Geotechnical and Geochemical Characterization of Coal Mine Waste for Restoring Environment

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***Abstract* — Mining is an essential activity required to be carried out for obtaining the raw materials for infrastructures, goods, carriers and energy. However extreme exploitation of mineral resources leave a negative impact on the environment affect air, water and soil leading to the destruction of ecosystem. Large quantities of waste are generated in the process of mining comprising of solid, liquid and gaseous substances. The solid waste generated due to mining activities are significant because of their sheer volume. The Geotechnical characterization of the waste such as particle size, plasticity, bulk density, dry density, durability, and shear strength are carried out to determine stability of the waste dumps for backfilling. Geochemical parameters of the waste are examined to understand the elemental distribution and leachability of the potentially harmful heavy metals and toxic elements. Water quality analysis of the 2 different coal mine samples have been studied to know their potential environmental impact. The Overburden material and water analysis results indicate that there is the possibility of potential environmental impact that could be due to acid mine drainage and associated weathering and leaching of heavy metals and other elements.**

Keywords — Backfilling; Geotechnical properties; Water quality; Overburden; Leachate

I. INTRODUCTION

Coal mining industry is one of the oldest and largest industries in India widely spread over several states. Currently 301.56 billion tonnes and 43.25 billion tonnes of coal and lignite reserves have been estimated by the Geological Survey of India up to a depth of 1200 meter as on 01. 04. 2014. MCL Report [1] During the extraction of coal, large quantities of wastes are also produced. Disposal of these waste cause environmental pollution, land degradation and deforestation of the area. Coal reserves cover an area of 2.3million hectares of land in India and there are already more than 1000 abandoned coal mines. Land degradation due to dumping of coal wastes are reported to be of the order of 04 hectare per million tonne of coal production. At this rate, there are more than 1400 ha of land degradation per year. However these uncontrolled disposals of coal mine waste such as solid waste, tailing, waste rock etc. leads to a number of environmental hazards, the most significant of which are drastic climate changes like rainfall, temperature and humidity. This huge nature of land degradation and deforestation also cause loss of oxygen fixing capacity, soil nutrient and adversely affect water table. The worse condition of roads and plying of large number of vehicles are also major contributors towards pollution of the environment. On the other hand, during the process of coal mining, huge area of land is excavated and there have been heaps of overburden or colliery waste materials all of which cause ecological problems such as changes in the land use pattern, topography, large abandoned pits, loss of top soil and vegetation, ground water contamination, greenhouse gas emission, slope instabity, air pollution, water pollution, soil pollution, biodiversity loss, and socioeconomic loss. Kumar [2].

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II. MATERIALS AND METHODS

A. Study area

In the present work, samples have been collected from Ib Valley Coalfields (MCL, 2012-13). IB Valley Coalfield lies between Lat. 21^0 41’ and 22^0 06’ and Long. 83^0 30’ and 84^0

08’ covering an area of 1375 Sq. Km in Jharsuguda district in the state of Odisha.

