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Use of calcareous fly ash for improving mechanical and physical characteristics of soils

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Abstract

Stabilization of soil is an old and well known process for improving soils of low load bearing capacity, high moisture content and swelling when sub bases or embankments are to be constructed in areas with weak soil deposit. Among stabilizers, lime and cement are widely used for modifying Atterberg limits, increasing density and CBR (California Bearing Ratio) as well as fly ashes as fly ash according to ASTM D 5239-98. Calcareous fly ashes may contribute to soil stabilization by entering free lime and cementing characteristics into soil. Other geotechnical applications such as face symmetrical or hard fill dam constructions could also be benefited from self-cementing fly ash character. In this paper, fly ash samples of different origin in relation to chemical composition and fineness are tested to determine the calcareous fly ashes influences on soil mechanic and physical characteristics. They are added in two soil samples categorized as CL or SW type at percentages 0, 10, 15 and 20% by mass of the total mixture and the Proctor density, CBR as well as swelling deformation after moist curing are measured. Furthermore, the resistance of the stabilized soil mixture to wet cycling according to relevant test method is estimated by measuring the loss of material after cycling. Based on the results, it seems that calcareous fly ash is an ideal stabilizer improving impressively the characteristics of soil. CBR values are increased from 100 to 200%, swelling is limited and resistance to wet cycling is increased. Taking into account the large volume of soil materials handled in geotechnical work that are mentioned, calcareous fly ash especially of high lime content, seems to be an attractive stabilizer.

Keywords: calcareous fly ash, soil stabilization

1 Introduction

Soils with poor engineering properties or swelling problems are often improved at a reasonable cost by mixing with hydrated lime, cement, fly ashes or chemical admixtures. The potential use of fly ash for soil improvement has been verified by many researchers and depends on the type and chemical composition of fly ash [1, 2, 3]. It can be used either as supplementary cementing material in combination with lime and cement or as hydraulic binder for stabilizing sub bases or embankments and enhancing impermeability of soils in hydraulic works [4]. Calcareous fly ashes are of high content in lime and often in sulfates and posses self-hardening properties apart from pozzolanic ones. Despite the abundant quantities produced in Europe (especially in central and south eastern countries), the calcareous fly ash utilization in civil engineering is relatively low [5]. One of the reasons for this fact is related to the lack of the European regulative frame for the use of these fly ashes in engineering projects. However, a better exploitation of this fly ash could lead considerable savings of local limestone deposits (which are used for sub bases in road construction) and environmental topography.

In the paper, two types of soils are mixed with Greek calcareous fly ashes of different chemical composition coming from various power stations of the Ptolemaida-Kardia area. The hydraulic and pozzolanic character of them have been investigated in the past [7] and as well as in many applications of them in engineering field [8, 9]. Most of them do not meet the ASTM C618 Standards for type C fly ashes or even national relevant specifications [6], but research showed that in mixtures with soil and percentages around 10, 15 and 20% by mass, the mechanical characteristics and resistance to wet cycling have been impressively improved.

2 Experimental program

The raw calcareous fly ashes used for testing their effectiveness in soil mixtures are described in Table 1. The quantities used originated from different power plants and were deducted from larger homogenized samples. All fly ashes were dry. Two categories of soils (Soil1 and Soil2) have been tested and characterized according to ASTM D 2487.

Table 1. Characteristics of raw calcareous fly ashes mixed with soils

Code No	Power plant	SO_3	Al_2O_3	CaO	Fe_2O_3	MgO	SiO_2	K_2O	Na_2O	CaO_{free}	Fineness R_{45} (%)	Apparent specific density (gr/cm3)
FA1	Amynteo	6.60	13.20	24.02	8.49	3.56	38.30	1.08	0.38	9.08	50.53	2.30
FA2	Kardia	8.09	12.06	35.34	6.88	3.72	30.10	0.99	0.36	7.93	37.50	2.48
FA3	Ptole/da	3.85	13.98	24.50	8.06	2.47	48.20	1.06	1.16	3.69	50.00	2.40
FA4	Amynteo	6.60	13.40	20.80	8.71	3.48	37.80	1.03	0.95	11.20	38.50	2.39

The granulometry of soil samples is given in Fig. 1 and 2. For Soil1 which was characterized as inorganic argillaceous material, particle size analysis was made and given in Fig. 3.

