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SILICA FUME-BASED ADMIXTURE IN THE FORM OF AQUEOUS SLURRY FOR SELF-COMPACTING CONCRETE

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Summary. The article is devoted to the elaboration of resource-saving method provided a stable aqueous silica fume dispersion which contains 20 to 45% by weight of silica fume which is a by-product of ferrosilicon production (in aggregated form) and a stabilizing agent in a form of high range water reducing admixture (polynaphthalene sulfonate condensate) as well as sodium hydroxide. This composition has been found highly suitable as an admixture for cementitious compositions in particular for Self Compacting Concrete to enhance its fluidity, resistance to segregation as well as durability and strength characteristics.

Key words: Self Compacting Concrete, silica fume, aqueous slurry, superplasticizer, sodium hydroxide, bead mill.

INTRODUCTION

The development of Self-Compacting Concrete (SCC) has recently been one of the most important developments in the building industry. It is a kind of concrete that can flow through and fill gaps of reinforcement and corners of moulds without any need for vibration and compaction during the pouring process. Fluidity and resistance to segregation of SCC ensures high degree of homogeneity with minimal content of voids and uniform strength, high degree of surface quality and high durability [1, 3].

The major difference in composition of traditional and self-compacting concrete lies in higher proportion of fine parts by 30-40% by volume. Additives increase resistance to segregation, movability and homogeneity of mixture. Higher proportion of fine parts with larger specific surface also increases the need for mixing water to form required amount of mastic cement to cover all grains of aggregate. Selection of the kind of additive depends on several factors: economical point of view, applicability and availability [18].

THE STATEMENT OF THE PROBLEM

Silica fume and superplasticizer are complementary materials to manufacture selflevelling concretes with great cohesion of the fresh mix [3, 11, 18]. One of the greatest advantages of using silica fume in SCC results from its small size. The addition of silica fume widens the size distribution of the cementitious particles in concrete, allowing more efficient particle packing, densifying the interfacial transition zone and converting CH into C–S–H, thus increasing strength and durability [2-8, 13-17].

However silica fume is not available in large amounts and it is also the most expensive mineral additive [2, 4]. On the other hand small particle size and low bulk density of silica fume makes it difficult to transport, distribute and handle. So, commercial suppliers are obliged to process silica fume using different methods of compaction in order to agglomerate the small individual particles into relatively large clumps containing millions of particles and measuring up to several millimeters in size (densified or pelletized) [5, 6, 13, 15, 19].

Besides it is well known that silica fume as produced powder can be converted into aqueous dispersions, so that its transportation, metering and general handling can be more readily accomplished [10]. For example, in Germany the silica fume is normally used in dry bulk form or as slurry [14]. Norway "Elkem" supplies microsilica as an aqueous suspension EMSAC®500 S (Slurry Product). The suspension has a solids content of 50 % by weight. It is easy to handle and pump, average bulk density is approximately 1400 $kg \cdot m^{-3}$. Addition of silica fume in a form of slurry is more straightforward. In a wet batch plant, SF slurry can be added directly into the pan mixer, preferably at the same time as the mixing water [7].

The problems with such dispersions are the poor economics associated with transporting large volumes of water when the dispersion has low concentrations (about 45 % or less) of solids or the poor stability resulting in gelling and solidification of dispersions which have a high solid concentration (greater than about 45 %). So, different types of stabilizing agent selected for phosphoric acid, citric acid, sodium or potassium salts of these acids [16] as well as amino alcohols [17] were patented. These methods are suitable to prepare aqueous slurries on the base of silica fume as produced powder. However, when silica fume is used in aggregated form (densified or pelletized) the problem of dispergating relatively large clumps into the small individual particles is added.

This problem is especially significant when aggregation of ultra fine particles of silica fume takes place during the drying process in sludge collectors (when silica fume slurry is disposed in landfills and its water content is drastically reduced). It is stipulated by gelling and the condensation polymerization accompanied with the formation of siloxane linkages [10]. Thus, aged agglomerated aqueous suspensions need to be redispersed before use in concrete. Nevertheless, the difficulty of redispersion of agglomerated silica fume, for example fine milling in a boll-and-tube mill, is stipulated due to the high interparticle forces (forces of the electrostatic charging, Van-der-Waal's forces and forces due moisture) [19].

