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Assessment and Characterization of Mine Waste and Fly Ash Material for Effective Utilization in Opencast Coal Mines

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***Abstract:** Coal is a major source of nonrenewable energy in India. Most of the Industries depend on the coal to meet the energy demand of the country. Coal mining is invariably associated with the generation of voids. The voids so generated are often filled with overburden (OB) and waste materials. To enhance the utilization, fly ash (FA) is also being used for filling the voids. However, these operations inevitably require excessive planning and control to minimize the environmental impact of mining. In order to evaluate the impact of backfilling the voids with coal mine wastes and fly ash, Overburden and fly ash materials have been collected from Talcher coalfield. The geotechnical characterization study of overburden (OB) sample and OB+30% fly ash samples have been carried out separately for backfilling. After addition of fly ash, it is observed that the permeability is increased but liquid limit, plastic limit, and plasticity index (PI) of the OB are decreased. The maximum dry unit weight of OB mixture decreases while optimum water content increases with the fly ash. The angle of internal friction of OB decreases after addition of the fly ash. Cohesion value of OB sample has not changed much after addition of the fly ash. The grain size analyses results show OB sample is poorly graded. The OB soil type is found to be poorly graded sand of low compressible clay (SP-CL). Similarly, the OB+30% fly ash soil type is of poorly graded sand of low compressible silty (SP-ML) type. The OB and OB+ 30% fly ash contain heavy metals such as Fe and Al in high quantity, mild concentrations of Zn, Cr, and Mn and low amounts of Cu, Co, As, and Se. B and Pb are found below the detection level. The decreasing order of heavy metals in the leachate samples observed to be Fe>Mn>Ni>Cu>Zn>Se>Co>Cd>Cr>As. The major mineral phases in OB and OB+30% fly ash samples are found to be quartz, kaolinite, muscovite, dickite, zinnwaldite, and illite.*

***Keywords:** Overburden; Fly ash; Backfilling; Geotechnical Analysis; Geochemical Analysis; Leaching; Mineralogy*

I. INTRODUCTION

Coal represents around 97% of the fossil fuel in India. Coal reserves of 315,148.81 million tonne up to 1200m depth are assessed by Geological Survey of India (GSI) as on 01.04.2017 for coal seams of 0.90m and above in thickness. The coal resources are existed in sedimentary rocks of more settled Gondwana establishments of peninsular India amounts to approx. 313,561.13 million tone and early Tertiary arrangements of north-eastern/northern hilly area up to approx. 1,587.68 million tonne [1]. India is the world's third-largest consumer of coal as it consumes around 8% of the total world's coal [2].

Around 46.28% of the energy demand in the country met from coal and lignite in 2015-16 [3].The mining leasehold area occupies around 0.7 million hectares which account for 0.21 percent of the total land mass in India [4]. India is ranked sixth with 2.7 % of the total world coal reserves. Opencast mining of coal is contributed to 93.31% of India's total coal production in 2016-17[5]. Opencast mining creates a large void once the coal is extracted. As per the current practice the void is required to be filled with waste material. Most of the time the waste generated from the mines such as overburden, partings, shales etc. are used for the purpose. On many occasion, it has been seen that the quantity of waste generated is not sufficient to fill the voids. Therefore, fly ash generated from the thermal power plants has been used as an alternate backfilling material. Sometimes fly ash used alone, some other times it is mixed with OB in different proportion [6] and filled in the mine void. Difficulties have been experienced in mining areas in terms of environmental pollution and stability issues after backfilling is done with mine waste such as Overburden, tailings, low-grade ores, partings etc. which may be partially attributed to a lack of noteworthy research and technical knowledge concerning stability, leachability, and compatibility. An assessment of the stability of waste materials, which are used in mine backfilling, may be useful in ascertaining the various stability and environmental issues associated with it. The assessment can guide us in planning the backfilled area, proper leachate collection and treatment facilities.

II. STUDY AREA

Talcher coalfield (Figure 1 and 2) is the largest repository of power grade coal with 50.969BT reserve in India. Talcher coalfield covers the south-eastern region of the Lower Gondwana belt inside the Mahanadi river valley basin surrounded by Latitude $20^0$53' to $21^0$12' N and Longitude: 84^0 to $85^0$23'E. The climate of the area is dry, arid, warm to hot with average temperature ranging from m 9.9^0C to 44.4^0C, average humidity range is around 26% to 83%, yearly average wind velocity is 7 Km/hr, and average annual rainfall is 1329 mm.

