Some aspects of lime treated fly ash and mine overburden composite samples

Banita Behera, Manoj Kumar Mishra*

Department of Mining Engineering, National Institute of Technology, Rourkela, India

*Corresponding Author. Ph: 91 661 246 2602, Fax: 91 661 2462022, Email: mkmishra@nitrkl.ac.in

Ph: 91 661 246 4609, 91 9861819713(M), Fax: 91 661 2462022, Email: banita@nitrkl.ac.in

Abstract

There is almost a linear relation exists between generation of electricity and production of fly ash from thermal units in India. It poses a very challenging task of safe handling, proper disposal and utilization of the fly ash. In order to increase its utilization prospects an investigation was carried out for use in mine haul road construction. The paper presents a series of laboratory tests and evaluates the effect of lime on strength behavior of fly ash - mine overburden mixes. Tests were performed with different percentages of lime (2%, 3%, 6%, and 9%). Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) analyses were conducted at 28 days cured specimens. The experimental results indicated that strength values of fly ash and overburden mixes increased due to lime treatment.

Keywords: Curing Period, Fly ash, Lime, Overburden, Unconfined compressive strength

1. Introduction

Fly ash is a waste by-product from thermal power plants. In order to improve the rate of use of the fly ash, lime treatment techniques have largely been developed across the world. The current annual production of coal ash worldwide is estimated around 600 million tones, with fly ash constituting about 500 million tons at 75-80% of the total ash produced (Ahmaruzzaman, 2010). Thus, the amount of fly ash generated from thermal power plants has been increasing throughout the world, and consuming several thousand hectares of precious land for the disposal of those. It has become a serious environmental problem. The beneficial effects of lime treatment on the performance of a broad range of soils or soil-fly ash mixtures have been widely documented (Bell, 1996; Consoli et al., 2001; Acosta et al., 2003; Faluyi and Amu, 2005; Rajasekaran, 2005; Goswami and Mahanta, 2007; Ghosh and Dey, 2009; Mackos et al., 2009). The overburden (O/B) material, particularly in coal mine is a very important raw material which has been traditionally used in a limited way almost restricted to the mine itself. The overburden is highly heterogeneous. Gradation results suggest that fines and coarse grains are approximately equally represented in the soil (Ulusay et al., 1995). In the present study, some aspects of lime treated fly ash and overburden mixtures were investigated for different mix ratios.

2. Materials and methods

2.1 Materials

The fly ash used in the present study was collected from electrostatic precipitators of a nearby thermal power unit of Rourkela Steel Plant, India. The fly ash used in the present study was collected from electrostatic precipitators of a thermal power unit of Rourkela Steel Plant, Orissa, India. The overburden used in this study was collected from Bharatpur opencast coal mine, Talcher, India. The additive selected was commercially available superior grade quick lime. The fly ash and overburden mixes were stabilized with 2%, 3%, 6%, and 9% of lime. Weight fractions of fly ash of 15%, 20% and 25% were used to mix with overburden.

2.2 Methods

The tests for specific gravity, consistency limits, free swell index, pH, and loss on ignition were carried out as per established procedures. The compaction characteristics of the fly ash, overburden and all the mixes were determined by conducting heavy compaction tests on specimens according to IS: 2720 - Part 8 (1983). Unconfined compressive strength (UCS) tests on compacted specimens were conducted according to IS: 2720 - Part 10 (1991). All specimens for the UCS test were prepared at their optimum water content. SEM and EDX techniques were used to study the morphological behaviour and elemental compositions of fly ash, overburden and all the mixes. A JEOL JSM 6480 LV, (Japan) model SEM fitted with EDX micro analyzer was used for the SEM and EDX studies.

3. Results and discussion

The physico-chemical properties of fly ash and mine overburden are reported in Table I. The specific gravity of fly ash is found to be less than that of mine overburden, due to the presence of cenospheres. Free swell index of fly ash is found to be negative due to flocculation. The morphological behavior of the overburden and fly ash are as shown in Figs. 1 and 2. The chemical composition of the mine overburden and fly ash are shown in Table II.

