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Hydraulic Conductivity of Fly ash Stabilized with Bentonite and Lime along with Effluent Characteristics of Leachate

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ABSTRACT: *This study is carried out on 17 (seventeen) numbers of samples to evaluate the hydraulic conductivity of waste material fly ash after treatment with different stabilizers in different mixing ratios with the help of optimum moisture content and maximum dry densities, including raw materials by tap water as a effluent. After that synthetic leachate such as tannery waste, dye is applied as an effluent to these samples. The result shows reliable values of hydraulic conductivity to achieve the exact purpose of research and to minimize the hydraulic conductivity as well as contamination occured by few heavy metals like Cd and Cr(vi) on few samples. The results shown are mostly reliable taking the field conditions kept into mind. In this paper, Class F fly ash is mixed with different modifier in different mix ratios by dry weight basis such as 20 to 50% of bentonite, 5 to 15% of lime. After compaction tests, with the help of MDD and OMC all the samples are examined for hydraulic conductivity tests and the effluent are collected for leachate analysis by tap water including synthetic leachates of two (02) types of salts with concentration 2.5 ppm, 5.0 ppm and 7.5 ppm for Cd and Cr(vi) as the hydraulic conductivity decreases after the improvement of waste fly ash by stabilizers. The results found for hydraulic conductivities are 6.1×10^{-4} cm/sec for fly ash, 2.13×10^{-9}cm/sec for bentonite and within the range of 3.73×10^{-5} to 2.13×10^{-9}cm/sec for all the mixes; for the leachate characteristics, values are within the range of ppm for Cd 0.005 to 0.004 ppm and 0.068 to 0.054 for Cr (vi) which resemble that the metal concentration decreases with the increment of mixes of stabilizers.*

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I. INTRODUCTION

The non-availability of quality construction materials with suitable strength and durability to meet the increasing demand in industrial world is assuming great importance. Efforts are now being increasingly made to take full advantage of the beneficial properties of the fly ash generated in huge quantities in thermal power plants to meet the demand for electricity which is otherwise disposed involving huge costs and environmental problems. Studies were made to find out applications of fly ash where it can be used effectively in bulk quantities in several civil engineering applications such as use as a fill material reported by [1-3], as a light-weight aggregate provided by Bin-Shafique et al.,[4] as a sub-base material showed by Ghosh and Subbarao, [5]. Fly ash is recycled as a construction material to take advantage of its pozzolanic characteristics. Pozzolanic or self-hardening characteristics depend on the availability of lime in fly ash. If there is insufficient bonding between the particles of fly ash due to lack of pozzolanic reaction, as in the case of low lime fly ash, it will be in a very loose state creating leaching and dusting problems. Bentonite is naturally available clay, generated from the deposition and alteration of volcanic ash which contains high amount of swelling clay minerals and has highly plastic characteristics (Mitchell and Soga 2005). The swelling capacity of bentonite, which in turn controls its hydraulic conductivity, depends upon the various physico-chemical and mineralogical factors. Bentonite primarily consists of a mineral called montmorillonite (Mitchell and Soga 2005) and when it interacts with water, it forms diffuse double layer resulting in the swelling of bentonite (Norrish 1954, Norrish and Quirk 1954, Madsen and Vonmoos 1989). As the bentonite swells it fills the pore spaces present between the solid particles in a soilmatrix and provide a lower value of hydraulic conductivity (Howell and Shackelford 1997, Komine 2008). However, chemicals present in the leachate suppress the thickness of diffuse double layer which in turn shrinks the swollen bentonite (Norrish and Quirk 1954). As the bentonite shrink, the flow path becomes open and the hydraulic conductivity increases (Quirk and Schofield 1955, Madsen and Mitchell 1989). Many studies have been carried out in the past to study the effect of chemicals on the behaviour of bentonite.

