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Research Article
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Compaction and Strength Characteristics of Lime-Blended Fly Ash

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Abstract

Fly ash is now regarded as a construction material and as a geotechnical material. This note presents some experimental data on fly ash, an industrial waste obtained from a thermal power station. Lime was used as a blend material to study its effect on various engineering properties of fly ash. Proctor compaction tests, unconfined compression tests and Proctor needle penetration tests were performed on lime-fly ash blends. Effect of curing on unconfined compressive strength was also studied. Addition of lime to fly ash decreased the maximum dry density and increased the optimum moisture content. 4% lime was found to be the optimum content with regard to unconfined compressive strength for all curing periods. Penetration resistance also reached its maximum value at 4% lime and thereafter decreased with increasing lime content.

Keywords: Fly ash; Compaction; Unconfined compression; Penetration resistance; Proctor needle

Introduction

Of all the industrial wastes, fly ash is being produced all over the world at a huge rate. Fly ash, which is an industrial waste generally obtained from thermal power stations, is a non-plastic silt material, extracted from the flue gases of a furnace fired with coal. It is non-plastic fine silt. Composition of fly ash varies with the nature of the coal burnt. Fly ash can be used as an alternative to conventional materials in the construction of geotechnical and geo-environmental infrastructure [1,2]. Fly ash can also be used for control of expansion resulting from alkali-silica reactivity [3,4]. As an additive, fly ash enhances the strength of the composite [5,6] because of the pozzolanic reaction. In combination with lime and bentonite, fly ash can be used as a barrier material also [7]. Fly ash is also a potential material for waste liner [8]. In combination with lime and bentonite, fly ash can be used as a barrier material also [7]. Fly ash has a number of potential uses in geotechnical works. It has been used as a backfill material, a base course material and an embankment material besides being used as a stabilizing agent [9]. Using an industrial by-product such as fly ash as an additive to civil engineering construction materials helps arrest its hazardous effects on environment [10,11]. This paper presents results obtained from an experimental study on the effect of lime on some engineering characteristics of fly ash such as compaction characteristics, unconfined compressive strength (UCC) and penetration resistance as obtained from Proctor needle penetration tests. Effect of curing on UCC and penetration resistance of lime-fly ash blends is also presented.

Experimental Investigation

A detailed test programme was conducted to study the effect of lime on some important engineering characteristics of fly ash. Effect of lime on compaction characteristics, stress-strain characteristics and penetration resistance measured from Proctor needle penetration test was studied. Effect of curing period on stress-strain characteristics of lime-fly ash blends was also studied.

Test materials

The fly ash used in the test programme was obtained from Vijayawada Thermal Power Station, Andhra Pradesh, India. It is a class-C fly ash. It is a non-plastic material composed of silt-sized particles. Table 1 shows the index properties of the fly ash. The standard test designations of the ASTM according to which the various index properties of fly ash were determined are also shown in Table 1. Liquid limit and plastic limit of the fly ash could not be determined, the ash being non-plastic. Hence, plasticity index of the ash is indicated as NP (Table 1). Silt content in the fly ash used was 92%. The USCS classification of fly ash is also given as 'NP' or 'non-plastic'. Table 2 shows the chemical composition of the fly ash. Hydrated lime [$Ca(OH)_2$] was used as an additive to fly ash in the test programme.

Variables studied and tests performed

The effect of the following variables on various engineering characteristics of fly ash was studied:

Lime content (%): 0, 4, 8, 12 and 16.

Curing period (Days): 0, 7 and 21 days

Proctor compaction tests: Air-dried fly ash was used in compaction tests. The required quantity of lime by weight of fly ash was added and thoroughly mixed along with an arbitrary amount of water chosen based on the dry weight of fly ash. The test was conducted following the standard test procedure (ASTM 2000, D 698a). Oven-dry water content was determined and the compaction curves plotted.

Unconfined compressive strength: Stress-strain characteristics of lime-fly ash blends were studied by conducting unconfined compression tests on cylindrical specimens of lime-fly ash blends. The cylindrical specimens of size 38 mm in diameter and 76 mm in height were prepared at the chosen water content and dry unit weight. The tests were conducted beyond failure. Cylindrical specimens prepared for unconfined compressive strength were kept in an incubator for curing them through time periods of 0, 7 and 21 days. At the end of the curing periods the specimens were tested. It may be mentioned here that curing was done only for samples prepared at the respective optimum moisture content (OMC) and maximum dry density (MDD) of the lime-fly ash. Two more cylindrical specimens were also tested

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Property	Standard designation	Fly ash
Specific Gravity	ASTM D854-02	2.1
Liquid Limit (%)	ASTM D4318-00	-
Plastic Limit (%)	ASTM D4318-00	-
Plasticity Index (%)	ASTM D4318-00	NP
Gravel (%) (>6.20-4.75 mm)	ASTM 98 D422-63	0
Sand (%) (4.75-0.075 mm)	ASTM 98 D422-63	0
Silt (%) (0.075-0.002 mm)	ASTM 98 D422-63	92
Clay (%) (<0.002 mm)	ASTM 98 D422-63	8
Free swell index (FSI)	ASTM D5890-02	Non swelling
USCS classification	ASTM D2487-00	ML

Table 1: Index properties of fly ash.

