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Effective utilization and environmental management of fly ash as a geoliner constituent material

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Key words: Environment pollution control, Fly ash, Geoliner, ICP-MS analysis, Leaching analysis, Municipal solid waste management.

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Abstract

Fly ash is a coal combustion byproduct. It is generally light grey in color and consists mostly of silt- and clay-sized glassy spheres. It is regarded as a solid waste material and hazardous to health as it causes many occupational diseases. One of the best methods to minimize the fly ash landfills impact is to utilize it in social and economical manner like in concrete production, due to its pozzolanic and cementitious properties, or by using it in other applications such as a geoliner construction material. The concept of utilizing fly ash as a geoliner firstly needs to optimize and analyze the characteristics of fly ash to be used as a worthy liner material. One of the factors, which need to be study for the formation of geoliner, is the geoliner contamination potential. Since material with potential contaminants cannot be used as liner material. The leaching water through ICP-MS analysis revealed that all the elements detected are below Indian standard of drinking water. Hence Fly ash can be used as a geoliner construction material and an alternative for waste management in India.

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Introduction

In India, Fly ash production is around 112 million tons in 2005–06 and it is anticipated to generate about 150–170 million tones of Fly ash per year by end of the 11th 5-year plan in 2012 (MOEF, 2007). Currently, the utilization of Fly ash in India has increased substantially in recent years from 13 million tons to 51 million tons .Fly ash is commonly used as replacement for clay, sand, limestone and gravel as a cheaper substitute and energy saver. The Government of India, through the department of Science and Technology (D.S.T.), has initiated the fly ash mission, under Technology Information and Assessment Council (TIFAC) as the implementing agency, in view of the overall concern for the environment and the need for the safe disposal and effective utilization of fly ash (Chand *et al*., 2009). Fly ash if doesn't disposed off in proper manner can cause occupational health hazards like silicosis , pneumoconiosis etc as well as can affect the local environment by causing heavy metal pollution through erosion and leachate generation which may contaminate surface and ground water by mobilization of its hazardous metals. (Sikka and Kansal, 1995). Thus a sound management of fly ash is needed to mitigate the environmental crisis of fly ash disposal by increasing its utilization. Thus it serves as social and environmental reasons for solid and hazardous waste utilization in an environmental friendly manner. One of the methods is utilization of fly ash as a constituent material for creation of a municipal waste dumping site. Creation of a geoliner starts with understanding of building materials and site characteristics. It's crucial to determine whether these are suitable for the structure supposed to be built. Geotechnical Engineering provides with the design and construction for structures like earth retaining structures, shallow foundations, deep foundations, and the assessment of stability for sloping ground. Geotechnical testing of materials play a key role in the early stages of design and construction by providing reliable and optimized data for building of geoliner to be used as a municipal waste dumping site. Different constituent materials behave differently depending on their geotechnical characteristics. In case of fine grained like materials, where the grains are smaller than 0.075 mm, the mineralogy and water content, etc. have greater influence than the grain sizes, on the engineering behavior of material (Sivakugan, N., 2000). Fly ash has a good potential for use in geotechnical applications because of its low specific gravity, ease of compaction, freely draining nature, insensitiveness to changes in moisture content, good frictional properties, as well as alkaline in nature, etc (Pandian, 2004). Bentonite has physico-chemical as well as mechanical characteristics to fulfill as a barrier material (Rao *et al.,* 2008). Also bentonite buffer will hold and prevent the geoliner from collapse of the excavation (Dixon *et al.,* 1985; Komaine, 2004). Among the compounds in landfill leachate, ammonium is one of the most toxic and can leak from the liner for a very long period of time (Pivato and Raga, 2006). The objective of the paper is to utilize industrial solid waste material fly ash, mixed with bentonite to make an impermeable sheet to be served as clay like material mix due to its closely packed particles, to acts as a natural shield between the MSW and the environment.