Lime and limestone are the most commonly employed precipitant agents due to their availability and low-cost in most countries (Mirbagherpand Hosseini 2004, Aziz et al. 2008). Lime precipitation can be employed to effectively treat inorganic effluent with a metal concentration of higher than 1000 mg/L. Other advantages of using lime precipitation include the simplicity of the process, inexpensive equipment requirement, and convenient and safe operations. Contamination of heavy metals in the environment is of major concern because of their toxicity and threat to human life and the environment (Purves1985). Many investigators have conducted researches on heavy metal contamination in soils resulting from various anthropogenic sources such as industrial and municipal wastes (Haines and Pocock1980, Parry et al. 1981, Culbard et al. 1983, Gibson and Farmer 1983, Olajire and Ayodele 1998). Stabilization of fly ash with proper additives may be one of the promising methods to mitigate the problem of leaching and dusting (Canter and Knox 1985). Ley and Sack (1984) reported different solidification techniques for waste disposal, among which stabilization with lime was one of the promising methods. Huang and Lovell (1990) studied the leaching behavior of bottom ash and its effects on ground water quality. Based on the results from leaching tests through extraction procedure (EP) toxicity test of bottom ashes were characterized as non-hazardous wastes and were recommended for use in different civil engineering applications as construction material. However it is very difficult to find significant literature on gypsum as a stabilization agent for expansive clays. Ameta et al. (2007) investigated for the economics of the use of lime–gypsum mixtures, and swelling pressure changes were reported. Investigation of Edil et al. (1992) on the suitability of compacted fly ash or fly ash-sand mixtures as a waste containment liner showed encouraging results. Weng and Huang (1994) used fly ash to remove heavy metals from industrial waste water. The protocols included leachate characterization of the ashes by the U.S. EPA toxicity characteristic leaching procedure (TCLP) and the ASTM water extraction procedure. Goh and Tay (1993) reported large scale leachate tests on municipal solidwaste incinerator fly ash stabilized with lime, as well as cement to simulate field recycling conditions as closely as possible. Fly ash containing higher amounts of freelime finds extensive bulk applications in civil engineering largely because of their ability to develop considerable strength due to pozzolanic reactions with the available reactive silica. Due to presence of montmorillonite mineral, the soil undergoes detrimental volume changes consequent upon temporal variation in moisture content, creating the deleterious effects on civil engineering structures (Chen 1975, Kumar et al. 2007, Kumar and Sharma 2004, Sharma et al. 2008, Walsh et al. 1993). However, orientation of particles and composition of a cohesive (i.e., clay) constituent along with percentage and grain size of granular material (i.e., sand or silt) controls the overall behavior of expansive soil (Gokhale and Jain 1972). Heavy metals are grouped within the category of environmental toxins and the investigations of these toxic heavy metals such as Fe, Mn, Cu, Zn, Co, Ba, Ag, As, Cd, Cr, Hg, Ni, Pb, Sb and Se showed special importance on environmental samples (Abollino et al. 2000, Novotry et al. 2000). These heavy metals are much toxic and have tendency to accumulate in the body and may result in chronic damage. The natural concentration of metals in fresh water varies depend upon in the soil (Opydo Jadwiga1989) and the underlying geological structures, the acidity of the water, its humus content and particulate matter concentration. There is a very much need to develop trace element analysis technique that allows separation of the different element species prior to trace element analysis. The nature of heavy metals as being persistent and the ability to accumulate in the environment unlike degradable organic pollutants raises many questions that need to be scrutinized extensively in relation to heavy metal laden waste treatment, waste minimization options and approach.

II. MATERIALS, SAMPLE PREPARATION AND PROGRAMME

(a) Materials

An attempt has been made to develop a cost-effective engineering material from wastes of Indian thermal power plants for land filling, construction of embankments and liners/covers. Class F fly ash sample has been used in this investigation as a land filling material. To recycle this waste material different additives viz., bentonite, and lime are mixed in various mix proportions with fly ash considering the economic aspect.

In this paper, all mixes are designated with common coding process as mentioned: FA stands for fly ash, B stands for bentonite, and L stands for lime. The Arabic numerals before FA, B, and L indicate their respective weight percentages in the mix. The test results on physical properties in Table 1 as per ASTM guidelines and chemical compositions in Table 2 of the fly ash sample, bentonite, and lime are presented. Properties of water used in this study are shown in Table 3.

