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Engineering properties of various graded medium to fine sand grouted with Ultrafin 12 cement

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ABSTRACT: The aim of this experimental study is to investigate the penetrability of Ultrafin 12 suspensions with or without dispersive agent into various graded medium-to-fine sand where chemical grouts can only penetrate. Initially, the basic rheological properties such as viscosity, setting time and stability of Ultrafin 12 suspensions with or without dispersive agent are studied. In addition, the penetration performance of Ultrafin 12 suspensions into various graded medium to fine sand specimens prepared at different relative densities is examined. It is seen that increase in relative density and finer percentage of sand specimens decreases the penetrability of Ultrafin 12 suspensions but the penetration performance of Ultrafin 12 suspensions is greatly increased by the addition of dispersive agent. Finally, the unconfined compressive strength and the permeability characteristics of various graded medium to fine sand specimens permeated with Ultrafin 12 suspensions with or without dispersive agent are studied. It is observed that increase in the fine-grained fraction and the relative density of sand specimens decreases the unconfined compressive strength. Furthermore, addition of dispersive agent to Ultrafin 12 suspensions increases the unconfined compressive strength of grouted sand specimens. Finally, permeability tests on grouted specimens with or without dispersive agent reveal that all specimens are impermeable.

1 INTRODUCTION

Permeation grouting is widely used in geotechnical engineering as a ground improvement technique which involves the injection of suitable suspension and/or solution into soil and rock to either reduce the permeability or improve the mechanical properties. The properties and behavior of microfine cement grouts have been a major research subject in recent years.

One of the main challenges in the utilization of microfine cement is its grain size distribution, which is quite finer than that of OPC. In addition, The application of chemical grouts are limited because of their lower strength, high cost and negative effects to human as well as the environment. As an alternative to chemical grouting of fine and medium grained sands, the use of grouts prepared with microfine cements has been proposed. The first microfine cement available commercially is MC-500, manufactured by Onoda Cement Corporation in Japan (Mollamahmutoglu and Yilmaz, 2007).

The main purpose of this experimental study is to evaluate the rheological properties of Ultrafin 12 suspensions with or without dispersive agent, their penetrability into various graded medium to fine sand specimens prepared at different relative densities and strength and permeability characteristics of successfully permeated sand samples.

2 MATERIAL AND METHODS

2.1 INDEX PROPERTIES OF THE SAND USED IN EXPERIMENTAL STUDIES

Quartz sand is used in this experimental study. The specific gravity of the sand is determined to be 2.61 in accordance with ASTM D 854-02, 2002.The sand used is first divided into two different subgroups. Each subgroup is obtained using two sets of sieves in such a way that the coarser fraction of sand particles is first passed through an upper sieve and then an appropriate lower sieve. The amount of sand particles retained on the appropriate lower sieves is collected and named as No.10-No.40 (medium sand), and No.40-No.200 (fine sand). To broaden the range of various graded sand samples, the subgroups are mechanically mixed with each other at different percentages by dry mass. In this way, 15 different graded sand samples are formed (Table 1-Samples 1 through 15) and their particle size distribution curves are shown in Figure 1

Table 1. Sand samples mixtures

Sample Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sand content (%)	Fine	100	90	80	75	70	60	55	50	45	40	35	30	20	10	0
	Medium	0	10	20	25	30	40	45	50	55	60	65	70	80	90	100
$\gamma_{dry\ (max.)}$		1,58	1,57	1,57	1,57	1,57	1,56	1,56	1,56	1,56	1,56	1,55	1,55	1,55	1,55	1,54
$\gamma_{dry\ (min.)}$		1,26	1,26	1,27	1,27	1,27	1,27	1,27	1,28	1,28	1,28	1,28	1,28	1,29	1,29	1,30

