



EFFECTIVENESS OF ULTRA-FINE GROUND SLAG IN CEMENT BINDERS

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ABSTRACT

Today it is generally recognized that the use of mineral fillers is one of significant reserves to enhance the efficiency of binders in cost as well as to improve the technical properties of cement composites. Mineral filler corresponding to the Portland cement fineness often replaces part of Portland cement. This technique allows saving Portland cement without reducing significantly the concrete strength. The ability to obtain ultra-fine mineral fillers from industrial by-products with high specific surface area appears with grinding technology development. Two types of ultra-fine ground granulated blast furnace slag with average grain size equal to 4.5 μm were obtained using modern grinding equipment such as centrifugal-elliptical mill and centrifugal dynamic classifier. Water-reducing effects of superplasticizer in Portland cement-slag compositions depending on types, quantity and fineness of slags as well as depending on C_3A and R_2O amounts in Portland cement clinker were studied. The results of reduction of binder amount per 1 kg of superplasticizer are presented and analyzed.

Key words: Ground granulated blast furnace slag, binder, superplasticizer, centrifugal-elliptical mill, centrifugal dynamic classifier.

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1. INTRODUCTION

The world practice of cement production is increasingly passing to the production of mixed cements which include mineral additives of various origins as this saves fuel and natural raw materials through the use of by-products [1-4]. Production of cements with mineral additives on the basis of by-products allows to increase volumes of cement production and concretes and also to receive high-quality concrete with the low amount of Portland cement per 1 MPa of strength [1,3,5-7]. The following factors of positive effects of fine mineral fillers on structure and physic-mechanical characteristics of cement compositions are distinguished in the literature: increase of the packing density of binder particles due to the placement of

micro-filler particles among cement particles [8-10]; increase of pozzolanic activity of filler due to its finer grinding [11-13]; acceleration of the initial stage of hardening of cement pastes with ultra-fine particles of mineral filler that can serve as centres of crystallization [14,15]; increase of plasticizing effect of superplasticizer in some compositions of Portland cement-mineral filler [14-16].

There are various technological methods to reduce the Portland cement amount and improve the technical properties of fresh and hardened cement composites [18-22]. The introduction of superplasticizer is one of the techniques. Polycarboxylate-based superplasticizers are used to produce modern types of concrete. The following tasks that are solved due to the introduction of superplasticizer can be distinguished: improving fluidity of paste and workability of fresh concrete [3,24,25], increasing strength at the early ages [3,8,12], reducing Portland cement amount [12,26], increasing rheological activity of mineral additives [14,23-26], improving distribution of fibers in cement composite structure [27,28]. Superplasticizer quantity to obtain equal-flowing cement pastes depends on the type and amount of ground granulated blast furnace slag (ggbfs) [10,14].

Compatibility of polycarboxylate superplasticizer and Portland cement was considered in the papers [29,30]. Good compatibility of superplasticizer and Portland cement is the high value of plasticizing or water-reducing effect of superplasticizer without reducing the concrete strength in the required time of hardening [29]. Reduction of water-reducing effect of superplasticizer can occur in Portland cement with tricalcium aluminate C_3A more than 6.3% and alkali metal oxides R_2O more than 0.79% that was stated in paper [29]. Under good compatibility the author of paper [29] understands the high water-reducing effect of superplasticizer in mixtures with very low water-to-cement ratio for high-strength concrete of transport constructions.

The study of possible water reduction using polycarboxylate superplasticizers with Ordinary Portland cement, in which the amount of C_3A and R_2O can vary widely as well as water reduction at replacing part of Portland cement with various fine ggbfs are relevant. Significant reduction of water quantity can be used to reduce Portland cement. The published data of the combined effect of mineralogical compositions of Portland cement and the properties of ggbfs on the water reduction introducing polycarboxylate superplasticizer is not enough.

Studies of the paper are aimed to assess the reduction of binder based on Portland cement-ggbfs introducing polycarboxylate superplasticizer into the fresh concrete. The objectives of the study are assessment of water-reducing effect of superplasticizer depending on type, quantity and fineness of ggbfs, depending on type and quantity of Portland cement as well as estimation of binder reduction per 1 kg of superplasticizer. It is necessary to determine the conditions under which the slag and superplasticizer provide significant savings of Portland cement clinker and binder.

2. MATERIALS AND METHODS

Two types of Portland cements with different C_3A and R_2O amounts were used in the research. The compositions of Portland cements are presented in Table 1. Two types of ggbfs with modulus of basicity $Mo=1.05$ and $Mo=0.66$ that were designated as S1 (basic slug) and S2 (acid slag), respectively, were used. The slags had the residues on the No.008 sieve that were 9% and 8% respectively and after further grinding slags had no residues on the No.008 sieve. Slag with $Mo=1.05$ was designated as S1-8 and S1-0 by the residues on the sieve. Slag with $Mo=0.66$ was designated as S2-8 and S2-0 by the residues on the sieve. Modern grinding equipment such as centrifugal-elliptical mill and centrifugal dynamic classifier were used.

