Shear Strength Parameters of Fly Ash-Lime-Metakaolin Mix

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Abstract— Over the years, due to rapid industrialisation and urbanisation, the demand of electricity has increased that leads to creation of more number of thermal power plants in the country.One of the important byproduct formed from thermal power plant is fly ash that causes disposal problems. As a part of development, India has taken initiative in developing infrastructure such as express highways, power projects and industrial structures etc., to meet the requirements of globalisation. All these developments require large quantities of material for its construction. This study is conducted to analyse the shear strength behaviour of fly ash added with lime and metakaolin so that it can be effectively used in construction field.The materials used in this study are fly ash, lime and metakaolin. Metakaolin is a dehydrated form of the Kaolinite clay mineral which accelerates the hydration of OPC. In this study, the shear strength parameters are analysed by conducting unconsolidated undrained (UU) triaxial tests. It is found that because of the formation of new pozzolanic products cohesion increases and angle of internal friction decreases with the increase in curing period.

Index Terms — Metakaolin, Kaolinite, shear strength, Unconsolidated Undrained triaxial tests, Pozzolanic products, Cohesion, Angle of internal friction.

1 Introduction

THE advancements in the field of electrical technology have transformed our day to day lives. And now, electricity has become the backbone of modern industrial society too. In recent years the rate of demand of electricity has increased due to rapid growth in urbanisation and industrialisation. One of the main sources of electricity generation in India is thermal power plants. Large quantities of fly ash are produced by thermal power plants where coal is used as fuel. According to studies, the total quantity of fly ash produced during the period 2010-2012 was of the order of 131.09 million tons and its generation has reached almost to 220 million tons by 2016.The present utilisation of fly ash in India is closer to 60% and the remaining about 40% of the fly ash produced is causing disposal problems. So it is necessary to utilise the waste generated effectively in order to reduce the disposal problems. As a part of development, India has taken initiative in developing infrastructure such as express highways, power projects and industrial structures etc., to meet the requirements of globalisation. All these developments require large quantities of material for its construction. This lead to the creation of interest to use the fly ash generated in construction fields. A study is conducted to analyse the strength behaviour of the waste material generated from thermal power plants.

Some additives like lime and metakaolin are added to fly ash for the improvisation of its self properties. Lime is a calcium containing material. It predominately consists of oxides, hydroxides and carbonates. Metakaolin is generally categorised as a supplementary cementing material or mineral admixture that complements the properties of concrete when it is used with cement. Metakaolin is a fine aluminosilicate having pozzolanic activity. It is manufactured by the calcination process of Kaolinite clays at a temperature of 650ºc to 750ºc.

In the present investigation an attempt has been made to study the increase in rate of shear strength gain in lime-fly ash mixes with the addition of a small percentage of metakaolin. A series of unconsolidated undrained triaxial tests are conducted to investigate shear strength parameters of fly ash-lime-metakaolin mix (reference mix).

2 Literature Review

This chapter briefly discuss the literature related to characteristics of fly ash, fly ash-lime mixes, metakaolin, x ray diffraction tests and scanning electron microscopy tests.

2.1 Studies on Fly Ash

A.Xu and S.L.Sarkar, “Microstructural Development in High Volume Fly Ash Cement System”

The results of research findings on the microstructural development in a high volume fly ash cement system containing 60% fly ash by weight of binder were presented in this paper. Though the one day strength of high volume fly ash mortar was very less compared to plain cement mortar, from 3 day onwards the strength starts to increase. As the microstructure develops the strength increases significantly at later ages and reaches 78% of the control specimen at 180 days.

McLaren R J and Digionia A.M,“The typical Engineering Properties of Fly ash”

A good knowledge on physical and engineering properties of coal fly ash is required for better planning, design and construction of both disposal and utilisation projects.This study was conducted to find out the typical values or range of values of physical and engineering properties of fly ash. Data on 131 class F fly ash samples and 26 class C fly ash samples were taken and then database was analysed to determine the typical values or range of values for physical and engineering parameters.

2.2 Studies on Fly Ash Lime Mixes

Sherwood P T and Ryley M D, “Use of Stabilised Pulverised Fuel Ash in road Construction”.

This paper presents the variation in the physical and chemical properties of pulverised fuel ash. The main aim of using fly ash is to eliminate its disposal problems, to reduce the demand for natural aggregate, cheapness and readily availability. The fraction of lime present in fly ash improves the self hardening properties of fly ash. The presence of higher amounts of free lime in fly ash improves the strength due to pozzolanic reactions with the available reactive silica.