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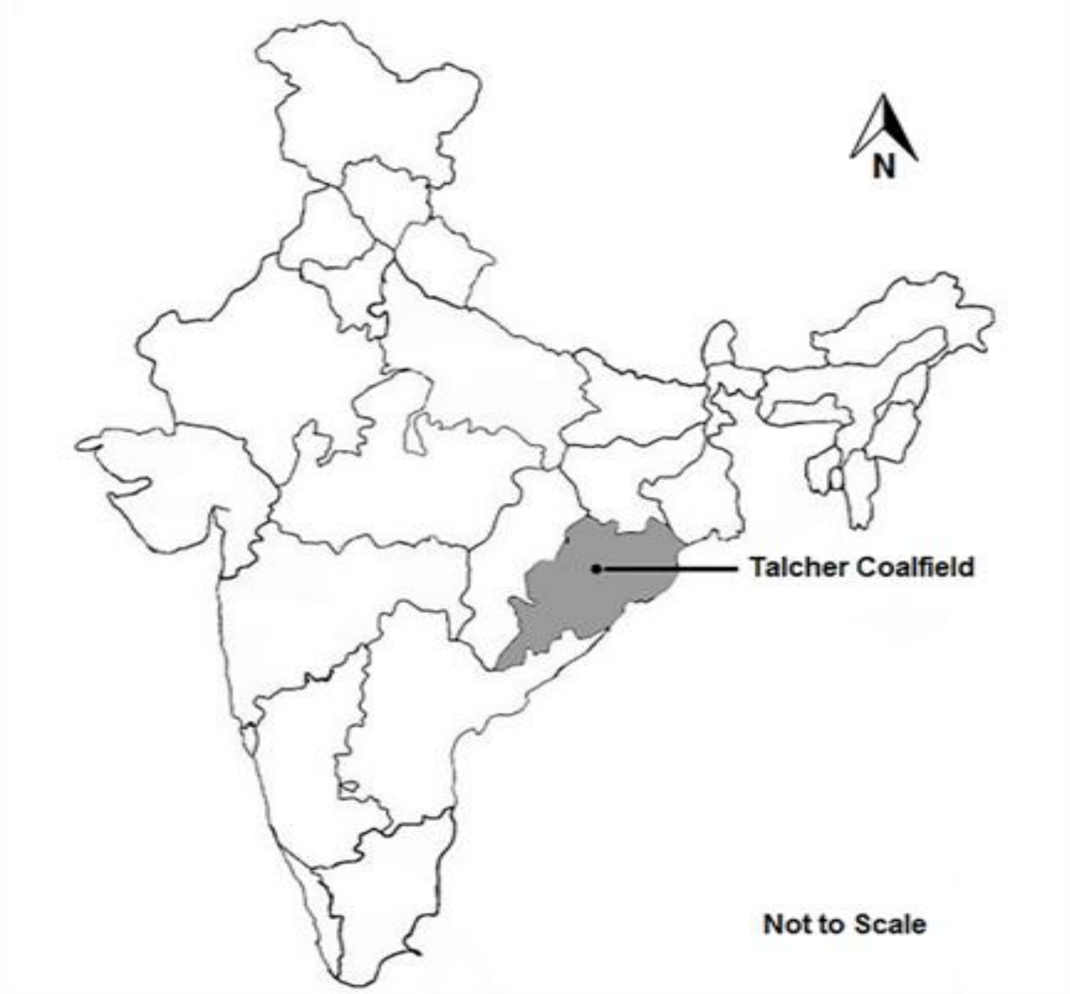

Figure 1: India map showing the study area

Figure 2: Google earth map of Talcher coalfield area

III. GEOLOGY

Talcher Coalfield is a portion of large synclinal Gondwana Basin of Raigarh-Hingir and Chhattisgarh Coalfields. The geological succession [7] and geological map [8] of the Talcher coalfield area are shown in Table 1 and Figure 3.

Table 1 Geological Succession of Talcher Coalfield [7]

Age	Formation	Lithology	Thickness
Recent		Alluvium and Laterite	
Up. Permian To Triassic	Kamthi	Fine to medium-grained Sandstone, Shale, Coal bands, with greenish sandstone, pink clays and pebbly sandstones at top	250m+
Lower Permian	Barakar	Medium to coarse-grained sandstones, shales, coal seams with oligomictic conglomerate at base	500m+
Lower Permian	Karharbari	Medium to coarse grained sandstones, shales, and coal seams (270m)	270m+
Lower Permian	Talchir	Dimictite, fine to medium grained greenish sandstones, shales, rhythmite, turbidite etc.	170 m +
……………………….………..Unconformity………………………………………………………			
Precambrian		Granites, Gneisses, amhibolites, migmatites, Khondalites etc.	

