50th IGC

50[th] INDIAN GEOTECHNICAL CONFERENCE
17[th] – 19[th] DECEMBER 2015, Pune, Maharashtra, India
Venue: College of Engineering (Estd. 1854), Pune, India

STRENGTH AND HYDRAULIC CONDUCTIVITY OF LIME STABILIZED FLY ASH

S.P.Singh[1], S.Chowdhury[2], S. Samantasinghar[3]

In India most of the thermal power plants are dependent on coal. Out of the total power generated, 56% of the power generated is from coal-based thermal power plant. The bituminous type coal used in India, the coal ash content is in the range of 30% to 50%. The operating conditions of thermal power plant sand the quality of coal used affects the quantity of fly Ash produced. The annual production of fly Ash presently in India is more than110 million tonnes and the land occupied by ash ponds is 65000 acres and the fly ash production is likely to cross 225 million tonnes by the year 2017. Such a vast quantity of fly ash does cause challenging problems, in the form of land usage, health risks, environmental hazards and disposal. Both in disposal as well as in utilization, extreme care has to be taken for protecting the interest of human life and environment.

Fly ash is poisonous in nature, easily combustible, corrosive and reactive and therefore causes harmful effects on the environment. Fly Ash particles fluctuating in size from 0.5 to 300 micron in equivalent diameter, being light weight, have prospective to get airborne easily and contaminate the environment. If not managed suitably fly ash disposal in sea/rivers/ponds can cause harm to aquatic life also. Slurry disposal lagoons/ settling tanks can become breeding grounds for mosquitoes and bacteria. It can also pollute the under-ground water resources with hints of poisonous metals present in it. Therefore proper disposal of fly ash is one of the major concerns to be dealt with; hence an advanced solution which would be effective, proficient and environmentally appropriate is required to overcome this difficulty of fly ash disposal. So, with suitable stabilization fly ash can be used as a substitute geo-material in many civil engineering constructions.

For promoting the usage of fly ash as one of the leading construction material or geomaterial, it is advisable to improve its engineering properties by stabilizing it with suitable stabilizer. Typically fly ash doesn’t possess strength itself; usually we used lime (CaO) and ordinary Portland cement (OPC) as additive for stabilizing fly ash. But a major issue with OPC is that its manufacturing processes are energy demanding and emit a large quantity of carbon di-oxide (CO_2). For example, roughly one ton of CO_2 is released for the manufacture of one ton of cement. Also, the raw materials available for cement production are being over-consumed while lime (CaO) reacts very slowly with fly ash to form pozzolanic material so it will take more time to achieve desired strength. Hence, civil engineering field is always in search for new, viable sustainable fly ash stabilizer.

The present work aims at assessment of the effectiveness of hydrated lime in stabilizing the fly ash and its appropriateness to be used as a construction material or geo-material. Fly ash used for research in this project was collected from the thermal power plant of NSPCL, Rourkela Steel Plant. For assessing

[1] Professor, Civil Engineering Department, NIT Rourkela, India, spsingh@nitrkl.ac.in
[2]M.Tech Student, Civil Engineering Department, NIT Rourkela, India, swaraj.marik@gmail.com
[3]M.Tech Student, Department of Civil Engineering, NIT Rourkela, India, 214ce1035@nitrkl.ac.in

the suitability of any construction material for various geotechnical engineering works its compaction properties, strength parameters and hydraulic conductivity properties are the most important properties to be tested.

In this project, an effort was made to assess the geo-engineering properties of fly ash along with the treated fly ash with different proportion of calcium hydroxide. The overall testing program was conducted in two phases. In the first phase, the physical and engineering properties of the fly ash samples were studied by conducting grain size distribution, hydrometer analysis, heavy compaction test, UCS test, falling head Permeability test and pH test of original fly ash samples. In the second phase, fly ash was mixed with 0%, 2%, 4%, 8 % and 12% of lime as a percentage of total weight of the mixture and with the resultant mixture modified proctor test was performed, corresponding to particular maximum dry density (MDD) and optimum moisture content (OMC) obtained from heavy compaction test the unconfined compressive strength (UCS) samples and permeability samples were prepared. The UCS and permeability samples were cured for 0, 3, 7, and 28 at a constant temperature of 27^0C before testing to evaluate the effectiveness of calcium hydroxide with flyash as an alternate geo-material.

