to 30 percent allows achieving the required parameters of compressive strength. This circumstance makes it possible to speak about the possibility of using blast-furnace granulated ground slag for building structures both in factory production and in the production of monolithic structures at the construction site.

## 1. Introduction

In modern construction conditions, when the cost of materials [1-6] has become one of the key factors on the construction worksite, saving the cement binder is an important and urgent task. One of the ways to save cement is to replace it with fine-grained blast-furnace granulated slag [7-12].

This material has been well studied as an active mineral additive in different kinds of cement, moreover, blast-furnace slag has been the main component in the production of slag-alkali binders and products based on them [13-17].

The application area of blast-furnace slag is large enough [18-23]:

1. Blast-furnace granulated ground slag is used for the manufacture of mortars and concretes, in the production of dry construction mixtures, in hydraulic, agricultural, road construction, as well as in the construction of industrial, public and residential buildings, and in the manufacture of artificial conglomerates.

2 Blast-furnace granulated slag is used to produce various types of cement. When producing clinker cements, ground slag is used as an additive. In the production of slag cements, ground slag is used as the main component.

3. Blast-furnace ground slag is used as a partial substitute for Portland cement in the production of lightweight concrete for the production of cellular and polystyrene concrete blocks. In the production



of building blocks by autoclave method with heat and moisture treatment it has been the most effective of all types.

The advantages of using blast-furnace slag include:

1. The use of granulated ground slag in the manufacture of concrete allows reducing the clinker cement outgo without reducing the strength parameters.
2. Portland cement saving varies widely - from 20 to 70%. The percentage of substitution depends on such factors as the Portland cement activity, concrete composition, grain composition of the sand, compaction conditions for the concrete mix, temperature and duration of the temperature-moisture treatment and others.
3. The use of temperature-moisture treatment and electric heating significantly improves the strength characteristics of structures.
4. Ground slag is a microfiller, which contributes to improving the structure of the construction and technical properties of concrete, improving the surface of the product.
5. The replacement of Portland cement with ground slag in an amount of 20-50% in the concrete structure leads to a stable improvement in frost resistance of the steam heated concrete.

Ground slag is used for the production of various types of cement, for the manufacture of mortars and concretes in various types of construction, concrete products, as well as for the production of dry construction mixtures.

One of the key points is the determination of the optimal dosage of binder substitution in the preparation of a concrete mixture with the required characteristics.

## **2. Determination of the optimal cement replacement dosage**

To select the composition of the concrete mixture and determine the optimal dosage of substitution of the binder, the following raw materials were used:

- inert fillers: natural sand manufactured by LLC "Trest Magnitostroy UPIM-1", as well as - rubble 5(4)-20(16) mm crushing class not lower than 1000 according to GOST standard 8267-93 produced by the Gumbay rubble complex LLC "Energo-Alliance";
- Portland cement type CEM I strength class 42.5N according to GOST standard 31108-2016 produced by "Dyckerhoff" (Sukhoi Log);
- blast-furnace granulated ground slag produced by LLC Mechel-Materials according to TU standard 38.32.22-012-99126491-207 "Mineral active additive for the production of concretes, mortars and dry building mixtures. Green Cems GGBS-450 (blast-furnace granulated ground slag). Technical conditions ».

As the basic composition was adopted concrete B25W6F200, mobility P4, in the manufacture of which a plasticizer based on polycarboxylate esters ReoTeckTM DR 8200 was used.

The concrete composition was calculated using the absolute volume method in order to obtain the necessary properties of concrete in structures established by state standards, technical conditions and design documentation for these structures with minimal cement consumption.

When carrying out preliminary selection of the concrete mix, the range of cement consumption was 310-360 kg / m<sup>3</sup> for concrete class B25. Based on the required strength, workability and other physical-mechanical characteristics, the optimum consumption is 340 kg / m<sup>3</sup>.

Selection of the composition with the replacement of slag was carried out by a proportional decrease in the consumption of cement (in weight). As a control, the composition was used, in which Portland cement is acting as a binder (this composition has the symbol "K").

The dosage of ground slag for the purpose of cement replacement varies between 10-50% in 10% increments. However, due to the lower activity of ground slag in comparison with cement, to achieve the required strength of concrete, the amount of slag replacing cement was increased by 20%. At the same time, the composition was adjusted in proportion to the proportional decrease in the amount of fine inert filler - sand.

Thus, as a result of the preliminary selection, the optimal composition of the concrete mix for concrete of class B25 was determined (Table 1).

