MASS UTILISATION OF FLY ASH AS BACKFILLING MATERIAL IN OPEN PIT MINES – A CASE STUDY

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ABSTRACT

This paper identifies the need of mass utilisation of fly ash in mine, and demonstrates the results of laboratory investigation through numerical analysis understanding the stability of overburden dump formed by mixing with 25% fly ash in opencast coal mine at Raigarh, India. Fly ash generated from the coal based thermal power plant is of great concern due to its disposal. Therefore proper utilization of the fly ash is highly demanded. It is observed that two types of dumps with alternative layer of only fly ash and overburden material, and overburden mixed with fly ash (25%) are found to be stable with safety factor more than 1.2. Geometry of the stable dump has total height of 120 m, 4 number of decks, individual deck height of 30 m, and slope of each deck as 32°. The dump formed with alternate layer of overburden and mixture of fly ash is found stable with a safety factor of 1.78 for the above geometry. Therefore, the above geometry of the back filling material was recommended for the above mine. As a part of reclamation with plantation, top soil of nearly 2 m thick was spread over the dump material in the field. Displacement pattern of the monitoring stations during November 2012 to the end of November 2013 indicated no significant displacement in the Overburden dumps with fly ash ensuring stability of the dump.

INTRODUCTION

Fly ash generation and utilisation scenario indicates urgent need of efforts from concerned agencies for reducing the gap of about 110 Million tonnes of Fly ash (FA) during 2011-12, and conducting need based research for innovative measures in proper utilisation of the Fly ash (Table 1). Although meticulous attempts are being made by CFARM-New Delhi under the Dept of Science and Technology, many more studies are required for eco-friendly application in mass utilisation of FA. Jindal Power Open Cast Coal Mine is captive mine of Jindal’s 1000 MW (4 x 250 MW) thermal power plant. The block is located between Longitudes - 83°29'40" to 83°32'32" (E) and Latitude - 22°09'15" to 22°05'44" (N) falling in the topo sheet number 64 N/12 (Survey of India). Administratively, the block is under Tamnar Tahsil of Raigarh District, Chhattisgarh. The block is well connected by Road. It is about 60 km from Raigarh town, which is district head quarter and nearest railway station on Mumbai - Howrah Main Line. Management of Jindal power opencast coal Mine-Tamnar, Raigarh, proposed to conduct scientific studies for the assessment of overburden dump slope stability using fly ash. However, its utilization is nearly 50% of the production (2009-10), which is very less in comparison to the major fly ash producing countries like China, U.S.A. and Germany [1].

<table>
<thead>
<tr>
<th>Year</th>
<th>FA Generation (Million Tonne)</th>
<th>FA Utilization (Million Tonne)</th>
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<tbody>
<tr>
<td>1994</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>2008</td>
<td>160</td>
<td>80</td>
</tr>
<tr>
<td>2011-2012</td>
<td>220</td>
<td>110</td>
</tr>
<tr>
<td>2031-2032</td>
<td>1000</td>
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As part of the studies, NIT-Rourkela conducted field investigations, and laboratory studies were carried out at Geotechnical Laboratory of NIT-Rourkela. National Thermal Power Corporation used about 60,000 tons of ash for backfilling underground mines of Singareni Colliery Company Limited, Southern India during 1999–2000 [2]. There is also a report of mine back filling using fly ash at Singrauli and Damoda opencast mines in India [3], [4]. Based on the various physico-mechanical properties and the field studies, empirical models and numerical modeling studies were conducted for the stability of dump slope. The main objective of the study was to determine stability of overburden dump formed by the utilization of fly ash. During 2012, low percentage of the Fly ash was used for mine fill purpose, and mass utilisation can be expected by proper use as back fill in open cast mines, such as the case study at JPL mine, conducted for the first time in India (Fig 1) [5].

![Utilisation of Fly Ash in various sectors during 2012 in India](image)