Key words: Flyash, lime stabilization, unconfined compressive strength (UCS), permeability.

STRENGTH AND HYDRAULIC CONDUCTIVITY OF LIME STABILIZED FLY ASH

S.P.Singh, Professor, Department of Civil Engineering, NIT Rourkela, Odisha, spsingh@nitrkl.ac
S.Chowdhury, M.Tech Student, Department of Civil Engineering, NIT Rourkela, swaraj.marik@gmail.com
S. Samantasinghar, Ph.D Student, Department of Civil Engineering, NIT Rourkela, 514ce1007@nitrkl.ac.in

ABSTRACT: Massive urbanization in the recent times has led a high increase in the power demands and eventually an increase in the production of fly ash generated as a waste material from thermal power plants which gives rise to lots of environmental and disposal problem. To decrease the environmental pollution and hazardous effects, it is imperative to utilize fly ash as a construction material in civil engineering. But fly ash as such does not have enough strength to be used as a construction material. So, it is advisable to improve the engineering properties of the fly ash by stabilizing it by adding other materials or additives. In present investigation fly ash is stabilized with lime i.e. calcium hydroxide (in different proportions (0, 2, 4, 8, 12%) by means of total weight (fly ash + lime) and the compaction characteristics, strength and hydraulic conductivity of the resultant mixture were determined by modified proctor test, Unconfined Compressive Strength Test (UCS) and falling head permeability test respectively. The UCS samples and permeability samples were prepared to correspond to particular maximum dry density (MDD) and optimum moisture content (OMC) and cured for 0, 3, 7, and 28 days under a constant temperature of 27^0C and the unconfined compressive strength (UCS) and coefficient of permeability (k) were determined. The results showed though there is not much alteration in maximum dry density and optimum moisture content with increasing lime content but it has been also observed that the presence of Ca(OH)2 has pronounced effect in enhancing the UCS manifolds of the stabilized fly ash specimens whereas the coefficient permeability decreased with increasing curing period.

INTRODUCTION

A huge amount of fly ash is produced by the thermal power plants to meet the power consumption, and it is rapidly increasing in every year. Flyash particles are being light weight, have a potential to get airborne easily and pollute the environment. If not managed properly fly ash disposal in sea/rivers/ponds can cause damage to aquatic life also. It can also contaminate the underground water resources with traces of toxic metals present in it. So, in recent days the proper disposal of fly ash becomes a burning concern to be dealt with. On that note an efficient and environmentally approved solution is required to get rid out if this problem; keeping that thing in mind many researchers prescribed about stabilization of fly ash and make it useable as a construction material.

To use fly ash as a construction material it is necessary to improve its engineering properties mainly strength characteristics and hydraulic conductivity by stabilizing it with some proper stabilizing agent. By using laboratory use hydrated lime as a stabilizing agent the strength property and hydraulic conductivity of fly ash can be improved. Various previous attempts have been made to examine the mechanism that increases the engineering properties of activated fly ash. Temperature and the type of activator have been identified as the major contributing factors in strengthening activated fly ash. The binary interaction "temperature-type of activator" is also significant when the time of curing is 2h and the activator/fly ash ratio factor is never a relevant one (Palomo et al. 1998). The primary reaction product formed in alkali-activated fly ash systems is an alkaline aluminosilicate-type gel regarded to be a zeolite, precursor. Using the Infrared Spectroscopy, it has been shown that there is an asymmetric stretching band (T–O), associated with that aluminosilicate-type gel (Criado et al. 2007a). Criado et al. (2007) used four different alkaline solutions with different soluble silica contents to activate fly ash. The primary reaction product was a sodium aluminosilicate gel. The percentage and composition of reaction products were found to depend on both the soluble silica content present in the activating solutions and the thermal curing time. Also, the amount of gel was observed to have a decisive effect on the mechanical strength developing in the material. Phetchuay et al. (2014) used a mixture of sodium silicate solution (NaSiO3), water and calcium carbide residue (CCR) as a liquid alkaline activator to improve the engineering properties of problematic silty clay. The influential factors studied are Na2SiO3/water ratio, Flyash (FA) replacement ratio, curing time, curing temperature and soaking condition for a fixed CCR content of 7%. Strength development is investigated via unconfined compression test. Scanning Electron Microscopy (SEM) observation is used to explain the role and contribution of influential factors on strength development. Horpibulsuk et al. (2012) investigated the possibility of using a mixture of CCR (contain large amount of Ca (OH) 2) and fly ash (cementitious material) to improve the strength of problematic silty clay in northeast Thailand. The influential factors involved in this study are water content, binder content, CCR:FA ratio, and curing time. The mechanism controlling the development of strength is also illustrated. Strength development is investigated using the unconfined compression test. A microstructural study using a scanning electron microscope and thermal gravity analysis are performed to understand the microstructural changes that accompany the influential factors.