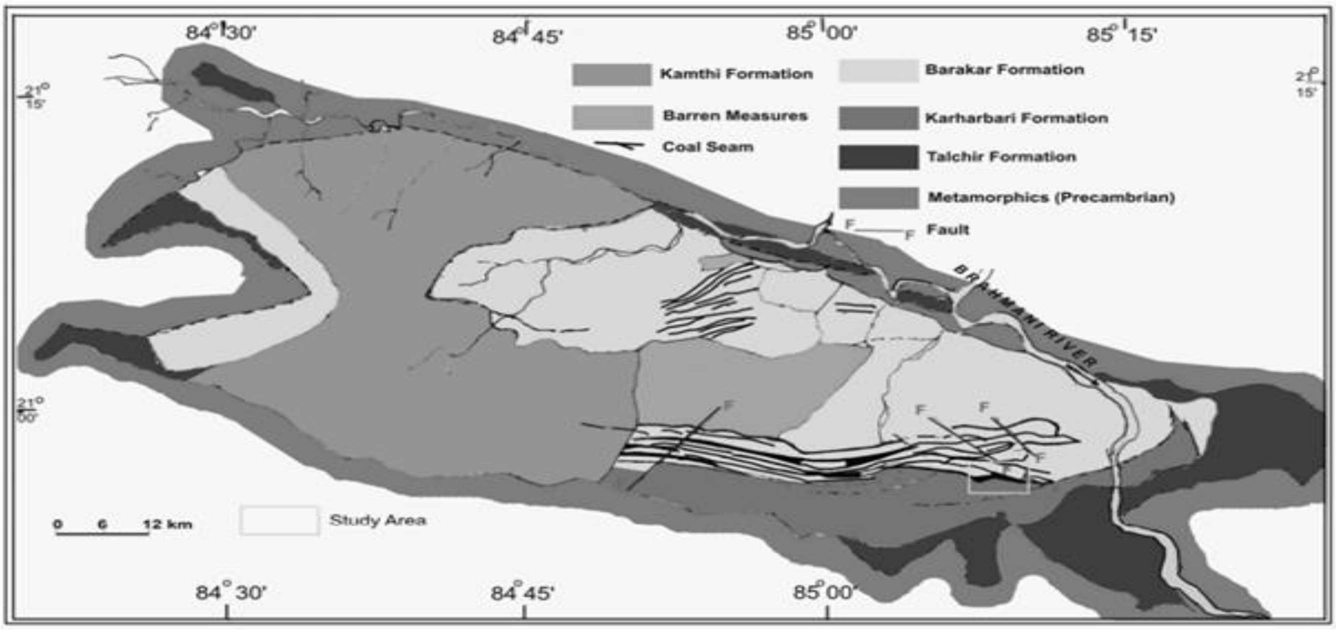

Figure 3: Geological Map of the Talcher coalfield area [8]

IV. MATERIALS AND METHODS

1.1 Sampling of Fly ash

Fly ash sample type F from the National thermal power plant is transported through pipeline to an abandoned Opencast mine. From the project area, fresh fly ash samples were collected. Then the samples were dried at 105^0 C for 48 hours before the experimentation [9]. Then 30% fly ash was mixed with each overburden sample.

1.2 Sampling of Overburden for Geotechnical Analysis

A Large amount of OB samples were collected up to a depth of 0.6m and mixed methodically from randomly selected points situated on the surface of the waste dumps of opencast mines at Talcher coalfield.

OB wastes were spread out on clean plastic mat to dry at ambient temperature. After drying, the waste materials were mixed thoroughly. The waste materials were then sieved with a sieve shaker. The less than 2 mm portion being homogenized for 30 minutes. The greater than 2 mm fraction is rejected. Then coning and quartering procedure was followed to obtain a representative sample [10].

1.3 Sampling of Overburden for Geochemical and Mineralogical Analysis

Mine overburden samples were collected arbitrarily from 0-15 cm depth, by digging pits 15×15×15cm^3 size. The samples were homogenized, sieved (200μm) and preserved at 4 ^{0}C until experimentation [11].

V. RESULT AND DISCUSSION

1.1 Geotechnical Analysis

Any material to be used effectively in backfilling in opencast mines has to be tested with its short and long-term mechanical properties and likely behaviour following placement. This will allow an assessment of the fill's ability to act as a ground support material. In this study, first of all 30% fly ash is added to the overburden. Then the OB and OB+30% FA samples are subjected to various geotechnical tests such as Slake Durability [12], Standard Proctor Compaction [13], Constant head Permeability [14], Atterberg Limits [15], Direct Shear [16], and Grain size analysis [17] as per the Indian Standards. IS: 2720-Part I, 1983 [18] is referred for preparation of dry soil sample for the experiments. The results of the geotechnical analyses have been presented in Table 2.

Table 2 Geotechnical Parameters Analyses Results of OB and OB+30%FA

Test Type	Parameters	OB	OB+30%FA
Slake Durability	Id1	96.65 %	Nil
	Id2	92.68 %	Nil
Standard Proctor Compaction	Maximum dry density	2.19 g/cm^3	1.79 g/cm^3
	Optimum moisture content	11.65 %	17.80 %
Constant head Permeability		5.84*10^{-4} cm/sec	8.89*10^{-4} cm/sec
Atterberg Limits	Liquid limit	18.05 %	14.88%
	Plastic limit	12.35 %	9.62 %
	Plasticity index	5.7 %	5.26 %
Direct Shear	Cohesion	0.13 kg/cm2	0.16 kg/cm2
	Angle of internal friction	32.61 degree	27.92 degree
Grain size	Coefficient of uniformity(u)	17.02	15.71
	Coefficient of curvature(c)	0.57	0.58
	Gravel (%)	16.9	16.1
	Coarse Sand (%)	19.1	19.2
	Medium Sand (%)	28.7	31.2
	Fine Sand (%)	26.7	24.4
	Silt and Clay (%)	8.6	9.1

1.2 Geochemical Analysis

Overburden soil has an important role in sustaining environmental value in mining area. Doran and Parkin (1994) [19] observed that overburden soil helps in maintaining the environmental quality, improve plant and animal health; and regulates biological productivity. Mining activities alter the soil quality and result in potentially toxic chemical viz. metals, metalloids and elements contamination, which leads to various harmful effects. Heavy metals in plants or animals in minor concentrations are not toxic, rather useful. However, lead, cadmium, and mercury are potentially toxic even in very small concentrations [20].

