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Influence of Lime on Hydraulic Conductivity and Leachate Characteristics of Fly Ash

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Abstract—*This paper highlights the effects of lime on the hydraulic conductivity and leachate characteristics of fly ash. The compaction characteristics of fly ash mixed with different lime content such as 0%, 2%, 4%, 8%, 12% and 15% were found out from light and heavy compaction tests. The hydraulic conductivity and leachate characteristics of compacted fly ash specimens were determined after 0, 7, 15, 30, 60 and 90 days of curing. All these samples were prepared corresponding to their respective MDD and OMC value and cured in water at an average temperature of 27 ^{0}C. The concentration of the major and trace elements like Cu, Fe, Zn, Ca, Ni, Pb and Cr etc. were found out by atomic absorption spectrometer. From the test results, it is found that lime treatment is an effective means of reducing the hydraulic conductivity and concentration of metals in the leachate emanating from compacted fly ash specimens.*

1. INTRODUCTION

The production of fly ash has been increased considerably. Hence, in order to get rid of disposal and dusting problem, this waste material is being used in several construction processes such as structural fills for low lying areas, embankment and subgrade for highways, backfill in retaining structures, mine stowing etc. as a replacement to conventional earth material. However, unstabilized fly ash is not suitable for construction works due to low bearing capacity and high compressibility. Therefore, some chemical additives like lime are used to improve the strength and stability of fly ash. Conversely, fly ash contains a number of soluble major and trace elements such as As, Fe, Cd, Hg, Zn, Pb and Cu, etc. There is possibility that leachate emanating from this fly ash bed may contaminate the ground water. Thus, fly ash stabilisation by lime treatment is an excellent method to mitigate the leachate characteristics of fly ash in addition to enhancing the strength and stability of the structure. A good number of literatures are available on the hydraulic conductivity and leachate characteristics of fly ash. Based on several investigations hydraulic conductivity of compacted Portland cement fly ash mixtures is affected by compaction effort [5]. The pH value of the pore water is one of the factors which governs the concentration of a metal in the leachate The ambience of high alkalinity in the pore fluid of the stabilized fly ash was conducive to the precipitation of some of the metals. The concentrations of Cu, Fe, Mg, Ni, and Zn in the leachate flowing out of the stabilized specimens were below allowable limits of drinking water quality, whereas concentrations of As, Cd, Cr, and Pb were above allowable limits, but below threshold limits [2]. Stabilization of fly ash with proper additives may be one of the promising methods to mitigate the problem of leaching and dusting [1]. The concentration of Calcium in the leachate depends upon the curing period [10]. The concentration of contaminants that leach out depends on the pH of the environment [9]. The hydraulic conductivity and the amount of chemical additives had an inverse relationship together [7], [8]. The strength and durability of fly ash increase due to addition of lime alone or in combination with gypsum and the decrease in hydraulic conductivity is due to reduction in interconnectivity of the pore channels due to formation of hydration products [3]. Class F fly ash stabilized with lime alone or in combination with small percentages of gypsum yields a strong impermeable matrix [4]. The reduction in hydraulic conductivity occurs if lime/gypsum is used as additive and it also depend on curing period. [6]

Scanning through the relevant literatures, it is perceived that research works on leachate characteristics of fly ash deposits is very limited and researchers have tried to reduce the concentration of major and trace elements in leachate. However, they are not coherent and extensive. So in this present investigation an effort has been made to know the effect of lime on the hydraulic conductivity and leachate characteristics of compacted fly ash specimens. In addition, the total metal concentration of fly ash and their maximum leaching ability were also found out by acid digestion and extraction method respectively in order to get confirmed whether it is in compliance with the specified water quality standards or not.

2. MATERIALS

2.1 Fly Ash

The fly ash used in the experimental work was procured from RSP Rourkela. Its physical properties and chemical composition are given in Table1.

2.2 Lime

The lime used in this investigation was commercially available superior grade quick lime.

