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An Investigation in to Compaction, California Bearing Ratio and Shear Strength Behaviour of Coal Mine Overburden Dump Material Mixed With Fly Ash

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Abstract*:* *Compaction, California Bearing Ratio (CBR) and shear strength behaviour of coal mine overburden dump material and fly ash mixed overburden dump material are studied by conducting a series of tests as per the standards. Test results are compared and analyzed to observe the changes occurred due to addition of fly ash and also to check the suitability of the mixture for various geotechnical applications viz. for road construction near captive coal mines and also as a fill material in the voids of open cast coal mines by mixing it with the overburden dumps. This investigation reveals that fly ash should be mixed in the range of 12.5% to 15% by mass (approx. 18% to 22% by volume) in the OB dumps, so that they can be compacted over a wide range of moisture content with very little variation in its unit weight. The test result also reveals that cohesion of OB dump material increases and friction angle reduces with the increase in fly ash content. The stress-strain behaviour of the overburden dump material and fly ash mixed overburden dump material exhibited post-peak softening behaviour.*

Keyword: *fly ash, overburden, compaction, shear strength, CBR*

1. Introduction

Power sector in India has been undergoing a monumental change which has redefined the outlook of power industry. Union government has launched an ambitious programme called ‘Power for All’. The programme requires accelerating the addition in generation capacity. The total installed power generation capacity of India in March 2016 stood at 2,88,665 MW. The coal based thermal power plants (TPP) account for 1,75,858 MW which stands at 60.92% of total installed capacity [1]. Indian coal is low in calorific value and high in ash content. The ash content varies in the range of 30% to 45%. Generation of same units of energy therefore lead to a production of a huge quantity of fly ash in coal based TPP in India *vis-a-vis* to other countries. Low utilization of the fly ash causes a substantial quantity of the same to be disposed off in the ash ponds.

Fly ash generation has increased from 85 MT in the year 2000-01 to 185 MT in 2014-15. Utilization of fly ash has also increased from 20% to 55% during the same years. Pandey *et al.* have assessed that the quantity of unutilized fly ash of 1500 MT (approx.) is occupying 65000 ha of land in India [2]. The concern of degradation of land is aggravating with the current utilization pattern. Statistics for the year 2014-15 indicates that a maximum of 42.26 % of the ash is utlized by the cement sector followed by 13.00% for mine filling and 11.72% for making bricks and tiles [3]. Stagnation in the production of the cement and brick over the last five years has lessened the consumption. It is therefore vital that new and feasible methods of disposal and utilization of fly ash must be explored.

Opencast coal mining contributes to 92% of coal production in India [4]. In order to achieve economic growth of 8% to 9%, the country’s coal demand is estimated to increase from 730 MT in 2010-11 to 2000 MT by 2030-31. As per an estimate, a thermal power plant of 1000 MW capacity produces 1.6 to 1.8 MT of fly ash per annum at 29% and 40% ash content respectively [5]. Enhanced production of coal in the coming years may lead to the generation of fly ash to nearly 600 MT by 2030 [6].

To ensure 100% utilization of fly ash from all the thermal power plants, Ministry of Environment, Forest and Climate Change (MoEF & CC), Govt. of India have issued a stringent notification, *dt.* Nov. 3, 2009 [7]. It compels all the mines located within 50 km by road from thermal power plants, to mix at least 25% fly ash by volume in the external and internal overburden (OB) dumps in the mine. However, disposal of fly ash by mixing it in OB dumps in the coal mines has not yet received the impetus even though almost one third of the thermal power plants in India are located in the close vicinity of the opencast coal mines. Location of thermal power plants and huge availability of fly ash in the proximity of coal mines can ensure economic disposal of fly ash by mixing it with OB dumps and to utilize the mixture for haul road construction in open cast coal mines.

Fly ash is non-plastic, fine powdery material generally having negligible cohesion in dry condition and internal friction angle in the range of 29^0 to 37^0, while

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under wet condition it hardens and strengthen with age due to its self-cementing properties and exhibits some cohesion [8-9].

The overburden dumps in most of the opencast coal mines are usually formed by end dumping method in which the dumper backs right up the dump face and unloads material directly down face from the face. The method results in formation of dumps with relatively low density and the dump face rests at an angle of repose. Compaction density is one of the most important parameter for any engineering fill design structures. Compaction improves the shear strength and other engineering properties of the fill [10-12]. If the overburden dumps are compacted near its maximum dry density, it will not only accommodate more volume of overburden material in the same area of land but also provide some space for disposing and mixing fly ash in the dumps which has now made mandatory by MoEF.

Plenty of research has been conducted by researchers on the compaction characteristics, California bearing ratio and other index properties of soil-fly ash mixtures in various ratios and has been successfully used in construction of earth structures such as embankments, earth dams, highways [13-18].

There is very limited information available for utilizing mixture of fly ash coal mine overburden dump material for similar structures. Tannant and Kumar mixed fly ash, kiln dust and mine spoil at 25:5:70 ratios and found the composite suitable for use in constructing coal mine haul road base and subbase layers [19]. Arora and Aydilek evaluated the engineering properties of Class F fly ash amended soils as highway base materials [20]. Behra and Mishra investigated the california bearing ratio characteristics of surface coal mine overburden material and fly ash mixes stabilized with lime for coal mine haul road construction and found that addition of lime improved the strength of fly ash-overburden mixes. During sample collection and preparation of overburden dump material, they discarded gravels, pebbles etc. and only sand, silt and clay portions were selected for the test. The influence of coarser fraction of rock fragments present on the overburden dumps on its compaction, shear and California bearing ratio were not taken in to consideration. They reported that the CBR value of overburden increased with the addition of fly ash in unsoaked condition and decreased in soaked condition due to saturation [21]. Mallick and Mishra carried out laboratory investigations on clinker-stablized fly ash - coal mine overburden mixes to evaluate their suitability for sub base of mine haul roads and found that the composite with 62 % fly ash and 8 % clinker content showed adequate mechanical strength suitable for the sub base of a mine haul road [22].

