*International Journal of Engineering and Technology Innovation, vol. 4, no. 3, 2014, pp. 161-169*

# Strength Studies of Dadri Fly Ash Modified with Lime Sludge – A Composite Material

Vaishali Sahu*, V. Gayathri

[1] Doctoral student, Department of Civil and Environmental Engineering, ITM University, Gurgaon, Haryana, India.

[2] Associate Professor and Head, Department of Civil and Environmental Engineering, ITM University, Gurgaon, Haryana, India.

Received 10 February 2014; received in revised form 02 April 2014; accepted 16 April 2014

## Abstract

The aim of the present work is to prepare a new type of fly ash–lime sludge composite totally composed with industrial by-products which can be utilized as road construction material. The lime sludge content was varied from 10% to 50% (at an interval of 10%) and the various composites were tested for unconfined compressive strength after 7 and 28 days curing period. The mix formula of this composite was optimized based on maximum strength and equal utilization of both the by-products. The composite with optimal mix formula (fly ash/lime sludge =1:1) results in highest strength. This paper outlines the characteristics of fly ash and lime sludge, method of preparation of compaction specimen and unconfined compression test specimen, testing procedure and salient results thereof. The strength formation mechanism of this composite is discussed. This composite can be further engineered as road construction material with competitive properties.

Keywords: fly ash, lime sludge, unconfined compressive strength

## 1. Introduction

In India, the highway and other pavement constructions develops rapidly in the recent past, large amount of granular materials and cementitious materials are depleted by those infrastructural constructions. The non-availability of quality construction materials to meet the increasing demand is assuming great importance. As high costs are involved in transporting them from long distances, in a vast country like India, this problem is of serious concern. In order to avert these problems, environmental and economic issues have stimulated interest in using alternative marginal materials which are ecologically safe and relatively economic. Efforts are now being increasingly made to take full advantage of the beneficial properties of the by-products of the industries. A huge quantity of industrial by-products such as fly ash from thermal power stations and sludge from drinking water treatment plants etc. is generated all over the world and has problems of environmentally safe disposal. Like other countries, the demand for electric power and drinking water had risen tremendously in India due to industrialization and rapid economic growth. This has resulted in setting up of large number of thermal power plants for the generation of electricity and water treatment plants for supplying good quality drinking water. From these plants, large quantities of fly ash and sludge are produced and disposed off in ash ponds and by landfilling respectively. It was reported that in 2008 – 2009, nearly 160 million tonnes of fly ash was being generated in India from thermal power plants out of which about 80 million tonnes of fly ash was utilized in different commercial applications [1]. Thermal power plant of Dadri, Uttar Pradesh, India

* Corresponding author. E-mail address: vaishalisahu@itmindia.edu; vaishalisahu27@gmail.com
Tel.: 0124-2365811, +919650129730; Fax: 0124-2367488

produces roughly 4000 metric tons of fly ash daily and approximately 40% is utilized in various applications. The volume of lime sludge produced from lime or lime-soda softening plants ranges from 0.3 to 6% of the water treated by volume [2]. Similarly, a water treatment plant located in New Delhi, India of capacity 0.5 MGD generates a bulk quantity of 5 tons of lime sludge every day.

Numerous studies have shown that major portion of fly ash is utilized as pavement material. Fly ashes do not exhibit any unconfined compressive strength both in dry and fully saturated conditions due to the absence of cohesion for dry fly ash and loss of apparent cohesion upon total saturation [7]. Fly ash possesses pozzolanic properties; therefore, it can be stabilized with cement or lime to achieve the strength required for use as base and subbase courses in pavements [10]. Stabilization of fly ash with compatible industrial waste is a new area of research and is gaining attention being an attractive and sustainable solution to many wastes. Few studies have been performed in recent past on mixing FA with industrial wastes, like blast furnace slag, phosphogypsum, copper slag and dolime etc. [6, 9, 11]. In this paper, a new type of fly ash-lime sludge composite used as road construction material is developed, it provides an opportunity and approach to recycle the massively produced fly ash and lime sludge. The optimum content of the mix formulations, the properties of the fly ash and lime sludge and the strength formation mechanism of this composite are studied.

