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Effect of Bentonite, Fly Ash and Silica Fume Cement Injections on Uniaxial Compressive Strength of Granular Bases

Ozcan Tan*, Gokhan Gungormus, and A. Sahin Zaimoglu*****

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Abstract

Injection is one of the methods to improve the engineering properties of bases. Various additions as well as cement are used for preparations of injection blends in order to lower costs and reach better results. For this purpose in the preparation of the injection blends, Bentonite (B), Fly Ash (FA) and Silica Fume (SF) were used at the ratios of 0-0.5-1-3%, 10-20-30-40% and 0-5-10-20%, respectively. Taguchi method was applied for the experiment and L_{16} Orthogonal Array (OA) with three factors and four levels were chosen. Granular bases having 0.70 relative density was settled into a cylindrical mold to which injection blends were injected. Effect of B, FA and SF over the uniaxial compressive strength of the samples of 7, 14, 28 days that have been prepared in this manner was investigated. In results of the experiments it was observed that the most effective parameter over the uniaxial compressive strength of 7, 14 and 28 days was silica fume.

Keywords: *fly ash, silica fume, granular soil, injection, optimization*

1. Introduction

The most serious problem that is frequently encountered in civil engineering applications is that base properties are not at the required level. Base improvement is classified as the improvement of cohesive and non-cohesive bases according to the kind of base and improvement of surface or deep bases depending on the distance of application region to the base elevation (Mitchell and Katti, 1981). Improvement of bases by injection blends is one of the methods used in improvement of deep and shallow bases. Injection is a compounded stabilization method that is defined as cement blends are injected into base in higher pressure in order to inject the blends in the cavities, cracks and pores or to form base-cement combination (Kim and Lee, 2000). The main injection applications are to form an impervious zone under the dam bodies, to form diaphragm walls, to fill the surroundings of anchor rods, to increase the carrying power of the ground base and to form domestic and industrial waste stores (Costas, 2006; Saiyouri *et al*., 2007). The blends used in injection are typically divided into two; as suspension and solution blends. Although the ties formed in the clay suspensions are weaker than the ties in the cement suspensions (Shroff and Shah, 1993), these combinations improve the geotechnical properties of base by forming fillings in the cavities. Difficulties and higher costs of injections in injection applications are the primary problems (Eklund and Stille, 2008). Therefore using various additions in injection blends in order to lower costs has become widespread. Conversely, for facilitating injectability of bases the blend that is injected must be made of the materials with pretty fine granules. This is a factor that increase costs as it needs chemical blends and cement with super finer granules. Using various waste materials such as fly ash and silica fume in injection blends increases the injectability and lowers the costs.

In this study injection blends have been prepared in different proportions using some waste materials such as Bentonite, fly ash and silica fume. Granular bases having 0.70 relative density was settled into a cylindrical mold to which injection blends were injected. Effect of Bentonite, fly ash and silica fume over the uniaxial compressive strength of the samples of 7, 14, 28 days that have been prepared in this manner was investigated by the Taguchi method. In results of the experiments it was observed that the most effective parameter over the uniaxial compressive strength of 7, 14 and 28 days was silica fume.

2. Materials and Methods

In the experiments PÇ 42.5 Portland cement has been supplied by Ankara Set Cement Plant. Fly ash F class was supplied by Ankara Çayırhan Thermal Power Plant. Silica fume was provided by Etibank Antalya Electrometallurgy Industry Inc. Plant. Bentonite was provided by Çankırı Karakayalar Quarry and gravel was provided by Erzincan Province. The properties of materials used

*Professor, Dept. of Civil Engineering, Karatay University, Konya, Turkey (E-mail: ozcan.tan@karatay.edu.tr)
**Civil Engineer, Kültür varlıklarını koruma Bol. Kur. Md., Erzurum, Turkey (E-mail: gok25han@gmail.com)
***Associate Professor, Dept. of Civil Engineering, Ataturk University, Erzurum, Turkey (Corresponding Author, E-mail: zaimoglu@atauni.edu.tr)