**Table 1.** Composition of concrete B25II4W6F1200.

Component of concrete mix, kg / m <sup>3</sup>	Saving cement (the proportion of cement replacement with slag)					
	K (0%)	10%	20%	30%	40%	50%
Cement	340	306	272	238	204	170
Slag	0	41	82	122	163	204
<i>TOTAL binder</i>	340	347	354	360	367	374
Rubble	1100	1100	1100	1100	1100	1100
Sand	850	843	836	830	823	816
Water	183	173	170	170	175	200
ReoTeck <sup>TM</sup> DR 8200 (0,6%)	2,04	2,08	2,12	2,16	2,20	2,24

Concrete samples-cubes, made to determine the compressive strength, have dimensions of 100 × 100 × 100 mm. During the preparation of the concrete mixture, the physical and mechanical characteristics were recorded, and they are given in Table 2. These tests were carried out in accordance with GOST standard 10181-2014 Concrete mixtures. Test methods.

**Table 2.** Physical and mechanical characteristics of concrete mix.

Parameter	Saving cement (the proportion of cement replacement with slag)					
	K (0%)	10%	20%	30%	40%	50%
Density, kg / m <sup>3</sup>	2463	2474	2439	2448	2441	2436
Precipitation of the cone, cm	16,0	16,0	19,0	18,0	16,0	20,0
Air entrainment, %	2,4	2,4	1,7	1,7	2,0	1,6
Consistency of the concrete mixture in time, h	0,5	0,5	0,5	0,5	0,5	0,5

The density of the concrete mix for a different dosage of slag is in the range of 2436 ÷ 2474 kg / m<sup>3</sup>, that means, the selected mixtures refer to heavy concrete.

Precipitation of the cone (OK) corresponds to the mobility of P4 (16-20 cm according to GOST standard 10181).

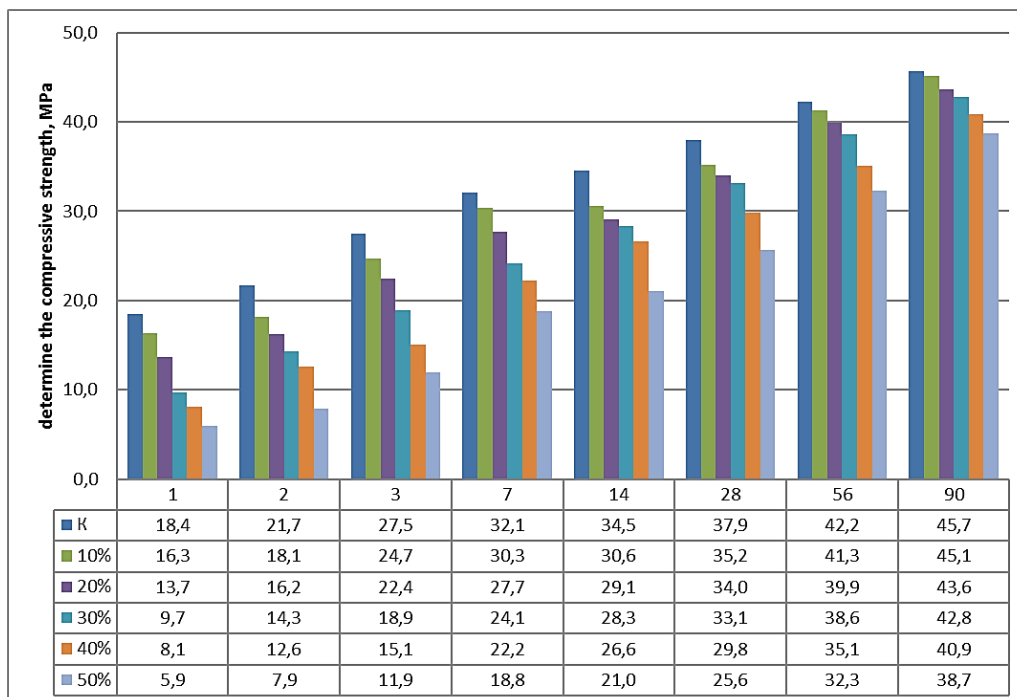
The consistency of the mixture in time is not more than 1 hour, after which the OK does not correspond to mobility P4.

