Performance Evaluation of fly ash Composite Material in Mine Haul Road

Soumya Ranjan Mallick*, Manoj K. Mishra*, Kalpataru T Parida#
*Department of Mining Engineering, National Institute of Technology, Rourkela, India
Department of Mining Engineering, OSME, Keonjhar, India

Heavy large capacity haul trucks are being increasingly used in opencast coal mines to meet the power demand now-a-days. These trucks require well-designed haul roads. For excavation of coal, opencast mines displace large amount of overburden material as waste. The current fly ash production is about 180 MT that will rise to about 225 MT by 2017 in India. This paper reports the detailed laboratory investigations carried out on development of fly ash composite materials with mine overburden, clinker and evaluation of their suitability for haul road. Proctor compaction tests, Unconfined Compressive Strength (UCS) tests, California Bearing Ratio (CBR) tests and P wave velocity tests were carried out at different curing periods. The stress-strain behavior of haul road with developed FCMs was evaluated. The composite with 62% fly ash, 30% overburden and 8% clinker exhibited adequate strength value for the haul road application.

Keywords: OMC-MDD, UCS, CBR, Fly ash, Mine Overburden material, Clinker

1.0 Introduction

Coal based power generation will remain as the major source of electrical energy in India. At present, out of installed capacity of 1, 63,000 MW, about 53% (86,500 MW) is coal based that generates more than 180 MT of coal ash per annum. The gainful utilization percentage of coal ash is 45-50%, rest being dumped near the plants and creates adverse situations.

There are around 170 opencast coal mines in India, majority nearer to thermal power plants. A typical surface coal mine has about 4-5 Km of permanent haul road in addition to 10-12 Km of branch roads. The hauling truck at times achieve gross vehicular weight of 4000 KN whose tire pressure are typically in the range of 600-700 KPa [2]. Critical strain limit varies between 1500-2000 micro-strains [4]. So the haul roads should have sufficient bearing capacity and stiffness. Haul roads with inadequate material adversely affects mine economics. Typically haulage cost is around 50% of total cost incurred by a surface coal mine [4]. The typical haul road construction materials are sourced from overburden dump. Those materials are mud stone, sand stone, crushed gravel etc. Sand, gravel, clay etc. are used only as filling material. These materials don’t offer any ground stability. Pot holes, sinking, rutting and settlement are major symptoms observed in all most all mines [3]. The grain sizes vary from fine to coarse particles with variable dimensions. It often creates instability and environmental problems. Overburden material is heterogeneous with equal percentage of fine and coarse grains [1].

Fly ash being very fine and reactive is more suitable for road construction compared to other materials. Bulk utilization of fly ash alone or fly ash stabilized with soil and additive has been reported by many researchers [6, 8, 9, 11 and 15]. The successful use of fly ash to stabilize soils suggests that their use in haul roads would have multiple benefits [2, 15]. 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 [12]. Its low specific gravity, ease of compaction, good frictional properties, freely draining nature and insensitiveness towards change in moisture content can be usefully utilized for construction of roads and embankments [5]. There are many reports on utilization of fly ash either alone or mixed with lime, gypsum or both. Fly ash has been extensively used for soil stabilization [18], as embankment material [22], structural fill [19], for injecting grouting [21], as a replacement to cement [20, 23], in roads and embankments [17] etc. The addition of fly ash reduced the dry density of the soil due to low specific gravity and unit weight [9]. Class F fly ash achieved compressive strength of 6.3MPa at 90 days curing and CBR of 172% at 28 days curing when mixed with 10% lime and 1% gypsum [6]. Lime Kin Dust (LKD) has been used successfully to achieve CBR 69-142 in one case [7]. This paper report the investigation conducted to develop alternate sub-base material with mine overburden, fly ash and clinker and determine the compressive strength and CBR values. Correlations between parameters have also been developed.

2.0 Materials and Methods

Class F type fly ash was collected in dry state by electrostatic precipitator from a thermal power unit of Rourkela Steel Plant. The overburden used for the investigation was collected from Basundhara opencast coal mine, MCL, Orissa. The additive selected for the study was clinker. The tests carried out to determine Atterberg limits, specific gravity, particle size distribution, pH, compaction characteristics, California Bearing Ratio, Unconfined Compressive Strength and ultrasonic pulse velocity etc. were as per the prescribed Indian standards. The specific gravity of mine overburden and fly ash were determined using volumetric flask method as per IS: 2720 part-III. Free swell index was determined as per IS: 2720 part-40. Grain size distributions were carried out through a standard set of sieves as per IS: 2720 part-IV. The Atterberg limits of mine overburden and fly ash were determined as per IS: 2720 part-V and part-VI. Liquid limit was determined using standard liquid limit apparatus designed by Casagrande.

