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Effect of superplasticizers on the rheological properties of fly ash suspensions containing activators of the pozzolanic reaction

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Abstract

Rheological studies have been carried out on the effect of a superplasticizer from the sulphonated melamine formaldehyde (SMF) group upon the properties of fly ash suspensions containing a small quantity of mineral admixtures such as cement, lime and gypsum. The superplasticizers' efficiency has appeared to depend greatly on the admixture used. The highest liquefaction degree was found in fly ash suspensions containing both cement and gypsum together and the next it was, when only cement was added. These suspensions exhibit features of a newtonian fluid of low plastic viscosity, when the water to solid ratio (w/s) is 0.3 and a superplasticizer has been used. However, fly ash suspensions with lime, under analogous conditions, produce a considerable increase of the rheological parameters. This may be explained by the effect of the very high specific surface area of hydrated lime upon the consistency of fly ash suspensions.

Keywords: Rheology; Fly ash; Admixture

1. Introduction

Fly ash is widely used in blended cements [1,2]. Its part in the development of the physical and strength features of cement pastes and concrete results first from its pozzolanic and hydraulic properties [3,4]. Recent interest is also focused on fly ashes containing products of the desulphuration of combustion gases as a material to be used in the manufacturing of binders and building materials [5,6].

Such a hardened suspension of fly ash containing products of the desulphuration of fumes may achieve a compressive strength of over 20 MPa after 28 days, while its permeability corresponds to that of loam ranging from 10^{-7} to 10^{-8} m/s [7]. Thus, such materials may be successfully used to stop leakage from waste collectors. It is possible to obtain low-permeability fly ash-based materials, where the ash contains desulphuration products, due to the reactions occurring in the system, the products of which seal up the materials structure. In these reactions, the pozzolanic activity of fly ash is raised by the waste components, which introduce calcium ions into the solution, as well as by the formation of binding compounds due to the hydration of the waste solid phases.

The great flood in Poland in 1997 has destroyed hundreds of kilometers of dams, which now need to be sealed and repaired. From among a number of technologies that may be applied in this case, some of them use fly ash-based materials. Studies have shown that a small addition of pozzolanic activators (lime, gypsum, cement) to the bituminous fly ash allows to obtain materials of a low permeability. The potential of activated fly ash utilization in sealing of dams as fillings at the damaged sites involves the hydraulic transport of the material. Thus, it is essential to learn the rheological properties of fly ash suspensions of that kind, as well as the potential to raise its flowability under lower content of water. As far as the rheological properties of suspensions obtained from cements containing fly ash have been rather good recognised, the rheological properties of fly ashes containing small amounts of pozzolanic activators, as well as the effect of a superplasticizer on such systems, have been studied in a much less extent.

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Table 1
Chemical composition of the materials (wt.%)

Component	Cement	Fly ash	Gypsum
Crystallization water	–	–	19.0
Loss on ignition	0.7	1.2	–
SiO_2	22.8	47.9	0.7
Fe_2O_3	3.0	8.4	0.3
Al_2O_3	4.8	27.5	0.4
CaO	66.3	4.2	33.7
MgO	1.4	3.2	0.0
SO_3	0.5	1.0	45.6
Na_2O	0.2	1.1	0.01
K_2O	0.7	3.1	0.02
CaO free	0.9	–	–

This work comprises the results of studies on the effect of a sulphonated melamine formaldehyde (SMF) superplasticizer on the rheological properties of fly ash suspensions containing a small amount of pozzolanic reaction activators in the form of hydrated lime, waste gypsum derived from desulphuration of combustion gases, and cement.

2. Experimental

2.1. Materials used

Bituminous fly ash has been used in the study. Hydrated lime, gypsum derived from desulphuration of combustion gases and Portland cement were used as admixtures to the fly ash. Chemical composition of the materials used in the experiments has been presented in the Table 1. The fly ash Blain's specific surface area was 2853 cm^2/g, whereas that of the hydrated lime was 18 000 cm^2/g as determined by the BET method.

Fly ash blends used in rheological tests were produced by homogenizing the components in a laboratory mill for 5 h.

