KSCE Journal of Civil Engineering (2016) 20(2):662-669

DOI 10.1007/s12205-015-0540-8

Geotechnical Engineering

pISSN 1226-7988, eISSN 1976-3808
www.springer.com/12205

Optimization of Consistency Limits and Plasticity Index of Fine-grained Soils Modified with Polypropylene Fibers and Additive Materials

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Received September 12, 2014/Revised December 25, 2014/Accepted March 24, 2015/Published Online May 26, 2015

Abstract

It is a well-known fact that water content has a significant effect on the engineering properties of fine-grained soils. There is a close relationship between consistency limits and geotechnical parameters of fine-grained soils. This experimental study was performed to investigate the effect of randomly distributed polypropylene fibers (PP) and some additive materials [e.g., Borogypsum (BG), Fly Ash (FA) and Cement (C)] on consistency limits and plasticity index of a fine-grained soil. The Taguchi method was applied to the experiments and standard L9 Orthogonal Array (OA) with four factors and three levels were chosen. A series of consistency limits were conducted on each specimen. 0-20% BG, 0-20% FA, 0-0.25% PP and 0-3% of C by total dry weight of mixture were used in the preparation of specimens. In the tests, distilled water (DW), DW + 0.05% Air-Entrainer (AE) and DW + 0.15% AE were used as mixture liquid. Experimental results showed that the most effective material for decreasing the liquid limit and plasticity index of the samples were fly ash, polypropylene fiber respectively. The plasticity index decreased with increasing of AE. The values of plasticity index for distilled water, distilled water + 0.05% air-entrainer and distilled water + 0.15% air-entrainer in optimum conditions were 16%, 14% and 8%, respectively.

Keywords: *plasticity index, polypropylene fibers, borogypsum, fly ash, air-entrainer*

1. Introduction

Clays are important constituent of soils and named as fine-grained soils in geotechnical engineering. Fine-grained soils, especially clays, may show considerably different engineering properties mainly depending on their water content. There is a close relationship between consistency limits and geotechnical parameters of fine-grained soils. It is well-known that the mixture does not become mud when liquids such as petrol and carbon tetrachloride instead of water are added to fine grained soils, especially to clay, as the mixture liquid (Önalp, 1983).

Since water plays an important role in the behavior with a significant clayey fraction, a range of water content has been defined that correlate strongly with the engineering properties of fine-grained soils. The range of water content over which a fine-grained soil behaves as a plastic is defined as the Plasticity Index PI (Anonymous, 2012). The plasticity index is a useful measure for the possibility to process the clay (Verrujit, 2001). Some research shows that this Parameter (PI) is important some of the geotechnical problems such as swelling potential, workability, construction of the clay core in a high dam, and airport construction, etc.; According to Sudjianto *et al.* (2011) plasticity index parameter to be influence is significant to swelling vertical of expansive soils, the swelling vertical linearly increase with increasing plasticity index. Naeini and Jahanfar (2011) indicated that medium plasticity clay showed comparatively higher undrained shear resistance value compared to other clay mixtures in all of NaCl concentrations, and the low plasticity clay showed the least undrained shear resistance value with various pore fluid salinity levels. Naeini and Moayed (2009) studied the effects of plasticity index and also reinforcing of soft clay on CBR values. They stated that as the PI increase the CBR value decreases and reinforcing clay with geogrid will increase the CBR value. Yıldız and Soğancı (2012) studied effect of freezing and thawing on strength and permeability of lime-stabilized clays (low plasticity and high plasticity). They found that the strength of two clays decreased 10% to 15% at the end of freeze-thaw cycles. According to Yıldız and Soğancı lime stabilization is more efficient on high plasticity clays.

In generally to improve workability and increase strength of fine-grained soils decrease the Plasticity Index (PI). For this purpose can be undertaken by a variety of ground improvement techniques such as the use of additive materials or different mixture liquid; Oza and Gundaliya (2013) studied black cotton soil characteristics with cement waste dust and lime. They indicated that there is a significant change in plasticity index of