The pH value was determined as per IS: 2720 part-26 to identify acidic or alkaline behaviour of mine overburden and fly ash. The measurement of pH was carried out (make: Systronics scale pH meter, India); with accuracy up to ± 0.02 units. Chemical compositions of mine overburden, fly ash and clinker were determined from EDX (Energy Dispersive X-ray) technique. The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of different compositions of (Fly ash-Overburden-Cement Clinker) were determined by modified proctor test as per IS: 2720 part-VIII. The prepared samples were compacted in five layers in the proctor mould.

2.1. Sample Preparation

The fly ash-overburden-clinker composite materials were prepared at their respective optimum moisture content and maximum dry density obtained from the modified proctor compaction test for determination of Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) and P-wave velocity. The raw materials as fly ash, mine overburden and clinker were blended together in required proportions in dry state. Then the required amount of water was added to respective mixtures and mixed thoroughly. Then the wet mixtures were compacted in the mould as per guidelines. The fly ash amount was kept more than 50% (Table 1).

Table 1: Various proportions of fly ash, mine overburden and clinker

Fly ash (%)	Overburden (%)	Clinker (%)	Fly ash (%)	Overburden (%)	Clinker (%)
90	10	0	70	30	0
88	10	2	68	30	2
86	10	4	66	30	4
84	10	6	64	30	6
82	10	8	62	30	8
80	20	0	60	40	0
78	20	2	58	40	2
76	20	4	56	40	4
74	20	6	54	40	6
72	20	8	52	40	8

2.2. Unconfined Compressive Strength Test

UCS tests were carried out as per IS: 2720 part-X. The specimens were 38mm in diameter and 76mm in height. Specimens were cured in a humidity chamber (relative humidity > 95%) at 30 $\pm$ 2^{0}C. The UCS of cured samples were determined in a strain controlled unconfined compression testing machine at a strain rate of 1.2mm/min.

2.3. California Bearing Ratio Test

CBR tests were carried out as per IS: 2720 part-XVI. The standard values are 13.44 KN at 2.5 mm and 20.16 KN at 5.0 mm penetration. The samples were soaked for 4 days in water and were allowed to drain for 15 minutes before test. Curing periods adopted were immediate, 7 days (3days moist curing + 4 days soaking) and 28 days (24 days moist curing +4 days soaking). Two surcharge discs, each of weight 2.5 kg were placed over the sample. A plunger of 50 mm diameter was used to penetrate into the sample at a rate of 1.25mm/min during the test.

2.4. Ultrasonic Pulse Velocity Test

Ultrasonic P- wave velocity test was carried out as per IS: 10782 (1983). All pulse velocity measurements were determined using an Ultrasonic Velocity Measurement System (make: GCTS, USA; Figure 1). This system includes 10 MHz bandwidth receiver pulse raise time less than 5 nano seconds, 20 MHz acquisition rate with 12bit resolution digitizing board, transducer platens with 200 KHz compression mode and 200 KHz shears mode. The test was carried out by applying two sensors to opposite surfaces of the specimen. Sufficient surface contact between the sensors and the specimen was maintained by a couplant as honey.

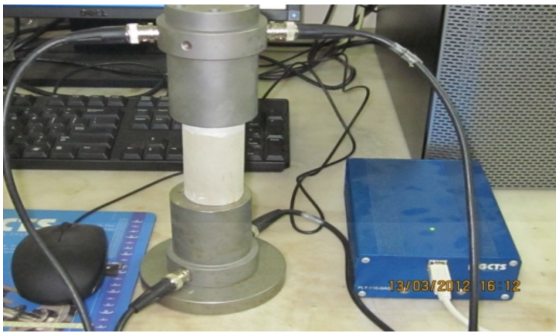


Figure 1: Ultrasonic Pulse Velocity Test

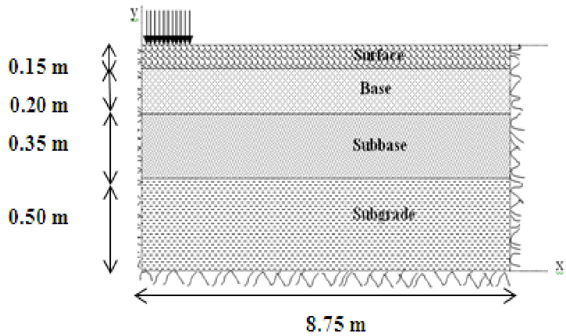


Figure 2: A schematic layout of existing haul road pavement

2.5 Numerical Modelling

Numerical simulation by Finite Element Method (FEM) using ANSYS (Version 10) was carried out to simulate the stress-strain behaviour of haul road pavement under axle loading condition (Figure 2). The numerical modelling was done in 2D axi-symmetric conditions [25]. 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 [3].