So, the aim of this investigation is to develop an effective method of utilizing high-volume wastes of Ferro-alloy works in a form of agglomerated aged silica fume slurries as a mineral additive for self-compacting concretes.

MATERIALS AND METHODS

Ordinary Portland cement CEM I 42.5 N (OPC) and two types of silica fume were used as raw materials. Silica fume SF-1 is undensified (as produced powder) while silica fume SF-2 is aggregated during the drying process of aqueous slurry (wet method of gas cleaning in a Ferro-alloy production) (Fig. 1). The chemical composition and physical properties of raw materials are given in Table 1.

Dispersion of aggregates of microsilica was carried out in the bead mill, used to produce ultrafine products in a liquid medium by grinding the slurry material by solid balls – glassy beads. Bead mill is a cylindrical vessel with a mixing rotor, providing different modes of mixing and circulation of beads. The mill is filled with the beads for 70-80 % of the volume. The beads are moved by rotation of the mill rotor thereby fine grinding agglomerates of silica fume (duration of grinding – 10 minutes).

Fig. 1. Silica Fume images: SF-1 undensified form (left); SF-2 aggregated form (right)

Table 1. Chemical composition and properties of the materials used

Composition (%) Properties	OPC	SF-1	SF-2
SiO_2	21.4	91.8	81.8
Al_2O_3	5.8	1.1	1.6
Fe_2O_3	3.4	0.65	3.0
CaO	61.5	2.4	1.1
MgO	1,7	0.05	0.2
K_2O	0.7	0.1	0.6
SO_3	2.5	0.35	3.6
Loss on ignition	1.2	3.6	7.2
Bulk density ($kg \cdot m^{-3}$)	1310	215	655
Fineness ($m^2 \cdot kg^{-1}$)	365 (Blaine)	18600 (BET)	0.14-20 mm

In this paper we have studied the effect of the type of a dispersion medium on the efficiency of fine grinding aggregated microsilica in a laboratory bead mill. Tap water, sodium hydroxide solution (pH=12, concentration of 1.5% in terms of Na_2O) and the solution of superplasticizer (pH=6.5, C=2.5 %) on the base of polynaphthalene sulfonate condensate (PNS) were used as the dispersion medium.

RESULTS AND DISCUSSION

Dispersing ability of liquids (dispersion medium) was estimated by the kinetics of sedimentation (settlement) of aqueous silica fume slurries prepared by fine grinding in the bead mill (concentration of solids is 45 %). It has been found that the highest sedimentation rate of particles is in the case of using tap water as the liquid medium (Fig. 2). In a solution of sodium hydroxide the rate of sedimentation decreases. This is due to the fact that in an alkaline environment along with the dispersion of aggregates of microsilica is its dissolution. According to [9] the solubility of amorphous silica increases rapidly under alkaline conditions at pH above 9. In the presence of alkali silica passes into solution as silicate ion, with further reaction with water it forms soluble monosilicone acid. When the amount of alkali is small monosilicone acid can polymerized forming stable colloidal particles. During the formation of soluble sodium silicate there is an additional dispersion of amorphous silica to highly concentrated state of lyosol – nanodispersed system [12].