Table 1 Physical Properties of Materials

Sl. No.	Properties	Fly Ash	Bentonite
1.	Specific gravity	2.21	2.80
2.	Sand size (4.75–0.075 mm), %	6.00	1.00
3.	Silt size (0.075–0.002 mm), %	84.00	26.80
4.	Clay size (< 0.002 mm), %	10.00	72.20
5.	Liquid limit (%)	NP	226.30
6.	Plastic limit (%)	NP	32.00
7.	Plasticity index (%)	—	193.70
8.	Optimum moisture content (%)	26.20	33.60
9.	Maximum dry density (kN/m^3)	13.00	13.72

Table 2 Chemical compositions of materials

Sl.No.	Chemical Compositions	Fly Ash (%)	Bentonite (%)	Lime (%)
1.	Loss on Ignition	1.14	9.52	7.85
2.	SiO_2	60.36	51.43	2.77
3.	Fe_2O_3	6.04	11.68	0.19
4.	Al_2O_3	28.21	19.16	1.66
5.	CaO	1.22	0.89	84.94
6.	MgO	0.87	2.70	1.75
7.	SO_3	0.65	Nil	0.11
8.	Na_2O	Few traces	3.49	Nil
9.	K_2O	Few traces	0.19	Nil
10.	pH	6.99	7.75	Nil

Table 3 Properties of water

Descriptions	pH	Conductivity (mS/cm)	Total Dissolved Solids (g/L)	Dissolved Oxygen (mg/L)
Water	6.67	0.061	0.040	5.67

(b) Sample Preparation

15 (Fifteen) different types of samples are prepared by various mix proportions where fly ash is first mixed with varying percentages of bentonite, (i.e., 20, 30, 40 and 50%) on a dry weight basis; after that fly ash is stabilized with 5, 10 and 15% lime. In total 17 (seventeen) numbers of hydraulic conductivity tests are conducted including fly ash and bentonite.

(c) Experimental Programme

An experimental set-up is designed for the present investigation to generate leachate from stabilized fly ash using tap water with a pH value of 7.2 used in the flow tests simulating field compaction and flow conditions as closely as possible. It is also possible to measure hydraulic conductivity of the stabilized material from this set-up. Stabilized material is compacted in a compaction mould of an internal diameter of 0.1 m to produce a specimen of 0.127 m in height. After curing the specimen in the mould itself, the specimen with the mould fitted into an integrated system, modeling field flow conditions under a constant head of 1.5 m of water permitting determination of hydraulic conductivity of stabilized fly ash with a provision for collection of the leachate at the outlet of the mould. The main advantage of this set-up is that it enables relatively larger samples to be tested in comparison to other waste extraction techniques and simulates the field flow conditions when water passes through stabilized and compacted fly ash. The proportions of lime employed on the basis of the dry weight of fly ash are 5, 10 and 15%. The specimens are designated following a common coding system consisting of three parts. The first term FA, stands for raw fly ash (fly ash), and the second, third and fourth terms show the percentages of bentonite (B), and lime (L) respectively.

III. EXPERIMENTAL SETUP

IV. RESULTS AND DISCUSSION

(a) Experimental Results

The hydraulic conductivity values of permeability tests are obtained from the fly ash is $8.55\times10^{\wedge-06}$ cm/sec, bentonite is $2.4\times10^{\wedge-09}$ cm/sec and the mixes of fly ash with bentonite percentages of 20, 30, 40 and 50 on the dry weight of fly ash are in the range of 1.38×10^{-08} to 1.22×10^{-08} cm/sec and hydraulic conductivity values of the mixes of fly ash stabilized with lime percentages of 5, 10 and 15 are in the ranges between 4.48×10^{-06} to 2.30×10^{-06} cm/sec. Hydraulic conductivity values of the mixes stabilized with 20, 30, 40 and 50% of bentonite and 5, 10 and 15 % of lime with fly ash are in the ranges between 4.14×10^{-06} to 1.85×10^{-06} cm/sec. All the experimental values are shown in Figure 1 to 5

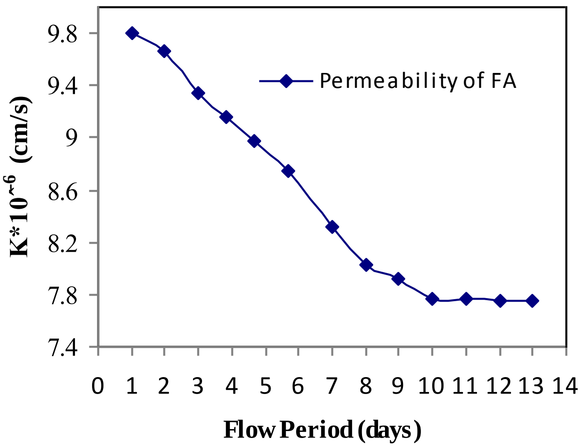

Fig. 1 Flow period versus hydraulic conductivity curves for fly ash.