3.0 Results and Discussion

3.1. Physical and Chemical Properties

The physical characteristics and chemical composition of the materials used in the investigation are discussed here. Coal ashes are predominantly silt sized with some sand sized fractions. It is observed that fly ash contains more than 50% coarse grained silts (0.020mm< particle size< 0.075mm) and hence belongs to non-plastic inorganic coarse sized fractions i.e. MLN group. Mine overburden contains mixture of poorly graded sand and silt and hence belongs to SM group [10]. Coefficient of uniformity (C_U) for fly ash and mine overburden are found to be 4.47 and 4.25 respectively. Coefficient of curvature (C_C) for fly ash and mine overburden are found to be 1.82 and 0.94 respectively (Figure 3). It represents that both fly ash and mine overburden are poorly graded [5]. The specific gravity of fly ash is less than that of mine overburden as it contains large number of cenospheres and less iron content [10]. Free swell index of mine overburden is found to be 18.1. As clay size fraction in fly ash is very less, its free swell index is negligible (Table 2).

Table 2: Physical properties of fly ash and mine overburden

Property		Fly ash	O/B
Specific Gravity		2.10	2.63
Atterberg Limits			
	Liquid Limit (%)	31.57	26.90
	Plastic Limit (%)	Non-plastic	17.10
	Shrinkage Limit (%)	…	16.02
	Plasticity Index (%)	…	9.80
Sieve Analysis (%)			
	Gravel (>4.75mm)	…	8
	Sand (4.75mm-0.075mm)	18	27
	(a) Coarse Sand	0	13
	(b) Medium Sand	0	6
	(c) Fine Sand	18	8
	Silt (0.075mm-0.002mm)	79.8	57
	(a) Coarse Silt	52	46
	(b) Medium Silt	16	10
	(c) Fine Silt	11.8	1
	Clay (<0.002mm)	2.2	8
	Coefficient of Uniformity ($C_U=D_{60}/D_{10}$)	4.47	4.25
	Coefficient of Curvature ($C_C=(D_{30})^2/D_{10} \times D_{60}$)	1.82	0.94
pH Value		7.10	5.5
Free Swell Index		Negligible	18.18

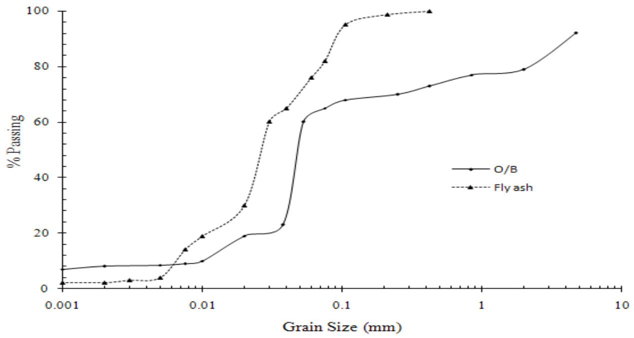


Figure 3: Grain size distribution curve of fly ash and mine overburden

The pH values indicate that fly ash is slightly alkaline and mine overburden is acidic in nature due to presence of free lime content and alkaline oxide content. The carbon content of the overburden material and fly ash is 9.65 and 1.6 respectively. High carbon content adversely affects material properties. The fly ash used has more than 93% of acidic constituents (SiO_2 + Al_2O_3+Fe_2O_3) where that for mine overburden is 85%. EDX analysis confirms that fly ash satisfy the chemical requirements for use as a pozzolona. Both mine overburden and fly ash contains vey less percentage of CaO. But the clinker contains around 67% of CaO (Table 3).

Table 3: Chemical composition (% by weight) of mine overburden (O/B), fly ash and clinker

Constituents	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	TiO_2	Na_2O	SO_3	LOI
Mine O/B	48.24	29.18	8.36	1.10	0.40	1.30	0.69	---	---	10.73
Fly Ash	53.11	33.64	6.44	0.55	1.45	0.83	2.05	0.13	---	1.8
Clinker	20.46	4.52	3.57	66.38	0.68	2.01	---	0.16	1.39	0.75

3.2. Compaction Characteristics

Modified proctor compaction has been carried out to consider higher standard of compaction. Maximum dry density (MDD) of the composites decreased with increase in fly ash percentage. The optimum moisture content (OMC) of all the composites were between 14% and 20%. The highest OMC found was 22.3% for fly ash only. The highest MDD obtained was 1941 kg/m^3 for mine overburden only whereas lowest MDD was 1296 kg/m^3 for fly ash only due to its non-cohesive nature (Figure 4).

Tests with additive showed an increasing trend in MDD and decreasing trend in OMC as compared to that in samples without additive (Figure 5, 6 and 7). As specific gravity of clinker is higher than that of fly ash and mine overburden, replacement of certain percentage of fly ash or mine overburden by clinker resulted in increased MDD.