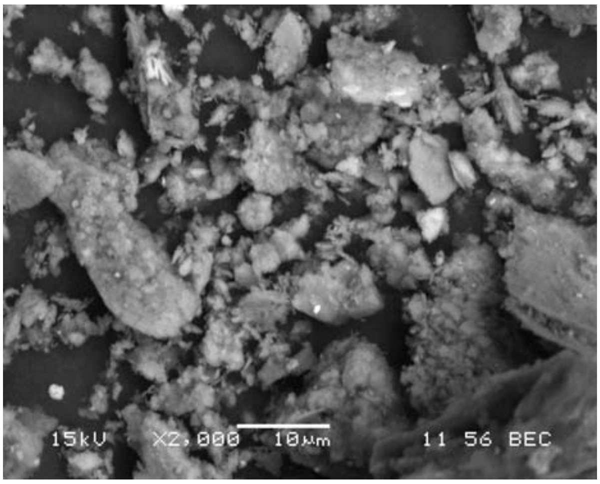

Fig. 1 Scanning electron micrograph of mine overburden

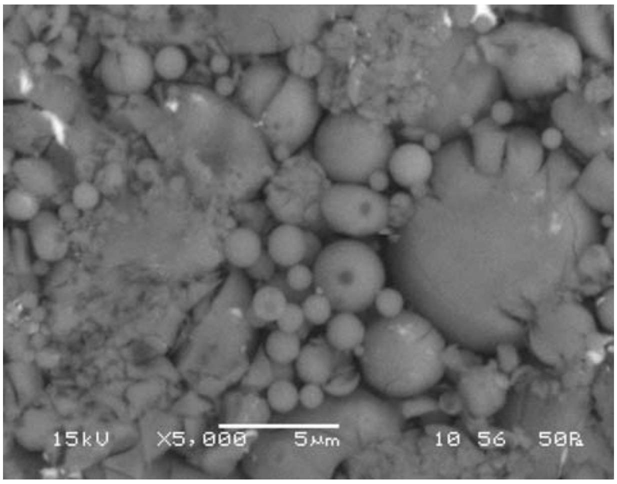

Fig. 2 Scanning electron micrograph of fly ash

Table I: Physico-chemical properties of fly ash and mine overburden

Property	Fly ash	Overburden
1. Specific gravity	2.16	2.6
2. Consistency limits		
Liquid limit (%)	30.75	25.70
Plastic limit (%)	Non-plastic	15.04
Shrinkage limit (%)	--	13.44
3. Plasticity Index (%)	--	10.66
4. Free swell index (%)	Negligible	20
5. pH value	7.2	4.85
6. Loss on ignition (%)	2	10

Table II: Chemical composition (% by weight) of O/B and fly ash

Constituents	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**K_2O**	**MgO**	**TiO_2**	**Na_2O**
O/B	55.33	31.65	9.24	1.21	0.43	1.37	0.77	--
Fly ash	52.13	35.64	6.47	0.53	1.46	0.52	3.02	0.2

3.1 Compaction behaviour

The optimum moisture content and maximum dry density values for fly ash, mine overburden and all the mixes are reported in Table III. The maximum dry density of flyash is lower than that of mine overburden as flyash is non-cohesive in nature.