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black cotton soil used with cement dust. Schmitz *et al*. (2004) examined a correlation between clay mineralogy and Atterberg limits. According to Schmitz *et al*. clay mineralogy can be useful in engineering practice not only qualitatively but quantitatively as well. Malkawi *et al.* (1999) investigated effects of organic matter on the physical and the physicochemical properties of an illitic soil. The authors summarized that at low organic content (up to 10%) the plasticity index slightly increased. On the other hand they stated that the values of plasticity index seems to be less affected by the difference in the oven temperature. According to Saride *et al.* (2013) high reduction in the plasticity of soil was noticed in lime treated soil than cement treated soil. Aksoy *et al.* studied seawater effect on consistency limits and compressibility characteristics of clays. Their study results show that seawater effect becomes significant when liquid limit, plasticity and shrinkage indices are more than 110%, 70% and 104%, respectively. Zentar *et al.* (2009) examines the effects of treatments inducing the reduction of salts and the organic content on the Atterberg limits of marine dredged sediments. According to Zentar *et al.* (2009) the liquid limits as the plasticity indexes decrease with reducing the organic content in the sediments. Palomino *et al.* (2011) stated that the NaCl concentration of the aqueous solution did impact the plasticity of the pure kaolin. Moavenian *et al.* summarized that the plasticity of soil reduced and the settlement time decreased when exposed to organic liquids.

As it is understood that the effect of additive materials on the plasticity index of fine grained soils was extensively investigated by many researchers. However, very few studies have been carried out on optimization of these materials (Ghasemi *et al.,* 2014; Ghasemi *et al.*, 2014).

One of the important and principle aims of this experimental study was performed to investigate the effect of randomly distributed polypropylene fibers, mixture liquid and additive materials (Borogypsum (BG), Fly Ash (FA) and Cement (C)) on plasticity index of a fine-grained soil. The Taguchi method was applied to the experiments and standard L9 Orthogonal Array (OA) with four factors and three levels were chosen. A series of consistency limits were conducted on each specimen. 0-20% BG, 0-20% FA, 0-0.25% PP and 0-3% of C by total dry weight of mixture were used in the preparation of specimens. In the tests, Distilled Water (DW), DW + 0.05% Air-Entrainer (AE) and DW + 0.15% AE were used as mixture liquid.

Table 1. Engineering Properties of Soil used in the Study

Liquid limit, w_L (%)	66
Plastic limit, w_P (%)	35
Plasticity index, PI (%)	31
Specific gravity, Gs	2,5
Maximum dry unit weight*, γ_{dmax} (kN/m^3)	15.4
Optimum water content*, w_{opt} (%)	22
Electric conductivity (mmhos/cm)	3.3
pH	6.9
Dispersion	1-2

*Obtained from standard proctor tests.

Table 2. Some Properties of Borogypsyum, Fly Ash, Cement

	Borogypsyum (%)	Fly ash (%)	Cement (%)
B_2O_3	1.62	--	--
CaO	27.8	6.6	59,61
SO_3	44.2	--	3,31
MgO	1.53	4.65	3,23
Na_2O	1.32	15.95	0,4
Al_2O_3	0.23	15.95	5,23
Fe_2O_3	0.84	16.3	3,3
SiO_2	20.95	47.5	21,02

Table 3. Properties of Reinforcement Materials used in the Study

Diameter, mm	0.05
Length, mm	12
Density, kN/m^3	9.1
Tensile strength, N/mm^2	320-400
Elastic modulus, N/mm^2	4000
Specific surface, m^2/N	20-30

Table 4. Properties of Air-entrainer used in the Study

Chemical structure	The liquid composed of special surfactants
Density, kg/l	0,99-1,03
pH	3-7
Freezing Point, °C	0
Total Chloride Ion Content	Maximum %0.1, does not contain chloride (TS EN 934-2)
Alkali Content (%Na_2O Equivalent)	Maximum %3

2. Test Procedure

Soil used in this study was obtained from a fine-grained soil deposit of Konaklı–Erzurum in the Eastern Anatolia Region of Turkey. Some index properties of the soil are given in Table 1. Also, some properties of borogypsyum, fly ash, cement and polypropylene fibers provided by the manufacturer are given in Tables 2 and Table 3. Some properties of the Air-Entrainer (AE) provided by the manufacturer are given in Table 4.

The use of quantity design in the Taguchi method to optimize a process with one or multiple performance characteristic includes the following steps: 1- to identify the performance characteristic and select process quantities (factors) to be evaluated; 2-to determine the number of quantity levels for the process and possible interaction between the process quantities (factors); 3-to select the appropriate orthogonal array and assignment of the process quantities (factors) to the orthogonal array; 4-to conduct the experiments based on the arrangement of the orthogonal array; 5-calculate the performance statistic; 6-to analyze the experimental result using the performance characteristic and ANOVA; 7-to select the optimal levels of process quantities (factors); 8-to verify the optimal process quantities (factors) through the confirmation experiment (Bayrak, 2010). Three major tools which are used in the Taguchi method are the Orthogonal Arrays (OA), analysis of variance (ANOVA) and the signal to noise ratios (S/N).