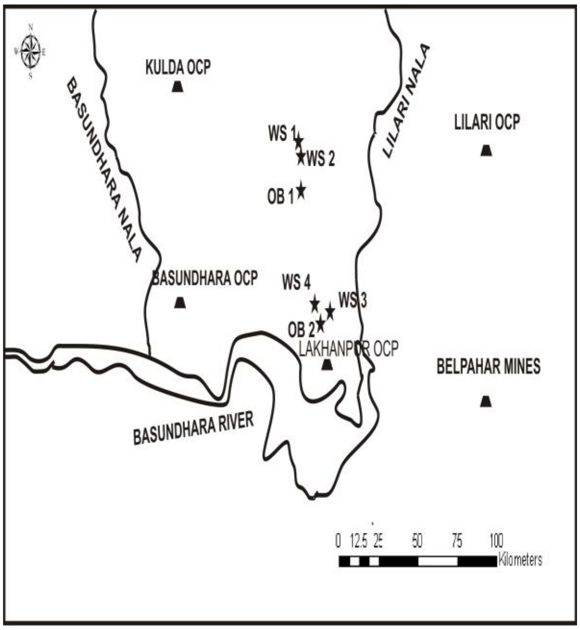

Fig 1: Location map of IB Valley coalfield showing sampling sites

OB1: Overburden sample of Kulda OCP

OB2: Overburden sample of Lakhanpur OCP

WS1: Water sample of Kulda OCP Settling pond

WS2: Water sample of Kulda OCP Central sump

WS3: Water sample of Lakhanpur OCP Settling pond

WS4: Water sample of Lakhanpur OCP Settling pond

B. Geology

IB Valley Coalfield is a portion of large synclinal Gondowna Basin of Raigarh-Hingir and Chhattisgarh Coalfields.

The stratigraphic progression begins with precambrian rocks at the base followed by an unconformity. Gondwana super groups such as Talchir, Karharabari, Barakar, lower Kamthi (Raniganj) of permain time and upper Kamthi Formation of trassic tme, are lie over the unconformity and Precambrian rocks. At the top recent and subrecent deposits are found. Senapaty and Behera [3]

The chief coal bearing formations in the IB Valley coalfield are Barakar & Karharbari of lower permain age. Barakar formation has around twenty carbonaceous horizons with quality ranging from E to G. These horizons after being clubbed recognized into five seams, namely Belpahar, Parkhani, Lajkura, Rampur & IB Seams. Parkhani seam is meagre in quality and thickness. It is usually not considered as mineable. Belpahar seam situated in the deep side of Lakhanpur OCP and in this seam mining operation is not expected in near future. Karharbari formation holds only thin coal bands below IB seam. MCL Report[4]

C. Sampling

Overburden (OB) Sampling: Large amount of OB were collected up to a depth of 0.6m and mixed thoroughly from randomly selected points located on the surface of the waste dumps of Lakhanpur Opencast Project (LOCP) and Kulda Opencast Project (KOCP) having coorindates 21° 45' 28.3" N 83° 49' 18.0" E and 21° 58' 9.9" N 83° 44' 29.7" E. Wastes were spread out on clean plastic tarps to dry at room temperature. To ensure complete drying, wastes are turned daily with a small plastic scoop until visibly dry (approximately 2 to 3 days depending upon ambient humidity). After drying, each composite is mixed for 5 minutes in a large stainless steel V -Blender to break up friable clods. The composite material is then sieved with a 2 mm screen, with the < 2 mm fraction being recombined and thoroughly homogenized by mixing in the V-Blender for 30 minutes. The > 2 mm fraction is discarded. Then coning and quatering procedure was followed to obtain a representative sample.

Fig 2: Over burden (OB) samples of LOCP and KOCP

D. Water Sampling

A total of 4 water samples were collectedA from LOCP and KOCP during premonsoon season in the year 2015 and 45 parameters were measured. 2 from central sump having coordinates 21° 45' 28.3" N 083° 49' 18.0" E and 22° 01' 54.7" N 83° 44' 43.2" E and 2 from Settling pond with coordinates 21° 46' 12.9" N 083° 50' 10.0" E and 22° 02' 11.4" N 83° 45' 0.3" E.

E. Reagent and solutions

All reagents used in the experiment were from Merck, Germany of analytical grade. Highly purified water prepared by a quartz bi-distillation unit was used throughout the study.

F. Experimental Investigation

The geotechnical properties of the coal mine wastes were determined using Indian standard (IS) and American Society for Testing and Materials (ASTM) methods. Coefficient of permeability was determined by Constant head method as per IS: 2720 (Part 17):1986 [5]. Maximum moisture content and dry density were calculated by Proctor-Compaction test as per IS: 2720(part VI):1975 [6]. Specific gravity was determined using density bottle method as per IS: 2720(part III/Sec. I):1980 [7]. Shear strength was assessed by direct shear test as per IS: 2720-39-2:1979[8].