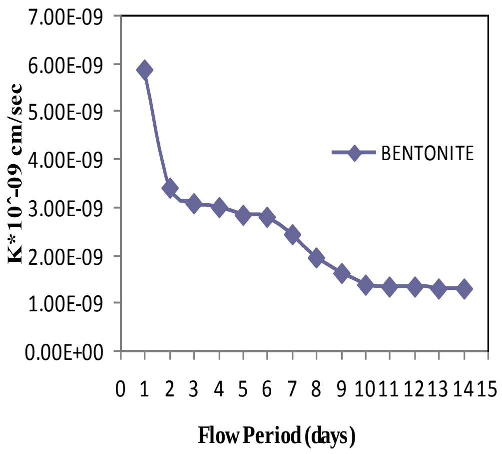

Fig. 2 Flow period versus hydraulic conductivity curves for bentonite.

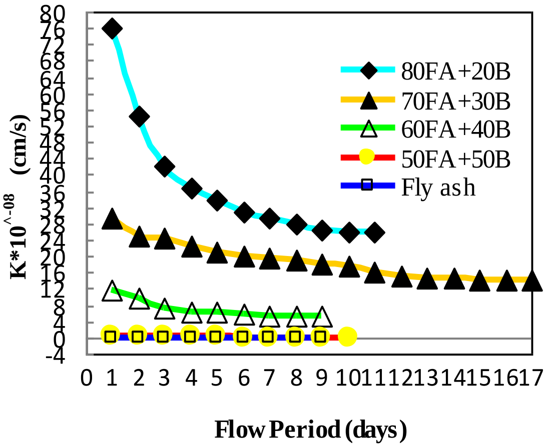

Fig. 3 Flow period versus hydraulic conductivity curves for fly ash and fly ash-bentonite mixes.

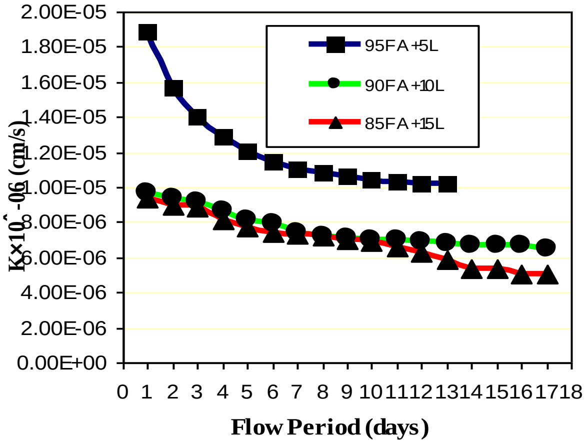

Fig. 4 Flow period versus hydraulic conductivity curves for fly ash-lime mixes.

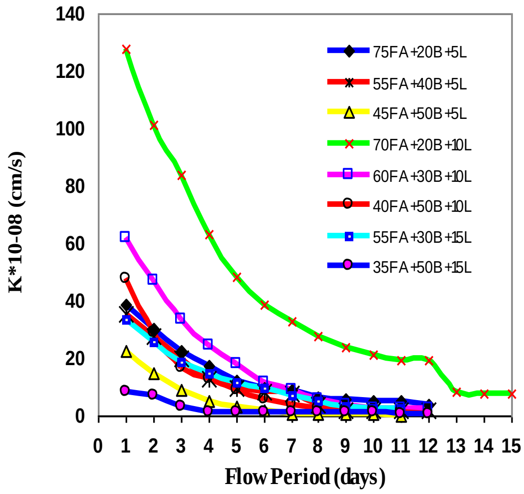

Fig. 5 Flow period versus hydraulic conductivity curves for fly ash-bentonite-lime.

(b) Discussions on Hydraulic Conductivity Test Results

Effects of hydraulic conductivity on fly ash stabilized with bentonite, with lime and with different percentages of bentonite and lime have been discussed in this section.