For popularizing the usage of fly ash as one of the dominant construction material, it is required to enhance and improve its engineering properties i.e. strength characteristics and hydraulic conductivity by stabilizing it by addition of suitable stabilizer as generally fly ash doesn’t possess strength itself and its hydraulic conductivity also very high. In present study laboratory use hydrated calcium hydroxide (Ca(OH)2) i.e. lime is used as a stabilizing agent to enhance the strength characteristics and hydraulic conductivity. Different percentages of Ca (OH) 2 were mixed with fly ash in terms of total weight and the resultant mixture was tested for improvement in the properties of the stabilized fly ash.

MATERIAL USED

The materials used for this study are flyash and commercially available superior grade hydrated lime was used. Fly ash used in this study was collected from the thermal power plant of Rourkela steel plant (RSP). The collected samples were mixed thoroughly to get the homogeneity and oven dried at the temperature of 105-110°C. Its physical properties are given in Table1.

The specific gravity of fly ash sample determined as per IS: 2720 (Part-III) was noted as 2.38 by taking an average of three trials. Particle size distribution for the fly ash sample was obtained following the procedure described in IS: 2720- PART (IV). Fig 1 presents the particle size distribution (PSD) curve of the fly ash sample. The percentage of flyash passing through 75μ sieve was found to be 88%. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) for fly ash was found to be 5.67 & 1.25 respectively, indicating uniform gradation of samples.