3.2 Compressive strength behaviour

The unconfined compression strength is an important parameter in pavement and soil stabilization applications. The unconfined compressive strength (UCS) of overburden material is often used as an index to quantify the improvement of materials due to treatment. Compressive strengths of mine overburden stabilized with 15%, 20%, and 25% fly ash were 0.9 to 1.36 MPa and 1.34 to 2.59 MPa at 7 and 28 days of curing respectively (Figs. 3 and 4). It is observed that the compressive strength of 15%FA+85%O/B mix stabilized with 2%, 3%, 6% and 9% of lime content increased by 15% to 18% as compared to that of other two mixes at 7 days of curing. It indicates that the reaction between reactive silica in fly ash and overburden takes place at a higher rate than that in other mixes. The behaviour is different at 28 days curing period. Mix containing 20%FA and 80%O/B exhibited highest strength as compared to other two mixes. The value is highest for 9% lime content because of its massive gel formation (Fig. 5(h)). The gel formation is attributed to the presence of calcium oxide, silica and alumina in high proportion (Sivapullaiah et al., 1995; Ghosh and Subbarao, 2001). Addition of lime improved the strength of fly ash and overburden mixes. The strength values achieved in all the mixes are more than 1 MPa except that for 25%FA+75%O/B at 7 days at 6% and 9% lime. The decreased values at 6% and 9% lime are attributed to low reactive silica content. It confirms to similar observation by Sivapullaiah et al. (1995). All the three mix types gave maximum strength values at 3% lime. Thus 3% lime is found to be optimum lime content at 7 days curing in all the mixes. A study reported that stresses induced in the base layer are about 300 to 650 kPa (Tannant and Kumar, 2000). The developed mixes exhibit higher values than those and hence can be useful for road construction.

Table III: Maximum dry density and optimum moisture content achieved from the compaction test

Mix	MDD (kg/m^3)	OMC (%)
Fly ash	1396	20.06
Mine overburden	2040	8.15
15%FA+85%O/B	1965	8.77
20%FA+80%O/B	1914	10.4
25%FA+75%O/B	1872	10.8
(15%FA+85%O/B)+2%L	1867	11.63
(15%FA+85%O/B)+3%L	1841	13.2
(15%FA+85%O/B)+6%L	1833	12.81
(15%FA+85%O/B)+9%L	1826	13.4
(20%FA+80%O/B)+2%L	1842	11
(20%FA+80%O/B)+3%L	1806	11.15
(20%FA+80%O/B)+6%L	1804	12.6
(20%FA+80%O/B)+9%L	1807	11.3
(25%FA+75%O/B)+2%L	1788	13.2
(25%FA+75%O/B)+3%L	1775	12.2
(25%FA+75%O/B)+6%L	1766	12.2
(25%FA+75%O/B)+9%L	1726	14.4

Note: MDD = Maximum dry density, OMC = Optimum moisture content, FA = Fly ash, O/B = Overburden, L = Lime.

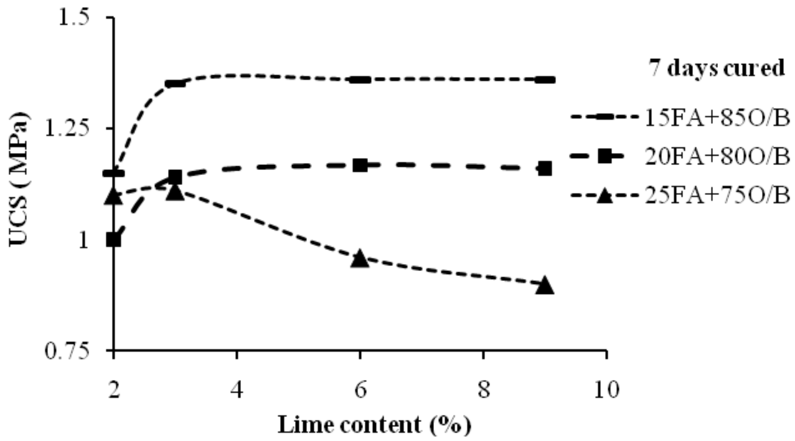

Fig. 3 Effect of lime on compressive strength of overburden-fly ash mixes at 7 days curing