Particle size distribution was examined using sieve analysis Singh and Chowdhury [9]. Slake durability index was measured using Slake durability apparatus as per ASTM D4644-878 [10]. Liquid limit, plastic limit, and plasticity were studied as per ASTM D 24349 [11]. Physico-chemical properties such as Temperature, pH, ORP, Conductivity, Turbidity, TDS, Salinity were studied using Horiba U-52G multi parameter water quality meter. As per the standard procedures given in Standard method for the examination of water and waste water, APHA 22 ND Edition [12], Chloride was measured using Argentometric method, Fluoride by Ion-Selective Electrod Method, Sodium and Potassium were determined with the help of Flamephotometer, Silica by Molybdosilicate method. Nitrate and phosphate were analysed by phenol disulphonic acid and Stannous Chloride Method respectively. Cyanide was measured using HPLC. Oil and grease was determined by Solid-Phase, Partition-Gravimetric metho, COD by open reflux method. Phenol by chloroform extraction method.

Heavy metal determination- Filtered water samples were acidified with 2% HNO3 to avoid metal precipitation. The resulting solutions were analysed with a Perkin Elmer AAS to determine metals such as Ca, Mg, Mn, Fe, Zn, Cu, Cd, Pb, Co, Se, As, Hg, and Cr.

III. RESULT AND DISCUSSION

TABLE I: GEOTECHNICAL ANALYSIS OF OB SAMPLES

Test Type	**Parameter**	**Lakhanpur OCP**	**Kulda OCP**
Slake Durability	Id1	97.3567 %	96.0099 %
	Id2	89.8325%	87.9127%
Standard Proctor Compaction	Maximum dry density	2.152 g/cm^3	2.3667 g/cm^3
	Optimum moisture content	15.2746%	16.4292%
Constant Head Permeability		4.302×10^{-5} m/sec	3.405×10^{-5} m/ sec
Atterberg Limit	Liquid limit	23.0120%	27.7100%
	Plastic limit	17.2610%	19.1392%
	Plasticity index	5.751%	8.5708%
Direct Shear	Cohesion	0.9234 kg/cm2	0.7560 kg/cm2
	Angle of internal friction	25.1677 degree	24.3211 degree
Specific Gravity		2.0012	2.1332
Grain size	Coefficient of uniformity (u)	22.4621	22.6013
	Coefficient of curvature (c)	0.5217	0.5661

Slake Durability index: Comparing the values of the first cycle and second cycle in the Gamble's table, the OB samples were found to be medium high durable for both the coal mines that could be due to higher grain size, minimum cohesiveness between the particles of OB, and water soluble binding materials in OB which gets dissolved easily. The sample should at least have medium durability to be used as filling materials and hence there will be less environmental degradation as durable materials are less prone to leaching and weathering.Standard Proctor Compaction: Compaction of the soil can lessen void space thus increases its shear strength and density and cuts its compressibility and permeability. 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 weigth between 1.7 to 2.2 g/cm3. Sahu and GuptA [13] Both samples almost satisfying this criteria. Shear strength: Sand having a bit or no fines (silt or clay) is supposed to have greater angle of friction. Sands with less quartz contain greater amounts of potassium-feldspar, plagioclase, calcite, and/or dolomite and these minerals generally have higher sliding frictional resistance compared to that of quartz. River sands with angle of friction around 300 have been well placed in use for backfilling in India. Soils lack of clay or silt is not cohesive. Greater is the cohesion value, more stable will be the slope. Sowers [14] The studied samples do not have the required angle of friction. However, if the waste materials are to be mixed up with binding materials like cement, fly ash etc. then they could be used in backfilling.

Grain size: Materials with coefficient of uniformity less than 4 is known to have a uniform distribution of grain size (poorly graded), while materials having coefficient of uniformity greater than 4 is observed to possess a wide range of grain sizes (well graded). It may be referred in table 1 that all the samples are well above 4. Hence, each of them could be used in backfilling. Sahu and Gupta [13] Permeability: 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 2.78×10-5m/sec. Each mine Sample has the required permeability. Therefore, they can be used in backfilling directly without being treated so far their permeability is concerned. Atterberg limit: Soils with liquid limit from 0-30 are used to have low compressibility. The liquid limits of the studied samples are 23.0120 and 27.71 for LOCP and KOCP respectively. This means, both of them are slightly plastic and could be used for backfilling

