Replacement of conventional material with FCMs in sub-base of opencast mine haul road to reduce strain-An investigation

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Abstract

Fly ash is a major by-product of thermal power plants. Fly ash occupies huge land areas and causes environmental pollution. So its gainful utilization is important. This paper presents detailed laboratory investigation carried out on clinker stabilized fly ash–mine overburden mixes to find out its suitability in sub-base of opencast mine haul road pavements. Proctor compaction test and unconfined compressive strength (UCS) tests were conducted on the developed composites. Clinker content in the mixture varied between 2% and 8%. Test results showed that an increase in mine overburden content in the mixture resulted in increase of maximum dry density (MDD) of the compacted mixture. An increase in percentage of clinker in the fly ash–mine overburden mixes increased enormously the Young's Modulus values.

Introduction:

Coal is a major available fossil fuel for power generation. Therefore coal based power generation will remain as the major source of electrical energy in India. The generation of coal ash in India is increasing rapidly due to increasing installation of coal based thermal power plants. In India, out of total installed power generation capacity of about 1, 63,000 MW, 86,500 MW (53%) is coal based which generates more than 160MT of fly ash per annum. Although continuous effects are being made to use coal ash, still around 50% of generated coal ash is disposed of without utilization.

A surface coal mine has about 2-5 km of permanent haul road and various other lumpy roads that are constructed from locally available material found near to mine area. Some of these materials are asphaltic concrete, mud stone, sand stone, crushed gravel etc. Asphaltic concrete is very costly. Further it becomes slicky in excessive rain. Its effectiveness is also sensitive to temperature, compaction procedure, etc. Sand, gravel, clay etc. are used only as filling material. The stability achieved with those materials is seldom adequate.

Heavy large capacity dumpers are used to haul coal from the mine to the power plants. Gross vehicular weight of these heavy large capacity dumpers is about 4000KN. The tire pressure used to support the weight of these trucks is 700KPa for 300T dumper capacity (Tannant and Kumar, 2000). Pot holes, rutting and settlement are major symptoms observed at all most all mines (Tannant and Regensburg, 2001). So it is necessary to construct haul roads with appropriate materials that would be able to take the load. Fly ash has the potential to address the issue.

Fly ash possesses attributes that are suitable for road construction.

Bulk utilization of fly ash alone or fly ash stabilized with soil and additive has been reported by many researchers (Cetin et al., 2010; Ghosh and Subbarao, 2006; Pandian and Krishna, 2002; Tannant and Kumar, 2000). Class F fly ash consists of siliceous and aluminous materials (pozzolans) that lack cementitious value by themselves, but chemically react with calcium oxide in presence of moisture to form cementitious compounds.

Butalia (2007) reported that fly ash acted as filler to fill voids in the granular pulverized pavement mix, reducing permeability of full depth reclamation stabilized base layer. Prabakar et al. (2004) studied on fly ash plus soil mixes and concluded that the addition of fly ash reduced the dry density of the soil due to low specific gravity and unit weight. The class-F fly ash stabilized with 10% lime & 1% gypsum achieved a compressive strength of 6.3 MPa after 90 days curing (Ghosh and Subbarao, 2006). The paper reports a few laboratory test results to evaluate the potential of fly ash with additive in replacing a part of the conventional material in haul road construction.

Materials & Methods:

The class F type fly ash was collected in dry state by electrostatic precipitator from a local thermal power unit. The overburden used for the investigation was collected from a nearly surface coal mine. Clinker as an additive was selected for the study to provide required amount of calcium oxide. The tests to determine Atterberg limits, Specific Gravity, Particle Size Distribution, pH, Compaction Characteristics, Unconfined Compressive Strength etc. were as per the prescribed Indian Standards. The samples were prepared at their respective optimum moisture content & maximum dry density obtained from the modified proctor compaction test. The following proportions of overburden-fly ash-clinker mixes were considered (Table 1).

Table 1: Various proportions of fly ash- overburden-clinker mixes

Fly ash (%)	Mine Overburden (%)	Clinker (%)
70	30	0
68	30	2
66	30	4
64	30	6
62	30	8
60	40	0
58	40	2
56	40	4
54	40	6
52	40	8

Result& Discussion:

The physical properties of fly ash & mine overburden are shown in table 2. The specific gravity of fly ash is found to be less than that of mine overburden due to presence of cenospheres creating more voids within the material.