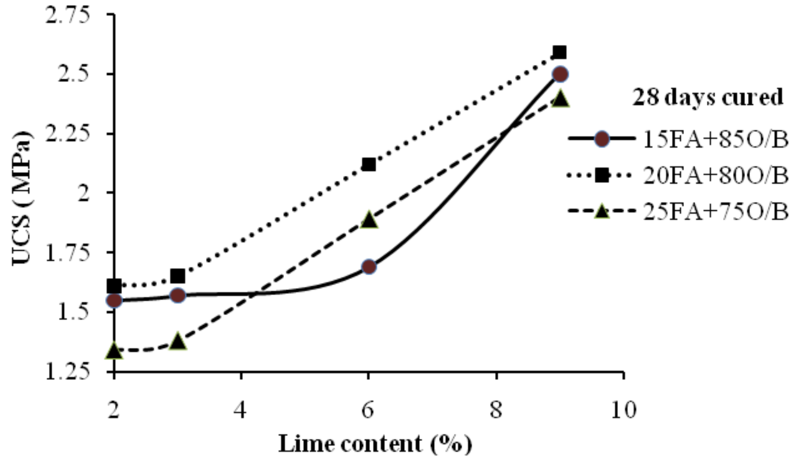

Fig. 4 Effect of lime on compressive strength of overburden-fly ash mixes at 28 days curing

3.3 Microscopy analysis (Fig. 5)

The SEM analyses reveal that the glassy portion of fly ash and overburden are preferentially attached by lime addition positively influencing the compressive strength values. The micrographs show cementitious compounds such as calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A H) were formed around fly ash and overburden particles as a result of the pozzolanic reaction after 28 days curing. These hydration products filled the pore spaces and maintained a bond between fly ash spheres and overburden particles. It confirms that increase in lime content produces a densified interlocking network and the strength development is also dependent on the amount of hydration products as well as their interlocking mechanisms (Lav and Lav, 2000). Massive formation of hydration products are noticed in (20%FA+80&O/B)+9%L composite resulting in high strength of the material.

