

Fine ground granulated blast furnace slag for saving quantity of binder

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Abstract. Nowadays, it is acknowledged that the use of mineral additives based on ground slag is one of ways of resource saving and improvement of technical properties of cement composites. Mineral additives with fineness similar to the Portland cement fineness are often used to replace part of Portland cement. Two kinds of ultra-fine ground granulated blast furnace slag that differ in composition and fineness were studied in the paper. Water-reduction due to effect of superplasticizer in slag-Portland cement compositions with amount of slag up to 70% was studied. The results of reduction of binder quantity per 1 kg of chemical admixture due to significant water-reduction are obtained and analysed. Correlations depending on kind, amount and fineness of slags, as well as depending on mineralogical composition of Portland cement were stated. The ultra-fine mineral additives based on ground slag with high specific surface area can be used for significant reduction of compositional binder.

1 Introduction

The cement production can involve high quantity of mineral additives of various origins since this economize fuel and natural raw materials due to use of by-products [1-5]. Production of cements with high quantity of mineral additives based on slags enable to increase volumes of cement and concrete production as well as to obtain high-performance concrete with low amount of Portland cement per 1 MPa of strength [2,3,6-9].

One can determine the following factors of positive influence of ultra-fine mineral additives on concrete structure and properties of cement composites that are discussed in the scientific papers: increase of packing density of mineral particles due to the optimum quantity of micro-particles that are place among cement particles [10-13]; increase of pozzolanic activity of quartz due to its finer grinding [14-16]; fast hardening of cement matrix at the initial stage of hydration since micro-additives can serve as crystallization centres [17,18]; increase of plasticizer effect in Portland cement-mineral additives compositions [19-22].

There are different technological ways of reduction of Portland cement consumption and improvement of properties of fresh and hardened concrete [22-27]. The use of

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superplasticizer is one of the ways. Polycarboxylate-based superplasticizers are mostly used to obtain contemporary kinds of concrete: self-compacting concrete, high-strength concrete, high-strength strain-hardening cement-based composites, etc. One can resolve the following tasks that due to use of superplasticizer: improve workability of fresh concrete [24-26], regulate increase of strength at the different ages [2, 15-17], reduce Portland cement [27-30], increase rheological activity of additives [3,6,12], improve allocation of fibers in concrete structure [29,30]. Superplasticizer amount to gain fresh concrete with equal workability depends on the kind and quantity of ground granulated blast furnace slag (ggbfs) as it was stated in paper [6,15].

The problem of compatibility of polycarboxylate admixtures and ordinary Portland cement was discussed in the papers [31-33]. One can consider as good compatibility of polycarboxylate admixture and Portland cement is the high value of water reduction due to superplasticizer use at the same time without reducing the concrete strength in the stated time of hardening [21,22,32]. Significant reduction of water quantity due to effect of superplasticizer can occur in mixtures with very low water-to-cement ratio where cement has aluminate C_3A up to 6.3% and alkali metal oxides R_2O up to 0.79% as it was stated in paper [32].

The determination of conditions of high reduction of mixing water in case of polycarboxylate admixture use in compositions of ggbfs - Ordinary Portland cement with different amount of C_3A and R_2O as well as with various fine ggbfs amounts are appropriate. Reduction of mixing water can be used to reduce binder quantity. The published data of the joint effect of properties of ggbfs and polycarboxylate admixtures on reduction of binder quantity per 1kg of admixture is not enough discussed in the scientific literature.

The aim of the paper is to assess the compositional binder reduction in mixtures based on ggbfs-OPC binder by using polycarboxylate admixture. It is necessary to study the water-reducing effect of admixture depending on properties of ggbfs, on properties and quantity of Portland cement as well as binder reduction per 1 kg of admixture. The task is to determine the conditions when mineral additive and admixture provide significant binder reduction.

2 Materials and Methods

Two types of Ordinary Portland cements (OPC) were used. They differed by C_3A and R_2O quantities. The mineralogical composition of Portland cements is presented in Table 1. Two types of ggbfs differed by modulus of basicity $Mo=1.1$ and $Mo=0.7$ and they were designated as Sb (basic slag) and Sa (acid slag), respectively. The slags had the residues on the No.008 sieve approximately 10%. Slags had no residues on the No.008 sieve after further grinding and 50% of the slag particles had the size less than $5\mu m$. Slag with $Mo=1.1$ was designated as Sb-10 and Sb-0 by the residues on the sieve. Slag with $Mo=0.7$ was designated as Sa-10 and Sa-0 by the residues on the sieve.

