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A Study of Soil Cement Properties by Using Soilcrete Stabilizer

소일크리트 고화재를 이용한 소일시멘트 특성에 관한 연구

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요 지

소일시멘트는 오래전부터 도로기층처리, 연약지반개량을 위해 사용되어온 재료지만 품질의 균질성과 내구성이 떨어지기 때문에 용도 확대에 한계가 있었다. 그러나, 최근 환경친화적인 목적에 관심이 커지면서 공원 산책로, 골프장, 보도 등과 같은 높은 강도가 요구되는 곳에 소일시멘트 포장의 적용사례가 증가하고 있다. 본 연구에서는 소일시멘트의 배합설계를 위하여 통계적인 분석기법을 적용하여 표준배합표를 작성하였으며, 소일시멘트 강도와 소일크리트 고화재, 잔골재율, 분산제 등의 관계를 규명하였다. 본 연구에 사용된 개량대상토로서는 국내에 많이 분포되어 있는 연약한 해성점토로서 개량압축강도는 50～150kg/cm² 범위로 하였다.

주요어 : 소일시멘트 통계적인 분석기법, 표준배합표, 소일크리트 고화재

ABSTRACT

Soil cement has been the typical material for the pavement and soft ground improvement. It has not been used up to date because that quality control is not easy and durability is not long enough for practical application. Since environmental influence is important, the application of high strength soil cement pavement has been increased for pedestrian roads of the garden, golf courses and sidewalks recently. In this study, the reference table was suggested for mixing design with appling statistical experimental technique to reference table. The reference table showed the relationship among improved strength, Soilcrete stabilizer, fine sand ratio and superplasticizer agent. The objective soil used in this study was the soft marine clay that is widely found in Korea, the compressive strength range of improved soil was between 50～150kg/cm^2

Keywords : Soil cement, Statisticlal experimental technique, Reference table, Soilcrete stabilizer

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1. Introduction

Soil cement is a mixture of pulverized soil material and measured amounts of Portland cement based soil stabilizer and water, compacted to high density. As the cement hydrates, the soil cement mixture becomes harder and more durable.

The soil material in soil cement can be almost any combination of sand, silt, clay and gravel or crushed sand. Local granular material (such as slag, caliche, limestone, scoria) plus a wide variety of waste(such as cinders, fly ash, and screenings from quarries and gravel pits) can be used to make soil cement. Also, old granular-base roads, with or without their bituminous surfaces, can be recycled to make good soil cement (ASTM 1995).

Soil cement is sometimes called cement-treated base or cement-stabilized-aggregate base. Regardless of what it is called, the principles governing its composition and construction are the same. Like in this study, engineering properties of Soilcrete stabilizer(Fly ash, Gypsum and Cement)-treated base is similar to that of the ordinary lean concrete, so we will intend to call the Soilcrete-soil mixture as 'soil cement' from now on. Soil cement is a traditional material for the above mentioned ground works. But it is not widely used because its quality is not homogeneous. The properties of soil materials, types and amounts of soil stabilizer uncertainly influence the quality of soilcement. Therefore, there are some restrictions on permanent structures. With increasing emphasis on nature conservation, the application cases of soilcement are rapidly increased at the light traffic road such as park, farm, forest, golf course etc.. Because the leavings of weathered soilcement can be returned to the surrounding nature without pollution.

Soilcrete stabilizer properly mixed with Fly ash, Gypsum and Cement was used for early stabilization of unconsolidated soil. The treated soil is clay, which is spreaded widely in Korea. And experimental design was applied to make the reference mixtures table of soilcement.

The design of experiment is the system by which one can efficiently and reliably evaluate all possible methods considered for a particular objective, that is, this system consists of the method of laying out calculations and experiments, data analysis method, and rationalization of the characteristic values.

