EFFECT OF SILICA FUME ON REDUCING RISK OF FREE LIME EXPANSION IN CEMENTLESS CONCRETE

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ABSTRACT

Composition and technology of fine-grained cementless concrete based on high-calcium ash from thermal power plants were developed by the Siberian State Mining & Metallurgical Academy. The concrete does not contain any natural (rubble, gravel, sand) or artificial (claydite, aggloporite, polystyrenefoam) aggregates. However, high-calcium ashes often contain 5 to 20% free calcium oxide which may cause concrete determination by its expansion in the presence of moisture.

In order to prevent expansion, silica fumewaste product from Kuznetsky Ferroalloy plant - was introduced into the concrete. To provide a better silica fume - free calcium oxide interaction, the ash was ground to a fineness of 4000 cm2 /g and hot water was used for mixing the concrete. Besides, concrete placed in a formwork was heated using a 4+3+8+3 h cycle. The use of 10 to 20% silica-fume by weight of ash and double heat treatment of concrete resulted in a 5 to 20 MPa strength class of concrete with free calcium oxide content reduced from 10 to 20 to 1 to 3%.

Keywords: High-Calcium Ash, Silica Fume, Cementless Fine-Grained Concrete, Silica Fume - Free Calcium Oxide Interaction.

INTRODUCTION

The paper presents the results of the study of the effect of silica fume on eliminating the risk of expansion due to hydration of free lime in a cementless fine-grained ash-slag concrete. The ash-slag concrete is based on a high-calcium ash from the Abakanskaya thermal power plant, slag sand with a particle size of 0 to 5 mm being used as an aggregate.

High-calcium ashes have good binding properties (Savinkina & Logvinenko 1979), (Papayianni 1993), but containing free calcium oxide, they affect concrete adversely. This negative effect can be eliminated by binding free calcium oxide with silica fume.

Previous investigations (Pavlenko 1992), (Pavlenko & Oreshkin 1992) showed that double heat treatment of the concrete components provided optimum results: using hot water (60 to 80°C) for mixing concrete and its heating at 80 to 90°C after placing and compacting.

MATERIALS

Fly ash

Fly ash from the Abakanskaya thermal power plant is produced by combustion of powdered coal from the Irsha-Borodinsky basin. It is collected by electrostatic filters and then removed by water to landfills where it loses its binding properties.

Samples from all electrostatic filters were taken for study. Characteristics of the ash are given in Table 1.

Table 1. Physical properties and chemical analysis of fly ash and silica fume

Physical properties	FA*	SF*	Chemical analysis	FA*	SF*
Fineness, Blaine, m2/kg	245	2200	SiO2 (total), %	39.45	90.11
Specific gravity, mg/m3	2.4	2.2	SiO2 (free)	24.20	90.00
Residue on sieve No 008	7.5	--	CaO (total)	31.20	0.71
Bulk density, mg/m3	1.2	0.2	CaO (free)	8.96	--
Water demand, %	42	40	MgO	6.31	0.97
Hydraulic activity, mg/g	--	102	Al2O3	7.11	1.93
			Fe2O3 +FeO	10.79	1.82
			SO3	0.86	0.89
			MnO	0.18	0.205
			TiO2	0.9	0.015
			Na2O	0.4	0.87
* - Fly ash			K2O	0.7	1.16
** - Silica fume			Loss on Ignition	1.85	2.25

According to Ivanov (Ivanov 1986), ash from the Abakanskaya thermal power plant is referred to as a coarse, polydispersed ash (ash particles are agglomerated). To destroy the agglomerated particles and fused cover of the ash, it should be ground to a fineness of 400 to 450 m2/kg. Grinding improves physical properties and chemical activity of the ash and eliminates expansion of the concrete.

The coefficient of quality (Ignatova 1990), determining binding properties of ash (C=CaO+Al2O3+MgO/SiO2=1.13), indicates that ash from the Abakanskaya thermal power plant has good binding properties ($C \geq 1$). Besides, the ash has a great reserve of a potential activity: high content of free silica in the amorphous state (24.2%) increases the binding properties of the ash after grinding of the ash and its heat treatment. The grinding also increases the activity of minerals containing magnesium.