Materials and methods

Study area

In the present study, Bokaro thermal power station (BTPS), Chandrapura Thermal Power Plants (CTPS) and TISCo Jamadoba were selected as they are nearer to Indian School of Mines (I.S.M.) Dhanbad as well as the area of Ph.D. interest "Jharia coalfiels (JCF) region". JCF is one of the most important coalfields in India, located in Dhanbad district, between latitude 23° 39' to 23° 48' N and longitude 86° 11' to 86° 27' E. There are about 15 large opencast mines which can be used as landfill sites for different waste materials like municipal solid wastes, industrial waste as well as fly-ash from thermal power plants. Development of a geoliner will reduce the problem of ground water contamination in these areas. Bokaro thermal power station is located at Bokaro in Jharkhand state .It is located around 23°47'07"N and 85° 52'48"E. The power plant is one of the coal based power plants of

DVC. It has an installed capacity of 630 MW. The study area 'CTPS' is situated at Chandrapura, Bokaro district, Jharkhand state, India at 23°45'N and 86°07'E. The power station has a production capacity of 780Mw electricity with a coal consumption of nearly 8000 tons/day. The total amount of ash generated /annum is approximately 15 lakh tons. The Tata Iron & Steel Company Limited (TISCo) consists of six collieries in the Jharia division, located in the Dhanbad district of Jharkhand, which is about 180 km away from Jamshedpur city, and 12 km away from Dhanbad district of Jharkhand. Tata Steel leased six of the metallurgical coal bearing properties in the Jharia coal fields, situated in the Damodar River Valley, with estimated reserves of 287 million tonnes. Spread across 5500 acres, these six collieries are grouped in two locations, Sijua and Jamadoba. Ash reduction since 1980s has helped increase productivity. In 1988, a fluidised Bed Combustion Power Plant was set up. Even before Tata Steel mined its first ton of coal, it gave itself the aim of conserving the resources in its mines, taking the first step in environment sustainability. All its mines are ISO-14001-Environmental Management System Certified.

Sampling

The Fly ash generated at the power plants were collected directly from the discharge points. In the power plant sampling pipes were provided at places near the discharge point or the storage point for collection of ash samples. The samples were directly collected into a bag and were suitable packed for transportation to Environmental Geotechnology lab of Indian School of Mines, Dhanbad. The main intention of this research was to determinate the physical and mechanical properties of coal fly ash and to evaluate its effectiveness as geoliner constituent material through geotechnical and leaching analysis. Below is the sketch of proposed design of Geoliner to be used as a municipal waste dumping over the mined out areas near Jharia coalfields region.

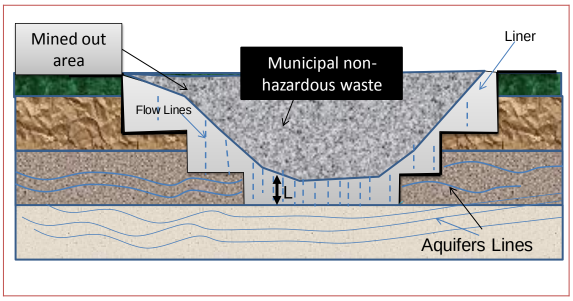

Fig. 1. Proposed design of Landfill liner for mined out areas of Jharia coalfield.

Fly ash

Fly ash is the by-product of coal combustion from coal based thermal power plants. It is extremely fine, glassy sphere, spherical in shape and bleed freely in mixture that looks similar to materials used in concrete technology. It is Fly ash when mixed with lime and water forms a siliceous/aluminosilicate material "pozzolan", a cementitious compound which increase the strength characteristics and durability of fly ash material. Due to good pozzolanic properties, very low in toxic heavy metals, compatible granulometry with soil, fly ash is considered to be an alternative material for geotechnical applications.