There are two main concerns in the disposal of fly ash related with its mixing in the OB dumps. One being the slope stability issues arising out of mixing of fly ash in OB dumps of open cast coal mines and secondly the contamination of ground water due to leachates. The research on slope stability issues indicates that the mixing and compaction of fly ash with the OB dump material changes the shear strength behaviour of the mixture, which is one of the most important inputs required for assessing the stability and design of fly ash mixed OB dump slopes [23-25].

This research work primarily aims to investigate the changes in compaction, CBR and shear strength behaviour of coal mine OB dump material altered due to mixing of fly ash.

2. Materials and Methods

Bulk quantities of OB dump material were collected from a large and partially consolidated OB dump of a large open-cast coal mine of South Eastern Coal Fields Limited (SECL), Bilaspur and fly ash collected from a thermal power plant located in Siltara Industrial Area, Raipur, Chhattishgarh, India. During collection of sample from the dump, larger rock fragments more than 80 mm in size were discarded at the site by visual observation. Particle size analysis of the dump samples was carried out as per IS 2720 Part 4, (1985) to prepare modelled gradation curve of OB dump material (prototype) [26]. Laboratory tests were carried out to characterize the dump material, which include specific gravity, point load strength index, slake durability tests, liquid and plastic limits. All the geotechnical characterization of OB dump material and fly ash and the relevant tests were carried out as per IS code [27-32].

2.1 Sample Preparation

Due to limitations of the shear box dimensions, it was not possible to test the prototype dump material. Therefore, the dump material size were scaled by some degrees and all the compaction and shear tests were performed on this reduced gradation which is parallel to the prototype. The rock fragments collected from the dump were sieved through different sieve sizes ranging from 80 mm to 2 μm and the fragments passing through these sieves were collected in separate bags /containers. Using parallel gradation technique developed by Lowe, these sized rock fragments are then mixed together to produce a well graded experimental sample having size distribution which is parallel to the modelled gradation curve (Prototype) having same gradation characteristics [33]. Numerous researchers have validated the effectiveness of this model to estimate the shear strength of rock fills and rail ballast [34-38]. The parallel gradation technique states that a smaller grain size distribution model of granular material of the same composition as of prototype material can be used for laboratory testing at a scaled down grain size, if both are having the same gradational characteristics. The scaling of gradation and particle size is decided by the limit of maximum particle diameter with respect to the size of the shear box.

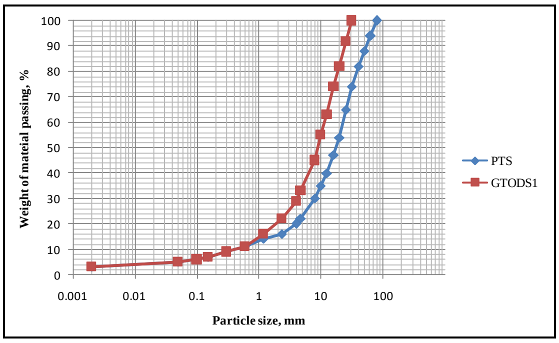

Figure 1. *Gradation of the prototype sample and prepared OB dump material sample GTODS1*

The quantity of various sizes of the materials required to achieve the desired gradation for preparing the specimen at the required density was determined by mass. This way sufficient numbers of samples of OB dump material having same uniformity coefficient and coefficient of curvature as that of prototype were prepared (Figure 1). The various important and relevant properties of overburden dump materials are listed in Table 1.

Two sets of samples were prepared by mixing fly ash in the OB dump material. First set of samples was prepared by mixing fly ash in GTODS1 in varying amounts of 5, 10, 12.5, 15 and 20% by mass and named as GTODS1M5FW, GTODS1M10FW, GTODS1M12.5FW, GTODS1M15FW and GTODS1M20FW respectively. These samples were subjected to compaction and CBR tests. The tests were conducted with two objectives. First objective was to optimize the amount of fly ash to be added in OB dump material which will cause little variation in its maximum dry unit weight with changes in moisture content and the other objective was to find out the range of fly ash percentages which can be mixed with OB dump material to utilize it as a road construction material.

Second set of samples was prepared by mixing approx. 13.5% and 17.5% fly ash by mass (which corresponds to approx. 20% and 25% by volume of fly ash) in the sample of OB dump material GTODS1 and named as GTODS1M20F and GTODS1M25F respectively.

Table 1. *Gradational characteristics of OB dump material sample GTODS1*

Gradation Characteristics	Prototype	OB dump material sample
Maximum fragment size, mm)	80	31.5
Average fragment size (mm)	18.5	9
Coefficient of uniformity, C_u	23	24
Coefficient of curvature, C_c	2.80	2.78
% fines less than 4.75 mm by mass	22	33
% fines less than 0.065 mm by mass		5
Group symbol as per IS	GW	GW
Sample name	Prototype Sample (PTS)	Gravel Overburden Dump Type Sample 1 (GTODS1)

2.2 Procter Compaction Tests

Heavy Procter compaction tests were conducted as per IS 2720 Part 8 to establish the maximum dry unit weight and optimum moisture of the overburden dump rock material and fly ash mixed overburden dump rock material mixture separately [30]. To measure the maximum dry unit weight and optimum moisture content of fly ash only, light compaction test were conducted following the procedures laid down as per IS 2720 Part 7 [39].

2.3 California Bearing Ratio Tests

CBR evaluates mechanical strength of the material used for road subgrades, subbase and base courses. It was developed by the California Department of Transportation before World War II. The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material. Both unsoaked and soaked CBR of the test mixture were determined. The general relationship between CBR and quality of sub-grade soil suggested by Bowels, for pavement construction is given in Table 2 [40].