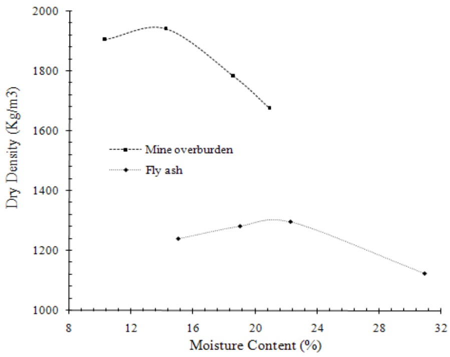


Figure 4: MDD-OMC relationship of fly ash and mine overburden

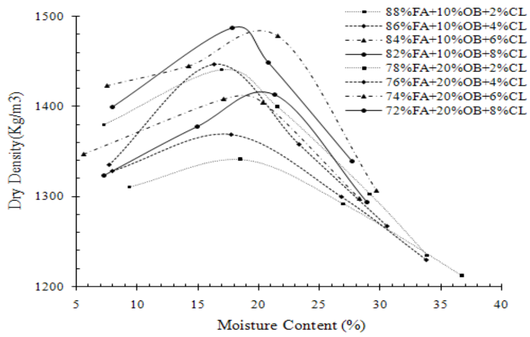


Figure 6: MDD-OMC relationship of the composites with 10% and 20% mine overburden

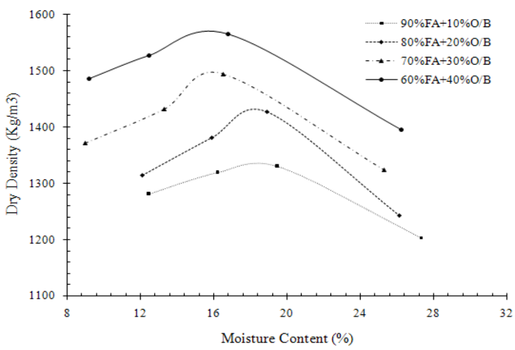


Figure 5: MDD-OMC relationship of composite without additive

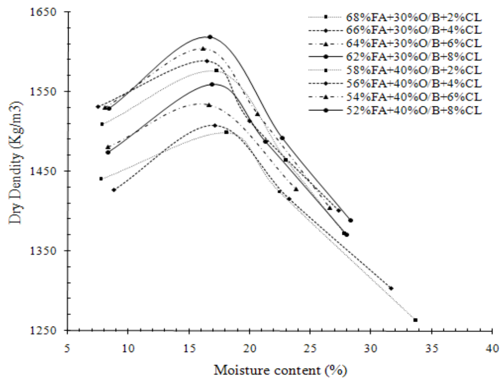
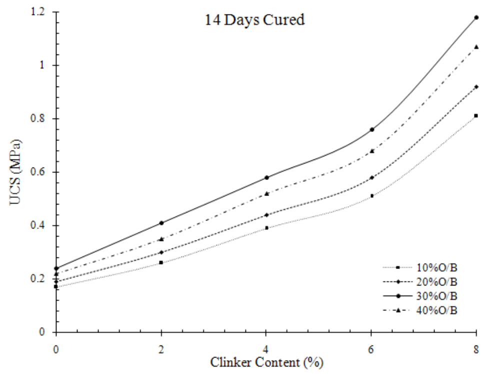


Figure 7: MDD-OMC relationship of composites with 30% and 40% mine overburden and 2 to 8 %additive

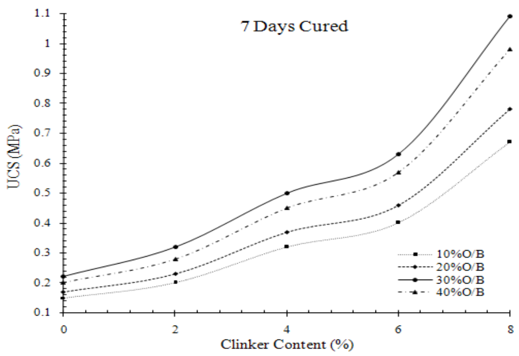
3.3. Unconfined Compressive Strength

The Unconfined compressive strength values of raw mine overburden and fly ash were 342 KPa and 132 KPa respectively. The untreated fly ash samples offering least resistance to external loading. The untreated fly ash-mine overburden mixes also did not show any appreciable strength values. The values were less than 300 KPa even after curing which classify the material unsuitable for sub-grade[13]. So it was essential to add additive to enhance strength values. Addition of clinker improved the UCS values. The UCS values of composites varied between 0.2 to 1.1 MPa for 2% to 8% clinker content at 7 days curing period. Similar values at 14 and 28 days curing periods were 0.23MPa to 1.4MPa. The corresponding elastic modulus and poisson's ratio values of the best composite was 186 MPa and 0.2 respectively. The values increased as the overburden content increased from 10% to 30% and then decreased at 40%. Maximum strength values were obtained for the composite with 62%FA and 8% clinker content at each curing period (Figures 9(a), 9(b) and 9(c)). The composites with 58%, 78% and 88% fly ash did not exhibit enough strength values at 2% clinker content at 7 and 14 days curing for sub-base application. All the samples in unconfined compressive loading conditions exhibited shear type failure (Figure 8).