Bentonite

Bentonite is basically a rock composed of crystalline-clay like mineral formed by devitrification and chemical alteration of glassy igneous materials. It belongs to family of non-metallic clay (smectite) with chemical name as hydrated aluminum silicate. Sodium bentonite possesses high swelling property, liquid limit and thermal durability as well as possesses thixotropic properties which make the material impermeable by creating a thin coat of water proof like material. Thus sodium bentonite was used as an additive material along with fly ash in our geotechnical experiments.

Physico-chemical and Mechanical analysis

The samples were analyzed in the laboratory using standard laboratory protocols. For the geotechnical parameters analysis IS: 2720 was used. For, preparation of sample IS: 2720 (part 1) - 1983 was used. The bulk density and natural moisture content was analyzed as per IS: 2720 (Part 2) – 1973 by core cutter method and Oven dry method respectively. Specific gravity was analyzed by the density bottle method as per IS: 2720 (Part 3 / Sec-2) – 1980. Water holding capacity and cation exchange capacity was determined using standard methods (Maiti, 2003). Grain size analysis was done by sieve method as per IS: 2720 (Part 4) - 1985. Atterberg's limit i.e., liquid limit test was done by Casagrande's method as per IS: 2720 (Part 5) - 1985, plastic limit and shrinkage limit as per IS: 2720 (Part 5) - 1985. Compaction was done in the laboratory by Standard Proctor Method as per IS: 2720 (Part 8) – 1983 and Permeability by Falling head parameter as per IS: 2720 (Part 17) – 1986.Direct shear test UU and CU was done as per IS: 2720 (Part 13)-1986. Consolidation and Compression Index was determined using IS: 2720 (Part15)-1965.

Leaching analysis

Leaching analysis of fly ash was made using ICP-MS analysis. It was performed using deionized water (1000ml water/ 100 g solid fly ash; pH 5) in a high-density polyethylene bottle and shaken on a rotatory shaker for 24 hours at room temperature. The eluate was filtered with 0.45 microns and was acidified with nitric acid (HNO_3 1% v/v) to less than pH 2.

Results and discussion

Physico-chemical properties of fly ash

Moisture content

The mean values of moisture content for CTPS, BTPS and TISCO fly ash have found to be around 2.71%, 2.74% and 2.9% which is within range of IS standard and ASTM C618 with maximum allowable moisture content of 3.0 percent. It indicates that moisture content is suitable for use of fly ash as geoliner constituent material (Fig.1).

Specific gravity

The specific gravity of CTPS , BTPS and TISCo fly ash have been observed around 1.57 to 2.5 According to standards, the Specific gravity value should be around 1.46-2.66 (Fig.2). It is one of the important physical properties needed for the use of fly ash for geotechnical applications. The specific gravity of ash varies largely depending on its chemical composition and particle structure like those containing high iron and hollow and porous materials have higher specific gravity. Specific gravity indicates that the ash fill tend to result in high dry densities and low permeability and suitable for liner constituent material.

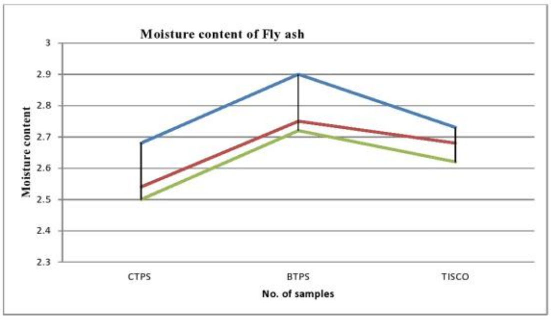

Fig.1. Moisture content of fly ash.

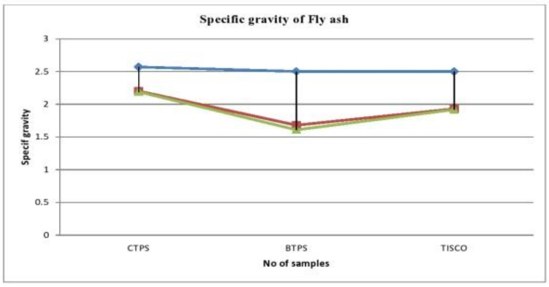

Fig.2. Specific gravity of fly ash.

