

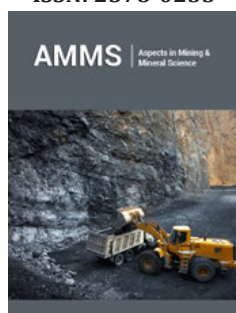
Effect of Superplasticizer Addition on Injectability of CEM II/B-M Based Cement Grouts

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Abstract

The use of very fine cement grouts for injection into fine-to-medium sands has been proposed to circumvent problems associated with the permanence and toxicity of chemical grouts and the inability of ordinary cement grouts to permeate soil formations finer than coarse sand. An experimental investigation was conducted in order to evaluate the penetrability of cement suspensions. Four gradations from CEM II/B-M (according to EN 197-1) type of cement were used having nominal maximum grain sizes of 100µm, 40µm, 20µm and 10µm. The properties of suspensions, with water-to-cement (W/C) ratios of 1:1, 2:1 and 3:1 by weight, were determined in terms of apparent viscosity. Penetrability was evaluated by conducting one-dimensional injections into five different, clean sands using a specially constructed device. Penetrability of cement suspensions increases with increasing cement fineness and water-to-cement (W/C) ratio. In cases of guaranteed injectability of cement suspensions, the use of superplasticizer is not required as it does not affect the result of the injection.

Keywords: Permeation grouting; Suspensions; Microfine cements; Superplasticizer; Sand fraction

Introduction

The safe construction and operation of many technical projects often requires the improvement of the properties and mechanical behavior of the soil formations. The shear behavior of a soil material is of particular interest because it has a direct impact on practical bearing capacity problems [1,2], stability of slopes and embankments [3,4] as well as permanent seismic movements of slopes [5,6]. Permeation grouting is commonly used in geotechnical engineering either to reduce the permeability or improve the mechanical properties of soil and rock [7]. Success in a given grouting operation requires that the grout is capable of being injected into the soil formation and that the desired improvements in the properties of the formations are attained. Grouts are generally categorized as suspension, or particulate grouts, which are prepared with ordinary Portland or other cements, clays, or cement-clay mixtures, and fine sands in some cases, and solution, or chemical grouts which include sodium-silicate formulations, acrylamides, acrylates, lignosulfonates, phenoplasts and aminoplasts as well as other materials that have no particles in suspension. Chemical solutions can be injected in fine sands or coarse silts but are more expensive and some of them pose a health and environmental hazard. Efforts have been made to extend the injectability range of suspension grouts by developing materials with very fine gradations [8-15].

Materials and Procedures

For the purposes of this investigation, a cement of type CEM II/B-M, according to EN 197-1, was used. The ordinary cement (designated as F0) was pulverized in order to produce three additional cements with nominal maximum grain sizes of 40µm, 20µm and 10µm, which are designated as F1, F2 and F3, respectively. Characteristic grain sizes and Blaine specific surface values for all cements are presented in Table 1. All suspensions were prepared using potable water. The water-to-cement (W/C) ratio of all suspensions used, was equal to 1:1, 2:1 and 3:1 by weight. A superplasticizer at a dosage of 1.4% by weight of dry cement, was used to improve the suspension properties of the microfine cements. This fixed superplasticizer

dosage was determined following a laboratory evaluation of the effect of various dosages on the apparent viscosity and the rheological characteristics of the pulverized cement suspensions [9]. Presented in (Table 2) are the apparent viscosity values of ordinary cement suspensions without superplasticizer and microfine cement suspensions with superplasticizer, obtained at $t=30\text{min}$ after preparation and at viscometer rotation speed equal to 60rpm. The grouted soils were clean, uniform sands with angular

grains. Five different sand gradations were used with grain sizes limited between sieve sizes (ASTM E11) Nos. 5 and 10, 10 and 14, 14 and 25, 25 and 50, and 50 and 100, and designated as S1, S2, S3, S4 and S5, respectively. The sands were grouted in dense condition (mean value of relative density, D_r , $98\pm1\%$) and were dry prior to grouting. The values of other properties of sands are presented in Table 2.

Table 1: Cements gradations. d_{95} , d_{90} , d_{85} , d_{50} , and d_{10} correspond to the particle diameter at which 95%, 90%, 85%, 50%, and 10% of the weight of the specimen is finer, respectively b Nominal maximum cement grain size.