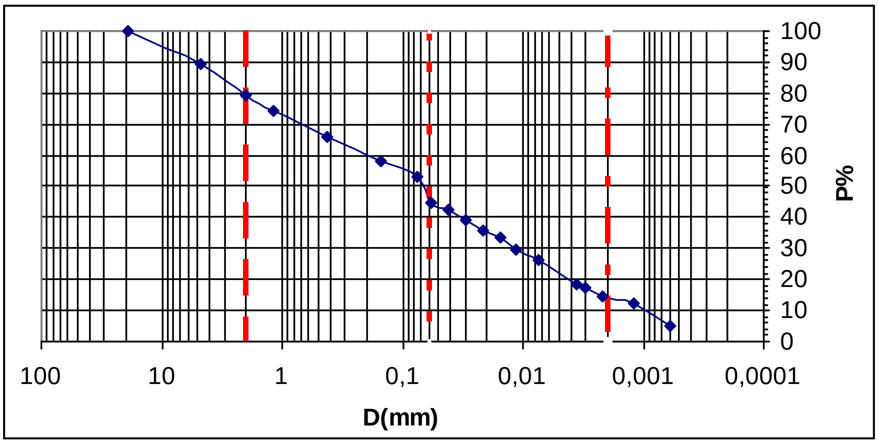

Fig. 1 Granulometry of Soil1

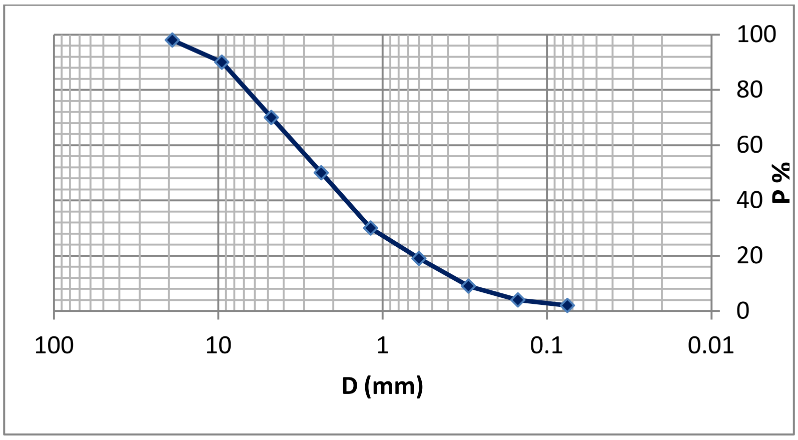

Fig. 2 Granulometry of Soil2

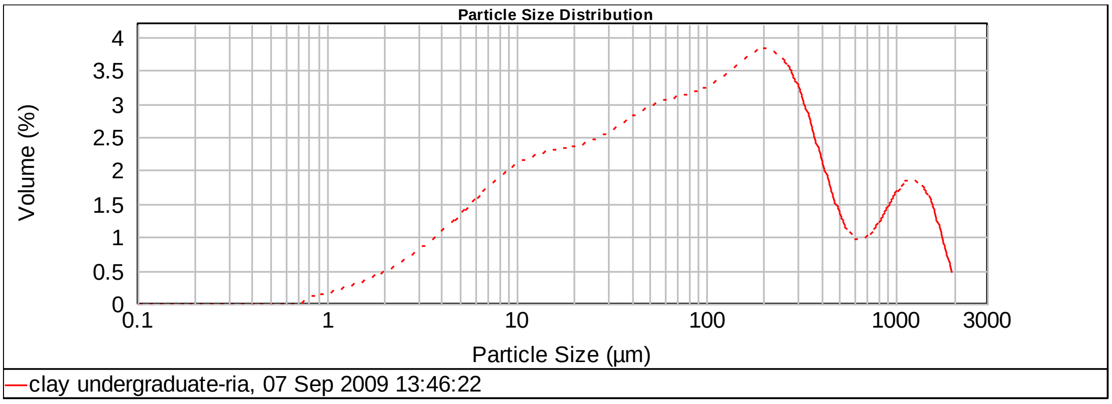

Fig. 3 Particle size analysis of Soil1

The Atterberg limits of soil samples are indicated in Table 2. According to above mentioned results of analysis, the Soil1 can be classified as CL (inorganic argillaceous of low plasticity) and Soil2 as SW (well-graded gravel and sand).