### 3. Results

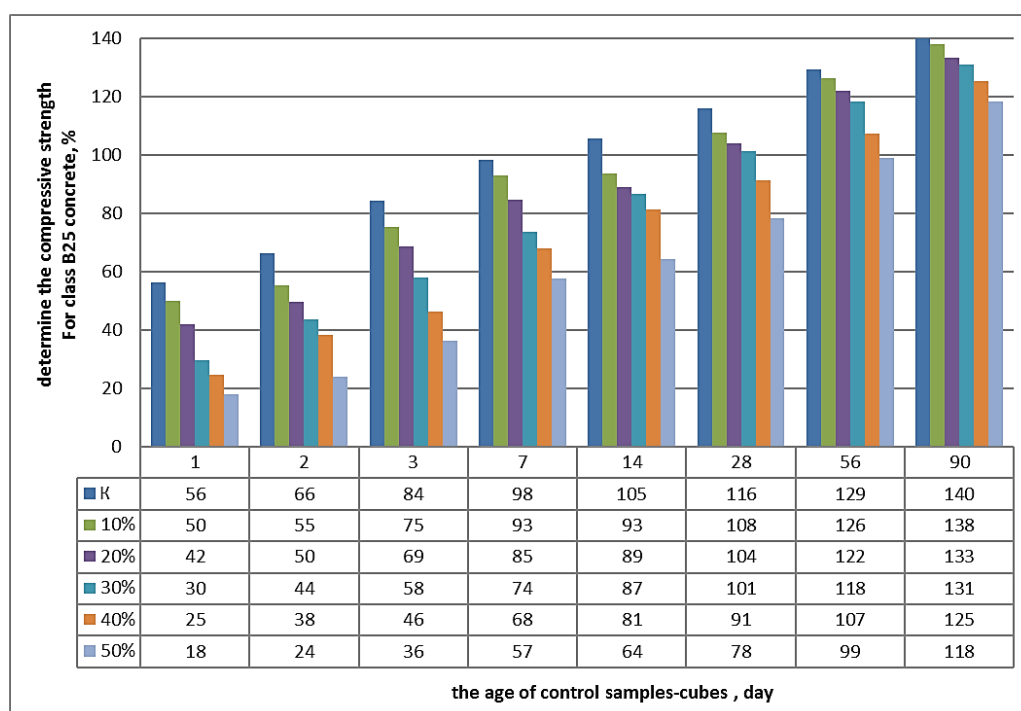
To determine the optimal dosage while maintaining the necessary physical and mechanical characteristics, the control samples-cubes were tested for compressive strength at the age of 1 day, 2 days, 3 days, 7 days, 14 days, 28 days, 56 days and 90 days. Tests of control samples of all series were made in accordance with GOST standard 10180-2012 Concretes. Methods for determining the strength of control samples.

Graphically, the results of testing concrete samples at different ages are shown in Figure 1.

For class B25 concrete, the compressive strength of the control samples at the age of 28 days should be at least 32.7 MPa. Using a plasticizer based on polycarboxylate esters ReoTeck<sup>TM</sup> DR 8200 allowed to reduce the amount of water at the same cement consumption, which was positively reflected in the strength in compression of the control samples. The strength limit of the control samples tested at the age of 28 days exceeds the level required for the concrete class B25 at 32.7 MPa for the K series (without cement substitution by slag), and also for substitution in the range of 10-30% (Figure 2) .



**Figure 1.** Test results of control samples.



**Figure 2.** Strength of control samples of composition No. 2, tested at different ages, according to the required class B25, in percent.

The carried out tests of concrete control samples for compositions of class B25 showed that substitution of cement with slag in the range of up to 30% allows to achieve the required parameters of compressive strength in 32.7 MPa. Consequently, a dosage of 30% is optimal.

#### 4. Conclusion

The tests carried out showed that the conditions for the preparation of concrete mixes when replacing cement with slag as compared with the base composition (symbol "K") do not differ in the direction of the technology complication, preliminary mixing of the binder, slag, inert fillers and subsequent watering are standard methods. For the developed compositions, the consistency time was not more than 1 hour, so the transportation time from the moment of preparing the mixture to the molding of products or structures should not exceed this. Other parameters of the concrete mixture with the replacement of cement with slag, such as: workability and mobility of the concrete mix, delamination in water separation and mix separation, air entrainment do not differ significantly from the base composition without cement replacement with slag. When observing the procedure for preparing a concrete mixture, these parameters are close to those of the basic composition.

The replacement of clinker cement in the preparation of a concrete mixture with granulated ground slag within the range of 10-30% makes it possible to obtain savings without deteriorating the physico-mechanical parameters.

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