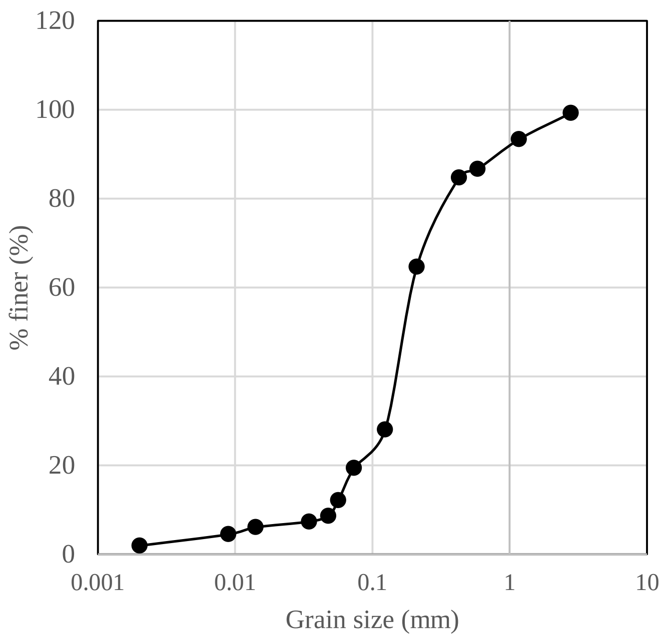

Fig. 1 Particle size distribution curve of fly ash

METHODOLOGY

The fly ash was collected from RSP, Rourkela. The specific gravity of fly ash sample determined as per IS: 2720 (Part-III) was noted as 2.38 by taking an average of three trials. Particle size distribution for the fly ash sample was obtained following the procedure described in IS: 2720- Part (IV). Fig 1 presents the particle size distribution (PSD) curve of the flyash sample. Table 1 enumerates the physical properties and the related PSD characteristics of the fly ash sample inferred from the curve. The standard laboratory used calcium hydroxide powder i.e. lime was brought from Rourkela market. Powdered hydrated lime was added with fly ash in powder form in terms of total weight. Lime content was varied from 0%, 2%, 4%, 8% and 12% by total weight of the fly ash and lime mixture.

Table 1: Physical characteristics of raw fly ash

Physical properties of the fly ash sample	Description
Colour	Light Grey
Sand fraction	12%
Silt and clay fraction	88%
Coefficient of curvature, C_c	1.25
Coefficient of uniformity, C_u	5.67
Specific gravity, G	2.38

Compaction characteristics

By using heavy compaction as per IS: 2720 (Part VII) 1980 the moisture content, dry density relationships were found. Fly ash was stabilized with different percentage of calcium hydroxide (0%, 2%, 4%, 8% and 12%) of its dry weight. optimum moisture content (OMC) and maximum dry density (MDD) were determined from the dry density and moisture content relationship. Similar compaction tests series were conducted by varying percentage of calcium hydroxide (0%, 2%, 4%, 8% and 12%) and the corresponding OMC and MDD were determined and are reported in Table 2.

Table 2: Heavy compaction characteristics of lime raw and stabilized flyash

Lime Content (%)	MDD (g/cc)	OMC (%)
0%	1.29	30.46
2%	1.33	30.24
4%	1.336	30.99
8%	1.3	31.98
12%	1.3	30.09

Unconfined compressive strength test

The test samples were of diameter 50 mm and 100 mm in height sheared at an axial strain rate of 1.25 mm/min till failure of the specimen. Flyash and lime stabilized fly ash samples were compacted to their corresponding MDD at OMC according to IS: 2720 (Part X). To evaluate the effects of curing conditions on strength properties the test specimen with varying curing periods of 0, 3, 7, 28 days before testing. For each testing three identical specimens were tested and the average value was reported.

Permeability test

Falling head permeability test for coefficient of permeability assessment was done by maintaining the MDD and OMC obtained in the earlier step. IS 2720 (Part-VIII) and (Part-X) were followed for conducting the modified proctor test and UCS test on the samples respectively. The UCS samples were cured for 0, 3, 7, 28 days at a constant temperature of 27^0C. As flyash is a fine grained material to determine its hydraulic conductivity falling head permeability test was conducted for raw and lime stabilized fly ash samples as per IS: 2720 (Part XVII)-1986. For evaluating hydraulic conductivity, test samples were prepared corresponding to their MDD and OMC in a permeability mould having diameter 10cm and

12.5cm height with heavy compaction energy of 2483 kJ/m^3 and were cured for 0, 3, 7 and 28 days.

RESULT AND DISCUSSION

The flyash mostly consist of fine sand to silt-size with a uniform gradation of particles as shown in Fig.1. The variations of optimum moisture content and maximum dry density with varying lime content are presented in Fig 2 & Fig 3. Initially with an increase in lime content MDD increases & OMC decreases but after that MDD decreases and OMC increases due to flocculation of particles.

The variation of maximum dry density (MDD) and optimum moisture content (OMC) with calcium hydroxide (Ca(OH)2) content doesn't vary over a broad range as Ca(OH)2 powder is a non-plastic material like fly ash and the water doesn't possess much lubricant effect resulting in the MDD and OMC doesn't alter much with Ca(OH)2 content. Table 2 presents experimentally obtained heavy compaction characteristics of Ca(OH)2 stabilized fly ash sample. From Figure 2 and Fig 3 it is clearly observed that MDD and OMC of the Ca(OH)2 stabilized fly ash samples doesn't alter much.