## 2. Materials used

### *2.1. Fly ash*

Fly ash under present study is collected from Dadri thermal power plant, Uttar Pradesh, India. It has an installed capacity of 800 MW (4*x*200) of power generation. The 147 MN (15000 metric tons) of washed coal used each day in the plant, about one-third remains as waste. The plant produces nearly 10 MN (1000 metric tons) of bottom ash and 39 MN (4000 metric tons) of fly ash every day. The fly ash is collected in a total of 24 ESP’s. Dadri fly ash is classified as class F.

### *2.2. Lime Sludge*

During the process of producing potable water some commercial products are added to raw water in order to assure its quality for human consumption. The addition of various chemical reagents to the raw water normally generates three types of sludge. They are alum based sludge, ferric based sludge and lime sludge. Lime sludge is a residue generated when lime is also added along with other chemicals to the water to reduce its hardness. The drinking water treatment plant, New Delhi, of capacity 0.5 million gallons per day (MGD) has used a lime softening process to remove hardness since beginning. Various chemical like calcium hydroxide (lime), poly aluminum chloride (PAC) and a flocculating agent were added to water. The dosage of lime and PAC in raw water is as per to reduce the hardness of the treated water to 200 mg/l. This softening produces around two thousand tons of lime sludge (dry weight basis) annually. This lime sludge is resulted from the clarifier, sedimentation tank and filtration units. The lime sludge so produced is collected in sump tank and then sent to the thickener unit where it gets converted into dry form. The plant is in commencement since October 2010 and so far it has produced nearly thousands of tons of sludge so far. The sludge has earlier been dumped near the river bank Yamuna and presently is discharged to the nearby landfill site in Ghazipur on payment basis. Disposal of lime sludge in municipal solid waste landfills poses a major financial burden as the water treatment plant needs to pay the cost of loading and transporting the sludge plus tipping charges. On the above of this, the landfill sites are restricting the other waste and allowing only the completely inert material. The plant is getting permission only for few hundred tons of sludge and rest being in kept in the plant itself. The heap of lime sludge in plant is shown in figure 1.

Copyright © TAETI

Fig. 1 Lime sludge heap at the water treatment plant, New Delhi

*2.3. Notation*

For easy reference, the Dadri fly ash and Lime sludge are designated as FA and LS, respectively, in this paper.

## 3. Experimental Program

The experimental program is carried out in two parts. In the first part, physical properties, chemical composition, morphology and mineralogy of fly ash and lime sludge are discussed. In the second part the compaction characteristics and unconfined compressive strength of different fly ash-lime sludge mix are investigated.

*3.1. Physical properties and chemical composition*

The physical properties of the Dadri fly ash and lime sludge are summarized in table 1.The specific gravity, G, of the fly ash and lime sludge was tested in a non-aqueous medium (kerosene) and an average value of three tests has been reported. The loss on ignition was determined using muffle furnace at a temperature of 1000 ± 25° C and found as 0.24 for FA. For LS, the LOI was found as 41.84, a high LOI indicates presence of large amount of volatile solids in lime sludge. A LOI of 44.5 for similar lime sludge (containing $CaCO_3$) from chemical industry was reported [8]. The specific gravity of FA and LS were 2.3 and 2.19 respectively, which are nearly same.

Table 1 Physical properties of fly ash and lime sludge

| Property | FA | LS |
|---|---|---|
| Specific gravity (G) | 2.3 | 2.19 |
| Loss on ignition (%) | 0.24 | 41.84 |

The chemical composition of fly ash and lime sludge was determined using the facilities available at the Central Soil and Materials Research Station at New Delhi. It was determined by X-ray fluorescence spectrometry and atomic absorption spectrophotometry as per the procedure described in IS 1727 - (1967) [4] and is presented in Table 2. In fly ash the oxides of silicon, aluminium and iron together constitutes 96% and the free lime content is low whereas in lime sludge the free lime content (CaO) is 51%. The morphological characteristics of FA and LS were studied by scanning electron microscopic technique. A small portion of material was kept in the oven at 105℃ for 24 hours for drying. The specimen was mounted on a specimen holder. A thin conducting layer of gold about 50 Å thickness was coated on the specimen surface with the aid of sputter coater Emitech K550X. Zeiss EVO series scanning electron microscope model EVO 18was used to examine the