Water holding capacity

The water holding capacity (WHC) of CTPS, BTPS and TISCo was found to be around 32.5, 38 and 40% respectively. WHC depends on sample texture and organic matter. As fly ash possess high percentage of silt having larger surface area, thus provides larger surface area for soil to hold water and exhibits higher water holding capacity. But for geotechnical application to achieve low permeability fly ash sample should be blended with additional complementary cementitious material to achieve higher water holding capacity.

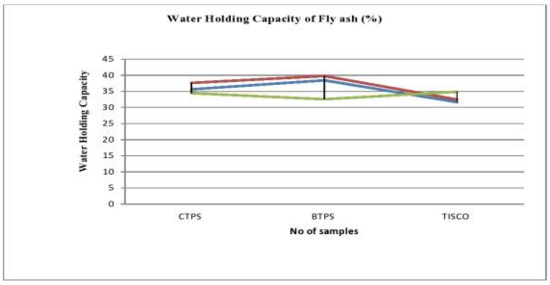

Fig.3. Water holding capacity of fly ash.

Cation exchange capacity

The cation exchange capacity of fly ash samples were found to be around 6.9 meq/ 100 g in CTPS, 7.1 meq/ 100 g in BTPS and 7.2 meq/ 100 g in TISCo Jamadoba fly ash (Fig.4). CEC is an index of the soil's capacity to exchange cations with the soil solution. It affects the ability of the soil to adsorb and retain cations and heavy metals. Due to CEC, adsortion on fly ash increases and the concentration of metal ions decrease in solution. Since the properties of Fly ash is similar to that of soil so Fly ash can act as a filter media by retaining cations and heavy metals due to presence of cation exchange capacity.

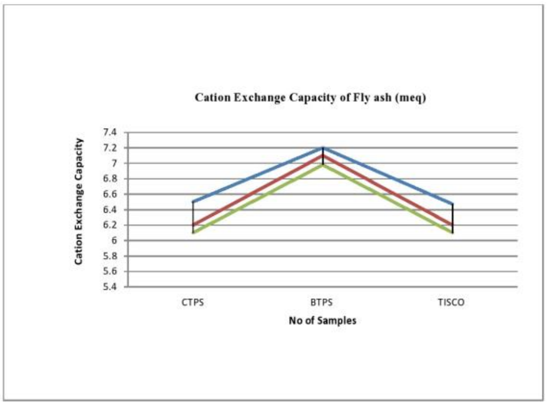

Fig.4. Cation exchange capacity of fly ash.

Sieve analysis

The Coefficient of Gradation (Cc) is a parameter that is also referred to as the coefficient of curvature. For soil to be considered well-graded Cc is usually between 1 and 3.From the values of uniformity coefficient (Cu) and Coefficient of Gradation (Cc) it is revealed that CTPS. BTPS and TISCO Fly Ash sample tested has properties of a poorly-graded soil that the Fly Ash particles are approximately equal in size. The Uniformity Coefficient (Cu) was found to be 2.27, 2.0 and 1.29 which is less than 4 for poorly graded (USCS) soil. The Coefficient of Gradation (Cc) was found to be 0.569, 0.720 and 0.938 which is less than 1 for poorly graded (USCS) soil. The graph of the sieve analysis particle-size distribution (BTPS, CTPS and TISCO) curve closely resembles an example of a silt-graded soil (Fig.5a,5b,5c).

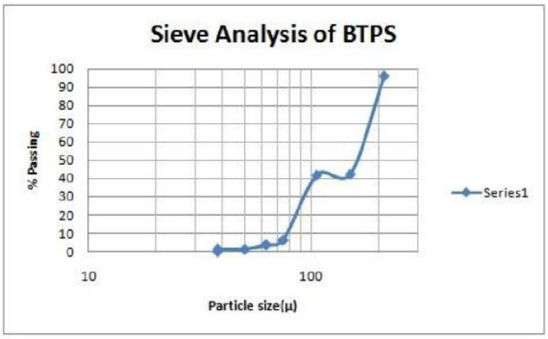

Fig.5a. Sieve analysis of BTPS fly ash.

