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Use of fly ash- lime mixtures in stabilization of a sand

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ABSTRACT: The objective of this paper is to present recent experiences with fly ash, and an extensive experimental study of a sand with fly ash- lime mixtures at various percentages. Due to the coal and lignite use by the thermal power plants in Turkey, approximately 15 million tons/ year fly ash is produced. Increase in the amount of fly ash results in an environmental problem in Turkey, as well as in many regions of the world. Fly ash applications in enginering in Turkey are not widely employed, although it is effectively used in engineering applications in some countries, and thereby reduce the potential impact on the environment. Lime alone has conventionally been used in cohesive soils for stabilization, wheras it is used to bind sand and fly ash here in this investigation. Some engineering properties of a sand with fly ash- lime mixtures is systematically characterized in proctor, permeability, oedometer, and CBR testing apparatuses. Modifications in compressibility, compression index, void ratio, permeability, dry unit weight, optimum water contents, and CBR values are described for further use by researchers.

1. INTRODUCTION

Fly ash is a solid waste material produced by the combustion of coal, carried out of the boiler by flue gases and extracted by cyclone seperators or electrostatic precipitators and filter bags. Fly ash was started to be used in the United States 1930s with the development of industry that uses electrical energy (Davis et al., 1937). An effective use of fly ash would provide considerable environmental benefits including reducing water- air pollution, and energy savings (Hausmann, 1990; Collins & Ciesielski, 1992). Little amount of fly ash are used in various application in Turkey, although 80% of fly ash produced across the world is effectively used in many engineering applications, thereby reduce the potential impact on the environment and avoid economical loss caused by the disposal of fly ash (Alkaya, 2002).

Lime as well as fly ash could be used for soil stabilization. A literature review reveales that investigations on fly ash and lime utilization for soil stabilization have been conducted in the past years by many researchers (Mitchell & Katti, 1981; Smith, 1993; Consoli et al., 1997; Consoli et al., 2001; Edil et al., 2006; Sezer et al., 2006), as the fly ashes could be used to control of volume change, increase strength ans as a drying agent (Ferguson, 1993). For example, Herrin & Mitchell (1961), and Brown (1996) described the physical and chemical mechanisms of reactions taken place in stabilization of soils with fly ash lime mixtures. Edil et al., (2006) indicated the effective of fly ash for stabilization of fine grained soils. According to ASTM C618, there are two types of fly ash based on their chemical composition; class F (low-lime) produced from burning bituminous coal or anthracite, and class C (high-lime) produced from burning lignite coal or subbituminous (Inan & Sezer, 2003). Class C fly ash provides more economical alternatives for a wide range of stabilization applications (Senol et al., 2002), whereas high-lime fly ashes have been oftenly used in earthwork projects to improve the engineering properties of soils (Ferguson, 1993).

The objective of this paper is to study the use of fly ash- lime mixtures in stabilization of a sand. An extensive series of experiments have been carried out on the mixture of soil-lime-fly ash at various ratios, namely; 5%, 10%, 15%, 20% and 25% by weight. Consolidation, standart proctor, falling head permeability and California Bearing Ratio tests were completed to investigate some engineering properties of fly ash–lime- sand mixtures

2. MATERIALS AND METHOD

Locally available river sand, collected from Adana region, (Ceyhan) was used in this study. The sand has a specific gravity of 2.68, median grain diameter (D_{50}) of 1.20 mm, coefficient of uniformity (C_u) of 6.87 and coefficient of curvature (C_c) of 1.04. The grain size distribution and the Scannin Electron Microscope pictures of the soil are shown in Figure 1. The sand was classified as 'SW' according to the Unified Soil Classification System (USCS). The maximum and minimum dry unit weights of the sand were determined as 19.79 kN/m^3 and 16.73 kN/m^3 respectively. As it can be seen from the Figure 1, it is a well- graded sand, between the diameter of 0.075 mm and 4.75 mm. Table 1 presents some specifications of the sand.