Copyright © TAETI

morphology of the materials. Figures 2(a) shows the scanning electron micrograph of FA at 5000 times magnification with spherical and smooth particles of various size ranges present. The LS particles are irregualr in shape and shows the clusttered structure (Fig. 2(b)). Figures 3(a) and (b) show the X-ray diffraction patterns of the Dadri fly ash and lime sludge respectively. The crystalline phases present were identified from the peaks in the pattern. The XRD pattern of Dadri fly ash showed the presence of crystalline phases hematite ($Fe_2O_3$), mullite (aluminum silicate), quartz ($SiO_2$), and sillimanite (aluminum silicon oxide). The phase compositions of Indian fly ashes as indicated by Chatterjee (2001) are: quartz 15-45%; mullite 15-30%; magnetite 1-5%; hematite 1-5%; and glass 25-35%. Figure 3(b) shown the presence of lime (CaO), hematite ($Fe_2O_3$), quartz ($SiO_2$) and alumina ($Al_2O_3$) in lime sludge.

Table 2 Chemical analysis of fly ash and sludge

| Element | Concentration | |
|---|---|---|
| | FA (%) | LS (%) |
| $SiO_2$ | 60.02 | 1.12 |
| $Al_2O_3$ | 29.77 | 0.98 |
| $TiO_2$ | 0.81 | 0.08 |
| $Fe_2O_3$ | 6.68 | 0.54 |
| MnO | 0.31 | 0.10 |
| MgO | 0.54 | 0.26 |
| CaO | 0.98 | 51.5 |
| $K_2O$ | 0.120 | 0.20 |
| $Na_2O$ | 0.067 | 0.08 |
| $P_2O_5$ | 0.40 | 2.72 |
| $SO_3$ | 0.065 | 0.58 |
| LOI | 0.24 | 41.84 |