The Taguchi method employs standard tables known as the Orthogonal Arrays (OA) for construction the design of experiments. The Orthogonal Array (OA) experimental design method was chosen to determine the experimental plan, L_9, since it is the most suitable for the conditions being investigated, four parameters with three levels each. The Taguchi method uses the S/N ratio (signal to noise) instead of the average value to interpret the trial result data into a value for the evaluation characteristics in the optimum setting analysis. This ratio expresses the scatter around a target value. There are three categories of performance characteristics, the larger the better (Eq. 1), the smaller the better (Eq. 2) and the nominal the better (Eq. 3).

$$\frac{S}{N} = -10\ \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right] \tag{1}$$

$$\frac{S}{N} = -10\ \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}Y_i^2\right] \tag{2}$$

$$\frac{S}{N} = -10\ \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_0)^2\right] \tag{3}$$

where S/N (S/N unit: dB) are performance statistics, defined as the signal to noise ratio, n the number of repetitions for an experimental combination, and Y_i a performance value of the i_{th} experiment and Y_o nominal value desired. In the Taguchi method, the experiment corresponding to optimum working conditions might have not been done during the whole period of the experimentation. In this case, the performance value corresponding to optimum working conditions can be predicted by utilizing the balanced characteristic of the OA (Ross, 1988). The Taguchi method is explained as a summary in this study. More detailed information about the Taguchi method can be found in Taguchi (1987), Phadke (1989), Logothetis (1992) and Roy (2001). BG, FA, PP and Cement (C) were added at different levels by weight of the total solid materials. Experimental factors and their levels to be studied are given in Table 5. An L9 OA was chosen to evaluate the experimental results. Details of the experimental design and approach are given in Table 6. The columns show the levels of factors and each row represents a trial condition.

Table 5. Test Factors used and Their Levels

Levels	Parameters			
	BG (%)	FA (%)	PP (%)	C(%)
1	0	0	0	0
2	10	10	0.15	1
3	20	20	0.25	3

Table 6. Chosen L_9 Experimental Plan (OA)

Trial	Parameters and their levels			
	BG (%)	FA (%)	PP (%)	C
1	0	0	0	0
2	0	10	0.15	1
3	0	20	0.25	3
4	10	0	0.15	3
5	10	10	0.25	0
6	10	20	0	1
7	20	0	0.25	1
8	20	10	0	3
9	20	20	0.15	0

The soil was dried in an oven at approximately 105°C. The required amounts of soil borogypsyum, fly ash, cement and polypropylene fibers were blended together under dry conditions. 0-20% of BG, 0-20% of FA, 0-3% of C and 0-0.25% of PF by total dry weight of mixture were used in the preparation of specimens. In the tests, DW (A serial), DW + 0.05% AE (B serial) and DW + 0.15% AE (C serial) were used as mixture liquid. Consistency limit tests were carried out the procedure in BS 1377, Part 2, 1990. Because the fibers tended to lump together, considerable care and time were spent to get a homogeneous distribution of the fibers in the mixtures.

Liquid limit tests are carried out by using fall cone penetration testing apparatus. In the tests, DW, DW + 0.05% AE and DW + 0.15% AE were used as mixture liquid. Thereafter samples had been mixed until they became homogenous and fall cone penetration test was conducted. In determination of flow curve, immersion depths, corresponding to 4 or 5 different water

Table 7. Liquid Limit, Plastic Limit and Plasticity Index Values

Trial No	SERİAL A (DW)			SERİAL B (DW + 0.05% AE)			SERİAL C (DW + 0.15% AE)		
	W_L	W_P	I_P $W_L - W_P$	W_L	W_P	I_P $W_L - W_P$	W_L	W_P	I_P $W_L - W_P$
1	62	39	23	68	35	33	64	30	34
2	68	30	38	72	22	50	62	25	37
3	59	36	23	62	34	28	58	27	31
4	71	14	57	64	29	35	61	39	22
5	66	21	45	58	41	17	59	39	20
6	54	32	22	55	25	30	58	46	12
7	67	48	19	61	33	28	68	36	32
8	68	37	31	58	29	29	67	38	29
9	58	17	41	54	34	20	56	47	9