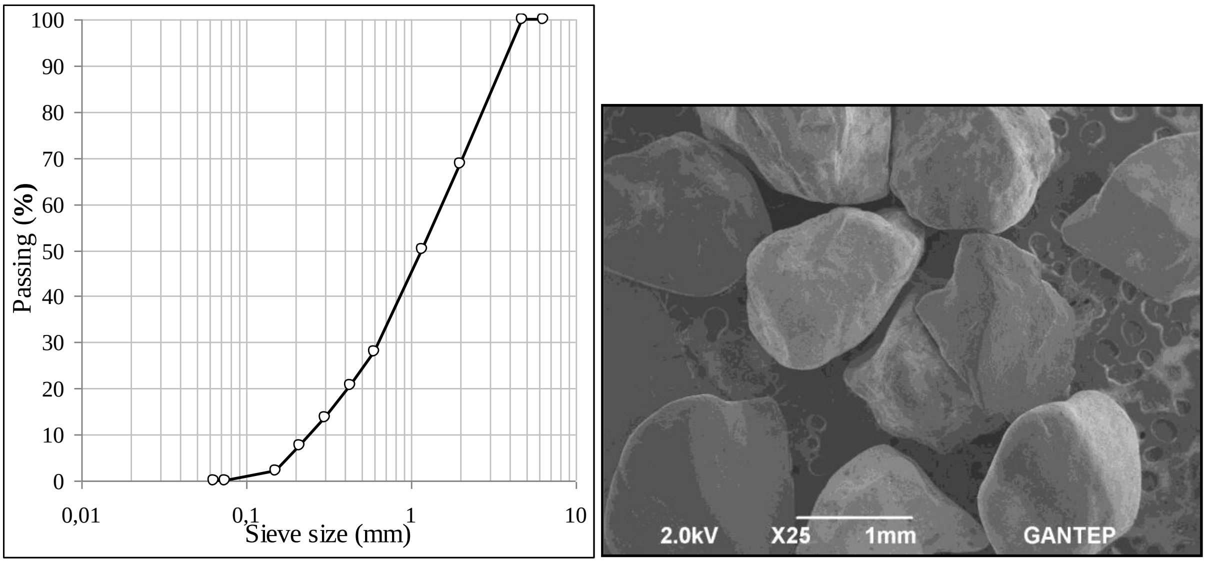

Figure 1. (a) Grain size distribution, (b) SEM picture of the sand used during the experimental study

Table 1. Some specifications of the sand

Unified Soil Classification System (USCS)	SW
Specific Gravity, G_s	2.68
Maximum void ratio, e_{max}	0.615
Minimum void ratio, e_{min}	0.328
Angle of Friction, ϕ	44^o
Coefficient of uniformity, C_u	6.87
Coefficient of curvature, C_c	1.04
Median Grain Size, D_{50}	1.20
Effective Grain Size, D_{10}	0.24

Fly ash used during the experimental works was obtained from Çatalağzı Thermal Power Station (ÇATES) in Zonguldak, Turkey. According to its chemical composition (26,43% of CaO), the fly ash used is identified as class C, and has a specific gravity (G_s) of 2,10. Table 2 presents the composition of the fly ash used in the study. CL 80 S type hydrated lime was also used in this study.

It is a product of AKAY Industry and Mining Company and produced in accordance with TS EN 459-1.

Table 2.Composition of Zonguldak Çatalağzı fly ash

Compositions (%)	CaO	Si O_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	Loss on ignition	G_s	Blaine fineness (m^2/kg)
Fly ash	26.43	25.07	11.25	12.84	3.66	0.52	0.443	0.653	18.68	2.10	739

ELE oedometer testing apparatus (ASTM D2435) was used to examine the consolidation characteristics of the sand with fly ash- lime mixtures. The maximum dry unit weight (γ_{drymax}) and optimum water content (w_{opt} %) for each test was determined by standard compaction test (ASTM 698). ELE falling head permeability testing equipment, a conventional laboratory testing method used to determine the permeability of fine grained soils with intermediate and low permeability, was employed (ASTM D5084). California Bearing Ratio (CBR) test was also performed (ASTM D1883-99) to obtain CBR values.

3. RESULTS AND DISCUSSIONS

Sands with 5% lime were tested in all the testing equipments by various fly ash mix ratios (5%: FA5 10%: FA10, 15%: FA15, 20%: FA20 and 25%: FA25 by weight). Testing program and the results obtained are shown in Table 3.