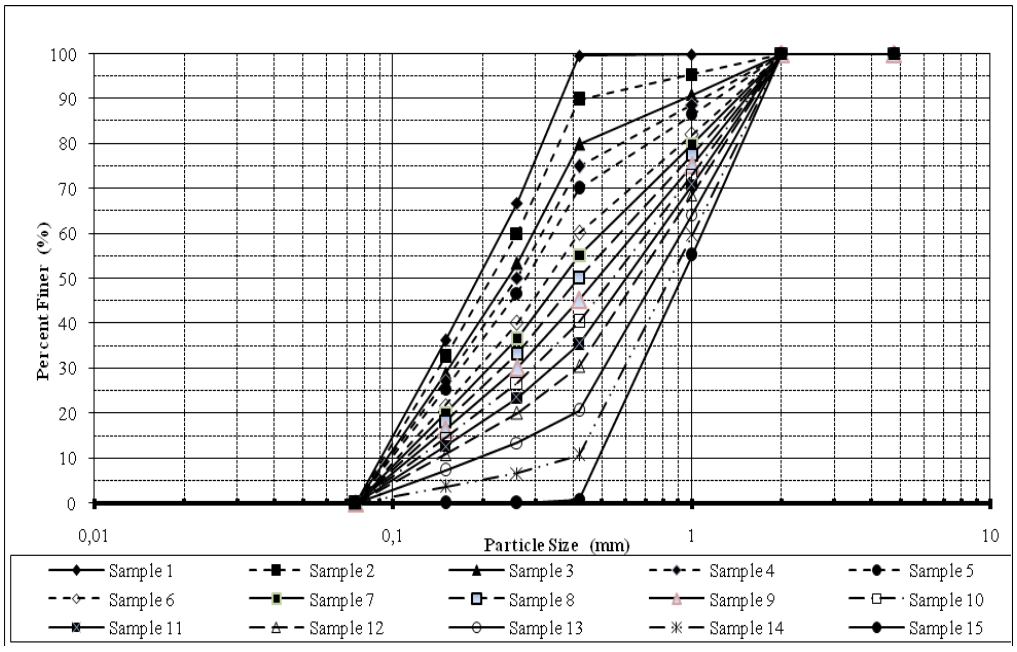

Figure 1. Particle size distribution of sands specimens

2.2 PREPARATION OF SAND SPECIMENS

In order to produce various graded sand specimens at desired relative densities, the maximum and the minimum dry unit weights of the samples are determined (Table 1) according to ASTM D 4253-00, 2002 and ASTM D 4254-00, 2002 standards respectively.

2.3 PROPERTIES OF ULTRAFIN 12

Cement is characterized as a microfine cement if the specific surface area is greater than 8000 cm^2/g and the corresponding 95% finer (D_{95}) particle size is smaller than 20 μm (BS EN 12715, 2000). In this context, the surface area of Ultrafin 12 is 2200 m^2/kg and 95% percent of its particles is finer than 12μm. Moreover, it is cement-based product.

2.4 PROPERTIES OF ADDITIVE

Because of the humidity and electrostatic interaction, fine cement particles tend to flocculate. When mixed with water, lumping of cement particles is inevitable although they are mixed vigorously. As a result, the viscosity of microfine cement suspension increases and the groutability decreases. To overcome this limitation, it is common practice to add dispersive agent or super plasticizer to the suspension to increase fluidity (Bremen, 1997; Perret et al., 2000; Saada, 2003; Eriksson et al., 2004) in amounts that vary between 1 and 5% of the dry mass of the cement (Mollamahmutoglu et al., 2007). In this study, Addiment Injektionshilfe 1 is used as a dispersive agent. Addiment Injektionshilfe 1 is a melamine-based dispersive agent and used to decrease interparticle attractive forces and enhance full wetting of the cement particles during mixing. According to the information given by the Addiment Injektionshilfe 1 supplier, its density varies from 1.180 to 1.220 g/cm^3.

2.5 INJECTION TEST APPARATUS

The injection test apparatus consists of a manometer, 5 molds for compressive strength tests, 3 molds for permeability, a grout tank with propeller and relevant connections. Molds are 53,60mm in diameter and 150mm in length. They are designed in a way that the height to diameter ratio of 2.0 can be obtained for compressive strength tests. The details of test apparatus are shown in Figure 2.