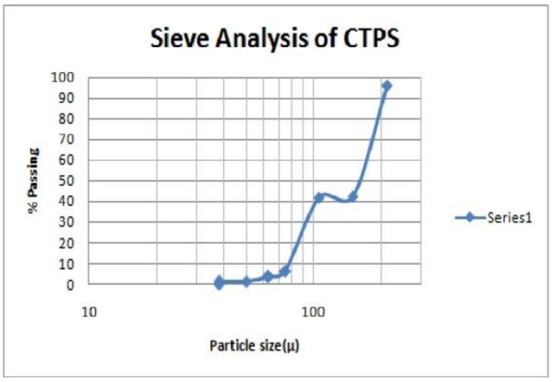

Fig.5b. Sieve analysis of CTPS fly ash.

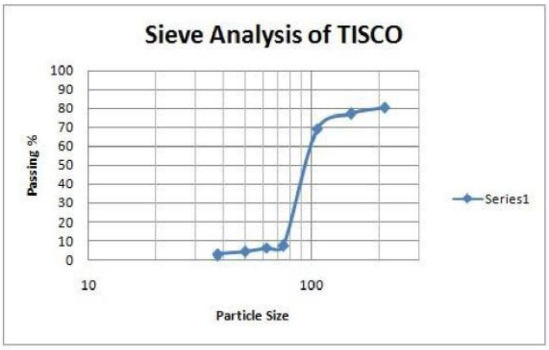

Fig.5c. Sieve analysis of TISCo Jamadoba fly ash.

Mechanical properties of fly ash

Table. 1. Geotechnical properties of fly ash alone and blended with bentonite in different proportions.

S.No.	Geotechnical Properties	Fly ash (FA)	CTPS			BPTS			TISCo Jamadoba		
			FA 90% +B10%	FA 80% +B20%	FA 70% +B30%	FA 90% +B10%	FA 80% +B20%	FA 70% +B30%	FA 90% +B10%	FA 80% +B20%	FA 70% +B30%
1	Atterberg's Limit (%)										
(a)	Liquid limit	39-48	38	44	66	37-48	46	68	39	48	68
(b)	Plastic Limit	Negligible	14	17	19	14	17	19	14	17	19
(c)	Shrinkage Limit	Negligible	11	13.5	13	11	13.33	13.1	10.9	13	13.1
2	Compaction: Optimum Moisture Content (%)	19-38	19.25	22.3	26.4	19.28	24	26.6	20.2	23.88	24
3	Compaction: Maximum Dry density(lb/ft³)	0.92-1.66	1.32	1.36	1.39	1.28	1.33	1.39	1.32	1.37	1.39
4	Permeability (cm/sec)	10^{-3}-10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-5}	10^{-6}	10^{-7}	10^{-5}	10^{-6}	10^{-7}
5	Direct Shear Analysis Cohesion(C) (kPa)	Negligible	8	18	28	8.88	17.9	26.8	8.9	20.1	28
(a)	Angle of Internal Friction (ϕ°)	30°-40°	44	44	44	43	43	43	44	44	44
6.	Consolidation/Compression Index	0.05-0.4	0.018-0.020	0.012-0.014	0.018-0.020	0.018-0.022	0.012-0.014	0.018-0.024	0.018-0.022	0.012-0.014	0.019-0.026