Table 2. *Relationship between CBR and quality of subgrade soil, Bowels (1992)*

CBR	Quality of sub-grade
0-3%	Very poor sub-grade
3-7%	Poor to fair sub-grade
7-20%	Fair sub-grade
20-50%	Good sub-grade
75%	Excellent sub-grade

2.4 Direct shear Tests

All the direct shear tests for this study were carried out using multispeed direct shear equipment having a shear box of 300 mm by 300 mm by 190 mm deep. In the direct shear test, the soil is first consolidated under an applied normal stress. After consolidation is completed, the specimen is sheared directly at a constant rate of deformation. The strain rates chosen were very low and of the order of 0.2 mm/min, so that excess pore pressure which might build up during the test could be dissipated easily. Collapse and weathering induced settlements of coal mine OB dump material occurs simultaneously on exposure to water. This causes a substantial reduction in the shear strength of the dump materials [41]. It is for this reason; all the direct shear tests conducted in this research are of consolidated drained type.

The prepared samples of OB dump materials and fly ash mixed dump materials were pre-treated by adding and mixing distilled water so that the optimum water content was obtained for each mixture and the same were compacted in the shear box in five different layers. In each layer compaction was conducted using a 2.5 kg rammer so as to obtain 90% compaction relative to the maximum dry density obtained for the mixtures. Consolidated drained direct shear tests were carried out as per IS method at five different values of normal stress levels and corresponding shear loads, vertical and horizontal (shear) displacements were monitored and recorded. The tests were carried out at applied normal stresses ranging from 73.57 to 469.79 KPa, which corresponds to average normal stresses built up in embankment fills/slope heights of 15 m to 60 m.

3. Results and Discussions

The important index, strength and other properties of OB dump material and fly ash are reported in Table 3 and 4. The density and specific gravity of fly ash was found lower than that obtained for mine overburden. The lower unit weight is of advantage in the case of its use as a backfill material as the stress on the base will be less. The relatively low unit weight of fly ash makes it well suited for placement over soft or weak foundation material such as found in coal mines.

***Table 3.** Geotechnical properties of OB dump material sample GTODS1*

Properties	Values
Specific gravity	2.65
Point load strength index (MPa)	0.4 to 1.00
Second cycle slake durability index	78%
Liquid limit	18.6%
Plastic limit	Non-plastic
Maximum dry density (kN/m^3)	19.83
Optimum moisture content (%)	9

***Table 4.** Geotechnical properties of fly ash*

Properties	Values
Specific gravity	2.1
Bulk density (kg/m^3)	906
Porosity	56.85%
Liquid limit	38.6%
Plastic limit	Non-plastic
Maximum dry density (kN/m^3)	13.34
Optimum moisture content (%)	25

3.1 Compaction Test

Figure 2 compares the compaction curves of fly ash and OB dump material sample GTODS1. The unit weight of fly ash does not vary much with change in moisture content as compared to that of OB dump material therefore the shape of the compaction curve of fly ash is relatively flat as compared to OB dump material. The change in unit weight of fly ash is less sensitive to variation in moisture content than that of dump material owing to its higher void content. The higher void content in fly ash restricts the buildup of pore pressures and allows the fly ash to be compacted over a wide range of moisture content [42-43].

Figure 3 combines the compaction curves of GTODS1 mixed with fly ash in various amount by mass. The compaction curves shows that the increase in fly ash content in the OB dumps material results in the reduction of maximum dry unit weight and increase in OMC. Addition of 20 % fly ash by mass in the OB dump material sample GTODS1 decreases the maximum dry unit weight of the sample from 19.83 kN/m^3 to 17.64 kN/m^3 and increases the OMC from 9% to 18%. The reduction in the maximum dry unit weight with the increase in fly ash content occurs mainly due to the lower specific gravity of the fly ash as compared to OB dump material and the immediate formation of hardened products which reduces the density of the treated mixture [44-45]. The other reason for reduction in maximum dry density is the cation exchange reaction. The reaction causes the flocculated and agglomerated particles to occupy larger spaces, thereby increasing the volume of voids and consequently reduces the maximum dry density of the sample. The cation exchange reaction causes an increase in the affinity of the mixture to the water required for reaction. Therefore the OMC of fly ash mixed OB dump material sample increases with the increase in fly ash content.

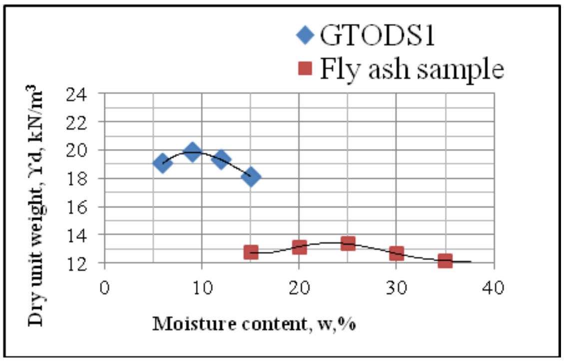

***Figure 2.** Compaction curves of fly ash and OB dump material sample GTODS1*

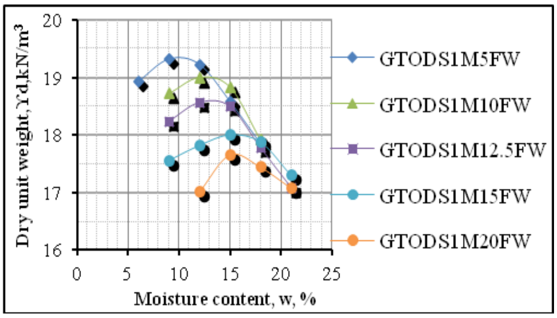

***Figure 3.** Effect of increasing fly ash content on compaction behaviour of GTODS1*

The compaction curves of fly ash mixed OB dump material shift rightward with the increase in fly ash content. The compaction curve shows a distinct peak for 5%, 10% and 20 % fly ash content whereas the curves are flat for sample containing 12.5% and 15 % fly ash by mass. This implies that that proper compaction of fly ash mixed OB dump material can be ensured by mixing 12.5% to 15% fly ash by mass. Mackiewicz and Ferguson reported that stabilization of soil using fly ash is more effective with 12% to 15% (dry weight basis) fly ash content [46]. Eskioglou and Oikonomou concluded that sand gravels mixture can be effectively stabilized by mixing fly ash content up to 10% [47].