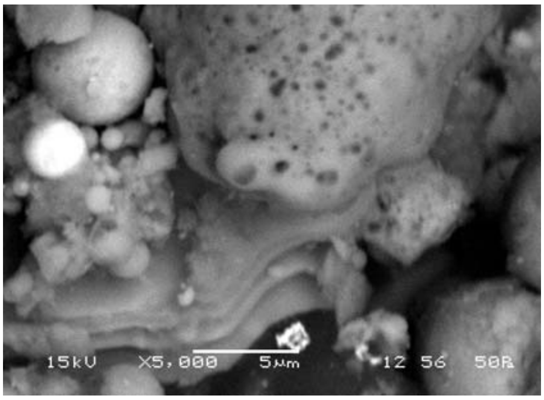

Fig. 5(a) (15%FA+85%O/B)+2%L

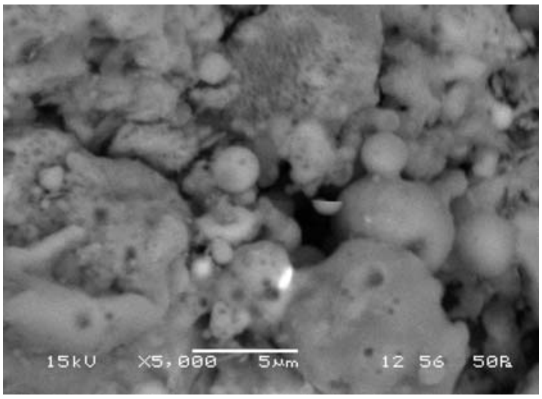

Fig. 5(b) (15%FA+85%O/B)+3%L

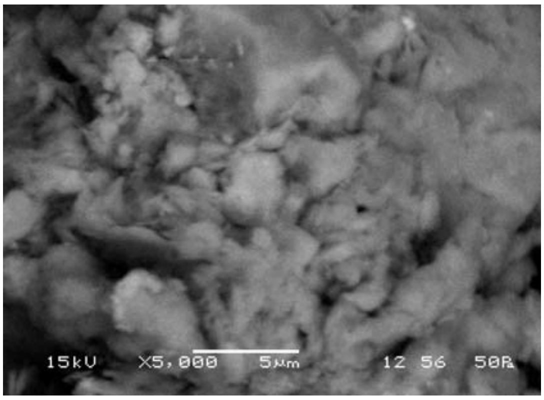

Fig. 5(c) (15%FA+85%O/B)+6%L

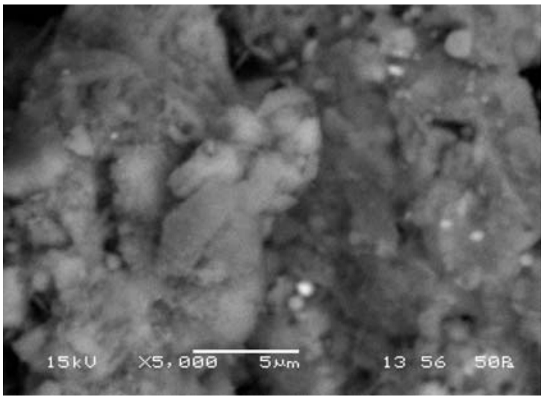

Fig. 5(d) (15%FA+85%O/B)+9%L

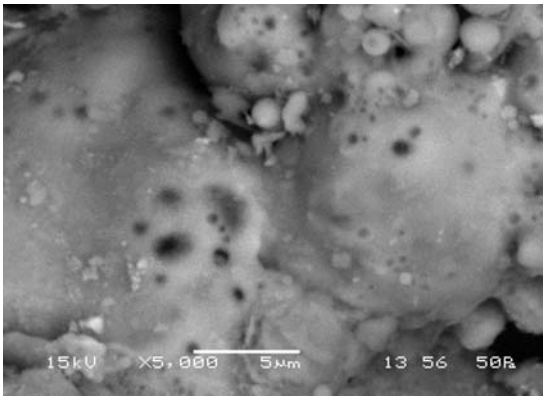

Fig. 5(e) (20%FA+80%O/B)+2%L

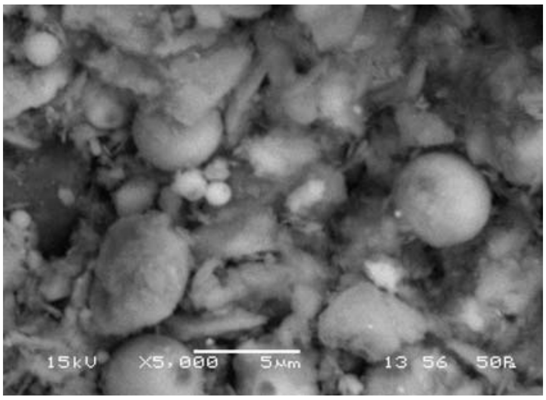

Fig. 5(f) (20%FA+80%O/B)+3%L

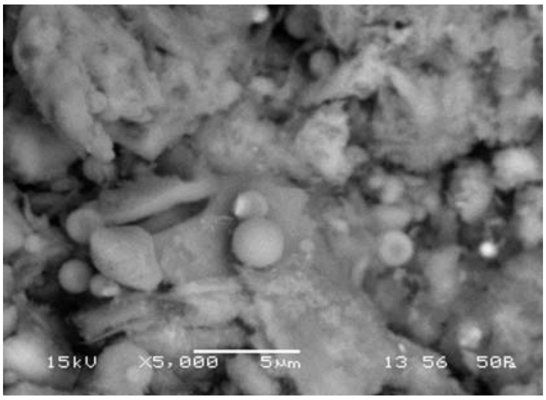