Table 1. Properties of RSP fly ash

Physical properties of Fly ash		Chemical composition	
Properties	Value	Constituents	Percentage
Specific gravity	2.44	SiO_2	59.2
Dry density (gm/cc)	1.16	Al_2O_3	17.9
OMC (%)	38.74	Fe_2O_3	9.5
Liquid limit (%)	56.8	CaO	3.2
Cu and Cc	8.34 and 2.08	MgO	1.3
Cohesion (kg/cm^2)	0.04	SO_4	1.2
Friction angle (Degrees)	44	Unburnt Carbon	7.0
Hydraulic conductivity (cm/sec)	$1.25X10^{-5}$	Others	0.7

3. EXPERIMENTAL PROGRAMME

3.1. Laboratory Compaction Test

Compaction is a process of increasing unit weight of soil by forcing the soil solids to move closer due to expulsion of air from the voids. In this study both light compaction and heavy compaction tests were done with different combination of fly ash and lime to determine the maximum dry density and optimum moisture content. In total 12 numbers of samples (six each for light and heavy compaction) were prepared by varying lime content as 0%, 2%, 4%, 8%, 12% and 15% of the dry mass of fly ash. The maximum dry density (MDD) and optimum moisture content (OMC) values for all the samples were determined from the compaction curves. The compaction curves are presented in Figs. 1 and 2.

3.2. Hydraulic Conductivity

In total twelve numbers of permeability samples (6 numbers of samples compacted in light compaction and rest 6 numbers of samples compacted in heavy compaction) were prepared with different combination of fly ash and lime and compacted by means of hydraulic jack to their respective MDD at OMC value obtained from light and heavy compaction tests. The permeability tests were performed according to the procedure prescribed in IS: 2720 (Part-36)-1987 in a constant head permeameter. The coefficient of permeability of fly ash specimens treated with different lime contents were evaluated after curing periods of 0, 7, 15, 30, 60 and 90 days. Further, the effluents coming out from the permeability mold at zero day of curing and 90 days of curing were collected in sampling bottles and were tested for the concentration of different elements in an atomic absorption spectrometer.

3.3. Leachate Analysis

This test is done in order to determine concentration of the elements in raw fly ash as well as leachate collected from fly ash specimens treated with different percentages of lime and cured for zero and ninety days. At first, the total concentration of major and trace elements present in the fly ash is determined by acid analysis according to Environmental Protection Agency (EPA 3050B method). The leachate characteristics of raw fly ash are determined by extraction method (Toxicity Characteristic Leaching Procedure 1311 method). In this method oven dried raw fly ash was taken with liquid to solid ratio (L/S) of 10 and it was stirred in magnetic stirrer for 24 hours. Then it was filtered with Whatman 42 filter paper in order to make the sample free from suspended particles and then subjected to leachate analysis . In order to check the effect of lime on the fly ash specimens, the leachate samples are collected after 0 and 90days of curing and the concentration of the elements like Cu, Fe, Ca, Ni, Pb, Cr, Mg were found out by atomic absorption spectrometer (Perkin Elmer) .

4. RESULT AND DISCUSSION

4.1. Water Content-Density Relationship for Stabilized Fly Ash

The light compaction and heavy compaction tests for all the mixes were performed according to IS: 2720(Part VII) 1974. Moisture content and dry density relationships obtained from light compaction and heavy compaction tests of all samples are presented in Fig. 1 and 2 respectively. From light compaction test, it was observed the optimum moisture content (OMC) varied from 37.92 % to 40.38%, whereas maximum dry density (MDD) ranged from 1.128 to 1.17gm/cc. But in case of heavy compaction test it was found that OMC was varied from 30.5 to 36.88 % and MDD from 1.29 to 1.33gm/cc.