In this study, we will use the method of carrying out efficient response analysis by using central composite orthogonal arrays for numerical analyses in, for example, design calculations and planning calculations. As long as the conditions are given, numerical values, computer calculations are possible no matter how complicated the problem is, but if one wishes to find the output changes when the initial conditions, boundary conditions, system parameters, etc., are varied. The number of conditions becomes enormous and the calculation is almost impossible. Therefore, orthogonal arrays can be used for more variables. Through the response analysis of the relation between content of Soilcrete stabilizer and water content of treated soil, surface value of workability index or strength trend can be plotted in 2 or 3 dimensional. From this statistical method we could make the reference mixtures table for the strength of 50～150kg・f/cm^2 soilcement (Japan Cement Association 1984).

2. Experimental Design

2.1 Materials

There are two typical hardening agents used in the shallow and deep soil mixing method, cement and lime. In the past, quicklime as dry hardening agent was used to improve soil, but ordinary Portland cement, as slurry, is now the primary agent.

Additives, which have a solidifying admixture or liquefying effect, tailored to the soil or cement blended with pozzolanic materials like blast furnace slag, fly ash, gypsum, etc. can be used. In particular, organic soils are very difficult to treat because soil acidity can affect the hydration reaction of ordinary Portland cement. In this case, special blended improved cements should be used.

The mixture of Soilcrete stabilizer consists of Fly ash, Gypsum and Cement. It makes the fibrous ettringite hydrates, which is especially effective for the hardening of organic and cohesive soil. The typical properties of Soilcrete stabilizer as shown in Table 1.

Table 1. The typical properties of Soilcrete stabilizaer

Specific Gravity ; 2.92, Specific Surface Area ; 6,530cm^2/g																	
Chemical Composition Ratio(%)		SiO_2		Al_2O_3		Fe_2O_3		CaO		MgO		Na_2O		K_2O		SO_3		Ignition loss
		31.7		7.9		1.3		44.3		2.3		1.1		0.8		8.5		1.5
Particle Distribution	Size(㎛)	1	2	3	4	6	8	10	12	16	20	24	30	40	60	80	100	d_{50}
	Accum. Ratio(%)	12	21	29	37	47	57	65	72	79	85	87	94	99	100	100	100	6.9

Table 2. The typical properties of soil material

Chemical Composition Ratio(%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Ignition loss
	65.1	16.6	5.8	0.5	1.2	0.4	2.8	-	7.5
Physical Properties	No.4 (%)	No.200 (%)	D_{60} (mm)	D_{30} (mm)	D_{10} (mm)	Cu	Cc	Gravity	Class
	92.4	1.8	0.9	0.3	0.15	9.0	0.7	2.45	SP-SM

2.1.1 Soil Materials

Achieved unconfined compressive strength of improved soil by in situ mixing with Soilcrete stabilizer depends on several parameters such as soil characteristics and type, quantity and mixing ratio of Soilcrete stabilizer.

Detailed soil investigation and laboratory tests to evaluate the water content and sand, silt, clay and humus content of the subsoil should be done before admixture selection. The most commonly used dosage of Soilcrete stabilizer lies between 100 and 200kg・f/m^3 of native soil and can reach, in some cases, 300kg・f/m^3 over.

The achieved unconfined compressive strength (q_u) varies between 10 and 50kg・f /cm^2. But because the target of compressive strength is 50kg・f/cm^2 over in this study, the dosage of Soilcrete stabilizer lay between 100 and 300kg・f/m^3.

In this study, we selected the yellowish clay that is found nationwide in Korea. The typical properties of the selected sample were shown as in Table 2.

2.1.2 Flowing soil cement admixture

In concrete technology, flowing concrete admixtures called superplasticizers have come into common use to improve the workability of fresh concrete and reduce water content.

Recently, chemical admixtures like superplsticizers and sand are also used for improving the consistency for soil cement. In this stduy, as flowing agent of soil cement, standard fine sand for mortar and lignin sulfonic acid-based dispersion agent for cement were used.