3.2 California Bearing Ratio Test

Both unsoaked and soasked CBR of the dump material sample GTODS1 and the same mixed with fly ash at 5%, 10%, 12.5%, 15% and 20% by mass were determined. The load *vs*. penetration curve of of these samples under unsoaked and soaked conditions is reported in Figure 4 and 5 respectively. The result of unsoaked and soaked CBR test is presented in Table 5.

Table 5. *Unsoaked and soaked CBR of overburden dump material sample and the same mixed with fly ash in various amounts by mass*

Sample	Unsoaked CBR (%)		Soaked CBR (%)	
	At 2.5 mm penetration	At 5 mm penetration	At 2.5 mm penetration	At 5 mm penetration
GTODS1	73.21	72.99	32.22	31.63
GTODS1M5FW	75.18	90.02	33.18	30.41
GTODS1M10FW	63.50	75.43	18.05	20.19
GTODS1M12.5FW	30.18	41.63	11.32	14.23
GTODS1M15FW	26.15	26.76	9.30	10.70
GTODS1M20FW	19.28	23.6	3.48	4.83

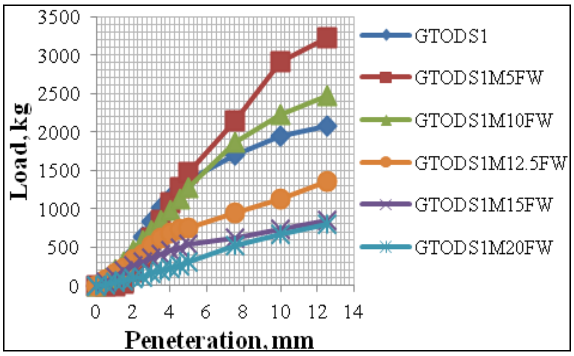

Figure 4. *Load vs penetration curve of unsoaked condition*

As indicated from Table, the unsoaked and soaked CBR value of OB dump material sample was found 73.21 % and 32.22 % respectively. The CBR value of fly ash mixed OB dump material samples ranged from 19.28 % to 90.02 % in unsoaked conditions, while under soaked condition, the CBR varied from 3.48 % to 33.18 %. The results of penetration (CBR) test reveals that CBR values of OB dump material sample GTODS1 and fly ash mixed OB dump material samples are much lower in soaked condition as compared to unsoaked condition. In unsoaked condition, capillary forces created at OMC provide additional resistance against penetration of the plunger. Under soaked condition, these capillary forces got destructed [21]. When OB dump material sample GTODS1 was mixed with 5 % fly ash by mass (GTODS1M5FW), both unsoaked and soaked CBR remains almost unchanged. With the further increase in fly ash content, both unsoaked and soaked CBR reduces. The soaked CBR value of fly ash mixed OB dump material samples GTODS1M5FW, GTODS1M10FW, GTODS1M12.5FW and GTODS1M15FW lies above 9%, whereas the CBR value of fly ash mixed OB dump material containing 20% fly ash is found less than 5%. Addition of fly ash also increases the percentage of fines in the dump material, thus reduces the penetration resistance. According to the relationship developed by Bowels between CBR and quality of subgrade soil, the OB dump material mixed with fly ash up to 15% by mass can be used as a subgrade material for construction of haul road in mines. The OB dump material mixed with 20% fly ash is unsuitable for subgrade material in areas of heavy rainfall, unless the sample is treated with lime or cement.

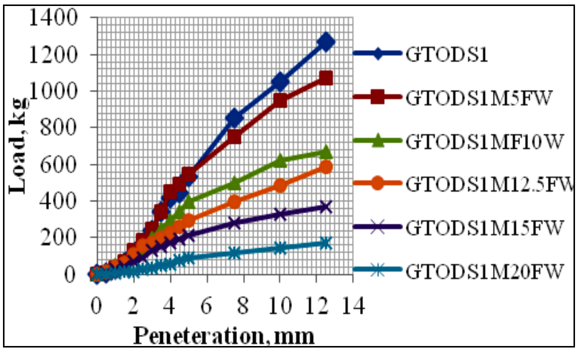

Figure 5. *Load vs penetration curve in soaked condition*

3.3 Shear Strength Test

The peak and residual shear strength values for GTODS1 were interpreted from the results shown in Figure 6. The differences in the shear strength were quantified by determining the intercept with the shear stress axis giving apparent cohesion (peak and residual) and the slopes of the trend lines, estimating the friction angles (peak and residual). The Mohr-Coulomb failure envelope was approximated as linear within the stress range used in these tests. The peak and residual internal friction angle of OB dump material sample GTODS1 compacted at OMC was 29.11^0 and 26.10^0 while the peak and residual apparent cohesion was 18.36 kPa and 7.65 kPa respectively.

The measured apparent cohesion in OB dump material sample is due to moisture present in the sample that causes induced suction and also because of presence of some clay and silt fractions. The amount of apparent cohesion for the sample was found very small. The apparent cohesion for OB dump material is generally neglected by geotechnical engineers for slope stability design. Presence of this apparent cohesion in coal mine spoil material has been reported by Ulusay et al. [48] and in soil quarry dust mixtures by Sridharan et al. [49]. The value compares favourably with those obtained for coal mine spoil material elsewhere [50-51].