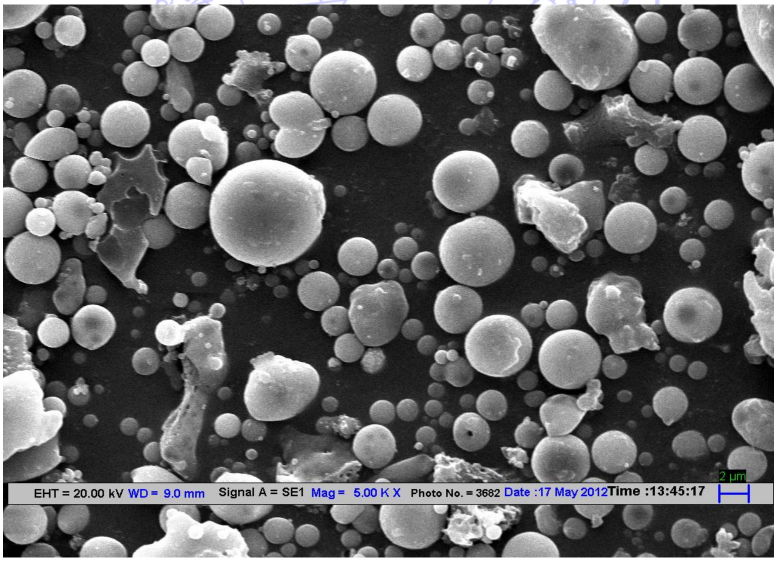


Fig. 2(a) SEM of Dadri fly ash

Copyright © TAETI

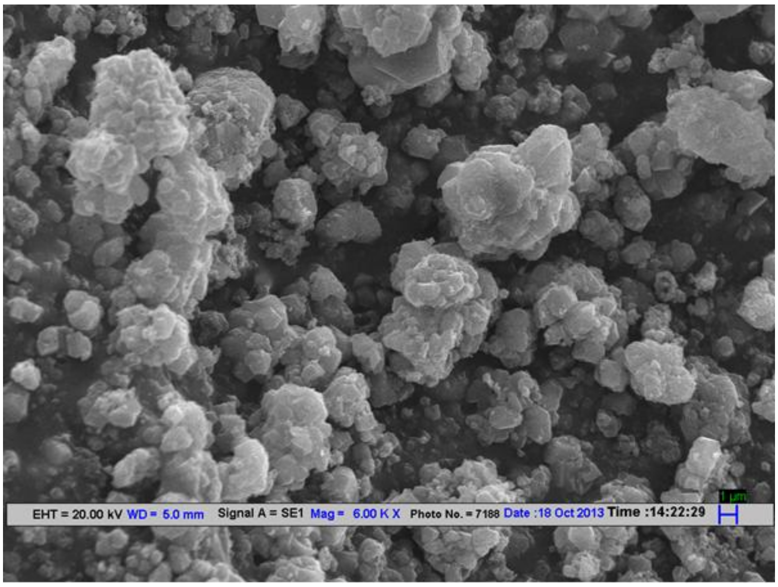


Fig. 2(b) SEM of lime sludge

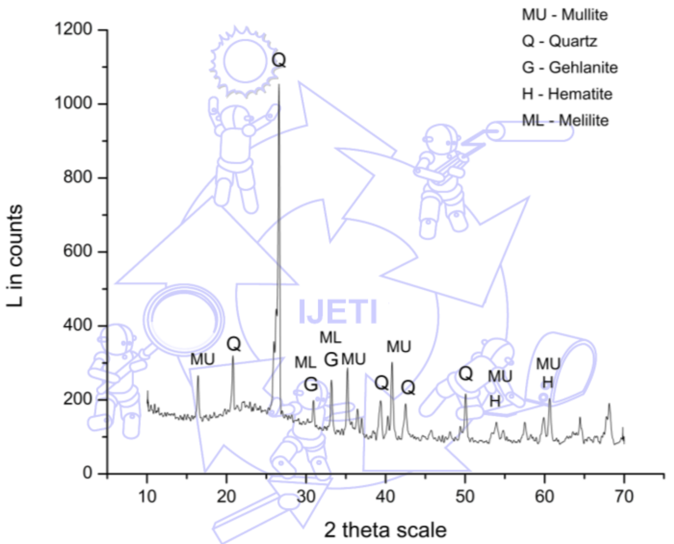


Fig. 3(a) X-ray diffraction pattern of Dadri fly ash

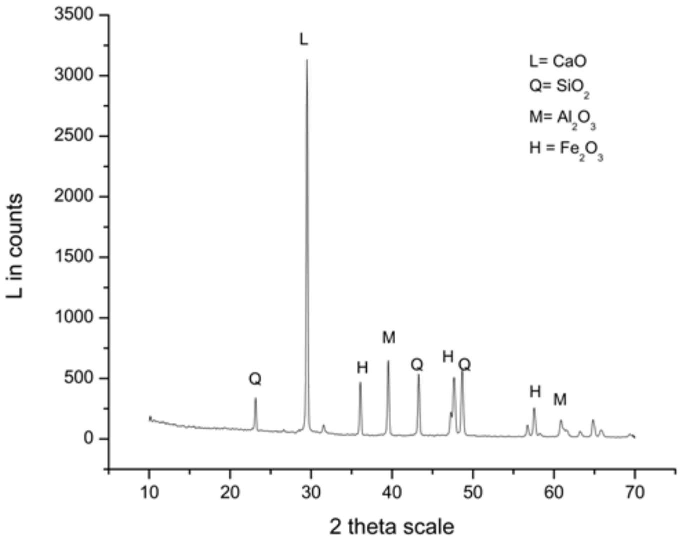


Fig. 3(b) X-ray diffraction pattern of lime sludge

Copyright © TAETI

### *3.2. Compaction characteristics and unconfined compressive strength*

Standard Proctor compaction test was carried out as per IS 2720 [3] to determine the maximum dry unit weight (MDD) and optimum moisture content (OMC) of FA modified with different content of LS**.** For each compaction test, about 3000 g of fly ash mixed with different content of lime sludge (0 to 50%) was used. Required amount of water was added and mixed thoroughly. The mix was compacted in the mould in three layers. The weight of the compacted mix together with the mould was found out and the weight of the compacted mix was determined. The compaction was repeated until the mix became sticky and wet. The results of the compaction test were presented in a plot of dry density versus water content. Unconfined compression (UC) tests were carried out on 38 mm diameter x 76 mm long cylindrical specimens. The specimens were prepared at their respective MDD and OMC state by static compaction technique. The unconfined compression tests were performed as per IS 2720 [3] procedure. Three specimens were prepared for each combination of variables and tested at a deformation rate of 0.4064 mm/min. The average value of the strength was considered.