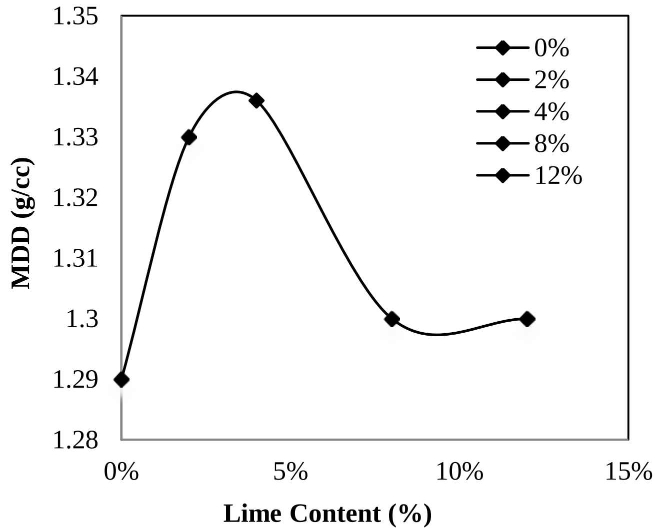

Fig. 2 Variation of MDD with lime content

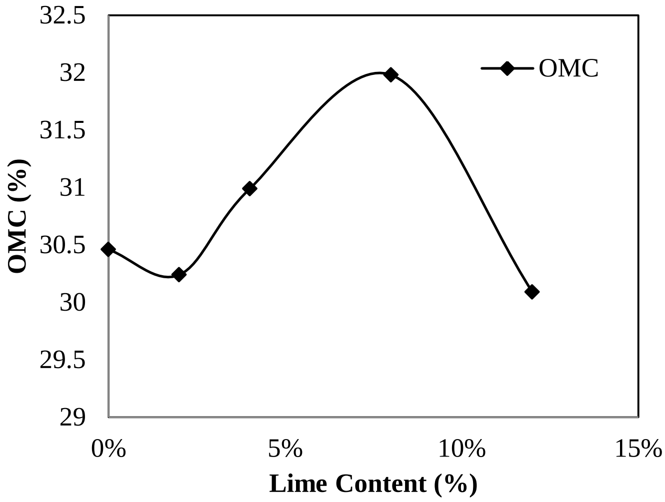

Fig. 3 Variation of OMC with lime content

The addition of lime to fly ash also leads to an increase in the strength and a decrease in the coefficient of permeability (k) of the stabilized fly ash sample as recorded from UCS test and falling head permeability test respectively. Fig 4(a) and Fig 4(b) show the variation of unconfined compression test values of the stabilized fly ash with different percentage of calcium hydroxide (i.e. 0%, 2%, 4%, 8%, 12%) and 0, 3, 7 and 28 days of curing periods respectively. In a similar manner, Fig 5(a) and Fig 5(b) show the variation of coefficient of permeability (k) of stabilized fly ash over varying $Ca(OH)_2$ content and curing periods respectively.