Table 8. S/N Ratios for Trials (W_L, W_P)

Trial	Parameters and their levels				Mixture Liquid (W_L)			Mixture Liquid (W_P)		
	BG	FA	PP	C	DW	DW + 0.05% AE	DW + 0.15% AE	DW	DW + 0.05% AE	DW + 0.15% AE
1	1	1	1	1	-35.848	-36.651	-36.124	-31.824	-30.884	-29.546
2	1	2	2	2	-36.651	-37.147	-35.848	-29.546	-26.855	-27.964
3	1	3	3	3	-35.418	-35.848	-35.269	-31.129	-30.633	-28.632
4	2	1	2	3	-37.026	-36.124	-35.707	-22.938	-29.252	-31.824
5	2	2	3	1	-36.391	-35.269	-35.418	-26.451	-32.258	-31.824
6	2	3	1	2	-34.648	-34.808	-35.269	-30.106	-27.964	-33.257
7	3	1	3	2	-36.522	-35.707	-36.651	-33.627	-30.373	-31.129
8	3	2	1	3	-36.651	-35.269	-36.522	-31.367	-29.252	-31.598
9	3	3	2	1	-35.269	-34.648	-34.964	-24.619	-30.633	-33.444
mean S/N ratio					-36.047	-35.719	-35.752	-29.067	-29.789	-31.024

content values, were used.

In plastic limit tests DW, DW + 0.05% AE and DW + 0.15% AE were used for clay sample and a number of mixes were prepared from dry to wet. Water contents were determined as plastic limit, at the time of these mixes were rolled onto the frosted glass and split occurred in the shape of sticks of 3 mm caliber and 8 mm length. In order to control the reliability of tests, each test was repeatedly conducted at least two times. Liquid limit (W_L), plastic limit (W_p) and plasticity index ($I_P = W_L - W_p$) obtained from the flow curves of clay samples for each serial (A, B, C) has been shown on the Table 7.

3. Results and Discussion

The results of the liquid limit, plastic limit and plasticity index are shown in (Fig. 1). Taguchi analyses were performed in order to determine the minimum liquid limit, plasticity limit and plasticity index for three different mixture liquid. S/N analysis was carried out in order to determine the effect of parameters on the consistency limits and plasticity index of three different mixture liquid results. The calculated S/N ratios of consistency limits and plasticity index were given in Table 8 and Table 9, respectively, using the test results (Fig. 1).

For the W_L, W_P and I_P of different mixture liquid, calculated average effects at each level of parameters are shown in Table 10 and 11. It is shown from Table 10 that the lowest value of average S/N for liquid limit at serial A, B and C were obtained on the level 2 of FA, level 1 of BG and level 2 of PP, respectively.

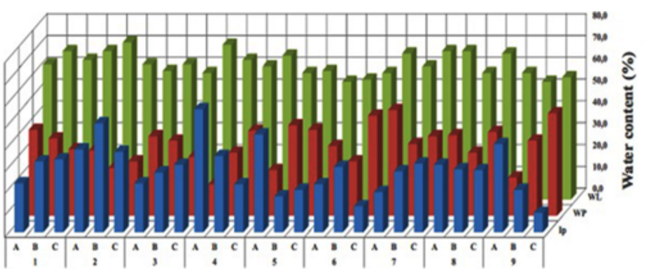

Fig. 1. Test Results for Each Trial

Table 9. S/N Ratios for Trials (I_P)

Trial	Parameters and their levels				Mixture Liquid		
	BG	FA	PP	C	DW	DW + 0.05% AE	DW + 0.15% AE
1	1	1	1	1	-27.241	-30.373	-30.633
2	1	2	2	2	-31.598	-34.160	-31.367
3	1	3	3	3	-27.241	-28.947	-29.831
4	2	1	2	3	-35.119	-30.884	-26.855
5	2	2	3	1	-33.066	-24.619	-26.028
6	2	3	1	2	-26.993	-29.546	-21.604
7	3	1	3	2	-25.745	-28.947	-30.106
8	3	2	1	3	-29.928	-29.252	-29.252
9	3	3	2	1	-32.330	-26.028	-19.121
mean S/N ratio					-29.918	-29.195	-27.200

On the other hand the lowest value of average S/N for plastic limit at serial A, B and C were obtained on the level 1 of PP, level 1 of C and level 2 of BG, respectively. It is seen that the lowest value of average S/N for plasticity index of DW mixture liquid was obtained on the level 2 of PP. For the plasticity index of DW + 0.05% AE and DW + 0.15% AE mixture liquid the lowest values of average S/N were obtained on the level 1 of BG. According to these results the most effective parameter on the plasticity index is BG.