Grain sizes ^a Specific Surface	Cement Type			
	F0	F1	F2	F3
d_{\max}^b (μm)	100	40	20	10
d_{95} (μm)	45.5	25.8	13.6	9.1
d_{90} (μm)	37	21.5	11.8	8.3
d_{85} (μm)	32	19	10.7	7.6
d_{50} (μm)	14	9.4	5.8	4.2
d_{10} (μm)	2.2	2.0	1.4	1.1
Blaine (m^2/kg)	466	591	735	942

Table 2: Apparent viscosity of cement suspensions.

Cement Type Designation	Nominal Maximum Grain Size d_{\max} (μm)	W/C ratio	Apparent Viscosity (mPa.s)
F0	100	1:01	213
		2:01	33
		3:01	13
F1	40	1:01	16
		2:01	2
		3:01	2
F2	20	1:01	36
		2:01	8
		3:01	2
F3	10	1:01	117
		2:01	22
		3:01	4

The special apparatus shown in Figure 1 was used for injecting sand columns with cement suspensions. It allows for adequate laboratory simulation of the injection process and investigation of the influence of the distance from injection point on the properties of grouted sand. The grouting column was made of thick PVC tube with an internal diameter of 7.5cm and a height of 144cm and was formed by placing at each end a 5cm thick gravel layer, between two screens of suitable aperture, and filling the remaining length (134cm) with dry sand in a dense or loose condition (Table 3). The sand was saturated, when required by the testing program, by upward flow of water pumped from the grout tank. Injection

was stopped when either the volume of the injected grout was equal to two void volumes of the sand in the column or when the injection pressure became equal to 700kPa. The grout pressure was continuously recorded during the injections, by installing one pressure sensor at the inflow pipe of the grouting column and six pressure sensors on the grouting column, at distances from the injection point equal to 4cm, 14cm, 34cm, 54cm, 83cm and 123cm, respectively. The pressure sensors (PWF-PA pressure transducers of Tokyo Sokki Kenkyujo) were placed in cyclical openings on the grouting columns using specially designed clamps and were connected to an automatic data acquisition system.

Table 3: Sand properties. *Sands in dense condition.

Sand	Specific Gravity, G_s	Void ratios		Permeability Coefficient, * k_{20} (cm/sec)
		Minimum, e_{min}	Maximum, e_{max}	
S1	2.71	0.66	1.06	2.31
S2	2.72	0.68	1.03	0.80
S3	2.72	0.69	1.07	0.22
S4	2.7	0.7	1.06	0.04
S5	2.72	0.72	1.12	0.013

**Figure 1:** Laboratory equipment for penetrability evaluation [8-14].

Experimental Results and Discussion

The grout ability of a suspension grout can be evaluated in terms of: (a) the ability of the grout to enter into the voids of a given soil and (b) the permeation distance that can be achieved under a predetermined maximum injection pressure. The terms “injectability” and “penetrability”, respectively, were selected to describe these two conditions or criteria. Thus, the penetrability of cement grouts was the objective of the investigation reported herein. All factors relating to penetrability were evaluated experimentally

by grouting sand columns with the apparatus shown in Figure 1 and the results obtained, are presented in Table 4. Penetrability was considered “optimal” when the entire amount of suspension penetrates the sand column with low impregnation pressure, “satisfactory” when all or almost the entire amount of suspension penetrates the sand column with increasing impregnation pressure, “marginal” when penetration length is greater than 60cm with maximum impregnation pressure and “low” when penetration length is less than 60cm with maximum impregnation pressure.

Table 4: Experimental results.

Sand Fraction	Cement Type Designation	Nominal Maximum Grain Size d_{max} (μm)	W/C Ratio	Penetration Length (cm)	Maximum Pressure (kPa)	Injection Result
S1	F2	20	2:01	>134	<50	Optimal
S2	F0	100	1:01	>134	88	Optimal
	F2	20	1:01	>134	<50	Optimal
	F0	100	2:01	>134	28	Optimal
	F2	20	2:01	>134	14	Optimal
	F3	10	2:01	>134	14	Optimal
	F0	100	3:01	>134	200	Optimal
	F2	20	3:01	>134	<50	Optimal
S3	F0	100	1:01	>134	1030	Satisfactory
	F2	20	1:01	>134	87	Optimal
	F3	10	1:01	>134	124	Optimal
	F0	100	2:01	>134	590	Satisfactory
	F2	20	2:01	>134	50	Optimal
	F3	10	2:01	>134	72	Optimal
	F0	100	3:01	>134	140	Optimal
	F2	20	3:01	>134	<50	Optimal
	F3	10	3:01	>134	<50	Optimal
S4	F2	20	1:01	10,7	873	Low
	F3	10	1:01	92,7	752	Marginal
	F2	20	2:01	>134	104	Satisfactory
	F3	10	2:01	83	848	Marginal
	F0	100	3:01	16,2	734	Low
	F2	20	3:01	>134	105	Optimal
	F3	10	3:01	>134	639	Satisfactory
S5	F2	20	3:01	13,4	746	Low
	F3	10	3:01	22,8	866	Low