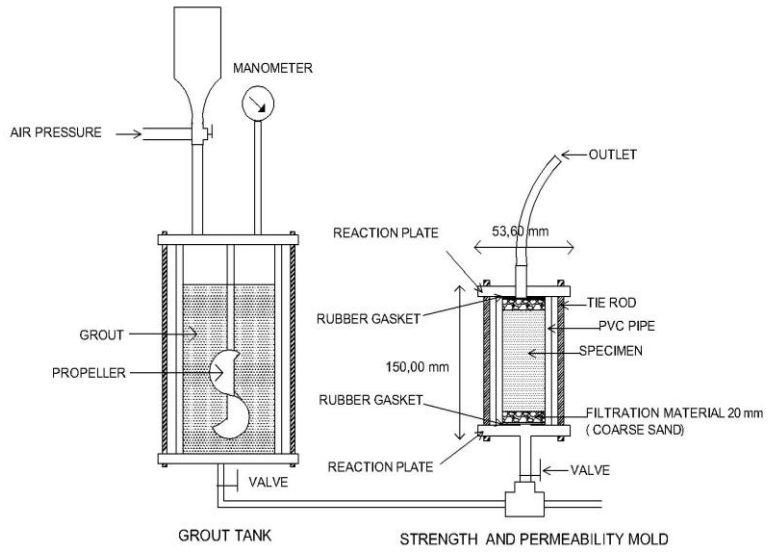

Figure 2. Technical details of the injection test apparatus

2.6 SPECIMEN PREPARATION FOR INJECTION

The inner surface of the molds is lightly lubricated to eliminate sample disturbance upon removal from molds after injection. To prepare the specimens, a coarse sand layer of about 20mm in thickness is first placed at the bottom of the molds to distribute the suspension evenly into the sample. Sand samples are then poured into molds in three equal layers. Each layer is compacted using a wooden tamp to achieve the desired relative density before placing the next layer. After placing the specimen at the achievable relative density, a coarse sand layer of about 20mm in thickness is also placed at the top of the molds. Then the top and bottom end-plates of the molds are clamped using tie rods (Figure 2). Finally, samples are saturated by applying upward flow of water before injection

2.7 PREPARATION OF SUSPENSIONS

The microfine cement and water are mixed thoroughly in a container by means of high-speed propeller-type mixer at 3,000 rpm for about three minutes. Dispersive agent, about 2% of the dry mass of Ultrafin 12 in mixture, is then added to the suspension and then mixed for two additional minutes to ensure the dispersion of cement particles in the suspensions. The grout is then transferred to the grouting tank where it is agitated at a speed of 150 rpm to avoid the sedimentation of cement grout during injection and is finally injected into the sand specimen in molds as agitation goes on. The injection pressure of 0.50 MPa is kept constant throughout testing.

2.8 RHEOLOGICAL PROPERTIES OF SUSPENSION

Stability tests are performed with reference to ASTM C 940-98a, 2002. Suspensions having applicable range of water/cement (W/C) ratios are placed in a 1,000 ml graduated cylinder and the volume of bleed liquid on top of grout to the total volume of the suspension at the end of two hours are recorded (Table 2). Table 2 indicates that the bleedings of grouts with W/C ratios of 0.8, 1.0, 1.2 and 1.5 are less then five percent and they are stable.

The setting time of Ultrafin 12 suspensions is determined according to ASTM C 191-04b, 2002. The initial and final setting times of suspensions are given in Table 2. Flow times obtained according to ASTM C 939-02, 2002, and the viscosities from Lombardi's approach are given in Table 2.

Table 2. Results of stability, setting time, flow time and viscosity tests

	Sedimentation				Setting Time				Viscosity			
	Ultrafin 12		Ultrafin 12 + Addiment		Ultrafin 12		Ultrafin 12 + Addiment		Ultrafin 12		Ultrafin 12 + Addiment	
W/C	Bleeding (%)	Explanation	Bleeding (%)	Explanation	Initial Setting Time (min.)	Final Setting Time (min.)	Initial Setting Time (min.)	Final Setting Time (min.)	Flow time (sec.)	Viscosity (cP)	Flow time (sec.)	Viscosity (cP)
0.8	0.00	Stable	0.00	Stable	360	440	410	790	52	45.05	51	43.74
1.0	0.00	Stable	0.00	Stable	370	467	420	880	41	24.50	40	23.15
1.2	1.33	Stable	1.32	Stable	433	693	470	1320	37	15.99	35	10.97
1.5	2.67	Stable	1.50	Stable	455	930	480	2680	34	8.33	33	3.50
2.0	8.15	Not stable	5.50	not stable	680	4058	—	—	33	2.61	31	1.22

3 RESULT AND DISCUSSION

3.1 PENETRABILITY

The ability of a grout to penetrate porous material is a function of the rheological properties of the grout suspension and the physical characteristics of the cement, as well as the physical characteristics of the soil (Schwarz and Krizek, 1994; Mollamahmutoglu, 2003; Mollamahmutoglu et al., 2007; Eklund and Stille, 2008)

The penetrability of the microfine cement suspensions, with or without dispersive agent, into various graded fine-to-medium sand specimens at different relative densities is investigated. The specimens are injected with the adopted W/C ratio of 1.0 (a ratio generally used for practical purposes) and the results of the groutability are presented in Table 4.