The ash contains negligible amounts of unburnt organic particles and sulfur compounds (1.85 and 0.85, respectively).

Silica fume

The waste product from the Kuznetsky Ferroalloy plant is a superdispersed powder of a light grey color with a high content of an amorphous silica which, under certain conditions (grinding of ash and double heat treatment), reacts with a free calcium oxide of the ash and protects concrete from deterioration during its performance.

The data on properties of silica fume are given in Table 1.

X-ray diffraction and differential thermal analysis show that the silicon dioxide is in the amorphous state and reveals hydraulic activity when interacted with lime. The hydraulic activity of the silica fume (102 mg CaO/g) was determined by the amount of lime absorbed by the silica fume from the saturated solution at 85°C.

Slag sand

The study of slag from the Abakanskaya thermal power plant was performed in accordance with the requirements of State Standard 26644-85 (Gosstroy USSR, 1986). The ordinary granulated fuel slag was graded to receive two grading fractions: 5 to 10 mm (slag rubble - 7.5%) and 0.14 to 5 mm (slag sand - 92.5%). The material above 5-mm particle size was tested for stability of the structure (silicate and ferruginous decomposition). The losses in weight of the slag (three samples) were maximum 6.7% (versus 8% standard) and 4.6% (versus 5% standard) for silicate and ferruginous decomposition tests, respectively. Frost resistance of the slag (three samples) was 96-102 cycles and after its grinding to 0 to 5 mm particle size it increased to 150-235 cycles. Thus, to achieve the 100 percent utilization of the slag, it should be ground to sand at a roller crusher.

The fineness modulus of the slag sand was 2.5 to 3.1. Its bulk and true densities were 1580 and 2200 kg/m3, respectively.

The chemical analysis of the slag sand is given in Table 2.

Table 2. Chemical analysis of slag sand

Oxides	Quantity, % by mass	
	According to State Standard 26644-85	
SiO2 (total)	not standardized	56.47
SiO2 (free)	not standardized	15.57
CaO (total)	not standardized	29.92
CaO (free)	not more than 1	0
MgO	not standardized	3.50
Al2O3	not standardized	8.16
FeO+Fe2O3	not standardized	9.63
MnO	not standardized	0.17
P2O5	not standardized	0.05
SO3	not more than 3	0.11
Loss on Ignition		
for dense slag	not standardized	0
for porous slag	not more than 3	0

The results of the tests show that the sand produced from the slag of the Abakanskaya thermal power plant may be used as a replacement for natural aggregates (crushed stone and sand) in fine-grained concretes and mortars.

EXPERIMENTAL DETAILS

Mixture proportioning

A lot of formulas and methods for proportioning concrete mixtures are available (Bazhenov 1975; Batrakov 1990; Buzhevich 1970; Stork 1971), however, none of them can be applied to a cementless concrete. It is attributable to the fact that high-calcium ash, being a multicomponent system, includes both binding (minerals) and inert substances and, to some extent, may serve as a microfiller.

Besides high-calcium ash, concrete was to contain silica fume to bind free calcium oxide and slag sand, to increase its strength and improve its deformation properties. High-calcium ash and silica fume were considered to be a single binder while slag sand was an aggregate.

A series of tests were made to determine mixture proportions for cementless concrete intended for load-bearing structures. First, the optimum ash-to-water ratio was determined (Fig.1) and then, the effect of the temperature of mixing water on a compressive strength of an ash concrete was studied (Fig. 2).