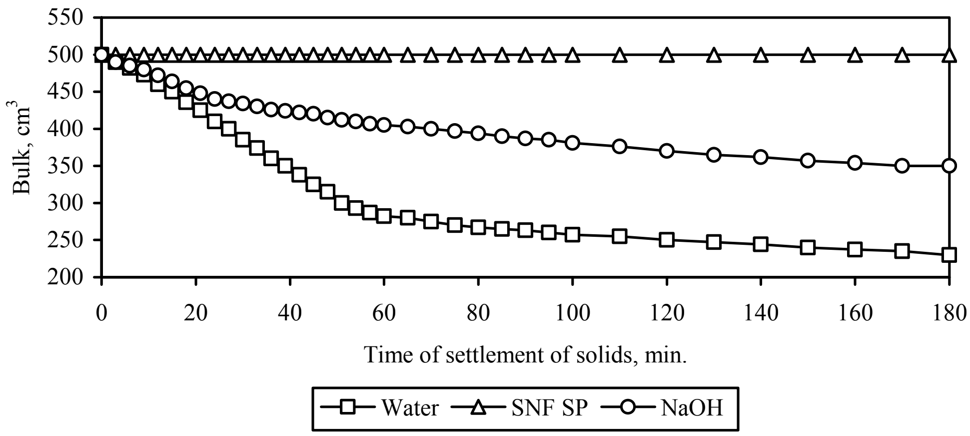

Fig. 2. The kinetics of sedimentation of aqueous silica fume slurries

When microsilica is dispersed in a solution of superplasticizer on the base of polynaphthalene sulfonate condensate (Mapei N 200) a stabilized with a surfactant colloidal system, which preserves sedimentation stability over 10 days, is formed. The volume of sediment after 7 days was only 15-20 ml.

When the complex solution (PNS + NaOH) is used as a liquid medium of the bead mill, the finer dispersion of aggregated microsilica is provided, as evidenced by the stable state of the microsilica suspension within 10-14 days. So, this method provides a stable aqueous silica fume dispersion which contains 20 to 45% by weight of silica fume which is a by-product of ferrosilicon production and a stabilizing agent in a form of high range water reducing admixture (polynaphthalene sulfonate condensate) as well as sodium hydroxide. The composition described herein has been found highly suitable as an admixture for cementitious compositions in particular for Self Compacting Concrete to enhance its fluidity, resistance to segregation as well as durability and strength characteristics.

It should be noted also that the presence of sodium hydroxide in the composition of above mentioned complex admixture makes it possible to use milled granulated blast furnace slag (GBFS) as a partial replacement of Portland cement in the formulation of concrete mixtures. The results obtained by [20] have showed a high effectiveness of the composition of silica fume with alkali admixture as an activator for the binding systems based on the combination of Portland cement, silica fume and slag.

The composition of the self compacting concrete mixture SCC-1 with the addition of silica fume-based aqueous slurry containing stabilizing agent (PNS + NaOH) is presented in Table 2. The properties of SCC-2 with addition of silica fume as a source of dry powder (SF-1) are investigated for comparison.

The slump-flow and T_{350} time was a test to assess the flowability and the flow rate of self-compacting concrete based on the slump test with the help of mini cone (Fig. 3). The properties of fresh concrete mixtures as well as mechanical and deformation properties of concretes are given in Table 3.

Table 2. The composition of SCC

Mixes	Content of ingredients, $kg \cdot m^{-3}$								
	OPC	Fine aggregate	Coarse aggregate	SF-1	SF-2	GBFS	PNS	NaOH	W/B
SCC-1	287	885	796	-	24.5	155	5.53	6.65	0.48
SCC-2	442	885	796	24.5	-	-	6.64	-	0.48

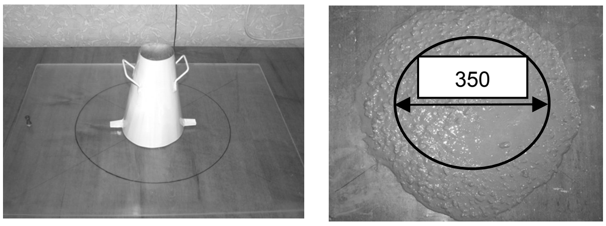

Fig. 3. The measurement of slump-flow and T_{350} time of SCC

Table 3. The properties of SCC

Mixes	Properties						
	Slump-flow, mm	T_{350} time, s	Compressive strength, MPa			Young's modulus (90 days), GPa	Shrinkage, $\varepsilon_b \cdot 10^{+3}$
			3 days	28 days	90 days		
SCC-1	445	3	11.5	35.0	58.5	40.2	0.64
SCC-2	495	2	31.0	55.4	67.5	42.3	0.58

CONCLUSION

The resource-saving method provided a stable aqueous silica fume dispersion which contains 20 to 45% by weight of silica fume which is a by-product of ferrosilicon production (in aggregated form) was developed. This dispersion is highly suitable as an admixture for cementitious compositions in particular for Self Compacting Concrete.