2.3 Studies on Metakaolin

Sanjay N Patil, Anil K Gupta and Subhash S Deshpande ,"Metakaolin-Pozzolanic Material for Cement in High Strength Concrete"

In this paper use of metakaolin which is having good pozzolanic activity in high strength concrete is studied. The author concluded that metakaolin reduces the size of pores in cement paste and transforms finer particles in to discontinuous pores. This leads to a decrease in permeability of concrete. Also it reduces heat of hydration leading to better shrinkage and crack control.

Shakir A.Al-Mishhadani,Amer M Ibrahem and Zeinab H Naji,"The Effect of Nano Metakaolin Material on Some Properties of Concrete"

In this paper the effect of nano metakaolin on some properties of concrete was examined. The nano metakaolin used was prepared by thermal activation of kaolin clay for 2 hours at 750^{0}C. The Splitting tensile strength of concrete with nano metakaolin is greater than strength of reference concrete with same water cement ratio.The improvement of splitting tensile strength of concrete is 0% when 3% nano metakaolin is replaced but it increase to 20% by 10% replacement. The improvement in water absorption for 3% nano metakaolin replacement is 16.6%.

3 Methodology

This chapter presents the details about the materials used and the experimental method adopted along with apparatus and the testing details.

3.1 Materials

3.1.1 Fly Ash

The fly ash used in the study was collected from Hindustan Newsprint Limited, Vellor, Kerala.It had a specific gravity of 2.24. The liquid limit was obtained as 34.179%.The maximum dry unit weight and optimum moisture content was obtained by standard proctor test as 0.99g/cm^3 and 54% respectively.

3.1.2 Lime

Commercially available lime in the market was adopted in the study .It had a specific gravity of 2.15.

3.1.3 Metakaolin

Metakaolin is a fine aluminosilicate material having pozzolanic activity. It is formed by calcination of Kaolinite clays at temperature in the range of 650^{o}c -750^{o}c.Metakaolin was collected from Ashirwaad Chemicals, Chennai. It had specific gravity of 2.42.

3.2 Sample Preparation Procedures

3.2.1 Unconsolidated Undrained Triaxial Tests

The fly ash was rubbed slightly by hand to separate the individual particles. A metallic mould having size 37.5 mm inner diameter and 75 mm long was used to prepare cylindrical specimens for the unconsolidated undrained triaxial test. The required quantity of lime (4 %) and metakaolin (5 %) corresponding to dry weight of fly ash was then mixed thoroughly and the water corresponding to optimum moisture content (OMC), was added to the mix. To ensure uniform compaction, specimen was compressed statically from both ends until the specimen just attained the required dimension. Then the specimen was removed with a hydraulic compression machine with sample extrusion facility. Curing was provided with the help of jute bags. In this method, the specimen is placed on jute bags. It is exposed to atmosphere for one day after preparation. After 24 hours it was covered using another jute bag and water was sprinkled over the top surface of the jute bag till the curing period was reached.

3.3 Sample Preparation Procedures Tests Conducted

Various tests were conducted based on relevant code of practice.

3.3.1 Standard Proctor Compaction Test

The required quantities of fly ash, lime and metakaolin were mixed in dry state and water was added to facilitate compaction. The mixture is filled up with three layers and each layer is compacted by imparting 25 numbers of blows by a hammer weight 2.6 kg having a free fall of 310 mm. A small quantity of the mix was removed for the water content determination. Further compacted mix was removed from the mould, crushed and water was added to continue the compaction process till moisture content reaches the optimum moisture content (OMC) and the corresponding dry unit weight obtained.

3.3.2 Unconsolidated Undrained Triaxial Test

A conventional triaxial apparatus has been adopted for the entire triaxial testing. A triaxial cell capable of withstanding consolidation pressure of more than 1 MPa and with the facility to test specimen of 37.5 mm diameter and 75 mm height was used. The consolidation pressure was applied and maintained with the means of air compressor. Further, axial loads were applied through a loading frame with deformation control system. The consolidation pressure of 50.0 kPa, 100 kPa and 200 kPa were used for testing the specimens at 7, 14 and 28 days of curing with jute bag curing method.

4 Test Results

This chapter presents the result of compaction studies, unconsolidated undrained test on the reference mix containing fly ash-lime- metakaolin. It may be recalled that the specimens of reference mix containing fly ash+4% lime+5% metakaolin were cured for 7,14 and 28 days with jute bag curing method.