Table 1. Mineralogical composition of Portland cements.

	C_3S	C_2S	C_3A	C_4AF	R_2O
CEM 42.5I (OPC-1)	60.9	14.9	5.5	13.6	0.59
CEM 42.5I (OPC-2)	62.8	15.7	8.0	11.3	0.93

Particles size distribution of slags was determined with laser diffraction particle size analyser. The average diameter of particles for both slags was around $5\mu m$.

3 Results and Discussion

Water reductions due to effect of superplasticizer in slag-Portland cement compositions with amount of slag up to 70% and quantity of admixture 0.5-1.0% were studied. Water reduction in pastes based on OPC-1 and ggbfs with admixture in the amount of 0.5% is shown in Figure 1. The cement paste had equal fluidity.

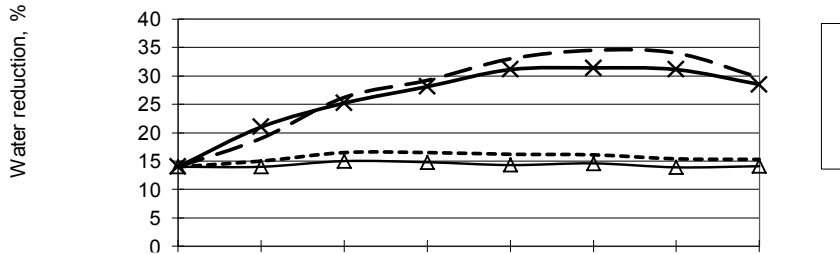


Fig. 1. Correlations between the water reduction using superplasticizer and type, amount and fineness of slag (OPC-1)

The value of water reduction using superplasticizer substantially depends on kind and amount of slag. The value of water reduction using superplasticizer increases marginally with increasing fineness that one can see analysing Figure 1. The value of water reduction using superplasticizer has enlarged from 14% to 30% using slag with $M_o=0.7$ in the amount of 40% of Portland cement mass. The maximum value of water reduction was gained in the slag-Portland cement composition with the 50% of slag Sa. The value of water reduction using superplasticizer has not changed by using slag Sb with $M_o=1.1$.

The value of water reduction using superplasticizer in slag-OPC2 compositions where Portland cement had higher quantity of C_3A and R_2O is shown in Figure 2.

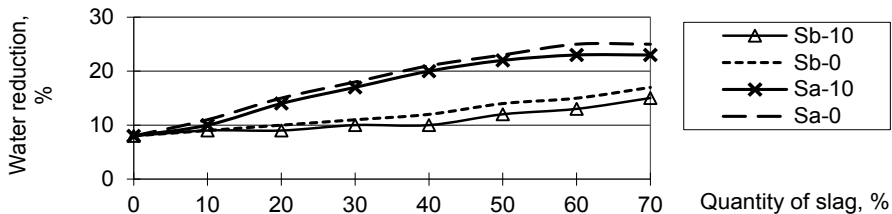


Fig. 2. Correlations between the water reduction using superplasticizer and type, amount and fineness of slag (OPC-2)

One can conclude by comparing the results in Figures 1 and 2 that the nature of all curves differs considerably with changing mineralogical composition of Portland cement in compositional binder. The value of water reduction using superplasticizer considerably depends on kind and amount of slag. Conversely the value of water reduction using superplasticizer slightly depends on fineness that one can see in Figure 2. The value of water reduction using superplasticizer has increased from 8% to 23% using slag Sa with $M_o=0.7$ up to 60% of Portland cement mass. The maximum value of the water reduction was gained in the slag-OPC2 composition with 60% of slag. The value of water reduction using superplasticizer increases with decrease of OPC-2 amount using slag Sb with $M_o=1.1$. It is necessary to pay attention that OPC-2 contains the increased quantity of C_3A and R_2O . Thus, the increase of the value of water reduction using superplasticizer may be

explained by C_3A and R_2O amount decrease in the Portland cement-slag binder provided OPC-2 reduction.