Figure 7 shows the plot of shear stress versus the horizontal (shear) displacement for the sample. It can be seen that sample show post-peak softening behaviour at all stress levels. The shear stress corresponding to a fixed normal stress increases initially until it reaches the peak strength, which then reduces gradually towards its residual strength. A plot of vertical displacements against shear displacement is used to identify the dilation or contraction behavior of the material during the test (Figure 8). At higher normal stress levels, the materials dilate after initial contraction at shear displacement near its peak stress value.

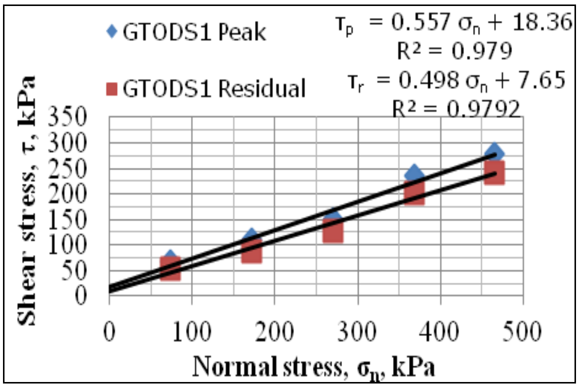

Figure 6. *Mohr-Coulomb failure envelopes for dump material sample GTODS1 at OMC*

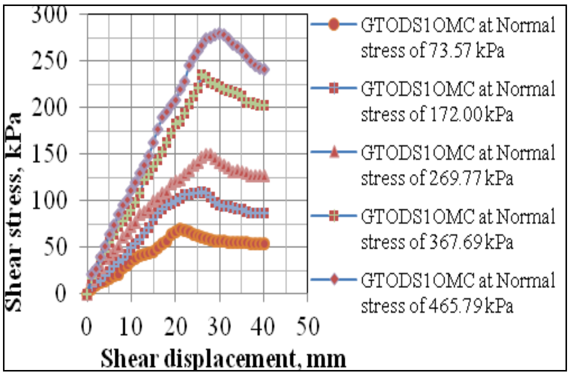

Figure 7. *Shear stress versus horizontal displacement curves for dump material sample GTODS1 at OMC*

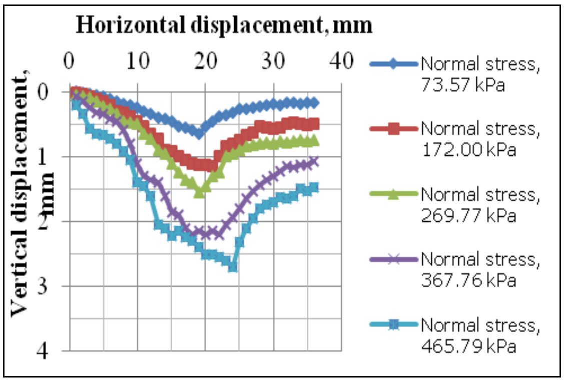

Figure 8. *Horizontal displacement versus vertical displacement curves for OB dump material sample GTODS1 at OMC*

Marsal's method was used to investigate the breakage of rock materials during shear test in which the volume of particle breakage while loading a specimen is defined by the changes in particle size distribution curves measured before and after loading [52]. Figure 9 shows the particle breakage occurred during shear test at normal stress level of 172 kPa. The Marsal's particle breakage index was found more than 30 %. The higher value indicated the particle crushing occurred during the shear test of rock fragments which are having lesser strength than the normal stress applied during the test. A closure look towards the gradation of test samples before and after the test revealed that maximum particle breakage was for the fragments sizes present in the range 31.5 to 16 mm. Larger size fragments were subjected to more particle breakage and crushing because of more contact area resulting in higher value of breakage index. Reduction in the strength of these fragments took place sharply in the wet condition due to dissolution of binding particles was also reported by Zafar and Rao [53]

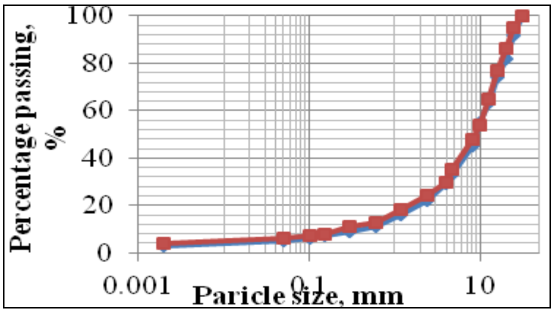

Figure 9. *Gradation curves of dump material sample GTODS1 before and after the shear test conducted at normal stress of 172 kPa*

Peak and residual Mohr-Coulomb friction envelope obtained for GTODS1M20F and GTODS1M25F is presented in Figure 10 and 11 respectively. The peak apparent cohesion of GTODS1M20F and GTODS1M25F is found 79.75 kPa and 83.22 kPa respectively. The peak apparent friction angle of GTODS1M20F and GTODS1M25F is found 21.33° and 17.69° respectively (Table 6). A significant reduction in the friction angle is observed with the addition of fly ash and increase in its content.