Table 1. Properties of Materials used in Experiments

Content	Cement (%)	Fly ash (%)	Silica fume (%)	Bentonite (%)
SiO_2	19.80	47.5	85-95	60.75
Al_2O_3	5.61	15.95	1-3	18.9
Fe_2O_3	3.42	16.3	0.5-1.0	3.05
CaO	62.97	6.6	0.8-1.2	2.75
MgO	1.76	4.65	1.0-2.0	2.1
SO_3	2.95	--	--	--
Na_2O	0.47	15.95	--	2.7
K_2O	0.87	--	--	0.95
LOI	2.17	--	0.5-1.0	--
Density	3.08 g/cm³	--	2.25 g/cm³	--
Compressive Strength (7 days)	244 kgf/cm²	--	--	--
Compressive Strength (28 days)	424 kgf/cm²	--	--	--

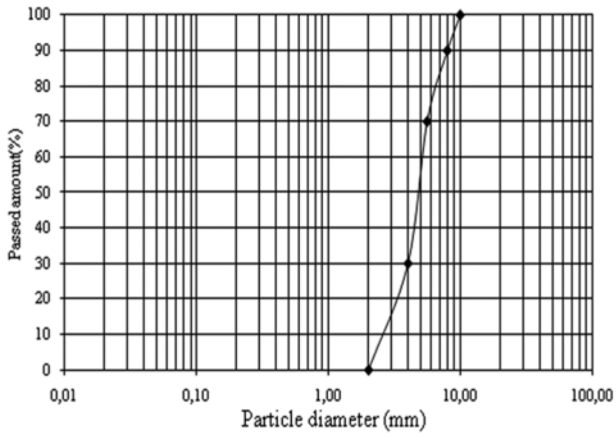

Fig. 1. Particle-size Distribution Curve of Injected Soil

Table 2. Physical Properties of Soil

Physical Properties	Value	Physical Properties	Value
γ_s (gr/cm^3)	2.68	D_{30} (mm)	4.0
γ_{kmax} (gr/cm^3)	1.79	D_{60} (mm)	5.2
γ_{kmin} (gr/cm^3)	1.45	C_u	2.00
e_{max} (%)	0.85	C_c	1.18
e_{min} (%)	0.50	k (cm/sn, D_r = 0.70)	1.66
D_{10} (mm)	2.6	Group symbol (USCS)	GP
D_{15} (mm)	2.9		

in experiments are given in Table 1. Grain size curve of gravel is shown in Fig. 1. Some geotechnical characteristics are given in Table 2.

Many experimental designs based on the principle of "less experiments more correct results" have been improved and practised largely in order to keep the costs of research and development expenditures at the lowest level. The purpose of the design is to obtain information maximum possible from the fewer experiments. Although the Taguchi Method has been developed only for quality-control and parameter design, it is

Table 3. Parameters and Their Levels used Experiments

Level	Parameter		
	Bentonite ratio (%)	Fly ash ratio (%)	Silica fume ratio (%)
1	0	10	0
2	0.5	20	5
3	1	30	10
4	3	40	20

Table 4. Orthogonal Array used in Experiments $L_{16}(4^5)$

Trial No.	Parameter and their levels		
	Bentonite ratio (%)	Fly ash ratio (%)	Silica fume ratio (%)
1	0	10	0
2	0	20	5
3	0	30	10
4	0	40	20
5	0.5	10	5
6	0.5	20	0
7	0.5	30	20
8	0.5	40	10
9	1	10	10
10	1	20	20
11	1	30	0
12	1	40	5
13	3	10	20
14	3	20	10
15	3	30	5
16	3	40	0

now used in quite different fields. This method is applied for specially developed orthogonal arrays. This design is a sample of all experiments. Standardized tables as known as Orthogonal Arrays (OA) are used for the experimental design. In this method two kinds of analysis are made: Standard Analysis and S/N (signal to noise) analysis. The detailed information was provided by Roy (2001) and Logothetis (1992).

Bentonite, fly ash and silica fume were chosen as the parameters. B, FA and SF were addedas a partial replacement o cement at different levels by weight of total solid materials. The parameters and their levels to be studied are given in Table 3.

An L_{16} OA was chosen to evaluate the experimental results. Details of the experimental design and approach are given in Table 4. The columns show the levels of parameters and each row represents a trial condition. Injection blends were prepared with W/S (water/solid; water/(cement+B+FA+SF)) ratio of 1.00. The uniaxial compressive strength of the blends have been defined for 7, 14 and 28 days by injecting them into the gravel samples (Dr = 0.70) in the cylindrical mold in 10 cm diameter and 20 cm height. The uniaxial compressive strength tests were performed according to ASTM C 109.