Table 2: Physical Properties of Fly ash and Overburden material

Property	Fly ash	O/B
Specific Gravity	2.10	2.63
Atterberg Limits		
Liquid Limit (%)	31.57	26.90
Plastic Limit (%)	NP	17.10
Shrinkage Limit (%)	…	16.02
Plasticity Index (%)	…	9.80
Sieve Analysis (%)		
Gravel (>4.75mm)	…	8
Sand (4.75mm-0.075mm)	18	27
Silt (0.075mm-0.002mm)	79.8	57
Clay (<0.002mm)	2.2	8
pH Value	7.10	5.5
Modified Procter Test Results		
OMC (%)	22.3	14.3
MDD (Kg/m^3)	1296	1941
CBR (**Un soaked Condition**)	18.0	26.0
CBR (**Soaked Condition**)	0.7	2.53

***NP-Non-Plastic**

The chemical composition of mine overburden and fly ash are shown in table 3. The chemical composition of fly ash and mine overburden indicate that it has less CaO content.

Table 3: Chemical Composition of Overburden & Fly ash

Constituents	Overburden (%)	Fly ash (%)
SiO_2	48.24	53.11
Al_2O_3	29.18	33.64
Fe_2O_3	8.36	6.44
CaO	1.10	0.55
MgO	1.30	0.83
K_2O	0.40	1.45
TiO_2	0.69	2.05
Na_2O	…	0.13
LOI	10.73	1.8

Compaction Characteristics:

Compaction is the process of increasing the density of soil by application of mechanical energy such as tamping, rolling and vibration. It is achieved by forcing the particles closer with a reduction in air voids. The maximum dry density of fly ash is lower than that of mine overburden as fly ash is non-cohesive in nature. Compaction characteristics showed that maximum dry density of fly ash-overburden mixes decreased with increase in fly ash content. The optimum moisture content was found to be more than 15% for all the composites (Figure 1).

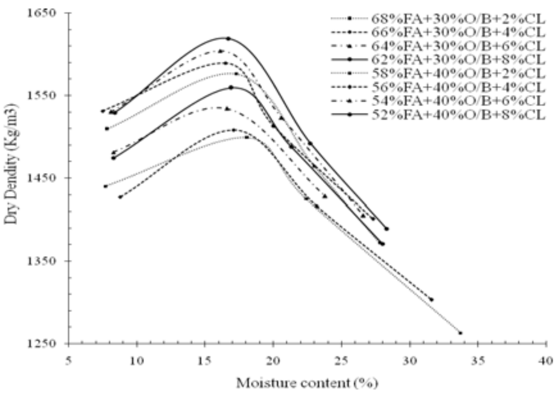

Figure 1: Compaction Characteristics of fly ash-overburden composites with Clinker as additive

Modulus Value:

Young's Modulus values were obtained from the unconfined compressive strength test. Unconfined compressive strength values of developed composite varied between 0.25MPa and 1.4MPa. The recommended value for hard sub-grade of road pavement is more than 380KPa (Das, 2006). The increment was relatively gradual when clinker percentage was increased from 2% to 6%, but increment was steep from 6% to 8%. Maximum Young's modulus value was achieved by 62%FA+30%OB+8%CL i.e. 200MPa (Figure 2).

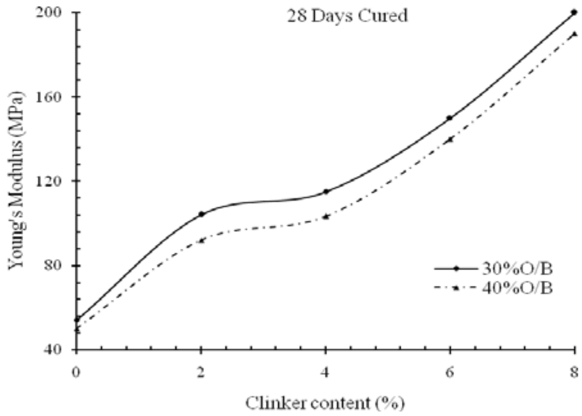

Figure 2: Young's Modulus of fly ash-overburden composite Cured for 7 Days

Numerical Modelling

Numerical simulation by Finite Element Method (FEM) was carried out to simulate the stress-strain behaviour of haul road pavement under axle loading condition. The code ANSYS (Version 10) was used for the study (Figure3(a)). The numerical modelling was done in 2D axi-symmetric conditions (Ottosen, 1984; Yamatomi and Kotake, 1986). The simulation was carried out using both conventional material as well as developed fly ash based composite material. The Poisson's ratio assumed for analysis is 0.4 (Tannant and Regensburg, 2001; Lav et al., 2006).