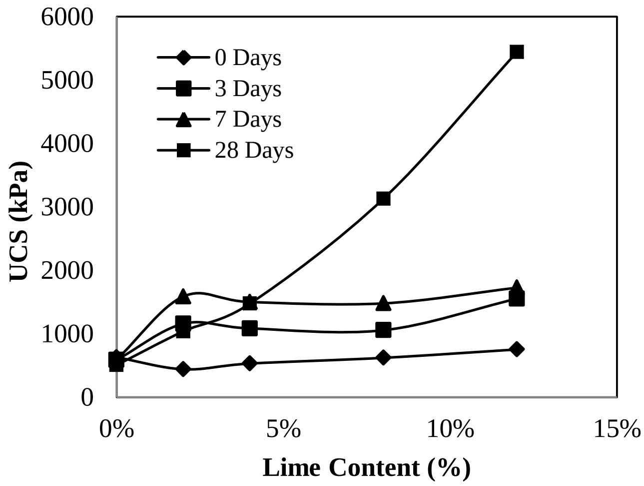

Fig. 4(a) Variation of UCS values with lime content

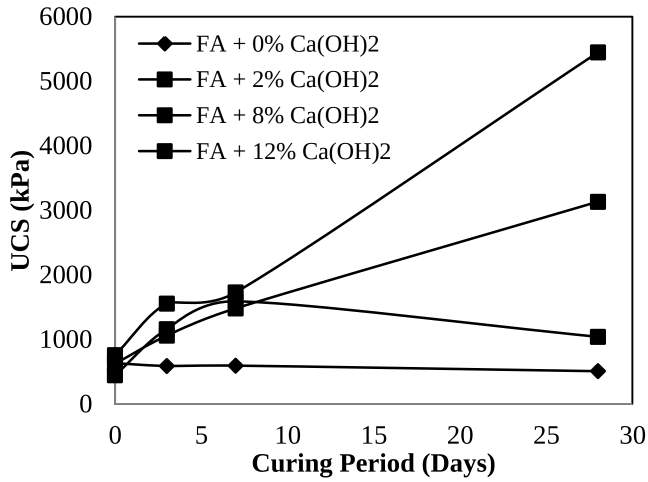

Fig. 4(b) Variation of UCS Values with curing period

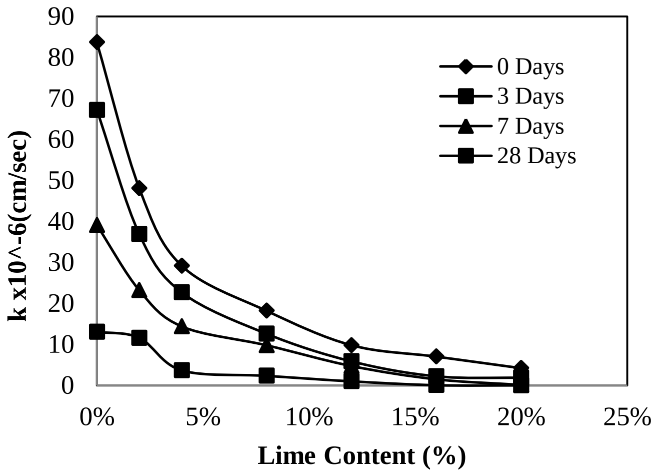

Fig. 5(a) Variation of coefficient of permeability (k) with lime content

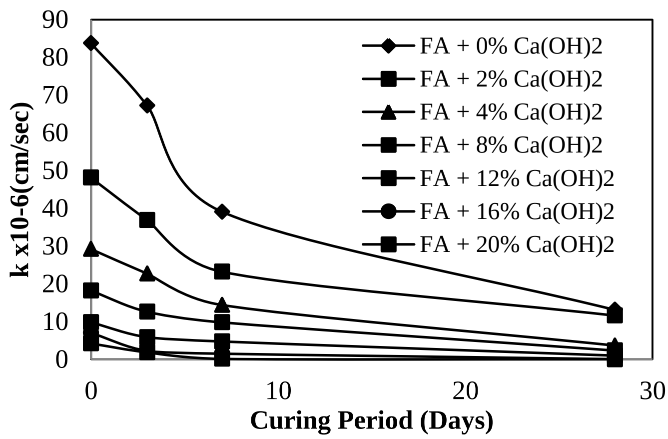

Fig. 5(b) Variation of coefficient of permeability (k) with curing period

From Fig 4(a) and Fig 4(b) it is observed that, for stabilized fly ash samples, peak obtained from unconfined compression test at 0%, 2%, 4%, 8% and 12% $Ca(OH)_2$ content are 506.94, 1039.74, 1478.059, 3132.448, 5444.73 kPa respectively corresponding to 28 days of curing period are given in Table 3.