The penetration of Ultrafin 12 suspension with W/C ratio of 1.0 becomes unsuccessful for the specimens 1, 2, 3, 4 at the relative density of 30%, for the specimens 1, 2, 3, 4, 5 and 6 at the relative density of 50%, and for the specimens 1, 2, 3, 5, 6, 8 and 10 at the relative densities of 70% as the percentage of finer particles increases. However, with the addition of dispersive agent to Ultrafin 12 suspensions, all specimens are successfully permeated.

Table 4. The permeation test results of Ultrafin 12 grout with or without dispersive agent

	Particle size (%)				**Grouting performance**	
Sample Name	**Fine**	**Medium**	**D_r (%)**	**W/C**	**Ultrafin 12**	**Ultrafin 12 + Addiment**
15	0	100	30	1	Successful	Successful
12	30	70	30	1	Successful	Successful
11	35	65	30	1	Successful	Successful
10	40	60	30	1	Successful	Successful
9	45	55	30	1	Successful	Successful
8	50	50	30	1	Successful	Successful
7	55	45	30	1	Successful	Successful
6	60	40	30	1	Successful	Successful
5	70	30	30	1	Successful	Successful
4	75	25	30	1	Filtration	Successful
3	80	20	30	1	Filtration	Successful
2	90	10	30	1	Filtration	Successful
1	100	0	30	1	Filtration	Successful
15	0	100	50	1	Successful	Successful
12	30	70	50	1	Successful	Successful
10	40	60	50	1	Successful	Successful
8	50	50	50	1	Successful	Successful
6	60	40	50	1	Filtration	Successful
5	70	30	50	1	Filtration	Successful
3	80	20	50	1	Filtration	Successful
2	90	10	50	1	Filtration	Successful
1	100	0	50	1	Filtration	Successful
12	30	70	70	1	Successful	Successful
10	40	60	70	1	Filtration	Successful
8	50	50	70	1	Filtration	Successful
6	60	40	70	1	Filtration	Successful
5	70	30	70	1	Filtration	Successful
3	80	20	70	1	Filtration	Successful
2	90	10	70	1	Filtration	Successful
1	100	0	70	1	Filtration	Successful

3.2 STRENGHT OF GROUTED SAMPLES

After grouting, the specimens are kept in molds until the grout sets. Then the specimens are removed from the molds and preserved in a humid room at 20°C until testing time. The grouted samples are tested for unconfined compression strength at the end of 1st, 3rd, 7th, 14th, 28th, and 56th days according to ASTM C 4219-02, 2002 and the test results are given in Table 5. The results show that the compressive strength increases with curing period. In addition, the unconfined compressive strength decreases with the increase of fine particle size percent and the relative density of sand specimens. Finally, the unconfined compressive strength of the grouted samples is increased by the presence of dispersive agent in Ultrafin 12 suspensions.