2.2 Experiment Method

2.2.1 Mixing Soilcement

Soilcrete stabilizer, clay, water, fine sand and superplasticizer are put into the mortar mixer at the same time to make soilcement. It takes 30 seconds to mix soilcement with low speed, and it continues mixing soilcement with high speed for 30 seconds. After leaving the mixed fresh soilcement for 90 seconds, it continues mixing soilcement again for 90 seconds.

2.2.2 Making and measuring specimens

After mixing soilcement, slump should be immediately measured using mortar slump cone to estimate the consistency of soilcement. And the KS cubic specimens of soilcement(size : 50×50×50mm) are made by the compaction method of mortar. These specimens are placed into the moisture chamber set. The compressive strengths of the cured specimens are measured at the 3, 7 and 28-day curing.

2.2.3 Photographs of hydrated texture

To examine the kind and configuration of hydrated texture, photographs of SEM(Scanning Electro Microscope) were taken at 3-day curing with 10K magnifications.

2.3 Experiment and results

The objective of experiment is to determine the reference mixtures table of Soilcrete treated soil. In order to be more economical and effective, factors and levels are arrayed by the central composite design. The fine sand lay between 0.5 and 1.5 weight ratio to unit soil, superplasticizers lay between 1.0 and 2.0 weight percent. to cement, Soilcrete stabilizer lay between 100 and 300kg/m^3, and the levels are 5 respectively.(Park 1995)

As a result, the number of design matrix consist of 8 control points, 2 center points and 6 axial points, that is, come into 16 mixes. The mixure and test result of each mix are shown as in Table 3.

3. Analysis of results

3.1 Correlation and regression analysis

3.1.1 Correlation Analysis

In order to find the correlation between dependent vaiables and properties acquired, we analized the data of Table 3. The results were shown as in Table 4.

From Table 4, the slump of workability index increases in some degree with the increasing content of fine sand,

Table 3. Design matrix and test results

Exp. No. (n)	Fine Sand		Superplasticizer		Soilcrete stabilizer		Slump (cm)	Compressive Strength (kg/cm^2)		
	X_1	ratio (soil$^{\times wt}$)	X_2	$C^{\times \%}$	X_3	kg/m^3		3days	7days	28days
1	-1	0.5	-1	1.0	-1	100	2.5	8	24	35
2	-1	0.5	-1	1.0	1	300	1.8	46	88	129
3	-1	0.5	1	2.0	-1	100	4.5	10	25	35
4	-1	0.5	1	2.0	1	300	1.9	53	111	158
5	1	1.5	-1	1.0	-1	100	3.5	25	42	55
6	1	1.5	-1	1.0	1	300	4.8	61	114	173
7	1	1.5	1	2.0	-1	100	6.5	24	38	52
8	1	1.5	1	2.0	1	300	5.1	65	124	186
9	0	1	0	1.5	0	200	4.9	21	34	79
10	0	1	0	1.5	0	200	6.0	18	31	67
11	-0.5	0.75	0	1.5	0	200	3.3	21	35	85
12	0.5	1.25	0	1.5	0	200	4.8	27	48	108
13	0	1	-0.5	1.25	0	200	2.9	31	57	115
14	0	1	0.5	1.75	0	200	4.1	25	49	95
15	0	1	0	1.5	-0.5	150	3.2	23	41	65
16	0	1	0	1.5	0.5	250	2.9	43	63	141

Table 4. Matrix of correlation coefficient

		Fine Sand	Super-plasticizer	Soilcrete stabilizert	Slump	Compressive Strength		
						3days	7days	28days
Slump		0.63	0.38	-0.23				
Compressive Strength	3days	0.31	0.05	0.86	-0.13			
	7days	0.20	0.07	0.85	-0.18	0.98		
	28days	0.22	0.05	0.93	-0.17	0.96	0.93	

superplasticizer, but it decreases in a little with the increasing content of Soilcrete stabilizer. While the coefficient between the compressive strength of treated soil and the content of Soilcrete stabilizer is very relatively correlative in plus.