Table 2. Atterberg limits of Soil1 and Soil2

Atterberg Limits	Soil 1 Value (%)	Soil 2 Value (%)
Liquid limit LL/WL	34.00	34.87
Plastic limit PL/WP	17.00	18.15
Plasticity Index P1	17.00	16.72
Mean value of natural moisture w (%)	2.88	2.68

The optimum moisture content of the max densities according to modified Proctor method for Soil1 and Soil2 are given in Fig. 4 and 5 and their values are 8.6 and 8.4% respectively.

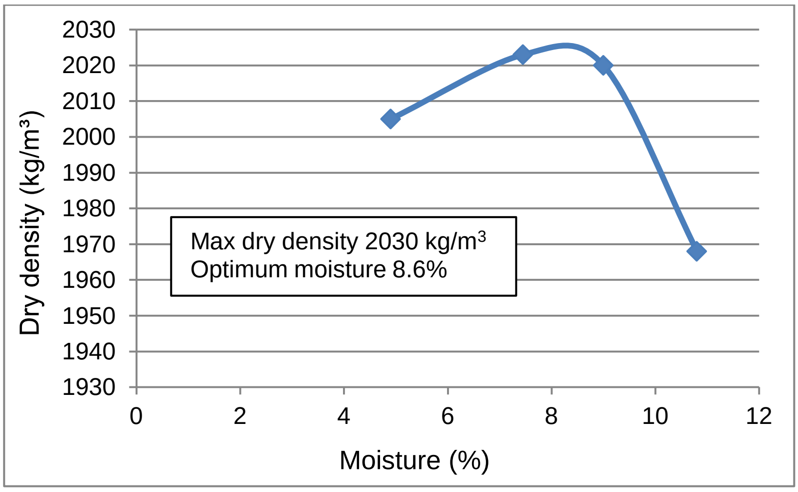

Fig. 4 Optimum moisture-dry density relationship of Soil1

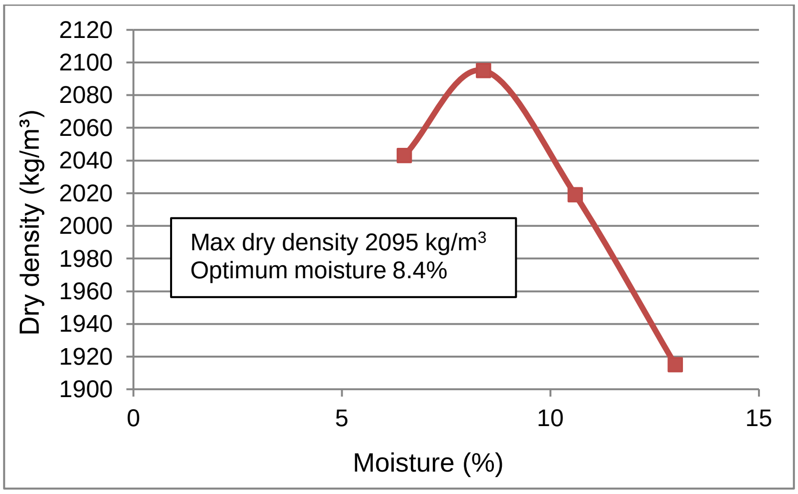

Fig. 5 Optimum moisture-dry density relationship of Soil2

The determination of Californian Bearing Ratio (CBR) according to ASTM D 1883-99 gave the results shown in Table 3. The corresponding values for Proctor densities of the Soil-fly ash mixtures that were tested are shown in Table 4.

Table 3. CBR values for Soil1 and Soil2

	Soil1			Soil2		
No of Knocks	10	20	30	10	20	30
Dry density (kg/m3)	1818	1875	2030	1791	2021	2097
CBR (%)	4.0	18.5	27.0	2.9	9.7	23.2
Swelling (%)	1	0	0	1	0	0

Table 4. Proctor density and optimum moisture for Soil and fly ash mixtures

Soil1-FA1 Mixtures	100%Soil1	90%Soil1 10%FA1	85%Soil1 15%FA1	80%Soil1 20%FA1	100%FA1
Max dry density (t/m3)	2.03	1.91	1.95	1.70	1.24
Optimum moisture (%)	8.60	10.70	13.80	15.90	30.80
Soil1-FA2 Mixtures	100%Soil1	90%Soil1 10%FA2	85%Soil1 15%FA2	80%Soil1 20%FA2	100%FA2
Max dry density (t/m3)	2.03	1.91	1.84	1.76	1.21
Optimum moisture (%)	8.60	11.20	13.40	15.70	32.90
Soil2-FA3 Mixtures	100%Soil2	91%Soil2 9%FA3	87%Soil2 13%FA3	83%Soil2 17%FA3	100%FA3
Max dry density (t/m3)	2.09	1.99	1.95	1.87	-
Optimum moisture (%)	8.4	8.40	10.10	10.30	-
Soil2-FA4 Mixtures	100%Soil2	91%Soil2 9%FA4	87%Soil2 13%FA4	83%Soil2 17%FA4	100%FA4
Max dry density (t/m3)	2.09	2.01	1.96	1.95	-
Optimum moisture (%)	8.4	8.80	9.80	10.50	-