Geochemical analysis and leachability study of backfilled materials such as mine overburden soil and fly ash will help us to understand various phenomena such as metal mobility, soil toxicity, leaching potential etc. The OB and OB+30% Fly ash samples are subjected to various geochemical examinations viz. pH, conductivity, organic carbon and trace metals as per the standards prescribed in Jackson,1958 [21] and Black, 1965 [22]. The results of the geochemical analyses have been presented in Table 3.

Table 3 Geochemical parameters Analyses Results of OB and OB+30%FA

Sample Id / Parameters	OB	OB+30%FA
Temp (^{0}C)	29.3	29.90
PH	3.64	5.64
Electrical Conductivity (µS/cm)	362.2	262.80
Organic Carbon (%)	0.89	0.74
Al (mg/kg)	1988	2217.00
B (mg/kg)	BDL	BDL
Ca (mg/kg)	729	753.00
Cd (mg/kg)	6.8	7.60
Co (mg/kg)	6	8.00
Cr (mg/kg)	35	36.10
Cu (mg/kg)	12	13.00
Fe (mg/kg)	2859	3058.00
K (mg/kg)	967	977.00
Mg (mg/kg)	756	794.00
Mn (mg/kg)	35	39.00
Na (mg/kg)	178.5	178.50
Ni (mg/kg)	10.5	14.00
Pb (mg/kg)	BDL	BDL
Zn (mg/kg)	36.5	38.00
As (mg/kg)	6	8.00
Se (mg/kg)	6.92	7.03

1.3 Leaching

Fly ash from various nearby Industries can be utilized in addition with OB as mixing of fly ash in optimum quantity in certain cases can increase the stability of backfilled materials due to its pozzolanic nature. However, leaching of backfilled materials is a serious matter of concern. Leaching produces various bio-toxic chemicals like heavy metals, metalloids etc, resulting in water and soil pollution, thereby posing a great risk for the aquatic living organisms, habitat, human beings etc. Leachability study of the waste conveys useful information about the susceptibility of the waste towards leaching. In the current work, three types of leaching agents viz. acid, rainwater and distilled water. The OB+ 30% fly ash samples were cured for fourteen days before leaching. Each sample was subjected to acid leaching, rainwater leaching, and distilled water leaching as per the method prescribed in EPA SW 1984 [23] Hence, a total of six different types of leachate samples three each were produced from the two samples. The results of the leaching analyses have been presented in Table 4.

Table 4 Leaching Experiment Results of OB and OB+30%FA samples

Parameters	OB-Acid	OB-Rainwater	OB-Distilled water	OB+30% FA-Acid	OB+30% FA -Rainwater	OB+30% FA-Distilled water	Max	Min	Mean	Std. Dev.
pH	2.92	4.21	4.81	5.23	5.42	5.73	5.73	2.92	4.72	1.03
EC	650	651	553	859	761	489	859	489	660.5	134.66
Nitrate	6.327	2.147	2.015	7.823	5.163	2.109	7.823	2.015	4.26	2.53
Sulfate	70.17	39.16	35.33	53.53	39.73	33.73	70.17	33.73	45.28	14.06
Chloride	2.153	1.46	1.44	3.84	2.71	1.136	3.84	1.136	2.12	1.02
Fluoride	0.38	0.09	0.08	0.8	0.6	0.9	0.9	0.08	0.48	0.35
As	BDL	BDL	BDL	BDL	BDL	BDL	0	0	0	0

Ni	0.362	0.245	0.221	0.712	0.203	0.033	0.712	0.033	0.296	0.23
Zn	0.085	0.0462	0.0236	0.0533	0.043	0.022	0.085	0.022	0.046	0.023
Co	0.024	0.012	0.013	0.056	0.026	0.009	0.056	0.009	0.023	0.017
Fe	0.851	0.431	0.232	3.724	1.361	0.269	3.724	0.232	1.145	1.334
Mn	0.562	0.274	0.146	2.495	1.036	0.272	2.495	0.146	0.798	0.891
Mg	5.322	2.307	2.839	7.872	2.521	2.783	7.872	2.307	3.941	2.218
K	16.65	14.51	12.83	20.51	11.65	13.64	20.51	11.65	14.965	3.197
Na	43.17	24.28	23.1	16.11	13.89	13.12	43.17	13.12	22.278	11.255
Ca	17.89	11.62	9.23	14.63	10.17	11.89	17.89	9.23	12.572	3.188
Cu	0.224	0.195	0.037	0.018	0.013	0.041	0.224	0.013	0.088	0.095
Se	0.081	0.024	0.023	0.006	0.002	0.011	0.081	0.002	0.025	0.029
Cd	0.014	0.008	0.007	0.023	0.013	0.006	0.023	0.006	0.012	0.006
Cr	0.021	0.008	0.002	0.031	0.009	0.003	0.031	0.002	0.012	0.011

1.4 Mineralogical Analysis

Mineralogy deals with the examination of minerals. A mineral is a natural homogeneous solid with a fixed crystallographic identity and chemical composition. If quartz is present in fairly large percentages in coal wastes, it may help to strengthen the refuse. The surfaces of quartz particles are very rough and contact between those rough surfaces provides increased frictional resistance to sliding and shear. The shearing resistance of the tailings is also dependent on the size and shape of the clay and quartz minerals.

Angular particles such as quartz interlock and provide more frictional resistance than thin, platy clay particles such as kaolinite, illite, dickite etc., that tend to interact face-to-face and have less frictional resistance [24]. In this research work, minerals of OB and OB+30% FA have been identified by XRD, SEM and FTIR as shown in figure 4,5,6,7,8,9,10 and 11.