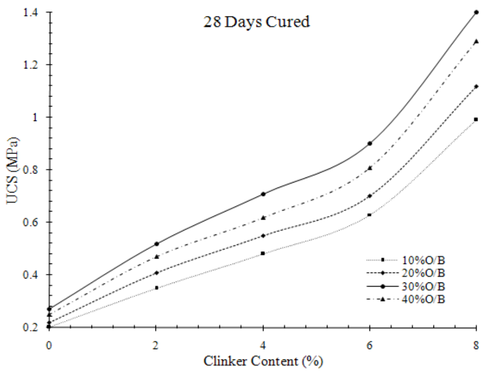
Figure 8: Failure of a few UCS samples



9(b)



9(a)



9(c)

Figure 9(a), 9(b) and 9(c): UCS values of fly ash-mine overburden-clinker mixes

3.4. California Bearing Ratio Behaviour

CBR value of a material is typically considered for any road construction application. In un-soaked condition CBR values of composites without additive varied between 18% and 26%. Mine overburden material showed high CBR value due to irregular grain sizes that offered more resistance to penetration as compared to that of fly ash which possess uniform sizes. As fly ash content increased in the composite CBR values decreased (Figure 10). The CBR values in soaked condition were less than 3% due to destruction of capillary forces as well as reduced frictional resistance.

However with addition of clinker there was appreciable increase in the CBR values. The CBR values immediately after soaking were between 9% and 80% (Figure 11(a)). Material with CBR value more than 50 is considered excellent for sub-grade of road pavement [14]. CBR values of composites increased with increase in overburden content that optimized for 62% fly ash and 8% clinker. The CBR values increased with curing period with more than 40% at 2% clinker content and higher as clinker content increased (Figures 11(b) and 11(c)). The CBR value obtained for the sample with 62% fly ash and 8% clinker was 141% at 28 days curing. There exist optimum quantities of CaO, Al_2O_3 and SiO_2 to react among themselves and exhibit maximum strength value. More availability of those does not add to strength gain [23].

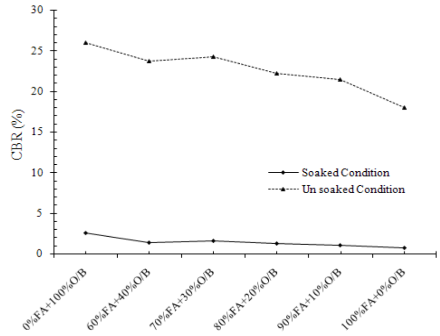
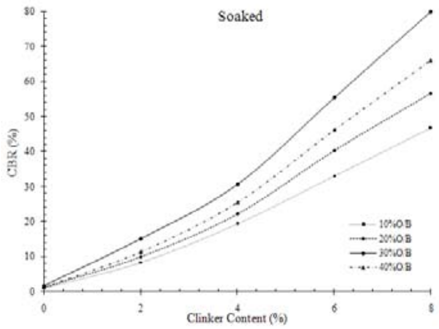
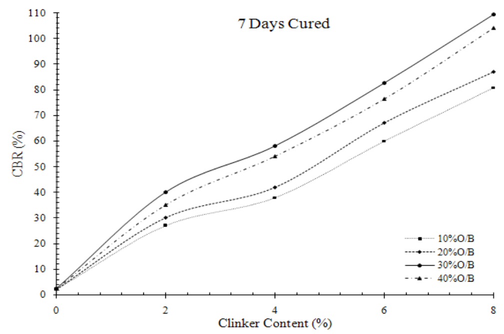


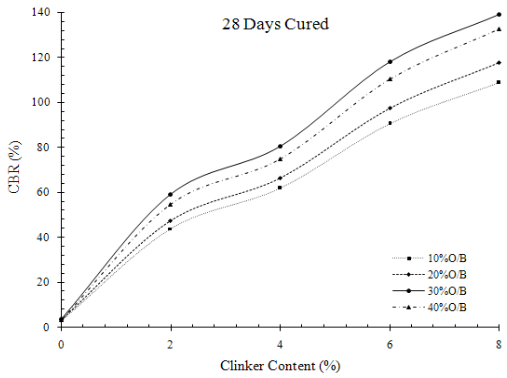
Figure 10: CBR values of composites in soaked and un-soaked condition



11(a)



11(b)

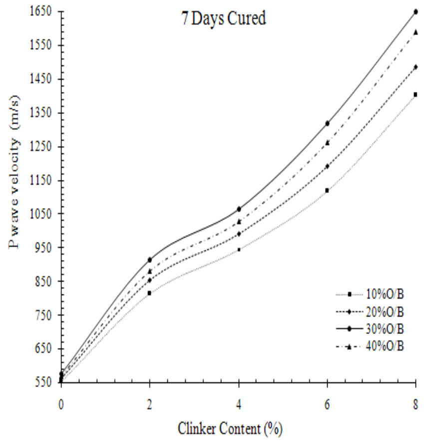


11(c)