Fig. 5(g) (20%FA+80%O/B)+6%L

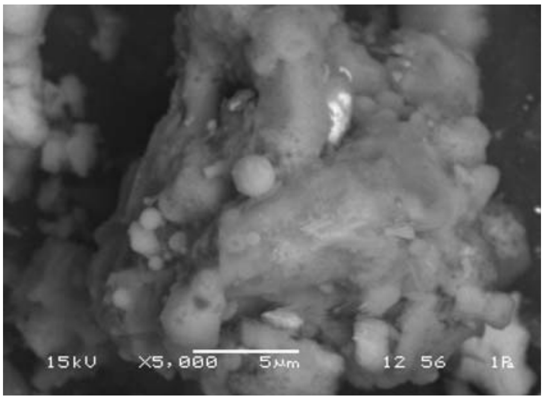

Fig. 5(h) (20%FA+80%O/B)+9%L

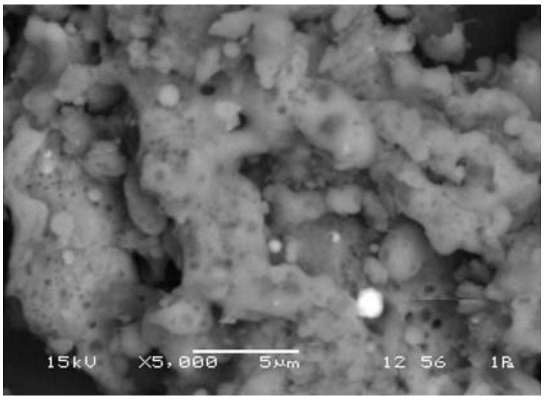

Fig. 5(i) (25%FA+75%O/B)+2%L

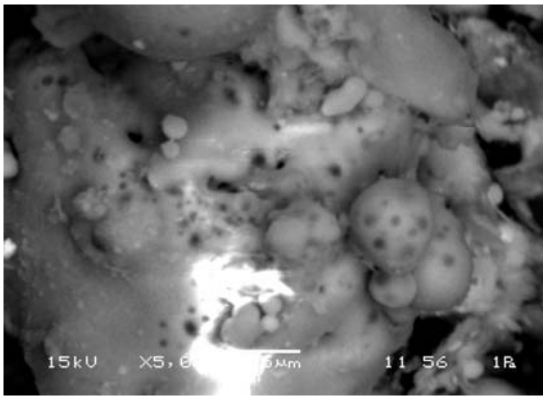

Fig. 5(j) (25%FA+75%O/B)+3%L

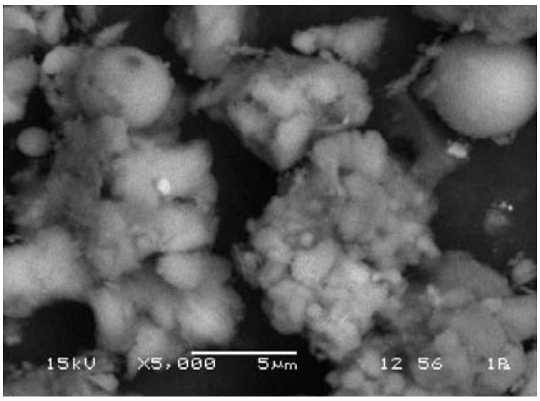

Fig. 5(k) (25%FA+75%O/B)+6%L

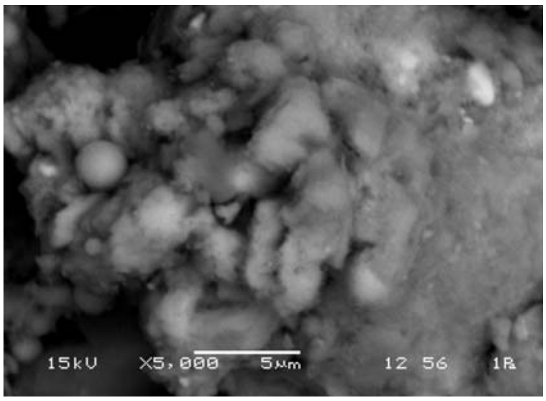

Fig. 5(l) (25%FA+75%O/B)+9%L

Fig 5: Scanning Electron micrographs of diff. compositions of Fly ash (FA), Over Burden (OB) &Lime (L)