4.1 Standard Proctor Compaction Test

The standard proctor compaction tests were conducted by varying the lime content from 2 to 8 % lime in fly ash. The results are shown in Fig. 4.1. Study of Fig. 4.1 (a) reveals that the dry unit weight of the fly ash was 1.016g/cm^3, which increased to 1.185g/cm^3 with the addition of 2% lime. The dry unit weight further increased to 1.224g/cm^3 and decreased to 1.215g/cm^3 with the addition of 4 and 6% of lime to the fly ash respectively.

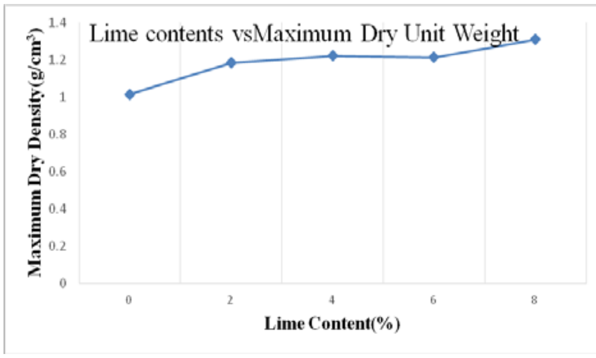

Fig. 1 (a): Maximum Dry Density vs Lime Content

Fig 4.1(b) presents the variation of optimum moisture content with the lime. Study of this figure reveals that the optimum moisture content of the fly ash was 48%, which decreased to 32 % with addition of 2 % lime. The optimum moisture content further increases to 38.0 and then decreases to 34% again with the addition of 4 and6% lime to the fly ash .The increase in dry unit weight with the addition of lime is due to the pozzolanic reaction between fly ash and lime and decrease is due to exceeded affinity of fly ash for lime, that is ions adsorbed by a fly ash are not available for pozzolanic reaction. The process has been referred to as lime fixation.

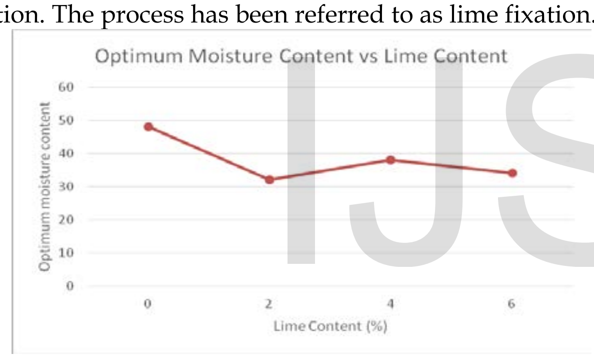

Fig. 1 (b): Optimum Moisture Content vs Lime Content

Therefore, a mix of fly ash+4% lime was chosen for further compaction study by varying the content of metakaolin. The variation of the maximum dry unit weight and optimum moisture content with metakaolin are shown in Fig 4.2 (a) and Fig 4.2(b) respectively. A study of Fig 4.2(a) reveals that the dry unit weight of fly ash + 4 % lime+5% metakaolin is 1.24g/cm³ which decreased to 1.23g/cm³ and then decreased to 1.175g/cm³ with the addition of 7.5 and 10% metakaolin.

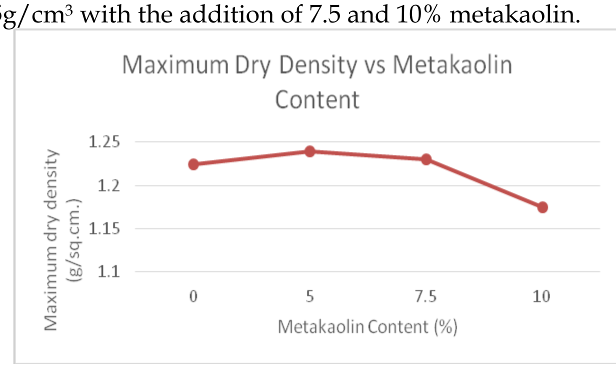

Fig. 2 (a): Maximum Dry Density vs Metakaolin Content

Fig 4.2 (b) presents the result of variation of optimum moisture content of the fly ash+4% lime with varying content of metakaolin. The results reveals that the optimum moisture content of fly ash + 4 % lime decreases from 38 to 37 % with the addition of 5 % and then increases to 39% by addition of 10 % metakaolin .Based up on the compaction study reported above, an optimum reference mix of fly ash + 4 % lime + 5 % metakaolin was selected for the further experimental work.