TABLE II: SOIL QUALITY OF OB SAMPLES

Paramater (mg/L)	**Lakhanpur OCP**	**Kulda OCP**
P^H	5.05	5.32
B	BDL	0.0225
Ca	0.467	0.927
Cd	BDL	BDL
Co	0.017	0.025
Cr	0.059	0.067
Cu	0.011	0.038
Fe	7.74	10.22

TABLE III: SOIL QUALITY OF OB SAMPLES

Paramater (mg/L)	**Lakhanpur OCP**	**Kulda OCP**
K	3.79	1.079
Mg	1.63	1.136
Mn	0.09	0.061
Na	0.035	0.324
Ni	0.0205	0.019
Pb	BDL	BDL
Zn	0.045	0.068
As	BDL	BDL
Se	BDL	BDL

PH: The PH of mine soil has direct link with overburden parent materials, and varies mostly depending on the quantity of acid-producing or acid-neutralizing material present in the overburden parent material. Oxidized, pre-weathered, overburden strata generally have very minute oxidizable pyrite, but may either be leached of carbonates. Sobek et al., [15] Mine soils developing in partially oxidized sandstone overburden had an initial surface pH of 5.5, while mine soils developing in unoxidized sandstone and siltstone overburden had an initial pH of 7.5. Roberts et al., [16] and Haering et al., [17]. The studied material has been derived from partially oxidized sandstone and could be vulnerable to leaching and weathering. The waste is acidic, which might be due to leaching of basic cations. Such condition may lead to H- ion toxicity and ultimately reduce plant growth.

Most common sources of heavy metals or toxic elements to waste and/or waste water are mining and extraction. It may be observed that mines soil contain heavy metals in objectionable amount except for B, Cd, Pb, As, Se (Table II and III). There is a greater risk associated with coal mine when acid mine drainage is formed. These metals could be leached out and subsequently contaminate the land, ground and surface water. Since the heavy metals are known to be carcinogenic, mutagenic, and teratogenic, their leaching should be prevented at the first place.

TABLE IV: WATER QUALITY OF COAL MINE WATER SAMPLES

Sl. No.	Parameters	Lakhanpur Mine Sump	Lakahnpur sediment ation pond	Kulda Mine Sump	Kulda sedimentation pond	Indian Standards (IS:10500)
1.	Odour	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable
2.	Colour (Hazen units), Maximum	3	1	2	2	<5
3.	pH	7.31	6.83	7.52	7.04	6.5 to 8.5
4.	Conductivity (ms/Sec)	0.765	0.111	0.496	0.436	
5.	Temperature (^oC)	31.14	31.07	32.23	32.00	
6.	Turbidity (NTU)	2.3	9.6	4.1	5.1	<5
7.	TDS (mg/L)	288	101	321	283	<500 mg/L
8.	TSS (mg/L)	23	9	24	21	
9.	DO (mg/L)	8.52	8.47	7.97	8.81	>6.5 mg/L
10.	DO (%)	115.2	114.2	109.4	121.0	
11.	BOD_3 (mg/L)	3.4	1.1	2.3	1.8	<3.0 mg/L
12.	Salinity (ppt)	0.4	0.0	0.1	0.2	
13.	Redox Potential (mV)	164	170	156	166	
14.	Total Alkalintiy (mg/L)	85	73	73.6	71.2	<200 mg/L
15.	Acidity (mg/L)	4	5	11	10	
16.	Total Hardness (mg/L)	112	97	121	118	<300 mg/L
17.	Chloride content (mg/L)	16	22	58.9	48.9	<250 mg/L
18.	Residual chlorine (mg/L)	0.08	0.10	0.18	0.16	< 0.2 mg/L
19.	Chemical Oxygen Demand (mg/L)	32.7	31.4	24.6	28.6	<250 mg/L
20.	Fluoride (mg/L)	0.2	0.3	0.1	0.6	< 1.5 mg/L
21.	Sulphate (mg/L)	102	58	97	68	< 200 mg/L
22.	Nitrate (mg/L)	3.70	6.89	10.9	11.7	< 45 mg/L
23.	Calcium (mg/L)	32.6	28.7	34.7	29.3	< 75 mg/L
24.	Magnesium (mg/L)	79.4	68.3	86.3	88.7	< 30 mg/L
25.	Manganese (mg/L)	BDL	BDL	BDL	BDL	< 0.05 mg/L
26.	Iron (mg/L)	0.51	0.45	0.72	0.59	< 3 mg/L
27.	Zinc (mg/L)	BDL	BDL	BDL	BDL	< 5.0 mg/L
28.	Copper (mg/L)	BDL	BDL	0.015	0.016	<0.05 mg/L
29.	Cadmium (mg/L)	0.006	0.004	0.003	0.005	< 0.01 mg/L
30.	Lead (mg/L)	BDL	BDL	BDL	BDL	< 0.05 mg/L
31.	Cobalt (mg/L)	0.012	0.013	0.006	0.008	
32.	Selenium (mg/L)	0.047	0.057	0.060	0.083	<0.01 mg/L