Table 3: UCS values (kPa) for lime stabilized fly ash

Curing Period (Days)	Peak UCS (kPa)				
	$Ca(OH)_2$ Content (%)				
	0%	**2%**	**4%**	**8%**	**12%**
0	631.0	441.84	532.09	622.12	754.65
3	588.1	1158.72	1086.30	1057.70	1555.25
7	593.3	1589.13	1502.68	1480.78	1728.435
28	506.9	1039.74	1478.06	3132.45	5444.73

From Fig 5(a) and Fig 5(b) a sharp decrement is observed in coefficient of permeability (k) values with higher lime content and curing period. It is observed that, for lime stabilized fly ash samples, k value obtained for 0%, 2%, 4%, 8% and 12% of lime content are 1.31×10^{-5}, 1.16×10^{-5}, 3.67×10^{-6}, 2.34×10^{-6}, 1×10^{-6} cm/sec respectively corresponding to 28 days of curing period. The coefficient of permeability values corresponding to different lime content and curing period is given in Table 4.

Table 4: Coefficient of permeability for lime stabilized fly ash

Curing Period (Days)	Coefficient of permeability in10^{-6} cm/sec				
	Lime content (%)				
	0%	**2%**	**4%**	**8%**	**12%**
0	83.7	48.1	29.2	18.2	9.81
3	67.2	36.9	22.7	12.6	5.87
7	39.1	23.2	14.4	9.8	4.74
28	13.1	11.6	3.67	2.34	1

CONCLUSIONS

- The present study aimed at to study the strength and hydraulic conductivity characteristics of lime stabilized fly ash. Experiment was carried out to determine the strength characteristics and coefficient of permeability of lime stabilized fly ash.
- The fly ash consists of most of the particles of fine sand to silt size. The Coefficient of uniformity (Cu) and coefficient of curvature (Cc) for flyash was found to be 5.67 & 1.25 respectively, indicating that it is a uniformly graded material.
- Initially with an increase in lime content MDD increases & OMC decreases but after that MDD decreases and OMC increases due to flocculation of particles. The maximum MDD and OMC value obtained for fly ash stabilized with 4% of lime was found to be 1.336 g/cc 30.99% respectively.
- The unconfined compressive strength increased with an increase in lime content of 12% and curing period after 28 days of curing at room temperature of 27ºC, is about 5444.73 kPa.
- Coefficient of permeability (k) decreased with increased in curing period and lime content. At 12% lime content and 28 days curing period k value is obtained as 1×10^{-6} cm/sec.

REFERENCES

1. Chowdhury S., Tiwari A., Singh S.P., and Pani A. (2015) "Alkali Activated Fly Ash: A New Generation Geo-Material", *5th Young Indian Geotechnical Engineers Conference*, pp 105-106.
2. Criado, M., Ferna´ndez-Jime´nez, A., Torre, A.G., Aranda, M.A.G. and Palomo, A., (2007a), "An XRD study of the effect of the SiO2/Na2O ratio on the alkali activation of fly ash." *Cement and Concrete Research*, Vol. 37, pp. 671–679.
3. Criado, M., Ferna´ndez-Jime´nez, A. and Palomo, A., (2007), "Alkali activation of fly ash: Effect of the SiO2/Na2O ratio Part I: FTIR study." *Microporous and Mesoporous Materials*, Vol. 106, pp. 180–191.
4. Horpibulsuk, S., Phetchuay, C. and Chinkulkijniwat, A., (2012), "Soil Stabilization by Calcium Carbide Residue and Fly Ash" *Journal of Materials in Civil Engineering*, vol. 24, pp. 184-193.
5. Palomoa, A., Grutzeckb, M.W. and Blancoa, M.T. (1999), "Alkali-activated fly ashes: cement for the future." *Cement and Concrete Research*, Vol. 29, pp. 1323–1329.
6. Phetchuay, C., Horpibulsuk, S., Suksiripattanapong, C., Chinkulkijniwat, A., Arulrajah, A. and Disfani, M.M., (2014), "Calcium carbide residue: Alkaline activator for clay–fly ash geopolymer." *Construction and Building Materials*, Vol. 69, pp. 285-294.
7. Zhang, M., Guo, H., Korchi, T., Zhang, G., and Tao, M. (2013), "Experimental feasibility study of geopolymer as the next-generation soil stabilizer, *Construction and Building Materials*; Vol. 47, pp. 1468–1478.