### *3.3. Method of fly ash-lime sludge mixture and specimen preparation*

#### *3.3.1. Fly ash-lime sludge mixture preparation*

The Dadri fly ash was stored in air tight container, and before using, it was ground lightly by hand and with a pestle to separate the individual particles. The lime sludge was received in dry state from the treatment plant. It was further dried in the oven at 40$^{\circ}$C for 1-2 hours to remove the rest moisture content if present any. The oven dried lime sludge was then sieved through 150 microns and 90 micron sieve, the portion passed by 150 microns and retained on 90 micron was used for all the experimental work. The total dry weight of the mixture required to prepare a specimen, *W*; is known from the specimen's dimensions and dry unit weight of the mix, $\gamma_d$. The MDD and OMC of respective mix were used for specimen preparation. All the tests were conducted on fly ash-lime sludge mixes with LS content of 0%, 10%, 20%, 30%, 40% and 50%. The various combinations of fly ash and lime sludge mix and the variables used in the study are reported in table 3. To prepare the fly ash-lime sludge mixture, first the required amounts of fly ash and lime sludge were weighed and mixed together in the dry state. The dry fly ash-lime sludge mixture was then mixed with the required amount of water and again mixed properly in wet state. All mixing was done manually and proper care was taken to prepare homogeneous mixtures at each stage of mixing.

Table 3 Variables used in the study

| FA (%) | LS (%) | Curing period (days) |
|---|---|---|
| 100 | 0 | 7 and 28 |
| 90 | 10 | 7 and 28 |
| 80 | 20 | 7 and 28 |
| 70 | 30 | 7 and 28 |
| 60 | 40 | 7 and 28 |
| 50 | 50 | 7 and 28 |

#### *3.3.2. Preparation of cylindrical specimen*

For unconfined compression tests, cylindrical specimens were prepared at the standard Proctor maximum dry unit weight and optimum moisture content of the mix. A 38 mm inner diameter and 76 mm long mould with additional detachable collars at both ends was used. To ensure uniform compaction, the entire required quantity of the moist fly ash-lime sludge mixture was placed inside the mould-collars assembly and compressed in the automatic compaction machine till the specimen reached the dimensions of the mould. The compacted specimen was extruded from the mould using a hydraulic jack.

Copyright © TAETI

*3.3.3. Method of curing*

The specimens extruded from the mould were closely, individually wrapped in polyethylene bags to prevent moisture loss and placed in a desiccator. A small quantity of water was kept at the bottom of the desiccator to maintain constant humidity (RH100%) within the desiccator. The desiccator was closed with a lid and kept in a room at ambient temperature.

## 4. Test Results and Discussion

*4.1. Compaction characteristics*

Standard Proctor test was carried out to determine the corresponding maximum dry unit weights (MDD) and optimum moisture contents (OMC) of the various combination of modified FA. The MDD and OMC determined from compaction studies are given in table 4 and the compaction curves for the various mixes are shown in figure 4. Figure 4 shows that the addition of LS to FA has increased the MDD and decreases the OMC of the FA. The optimum moisture content (OMC) for FA varied from 22% to 20% and the maximum dry density ranged from 12.7 to 14.1 kN/m$^3$ on LS addition from 10% to 50% at an interval of 10%. The MDD achieved at equal proportion of FA and LS was the maximum among the various composites. The size of particles of fly ash is larger than that of lime sludge; hence lime sludge particles fill the voids between fly ash particles giving rise to a dense mix, which results into a higher maximum dry density up to 50% lime sludge content. It appears that all voids between fly ash particles are filled up by addition of lime sludge. The addition of finer particles of LS to FA has filled all the voids of the FA and resulted into a dense mix and hence increases the density of the mix. The MDD and OMC at 50% LS addition was 14.1 kN/m$^3$ and 20% respectively.