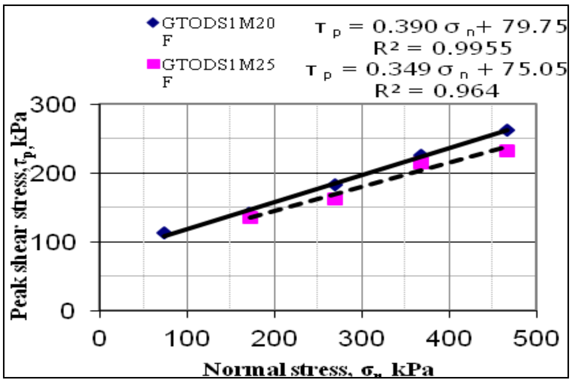

Figure 10. *Peak shear strength envelope of GTODS1 mixed with 20% and 25 % fly ash by volume*

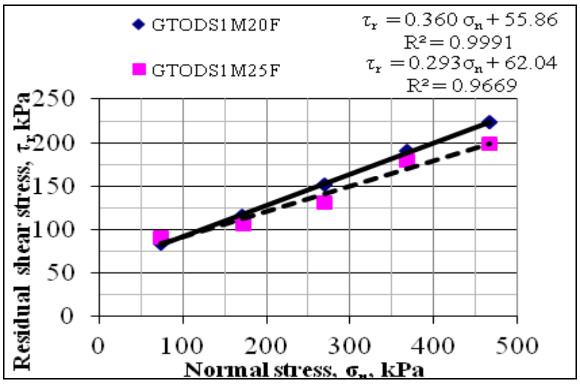

Figure 11. *Residual shear strength envelope of GTODS1 mixed with 20% and 25 % fly ash by volume*

Table 7 presents the mobilized peak and residual shear stress for samples of OB dump material and corresponding fly ash mixed OB dump material samples. It is very evident from the table that the overall mobilized peak and residual shear stress for the fly ash mixed OB dump material increases up to normal stress level of 269.775 kPa as compared to OB dump material. Beyond this level, both peak and residual shear stress reduces slightly as compared to the sample containing no fly ash. At high normal stress, particle crushing of the coarse fractions of the dump material occurs and results in decrease in shear resistance. Similar trend of decrease in ultimate shear strength was reported by Gupta and Paul [26].

Table 6. *Peak and residual shear strength parameters of overburden dump material and fly ash mixed overburden dump material*

Sample	Peak Cohesion (kPa)	Peak Internal friction angle	Residual Cohesion (kPa)	Residual Internal friction angle
GTODS1	18.36	29.11^0	7.65	26.10^0
GTODS1M20F	79.79	21.33^0	55.86	19.80^0
GTODS1M25F	83.32	17.69^0	64.79	15.26^0

Table 7. *Mobilized peak and residual shear stress for GTODS1, GTODS1M20F and GTODS1M25F*

Sample	Normal stress (kPa)	Peak shear stress (kPa)	Residual shear stress (kPa)
GTODS1	73.57	69.18	54.18
	172.00	109.6	86.78
	269.77	150.03	126.56
	367.76	235.44	202.01
	465.79	279.77	240.75
GTODS1 mixed with 20% fly ash by volume (GTODS1M20F)	73.57	112.90	84.17
	172.00	140.95	116.12
	269.77	183.34	151.33
	367.76	226.39	189.88
	465.79	261.61	224.14
GTODS1 mixed with 25% fly ash by volume (GTODS1M25F)	73.57	105.54	91.35
	172.00	135.68	105.69
	269.77	178.06	131.12
	367.76	196.00	178.72
	465.79	232.20	198.50

The test result reveals that addition of fly ash improves the cohesion of the OB dump material sample significantly. The improvement in cohesion is attributed to greater degree of void filling in between the rock particles by the fly ash and some hardening of the mixture due to fly ash water reaction. However, the internal friction angle all the OB dump material samples reduce considerably with the addition of fly ash. The addition of fly ash in cohesionless dump material reduces particle to particle contact as it get trapped between the rock particles causing decrease in its friction angle. Prabakar obtained similar trend of increase in cohesion of soil mixed with fly ash [54]. It was also reported that the variation of friction angle with fly ash content shows a nonlinear trend. The results also corroborate the findings of Jayanthu as well as Krishna and Nayak obtained on shear strength parameters on fly ash mixed with OB dump material [24,55].

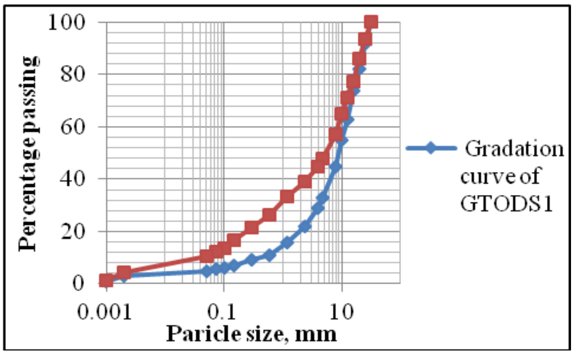

Figure 12. *Change in gradation of OB dump material GTODS1 with the addition of fly ash*

The gradational characteristics of the OB dump material also changes with the addition of fly ash. Figure 12 shows the effect of mixing 25% fly ash by volume in the gradation curve of OB dump material GTODS1. With the addition of fly ash, the coefficient of uniformity of OB dump material sample GTODS1 increases to 180 from 24 and coefficient of curvature reduced to 1.42 from 2.8. The increase in the percentage of fines in the case of fly ash mixed OB dump material sample results in reduced dilational behaviour at higher normal stress levels.

4. Conclusions

Following conclusions can be drawn on the basis of above study:

- Proper compaction of OB dump material over a wide range of moisture content can be ensured by mixing it with the fly ash in the range of 12.5% to 15% by mass.
- On the basis of soaked and unsoaked CBR of dump material investigated, it can be concluded that fly ash in the range of 5% to 15% by mass can be mixed with OB dump material to utilize the mixture as a sub-base and sub grade material for the construction of embankment and roads.
- The soaked CBR value of fly ash mixed OB dump material decreases sharply with the increase in fly ash proportions. The soaked CBR value for investigated dump material sample mixed with 20% fly ash by mass was found less than 5% and hence unsuitable as subgrade material in areas of heavy rainfall.
- The overall mobilized peak and residual shear stress increases for the fly ash mixed OB dump material as compared to OB dump material at low normal stress level of up to 269.77 kPa, but as the normal stress increases beyond this level, both peak and residual shear stress for fly ash mixed OB dump material reduces significantly as compared to the OB dump material.
- Addition of fly ash increases the cohesion of the OB dump material significantly and reduces the peak and residual friction angle of OB dump material. Mixing of fly ash changes the gradation of the mixture and affects its shear strength behaviour.