Table 5. Unconfined compressive strengths of injected samples

Sample Name	Particle size (%)		D_r (%)	W / C	Ultrafin 12						Ultrafin 12+Addiment					
					Unconfined compressive strength, MPa						Unconfined compressive strength, MPa					
	Fine	Medium			1st day	3rd day	7th day	14th day	28th day	56th day	1st day	3rd day	7th day	14th day	28th day	56th day
15	0	100	30	1	0.58	1.16	2.90	5.08	10.30	11.80	0.62	1.32	2.99	6.04	10.90	12.56
12	30	70	30	1	0.52	1.12	2.79	4.98	10.00	11.60	0.54	1.15	2.79	5.75	10.33	11.96
11	35	65	30	1	0.49	1.00	2.51	4.29	8.72	10.20	0.50	1.02	2.76	5.06	9.18	10.52
10	40	60	30	1	0.47	0.95	2.38	4.21	8.55	9.80	0.48	0.97	2.61	4.79	8.74	10.11
9	45	55	30	1	0.45	0.91	2.27	4.02	8.22	9.50	0.46	0.92	2.48	4.59	8.40	9.80
8	50	50	30	1	0.43	0.86	2.16	3.85	7.89	9.20	0.45	0.89	2.42	4.46	8.11	9.49
7	55	45	30	1	0.41	0.81	2.03	3.61	7.35	8.60	0.40	0.83	2.24	4.22	7.59	8.87
6	60	40	30	1	0.37	0.77	1.92	3.48	7.02	8.20	0.36	0.75	2.03	3.91	7.24	8.46
5	70	30	30	1	0.33	0.69	1.73	3.22	6.08	7.80	0.32	0.61	1.51	3.41	6.32	7.37
4	75	25	30	1	---	---	---	---	---	---	0.28	0.57	1.53	2.81	5.13	5.93
3	80	20	30	1	---	---	---	---	---	---	0.24	0.49	1.33	2.44	4.42	5.06
2	90	10	30	1	---	---	---	---	---	---	0.14	0.28	0.76	1.43	2.58	3.02
1	100	0	30	1	---	---	---	---	---	---	0.10	0.22	0.59	1.13	2.09	2.44
15	0	100	50	1	0.40	0.52	1.17	1.83	4.01	4.66	0.48	0.77	1.53	3.19	6.11	7.21
12	30	70	50	1	0.25	0.49	1.15	1.95	3.91	4.91	0.37	0.61	1.21	2.67	5.03	6.14
10	40	60	50	1	0.19	0.45	0.87	1.56	3.18	4.30	0.26	0.52	1.07	2.01	4.33	5.55
8	50	50	50	1	0.16	0.33	0.81	1.51	2.99	3.70	0.21	0.37	0.93	1.79	3.60	4.45
6	60	40	50	1	---	---	---	---	---	---	0.18	0.38	0.92	1.68	3.28	4.12
5	70	30	50	1	---	---	---	---	---	---	0.15	0.32	0.78	1.42	2.78	3.49
3	80	20	50	1	---	---	---	---	---	---	0.13	0.27	0.66	1.21	2.36	2.96
2	90	10	50	1	---	---	---	---	---	---	0.11	0.23	0.56	1.02	2.00	2.51
1	100	0	50	1	---	---	---	---	---	---	0.08	0.18	0.43	0.79	1.54	1.93
12	30	70	70	1	0.21	0.41	1.02	1.76	3.63	4.21	0.27	0.56	1.38	2.50	4.89	5.67
10	40	60	70	1	---	---	---	---	---	---	0.23	0.48	1.17	2.12	4.15	4.81
8	50	50	70	1	---	---	---	---	---	---	0.19	0.40	0.99	1.80	3.51	4.07
6	60	40	70	1	---	---	---	---	---	---	0.16	0.34	0.84	1.52	2.98	3.45
5	70	30	70	1	---	---	---	---	---	---	0.14	0.29	0.71	1.29	2.52	2.93
3	80	20	70	1	---	---	---	---	---	---	0.12	0.25	0.60	1.09	2.14	2.48
2	90	10	70	1	---	---	---	---	---	---	0.10	0.21	0.51	0.93	1.81	2.10
1	100	0	70	1	---	---	---	---	---	---	0.08	0.16	0.39	0.71	1.39	1.62

3.3 PERMEABILITY OF GROUTED SAMPLES

The permeabilities of grouted sand specimens are investigated by performing falling head permeability tests in accordance with ASTM C 5856-95, 2002. No flow of water is observed through grouted specimens after two months of testing period.

4. CONCLUSIONS

The Ultrafin 12 grouts with applicable range of W/C ratios of 0.8, 1.0, 1.2 and 1.5 have a good bleeding and flow characteristics.

The penetrability of Ultrafin 12 suspensions decreases with the increase of relative density as well as the percentage of fine particle size of sand specimens. However, the presence of dispersive agent in Ultrafin 12 suspensions greatly increases their penetrability.

The unconfined compressive strength of sand specimens permeated with Ultrafin 12 suspensions increases with curing period. Additionally, presence of dispersive agent within Ultrafin 12 suspensions increases the unconfined compressive strength of sand specimens. However, the unconfined compressive strength of grouted sand specimens decreases with the increase of fine grained percentage as well as the relative density of sand specimens.

Specimens permeated with Ultrafin 12 suspensions with or without dispersive agent are subjected to falling head permeability tests and found to be impermeable after two months of testing period.

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