The use of an efficient classifier to separate ultra-fine slag particles in the air flow makes it possible to obtain suitable particle size distribution of mineral additives as shown in Figure 1.

Table 1 mineralogical compositions of cements

designation	C ₃ S	C ₂ S	C ₃ A	C ₄ A F	R ₂ O
CEM 42.5I (OPC-1)	62,4	14,6	5,8	13,4	0,6 2
CEM 42.5I (OPC-2)	63,9	15,4	8,2	11,1	0,9 1

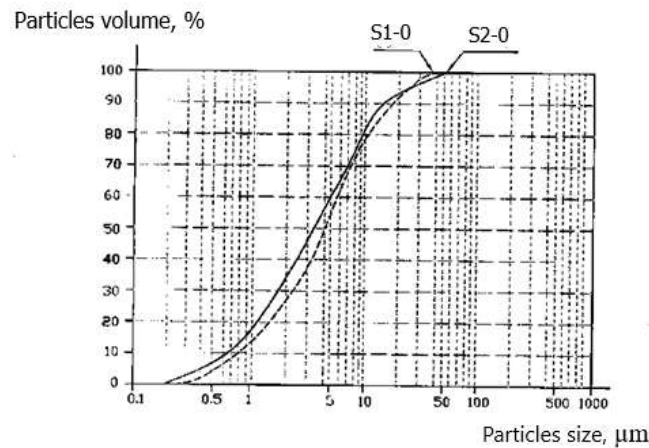


Figure 1 Particles size distributions

Particles size distributions of slags after additional grinding were determined using laser diffraction particle size analyzer and are shown in Figure 1. The average diameter of the slag particles was approximately 4.5 μm.

3. RESULTS AND DISCUSSION

Reduction of water quantity in equal-flow pastes based on OPC-1 and ggbfs with introduction of superplasticizer in the amount of 0.4% is shown in Figure 2.

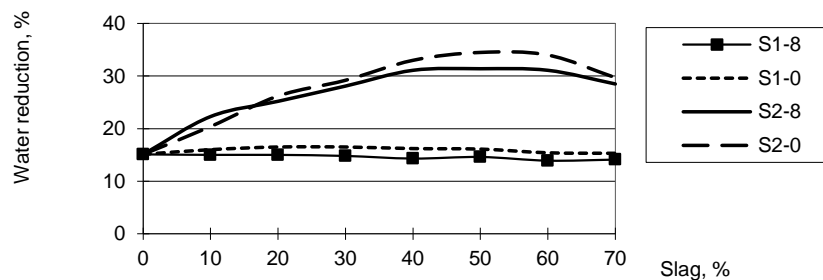


Figure 2 Water-reducing effect of superplasticizer depending on type, amount and fineness of slag (OPC-1)

The water-reducing effect of superplasticizer largely depends on type and quantity of slag and increases slightly with increasing fineness that one can see from the analysis of Figure 2. The water-reducing effect of superplasticizer has increased from 15.2% to 31.1%, i.e. more than twice when using slag with $M_o=0.66$ in the amount of 40% of Portland cement mass. The maximum value of the water-reducing effect of superplasticizer was obtained in the Portland cement-slag composition with the ratio of 50:50 that confirms the results of paper

[10]. Water-reducing effect of superplasticizer has not changed when using slag with $M_o=1.05$.

Evaluation of the water-reducing effect of superplasticizer in Portland cement-slag compositions where Portland cement had the high contents of C_3A and R_2O was the next task of this study. The results are shown in Figure 3.

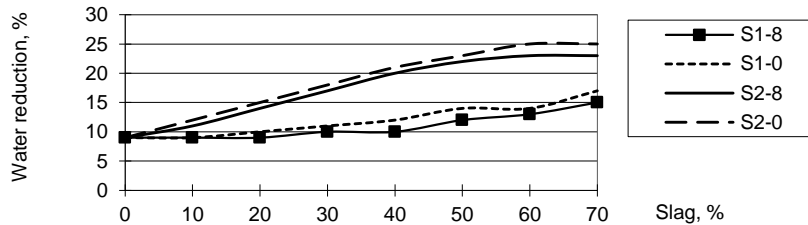


Figure 3 Water-reducing effect of superplasticizer depending on type, amount and fineness of slag (OPC-2)

It can be concluded by comparing the data in Figures 2 and 3 that the character of the curves varies significantly with the change of the mineralogical composition of Portland cement in the Portland cement-slag binder. The water-reducing effect of superplasticizer significantly depends on type and quantity of slag and increases slightly with increasing fineness that one can see from the analysis of Fig.3. The water-reducing effect of superplasticizer has increased from 9% to 24%, i.e. two and a half times when using slag with $M_o=0.66$ in the amount of 60% of Portland cement mass. The maximum value of the water-reducing effect of superplasticizer was obtained in the Portland cement-slag composition with the ratio of 40: 60 with decrease of OPC-2 amount. When using slag with $M_o=1.05$, the water-reducing effect of superplasticizer increases with decrease of OPC-2 amount. As noted above, OPC-2 contains the increased quantity of C_3A and R_2O . Thus, the increase of water-reducing effect of superplasticizer at the OPC-2 reduction may be explained by the decrease of C_3A and R_2O amounts in the Portland cement-slag binder.