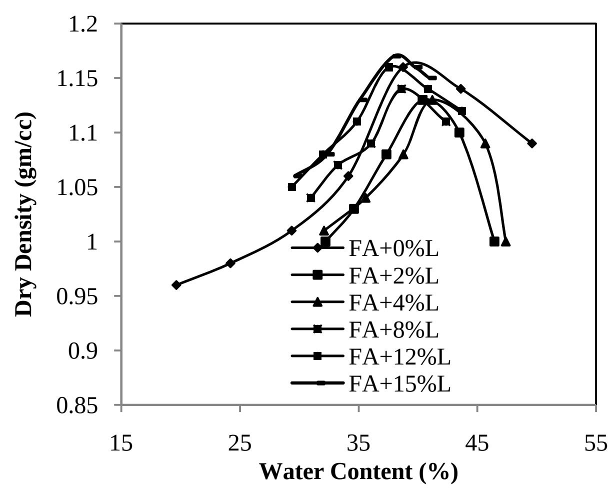

Fig. 1: Compaction curve of fly ash–lime mixture for light compaction

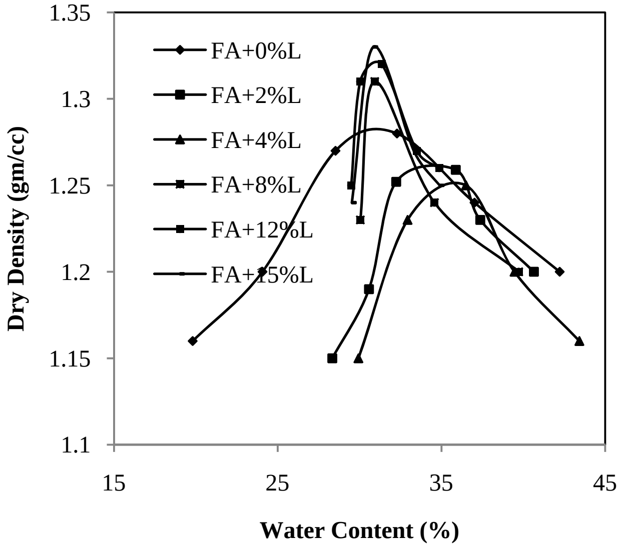

Fig. 2: Compaction curve of fly ash–lime mixture for heavy compaction

From compaction test results it was found that for light compaction test, with increase in lime content the OMC value increases up to 4% and thereafter, it decreases whereas in case of heavy compaction test, the OMC increases up to 2% lime addition and thereafter, it decreases. Similarly, the MDD in case of light compaction test decreases with increase in lime content up to 4% and thereafter it increases whereas in case of heavy compaction test the same value decreases up to 2% lime addition and thereafter, it increases. With further increase in moisture content, dry unit weight begins to increase as the menisci are broken and the particles are able to move and acquire a closer packing. The MDD results when fly ash is fully saturated, when water content is increased further there happens to be fall in unit weight.

Table 2: Variation of OMC and MDD with lime content Note:FA=fly ash and L=lime

Mix Proportion	Standard proctor		Modified Proctor	
	OMC (%)	MDD (gm/cc)	OMC (%)	MDD (gm/cc)
FA+0%L	38.74	1.160	31.00	1.284
FA+2%L	40.38	1.130	36.88	1.259
FA+4%L	41.20	1.128	36.50	1.250
FA+8%L	38.62	1.140	32.57	1.290
FA+12%L	38.00	1.160	30.80	1.324
FA+15%L	37.92	1.170	30.50	1.330

4.2 Hydraulic Conductivity

Fig. 3 and Fig. 4 shows the variation of hydraulic conductivity with lime content for different curing periods. It is observed from Table 2 that as OMC increases hydraulic conductivity decreases. Initially, i.e at 0 days, the decrease in hydraulic conductivity occurs with increase in OMC and it also depends on the compaction effort. Samples having more compaction show less value of permeability. With increase in curing period the permeability decreases. This is due to the formation of C-S-H gel which clogs the pore. However, sample with no lime content showed marginal change in hydraulic conductivity value.

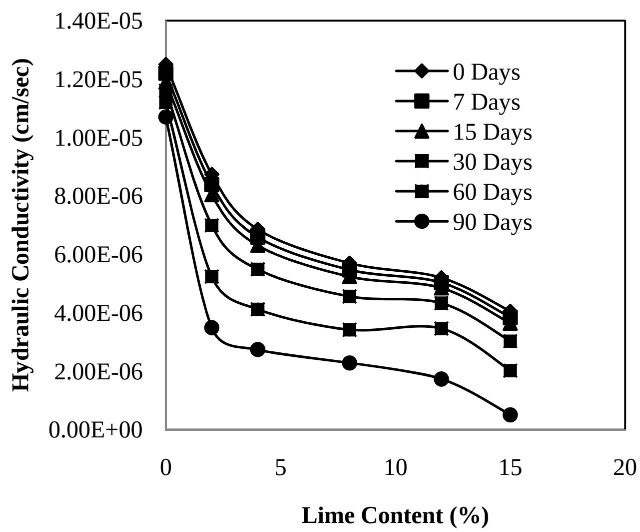

Fig. 3: Variation of hydraulic conductivity with lime content for light compaction