B was pre-hydrated in a 90% water 10% bentonite slurry and cured for 24 hours before it was introduced to do blend (Huang, 1997). During the first 2 minutes the solid materials (cement, fly ash and silica fume) that have been already blended homogeneously have been added slowly and in the 3.minutes it was added by Bentonite-water compound that has been waited for 24 hours.

The mixing speed was 1000 rpm and the mixing period was 5 minutes. (Toumbakari *et al*., 1999; Huang, 2001). The blender was constantly working while all of these ingredients were being added and the mixing procedure continued for 5 minutes. Injection pressure is set to 1 atmosphere pressure. The injection process was made through bottom to the top. The same process has also been repeated for the comparison samples that are injected by only cement mortar. The injected and comparison samples have been removed after 24 hours from the mold and kept in the water bath that is saturated for lime in the constant temperature 23±2°C.

3. Results and Discussions

S/N analysis was done in order to determine the effect of parameters on the unconfined compressive strength (7, 14 and 28 days) results. S/N values of experiment results (7, 14, 28 days) are given in Table 5. Average S/N values of parameter levels (7,14, 28 days) are given in Table 6. Variance analysis table (7, 14, 28 days) is given in Table 7. The results obtained from the experiments have been evaluated by the Taguchi Method and the diagrams indicating the effects of the parameters over the uniaxial compressive strength for 7, 14 and 28 days were transferred in the Figs. 2, 3 and 4. Abbreviations B, FA and SF in the Figs. 2-4 indicate respectively. In the figures, abbreviation B1 means that Bentonite indicates first level.

It can be seen from the variance analysis results (Table 7) for the unconfined compressive strength, the most effective factor was SF. For the three different unconfined compressive strength (7,14 and 28 days), the contribution of SF is 62.03%, 58.84% and 66.84%, respectively. Also Figs. 2, 3 and 4 shows the most

Table 5. S/N Values of Experiment Results (7, 14, 28 days)

Trial Number	Parameter and their levels			S/N Ratio		
	Bentonite	Fly ash	Silica Fume	7 days	14 days	28 days
1	1	1	1	2,33	5,75	11,76
2	1	2	2	2,66	5,18	7,28
3	1	3	3	4,57	5,78	10,82
4	1	4	4	4,75	8,58	13,24
5	2	1	2	6,95	7,82	11,91
6	2	2	1	0,08	2,67	5,80
7	2	3	4	7,89	9,52	16,02
8	2	4	3	2,48	5,49	9,84
9	3	1	3	9,97	11,88	14,24
10	3	2	4	8,08	13,62	16,53
11	3	3	1	-0,39	5,72	7,72
12	3	4	2	0,20	2,14	4,74
13	4	1	4	11,58	15,03	17,80
14	4	2	3	7,62	11,15	13,64
15	4	3	2	1,11	7,34	10,16
16	4	4	1	-0,92	1,39	3,63
Average S/N Ratio				4,31	7,44	10,95

Table 6. Average S/N Ratios of Parameter Levels (7, 14, 28 days)

Time	Level	S/N Ratio		
		Bentonite	Fly ash	Silica fume
7 days	1. Level	3,58	7,71	0,27
	2. Level	4,35	4,61	2,73
	3. Level	4,46	3,30	6,16
	4. Level	4,85	1,63	8,07
14 days	1. Level	6,33	10,12	3,88
	2. Level	6,37	8,16	5,62
	3. Level	8,34	7,09	8,58
	4. Level	8,73	4,40	11,69
28 days	1. Level	10,78	13,93	7,23
	2. Level	10,89	10,81	8,52
	3. Level	10,81	11,18	12,14
	4. Level	11,31	7,87	15,90

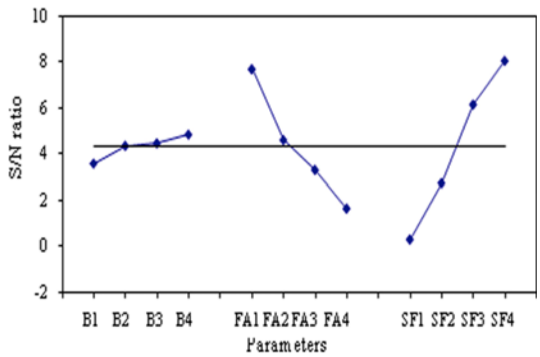

Fig. 2. Response Graphs of Main Effects for Uniaxial Compressive Strength (7 days)