Decrease of amount of compositional binder per 1 kg of superplasticizer was calculated in compositions of Sa slag - Ordinary Portland cement where the ratio was 50:50 per cent. Two laboratorial batches with OPC-1 and OPC-2 were made to calculate the possible decrease of amount of compositional binder. One reference bath without superplasticizer and two baths with superplasticizer with the quantity of 0.5 and 1% of binder mass were made as shown in Tables 2 and 3.

Fresh concrete with workability of 10 cm slump at the same water-to-binder ratio ($W/B=0.37$) were used.

Table 2. Evaluation of economy of the binder based on Sa-OPC1

No	Binder, kg/m ³	SP, %	SP, kg/m ³	W/B	Compressive strength at 28 days, MPa	Binder reduction, kg/m ³	Binder reduction per 1 kg of SP, kg
1	450	0	0	0.37	58.6	-	-
2	390	0.5	1.95	0.37	58.3	60	30.7
3	320	1.0	3.2	0.37	59.1	130	40.6

Table 3. Evaluation of economy of the binder based on Sa-OPC2

No	Binder, kg/m ³	SP, %	SP, kg/m ³	W/B	Compressive strength at 28 days, MPa	Binder reduction, kg/m ³	Binder reduction per 1 kg of SP, kg
1	450	0	0	0.37	60.3	-	-
2	408	0.5	2.04	0.37	61.9	42	20.5
3	355	1.0	3.55	0.37	61.4	95	26.7

One can conclude that the value of decrease of compositional binder per 1 kg of superplasticizer increases at the increased superplasticizer amount as shown in Tables 2 and 3. The significant binder reduction per 1 kg of superplasticizer can be achieved in compositions based on OPC-1. It can be explained that the higher water reduction of superplasticizer was obtained on the Portland cement OPC-1 due to its mineralogical composition. Economy of compositional binder per 1 kg of superplasticizer (SP) one can see in Figure 3.

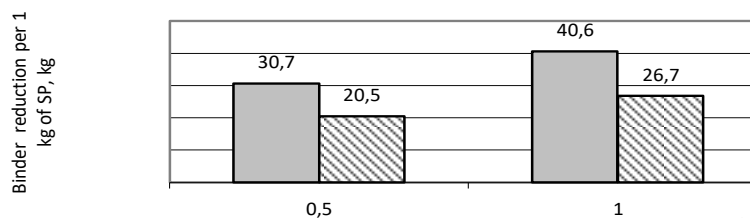


Fig. 3. Economy of compositional binder per 1 kg of superplasticizer

The amount of C_3A and R_2O in both Portland cements must be taken into account in order to obtain significant reduction of water due to use polycarboxylate superplasticizer. It can be concluded from Figures 1 and 2. Water reduction due to use polycarboxylate superplasticizer ensures the increase of concrete strength. The concrete strength increase can be used to reduce the binder quantity. One can conclude that the binder economy per 1

kg of superplasticizer depends significantly on the properties of slag and Portland cement as well as their ratio in the compositional binder.