In order to determine the effects of borogypsyum, fly ash, polypropylene fibers and cement on the consistency limits and plasticity index of distilled water, distilled water+0.05% air-entrainer and distilled water + 0.15% air-entrainer, analysis of variance (ANOVA) was performed. The results of variance analyses (ANOVA) are given in Table 12 and 13.

It is seen from Table 12 that the most effective parameter on the liquid limit at DW, DW + 0.05% AE and DW + 0.15% AE are FA, BG and FA, respectively. On the other hand the most effective parameter on the plastic limit at DW, DW + 0.05% AE and DW + 0.15% AE are PP, C and BG, respectively. The most effective parameter on the plasticity index at DW, DW + 0.05%

Table 10. Average Effects of Factors (W_L, W_P)

	Parameters	S/N ratio (W_L)			S/N ratio (W_P)		
		1. Level	2. Level	3. Level	1. Level	2. Level	3. Level
DW	BG	-35.972	-36.022	-36.147	-30.833	-26.499	-29.871
	FA	-36.465	-36.564	-35.112	-29.463	-29.121	-28.618
	PP	-35.716	-36.315	-36.110	-31.099	-25.701	-30.402
	C	-35.836	-35.940	-36.365	-27.632	-31.093	-28.478
DW + 0.05% AE	BG	-36.549	-35.400	-35.208	-29.457	-29.825	-30.086
	FA	-36.161	-35.895	-35.101	-30.170	-29.455	-29.743
	PP	-35.576	-35.973	-35.608	-29.367	-28.913	-31.088
	C	-35.523	-35.887	-35.747	-31.258	-28.397	-29.712
DW + 0.15% AE	BG	-35.747	-35.465	-36.046	-28.714	-32.301	-32.057
	FA	-36.161	-35.929	-35.167	-30.833	-30.462	-31.778
	PP	-35.972	-35.507	-35.779	-31.467	-31.077	-30.528
	C	-35.502	-35.923	-35.833	-31.605	-30.783	-30.685

Table 11. Average Effects of Factors (I_P)

	Parameters	S/N ratio		
		1. Level	2. Level	3. Level
DW	BG	-28.693	-31.726	-29.334
	FA	-29.368	-31.531	- 28.855
	PP	-28.054	-33.016	-28.684
	C	-30.879	-28.112	-30.762
DW + 0.05% AE	BG	-31.160	-28.35	-28.076
	FA	-30.068	-29.344	-28.174
	PP	-29.724	-30.357	-27.505
	C	-27.007	-30.884	-29.694
DW + 0.15% AE	BG	-30.61	-24.829	-26.160
	FA	-29.198	-28.882	- 23.519
	PP	-27.163	-25.781	-28.655
	C	-25.261	-27.692	-28.646

Table 13. Results of Variance Analyses (ANOVA; I_P)

	Parameter	DOF	(SS)	(V)	(S')	P (%)
DW	BG	2	15.33	7.665	15.33	17.844
	FA	2	12.1	6.05	12.1	14.085
	PP	2	43.786	21.893	43.786	50.965
	C	2	14.694	7.347	14.694	17.104
DW + 0.05% AE	BG	2	17.485	8.742	17.485	29.092
	FA	2	5.482	2.741	5.482	9.121
	PP	2	13.463	6.731	13.463	22.4
	C	2	23.671	11.835	23.671	39.385
DW + 0.15% AE	BG	2	54.993	27.496	54.993	37.461
	FA	2	61.123	30.561	61.123	41.637
	PP	2	12.398	6.199	12.398	8.445
	C	2	18.282	9.141	18.282	12.454

DOF: Degree of freedom; SS: Sum of square deviation; V: Variance; S': Pure Sum; P: Percent contribution

Table 12. Results of Variance Analyses (ANOVA; W_L, W_P)