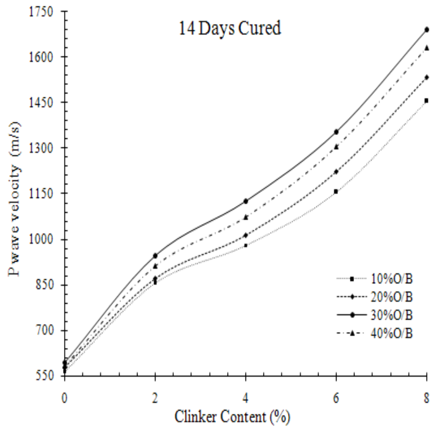
Figure 11(a), 11(b) and 11(c): CBR values of fly ash-mine overburden-clinker mixes

3.5. Ultrasonic Pulse Velocity

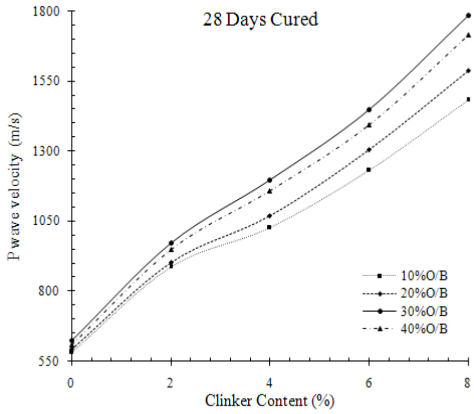
Ultrasonic pulse velocity test was carried out to evaluate the effect of clinker content as well as curing period on the developed composites. The developed clinker treated composite materials were tested at 7, 14 and 28 days curing period. The results of untreated composites are not reported here due to their marginal values. P wave velocities varied between 750 m/s to 1450 m/s maximum being with 62% fly ash and 8% clinker content at 7 days curing (Figure 12(a)). The trend is same at 14 and 28 days curing periods with an increase in p wave velocities (Figures 12(b) and 12(c)). P wave velocities increased with clinker content as well as curing periods. The results compare favourably with that observed elsewhere for material with fly ash and cement binder. At initial stages of curing the composites had high moisture content before hydration started that caused instability in the specimen and allowed pulse velocity to pass through shortest possible path. As hydration progresses with higher clinker content, the p wave velocity took longer time to pass through that with higher strength and CBR values.



12(a)



12(b)



12(c)

Figure 12(a), 12(b) and 12(c): P wave velocity values of fly ash-mine overburden-clinker mixes

3.6. Numerical Simulation

The stress-strain behaviour of the haul road pavement was evaluated through numerical simulation. The elastic properties, thickness of each layer, type of material used for simulation are given in table 4. The developed composite material i.e. 62%FA+30%O/B+8%CL exhibiting maximum strength value was considered for the purpose to replace the conventional sub-base material.

Analysis was carried out considering the existing dimension with 520 KPa, 555 KPa and 700 KPa load that represent the effect of 80 T, 200 T and 300 T dumper capacities respectively. It is observed that as the load or dumper capacity increased the maximum strain and stress of haul road pavement increased. The maximum strain value 5636 micro-strain for 80T dumper capacity was much higher compared to critical strain limit. When sub-base material was replaced with best obtained FCM the strain value reduced by 40% i.e. to 3360 micro-strain. Maximum stress reduced by 7% for 80 T dumper capacities.

Similar values were obtained for 200 T and 300 T dumper capacities. But the rises in maximum stress and strain values with existing dimension were steeper when dumper capacity increased to 300 T i.e. 637 KPa and 7587 micro-strain respectively (Figure 13). Maximum stress and strain values were 590 KPa and 4524 micro-strain respectively for 300 T dumper capacity using FCM in sub-base. The stress and strain values for both cases i.e. with conventional material as well as with replaced fly ash composite in sub-base were above critical strain limit. It increases the probability of failure in haul road pavement. Hence further analyses were carried out by changing thickness of layers as well as material properties.

Table 4: Young’s modulus, E (MPa) and Thickness, t (m) of the pavement layers for different cases

Case ID	Construction Materials	Layer							
		Surface		Base		Sub-base		Sub-grade	
		E	t	E	t	E	t	E	t
A	Conventional Material	180	0.15	90	0.2	60	0.35	50	0.5
B	Only Sub-base replaced with FCM	180	0.15	90	0.2	186	0.35	50	0.5
C	Surface course and Base course changed	500	0.15	350	0.2	186	0.35	50	0.5
D	Thickness increased	500	0.15	350	0.2	186	0.5	50	1.0
E		500	0.15	350	0.2	186	1.0	50	2.0
F		500	0.3	350	0.4	186	1.0	50	2.0
G		500	0.5	350	1	186	1	50	2.0
H	Optimum Thickness	500	0.5	350	1	186	1.5	50	2.0