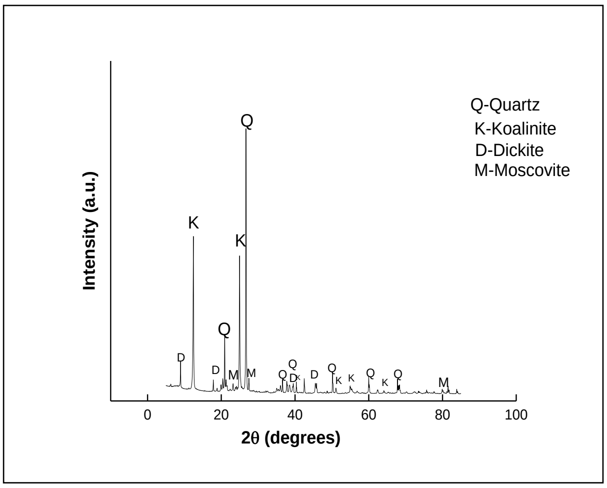

Figure 4: XRD pattern of OB

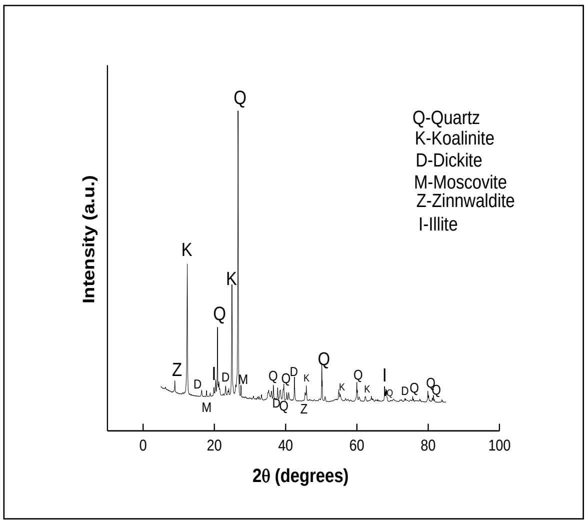

Figure 5: XRD pattern of OB+30%FA

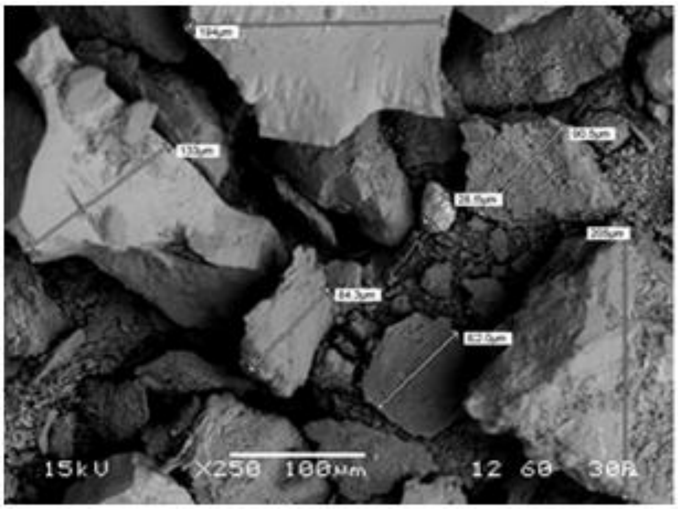

Figure 6: SEM image (100µm) of OB

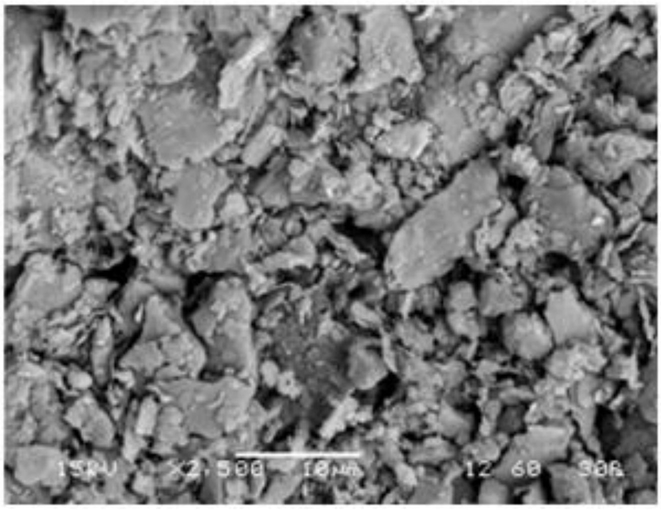

Figure 7: SEM image (10µm) of OB

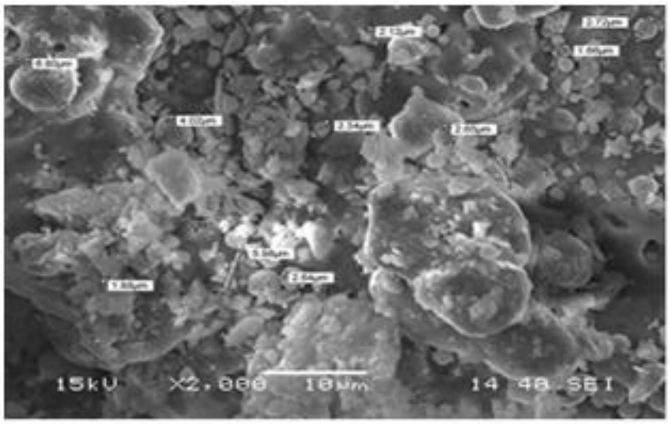

Figure 8: SEM image (10µm) of OB+30%FA

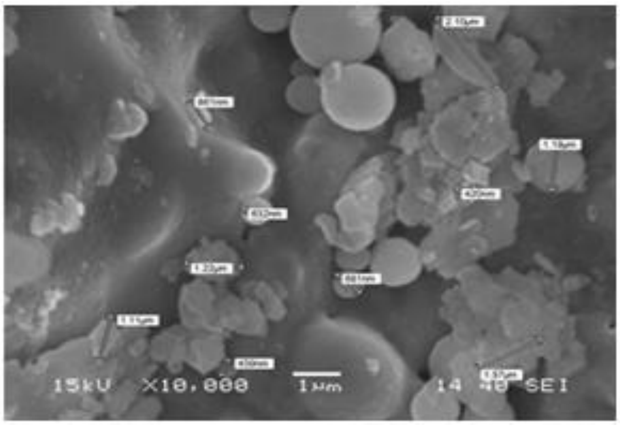

Figure 9: SEM image (1µm) of OB+30%FA

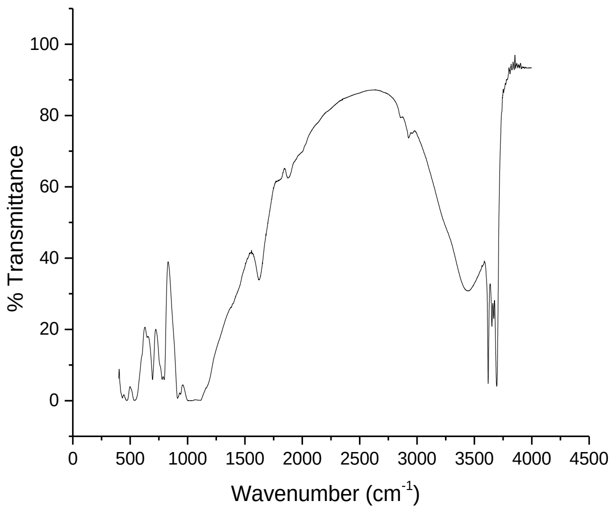

Figure 10: FTIR spectra of OB

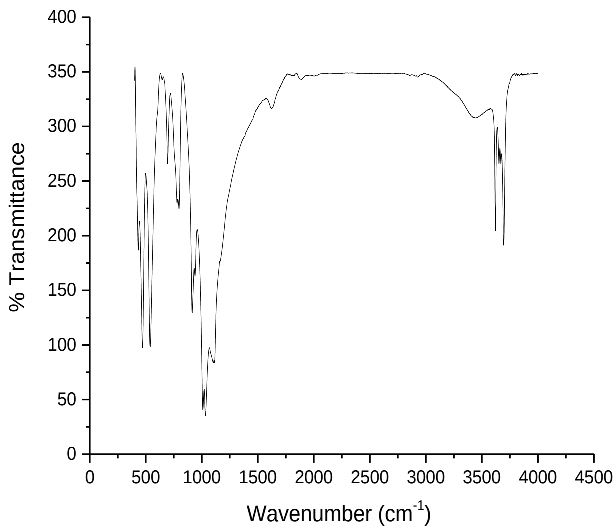

Figure 11: FTIR spectra of OB+30%FA

Slake durability test: Only the gravel fractions of the OB sample were subjected to Slake durability test. Durable materials are less prone to leaching and weathering. Gamble's Slake durability classification table has been referred to ascertain the durability of overburden samples. The sample should at least have medium durability to be used as filling materials i.e. Id1 should be greater than 95 and Id2 greater than 85 [10].

The OB Sample is found to have medium-high durability.

Standard Proctor Compaction: Compaction of the soil can minimize void space thus increases its shear strength and density and cuts its compressibility and permeability. MDD of OB is higher than that of OB+30% Fly ash whereas OMC is higher in case of OB+30% Fly ash than OB. The increase of quantity of fly ash cause addition of finer fraction and lower weight and hence decrease the dry densities of OB-fly ash sample**.** The compacted density of the sample is pretty close to the compacted densities of sand, which has been successfully used as hydraulic stowing material in India. Sand mainly has a compacted dry density unit weight between 1.7 to 2.2 g/cm3 [25].

Permeability: The nature of water flow through an unconsolidated material will have a great effect on physical properties of that material. Permeability can influence the rate of settlement of a saturated soil under load. The stability of slope can be massively affected by the permeability of the soil to be used.

Stowing material should have permeability around 2.78×10^{-3} cm/sec. [26] Kim et al. (2005) [27] observed that addition of fly to soil increases hydraulic conductivity of the soil sample because of the rise in silt-sized particles which make the soil sample relatively coarser. Subsequently, flocculation and agglomeration reaction takes place in the soil-fly ash mixture.