		W_L					W_P				
	Parameter	DOF	(SS)	(V)	(S')	P (%)	DOF	(SS)	(V)	(S')	P (%)
DW	BG	2	0.048	0.024	0.048	0.955	2	31.084	15.542	31.084	30.054
	FA	2	3.953	1.976	3.953	78.620	2	1.082	0.541	1.082	1.047
	PP	2	0.556	0.278	0.556	11.073	2	51.721	25.860	51.721	50.007
	C	2	0.470	0.235	0.470	9.348	2	19.537	9.768	19.537	18.890
DW + 0.05% AE	BG	2	3.153	1.576	3.153	57.647	2	0.598	0.299	0.598	2.775
	FA	2	1.820	0.910	1.820	33.289	2	0.775	0.387	0.775	3.596
	PP	2	0.291	0.145	0.291	5.322	2	7.898	3.949	7.898	36.606
	C	2	0.201	0.100	0.201	3.690	2	12.303	6.151	12.303	57.021
DW + 0.15% AE	BG	2	0.506	0.253	0.506	18.427	2	24.105	12.052	24.105	81.073
	FA	2	1.620	0.810	1.620	58.935	2	2.760	1.380	2.760	9.285
	PP	2	0.326	0.163	0.326	11.891	2	1.334	0.667	1.334	4.489
	C	2	0.295	0.147	0.295	10.741	2	1.530	0.765	1.530	5.147

AE and DW + 0.15% AE are PP, C and FA, respectively, in Table 13. The graphics showing the effects of parameters on the consistency limits and plasticity index at DW, DW + 0.05% AE and DW + 0.15% AE are given in Figs. 2, 3 and 4.

All Figs. 2, 3 and 4 clearly show that the most effective parameter on the liquid limit for all serials is FA. It is seen that the liquid limit for DW mixture liquid decreased with increasing of BG and C ratio in Fig. 2. The most effective parameter on the