The maximum stress and strain obtained just below the wheel load were 651KPa and 6532 micro-strains with conventional material (Figure 3(b) and 3(c)). When the sub-base was replaced with the developed composite consisting of 62%FA and 30%O/B with 8% clinker, those values reduced to 573KPa and 4120 micro-strain respectively. Those values are still higher for better haul road economics. Different scenarios were considered with varying stiffness of surface and base courses, but with fixed sub-grade. The values represent stiff base and surface courses that are typically recommended for haul road construction. When the fly ash based composite materials were used in sub-base for those cases, the stress and strain values reduced drastically (Figure 3(d), 3(e), 3(f) and 3(g)). The reduced values were less than critical strain values of 1500-2000 micro-strains. The respective strain values varied depending on curing period as well as clinker content in the composites.

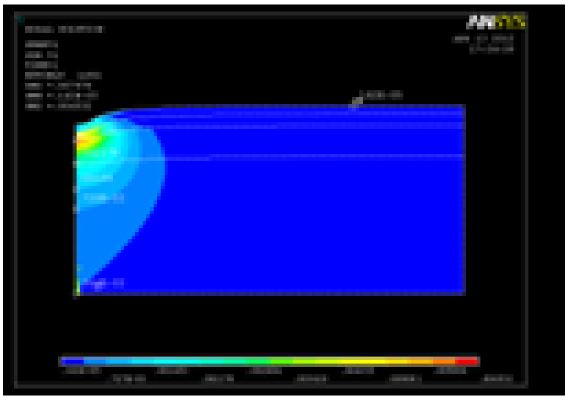

Figure 3(a): A typical simulation model

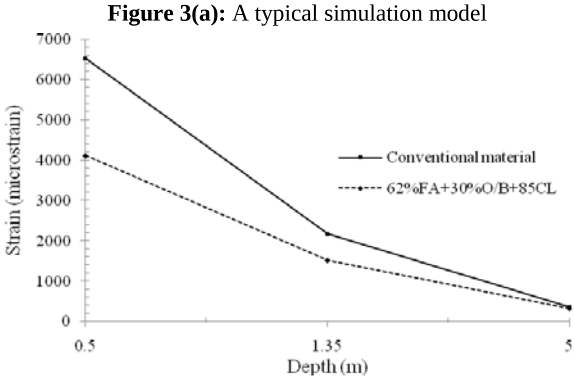

Figure 3(b): Strain behaviour of Conventional Material and Developed FCM

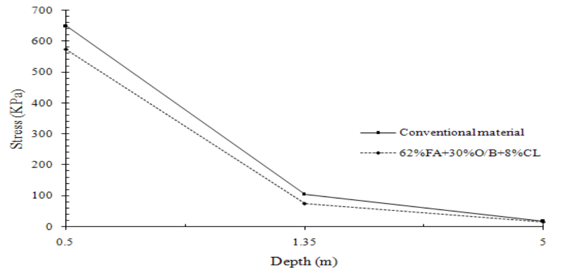

Figure 3(c): Stress behaviour of Conventional Material and Developed FCM

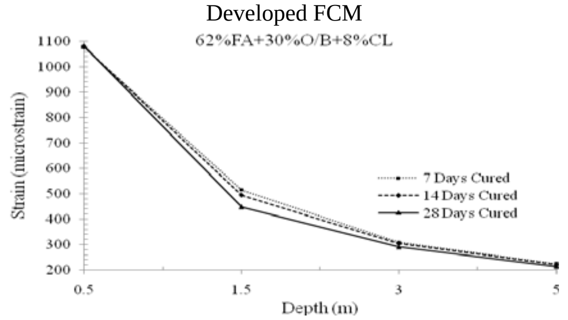

Figure 3(d): Strain behaviour of Developed FCM

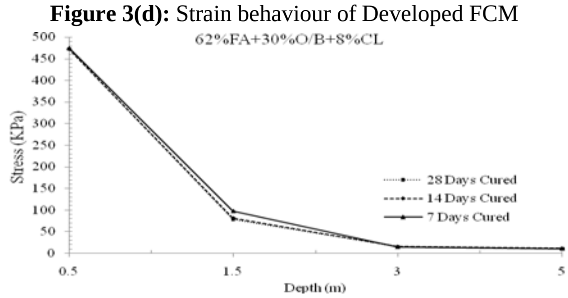

Figure 3(e): Stress behaviour of Developed FCM

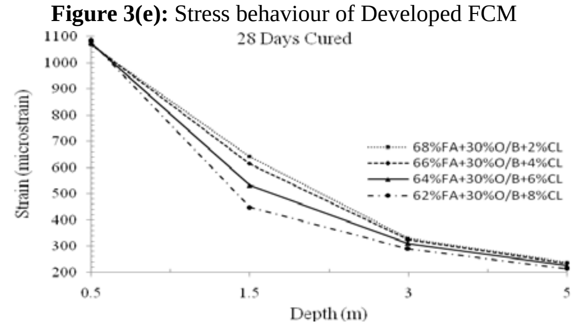

Figure 3(f): Strain behaviour of Developed FCMs

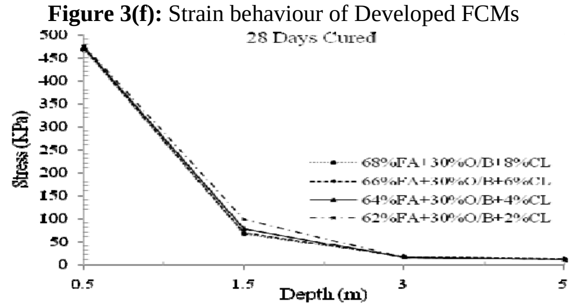

Figure 3(g): Stress behaviour of Developed FCMs

Conclusion:

The investigation analyzed the effect of replacing conventional material with FCMs for strain reduction. The strength enhancement was achieved with addition of clinker. Unlike hydrated lime or quick lime which is costly, clinker is relatively cheaper. The result showed that about 65-70% of conventional material can be replaced with corresponding amount of fly ash without compromising the strength values.