Direct Shear Test: Maximum resistance of a soil to shear stresses on the failure plane is measured in terms of its Shear strength. Factors such as the degree of saturation and drainage conditions of the soil affect the parameters of the shear strength. From the experimental data, the shear strength parameters are determined by Mohr-Coulomb strength equation. ($\tau = c + \sigma \tan \phi$) where, τ = shearing resistance of soil at failure; c = apparent cohesion of soil; σ = total normal stress on failure plane; ϕ= angle of internal friction of soil [28].

The angle of internal friction decreases as the percentage of fly ash rises. However, cohesion has been improved which means more interlocking between the particles in OB+30%FA ash mixture.

Particle Size Distribution: Soil gradation is a good indicator of engineering characteristics such as compressibility, shear strength, and hydraulic conductivity. Keeping this in mind, the grain size analysis was carried out for all the OB and OB+30% fly ash. Soils have been classified into three broad categories based on its particles sizes such as very coarse soil, coarse soil, and fine soil. The very coarse soil is divided into boulder size (>300 mm) and cobble size (80-300mm). The coarse soil is classified into 2 subclasses such as gravel size and sand size. Further, the gravel size is classified to coarse size (20-80mm) and fine size (4.75-20) and the sand size is divided into coarse sand (2 - 4.75 mm), medium sand (0.425 - 2 mm), and fine sand (0.075 - 0.425 mm). The fine soils are divided into silt size (0.002 - 0.075 mm) and clay size (< 0.002 mm). When the coefficient of uniformity Cu is greater than 4 to 6 (for coarse and fine-grained soil respectively), the soil is considered to be a well-graded soil. Whereas, if the Cu is lower than 4, the soil is said to be poorly graded or uniformly graded. Similarly, when the coefficient of curvature Cc is more than 1 and less than 3 ($1 < Cc < 3$), the soil is considered to be well-graded soil, otherwise poorly graded or uniformly graded soil [29]. The samples are found to have Cu greater 6, but the Cc values are less than 1. Therefore both OB and OB+30%FA materials are considered to be poorly graded ones.

Liquid limit, Plastic limit and Plasticity Index: Morgenstern and Eigenbrod (1974) [30] stated that when the liquid limits for the weathered particles are in the range of 20 to 50, rocks exhibit only small amount of slaking and are generally slightly plastic. However, an important aspect of wastes having plastic properties is that when excess pore pressures are there in the fill, it may not be quickly dissipated as the material is subjected to increase in stress. Thus, it would be desirable that the waste materials should be non-plastic in order to be considered as suitable backfilling material. The liquid limit, plastic limit and plasticity index of OB is higher than that of OB+ fly ash. This may be due to the flocculation/ agglomeration reaction caused by fly ash particles with soil [31]

Mineralogy: XRD: The mineral phase XRD pattern, resulting peaks (Figure 4 and 5) are compared to the standard JCPDS number. The major mineral phases in OB and OB+30%FA samples are found to be quartz (JCPDS no. 46-1045), kaolinite (JCPDS no. 75-1593), muscovite (JCPDS no. 07-0042), dickite (JCPDS no. 76-0632), zinnwaldite (JCPDS no. 42-1399), and illite (JCPDS no. 26-0911).

The bands at 900 cm^{-1} and 1160 cm^{-1} may be due to the presence of SO_4^{2-}groups [32]. Presence of Quartz can be attributed to absorption band at 1200 to 1000 cm^{-1} as in this region, Si-O stretching mode includes motion mainly because of oxygen atom. Again absorption band at 850 to 600 cm^{-1} is associated with Si-O stretching mode motion of Silicon. Absorption bands at 600 to 390 cm-1 and 380 to 100 cm-1 may be associated with Si-O bending modes and distortion modes respectively [33].

The SEM images (Figure 6, 7, 8, and 9) show sand Size (0.0625 to 2 mm), silt-size and aggregated clay size OB and OB+30% FA particles. OB+30% FA Samples are having micro-cracks and pores (mainly Figure 8 and 9). Reasonable pozzolanic activity of fly ash with OB has been confirmed in SEM images as glassy fibrous particles are observed though no peaks for calcium silicate hydrate and calcium aluminium hydrate is observed in XRD analysis. In OB+30% FA sample, aggregation is observed due to the pozzolanic activity of FA particles. Big agglomerated particles are seen in all the OB+30% FA mixture samples. Several spherical particles together with irregularly shaped particles are observed. The rounded particles are mostly glassy. The angular particles are typically made of crystalline solids such as quartz, mullite, magnetite, hematite etc. The spherical particles represent magnetic components of any fly ash sample and spheroid particles are correspond to a non-magnetic fraction of the fly ash sample (Figure 8 and 9) [34].

Geochemistry: The physicochemical parameters of the samples are presented in Table 3.

It can be seen from the results that the OB soil is acidic as its pH is 3.64 while OB+30% FA soil pH is 5.64. The organic carbon content of OB and OB+30% FA is very low of 0.89% and 0.74%. The electrical conductivity is 362.2 and 262.80 µS/cm for OB and OB+30% FA. Both the OB and OB+30%FA soil is mostly acidic, low in organic carbon content and slightly high in conductivity. Hence, these soil may not support plantation.