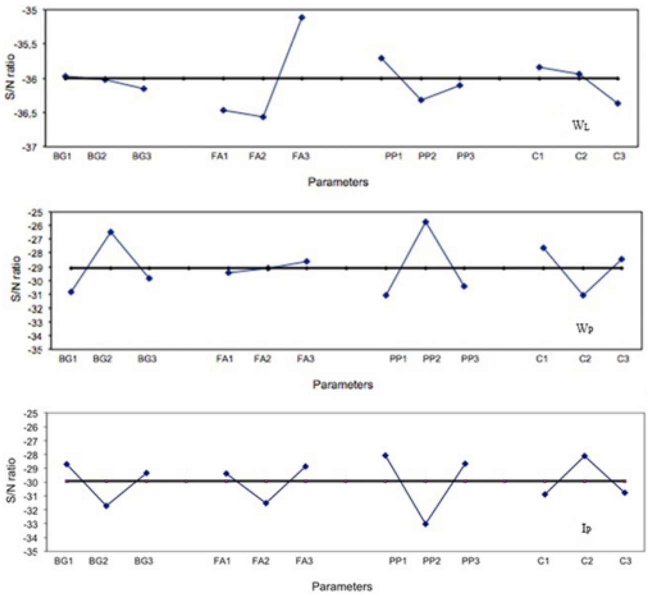

Fig. 2. Response Graphs of Main Effects for DW

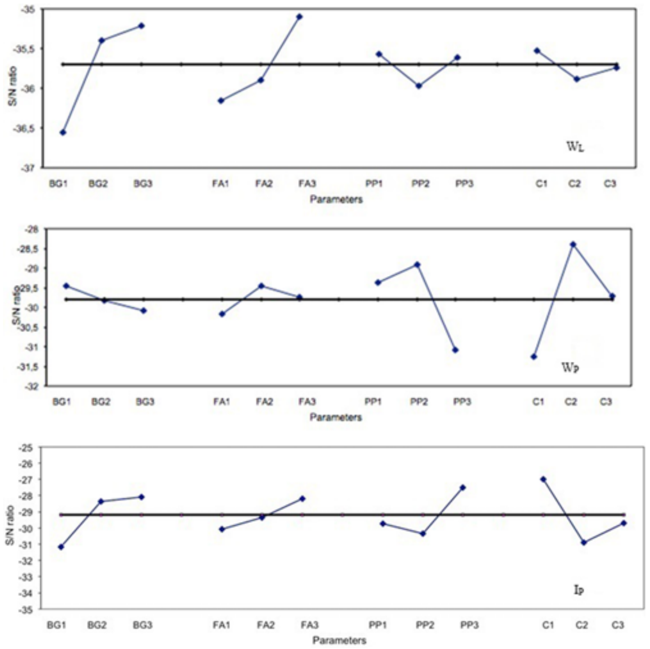

Fig. 3. Response Graphs of Main Effects for DW + 0.05% AE

plastic limit for DW mixture liquid is BG and PP. It is also seen that the plastic limit for DW mixture liquid increased with increasing of FA. Fig. 2 show that the most effective parameter on the plasticity index for distilled water mixture liquid is PP. It is seen that the plasticity index for distilled water mixture liquid decreased with increasing of PP ratio. 10% BG and 10% FA ratio decrease plasticity index for DW mixture liquid. The results corresponded to the study of Moavenian and Yasrobi (2008). They mixed clay with different concentrations of ethylene glycol and methanol. According to this study decrease in liquid limit of the soils is attributed to collapse of the diffuse double layer.

The liquid limit (for DW + 0.05% AE mixture liquid) increased

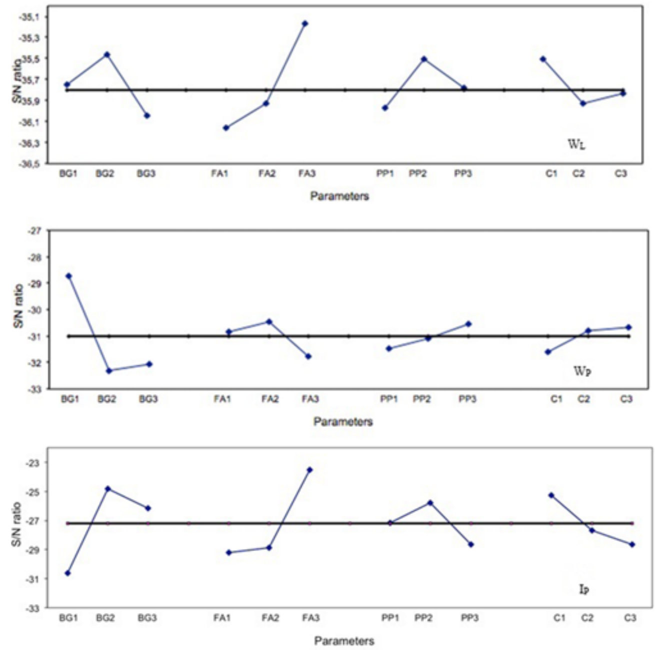

Fig. 4. Response Graphs of Main Effects for DW + 0.15% AE

with increasing of BG in Fig. 3. The most effective parameter on the plastic limit for DW + 0.05% AE mixture liquid is C. It is also seen that the plastic limit for DW + 0.05% AE mixture liquid decreased with increasing of BG ratio. Fig. 3 show that the most effective parameter on the plasticity index for DW + 0.05% AE mixture liquid is C. It is seen that the plasticity index for DW + 0.05% AE mixture liquid decreased with increasing of C ratio. On the other hand with the increase of FA ratio, there is a increase in the plasticity index for DW + 0.05% AE mixture liquid. Similarly, Prapaker *et al.* (2004) have reported that the increase in the cohesion of soil and fly ash matrix might be due to the soil texture admixed with fly ash and its characteristics.

The most effective parameter on the plastic limit for DW + 0.15% AE mixture liquid is BG in Fig. 4. It is shown that the plastic limit for DW + 0.15% AE mixture liquid increased with increasing of PP and C. Fig. 4. shows that with the increase of the FA (fly ash), there is an important increase in the plasticity index for DW + 0.15% AE mixture liquid. With the increase of C ratio, there is a decrease in the plasticity index for DW + 0.05% AE mixture liquid. While 0.15% PP ratio decreases the plasticity index (DW and DW + 0.05% AE mixture liquid), 0.15% PP ratio increases the plasticity index for DW + 0.15% AE mixture liquid. With the increase of the borogypsyum ratio, there is a increase in the plasticity index (DW + 0.05% AE mixture liquid). Generally the addition of PP and C with DW + 0.15% AE led to an increase in the plastic limit. This resulted in a reduction of the plasticity index of clay.

Usually air-entrainer does not react and it is only created discrete bubbles shaped small spheres in the mixture. Presence of AE in the mixture liquid decreases interlayer space of clay particle thus this phenomenon was reduced the plasticity index of soil in general.