Reduction of binder amount per 1 kg of superplasticizer was estimated using Portland cement – S2 slag compositions with the ratio of 50:50. Two series in which three laboratorial batches using OPC-1 and OPC-2 were made to evaluate the possible reduction of binder. One control composition without superplasticizer and two compositions with superplasticizer in the amount of 0.4 and 0.8% of binder mass were made in each series (Tables 2 and 3).

Table 2 Estimation of savings of the binder based on OPC-1

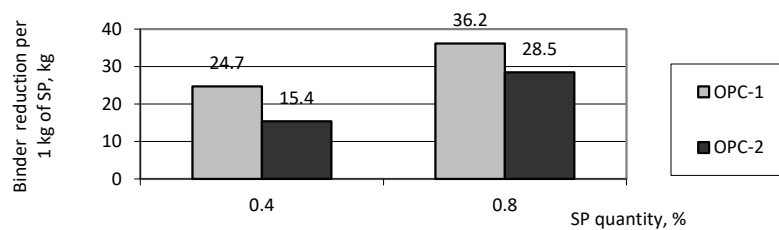
No	SP, %	OPC, kg/m ³	SP, kg/m ³	W/B	Slump, cm	Compressive strength at 28 days, MPa	Binder reduction, kg/m ³	Binder reduction per 1 kg of SP, kg
1	0	430	0	0.38	9	59.1	-	-
2	0.4	390	1.62	0.38	9	59.8	40	24.7
3	0.8	330	2.76	0.38	9	59.5	100	36.2

Fresh concrete mixes with the slump equal to 9 cm and the same water-to-binder ratio (W/B) were manufactured. Fine and coarse aggregates with the fixed ratio was introduced in the fresh concrete mixes after the introduction of superplasticizer to achieve the initial workability of the mixes, namely slump equal to 9 cm. Binder amount per 1 m³ was recalculated using the calculation-experimental method of concrete design. The samples were steamed at the temperature of 50°C.

Table 3 Estimation of savings of the binder based on OPC-2

No	SP, %	OPC, kg/m ³	SP, kg/m ³	W/B	Slump, cm	Compressive strength at 28 days, MPa	Binder reduction, kg/m ³	Binder reduction per 1 kg of SP, kg
1	0	430	0	0.38	9	59.5	-	-
2	0.4	405	1.62	0.38	9	59.9	25	15.4
3	0.8	350	2.80	0.38	9	59.3	80	28.5

From the analysis of Tables 2 and 3 it can be concluded that the binder reduction per 1 kg of superplasticizer increases with the increase of superplasticizer amount. It is possible to achieve greater binder reduction per 1 kg of superplasticizer using binder based on OPC-1. This was to be expected as the higher water-reducing effect of superplasticizer was obtained on this Portland cement. Comparative evaluation of the saving of binder per 1 kg of superplasticizer (SP) is presented in Figure 4.

**Figure 4** Comparative evaluation of the saving of binder per 1 kg of superplasticizer

It is necessary to take into account the content of C_3A and R_2O in Portland cement to obtain significant reduction of water when using polycarboxylate modifier that can be concluded from Figures 1 and 2. Reduction of water quantity through the use of polycarboxylate superplasticizer leads to the increase of concrete strength that can be used to reduce the binder quantity in concretes with the same strength. However, the reduction of the binder per 1 kg of superplasticizer depends significantly on the type of slag and Portland cement as well as their ratio in the composite binder.

4. CONCLUSION

In this paper, the reduction of the binder per 1 kg of polycarboxylate superplasticizer has been stated. Firstly, the water reduction using polycarboxylate superplasticizers in binders based on Ordinary Portland cement with different amounts of C_3A and R_2O as well as with different types and amounts of ground granulated blast furnace slag are studied. The combined effect of mineralogical compositions of Portland cement and the properties of ggbfs on the water reduction introducing polycarboxylate superplasticizer is stated. Assessment of water-reducing effect of superplasticizer depending on type, quantity and fineness of ggbfs, depending on type and quantity of Portland cement were carried out. Significant reduction of water quantity can be used to reduce binder quantity. Then, estimation of binder reduction per 1 kg of superplasticizer is calculated.

The result has shown that it is necessary to take into account the mineralogical composition of Portland cement to obtain high reduction of water introducing superplasticizer and, accordingly, high reduction of binder. For example, the maximum water reduction was obtained for binder at cement-to-slag ratio of 50:50 provided the use of Portland cement with normalized mineralogical composition. In the case of Portland cement with the high content of C_3A and R_2O most of this Portland cement should be replaced with slag.

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