Effect of hydraulic conductivity on fly ash stabilized with bentonite, and with lime

The effects of hydraulic conductivity on raw fly ash and raw bentonite including with fly ash stabilized with bentonite from 20 to 50% are discussed based on the test results as shown in Figure 1, 2 and 3. From the Figure 3, it is noticed that obtained results of k for up to 50% bentonite with fly ash ranges from 1.38×10^{-08} to 1.22×10^{-08} cm/sec which reveals that values of k decreases with the increase of bentonite percentages compare with raw fly ash . This declination in hydraulic conductivity may be due to the rearrangements of particles (Pal and Ghosh 2013). The increment in bentonite percentages with fly ashes, the hydraulic conductivity decreases which may be due to when same mixes are compacted, and the inter-connectivity of the pore channels decreases when water is passes through for permeability test saturating the sample, which causes the reduction in void spaces with the increase in content of particles (Ghosh 1996, Pal 2008).

From Figure 4, results observed are within the ranges of 4.48×10^{-06} to 2.30×10^{-06} cm/sec on fly ash stabilized with lime of 5 to 15%. With the addition of lime content up to 10%, hydraulic conductivity gradually decreases with fly ash; due to the higher amount of lime percentages calcium ions of lime reduce plasticity and hence, different chemical reaction occurs and cation exchange increases with flocculation occurred in the samples. Due to production of flocs between the particles in less time duration, and also agglomeration takes place, results the reduction in hydraulic conductivity (Ghosh and Subbarao 1998). But with the enhancement of more lime percentages such as 15% lime addition in the mix, occupied void spaces by coarser particles in fly ash, which results small decrease in hydraulic conductivity.

Effect of hydraulic conductivity on fly ash stabilized with different percentages of bentonite and lime

Figure 5 also demonstrates that with the inclusion of various percentages of bentonite, i.e., 20, 30, 40 and 50% with different percentages of lime such as 5, 10 and 15% lime with fly ashes, shows the hydraulic conductivity results from 13.91×10^{-08} to 1.12×10^{-08} cm/sec, 4.22×10^{-07} to 1.11×10^{-07}cm/sec and 3.33×10^{-07} to 2.34×10^{-07}cm/sec respectively. Decreasing trend of hydraulic conductivity from 13.91×10^{-08} to 1.12×10^{-08} cm/sec for the mixes of 5% lime addition with bentonite of 20 to 50%, the values are in the ranges from 4.22×10^{-07} to 1.11×10^{-07} cm/sec for the mixes of 10% lime addition with bentonite of 20 to 50% and values from 3.33×10^{-07} to 2.34×10^{-07} cm/sec for the mixes of 15% lime with bentonite of 20 to 50%, which reveals that the small amount increment of hydraulic conductivity values for the mixes are due to the solid particles of mixes filled up between voids firmly and get densified where lime fixation process take vital role for the reaction of material particles. It may be recognized that Ca $(OH)_2$ enhanced the total procedure of permeability test and some cation exchange capacity takes place which consequences the fluctuations of values for different mixes.

(c) Environmental Analysis and Results with Discussions

After hydraulic conductivity tests environmental effects are found out on few samples after collecting the effluents by tap water and using synthetic leachates of potassium di-chromate (K2Cr2O7) and cadmium nitrate [Cd(NO3)2] salt solutions. The apparatus used for heavy metal concentration from the leachates is Atomic Absorption Spectrophotometer (AAS). The concentrations observed for Cd and Cr(vi) is within permissible limit, i.e., in the range of 0.068 to 0.003 ppm for Cd metal and 0.123 to 0.005 ppm for Cr(vi) metal. The detail concentrations of metal such as Cd and Cr(vi) by tap water and synthetic leachate of different salts are shown in Table 4.

Table 4: Concentration of heavy metals Cd and Cr (vi) by tap water and synthetic leachate using Cd(NO3)2 and K2Cr2O7 salts.