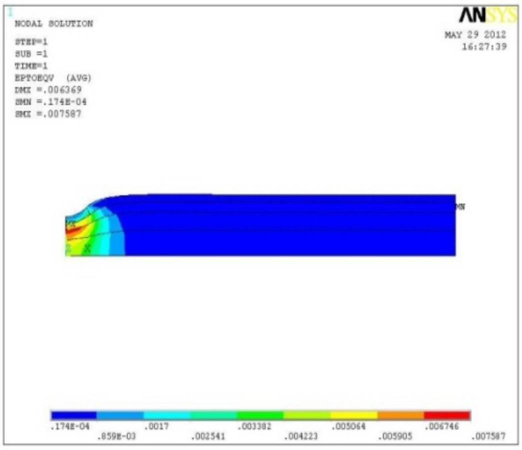


Figure 13: Maximum strain of haul road pavement with conventional material for 300 T Dumper

Material properties have direct effect on stiffness of pavement. Analyses were carried out considering construction material with high elastic values in surface course and base course for 80 T, 200 T and 300 T dumper capacities. The obtained stress and strain values are above the critical limit of 1500 to 2000 micro-strain. Hence change in the thickness of pavement layers was also considered and simulation carried out. The thickness of the total haul road pavement changed. Maximum thickness of pavement considered was 5.0 m [2]. It was observed that as total pavement thickness increased maximum stress and strain values decreased. The maximum strain obtained were more than critical strain limit up to 3.35 m thicknesses for each case i.e. for 80 T, 200 T and 300 T dumper capacities. However as the thickness of pavement increase from 3.35m to higher value, maximum strain values were less than the critical strain limit for 80 T and 200 T dumper capacities. For 300 T dumper the value was slightly higher i.e. 1570 micro-strain. The strain values were less than the critical strain limit for all considered cases beyond the pavement thickness of 4.5 m. At a thickness of 5.0 m dumper with 300 T capacity produced maximum stress and strain values of 462.1 KPa and 1094 micro-strain respectively. The detail stress and strain values obtained for different dimensions are given in table 5.

Table 5: Maximum strain and stress values for different pavement thickness and dumper capacity

Pavement Thickness (m)		Dumper Capacity					
		80T		200T		300T	
		Maximum Stress (KPa)	Maximum Strain(micro-strain)	Maximum Stress (KPa)	Maximum Strain(micro-strain)	Maximum Stress (KPa)	Maximum Strain(micro-strain)
1.2	Conventional Material	473.7	5636	505.5	6015	637.6	7587
	Only Sub-base replaced with FCM	438.6	3360	468.1	3587	590.4	4524
	Upper Layers replaced	484	2685	516.6	2866	651.5	3614
1.85		414.6	1996	442.5	2130	558.2	2687
3.35		377.8	1937	403.2	2067	508.6	2607
3.7		373.5	1174	398.6	1253	502.8	1580
4.5		339.2	822	362	877	456.6	1107
5.0		343.3	812	366.4	867	462.1	1094

4.0 Conclusions

The investigation evaluated the geotechnical characteristics of twenty different composite materials with fly ash as major percentages as a replacement of conventional material in the sub-base of surface coal mine haul road. The following conclusions are drawn from the investigation.

i. Addition of clinker enhances strength values significantly.
ii. The curing period as well as the clinker percentage has strong influence on the strength behaviour of composites.
iii. At 8% clinker content most of the composites achieved the desired CBR strength values at soaked condition. Similar observations were also made for UCS values at 7 days curing.
iv. The UCS and CBR values of the optimum composite exceed the minimum required values for use in sub-base of haul road. The P Wave velocity results confirm to the observation
v. The composite with 62% fly ash and 8% clinker content exhibits best result for haul road application as a sub-base material.
vi. The fly ash based composite materials would facilitate use of high percentage of fly ash in haul road while improving the performance of haul road for better mine economics.

Acknowledgements

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References

[1] Ulusay, R., Arlkan, F., Yoleri M.F. and 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, Engg. Geol. 40, pp. 77 – 101.