Atterberg's Limit

Atterberg's limit is very important geotechnical property used in classification and correlation of sample with geotechnical engineering properties. It depends on the fabric and carbon content of fly ash. Liquid limit of sample was found to be in the range of 39-48 which signifies that the sample offers some resistance to the flow and hence has infinitesimal shearing strength. Since the fly ash has no plasticity means it becomes brittle and if the pressure is applied, the sample will simply collapse. No shrinkage limit indicates that any loss of moisture may result in more volume reduction of the sample. The value of plastic and shrinkage limit infers that the fly ash sample is non- cohesive in nature and needs the addition of some additive materials like Bentonite, gypsum, lime etc so that the sample can be used for the formation of a low hydraulic conductivity geoliner. Among various combinations of fly and bentonite it was inferred that the liquid limit value is better in case of fly ash blended with 30 percent of bentonite. It also shows increased value of cohesiveness when compared to increased value of plastic and shrinkage limits of fly ash and various mixes.

Compaction

Compaction analysis of fly ash shows that the max dry unit weight decreases and the optimum water content increases in each case. The max dry unit weight was found to be in the range of 1.30-1.39 lb/ft³ and optimum moisture content 24-26%. The increase in optimum moisture content was due to water absorption by fly ash and increase in amount of held water within the flocculent fly ash structure and also follows from the need to release the capillary tension from the greater exposed surface of the fine fly ash particles. Maximum dry density was achieved to reduce permeability and prevent cracking in land fill barrier and to have a stronger material to prevent build-up of high pore water pressure. Thus an increased max dry density would produce a fly ash material which is stronger, less compressible and less permeable and can be used as a constituent material in the construction of a landfill barrier.

Permeability

Permeability is an important factor for designing of geoliner. The low permeable liners are advised to be used with permeability 10^{-7} to 10^{-9}. It is a determining factor to predict loss of water, leachate migration and stability of slopes. Densities analysis of the fly ash sample signifies that the fly ash has a low proportion of pore space and therefore possesses low porosity which in turn signifies low permeability. Coefficient of permeability of fly ash depends on its grain, degree of compaction and pozzolanic activity. The permeability of fly ash alone was found to be maximum 10^{-4} which is not suitable as a liner material classification. This low value is due to more availability of free calcium that results in cementation and reduction in permeability. But when fly ash was blended with bentonite, the coefficient of permeability has increased to 10^{-7} which is the minimum required permeability parameter for liner formation (USEPA, 2000). Since Fly ash consists almost entirely of spherical shaped particles, the particles are able to densely pack during compaction, resulting in comparatively low permeability value and minimum seepage of water.

Direct Shear Analysis

Direct shear analysis is a rapid, inexpensive and simple strength analysis test of building materials. In case of geoliner, which are compacted at optimum water content, the material remains partly saturated and it is necessary to conduct undrained test to determine its shear parameters. It was used to determine the shear strength of a cohensionless soil (i.e. angle of internal friction; f), the straight-line approximation of the Mohr-Coulomb failure envelope curve can be drawn, f may be determined, and, for cohensionless soils (c = 0), the shear strength can be computed. The shear strength along the surface of contact of soil and foundation can be determined by Coulomb-Mohr equation. (Das, B.M., 2005). The angle of internal friction for fly ash only was found to be in the range of 30°-40° and the cohesion value was found to be negligible. When the fly ash was blended with bentonite in various proportions, the angle of internal friction was found to be 44, 43 and 44 degree in case of BTPS, CYPA and TISCo fly ashes. The advantages of the direct shear test over other shear tests are the simplicity of setup and equipment used and the ability to test under differing saturation, drainage, and consolidation conditions.

Consolidation analysis

The One-dimensional Consolidation test is used to determine the consolidation characteristics of materials of low permeability. Since fly ash possesses low permeability, the consolidation test was used to determine its sediment parameters and its compressibility characteristics. Increments in a conventional consolidation test are generally of 24 hr duration and should cover the stress range from the initial stress state of the fly ash to the final stress state that the fly ash layer is expected to experience due to the proposed construction design. The compressibility characteristics of the soil are the parameters needed to estimate the amount of consolidation settlement. The compression index for fly ash alone was found to be 0.05-0.4 while upon addition of bentonite it was increased from 0.012 to 0.026 on a whole. More compression index indicates more stiffness and strength of materials. The increase in compression index shows that the fly ash along with bentonite mix can be a better liner material than fly ash alone.