**Fig 1: Utilisation of Fly Ash in various sectors during 2012 in India**

**GEOMINING CONDITION**

In general, area of the coal block - Jindal Power Open Cast Coal Mine is almost flat with small undulations from surface. The lithological section comprises about 3-4 m unconsolidated loose soil/alluvium. Below the top soil there is weathered shale/sandstone up to 6–8 m depth. The weathered shale and sandstone are comparatively loose in nature and can be excavated without blasting. Below weathered zone (which varies from 3 – 10 m), the rock is hard, compact and massive in nature and can be excavated only after blasting. Thus the average depth of the excavation of these excavations, which can be removed, is about 16 m. In the sub-block IV/2 & IV/3 only lower groups of Gondwana sediments have been deposited. Strata are gently dipping by 2 to 5° southwesterly. The general strike of the sediments is in NW-SE, and almost uniform throughout the block. Two normal faults of small magnitude have been deciphered based on the level difference of the floor of the seams, though the presence of some minor faults of less than 5 m throw cannot be overruled.
The Mand Raigarh basin is a part of IB River - Mand - Korba master basin lying within the Mahanadi graben. The sub-block IV/2 & IV/3 of Gare-Pelma area is structurally undisturbed except one small fault (throw 0-15 m) trending NE-SW with westerly throws. The strike of the bed is NW-SE in general with dip varies from 2° to 6° southwesterly. The strata shows rolling dip. In the sub block IV/2 & IV/3 total 10 number of persistent coal seams have been established. They are seam X to I in descending order. Seam I is impersistent due to metamorphism in the central and eastern part of the block. Depth of mine working is about 36 m with six benches of 6 m height. Ultimate depth of the mine would be about 120 m from RL of 271 to 151 m. Back hoe in combination of dumper with 6 m bench height is adopted for excavation in the mine. It is also proposed to have 6 m height benches at the time of formation of ultimate pit slope.

**Bench parameters being followed at present are**

- **Bench height** = 6 m
- **Numbers of working benches** = 6
- **Width of the bench** = 20 m
- **Gradient of the ramp** = 1 in 16

**LABORATORY INVESTIGATIONS**

Physio-mechanical properties (Uniaxial Compressive Strength and Density), of the Bore hole # 32 and 44 indicating that the strata overlying seam IX consists of Alternative bands of fine grained sandstone and shale with compressive strength of about 14 MPa. Density of the coal in the seams IX, VIII, VII are in the range of 1.340-1.43, 1.41-1.63, and 1.57-1.67 g/cc respectively. Shear Strength Parameters; Cohesion, $C$ in $t/m^2$, and Angle of internal friction $\Phi$ are in the range of 0.2 to 0.7 and 35 to 38 degrees, respectively.

**METHODOLOGY FOR DUMPING OF FLY ASH**

It was proposed earlier to have internal overburden dumps of maximum height of 30 m in each individual deck with four decks up to 120 m overall dump height. Presently overburden dump height is about 72 m with a maximum deck height up to 25 m in this mine. Stability analyses for the proposed dumps were undertaken using various techniques for the maximum dump height of 120 m, which is the ultimate depth of the mine. Ground Water level conditions are below the 13 m from the surface and benches are generally dry.

Jindal Power Limited, Tamnar has already have captive thermal power plants of 1000 MW and generating fly ash, a solid coal combustion residue form due to the burning of coal, of nearly 16000 tons per day. Therefore, quantity of fly ash generated requires large area for its dumping. In last two decade it was realized that fly ash is no more a waste. Its utilization has increased by several folds, and particularly in mining industries. Fly ash is being used at JPL along with overburden material for backfilling in the mine as per the DGMS guide line. Mixing overburden with fly ash improves the mechanical strength of dump as fly ash absorbs the moisture from clay as well as substantially increases the strength of the resultant mixture due to the pozzolanic properties of ash [6]. Location of the study site and a view for the dumping of fly ash at Jindal Power Open Cast Coal Mine, Tamnar is shown in Figure 2, and 3, respectively.
Initially a row of overburden was dumped forming an embankment with a width of greater than 15 m and height up to 5 m all around the proposed area for fly ash dump. A number of such areas were formed in a layer wherein the fly ash was dumped so that each dump of fly ash was separated by another overburden dump of 15 m wide in order to control the airborne quality of the fly ash. Fly ash was dumped within this area surrounded by overburden in alternate layers of height not exceeding 5 m in each layer. Therefore, each layer of overburden was followed by a layer of mixture of fly ash and overburden (fly ash 25%) and so on up to the height of 30 m. Figure 4, 5 and 6 shows photograph of fly ash and OB in the overburden dump.