Mix proportions	Concentration of **Cd** in ppm (mg/L) by Tap water	Concentration of **Cr (vi)** in ppm (mg/L) by Tap Water	Concentration of **Cd** in ppm (mg/L) by synthetic leachate			Concentration of **Cr (vi)** in ppm (mg/L) by synthetic leachate		
			For 2.5 ppm	For 5.0 ppm	For 7.5 ppm	For 2.5 ppm	For 5.0 ppm	For 7.5 ppm
Fly ash	0.080	0.120	0.092	0.093	0.110	0.128	0.135	0.138
Bentonite	0.060	0.090	0.066	0.079	0.103	0.094	0.116	0.127
80FA+20B	0.068	0.098	0.085	0.090	0.097	0.122	0.135	0.139
70FA+30B	0.062	0.087	0.066	0.074	0.083	0.098	0.123	0.127
60FA+40B	0.054	0.085	0.064	0.068	0.075	0.093	0.115	0.124
50FA+50B	0.051	0.077	0.064	0.075	0.079	0.091	0.111	0.130
90FA+10L	0.057	0.069	0.066	0.074	0.088	0.086	0.096	0.137
85FA+15L	0.052	0.065	0.054	0.063	0.081	0.066	0.075	0.079
75FA+20B+5L	0.060	0.074	0.067	0.075	0.077	0.061	0.065	0.066
65FA+30B+5L	0.055	0.065	0.059	0.062	0.063	0.0.043	0.054	0.058
60FA+30B+10L	0.098	0.241	0.045	0.052	0.056	0.040	0.046	0.053
40FA+50B+10L	0.080	0.145	0.044	0.047	0.049	0.041	0.042	0.042
55FA+30B+15L	0.085	0.135	0.049	0.052	0.059	0.132	0.105	0.122

For all the mixes the observed concentration of Cd and Cr (vi) heavy metals were within the allowable limits. However, the concentrations of these two metals were below the threshold limit also.

Effect of Bentonite Content

Bentonite used in the leachability study with the fly ash taken an important role in this study. Calcium ion and sodium ions reacted with silica contents of fly ash. The inter-connectivity of the pore channels decreases when water is passes through for permeability test as well as for leachability test saturating the sample, which causes the reduction in void spaces with the increase in content of particles (Ghosh 1996, Pal 2008) , which results the decrement of heavy metal concentration of Cd and Cr (vi) through fly ash-bentonite mixes.

Effect of Lime Content

The lime leachability studies on fly ashes amended with lime contents in the range of 5 to 15% are conducted. The addition of lime triggers the onset of pozzolanic reaction early, by increasing the solubility of silica as it breaks the Si-O bonds in the silica rich glassy phases of fly ash. The hydration of fly ash begins immediately with the depolymerization of glassy phases releasing alumina and silica. This in turn produces cementing compounds such as calcium silicate gel which gradually crystallizes with time attributing strength to fly ash particles. The nature and amount of compounds formed vary both with the amount of lime added and duration of curing period. With curing, Ca (OH)2 is consumed by the pozzolanic reactions resulting in the precipitation of various calcium silicates, aluminates and alumino silicates which is also observed by Moghal and Sivapullaih (2012).

V. CONCLUSION

An experimental study is carried out to investigate the potential of fly ash after stabilized with bentonite and lime. The hydraulic conductivity of fly ash stabilized with bentonite (20 to 50%), lime (5 to 15%) including raw materials fly ash, bentonite are studied through laboratory experiments. Permeability tests are conducted by variable head permeameter. Based on the experimental as well as environmental results following conclusion may be outlined:

- The hydraulic conductivity of these raw materials and their mixes such as fly ash-bentonite (20 to 50%), fly ash-lime (5 to 15%), fly ash-bentonite (20 to 50%)-lime (5 to 15%) play an important role correlated with the mixes which will be always considerable for lining system.
- The obtained results are not abrupt; this nature is functional for field application and in a construction site considering environmental aspects.
- In general, hydraulic conductivity shows decreasing trend of all the mixes, which are correlated with flowing properties of soil media to provide a liner in the land filling site to prevent the contamination of leachate materials from the ground surfaces..
- Composite is very much effective for field applications as land fill, embankment and road sub-base; mix contains maximum percentage (i.e., 33.5 to 99.5%) of fly ash which is waste materials and abundantly available with free of cost, and very little percentages of bentonite (i.e., 20 to 50%), and lime (i.e., 5.0 to 15%) added to it. It's a new concept and very much useful in the field of geotechnical engineering.

REFRENCES

[1]. DiGioia, A. M., and Nuzzo, W. L.(1972) "Fly ash as Structural Fill", J. Power division, ASCE 98 (1):77-92.

[2]. Faber, J.H, and DiGioa, A.M. (1974) "Use of fly ash in embankment construction", Washinton D.C., USA: Transportation Research Board; p.13-19.

[3]. Horiuchi, S., Kawaguchi, M., and Yasuhara, K.(2000). "Effective use of fly ash slurry as fill material". J Hazard Mater 76:301–337.