Leaching analysis of fly ash through ICPMS study

Leaching analysis

The total metal content for a specific ash source depends on the composition of the coal. The potential for leaching in fly ash depends on the total metal content in it as well as the phase in which metal is incorporated such as glass phase or within crystalline compounds, which will hydrate. The metals in the glass phase are expected to leach at much lower rate than that from the crystalline phase. Since the degree of crystalline is a function of boiler design and remains relatively constant for a given source, leachable materials remain relatively constant for a given ash source.

The minimum amount of sample required for analysis ICP -MS analysis of eluate /leachate water, was 50mL. It was examined carefully to have less than 0.1% total dissolved solids in all the water samples. The detection limit is from 0.01 ppb to 0.1 ppm and the precision is fine with relative standard deviation less than 4.3%. The enhanced ICP MS provides the low detection limits needed to define background and anomalous levels. The leaching test showed that the heavy metal leachate or eluate were considerably low when compared to Indian standard of drinking water.

Hence Fly ash will not cause pollution to underlying groundwater and can be used as a geoliner constituent material.

Table. 2. Leaching analysis of fly ash.

S. No.	Metals/ Elements/ Elute	Drinking water standard (IS 10500)	ICPMS analysis of fly ash samples (ppm)			Eluate from fly ash samples (ppb)		
			BTPS	CTPS	TISCO	BTPS	CTPS	TISCO
1	pH	6.8-8.5	7.90	7.98	10.16	1.47	1.40	1.47
2	As	0.05	<0.2	6.7	4			
3	Cd	0.10	0.16	0.65	0.22	0.06	<0.05	0.31
4	Cr	0.10	129	172	116	4	1.2	21.5
5	Cu	--	58.51	82.37	68.75	48	9.2	453.7
6	Fe	0.30	4.46	4.7	3.51	12	124	19
7	Hg	0.001	ND	ND	ND	<0.1	<0.1	<0.1
8	Ni	0.12	50.9	68.2	54.7	8.5	8.3	69.3
9	Pb	0.10	35.21	86.98	40.09	5.7	2	39
10	Zn	--	55.8	135.9	84	65.9	19.2	811.3

pH

The pH is a critical factor determining the health of a water channel. It indicates the sample's acidity, but is actually a measurement of the potential activity of hydrogen ions (H+) in the sample. It is responsible for changes in mechanisms involved in leaching of metal ions from fly ash. Initially the pH of fly ash was found to be slightly alkaline in the range of 7.9-10.16. At high alkaline pH, the concentration of most of metal ions increases in the leaching solution due to dissolution of these metal ions from their carbonates and hydroxides salts. After the acidification of eluate, the pH found to be below required surface precipitation, thus it indicates that the fly ash will absorb metal ions through ion exchange and or adsorption on to the surface.

Conclusion

Fly ash is readily available in huge quantities and is inexpensive. The physico-chemical and geotechnical properties of fly ash showed that the fly ash has potential to be used in geoliner formation. The fly ash sample is class F fly ash and has pH less than 11 which means that this fly ash do not harden by itself and will be requiring additional supplementary cementitious material for hardening such as bentonite. The thixotropic property of bentonite makes it a suitable additive material for geoliner building material. The ICP-MS analysis showed that fly ash leachate doesn't contain any heavy metals beyond drinking water standard and hence can be used as a constituent material in geoliner construction. The thorough investigations carried out on fly ash shows that fly ash has good prospective for utilization in geotechnical applications. This not only solves the problems associated with the disposal of solid industrial waste material fly ash but also helps in its utilization as a geoliner constituent material for creation of an economically sound and environmental friendly geoliner to be used as a municipal waste dumping site around Jharia coalfield region.

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