But the compressive strength of treated soil was decreased a little with the increasing slump. Because it is difficult to get the optimum compaction at treated highly workable soil.

3.1.2 The regression model

Response surface analysis is the multiple regression models that can explain several independent variables on the 2-dimensional or 3-dimensional coordinates through statistical testing and estimation. Then both the independent and dependent variables are quantitative.

The response relationship between the dependent variable y and independent variables x_1, x_2, ……, x_k is the 2nd order polynomial regression model, and the equation is shown as in formula (3.1).

$$y = \beta_o + \sum_{i=0}^{k} \beta_1 x_i^2 + \sum_{i>j} \beta_{ij} x_i x_j + \varepsilon \quad (3.1)$$

The possible number of independent variables is 10. Each variable is independent and come into $\varepsilon \sim N(0, \sigma^2)$. ε is experimental error. Therefore the fitted response surface through the least square method is expressed as shown in formula (3.2).

$$y = \beta_o + \sum_{i=0}^{k} \beta_1 x_i^2 + \sum_{i>j} \beta_{ij} x_i x_j \quad (3.2)$$

From the equation (3.2), if design matrix, data vector, regression coefficient vector are specified as X, y, β respectively, matrices can be formed. And then regression coefficient β can be calculated through the least square method by the formula (3.3).

$$X = \begin{pmatrix} 1 & x_{11} & x_{21} & \cdots & x_{k1} \\ 1 & x_{12} & x_{22} & \cdots & x_{k2} \\ 1 & x_{13} & x_{23} & \cdots & x_{k3} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_{1n} & x_{2n} & \cdots & x_{kn} \end{pmatrix} \quad \beta = \begin{pmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \vdots \\ \beta_k \end{pmatrix}$$

$$y = \begin{pmatrix} y_0 \\ y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix} \quad \beta = (X'X)^{-1}X'y \quad (3.3)$$

X′ is transpose matrix, $(X'X)^{-1}$ is inverse matrix that design matrix X multiplies transpose matrix X′.

3.1.3 Regression analysis

From the Table 4, the effective factors of slump are determined as fine sand, superplasticizer, and Soilcrete stabilizer. And the effective factors of compressive strength are determined as fine sand and Soilcrete stabilizer. The regression coefficients were calculated by equations (3.1)～(3.3), and the accuracy of regression coefficients were tested as follows (Park 1987).

(1) Testing the accuracy for the slump regression equation.

The results of the variance analysis for the slump regression equation are given in the Table 5. From the Table 5, the coefficient of determination R^2(78%) for the fitted slump regression equation is high in some degree. While the testing results for the coefficient of regression $\beta_{(0)}$～$_{(33)}$ are given in the Table 6.

From Table 6, the effective factors of T test are $\beta_{(1)}$(fine sand), $\beta_{(2)}$(superplaticizer), $\beta_{(23)}$ (interaction between superplasticizer and Soilcrete stabilizer), $\beta_{(3)}$ (Soilcrete stabilizer), $\beta_{(13)}$ (interaction between fine sand and Soilcrete stabilizer) in order. Therefore, the relationship between output y and factors is given by the following equation.

$$y = 4.06 + 1.17\times(Sand) + 0.71\times(SP) - 0.42(SCS) + 1.98\times(Sand)^2 + 0.15\times[(Sand)\cdot(SP)] + 0.40\times[(Sand)\cdot(SCS)] - 0.22\times(SP)^2 - 0.58\times[(SP)\cdot(SCS)] - 2.02\times(SCS)^2 \quad (3.4)$$

where, SP=superplasticizer.
SCS=Soilcrete stabilizer

Table 5. Analysis of variance table for the slump regression equation

Factors	Sum of Squares	Degree of freedom	Mean square	Critical value F_0	R^2
Regression	22.7	9	2.53	2.41	0.7835
Residual	6.3	6	1.05	-	-
Sum of Squares	29.0	15	-	-	-