Table 4 Compaction characteristics of DFA

| Compacted material | MDD kN/m$^3$ | OMC (%) |
|---|---|---|
| FA100:LS0 | 12.7 | 22 |
| FA90:LS10 | 13.45 | 22 |
| FA80:LS20 | 13.6 | 22 |
| FA70:LS30 | 13.76 | 20 |
| FA60:LS40 | 13.92 | 20 |
| FA50:LS50 | 14.1 | 20 |

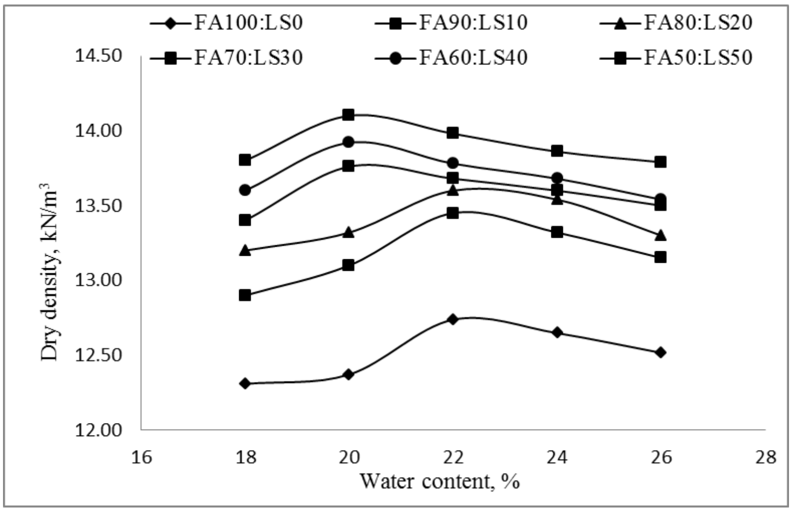


Fig. 4 Compaction curve of FA with different LS content

Copyright © TAETI

*4.2. Effect of lime sludge addition on UCS of fly ash*

Fig. 5 shows the variation of UCS with lime sludge addition to fly ash mixes cured for 7 and 28 days. It can be seen from here that the UCS increases continuously with increase in lime sludge content. This increase may be due to the presence of calcium oxide in lime sludge which endorses cementious properties. The CaO in fine lime sludge particles hydrate and form $Ca(OH)_2$ when water is added, some hydration products, e.g. calcium aluminate hydrate and calcium silicate hydrate (C-A-H and C-S-H) are formed in the pozzolanic reaction when it reacts with available $SiO_2$ and $Al_2O_3$ of fly ash, so the fly ash-lime sludge composite gains certain strength. The quantity of gel increases with LS content which bind up the fly ash particles more efficiently giving rise to an increase in the compressive strength. The chemical composition of FA shows that the sum of silica and alumina content of the Dadri fly ash is approximately 96% and calcium available in lime sludge is 51%, these silica-calcium and alumina-calcium are utilized for gel formation during the pozzolanic reaction and hence the strength increases continuously with increase in lime sludge content. The highest 7 and 28 days strength achieved was 178 and 305 kPa at 50% LS content. Hence for equal utilization of both the potential industrial waste, a composite with 50% fly ash and 50% lime sludge can be judiciously formulated to be used in pavement substructure. IRC-88-1984 [5] recommended practice for lime, fly ash stabilized soil base/subbase in pavement construction. In terms of the unconfined compressive, the lime stabilized soil used for sub base should have strength of 700 kPa at 28 days curing. The resulted 28 days UCS for FA:LS composite is less than the standard minimum value and hence further enhancement in UCS by stabilizing this composite with cement, gypsum or commercial lime.

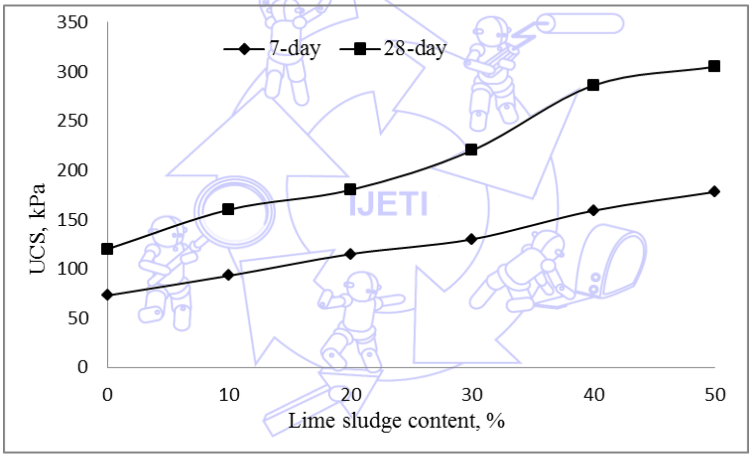


Fig. 5 Variation of unconfined compressive strength (UCS) with lime sludge content for 7 and 28 days curing