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References

[1]Annual Report, “Status of Power Generation” 2016, Central Electricity Authority, Ministry of Power. New Delhi, 2016 httpp://powermin.nic.in.

[2] Pandey, V. C., Singh, J. S., Singh, R. P., Singh, N. and Yunus, M., “Arsenic hazards in coal fly ash and its fate in Indian scenario”, Resources Conservation and Recycling, 55, PP. 819–835, 2011

[3] Annual Report, “Fly ash generation on coal/lignite based thermal power stations and its utilization in the country for the year 2014-15”, Central Electricity Authority, Ministry of Power, New Delhi. 2015 httpp://cea.nic.in.

[4] Report “Provisional Coal Statistics 2014-15”, Coal Controller’s Organization Ministry of Coal, Government of India, 2015 , htpp://www.coal.nic.in

[5] Chattopadhyay, G. C., “Issues in utilization of ash by thermal power plants in the country”, Journal of Government Audit and Accounts, Indian Audits and Accounts Department, 3, PP. 1-4, 2015

[6] Krishnan, S. S., “Fly ash utilization: A key policy pathway for low carbon inclusive growth”, Proceedings of 2nd Annual International Summit on Fly ash Utilization- 9-10 October 2013, PP. 1-22, 2013

[7] Ministry of Environment and Forest Notification, The Gazette of India: Extraordinary Part II, Section 3 (ii), New Delhi, Govt. of India, 3 Nov. 2009

[8]Pandian, N.S., “Fly ash characterization with reference to geotechnical applications”, Journal of the Indian Institute of Sciernce, 84, PP. 189-216, 2004

[9]Porbaha, A., Pradhan, T.B.S. and Yamane, N., “Time effect on shear strength and permeability of fly ash”, Journal of Energy Engineering, 15, PP.15-31, 2000

[10]Sridharan, A., Soosan, T.G., Jose, B. and Abraham, B. M., “Shear strength studies on soil-quarry dust mixtures”, Journal of Geotechnical and Geological Engineering, 24, PP. 1163–1179, 2006

[11]Ugbe, Felix C., “Effect of multicyclic compaction on cohesion in lateritic soils”, Archives of Applied Science Research, 3 (3), PP. 115-121, 2011

[12]WangLong, Xei, Xiaogouang and Hai, Luan, “Influence of compaction methods on shear performance of graded crushed stone”, Journal of Materials in Civil Engineering, 23, Issue 10, 1483-1487, 2011

[13]Erdal, C., “Use of class c fly ashes for the stabilization of an expansive soil”, Journal of Geotechnical and Geoenvironmental Engineering, 127, Issue 7, PP. 568-57, 2001

[14] Pandian, N. S., and Krishna, K. C., “California bearing ratio behavior of cement stabilized fly ash-soil mixes”, Journal of Testing and Evaluation, 30, Issue 6, PP.1-5, 2002

[15] Prabakar, J., Dendorkar N., and Morchhale R. K., “Influence of fly ash on strength behavior of typical soils”, Construction and Building Materials, 18, PP. 263-267, 2004

[16]Phani Kumar, B. R. and Sharma, Radhey S., “Effect of fly ash on engineering properties of expansive soils”, Journal of Geotechnical and

Geoenvironmental Engineering, 130 (7), PP. 764-767, 2004

[17]Lopes, L. S. E., Szeliga, L. Casagrande, M. D. T., and Motta, L. M. G., "Applicability of coal ashes to be used for stabilized pavements base", Geo Congress, 55 (21), PP. 2562-7759, 2012

[18] Mir, B. A., and Sridharan, A., "Physical and compaction behavior of clay soil- fly ash mixtures", Journal of Geotechnical and Geological Engineering, PP.1059–1072, 2013

[19]Tannant, D. D., and Kumar, V., "Properties of fly ash stabilized haul road construction materials", International Journal of Surface Mining Reclamation and Environment, 14, PP.121–13, 2000

[20]Arora, S., and Aydilek, A. H., "Class F fly ash amended soils as highway base materials", Journal of Materials in Civil Engineering, 17 (6), PP. 640-649, 2006

[21]Behra, B., and Mishra, M. K., "California bearing ratio and brazilian tensile strength of mine overburden - fly ash-lime mixtures for mine haul road construction", Journal of Geotechnical and Geological Engineering, 30, PP. 449-459, 2012

[22] Mallick, S. R., and Mishra, M. K., "Geotechnical characterization of clinker-stablized fly ash-coal mine overburden mixes for subbase of mine haul road", Coal Combustion and gasification Products, 5, PP. 49-56, 2013

[23]Singh, T. N., "Assessment of coal mine overburden dump behaviour using numerical modelling", Proceedings of Rock Mechanics. Fuenkajorn & Phien-wej (eds), PP. 25-36, 2011

[24] Jayanthu, S., Das, S. K., and Equeenuddin, Sk Md., "Stability of fly ash and overburden material in opencast mines- A case Study", Proceedings of International Conference on Chemical Civil and Environmental Engineering, PP. 276-278, 2012

[25]Gupta, A. K., and Paul, B., "Augmenting the stability of OB dump by using fly ash: A geotechnical approach to sustainably manage OB dump at Jharia Coalfield, India", Current World Environment, Volume 11(1), PP.204-211, 2016