The optimum conditions correspond to minimum consistency limits and plasticity index. In Figs. 2, 3 and 4, the levels corresponding to the lowest S/N ratios are chosen for each factor for which they indicate the best condition. It can be seen from Fig. 2 that BG1 (0%), FA3 (20%), PP1 (0%) and C1 (0%) are the optimum conditions for the liquid limit (DW). For the liquid limit (DW + 0.05% AE), 20% BG, 20% FA, 0% PP and 0% C are the optimum conditions. It can be seen from Fig. 4 that BG2 (10%), FA3 (20%), PP2 (0.15%) and C1 (0%) are the optimum conditions for the liquid limit (DW + 0.15% AE). The values of liquid limit for distilled water, distilled water + 0.05% air-entrainer and distilled water + 0.15% air-entrainer in optimum conditions were 53%, 52% and 52%, respectively.

From Fig. 2, BG2, FA1, PP2 and C1 are the optimum conditions for the plastic limit (DW). For the plastic limit (DW + 0.05% AE), 0% BG, 10% FA , 0.15% PP and 1% C are the optimum conditions. Fig. 4 shows that BG1 (0%), FA2 (10%), PP3 (0.25 %) and C3 (3%) are the optimum conditions for the plastic limit (DW + 0.15% AE). The values of plastic limit for distilled water, distilled water + 0.05% air-entrainer and distilled water + 0.15% air-entrainer in optimum conditions were 12%, 22% and 23%, respectively.

It can be seen from Fig. 2 that BG1 (0%), FA3 (20%), PP1 (0%) and C2 (1%) are the optimum conditions for the plasticity index (DW). For the plasticity index (DW + 0.05% AE), 20% BG (BG3), 20% FA (FA3), 0.25% PP (PP3) and 0% C (C1) are the optimum conditions. It can be seen from Fig. 3 that BG2 (10%), FA3 (20%), PP2 (0.15%) and C1 (0%) are the optimum conditions for the plasticity index (DW + 0.15% AE). The values of plasticity index for distilled water, distilled water + 0.05% air-entrainer and distilled water + 0.15% air-entrainer in optimum conditions were 16%, 14% and 8%, respectively. The plasticity index decreased with increasing of AE. This decrease in the plasticity index at DW, DW + 0.05% AE and DW+0.15% AE is attributed to the fact that addition of AE into the mixture liquid results in becomes voids.

4. Conclusions

The effect of randomly distributed Polypropylene Fibers (PP) and additive materials Borogypsum (BG), Fly Ash (FA) and Cement (C) on plasticity index (distilled water, distilled water+0.05% air-entrainer and distilled water + 0.15% air-entrainer mixture liquid) were investigated and the optimum conditions were determined for three mixture liquid (DW, DW + 0.05% AE and DW + 0.15% AE mixture liquid). The conclusions drawn from this study are summarized as follows:

1. The most effective parameter on the liquid limit for all serials is FA.
2. The liquid limit for DW mixture liquid decreased with increasing of BG and C ratio.
3. In DW mixture liquid the plastic limit increased with increasing of FA.
4. The liquid limit for serial B increased with increasing of BG. The most effective parameter on the plastic limit for DW + 0.05% AE mixture liquid is C.
6. The most effective parameter on the plastic limit for serial C is BG. The plastic limit for DW + 0.15% AE mixture liquid increased with increasing of PP and C.
7. Among the four factors and levels tested, borogypsyum are the most effective parameter on the plasticity index at DW + 0.05% AE and DW + 0.15% AE mixture liquid.
8. The plasticity index for distilled water mixture liquid decreased with increasing of PP ratio.
9. With the increase of C ratio, there is a decrease in the plasticity index for DW + 0.05% AE mixture liquid.
10. While 0.15% PP ratio decreases the plasticity index (DW and DW + 0.05% AE mixture liquid), 0.15% PP ratio increases the plasticity index for DW + 0.15% AE mixture liquid
11. The plasticity index for DW + 0.05% AE mixture liquid decreased with increasing of C ratio
12. The experimental results indicated that the optimum conditions are BG1 (0%), FA3 (20%), PP1 (0%), C2 (1%) for the plasticity index (DW), 20% BG (BG3), 20% FA (FA3), 0.25% PP (PP3), 0% C (C1) for the plasticity index (DW+ 0.05% AE) and BG2 (10%), FA3 (20%), PP2 (0.15%), C1 (0%) for the plasticity index (DW + 0.15% AE).

This paper reveals that polypropylene fibers and additive materials can be used to improve the plasticity index of fine-grained soils for the geotechnical applications. However, it should be added that further studies on the different fine-grained soils and different additive materials are needed to make more reasonable judgments.

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