References

1. J. Koplík, L. Kalina, J. Másilko, F. Šoukal, *Materials*, **9(7)**, 533 (2016)
2. L. F. Kazanskaya, O. M. Smirnova, *International Journal of Civil Engineering and Technology*, **9(11)**, pp. 3006–3012 (2018)
3. O. Smirnova, *Journal of King Saud University-Engineering Sciences*, **29.4**: 381-387 (2017)
4. F. Ptáček, T. Opravil, J. Havlica, M. T. Palou, L. Kalina, *Journal of Thermal Analysis and Calorimetry*, **124(2)**, 629-638 (2016)
5. R. Tayeb, L. Soltane, A. Tafraoui, M. Abderrahmane, *International Review of Civil Engineering (IRECE)*, **8(4)**, pp. 152-159 (2017)
6. T. Petrova, O. Smirnova, In *Modern Building Materials, Structures and Techniques. Proceedings of the International Conference*, Vol. **10**, p. 250 (Vilnius Gediminas Technical University, Department of Construction Economics & Property, 2010)
7. N. A. Belyakov, *International Journal of Civil Engineering and Technology*, **9(13)**, pp. 1223-1228 (2018)
8. A. Kharitonov, M. Korobkova, O. Smirnova, *Procedia Engineering*, **108**, pp. 239-244 (2015)
9. L. F. Kazanskaya, Thesis for the degree of doctor of technical Sciences, 326p. (Saint-Petersburg, 2000)
10. Y. Belentsov, N. Shangina, M. Larisa, A. Kharitonov, In *IOP Conference Series: Earth and Environmental Science*, **90**, No. 1, p. 012086, IOP Publishing. (2017)
11. A. Kharitonov, A. Ryabova, Y. Pukharenko, *Procedia engineering*, **165**, 1152-1161 (2016)
12. O. M. Smirnova, *International Journal of Civil Engineering and Technology*, **9(8)**, pp. 1724–1732 (2018)
13. G. Girskas, G. Skripkiūnas, G. Šahmenko, A. Korjakins, *Construction and Building Materials*, **117**, pp. 99-106 (2016)
14. G. Bumanis, J. Zorica, D. Bajare, A. Korjakins, *Energy Procedia*, **147**, 301-308 (2018)
15. O. M. Smirnova, D. A. Potyomkin, *International Journal of Civil Engineering and Technology*, **9(7)**, pp. 874–880 (2018)
16. Genadijs Sahmenko, Sandis Aispurs, Aleksandrs Korjakins. *Environment. Technology. Resources*, **III**, pp. 286-291, (2017)
17. O. M. Smirnova, *Procedia Engineering*, **172**, pp. 1039-1043 (2017)
18. L. Kalina, V. Bílek, R. Novotný, M. Mončeková, J. Másilko, J. Koplík, *Materials*, **9(5)**, 395 (2016)
19. A. Plugin, E. Dedeneva, T. Kostyuk, D. Bondarenko, O. Demina, In *MATEC Web of Conferences*, Vol. **116**, p. 01010, EDP Sciences (2017)
20. O. M. Smirnova, *International Journal of Civil Engineering and Technology*, **9(8)**, pp. 1733–1740 (2018)
21. O. M. Smirnova, *International Journal of Civil Engineering and Technology*, **9(10)**, pp. 1966–1973 (2018)

22. Olga Smirnova, *ARPN Journal of Engineering and Applied Sciences*, vol. **14**, no. 3, pp. 600-610 (2019)
23. K. Ezziane, H. Soualhi, *KSCE Journal of Civil Engineering*, **22(7)**, 2480-2491 (2018)
24. L. Kherraf, M. Belachia, H. Hebhoub, A. Abdelouehed, *International Review of Civil Engineering (IRECE)*, **9(1)**, pp. 31-39 (2018)
25. O. M. Smirnova, *International Journal of Civil Engineering and Technology*, **9(10)**, pp.1991–2000 (2018)
26. A. Shaybadullina, Y. Ginchitskaya, O. Smirnova, In *Solid State Phenomena*, Vol. **276**, pp. 122-127, Trans Tech Publications (2018)
27. A. A. Plugin, T. O. Kostiuk, O. A. Plugin, D. O. Bondarenko, Yu. A. Sukhanova, N. N. Partala,, *International Journal of Engineering Research in Africa*, **31**, pp.59-68 (2017)
28. A. G. Protosenya, M. A. Karasev, N. A. Belyakov, *International Journal of Applied Engineering Research*, **22**, pp.10857 – 10866 (2016)
29. O. M. Smirnova, Y. A. Belentsov, A. M. Kharitonov, *Journal of Traffic and Transportation Engineering (English Edition)* (2018) doi.org/10.1016/j.jtte.2017.12.004
30. A. A. Mechtcherine V. *RILEM Bookseries*. **15**, pp.266-274 (2018)
31. Yu. A. Belentsov, O. M. Smirnova *International Journal of Civil Engineering and Technology*, **9(11)**, pp. 2999–3005 (2018)
32. O. M. Smirnova, *Magazine of Civil Engineering*, **6**, pp.12-22 (2016)
33. J. Y. Yoon, J. H. Kim, *Construction and Building Materials*, **158**, pp. 423-431 (2018)