The CBR values were measured according to ASTM D 1883-99 and curves were plotted for each percentage of soil-fly ash mixture concerning the dry density and CBR%. Then the CBR% values corresponding to 95% of the dry maximum density were recorded at the diagrams and are presented in Table 5.

Table 5. CBR values for Soil-fly ash mixtures corresponding to 95% of the max. dry density

Soil1+FA1	Soil1	90%Soil1 10%FA1	85%Soil1 15%FA1	80%Soil1 20%FA1	100%FA1
CBR %	18.5	28.0	127.0	97.0	195.0
Swelling			from 0-3%		
Soil1+FA2	Soil1	90%Soil1 10%FA2	85%Soil1 15%FA2	80%Soil1 20%FA2	100%FA2
CBR %	18.5	167.0	148.0	144.0	227.0
Swelling			from 0-5%		
Soil2+FA3	Soil2	91%Soil2 9%FA3	87%Soil2 13%FA3	83%Soil2 17%FA3	100%FA3
CBR %	9.7	27.0	41.0	54.0	-
Swelling		from 0-1%			
Soil2+FA4	Soil2	91%Soil2 9%FA4	87%Soil2 13%FA4	83%Soil2 17%FA4	100%FA4
CBR %	9.7	152.0	156.0	181.0	-
Swelling		from 0-1%			

Furthermore, the non-restricted axial compressive strength and modulus of elasticity were determined in Soil2-FA3 and Soil2-FA4 mixtures after preparation of specimens according to BS 1924:1975 and EN 13286-43:2003 methodologies respectively. The results are given in Fig. 6, 7, 8 and 9.