[4]. Mitchell, J.K., and Soga, K.(2005). "Fundamentals of Soil Behavior". 3rd Edition, John Wiley & Sons, Hoboken.

[5]. Norrish, K.(1954). "Crystalline Swelling of Montmorillonite: Manner of Swelling of Montmorillonite", Nature volume 173, p. 256–257.

[6]. Norrish, K. and Quirk, J. P.(1954). "Crystalline Swelling of Montmorillonite: Use of Electrolytes to Control Swelling", Nature volume 173, p 255–256.

[7]. Madsen, F.T. and Miller-Vonmoos, M.(1989). "The swelling behavior of clays", Appl. Clay Sci.,4: 143-156.

[8]. Aziz, H.A., Adlan, M.N., and Ariffin, K.S. (2008). "**Heavy metals (Cd, Pb, Zn, Ni, Cu and Cr(III)) removal from water in Malaysia: post treatment by high quality limestone",** Bioresour. Technol., 99, pp. 1578-1583.

[9]. Purves, D.(1985). "Trace Element Contamination of the Environment", Fundamental Aspects of Pollution Control and Environmental Science No. 7. Elsevier, Amsterdam.

[10]. Haines, R.C., and Pocock, R.L.(1980). "Heavy metal land contamina- tion: Background levels and site case histories in the London Borough of Greenwich", Res. Note 16, Birmingham, Joint Unit for Research on the Urban Environment, Univ. of Aston, Birmingham .

[11]. Parry, G.D.R., Johnson, M.S. and Bell, R.M.(1981). "Trace metal surveys of soil as a component of strategic and local planning policy development", Environ. Pollut, Ser. B 2:97-107.

[12]. Culbard, E.B., Thornton, I. Watt, J. Moorcroft, S. and Brooks, K.(1983). "Sources and distribution of lead and cadmium in United Kingdom dusts and soils", p. 426-429. In Proc. of 4th Int. Conf. on Heavy Metals in the Environment, CEP, Edinburgh (1983).

[13]. Gibson, M.J., and Farmer, J.G. (1983). "A survey of trace metal contamination in Glasgow urban soils", In Proc. 4th Int. Conf. on Heavy Metals in the Environment. 2:1141-1144.

[14]. Olajire AA, Ayodele E.T.(1998)."Heavy metal analysis of solid municipal wastes in the western part of Nigeria", Water Air Soil Pollut, 103:219–228.

[15]. Annual Book of ASTM Standards. (2012) "ASTM C618 Standard specification for coal fly ash and raw or calcite natural pozzolan for use in concrete".

[16]. IS: 6186.(1971) Specification for Bentonite.

[17]. Annual Book of ASTM Standards. (2011).ASTM C1529. Standard Specification for Quicklime, Hydrated Lime, and Limestone for Environmental Uses (2011).

[18]. Pal, S.K. and Ghosh, A. (2013). "Volume change behavior of fly ash-montmorillonite clay mixtures, International Journal of Geomechanics, 14 (1), 59-68.

[19]. Ghosh A, Subbarao C. (1998). "Hydraulic conductivity and leachate characteristics of stabilized fly ash", J Environ Eng , ASCE, 124(9):812–820.

[20]. Ghosh, A. (1996). "Environmental and engineering characteristics of stabilized low lime-fly ash.Ph.D. Dissertation, Indian Institute of Technology, Kharagpur, India.
[21]. Pal, S.K. (2008) "Geotechnical properties of class F fly ash mixed with Montmorillonite clay and development of correlations for design parameters", Doctoral Dissertation, Bengal Engineering and Science University, Shibpur [Formerly, Bengal Engineering College (A Deemed University), Shibpur], Howrah.
[22]. Sivapullaiah, P.V., and Moghal, A. A. B. (2011). "Role of gypsum in the strength development of fly ashes with lime", J Mater Civ Eng 23(2):197–206.
[23]. Greaves H. (1996) "An introduction to lime stabilization", Proc. Seminar on Lime Stabilization, Thomas Telford, London, pp.5–12.
[24]. Fraay. A.L.A., Bijen. J.M.,de Haan. Y. M. (1989). "The reaction of fly ash in concrete a critical examination",Cement and Concrete Research, vol. 19, pp. 235-246.