33.	Arsenic (mg/L)	0.003	BDL	0.013	0.001	<0.05 mg/L
34.	Mercury (mg/L)	BDL	BDL	BDL	BDL	<0.001 mg/L
35.	Chromium (mg/L)	BDL	BDL	BDL	BDL	< 0.05 mg/L
36.	Cyanide (mg/L)	BDL	BDL	BDL	0.006	<0.2 mg/L
37.	Nickel(mg/L)	0.025	BDL	BDL	BDL	< 3.0 mg/L
38.	Phenol (mg/L)	BDL	BDL	BDL	BDL	< 1.0 mg/L
39.	Oil and grease (mg/L)	2.81	1.03	0.92	0.77	<10 mg/L
40.	Phosphate (mg/L)	1.21	0.42	2.31	1.30	<10 mg/L
41.	Sodium (mg/L)	10.3	5.0	18.3	18.1	
42.	Potassium (mg/L)	40.5	7.4	12.2	9.3	
43.	Total Coliform (CFU/mL)	Nil	Nil	Nil	Nil	Nil/ 100 ml
44.	Silica (mg/L)	3.502	3.441	2.692	2.27	
45.	Boron (mg/L)	BDL	BDL	0.018	BDL	<2.0 mg/L

TABLE V: EFFLUENT QUALITY OF COAL MINE SAMPLES

Sl. No	Parameters	Lakhanpur Mine Sump	Lakahnpur sedimentation pond	Kulda Mine Sump	Kulda sedimentation pond	MOEF Standards
1.	pH	7.31	6.83	7.52	7.04	5.5-9.0
2.	Oil and grease(mg/L)	2.81	1.03	0.92	0.77	10
3.	TSS	23	9	24	21	100
4.	Chemical Oxygen Demand (mg/L)	32.7	31.4	24.6	28.6	250

For water and effluent quality, table IV and V may be referred. Since water sampling has been done in premonsoon season most of the parameters are below the Indian and Ministry of Environment and forest (MoEF) standards. However, one should note that it has been also possible due to the remediation technique adopted by mine authorities at the site itself and thanks to the stringent policies of the MoEF and State Pollution Control Board (SPCB) of Odisha State and should be continued. This could also be because, the design of the settling ponds are such that contaminants could be settled down there itself with time. In addition, there are wetlands near the sumps and the mine sites are being treated time to time.

IV. CONCLUSION

With amplified stress on opencast mining to boost coal production, the quantity of waste generated is also growing alarmingly, triggering in serious environmental and stability problems. This trash is typically disposed in the form of refuse piles and behind embankment type remaining structures. However, they can be utilised as backfilling material provided that they meet the geotechnical criteria for stability. It was observed that in each mine the over burden material does not meet some important technical criteria viz. angle of friction, cohesion, etc. that is expected from a good backfilling material. However, both of them have great possibility and with little alteration and treatment such as by mixing the over burden sample with cement, flyash or additional binding materials and by removing some fine particles, both of them could be used in backfilling. The water quality and effluent quality of the mine water sources and nearby areas should be routinely measured to ensure proper safety and working environment.

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