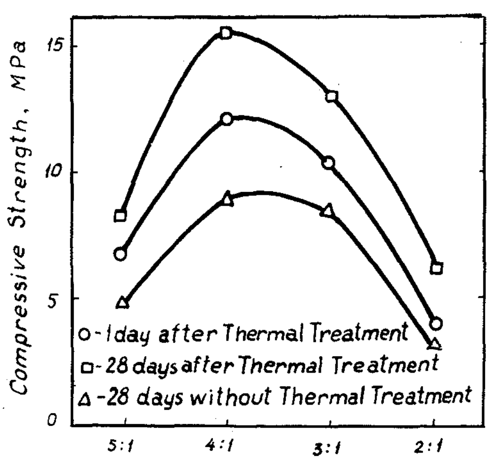

Fig.1 Compressive strength of cementless concrete versus ash-to-water ratio (A/W)

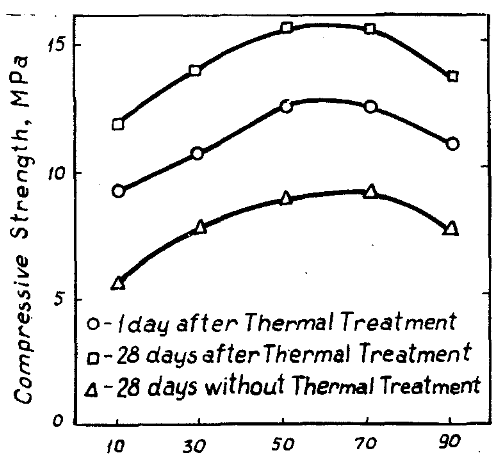

Fig.2 Compressive strength of cementless ash concrete versus the temperature of mixing water (t°C)

As can be seen from the data, the best results were obtained with the ash-to-water ratio of 4:1 and with the temperature of mixing water of 60 to 80°C. However, a slight expansion of cube specimens at their open surface was observed but without visible cracks.

To eliminate expansion, silica fume was introduced into the mixture having the optimum mixture proportions (a/w=4:1; the temperature of water is 70°C) in the quantities of 5, 10, 15 and 20% by mass of the ash. Both unground and ground ashes were used, their fineness being 245 and 440 m2/kg, respectively. The data on the compressive strength of concrete are given in Fig.3.

It is evident that concrete containing 10% silica fume had the highest strength. The strength of the concrete containing ground ash was higher than that of concrete with unground ash.

The next stage of the tests was to determine the maximum amount of an aggregate (slag sand) in a cementless concrete mixture based on ground ash and containing 10% silica fume (Fig.4).

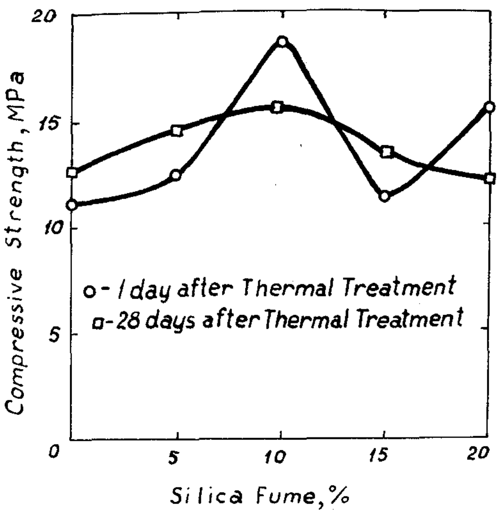

Fig.3. Compressive strength of cementless ash concrete versus the amount of silica fume

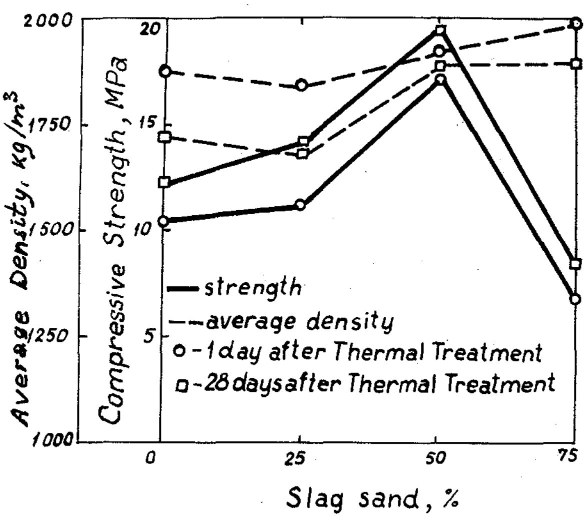

Fig.4. Compressive strength of cementless ash concrete versus the amount of slag sand

As can be observed from the data given in Fig.4, the strength of concrete increased with the introduction of up to 50% slag sand into the ash concrete mixture containing 10% silica fume.