Table 7. Variance Analysis (7, 14, 28 days)

Parameters	7 days			14 days			28 days		
	Degree of freedom (DOF)	Sum of square deviation (SS)	Contribution of factors SS %	Degree of freedom (DOF)	Sum of square deviation (SS)	Contribution of factors SS %	Degree of freedom (DOF)	Sum of square deviation (SS)	Contribution of factors SS %
Bentonite	3	3,40	1,45	3	19,40	8,08	3	0,73	0,27
Fly ash	3	79,44	33,87	3	66,82	27,84	3	73,88	27,05
Silica fume	3	145,50	62,03	3	141,19	58,84	3	182,53	66,84
Unknown	6	6,22	2,65	6	12,57	5,24	6	15,95	5,84
Total	15	234,56	100.00	15	239,98	100	15	273,09	100

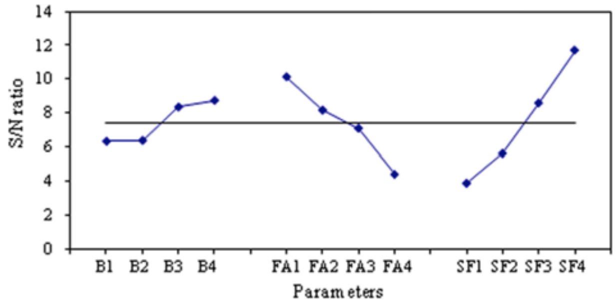

Fig. 3. Response Graphs of Main Effects for Uniaxial Compressive Strength (14 days)

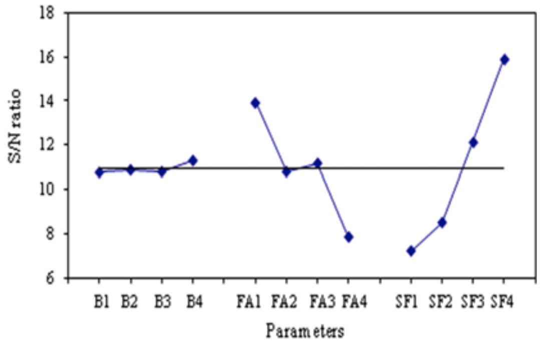

Fig. 4. Response Graphs of Main Effects for Uniaxial Compressive Strength (28 days)

effective parameter on the unconfined compressive strength (7, 14 and 28 days) is silica fume. With the increase of silica fume ratio, there is an important increase in the unconfined compressive strength (7, 14 and 28 days). Effect of bentonite on the unconfined compressive strength (7, 14 and 28 days) is very slightly. Figs. 2, 3 and 4 shows with the increase of the fly ash, there is decrease in the unconfined compressive strength (7, 14 and 28 days).

Table 9. Uniaxial Compressive Strength of Comparison Samples (7, 14 and 28 days)

Time	Uniaxial compressive strength (MPa)			
	1	2	3	Average
7. days	1,42	1,64	1,44	1,50
14. days	2,07	2,10	2,08	2,08
28. days	2,56	2,56	2,55	2,56

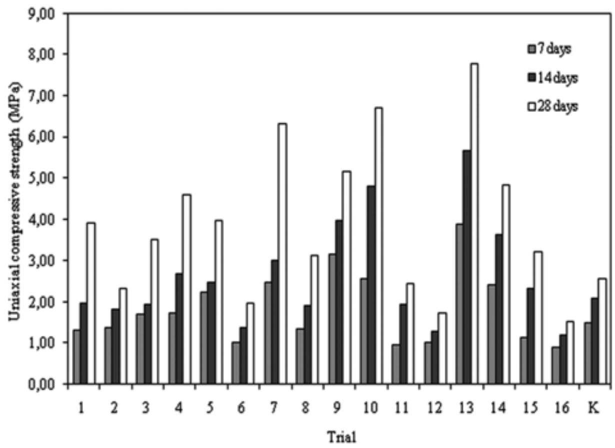

Fig. 5. Uniaxial Compressive Strength of the Samples

The uniaxial compressive strength for 7, 14 and 28 days that have been obtained for all samples is given in Table 8. The uniaxial compressive strength for 7, 14 and 28 days of comparison samples is shown in Table 9. The histogram that has been drawn by aid of these values is shown in Fig. 5.