Table 3. Summary of specimen data

Sample	Maximum dry unit weight (γ_{drymax}) (kN/m^3)	Optimum water content (w_{opt}) (%)	CBR value (%)	Permeability (k) (m/sec)	Void ratio (e)		Intergranular void ratio(e_s)	
					e_0	e_f	e_{s0}	$\mathbf{e}_{sf}$
FA5	21,35	7,5	10,3	8,73x10^{-4}	0,530	0,459	0,731	0,650
FA10	20,80	8,7	16,1	5,68x10^{-4}	0,600	0,470	0,940	0,784
FA15	20,33	9,1	23,6	4,05x10^{-4}	0,613	0,476	1,104	0,926
FA20	19,60	9,6	32,2	3,63x10^{-4}	0,638	0,500	1,307	1,114
FA25	18,35	10,1	42,9	2,84x10^{-4}	0,657	0,523	1,531	1,328

The results of the oedometer tests conducted in various specimens prepared in loose cases are shown in Figures 2 and 3. Figure 2 presents the variation of void ratio (e), intergranular void ratio (e_s) with different oedometer pressures (σ_v). Figure 3 presents intergranular void ratio (e_s) vs. fly ash content (%) under different oedometer pressure values. It is seen that the initial void ratio values (e_o) of the mixtures increase with the increasing fly as content. The compressibility of the sand- lime- fly ash mixture increases with the increasing fly ash content. Similarly, e_s values increases as the fly ash content increases at all oedometer pressure values. The readers are referred to the study by Monkul (2005) for more details in estimating the e_s values. The tests were carried out immediately after the specimens had been prepared in the testing equipment. Therefore, it should be kept in the mind that it could be expected to have different results at different curing times.

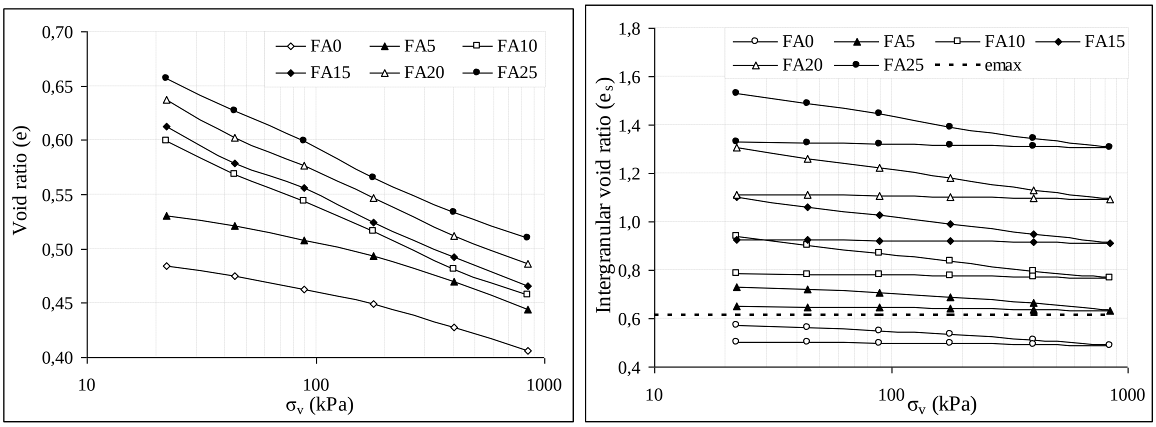

Figure 2. Variation of (a) void ratio, (b) intergranular void ratio with different oedometer pressures