After processing the results of the study by a computer, the optimum mixture proportions for a cementless fine-grained ash-slag concrete were developed (Table 3).

Table 3. Optimum mixture proportions

	Quantities, (kg/m3)				Mixture slump (cm)	Average density (kg/m3)	Compressive strength (MPa)
	Fly ash	Silica fume	Slag sand	Water			
For load-bearing structures	650	70	720	480	8-10	1920	15-20

To improve properties of the concrete developed, to predict its service life, to eliminate the reaction between free calcium oxide and water and to prevent expansion of the concrete, the effect of silica fume on the process of binding free calcium oxide in the concrete was studied. Some procedures were performed to assist the process of binding free CaO by the amorphous silica and converting the free CaO into 2CaO. SiO2 and 3CaO. SiO2 or, in the presence of water and heat, into hydrosilicates. They were as follows: grinding of ash which destroyed agglomerated particles and fused cover of the ash, using hot water for mixing concrete and subsequent heating of the concrete after its placing using a 3+9+3 h cycle (Pavlenko 1995).

Electron microscopy, X-ray diffractometry, chemical and differential thermal analysis were used to identify the reaction between silica fume and free CaO. The election microscopy revealed this reaction (Fig. 5, 6).

Fig. 5. Reaction of hydration between free CaO and silicon dioxide. Electron micrograph x 14600. At 24 h.

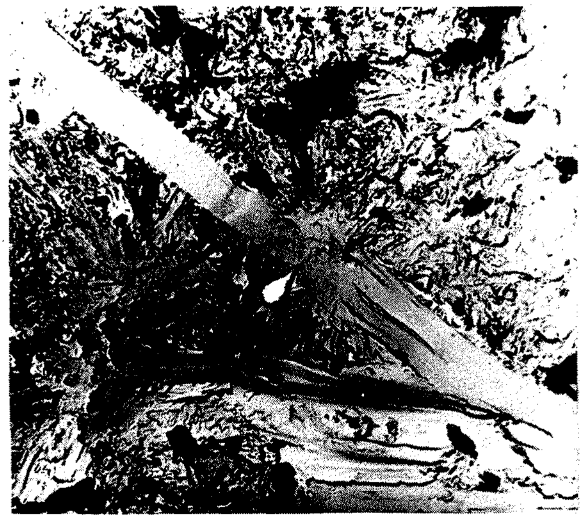

Fig. 6. Large crystals of calcium hydrosilicate. Electron micrograph x 12400. At 180 days.

X-ray analysis of the materials and concrete also indicated that the formation of hydrosilicates of calcium occured not only due to the hydration of minerals but also due to binding free CaO by silicon oxides and their interaction with water.

If we take the free CaO content in fresh concrete mixture as 100% (free CaO will be equal to 2.78% of the total mixture), its content will amount to 0.69, 0.51, 0.32 and 0.28% at 24 hours, 28, 90 and 180 days, respectively.

Differential thermal analysis and dynamic weighing of specimens were used to determine the degree of ash hydration, the amount of new formation being defined by loss in weight.

RESULTS

The reduction of free calcium oxide in the cementless ash-slag concrete from 2.78 to 0.28% due to the reaction between CaO and silica fume increased its strength by 20%. The use of slag sand resulted in a 60-7-% increase in the concrete strength. The expansion of concrete in the presence of free lime was eliminated.

The concrete developed was used for the production of small blocks at Abakanskaya thermal power plant and produced satisfactory performance.

CONCLUSIONS

The study of the effect of silica-fume on diminishing risk of expansion due to hydration of free lime in cementless fine-grained concrete confirmed good performance of the concrete consisting entirely of industrial waste products (high-calcium ash, slag sand and silica fume) prepared with hot water (60-80°C) and after its curing at 80-90°C.

The concrete developed and technology of its preparation, placing and heat treatment may be used for the production of bricks, small blocks and also for the construction of one-, two-storey cast in-situ houses.

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