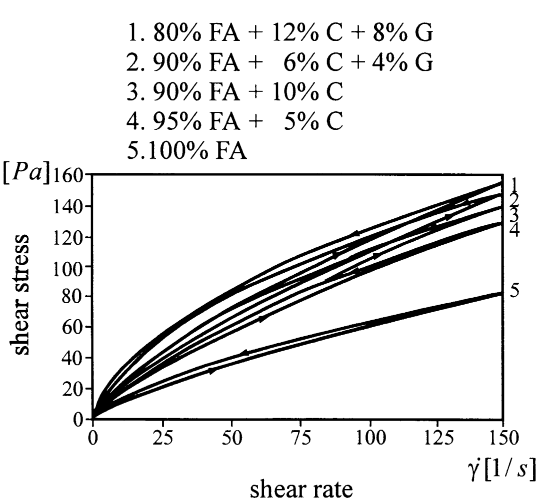

Fig. 1. Flow curves of fly ash suspensions containing gypsum and cement.

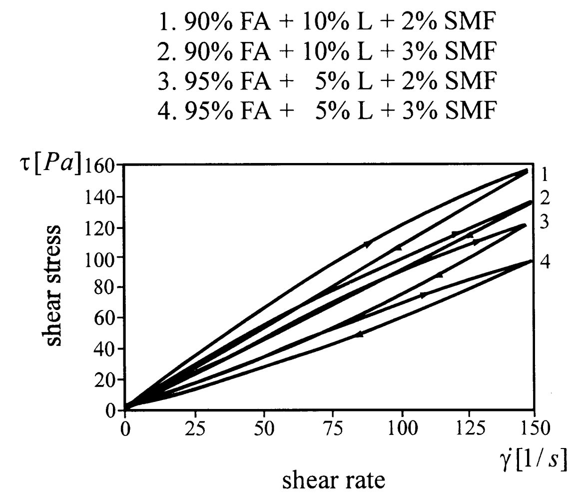

Fig. 2. Flow curves of fly ash suspensions containing lime and superplastizer SMF.

Fly ash mixtures containing 5% and 10% by mass of hydrated lime, 5% and 10% by mass of cement and mixtures of 4% of gypsum and 6% of cement, as well as 8% of gypsum and 12% of cement have been prepared. A superplasticizer from the group of SMF condensate has been used. The basic solution contained 20% of SMF (a sodium salt of) in water. That solution was applied to the suspensions in quantities 1, 2 and 3 wt.%, respectively, in relation to the solid phase, by adding the superplasticizer to the mixing water.

2.2. Rheological measurements

The rheological measurements we carried out using the rotational viscosimeter type Viscotester VT 550 (Haake). The tests were performed at a constant temperature of 21°C and at a constant water to solid ratio

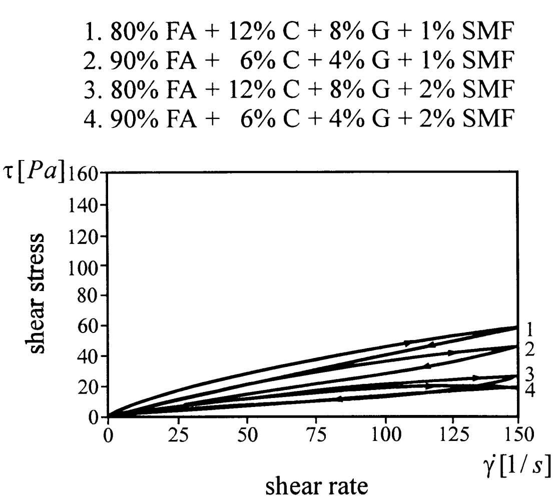

Fig. 3. Flow curves of fly ash suspensions containing gypsum, cement and superplastizer SMF.