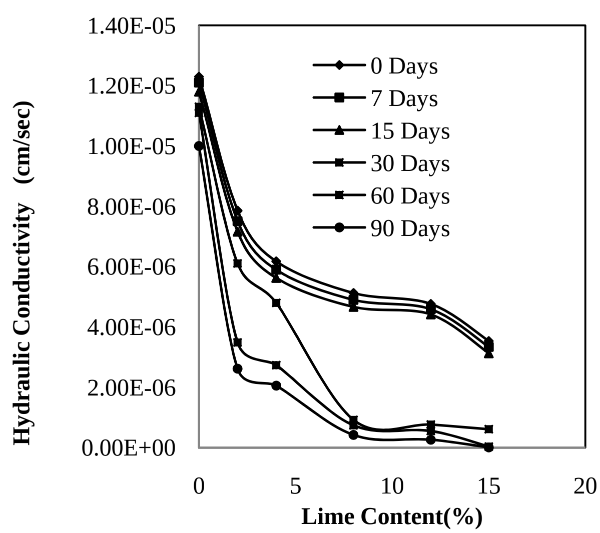

Fig. 4: Variation of hydraulic conductivity with lime content for heavy compaction

The samples containing higher doses of lime shows significant decrease in hydraulic conductivity value. It was found that at 90 days curing, it reduces about 10 times for samples compacted in light compaction whereas in case of heavy compaction, it decreases about 100 times than the stabilized specimen. In a nutshell, permeability depends on lime content, compaction effort, water content and curing period.

4.3. Leachate Analysis

Table 5 shows the concentration of metals in the leachate collected from permeability mold after 0 days and 90 days curing .From the test it was observed that concentration of all the was less than that of leachate sample of raw fly ash collected from acid digestion and extraction method (Table 3). At 0 days curing the concentration of all the metals were approximately same for at different lime contents whereas with increase in curing period the concentration of metals was found to be decreased. At higher curing period i.e at 90 days, with increase in lime content the concentration of metals in the leachate decreases .This is due to presence of alkaline medium which is unfavorable for metal precipitation and also due to encapsulation of metals by the hydration products. It is also observed that the concentration of other metals is below the threshold limit of IS-10500 and WHO water quality standard (Table 2).

Table 3: Allowable and threshold limits of concentration of metals in drinking water

Sl no	Elements	Content ranges in fly ash (mg/kg)	WHO		IS-10500	
			Allowable limit (mg/l)	Threshold limit (mg/l)	Allowable limit (mg/l)	Threshold limit (mg/l)
1	As	2.3-6300	0.01	1.00	0.05	5.00
2	Ca	-	200	20000.00	200	20000.00
3	Cr	10-1000	0.05	5.00	0.05	5.00
4	Cu	14-2800	1.0	100.00	1.5	150
5	Fe	36-1333	0.3	30	0.3	30
6	Pb	3.1-50000	0.05	5	0.1	10
7	Hg	0.002-1.	0.001	0.1	0.001	0.1
8	Ni	6.3-4300	0.02	2	0.02	2
10	Zn	10-3500	5	500	5	500
11	Mg	-	150	15000.00	-	-

Table 4: Concentration of metals in leachate sample of raw fly ash

Sample ID	Concentration of metals (mg/l)						
	Ca	Cu	Fe	Pb	Cr	Ni	Zn
N1	46.409	1.543	23.350	1.699	2.464	1.48	2.172
N2	35.219	0.06	0.057	0.325	1.875	0.159	0.315

N1 denotes the sample prepared from acid digestion of raw fly ash and N2 denotes the extracted leachate sample of raw fly ash (L/S=10).

Table 5: Concentration of elements in leachate sample after 0 and 90 days of curing

Elements	Concentration of elements in leachate on 0days curing(mg/l)				Concentration of elements in leachate on 90days curing(mg/l)			
	FA+0 %L	FA+2 %L	FA+4 %L	FA+8 %L	FA+0 %L	FA+2 %L	FA+4 %L	FA+8 %L
Cu	0.05	0.046	0.037	0.031	0.049	0.02	0.015	0.01
Zn	0.283	0.217	0.242	0.258	0.117	0.044	0.037	0.021
Ca	35.119	53.721	54.112	54.180	35.063	52.262	47.321	37.548
Pb	0.325	2.756	3.152	1.006	0.194	0.172	0.139	0.011
Cr	0.203	0.224	0.238	0.252	0.152	0.162	0.153	0.106
Fe	0.05	0.047	0.049	0.058	0.02	0.032	0.025	0.017
Ni	0.161	0.159	0.158	0.164	0.114	0.057	0.043	0.038
Mg	5.308	4.741	4.579	4.426	4.261	0.126	0.121	0.103