Table 6. Testing table for the coefficient of slump regression

Coefficient of Regression	Estimated Coefficient	Standard Error	Critical value for T test
$\beta_{(0)}$; Constant	4.06	0.39	10.51
$\beta_{(1)}$; Fine Sand	1.17	0.35	3.34
$\beta_{(2)}$; Superplasticizer	0.71	0.35	2.01
$\beta_{(3)}$; Soilcrete stabilizer	-0.42	0.35	-1.19
$\beta_{(11)}$	1.98	2.37	0.83
$\beta_{(12)}$	0.15	0.36	0.41
$\beta_{(13)}$	0.40	0.36	1.11
$\beta_{(22)}$	-0.22	2.37	-0.09
$\beta_{(23)}$	-0.58	0.36	-1.59
$\beta_{(33)}$	-2.02	2.37	-0.85

Table 7. Analysis of the variance table for the compressive strength regression

Factors	Sum of squares	Degree of fredom	Mean square	Critical value F_0	R^2
Regression	32481.5	5	6496.3	29.9	0.9373
Residual	2172.3	10	217.2	-	-
Sum of Squares	34653.8	15	-	-	-

Table 8. Testing table for the coefficient of compressive strength regression

Coefficient of regression	Estimated coefficient	Standard error	Critical value for T test
$\beta_{(0)}$; Constant	93.4	5.56	16.82
$\beta_{(1)}$; Fine Sand	14.2	5.06	2.80
$\beta_{(2)}$; Soilcrete stabilizer	59.6	5.06	11.80
$\beta_{(11)}$	-8.1	29.74	-0.27
$\beta_{(12)}$	4.4	5.21	0.84
$\beta_{(22)}$	17.9	29.74	0.60

(2) Testing the accuracy for the slump regression equation

From Table 4, superplasticizer does not have an influence on the compressive strength. Therefore fine sand and Soilcrete stabilizer were only selected as effective factors for the regression model of compressive strength. And the results of the variance analysis for the compressive strength regression equation are given in Table 7.

From Table 7, the coefficient of determination R^2(93.7%) for the fitted compressive strength regression equation is relatively high and so it is very good. While the testing results for the coefficient of regression $\beta_{(0)} \sim \beta_{(33)}$ are given in Table 8.

From the Table 8, the effective factors of T test are $\beta_{(2)}$ (Soilcrete stabilizer), $\beta_{(1)}$(fine sand) in order. Therefore, the relationship between output y and factors is given by the following equation.

$$y = 93.4 + 14.2\times(Sand) + 59.6\times(SCS) - 8.1\times(Sand)^2 + 4.4\times[(Sand)\cdot(SCS)] + 17.9\times(SCS)^2 \qquad (3.5)$$

3.2 Contour lines on the response surface

From the Table 8 and Table 9, the contour line for the slump between sand ratio by soil and the content of Soilcrete stabilizer or superplaticizer is given in the Figure 1. And the contour line for the compressive strength between sand ratio by soil and the content of Soilcrete stabilizer is given in the Figure 2.

3.3 Suggestion Reference Mixtures for the Soilcrete Treated Clay

If the Figure 2 would be superimposed on the Figure 1(a), from the combinations between compressive strength and slump, the content of Soilcrete stabilizer and sand ratio pairs could be determined by the superimposing diagram. And if the Figure 2 would be superimposed on the Figure 1(b), the content of Soilcrete stabilizer, sand ratio and superplaticizer ratio pairs could be determined as the same way.