The side of the overburden dump is benched and the angle of slope is about 32°. Dump is compacted; width of the dump is about 40 m and the overall slope is about 27° from the horizontal. The toe of the dump is protected by putting the compact rocks (Overburden material) in order to restrict the possibility of any failure in future.
Fig. 4: Dumping of fly ash and OB in the dump

Fig. 5: Close view of fly ash and overburden at dump site

Fig. 6: Dumping of fly ash within overburden at dump site
EXPERIMENTAL INVESTIGATION

Various samples of overburden, soil and fly ash from the dump site were supplied by the Jindal Power Limited for finding out various geotechnical properties through the laboratory study. Different geotechnical tests were conducted for the overburden and the fly ash samples collected from the site. Laboratory geotechnical investigation was carried out for determination of grain size distribution, specific gravity, compaction characteristics (optimum moisture content and maximum dry density), and shear strength characteristics following Bureau of Indian standard (BIS) methods. The parameters like density, and shear parameters cohesion \(C\) and angle of internal friction \(\phi\) (angle of repose) are determined for both overburden and fly ash to analyze stability of dumped slope. The typical grain size distribution of the overburden and fly ash is shown in Figure 7. The particle size of the overburden ranges between gravel, sand and silt. However, the grain size distribution of fly ash and most of the fly ash corresponds to the silt size. The specific gravity of the fly ash found to be very low (average value of 2.15) in comparison to specific gravity of over burden as 2.79. This low specific gravity of fly ash reduces the total weight of the dumped slope and may help in increasing the stability of the dumped slope.

![Fig. 7: Grain size distribution of typical overburden (OB) and fly ash](image)

The laboratory compaction characteristics of the fly ash are shown in Figure 8, and it was observed that the optimum moisture content (OMC) was found to be 22.9% and maximum dry density (MDD) as 1.27 gm/cc. The MDD of the overburden is 1.87 gm/cc and OMC is 11.4%. It was observed that the OMC is 12.85% and MDD found to 1.74 gm/cc for the mixture. This reduction in MDD is due to low MDD of fly ash. One-way this also helps in reducing the self-weight (driving force) of the slope.
The shear strength characteristics of the overburden and mixture of fly ash with overburden are shown in Table 2. These properties are used for the stability analysis of dumped slope.

**TABLE 2: Shear parameters for the overburden, soil and mixture of fly ash and OB**

<table>
<thead>
<tr>
<th>Sample type</th>
<th>Cohesion (kN/m²)</th>
<th>Angle of internal friction (°), Degree</th>
</tr>
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<tbody>
<tr>
<td>Overburden</td>
<td>41.8</td>
<td>28.5</td>
</tr>
<tr>
<td>Fly ash + OB</td>
<td>89.6</td>
<td>22.9</td>
</tr>
<tr>
<td>Soil</td>
<td>78.2</td>
<td>20.5</td>
</tr>
</tbody>
</table>

**SLOPE STABILITY ANALYSIS**

The stability of dumped slope is analyzed by PLAXIS software, Version 9 using the above geotechnical parameters. PLAXIS is a finite element program for geotechnical applications in which Mohr- Coulomb models are used to simulate the behavior of dump material. Its implementation consists of three stages, known as input stage, calculation stage and post processing (curves) stage. Input stage contains model design, assigning the material parameters, boundary conditions, loading and meshing. In the present analysis 15-node triangular element is considered for meshing which contains 12 stress points. In PLAXIS, stresses and strains are calculated at individual Gaussian integration points rather than at nodes. In the calculation stage, analysis type is chosen such as Plastic, dynamic, consolidation and phi-c reduction. The assigned loads are activated in this stage and analyzed. In the post processing stage, curves are plotted between various calculated parameters such as load Vs displacement. In PLAXIS Phi-c reduction method is used to compute factor of safety (FOS) for dump slope stability. The total multiplier $\Sigma Msf$ (Eqn. 1) is used to define the value of the dump material strength parameters at a given stage in the analysis.

$$\Sigma Msf = \frac{\tan \Phi}{\tan \Phi_p} = \frac{c}{c_p}$$  \hspace{1cm} (1)
The safety factor is then defined as the value of $\sum M_{af}$ at failure, provided that at failure more or less constant value is obtained for a number of successive load steps. Different trials were made with overburden and mixture of overburden and fly ash with overall slope angle of 27°. Here two trials are presented.

This trial-1 was made with the overburden and mixture of over burden with 25% fly ash. The results are shown in Figure 9. The Factor of Safety obtained was 1.75, and as it is much higher than 1.2. This overburden does satisfy the minimum requirement and can be used along with the fly ash.

![Fig. 9: Failure surface with factor of safety 1.75 as per PLAXIS analysis for Trial 1](image)

This trial-2 was made for the dump prepared by alternate layer of overburden and mixture of overburden and 25% fly ash along with the incorporation of top soil of nearly 2 meter thickness at the top of the dump for the reclamation purpose. The Factor of Safety obtained was 1.78, and as it is more than 1.2. This indicates that at the end the dump after dozing of top soil, the dump satisfies the minimum requirement and can be used. However, top soil should be protected against rainfall by taking measures like plantation, geosynthetics, or jute/coir reinforcement. The compaction control may be periodically checked for proper compaction of overburden and fly ash mixture. Slope stability of the overburden dump after mixing of fly ash, it was observed that on the application of 25% fly ash mixture safety factor has increased to 1.78, which was only 1.32 with 8% fly ash mixture with overburden. This increase may be attributed to the increase in cohesion of the mixture due to self-cementing properties of fly ash generated from the combustion of sub-bituminous coal. In presence of water, the fly ash will harden and get strength over time. Fig. 10 to 12c shows a view of the overburden dump form by utilizing fly ash at Jindal Power Limited, Tamnar, along with the top soil and the plantation over the admixture of Ob and fly ash.