3.4 Energy-Dispersive X-ray analysis (Table IV)

EDX is an analytical technique for elemental analysis or chemical characterization. The EDX analyses of all the mixes were carried out to observe the effect of hydration at 28 days of curing. There was variation in elemental composition in various mixes. In all mixes calcium content increases due to increase in lime content. Alumina content also increases with increase in fly ash content in the mixes. But, increase in lime content reduces the alumina percentage in all mixes. The silica content reflects a variable trend. But with an increase in fly ash content the silica content shows decreasing trend at 3% and 6% lime at 28 days curing. These results confirm to similar observation reported elsewhere (Cetin et al., 2010). All the mixes contain very small or negligible percentages of Na, Mg, P, S, Mn, Cu, Ba and Mo elements. The chemical composition of all the mixes indicates that they contain high percentages of silica, alumina, iron and calcium oxides as well as small percentages of other elements. Among all these oxides, calcium oxide is very reactive. In the presence of aqueous solution, calcium oxide undergoes hydration. The formation of calcium silicate hydrate (C-S-H) gel and calcium aluminate hydrate (C-A-H) gel leads to increase in calcium content. The effectiveness of the lime treatment depends on the quality and quantity of lime as well as the chemical composition of the soil/fly ash. The strength developed is obviously influenced by the quantity of cementitious gel produced and consequently by the amount of lime consumed (Abdelmadjid and Muzahim, 2008).

4. Conclusion

Based on the test results obtained in this investigation, the following conclusions have been drawn:

1. Lime content showed a significant effect on the strength development and pozzolanic reaction rate of natural pozzolans.
2. The unconfined compressive strength of mine overburden mixed with 15% fly ash and 3% lime achieved was 1.35 MPa for 7 days curing and the strength of the same mix increased by 16% at 28 days curing.
3. The morphology of all the mixes showed the formation of hydrated gel at 28 days curing. The voids between the particles were filled by growing hydrates with curing time.
4. Microanalysis and compositional analysis confirmed the formation of new cementitious compounds such as calcium silicate hydrate (C-S-H) gel and calcium aluminate hydrate (C-A H) gel which leads to increase in strength of the material over time.

Table IV: Chemical compositions of all the mixes at 28 days curing

Elements in oxide form	(15FA+ 85O/B) +2L	(15FA+ 85O/B) +3L	(15FA+ 85O/B) +6L	(15FA+ 85O/B) +9L	(20FA+ 80O/B) +2L	(20FA+ 80O/B) +3L	(20FA+ 80O/B) +6L	(20FA+ 80O/B) +9L	(25FA+ 75O/B) +2L	(25FA+ 75O/B) +3L	(25FA+ 75O/B) +6L	(25FA+ 75O/B) +9L
Na	1.92	--	0.32	1.14	0.12	--	0.8	0.01	0.05	--	--	0.05
Mg	1.86	0.1	0.5	0.93	1.06	1.37	2.21	0.54	1.02	--	--	1.62
Al	29.5	24.3	23.2	15.5	29.6	26.8	25.8	20.1	33.2	30.6	26.4	21.8
Si	42.4	58.9	43.7	42.8	49.7	47.7	39.7	53.5	45.7	26.8	24.6	29.9
P	0.39	--	0.04	--	--	0.37	--	--	0.2	0.36	--	--
S	0.09	0.62	0.38	--	0.53	--	1.24	1.1	--	0.79	--	0.07
K	0.08	3.35	4.42	1.48	2.49	1.49	2.61	0.76	2.48	4.81	2.05	1.44
Ca	3.69	4.92	7.63	19	1.6	7.01	16.5	12.4	3.83	17.7	23.2	27.7
Ti	2.22	--	1.47	2.04	3.39	1.2	1.02	0.22	3.54	8.18	6.47	0.8
Mn	--	--	0.58	0.34	--	--	--	0.14	--	3.71	1.98	--
Fe	11.4	3.42	12.4	2.17	4.99	6.97	4.81	3.36	5.06	2.25	12.2	11.8
Cu	3.43		3.23	7.62	1.68	--	2.96	2.42	0.74	0.52		1.58
Zn	2.2	2.51	1.21	1.3	2.57	2.31	2	2.24	0.7	4.28	3.1	0.67
Ba	0.84	1.88	--	2.23	2.24	2.95	0.4	3.28	3.57	--	--	2.52
Mo	--	--	0.85	3.5	--	1.82	--	--	--	--	--	0.05

(The mix compositions FA, OB and L indicate respective percentages)

5. Acknowledgements

The authors acknowledge the fund provided by Fly Ash Unit, Department of Science and Technology, Govt. of India under R&D Scheme vide approval No: *FAU/DST/600(17)/2008-09* dated *12.09.2008.*

6. References

Abdelmadjid, L., Muzahim, A., 2008. Effect of Hydrated Lime on the Engineering Behaviour and the Microstructure of Highly Expansive Clay. The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), Goa, India, pp. 3590-3598.