The effect of superplasticizer addition on cement suspensions penetrability was investigated by examining dry columns of the sand fraction S2 (Nos. 10-14), impregnated with suspensions of fine-grained (II-F3-2) and common (II-F0-2) cement type CEM II/B-M containing superplasticizer. To perform the required comparisons, the impregnations were repeated using the same materials (sand and cement) but the suspensions did not contain a superplasticizer (suspensions II-F3-2-X and II-F0-2-X, respectively). This test was not large-scale, as it is common practice in field applications to use superplasticizers to improve the rheological behavior of fine-grained cement suspensions. On the other hand, for the same reason it is not necessary to add such materials to common cement suspensions. Table 5 presents the data of impregnations performed in order to evaluate the effect of superplasticizer addition on the injectability of cement suspensions. Regarding injections of fine-grained cement suspensions (II-F3-2 and II-F3-2-X) in S2 (Nos. 10-14 sand columns, it was observed that the columns were completely

impregnated with low maximum impregnation pressures (<50kPa) and the volume of suspension compressed was twice the volume of voids in the soil column. The only difference found is the water-to-cement ratio of the suspension after it exits the sand column. Note that the initial water-to-cement (W/C) ratio of the suspension was 2:1. Collection of the suspension from the outlet column for the suspension without the addition of superplasticizer (II-F3-2-X) yielded water-to-cement ratio values ranging from 1.65:1 to 1.77:1. Correspondingly, the values of water-to-cement ratio at the outlet of the suspension column with the addition of superplasticizer (II-F3-2) showed a range from 1.74:1 to 1.82:1 approaching the initial water-to-cement ratio of the suspension prepared. From the impregnations in S1 sand columns (Nos. 10-14) with common cement suspensions of type CEM II/B-M (II-F0-2-X and II-F0-2), it emerged that the use of superplasticizer did not affect their penetrability, as complete impregnation was observed and low values of the maximum impregnation pressure. Collection of the

suspension from the outlet column for the suspension without the addition of superplasticizer (II-F0-2-X) yielded water-to-cement ratio values ranging from 2.07:1 to 2.11:1. Correspondingly, the values of water-to-cement ratio at the outlet of the suspension column with the addition of superplasticizer (II-F0-2) ranged from

1.97:1 to 2:1. From the above investigation it was found that in cases of guaranteed injectability of cement suspensions, the use of superplasticizer is not required as it does not affect the result of the injection.

Table 5: Results of impregnations on long sand columns to investigate the effect of superplasticizer addition on the suspensions injectability. *O: Optimal Penetration.

Suspension Type	Sand Fraction	Superplasticizer Dosage (%) by Weight of Dry Cement	Maximum Grouting Pressure (kPa)	Injection Result
II-F0-2-X	10-14	0.0	28	*O
II-F0-2	10-14	1.4	<50	O
II-F3-2-X	10-14	0.0	<50	O
II-F3-2	10-14	1.4	14	O

Conclusion

Based on the results obtained and the observations made during this investigation, the following conclusions may be advanced:

- In cases of guaranteed cement suspensions injectability, the use of superplasticizer is not required as it does not affect the result of the injection.
- Microfine cement suspensions with water-to-cement (W/C) ratios of 2:1 and 3:1 can be injected in medium-to-fine sands.
- The increase of cement fineness improves the injectability of cement suspensions rendering them effective for grouting of medium-to-fine sands.
- Suspension grouts prepared with fine-grained cements are an environmentally safer alternative to chemical grouting.

The overall problem is extremely complicated, and available information from research efforts and field experiences is sparse; furthermore, each field situation presents its own unique set of circumstances. Accordingly, the results reported herein must be utilized with full awareness of their origin, and caution is urged when attempting to generalize them to other situations not explicitly addressed.

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