REFERENCES

1. Brouwers H.J.H., Radix H.J., 2005: Self-Compacting Concrete: Theoretical and experimental study. Cem. Concr. Res. 35(11), p. 2116-2136.
2. Collepardi M. [et al], 2007: Beneficiated Fly Ash Versus Normal Fly Ash or Silica Fume. Proc. of 9th CANMET/ACI Intern. Conf.: Warsaw, p. 1-8.
3. Collepardi M., 2001: Main Ingredients and Basic Principles for SCC Production. Proc. of CUC Conf. on Self Compacting Concrete for Tunnel Linings: Switzerland, p. 1-14.
4. Collepardi M. [et al], 2004: Optimization of Silica Fume, Fly Ash and Amorphous Nano-Silica in Superplasticized High-Performance Concretes. Proc. of Eighth CANMET/ACI Intern. Conf.: Las Vegas, p. 495-506.
5. Diamond S., Sahu S., 2006: Densified silica fume: particle size and dispersion in concrete. J. Materials and Structures. 39(9), p. 849-859.

6. Diamond S., Sahu S., Thaulow N., 2004: Reaction products of densified silica fume on agglomerates in concrete. Cem. Concr. Res. 34(9), p. 1625-1632.
7. Dunster A., 2009: Silica Fume in Concrete: Information Paper. IP 5/09. IHS BRE Press, Watford, p. 1-12.
8. Holland T.C., 1998: High-Performance Concrete: As High as It Gets. The Concrete Producer. 16(7), p. 501-505.
9. Iler R.K., 1979. The chemistry of silica: solubility, polymerization, colloid and surface properties, and biochemistry. New York: Wiley, 866 p.
10. Kaprielov S.S., Sheinfeld A.V., 1995: The new method of production of fluidized concentrated suspensions of microsilica. Concrete and reinforced concrete. 6, p. 2-6 (in Russian).
11. Korpa A., Kowald T., Trettin R., 2008: Hydration behavior, structure and morphology of hydration phases in advances cement-based systems containing micro and nanoscale pozzolanic additives. Cem. Concr. Res. 38(7), p. 955-962.
12. Lotov V.A., 2006: Nanodispersed systems in the technology of buildings materials and products. Building materials. 8, p. 5-7 (in Russian).
13. Maas A.J., Ideker J.H., Juenger M.C., 2007: Alkali silica reactivity of agglomerated silica fume. Cem. Concr. Res. 37(2), p. 166-174.
14. Marchuk V., 2004: Dispersibility of the silica fume slurry in cement paste and mortar. Betontechnische Berichte (Concrete Technology Reports) 2001-2003: Düsseldorf: VBT, Verl. Bau und Technik. 29, p. 125-132.
15. Moranville-Regourd M., 1999: Portland Cement – based Binders – Cements for the next millennium. Proc. of the Intern. Conf. "Creating with Concrete": Dundee, p. 87-99.
16. Rosenberg, Gaidis A.M., Kindt J.M., Joseph L., 1988: Silica fume slurry. European Patent Application EP0263606.
17. Scheiner P., Mass M., 1993: Stabilized microsilica slurries and cement compositions containing the same. Patent US, No5,176,752.
18. Sliwinski J. [et al], 2010. New Generation Cement Concretes. Ideas, Design, Technology and Applications 3. LLP – Erasmus: 9203-0574/IP/Košice 03/REN: 189 p.
19. Yajun J., Cahyadi J.H., 2003: Effects of densified silica fume on microstructure and compressive strength of blended cement pastes. Cem. Concr. Res. 33(10), p. 1543-1548.
20. Živica V., 2006: Effectiveness of new silica fume alkali activator. Cem. Concr. Compos. 28 (1), p. 21-25.

ДОБАВКА НА ОСНОВЕ МИКРОКРЕМНЕЗЕМА В ВИДЕ ВОДНОГО ШЛАМА ДЛЯ САМОУПЛОТНЯЮЩЕГОСЯ БЕТОНА

Аннотация. Статья посвящена разработке ресурсосберегающего способа получения стабильной водной дисперсии микрокремнезема, содержащей 20-45 % по массе микрокремнезема – побочного продукта производства ферросплавов (в агрегированной форме) и стабилизатора в форме суперпластификатора (конденсат полиметиленнафталинсульфоната) и гидроксида натрия. Этот состав показал высокую эффективность как добавка для вяжущих систем, в частности для самоуплотняющегося бетона, повышающая текучесть и устойчивость к сегрегации смесей, а также прочность и долговечность бетона.

Ключевые слова: самоуплотняющийся бетон, водный шлам, суперпластификатор, гидроксид натрия, бисерная мельница.