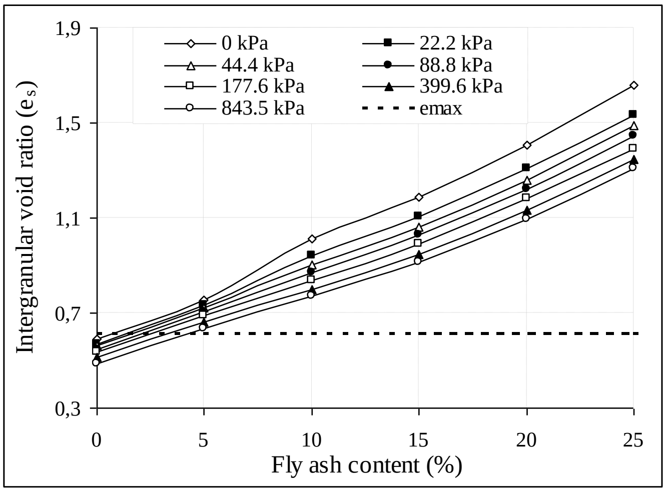

Figure 3. Intergranular void ratio vs. fly ash content under different stresses

From the standard proctor test results (Figure 4) it is seen that addition of fly ash increases the optimum water content (w_{opt}) and decreases the maximum dry unit weight (γ_{drymax}). Also, a less variation of dry unit weight over a much wider range of water contents is observed, as the fly ash content increases. This could be because of the presence of lower specific gravity fly ash.

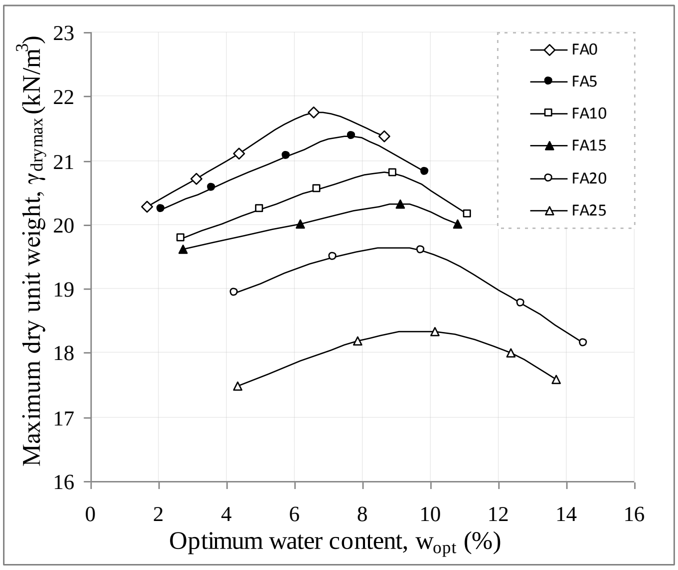

Figure 4. Effect of fly ash on the sand with lime in compaction tests

Based on the tests employed in the falling head permeability testing equipment, a sharp decrease in permeability (k) values with an increase in fly ash content is observed (Figure 5). This could be because of the filling of voids, and cementations taken place between the sand grains. Completing the procedures required to be followed for standard compaction tests, and waiting for two days in a soaked case, the falling head permeability tests were carried out to determine the k values.

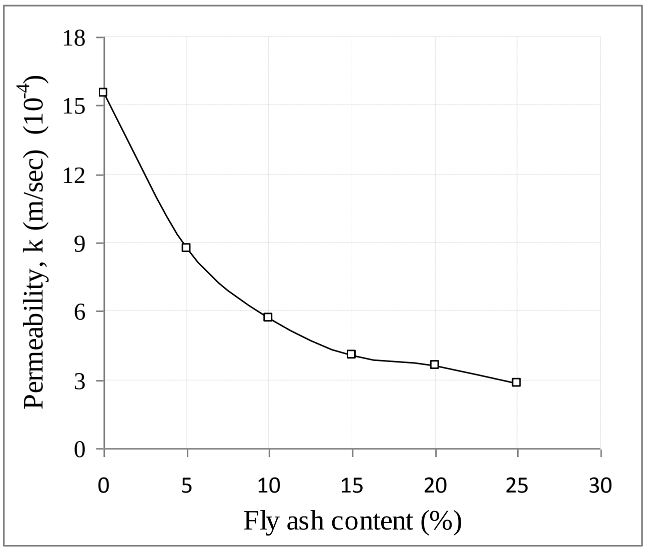

Figure 5. Effect fly ash on the sand with lime in coefficient of permeability (k)