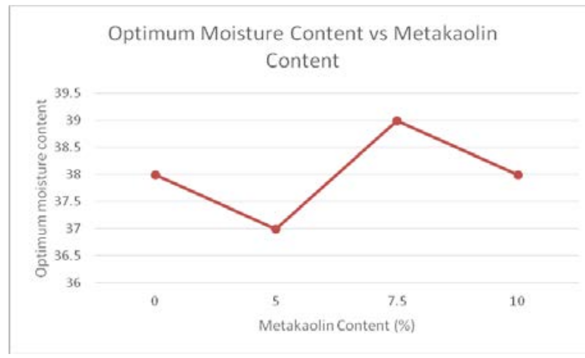

Fig. 2 (b): Optimum Moisture Content vs Metakaolin Content

4.2 Unconsolidated Undrained Triaxial Test

The stress-strain curves for the reference mix cured for 7, 14 and 28 days and at confining pressure of 50 to 200 kPa are shown in Fig. 4.3 (a), Fig 4.3 (b) and Fig 4.3 (c) respectively. Study of Figs. 4.3 (a), (b) and (c) reveal that the peak deviator stress of the reference mix increases with the increase in the curing period. For example, reference mix cured for 7 days with a confining pressure of 50 kPa has shown a peak deviator stress of 8.15 N/cm², which increased to 11.83 N/cm², 14.37 N/cm² respectively when the curing period, increased to 14 and 28 days. Similar trend of increase in deviator stress with the increase in curing period was observed at other confining pressure as evident from Fig 4.3 (a), Fig 4.3 (b) and Fig 4.3 (c).The increase in deviator stress with the increase in curing period is attributed to the formation of hydrate product (calcium silicate hydrate and calcium aluminate hydrate) by pozzolanic reaction leading to increase in deviator stress with the increase in curing period. Further study of Figs . 4.3 (a), (b) and (c) reveals that the peak deviator stress increases with the increase in confining pressure at all periods. For example, for the specimen cured for 7 days and at confining pressure of 50 kPa, a peak deviator stress of 8.15 N/cm² increased to 13.35 N/cm² and 16.67 N/cm² with the change in the confining pressure to 100 kPa and 200 kPa, respectively. Similar trend of increase in deviator stress with the increase in confining pressure was observed at other curing periods as evident Fig 4.3 (a), (b) and (c).