Acosta, H.A., Edil, T.B., Benson, C.H., 2003. Soil stabilization and drying using fly ash. *Geo Engineering Report No. 03-03*, *Geo Engineering Program*, University of Wisconsin, Madison, USA.

Ahmaruzzaman, M., 2010. A review on the utilization of fly ash. Journal of Progress in Energy and Combustion Science, vol. 36, no. 3, pp. 327-363.

Bell, F.G., 1996. Lime stabilization of clay minerals and soils. Journal of Engineering Geology, vol. 42, no. 4, pp. 223-237.

Cetin, B., Aydilek, A.H., Guney, Y., 2010. Stabilization of recycled base materials with high carbon fly ash. Journal of Resources, Conservation and Recycling, vol. 54, no. 11, pp. 878–892.

Consoli, N.C., Prietto, P.D.M., Carraro J.A.H., Heineck, K.S., 2001. Behavior of compacted soil-fly ash-carbide lime mixtures. *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 127, no. 7, pp. 774-782.

Faluyi, S.O., Amu, O.O., 2005. Effects of Lime Stabilization on the pH Values of Lateritic Soils in Ado-Ekiti, Nigeria. Journal of Applied Sciences, vol. 5, no. 1, pp. 192-194.

Ghosh, A., Subbarao, C., 2001, Microstructural Development in Fly Ash Modified with Lime and Gypsum, Journal of Materials in Civil Engineering, vol. 13, no. 1, pp. 65-70.

Ghosh A., Dey, U., 2009. Bearing ratio of reinforced fly ash overlying soft soil and deformation modulus of fly ash. Journal of Geotextiles and Geomembranes, vol. 27, no. 4, pp. 313-320.

Goswami, R.K., Mahanta, C., 2007. Leaching characteristics of residual lateritic soils stabilised with fly ash and lime for geotechnical applications. Journal of Waste Management, vol. 27, no. 4, pp 466-481.

IS: 2720 Part 8, 1983. Laboratory determination of water content – dry density relation using heavy compaction. Indian Standard methods of test for soils, Bureau of Indian Standards, New Delhi, pp. 1-9.

IS: 2720 Part 10, 1991. Determination of Unconfined compressive strength. Indian Standard methods of test for soils, Bureau of Indian Standards, New Delhi, pp. 1-4.

Lav, A.H., Lav, M.A., 2000. Microstructural development of stabilized fly ash pavement base material, Journal of Materials in Civil Engineering, vol. 12, no. 2, pp. 157-163.

Mackos, R., Butalia, T., Wolfe W., Walker, H. W., 2009. Use of lime-activated class F fly ash in the full depth reclamation of asphalt pavements: environmental aspects. Proceedings of World of Coal Ash Conference ’09, Lexington, Kentucky, USA, paper no. 121.

Rajasekaran, G., 2005. Sulphate attack and ettringite formation in the lime and cement stabilized marine clays. Journal of Ocean Engineering, vol. 32, no. 8-9, pp. 1133-1159.

Sivapullaiah, P.V., Prashanth, J.P., Sridharan, A., 1995, Optimization of lime content for fly ash, Journal of Testing and Evaluation, vol. 23, no. 3, pp. 222-227.

Tannant, D.D., Kumar, V., 2000. Properties of fly ash stabilized haul road construction Materials. Journal of Surface Mining, Reclamation and Environment, vol.14, no. 2, pp. 121-135.

Ulusay, R., Arlkan, F., Yoleri, M.F., Caglan, D., 1995. Engineering geological characterization of coal mine waste material and an evaluation in the context of back-analysis of spoil pile instabilities in a strip mine, SW Turkey. Journal of Engineering Geology, vol. 40, no. 1-2, pp. 77-101.