The highest values in the uniaxial compressive strength of the samples exposed to injections (7, 14 and 28 days) is obtained in the experiment trial no13 in which 3%.

Table 8. Uniaxial Compressive Strength of the Samples (7, 14 and 28 days)

Trial	Uniaxial compressive strength (MPa)								
	7 days			14 days			28 days		
	1	2	3	1	2	3	1	2	3
1	1,21	1,42	1,32	2,23	1,83	1,83	4,21	3,81	3,66
2	1,46	1,30	1,33	1,71	1,94	1,82	2,38	2,48	2,12
3	1,70	1,78	1,61	1,91	2,05	1,89	3,50	3,21	3,79
4	1,76	1,82	1,62	2,69	2,69	2,68	4,49	4,70	4,60
5	2,23	2,13	2,33	2,46	2,41	2,51	3,65	4,00	4,23
6	1,18	0,99	0,91	1,37	1,35	1,36	1,84	2,13	1,91
7	2,61	2,36	2,49	3,00	2,87	3,12	6,33	6,27	6,38
8	1,51	1,35	1,19	1,68	1,87	2,20	3,47	2,81	3,14
9	3,07	3,24	3,15	3,76	4,33	3,77	5,05	5,26	5,16
10	2,79	2,41	2,45	4,64	4,97	4,80	6,50	6,94	6,69
11	0,90	1,02	0,96	1,94	1,85	2,02	2,30	2,58	2,44
12	1,01	1,03	1,03	1,28	1,28	1,28	1,81	1,73	1,65
13	3,30	3,95	4,37	5,86	5,44	5,65	7,90	7,39	8,05
14	2,32	2,68	2,27	3,62	3,44	3,80	5,00	4,81	4,63
15	1,12	1,24	1,07	2,38	2,28	2,33	3,20	3,20	3,26
16	0,93	0,90	0,87	1,09	1,18	1,27	1,55	1,48	1,53

Bentonite, 10% fly ash and 20% silica fume is used in injection blend. The highest uniaxial compressive strength for 7, 14 and 28 days is 4.37 MPa, 5.86 MPa and 8.05 MPa respectively.

In the analysis made to define optimum blend proportions and the greatest uniaxial compressive strength optimum blend proportions have been defined for 7, 14 and 28 days.

is 3% Bentonite, 10% fly ash and 20% silica fume. Expected uniaxial compressive strength has been calculated as 3.99 MPa, 6.06 MPa and 9.16 MPa respectively. Verification experiments results made in optimum conditions are in 90% reliability interval. They are quite near these values.

The highest values in the uniaxial compressive strength in the experiments made using only cement (7,14, and 28 days) are 1.64 MPa, 2.10 MPa, and 2.56 MPa respectively.

According to these values the uniaxial compressive strength in the experiments made using only cement is lower than that of samples with solid additions. This is caused by the facts that water/cement proportion is high, the precipitation, viscosity and setting time characteristics of the blends made by using only cement are not at the level required.

When the effects of parameters and levels over the experiments is investigated it has been observed that the most effective parameter over the uniaxial compressive strength of the samples exposed to injection for 7, 14 and 28 days is silica fume. The more silica fumes in injection blend, the more uniaxial compressive strength. The effect of fly ash over the uniaxial compressive strength for 7, 14 and 28 days of injected samples decreased. The least effective parameter over the uniaxial compressive strength is Bentonite.

4. Conclusions

1. Effect of bentonite on the unconfined compressive strength (7, 14 and 28 days) is very slightly
2. The most effective parameter on the unconfined compressive strength (7, 14 and 28 days) is silica fume.
3. Optimum blending conditions have been defined as 3% Bentonite, 10% fly ash and 20% silica fume.
4. These proportions improve the characteristics of injection blend such as workability, water desorption, viscosity, homogeneity and setting time.

This study indicates that certain amounts of Bentonite, fly ash and silica fume can be used together in cement injection preparation. Effectiveness percentage and optimum mixing proportions can be defined by making similar studies for the proportions of granule length distribution, relative density and material rates.

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