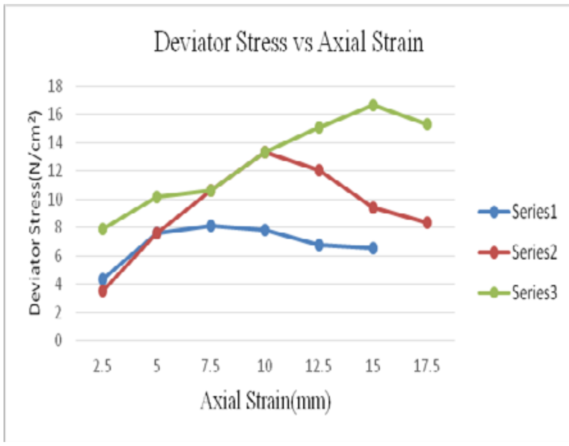

Fig 3 (a): Stress Strain Curves of Reference Mix at 7 days

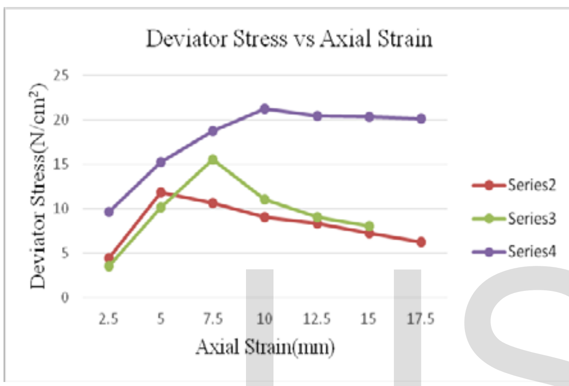

Fig 3 (b): Stress Strain Curves of Reference Mix at 14 days

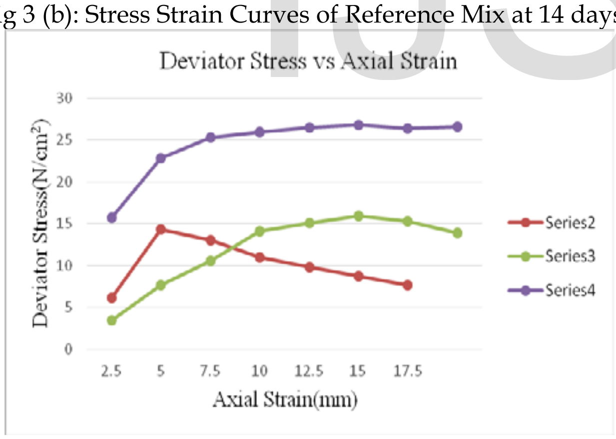

Fig 3 (c): Stress Strain Curves of Reference Mix at 28 days

4.3 Shear Strength Parameter from UU Triaxial Test

The results of unconsolidated undrained triaxial tests were used to make p-q plots and the values of shear strength parameters are tabulated in Table.4.1.

TABLE 1 SHEAR STRENGTH PARAMETERS FOR THE REFERENCE MIX CURED FOR 7, 4 AND 28 DAYS

Curing Period (Days)	Cohesion C (kPa)	Angle of Internal Friction, φ
7	250	16
14	350	15
28	450	11.5

Results from Table 4.1 reveal that the cohesion is increased and angle of internal friction is decreased of the reference mix with the increase in curing period. For example, the cohesion of reference is increased from 250kPa to 450kPa when curing period is raised from 7 to 28 days. The friction angle reduces from 16° to 11.5° with the increase of curing period from 7 to 28 days. This increase in cohesion and decrease in internal friction are due to the formation of pozzolanic reactions. Pozzolanic products like calcium silicate hydrate and calcium aluminate hydrate gel are formed here. These gel structures get transformed into more crystalline form with the extension of curing period. This transformation makes the sample more rigid and leads to the reduction in internal friction between particles corresponding to extended curing period.

5 CONCLUSION

Waste conversion is the powerful term used as part of effective solid waste management technique. Under this perception the definitive objective should be to convert whole waste material produced into useful engineering material. At the end, it is found that large scale utilization of this waste material is possible in construction field. To accomplish this objective unconsolidated undrained test was conducted on fly ash-lime-metakaolin to found out strength behaviour of this material. Based on the results and discussion presented in this chapter, the following is concluded.

- The reference mix obtained from experiments includes flyash+4%lime + 5%metakaolin.
- As curing period increases peak deviator stress increases due to the formation of pozzolanic product calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).
- As confining pressure increases peak deviator stress increases due to the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).
- The cohesion value increases with the increase in curing period as the sample becomes more rigid.

REFERENCES

[1] Shaik Jabiulla and Dr.D Neeraja, "Performance Evaluation of Meta-

kaolin and Fly Ash Based Geo-Polymer Concrete",International Journal for Technological Research in Engineering, Vol.02,No.07,March 2015.

[2] Shakir A.Al-Mishhadani,Amer M Ibrahem and Zeinab H Naji "The Effect of Nano Metakaolin Material on Some Properties of Concrete"Diyala Journalof Engineering Sciences,Vol.06.No.01,pp.50-61,March 2013.

[3] C. Shi, "Early microstructure development of activated lime-fly ash pastes", *Cement and Concrete Research*, vol. 26, no. 9, pp. 1351-1359, 1996.

[4] A. Xu and S. L. Sarkar, "Micro structural developments in high-volume fly ash cement system", *Materials in Civil Engineering*, vol. 1, pp. 117-136, 1994.

[5] Gray, D.H. and Lin, Y.K. "Engineering properties of compacted fly ash." *Journal of Soil Mechanics and Foundation Division, ASCE*, 98(4), 361-377, 1972.

[6] Sherwood, P T. and Ryley, M D. "Use Of Stabilized Pulverized Fuel Ash in Road Construction," *Road Research Laboratory Report*, Ministry of Transport, UK, 49, 1-44, 1966.

[7] B. V. Venkatarama Reddy and K. Gourav. "Strength of Lime-Fly Ash Compacts using Different Curing Techniques and Gypsum Additive" pp. 1793-1808, 2011.

[8] Basumajumdar A.,Das A.K.,Bandyopadhyay., and Maitra S "Some studies on the reaction between fly ash and lime" *Indian Academy of Sciences,* pp. 131–136, 2005.

[9] Ambarish Ghosh and Chillara Subbarao "Microstructural Development in Fly Ash Modified with Lime and Gypsum",Journalof Materials in Civil Engineering/January/February 2001.

[10] Shi, C. "Studies on several factors affecting hydration and properties of lime-pozzolan cements." *Journal of Materials in Civil Engineering*, 13(6), 441-445, 2001.