Potentially toxic metals and elemental concentrations of the samples are presented in Table 3. In case of OB, the concentrations of Al, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Zn, As, Pb, and Se are 1988 mg/kg, below detection limit (BDL), 729 mg/kg, 6.8 mg/kg, 6 mg/kg, 35 mg/kg, 12 mg/kg, 2895 mg/kg, 967 mg/kg, 756 mg/kg, 35 mg/kg, 178.5 mg/kg, 10.5 mg/kg, BDL, 36.5 mg/kg, 6 mg/kg, BDL, and 6.92 mg/kg. The decreasing order of heavy metals for OB are found to be Fe>Al>K>Mg>Ca>Na>Zn>Mn>Cr>Cu>Ni>Se>Cd>Co>As>B>Pb. For OB+30% FA, the average concentrations of Al, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Zn, As, and Se are 2217 mg/kg, BDL, 753 mg/kg, 7.60 mg/kg, 8 mg/kg, 36.10 mg/kg, 13 mg/kg, 3058 mg/kg, 977 mg/kg, 794 mg/kg, 39 mg/kg, 178.50 mg/kg, 14 mg/kg, BDL, 38 mg/kg, 8 mg/kg and 7.03 mg/kg. The decreasing order of heavy metals for OB+30%FA are found to be Fe>Al>K>Mg>Ca>Na>Mn>Zn>Cr>Ni>Cu>Co>As>Cd >Se>B>Pb. The Heavy metals for which standards are available are found to be under the standards (Tables 5) [35].

Table 5 Indian Safety Limit for Soil [35]

Elements	Co	Cr	Cu	Mn	Ni	Pb	Zn
Standard (mg/kg or ppm)	60–100	NA	135–270	NA	75–150	250–500	300–600

Leaching: The leachate quality analysis results of the mine have been presented in Table 4. The pH in the leachate samples are found be acidic for both OB and OB+30% FA with lowest pH of 2.92 is observed in OB acid leachate sample. They do not conform to the permissible limits of 6.5-8.5 [36]. EC varies from 489 to 859 µS/cm with an average of 660.5 µS/cm. Nitrate ranges from 2.015 to 7.823 mg/l. Sulfate varies from 35.33-70.17 mg/l with a mean concentration of 45.28, which is well below the permissible limit. Chloride ranges from 1.136 to 3.84 mg/l. Fluoride is found in the range of 0.08 to 0.9 mg/l with an average of 0.48 mg/l, that is below the permissible limit of 1mg/l. Among the trace elements, As is found below detection level. Ni varies from 0.033 to 0.712 mg/l, Zn ranges from 0.022 to 0.085 mg/l, Co varies from 0.009 to 0.056 mg/l with an average of 0.023 mg/l, Fe ranges from 0.232 to 3.724 mg/l with an average of 1.145, which is above the tolerable limit. Mn varies from 0.146 to 2.495 mg/l with a mean of 0.798, Mg varies from 2.307 to 7.872mg/l, K ranges from 11.65 to 20.510 mg/l, Na varies from 13.12 to 43.17 mg/l. Ca is found to be between 9.23 and 17.89 mg/l. Cu varies from 0.013 to 0.224 mg/l with an average of 0.088. Se varies from 0.002 to 0.081 mg/l with an average of 0.025 mg/l. Cd is observed in the range of 0.006 to 0.023 mg/l with an average of 0.012 mg/l. Cr is found to be ranged from 0.002 to 0.031 mg/l with an average of 0.012 mg/l. The decreasing order of heavy metals observed in the leachate samples are Fe>Mn>Ni>Cu>Zn>Se>Co>Cd>Cr>As. When OB and OB+30% fly ash is subjected to leaching it is observed that the leaching potential of acid is more than both rainwater and distilled water. After further analysis, we also observed that the leaching potential of rainwater is more than distilled water.

VI. CONCLUSION

In this paper, we presented geotechnical, geochemical, and mineralogical characterization of Overburden and Overburden+30% fly ash to examine their feasibility to be used in backfilling in opencast mines. The geotechnical tests carried out in this study establishes that the OB sample is of medium-high durability. So they can be used for backfilling. After addition of fly ash, the permeability increases for the OB sample, while liquid limit, plastic limit, and plasticity index (PI) decrease after addition of 30% fly ash; which is good from backfilling point of view. The maximum dry unit weight of OB mixtures is expectedly decreased with 30% fly ash contents while optimum water content is increased as the amount of fly ash in the mixture increased. All the samples conform to the recommended maximum dry density value and thus can be considered suitable for backfilling in terms of MDD. The angle of internal friction decreases as the percentage of fly ash rises in the OB-fly ash mixture. Cohesion value of OB sample is increased after addition of fly ash. The grain size analysis results show that all the samples are poorly graded. The soil type is found to poorly graded sand of low compressible clay (SP-CL). Similarly, the fly ash sample is found to be poorly graded and the fly ash soil type is of poorly graded sand of low compressible silty (SP-ML) type. From the foregoing, it is confirmed that to a reasonable extent, 30% of fly ash can offer the potential for stabilization of OB in backfilling.

Geochemical examination has confirmed that both the OB and OB+ FA soil is mostly acidic, low in organic carbon content, slightly high in conductivity, and contaminated with heavy metals. This may not support plantation as effectively as any other normal fertile soil. The OB and OB+ 30%FA is susceptible to leaching which may lead to contamination of water and soil. The chief minerals present in the samples are found to be quartz, kaolinite, muscovite, dickite, zinnwaldite, and illite.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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