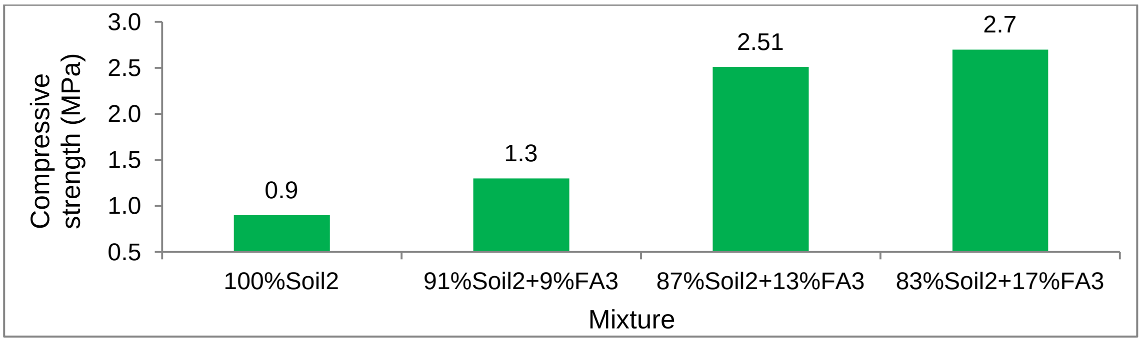

Fig. 6 Influence of FA3 addition to strength of Soil2 mixture

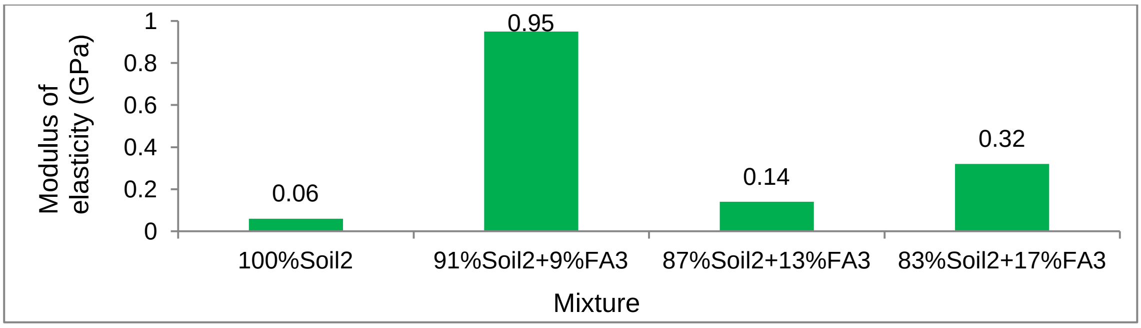

Fig. 7 Influence of FA3 addition to modulus of elasticity of Soil2 mixture

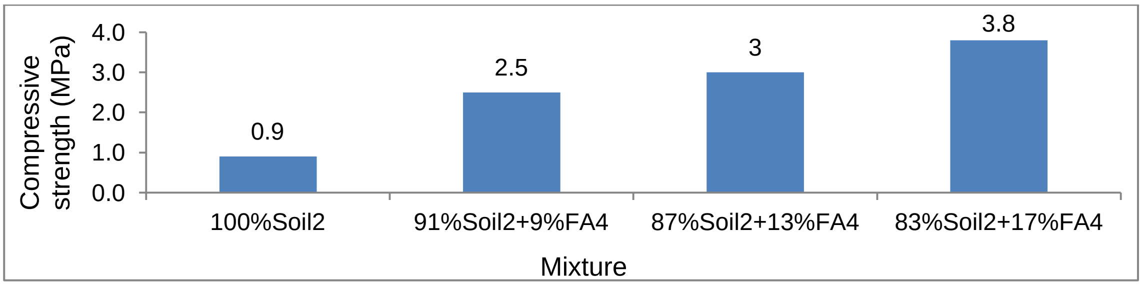

Fig. 8 Influence of FA4 addition to strength of Soil2 mixture

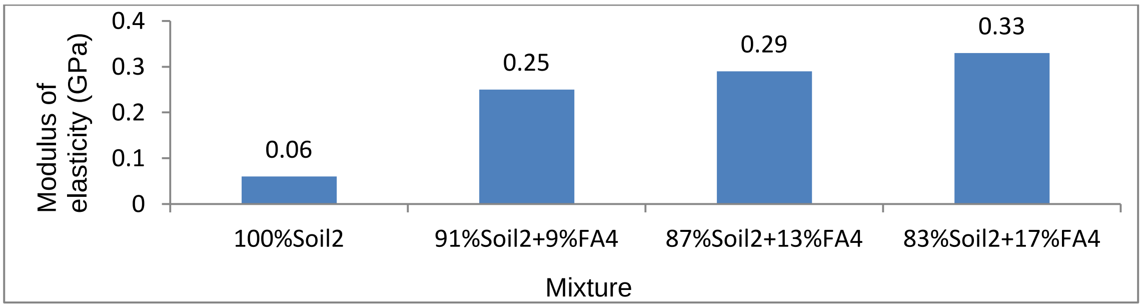

Fig. 9 Influence of FA4 addition to modulus of elasticity of Soil2 mixture

Since for hydraulic works soil mixtures are often modified with fly ash, the mixtures of Soil2-FA3 and Soil2-FA3 were subjected to shake durability test method proposed by Franklin and Chandra (1972). Parts of compacted to max density mixtures of soil and fly ash about 50±10 gr were placed inside the cylindrical drums of Franklin equipment and turned around with a frequency 20 cycles per minute.

After the end of the test method and drying of the material the shake-durability index was calculated by using equation:

$$I_d = \frac{B-D}{A-D}$$

Where A is the weight of the dry sample, B is the weight of the dry sample after treatment within the water, D is the weight of the cylindrical drum and I_d is the shake durability index. The results of testing the modified with fly ash mixtures are given in Fig. 10.