[2] Tannant, D.D. and Kumar, V. (2000), Properties of fly ash stabilized haul road construction Materials, Int. J. Surf. Mining, Reclamation Environ. 14, pp. 121 – 135.
[3] Tannant, D.D. and Regensburg, B. (2001), Guidelines for mine haul road design, University of Alberta, Canada.
[4] Thompson, R.J. and Visser, A.T. (2003), Mine haul road maintenance management systems, The South African Institute of Mining and Metallurgy, pp. 303 – 312.
[5] Pandian, N.S. (2004) , Fly ash characterization with reference to geotechnical applications, Indian Inst. of Sci. 84, pp. 189 – 216.
[6] Ghosh A. and Subbarao, C. (2006), Tensile Strength Bearing Ratio and Slake Durability of Class F Fly Ash Stabilized with Lime and Gypsum, Materials in Civil Engg., 18, pp. 18 –27.
[7] Cetin, B., Aydilek, A.H. and Guney, Y. (2010), Stabilization of recycled base materials with high carbon fly ash, Resources, Conser. Recycl. 54, pp. 878 – 892.
[8] Sahu, B.K. (2005), Use of fly ash for stabilizing sub-standard road construction materials in Botswana, Fly Ash Utilization Programme (FAUP), TIFAC Fly ash India, DST, New Delhi, Aug 11-13.
[9] Prabakar, J., Dendorkar, N. and Morchhale, R.K. (2004), Influence of fly ash on strength behaviour of typical soils, Const. Building Mater. 18, pp. 263 – 267.
[10] Sridharan A. and Prakash, K. (2007), Geotechnical Engineering Characterization of Coal Ashes, CBS Publ., New Delhi, India.
[11] Pandian, N.S. and Krishna, K.C. (2002), California Bearing Ratio behaviour of cement stabilized fly ash-soil mixes, Journal of Testing and Evaluation 30, pp. 492 – 496.
[12] Cockrell, C.F. and Leonard, J.W. (1970), Characterization and Utilization Studies of Limestone Modified Fly ash, Coal Research Bureau, 60, Morgantown, W.V.,.
[13] Das, B.M. (1994), Principles of Geotechnical Engineering. PWS-Kent Publishing Company, Boston, 3rd Edi.
[14] Bowles, J. (1992), Engineering properties of soil and their measurements, McGraw-Hill Boston, 4th Edi.
[15] Behera, B. and Mishra, M.K. (2011), Strength behaviour of surface coal mine overburden-fly ash mixes stabilized with quick lime, Int. J. Surf. Mining, Reclamation Environ., pp. 1-17.
[16] Sivapullaiah, P.V., Prasanth, J.P. and Sridharan, A. (1995), Optimization of lime content for fly ash, Journal of Testing and Evaluation, JUTVA, Vol. 23, No. 3, pp 222-227.
[17] Singh, S.P. and Kumar, P. (2005), Utilisation of fibre reinforced fly ash in road sub-bases, Fly Ash Utilization Programme (FAUP), TIFAC, Fly ash India, DST, New Delhi.
[18] Chu, T. Y., Davidson, D. T.,. Goecker, W. L and Moh, Z. C. (1955), Soil stabilization with lime-fly ash mixtures: preliminary studies with silty and clayey soils. Highway Research Board Bulletin 108, pp. 102-112
[19] DiGioia, A. M. and Nuzzo, W. L. (1972), Fly ash as structural fill, Journal of Power Div., ASCE, vol. 98 (1), pp. 77-92
[20] Gopalan, M.K. and Haque, M.N. (1986), Strength development of clinically cured plain and fly ash concretes, in Proceed. of Aus. Road Research Board, Vol. 13, Pt. 5, pp. 27–33
[21] Joshi, R.C., Natt, G.S. and Wright, P.J. (1981), Soil improvement by lime-fly ash slurry injection, in Proc. 10th Int. Conference on Soil Mechanics & Foundation Engg., Stockholm, vol. 3, pp. 707-712
[22] Raymond, S. (1961), Pulverized fuel ash as embankment material, In Proc., of The Institution of Civil Engineers, Vol. 19, pp. 515-536
[23] Xu, A. and Sarkar, S. L. (1994), Micro structural developments in high-volume fly ash cement system. Journal of Materials in Civil Engg., ASCE, Vol. 1, pp. 117-136
[24] Lin, Y. Kuo, S.F., Hsiao, C. and Lai, C.P. (2007), Investigation of Pulse Velocity-Strength Relationship of Hardened Concrete, ACI Materials Journal, 104(4), pp.344–350.
[25] Ottosen N.S. (1984), Evaluation of concrete cylinder tests using finite element, Journal of engineering mechanics ASCE, Vol. 110, No.3, pp. 465-481.

Bio-Data of Authors

	Mr. Soumya Ranjan Mallick, M.Tech Senior Research Fellow Department of Mining Engineering National Institute of Technology, Rourkela-769008, India Email: mallicksoumyaranjan@gmail.com
	Dr Manoj Ku Mishra graduated with a B.S. degree in Mining Engg. from R.E.C. Rourkela in1985. He worked for five years at various capacities for both underground and surface coal mines before pursuing higher studies. He obtained M.S. and Ph.D. from SIUC, USA and IIT Khragapur in 1992 and 2004 respectively. He has been into teaching and research since 1993 and presently an Associate Professor in the department of Mining Engg., NIT Rourkela. His research interests are rock mechanics, slope stability, blast vibration, ground control and gainful application of fly ash. His contact is mkmishra@nitrkl.ac.in.
	Er Kalpataru T Parida holds a graduate degree in Mining Engg from NIT, Rourkela (1985). He has been teaching various subjects as surveying, mining methods, mine development in many technical institutes of nation since then. Currently he is a Sr. Lecturer and Head of the Dept of Mining Engineering, OSME at Keonjhar. He is also pursuing higher studies in environment engineering in IGIT, Sarang since 2011. His research interests are pollution control measures and waste management. Email: c.mohapatra.metta@gmail.com