References:

- Thompson R.J. and Visser A.T., Mine haul road maintenance management systems, Journal of The South African Institute of Mining and Metallurgy, ISSN 0038-223X/3.00 + 0.00 (2003): pp. 303-312.
- Tannant D.D. and Kumar V., Properties of fly ash stabilized haul road construction Materials, Int. Journal of Surface. Mining, Reclamation Environ., 14 (2000): pp. 121-135.
- Tannant D.D. and Regensburg B., Guidelines for Mine Haul Road Design, University of Alberta, Canada, 2001.
- Sahu B.K., Use of fly ash for stabilizing sub-standard road construction materials in Botswana, in: Proc. of Fly ash India 2005, Fly ash Utilisation Programme, TIFAC, DST, New Delhi, 2005, pp. VIII 10.1-10.9.
- Lav A.H., Lav M.A. and Goktpe A.B., Analysis and design of a stabilized fly ash as pavement base material, Journal of Fuel, 85 (2006): pp. 2359-2370.
- Butalia S.T., Rehabilitating asphalt highways: coal fly ash used on Ohio full depth reclamation projects, Case Study–18, Coal Combustion Product Partnership, Environmental Protection Agency, USA, 2007, pp. 1-4.
- Cetin B., Aydilek A.H. and Guney Y., Stabilization of recycled base materials with high carbon fly ash, Journal of Resources, Conser. Recycl. 54 (2010): pp. 878-892.
- Ghosh A. and Subbarao C., Tensile Strength Bearing Ratio and Slake Durability of Class F Fly Ash Stabilized with Lime and Gypsum, Journal of Materials in Civil Engineering, ASCE,18(2006):pp.18-27.
- Prabakar J., Dendorkar N., and Morchhale R.K., Influence of fly ash on strength behaviour of typical soils, Const. Building Mater. 18 (2004), pp. 263–267.
- Das B.M. (2006) Fundamentals of Geotechnical Engineering, Thomson Publication, 2nd Edition.

- N.S. Ottosen, 1984, Evaluation of concrete cylinder tests using finite element, Journal of Engineering Mechanics, ASCE, vol. 110, No. 3, pp 465-481.
- J. Yamatani and Y. Kotake, 1986, pillar control and effects of backfilling support at Osaka mines, Int. J. Rock Mech. Sc. Geo. Mech., Abstract, Vol. 23, No. 2, pp 44-53.