![Fig. 10: A view of the top soil on the fly ash+OB dump at Jindal Power Limited, Tamnar](image)
SLOPE STABILITY MONITORING

As per the DGMS permission for fly ash filling in opencast working along with overburden, height of dump was limited to 30 m. The height of dump at study site was about 25 m. Stability of Dump slopes was monitored with total station and monitoring stations fixed at an interval of 20 to 30 m on the dumps at a distance of about 5 m from the crest of the dump slope (Fig 11) [6]. 47 monitoring stations were installed with 1.0 m long pipes and masonry pillars; 23 stations in the Pit 1 and 24 stations in Pit 2 (Fig 12 and 13). Final stage dump consist of 2 m top soil above the layers of OB and OB mixed fly ash material. Fig 14 shows GPS survey for monitoring the location of the stations.

Fig 11: Monitoring stations at an interval of 30 m on the dumps at a distance of about 5 m from the crest of the dump slope

Fig 12: Monitoring stations were installed with 1.0 m long pipes and masonry pillars
Maximum Vertical deformation of -0.018 m was noticed in Pit 1, while the Vertical deformation was limited to -0.01 m in Pit 2. Negative deformation may be considered as settlement of the material over time. The analysis of the RLs of the monitoring stations in Pit-1 and Pit-2, respectively during November 2012 to Nov’2013 indicated stability of the dumps. As the dump was formed a year back, it was also observed that settlement of the dump material at some places may take about a year. Plantation on the same dump is under progress with successful survival rate of the species such as banana, Teak, mango etc. Fig 15 illustrates the preparation for the plantation, while a well grown banana trees on the dump are shown in Fig 16.
8.0 CONCLUSIONS

Fly ash generation and utilisation scenario indicates urgent need of efforts from concerned agencies for reducing the gap of about 110 Million tones of Fly ash (FA) during 2011-12. Although meticulous attempts are being made by CFARM-New Delhi under the Dept of Science and Technology, many more studies are required for eco-friendly application in mass utilisation of FA. Considering the importance of mass utilisation of Fly ash in the coal mining area, and limitations of available technology for its utilisation it is recommended to undertake experimental studies for mass utilisation of the ever increasing Fly Ash production in India. One such experimental trial conducted for the first time in India at M/s JPL mines proved stability of the dumps with 25% Fly ash as admixture in the OB dumps. Dumps with alternative layer of overburden and overburden mixed with fly ash (only 25%) are found to be stable with safety factor more than 1.2 for the following geometry of the dump:

- Total height of the dump: 120 m
- Number of decks: 4
- Height of individual deck: 30 m
- Slope of each deck: 32°

Fig. 16: A view of the plantation over OB+FA dump at Jindal Power Limited, Tamnar

Beside the dump form with alternate layer of overburden and mixture of fly ash and overburden after dozing the top soil of nearly 2 m thick at the top, the slope also found stable with safety factor 1.78 for the above geometry. For the long term stability of the slope Top soil should be protected against rainfall by taking measures like plantation, geosynthetics, or jute/coir reinforcement. The compaction control should be periodically checked for proper compaction of overburden and fly ash mixture. As it was observed rainfall intensity is high during monsoon/cyclone, so gully drains may be provided along the slope at regular intervals. Toe walls and peripherals drains may be required after observation of the dump slope during heavy rainfall. In view of impetus on the application of innovative technologies at the earliest in India, there is an urgent need to formulate expert committees in various disciplines including academia, research, regulatory and field personal besides CFARM-DST for formulating reliable guidelines near future. Displacement pattern of the monitoring stations during November 2012 to the end of November 2013 indicated no significant displacement in the Overburden dumps with fly ash ensuring stability of the dump.
9.0 ACKNOWLEDGEMENT
Thanks are due to the officers of Jindal Power Limited, Tamnar, Raigarh for providing necessary financial and logistic support for carrying out this work, and also to the National Institute of Technology, Rourkela for allowing to do this scientific study.

10.0 REFERENCES