CBR values increases with incerasing fly ash content. CBR testing results on the sand- lime- fly ash mixtures are shown in Figures 6 and 7. The tests on sand- lime- fly ash mixtures at various mix ratios were prepared at the optimum water content determined previously in compaction tests. Following the compaction of the specimens at five layers with 56 blows per layer, a surcharge plate of 2.44 kPa was placed on the specimen prior to testing. The loads were carefully recorded as a function of penetration up to a total penetration of 6.0 mm. Load penetration curves were drawn for each case, and required corrections were applied based on the procedures identified in standards (Figure 6). Then, CBR values obtained from the load-penetration curves were plotted (Figure 7). CBR values reported in the present investigation are estimated using the stresses at 5.0 mm penetration, as the CBR values at 5.0 mm penetration was observed higher than that at 2.5 mm penetration.

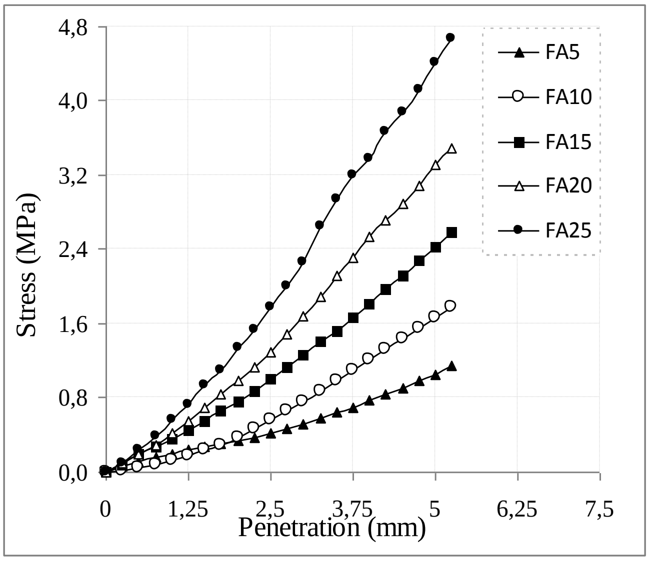

Figure 6. Effects of fly ash on the penetration vs. stress relationships of the sand with 5% lime

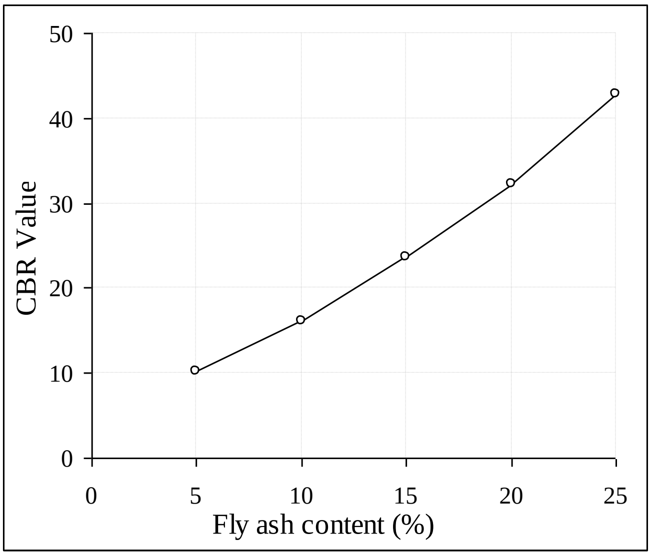

Figure 7. Effects of the fly as content on the CBR value of the sand with 5% lime

6. CONCLUSIONS

The tests reported in this paper show five facets of the behaviour sand- lime mixtures with various fly ash (Class C) contents.

(i) Some improvements are shown to be associated with an increase in fly ash content in the specimens of sand with 5% lime.
(ii) Initial void ratio (e_o), and intergranular void ratio values of the mixtures increase with the increasing fly ash content at all oedometer pressure values employed in the experimental studies.
(iii) Addition of fly ash increases the optimum water content (w_{opt}) and decreases the maximum dry unit weight (γ_{drymax}).
(iv) A decrease in permeability (k) values with an increase in fly ash content is observed.
(v) CBR values increases as the fly ash content increases.

The tests were carried out immediately after the specimens had been prepared in the testing equipment. Therefore, it should be kept in the mind that it could be expected to have different results at different curing times.

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