[26]IS: 2720 Part 4, "Grain size analysis", Indian standard methods of test for soils, Bureau of Indian Standards, PP. 1-39, 1985

[27]IS: 2720 Part 3, "Determination of specific gravity". Indian standard methods of test for soils, Bureau of Indian Standards, New Delhi, PP.1-8, 1980

[28]IS: 8764, "Determination of point load strength index of rocks" Indian standard methods, Bureau of Indian Standards, New Delhi, PP. 1-1, 1998

[29]IS: 10050, "Method for determination of slake durability index of rock", Indian standard methods, Bureau of Indian Standards, New Delhi, PP. 1-7, 1981

[30]IS: 2720 Part 8, "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, 1983

[31] IS: 2720 Part 39 Section 1, "Direct shear test for soil containing gravel more than 4.75 mm size", Indian standard methods of test for soils, Bureau of Indian Standards, PP. 1-17, 1977

[32] IS: 2720 Part 16, "Laboratory determination of CBR", Indian standard methods of test for soils, Bureau of Indian Standards, New Delhi, PP.1–15, 1987

[33] Lowe J., "Shear Strength of coarse embankment dam materials", Proceedings of 8th Congress on Large dams, PP.745-761, 1964

[34]Sitharam, T. G., and Nimbkar, M. S., "Micromechanical modelling of granular material: Effect of particle size and gradation", Journal of Geotechnical and Geological Engineering, 18, PP. 91-117, 2000

[35] Varadarajan, A., Sharma, K. G., Venkatachalam, K., and Gupta, A. K., "Testing and modelling of two rockfill materials",Journal of Geotechnical and eoenvironmental Engineering, PP. 206-218, 2003

[36]Cambio Domenica, and Ge Louis, "Effect of parallel gradation on strength properties of ballast Material", Proceedings of Advances in Measurement and Modeling of Soil Behavior, Denver, Colarado, PP.1-7, 2007

[37] Sevi Adam, F., "Physical modelling of rail road ballast using the parallel gradation scaling technique within the cyclical triaxial framework", PhD Thesis, Missouri University of Science and Technology, PP.7-13, 2008

[38]Ali G., Sadeghpour, Amir H., and Mohamadzadeh M., "An Experimental study on the behaviour of rockfill materials using large scale tests", Electronic Journal of Geotechnical Engg., 13 (G), PP.1-16, 2008

[39]IS: 2720 Part 7, "Determination of water content-dry density relation using light compaction", Indian standard methods of test for soils, Bureau of Indian Standards, New Delhi, PP.1-8, 1980

[40]Bowels, J., "Engineering Properties of Soil and Their Measurements", 4th ed., Mc Graw- Hill, Boston, 1992

[41]Williams, D. J., and Kho, A. K., "Settlement and shear strength of uncemented coal mine overburden materials placed loose under dry and wet conditions", Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris, PP. 441-444, 2013

[42]Toth, P. S., Chan, H. T., and Cragg, C. B., "Coal ash as a structural fill with special reference to Ontario experience", Canadian Geotechnical Journal, 25 (4), PP. 694–704, 1988

[43] Sridharan, A., Pandian, N. S., and Srinavas, S., "Compaction behaviour of Indian coal ashes", Proceedings of Ground Improvement. Thomas Telford, UK, 5, PP. 13–22, 2001

[44]Lees, G., Abdelkader, M. O., and Hamdani, S. K., "Effect of the clay fraction on some mechanical properties of lime–soil mixtures", J Inst Highw Eng, 11, PP. 3–9, 1982

[45]Bell, F. G., "Lime stabilization of clay minerals and soils. Engineering Geology", 42, PP.223–237, 1996

[46]Mackiewicz, S. M., and Ferguson, E. G., "Stabilization of soil with self cementing coal ashes", World of Coal Ash, Lexington, Kentucky, USA, 11-15 April, PP. 1-7, 2005

[47] Eskioglou, P., and Oikonomou, N., "Protection of environment by the use of fly ash in road construction", Global Nest Journal, 10, Issue 10, PP. 1-6, 2008

[48]Ulusay, R., Arikan, F., Yoleri, M. F., and Caglan, D., "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, 40, PP. 77-101, 1995

[49]Sridharan, A., Soosan, T. G., Jose, B., and Abraham, B. M., "Shear strength studies on soil-quarry dust mixtures", Journal of Geotechnical and Geological Engineering, 24, PP. 1163–1179, 2006

[50] Koner, R., and Chakravarty, D., "Stability study of the mine overburden dump slope: a micromechanical approach", Studia Geotechnica et Mechanica, 32, PP. 35-57, 2010

[51]Kainthola, A., Verma, D., and Singh, T. N., "Computational analysis for the stability of black cotton soil bench in open cast coal mine in Wardha valley coalfield. Maharashtra, India", International Journal of Economic and Environmental Geology, 2, Issue 1, PP.11-18, 2011

[52]Marsal, R. J., "Mechanical Properties of Rockfill", In Hirschfeld R.C. and Poulos, S.J Embankment-Dam Engineering (Casagrande Volume): John Wiley and Sons, New York, PP. 109-200, 1973

[53] Zafar, S., and Rao, K. S., "Effect of moisture and confining pressure on mechanical behaviour of Shivalic sandstone", International Journal for Applied Science and Engineering Technology, 2(12), PP. 145-150, 2014

[54] Prabakar, J., Dendorkar, N., and Morchhale, R. K., "Influence of fly ash on strength behaviour of typical soils", Construction and Building Materials, 18, PP. 263–267, 2004

[55] Krishna, R., and Nayak, D. S., "Slope stability analysis using geogrid software", International Conference on Emerging Trends in Science Technology Engineering and Management. 09-10 October 2015, Malla Reddy Engineering College, PP. 27-35, 2015