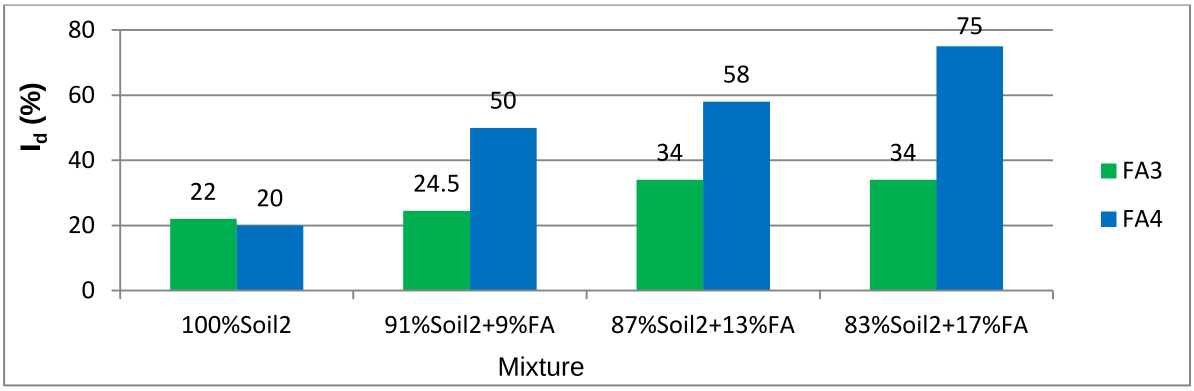

Fig. 10 Shake durability index of mixtures Soil2-FA3 and Soil2-FA4

3 Discussion of results

Regarding the characteristics of the soil samples Soil1 and Soil 2, it seems that they do not differ essentially. This makes the comparison of various fly ash influences relatively easier. The four samples of fly ash FA1, FA2, FA3 and FA4 emanate from three different power plants. The FA1 and FA4 from Amynteo power plant differ actually in finesse. Both of them are of high CaO_{free} content and sulfates (SO_3 6-7%). The FA2 from Kardia is of high sulfate (SO_3 8.09%) and medium CaO_{free} content ≈8.69%. The FA3 is of low sulfate and low CaO_{free} content.

According to Table 4, with addition of fly ash in all soil mixtures the optimum moisture is increased and maximum dry density reduced. The CBR values in all soil-fly ash mixtures are impressively increased compared with those of soils. For net fly ash, FA1 and FA2 samples the CBR values are very high, 195 and 227% respectively. Also it seems that the rich in lime fly ash FA1, FA2 and FA4 exhibited a higher CBR value which means better contribution to strength development.

The uniaxial unrestricted compressive strength as well as modulus of elasticity are also increased with additions of fly ash and again then high content in free lime fly ash FA4 developed higher strength values.

Problem of swelling during determination of CBR have not appeared in any of the samples with fly ash. Furthermore, testing durability (in particular corrosion) after cycling in running water, it seems that in all cases the resistance of soil-fly ash mixtures are significantly higher compared to control soil samples and the performance of FA4 with high lime and sulfate content is better than FA3.

Based on results it could be said that fly ash addition in soil is much advantageous improving its mechanical and physical characteristics. In addition the performance of high in free lime fly ashes seems to be better with soils.

Taken into account that rich in lime fly ashes are not allowed to be used in applications of constructional sector, this good performance open a field for their utilization.

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References

[1] Ferguson G., Use of Self Cementious Fly Ashes as a Soil Stabilization Agent, ASCE Geotechnical Special Publication, 36:ASCE, 1993

[2] Edil T.B., Acosta H., Benson C.H., Stabilizing fine grained soils with fly ash, ASCE Journal of Materials in Civil Engineering, 2006, 18 (2) 283-294

[3] ACAA, 2008, Soil Stabilization and Pavement Recycling with Self Cementing Coal Fly ash, Education Foundation ACAA, 2008, pp 1-58

[4] Golden D., Expanding Coal ash Utilization in Concrete Construction, Proc. Of Conf. Concrete Technology for Sustainable Development in the Twenty-First Century, Hyderaba, India, 9-11Feb 1999, Editor P.K. Mehta, pp 97-125

[5] Bech N., Feurborn J.-ECOBA, Coal Ash Utilization in Europe, CD Proc. Of the Int. Conf. EUROCOALASH 2008, Warsow, Poland, 6-8 October 2008

[6] Hellinic Specifications on the “Use of Calcareous Fly Ash in Concrete and Concrete Products”, Ministry of Public Works,ΦΕΚ 551/07, 2007

[7] Papayianni I. An investigation on the pozzolanicity and hydraulic reactivity of a High Calcium Fly Ash, Magazine of Concrete Research, Vol. 39, No 138, 1987, pp 19-28

[8] Papayianni I., High calcium fly ash applications in Engineering field, CD Proc. Of the 11th Int. conference on Advances in Concrete Technology and Sustainable Development, 9-12 May 2010, Jinan, China

[9] Kolias S., Karachalios A., Stabilization of argillaceous soils with calcareous fly ash with and without cement, Proc. Of the 1st Hellinic Conf. of EVIPAR, 24-26 November 2005, Thessaloniki, editors: I. Papayianni, S. Tsimas