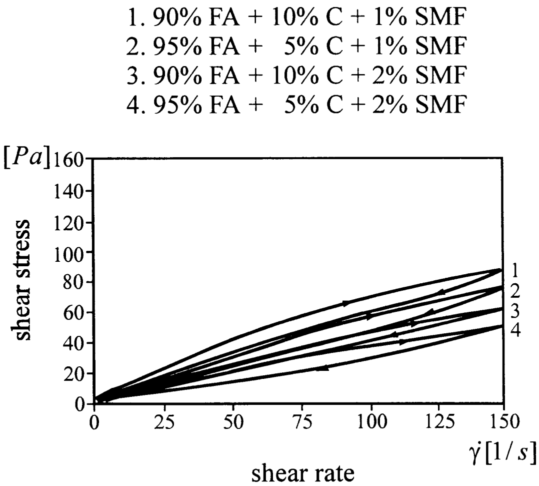

Fig. 4. Flow curves of fly ash suspensions containing cement and superplastizer SMF.

(w/s) of 0.3. Measurements started 12 min after mixing with water. The rheological properties of fly ash suspensions were determined from the flow curves at growing and reduced rates of shearing in the range from 0 to 150 s^{-1}. The yield value and plastic viscosity were determined from the descending part of the flow curve, according to the Bingham's model.

3. Results and discussion

Flow curves of the studied fly ash suspensions have been shown in Figs. 1–4. Calculated yield values and plastic viscosities of the suspensions are given in Table 2.

Rheological studies of fly ash suspensions containing small amounts of activators of the pozzolanic reaction in the form of cement (5% and 10% by mass), lime (5% and 10% by mass), as well as cement and gypsum mixtures (6% and 4%, and 12% and 8% of mass) have shown that whatever the admixture was, its addition impaired the rheological properties in all studied cases (Fig. 1). It has been found that the hydrated lime produces higher increase in the rheological parameters of the fly ash suspension. In this case, rheological measurements at a water to solid ratio (w/s) maintained at 0.3 was not possible.

Addition of a superplasticizer to the tested fly ash suspensions results in their liquefaction, but also in this case, the suspensions containing addition of hydrated lime have produced the least liquefaction degree (Fig. 2). For these suspensions at a superplasticizer content of 1% by mass, the rheological measurement at a w/s = 0.3 is not possible. However, fly ash suspensions containing added cement and gypsum blend produce a considerable liquefaction under the same conditions (Fig. 3). Such suspensions exhibit properties typical of newtonian liquids and are characterised by low plastic viscosities (Table 2) in the range of 0.20–0.28 Pa·s. A little bit lower liquefaction degree may be observed in fly ash suspensions containing added cement (Fig. 4). The considerable increase both in the yield value and plastic viscosity in fly ash suspensions doped with hydrated lime, as well as the low efficiency of the superplasticizer in this case, may be explained by the effect of the very high specific surface area of the hydrated lime upon the consistency of fly ash suspensions.

4. Conclusions

(1) Doping of fly ash by small amounts of pozzolanic reaction activators in the form of hydrated lime, cement and gypsum raises both to the yield value and plastic viscosity when compared with suspensions free of such admixtures. Hydrated lime appeared to produce the highest increase in these parameters.

(2) The superplasticizer's efficiency in fly ash suspensions containing small amounts of mineral admixtures depends greatly on their kind and has been found to be the least when the fly ash suspensions have been doped with hydrated lime.

Table 2
Yield value τ_0 (Pa) and plastic viscosity η_{pl} (Pa·s) of fly ash suspensions containing Portland cement, gypsum and hydrated lime (w/s = 0.3)

Composition of materials	Without SMF		1% SMF [η_{pl} (Pa·s)]	2% SMF [η_{pl} (Pa·s)]	3% SMF [η_{pl} (Pa·s)]
	τ_0 (Pa)	η_{pl} (Pa·s)			
100% FA	15	0.48	0.31	0.27	0.20
90% FA + 6% C + 4% G	20	0.90	0.20	0.14	0.14
80% FA + 12% C + 8% G	30	0.92	0.28	0.15	0.15
95% FA + 5% C	20	0.76	0.48	0.33	0.32
90% FA + 10% C	28	0.86	0.53	0.40	0.36
95% FA + 5% L	[a]	[a]	[a]	0.80	0.66
90% FA + 10% L	[a]	[a]	[a]	1.10	0.91

FA = fly ash, C = cement, G = gypsum, L = lime.

[a] Measurement unattainable.

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