Table 6: Values leachate load ratio for metals in leachate cured for 90 Days

Mix Proportion	Leachate load ratio of of metals							
	Cu	Zn	Ca	Pb	Cr	Fe	Ni	Mg
FA+0 %L	1.19	2.825	1.17	1.95	1.56	2.92	1.64	1.45
FA+2 %L	5.75	12.35	2.57	40.12	3.46	3.67	6.98	94.22
FA+4 %L	6.17	16.37	2.86	56.77	3.89	4.90	9.19	94.74
FA+8 %L	4.51	17.8	2.10	133.2	3.46	4.96	6.28	62.59

4.3.1. Leachate–Load Ratio

The environmental impact of fly ash utilization in polluting the ground water is determined by evaluating the quantity of metals emanating from fly ash bed. The hydraulic conductivity of liner material plays a pivotal role in controlling the migration of toxic metals and confining it at the source of generation. Ground water pollution by leachate mainly depends on the concentrations of the heavy and trace elements present in it. The total amount of a metal in the leachate depends on the hydraulic conductivity of the material and on the concentration of the metal in the leachate. The effect of lime stabilization in mitigating the leachate characteristics of fly ash is studied through the term leachate load ratio which is defined as the ratio of the total metal emanating from an unstabilized specimen per day to that of the total metal emanating from a stabilized specimen per day

Leachate load ratio (R) = total metal emanating from unstabilized specimen per day/total metal emanating from stabilized specimen per day.

$R=(K_1 \times i \times A \times t \times C_1)/(K_2 \times i \times A \times t \times C_2)$

Where K_1=hydraulic conductivity of unstabilized specimen (cm/sec)

i=hydraulic gradient of unstabilized specimen

A=cross-sectional area of the specimen (cm^2)

t=time (sec)

C_1=concentration of the elements in the leachate emanating from unstabilized specimen (mg/l)

And

K_2=hydraulic conductivity of stabilized specimen (cm/sec)

i=hydraulic gradient of stabilized specimen

A=cross-sectional area of the specimen (cm^2)

t=time (sec)

C_2=concentration of the elements in the leachate emanating from stabilized specimen (mg/l)

When the value of $R>1$ it indicates that the total metal coming out of the stabilized specimen per day is less than the total metal emanating from unstabilized specimen. Table 6 shows that the leachate load ratio for all the elements are greater than 1. Therefore, the total metal coming out of the stabilized specimen is less than the total metal emanating from unstabilized specimen.

5. CONCLUSION

Disposal of fly ash is a major issue faced by the coal based thermal power plants. It requires a huge disposal area and creates environmental problem like leaching and dusting. Stabilization of fly ash by chemical additives is one of the promising methods to transform the waste material into a safe construction material. The primary objective of this study is to reduce the concentration of metals in the leachate emanating from the fly ash bed and also to prevent the leachate effluents from contaminating the ground water.

In this experimental investigation the fly ash in combination with different percentages of lime were compacted to their respective OMC and MDD value obtained from light compaction and heavy compaction test and subjected to different tests such as hydraulic conductivity and leachate analysis after 0,7,15,30,60 and 90 days of curing. The effect of lime content, curing period on hydraulic conductivity and leachate characteristics of compacted fly ash specimens was studied. Based on the experimental investigation the following conclusions can be drawn.

The concentration of metals in leachate majorly depend on two factors, pH and hydraulic conductivity. With increase in lime content, compaction effort, and curing period, the hydraulic conductivity value was found to be decreased. At higher curing period the reduction in hydraulic conductivity is due to the formation of C-S-H gel which clogs the pores and decreases the capillary voids. From leachate analysis it was found that at higher curing period with increase in lime content the concentration of metals in the leachate decreases. The leachate load ratio values of all the metals are greater than 1.Therefore, the total metal coming out from the stabilized specimen is less than the total metal coming out from the unstabilized specimen. The reduction in concentration of all the metals is due to presence of alkaline medium which is unfavorable for metal precipitation and also due to encapsulation of metals by the hydration products. It is also observed that the concentration of other metals is below the threshold limit of IS-10500 and WHO water quality standard. Thus, lime treatment was found to be effective in reducing the hydraulic conductivity and concentration of the metals coming out of the compacted fly ash specimens

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