*4.3. Effect of curing on UCS*

For all the various composites types, the rate of gain in strength increases with the curing period from 7 to 28 days. The reason for continuous rapid increase in strength may be the slow pozzolanic reaction and the amount of gel formed in the mix which increases with curing period. An average increase of 15% was observed from 7 to 28 days of curing.

## 5. Conclusion

In order to reuse the industrial by-products widely distributing in India, a new type of fly ash–lime sludge composite prepared to be engineered as road construction material. The dry density of fly ash increases with the increase of lime sludge content. The MDD achieved at 50% lime sludge addition was 14.1 $kN/m^3$ at 20% OMC. The optimum formulation of the stabilized composite have a fly ash/lime sludge ratio around 1:1 the composite with optimum proportion has a reasonable 7-day strength (178 kPa) and a 28-day strength (305 kPa), the strength after further improvement can meet the Indian criteria of

Copyright © TAETI

flexible road sub base material. The hydration product $Ca(OH)_2$, C-A-H, C-S-H are yielded with the hydration reaction of the fly ash and lime sludge, those hydration products act as binder in the composite. The engineering of fly ash–lime sludge as road construction material should be an alternative approach to massively reuse these industrial by-products.

## References


[1] A. R. Thakkar, "Environmental aspects of fly ash utilization and its regulation," Proc., Utilization of Fly Ash, Surat, 2011.

[2] AWWA, Research Foundation. Disposal of wastes from water treatment plants – Part 2, Section 1, Report on what is known. Jour. 61:11:619, 1969.

[3] IS:2720, Part 10: Methods of Test for Soils: Determination of Unconfined Compressive Strength, Bureau of Indian Standards, Compendium of Indian standards on soil engineering, New Delhi, India, pp. 202-205, 1973.

[4] IS:1727 Methods of Test for Pozzolanic Materials, Bureau of Indian Standards, 1967.

[5] Recommended Practice for Lime Fly Ash Stabilized Soil Base/Sub Base in Pavement Construction, Indian Road Congress standards (IRC), Indian road congress-New Delhi, 1984.

[6] J. T. Shahu, S. Patel, and A. Senapati. "Engineering properties of copper slag-fly ash-dolime mix and its utilization in base course of flexible pavement," Journal of Materials in Civil Engineering, vol. 25, no. 12, pp. 1871-1879, 2013.

[7] L. Li, F. Santos, Y. Li, W. Shao, Q. Zhao, and F. Amini, "Evaluation of fly ash and soil mixtures for use in highway embankments," Proc. of Geotechnical special publications, Geocongress 2012: State of the art and practice in geotechnical engineering, Oakland, California, United States, pp. 3672-3680.

[8] M. K. Singh and M. Garg, "Utilization of waste lime sludge as building materials." J. Scientific and Industrial Research, vol. 67, pp. 161-166, 2008.

[9] S. P. Singh, D. P. Tripathy, and P. G. Ranjith. "Performance evaluation of cement stabilized fly ash–GBFS mixes as a highway construction material," Waste Management, vol. 28, no. 8, pp. 1331-1337, 2008.

[10] S. R. Kaniraj and V. Gayathri, "Permeability and consolidation characteristics of compacted fly ash," Journal of Energy Engineering, vol. 130, no. 1, 2008.

[11] W. Shen, M. Zhou, W. Ma, J. Q. Hu, and Z. Cai, "Investigation on the application of steel slag–fly ash–phosphogypsum solidified material as road base material," Journal of Hazardous Materials, vol. 164, no. 1, pp. 99-104, 2009.


IJETI

Copyright © TAETI