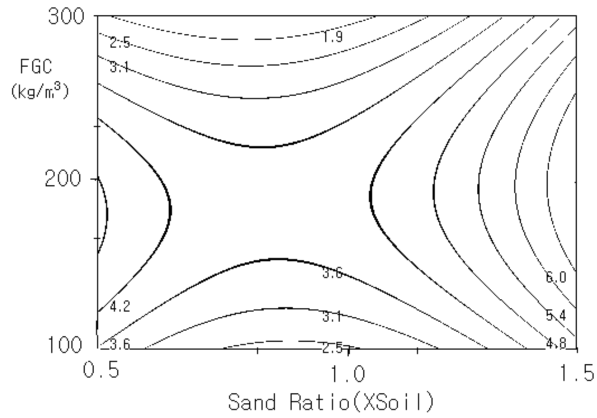

Figure 1(a). Slump contour lines of relationship between sand ratio and Soilcrete stabilizer content

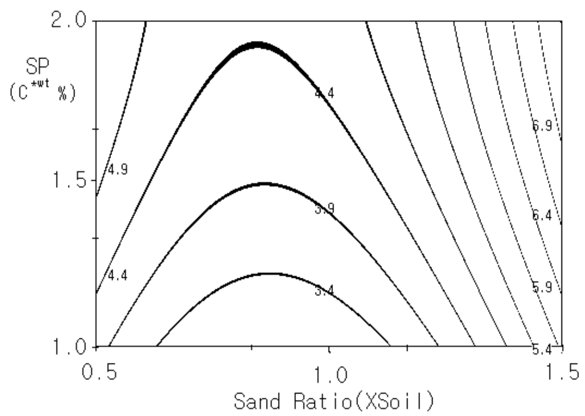

Figure 1(b). Slump contour lines of relationship between sand ratio and SP content

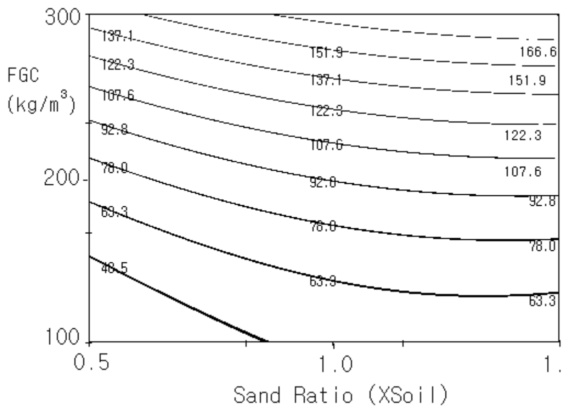

Figure 2. Compressive strength contour lines of relationship between sand ratio and Soilcrete stabilizer content

As the results, the combinations of mixtures with regard to the design strength of the Soilcrete treated clay are suggested as Table 9.

Table 9. Reference mixtures table with regard to the Soilcrete treated clay

Design properties		Unit weight		
Mixing strength (kg/cm^2)	Slump (cm)	Soilcrete stabilizer (kg/m^3)	Sand Ratio (×Soil)	Superplsticizer (Soilcrete stabilizer$^{\times wt}$%)
50	2	100	0.8	1.0
	4	135	0.6	1.2
	6	(140)	(0.4)	(1.4)
100	2	(220)	(0.8)	(1.1)
	4	210	1.1	1.3
	6	200	1.4	1.5
150	2	280	0.8	(1.1)
	4	260	1.2	1.3
	6	260	1.5	1.5

Table 9, with respect to the pairs of the mixing strength 50kg · f/cm^2 combined with the slump 6cm(hereafter, stands for 50-6) and 100-2, the mixtures were determined by assumption because they could not be determined on the response surface. As the slump increases, sand ratio and the content of superplasticizer increase. The content of Soilcrete stabilizer is controversial. That is, as the slump increases, the content of Soilcrete stabilizer increases at the low strength of the about 50kg · f/cm^2, but the content of Soilcrete stabilizer decreases slightly at the high strength of the about 100kg · f/cm^2 inversely. These controversial results are concluded to cause to the low accuracy of the estimated slump regression model because the experimental scope is relatively wide.

3.4 Examination of Hydrated Textures

After Soilcrete stabilizer was added 200kg · f/m^3 to the testing clay, the hardened soilcement 3days aged was taken by SEM instrument for observation of the hydrated textures. And to compare the Soilcrete treated soil, ordinary Portland cement treated soil specimens were also molded. The magnification of SEM photographs is 10K(Figure 3, Figure 4).

If the needle-shaped ettringite hydrates are produced in large quantities shown in Figure 3, they can make an effective restriction of the soil particle and increase the strength. For using the Soilcrete stabilizer treated in pozzolanic cement, consolidation effect can be promoted from initial period.

Therefore, it is proved that the pozzlanic hardening agent used in this study will be profitable in the uncompressed soil with lots of organic materials such as estuary-dredged soil and in the improvement of the very soft ground with high water content.

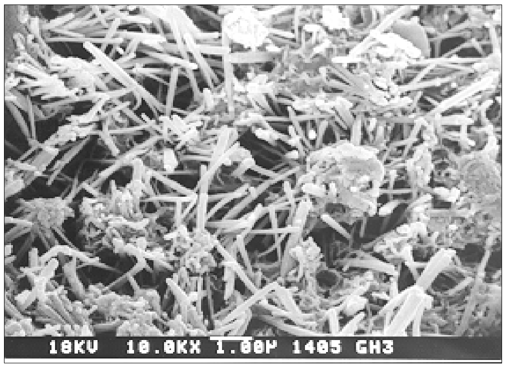

Figure 3. Soilcrete treated soilcement

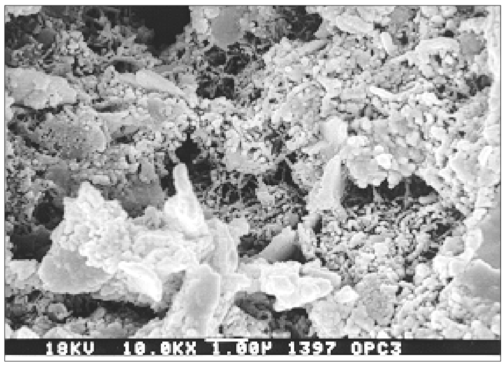

Figure 4. OPC treated soilcement

4. Case study

□ Project name : Pavement of trail near Suwon Stream.

□ Modification of design : Change concrete pavement to earth-friendly soilcement pavement

□ Purpose : To provide the citizens with a convenient and cozy rest area, Suwon Stream and its surrounding area are renovated into earth-friendly, clean and beautiful ones.

□ Required Equipment : Roller, compact, dump trucks, backhoe loader and soilcement mixing system

□ Unconfined strength of soilcement on site : 9 specimens were formed on site to measure 3,7, and 28-days strength. According to the results from the unconfined tests, 3-day strength was 52kg · f/cm^2, 7-day strength was 103kg · f/cm^2 and 28-day strength was 187kg · f/cm^2. 28-day strength was measured to be higher than the required strength of 180kg · f/cm^2

5. Conclusions

Through the statistical analysis from experimental requirement of this study, we found the following results from the study on the mixing design of the high-strength soilcement

(1) Soilcrete slump of fluxional standard is affected by content of fine sand, the increasing content of superplasticizer, the increasing content of Soilcrete stabilizer, and interaction in each factor and the 2nd degree in order. The 2nd order polynomial regression model for estimating slump is made properly in the equation (3.4). Also, from the Table 5, the coefficient of determination R^2 for regression equation is relatively good by 78.4%

(2) The compressive strength of soilcement is affected by Soilcrete stabilizer, fine sand, and interaction in each factor and the 2nd degree in order. The 2nd order polynomial regression model for estimating the compressive strength is made suitably in the equation (3.5). From the Table 7, the coefficient of determination R^2 for regression equation is very good by 93.7%

(3) Using the response surface regression analysis in some degree could make the practical reference table of mixtures. And if the experimental scope is divided into more detail, we can get the more accurate reference table of mixtures than mixing in the field

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