Component	Range (wt %)
SiO_2	61-64.29
Alumina	21.6-27.04
Fe_2O_3	3.09-3.86
TiO_2	1.25-1.69
MnO	Up to 0.05
CaO	1.02-3.39
MgO	0.5-1.58
Phosphorus	0.02-0.14
SO_3	Up – 0.07
K_2O	0.08-1.83
Na_2O	0.28-0.48
Loss of ignition	0.2-0.85

Table 2: Chemical composition of fly ash.

which were prepared with fly ash alone (0% lime), one at the water content of 17.6% (dry of optimum) and the other at 23.73% (wet of optimum). The dry density corresponding to the dry of optimum of 17.6% and the wet of optimum of 23.73% was the same at 13.85 kN/m³.

Penetration resistance: Penetration test was conducted for the estimation of shear resistance of various lime-fly ash blends. Proctor needle was used for performing the test. Lime-fly ash blends were compacted at various contents of lime in the Proctor's mould corresponding to OMC and MDD. Further, at 0% lime, two more specimens were prepared in Proctor's mould corresponding to a dry density of 13.85 kN/m³ one at wet of optimum of 23.73% and the other dry of optimum of 17.6%. A Proctor needle, to which a shoe of 5 mm diameter was attached, was kept vertically on the surface of the blend and pushed into it up to a depth of 40 mm. It may be mentioned here that, as the blends of fly ash were very stiff, the Proctor needle could not be pushed beyond 40 mm. The penetration force was read at the penetration of 40 mm, as indicated by the sliding ring on the stem of the apparatus.

Results and Discussion

Compaction characteristics of lime-fly ash blends

Figure 1 shows the compaction curves for lime-fly ash blends for varying lime contents. The maximum dry density (MDD) decreased and optimum moisture content (OMC) increased with increasing lime contents. Though flocculation and cementation take place upon addition of lime to fly ash, lime absorbs water which leads to increase in water voids and a consequent increase in optimum moisture content (OMC) and decrease in maximum dry density (MDD). Table 3 shows the values of OMC and MDD for varying lime contents. There was no indication of OMC or MDD reaching an optimum value within the range of lime content of 0% to 16% used in the test programme.

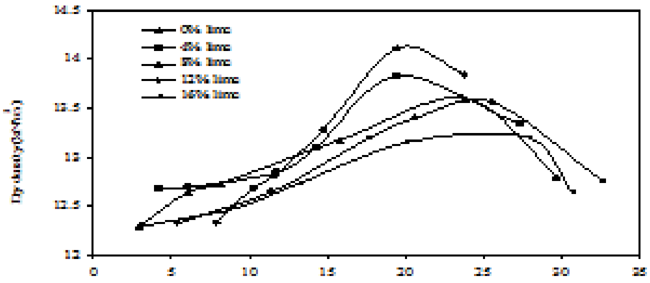

Figure 1: Compaction curves for lime-fly ash blends.

Lime content (%)	MDD (kN/m³)	% decrease in MDD	OMC (%)	% increase in OMC
0	14.12	---	20	---
4	13.83	2.0	20	0
8	13.6	3.7	24.2	21
12	13.6	3.7	24.8	24
16	13.21	6.5	27.6	38

Table 3: Effect of lime on compaction characteristics.

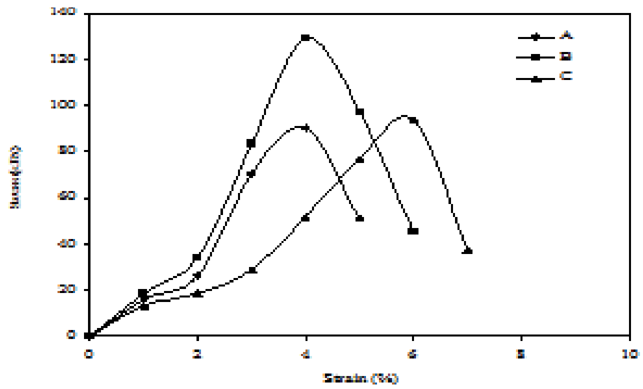

Figure 2: Stress-strain characteristics of fly ash alone at different placement conditions (0% lime).

MDD kept on decreasing and OMC kept on increasing. Therefore, the maximum % in decrease in MDD was 6.5% at 16% lime content and the maximum % increase in OMC was 38% at 16% lime content.

Stress-strain characteristics of lime-fly ash blends

Effect of lime: Figure 2 shows the stress-strain curves for three samples, A, B and C, of fly ash alone (0% lime). Of the three samples, sample B was compacted at the OMC and the MDD of fly ash and samples A and C were compacted at a dry density of 13.85 kN/m³ arbitrarily chosen from the compaction curve of fly ash. The water contents of samples A and C were 17.6% and 23.73%. The peak stress at which failure occurred was highest for sample B at 129.3 kPa at a low failure strain of 4%. This is on the expected lines because sample B was compacted at MDD. Of the samples A and C, compacted respectively dry of optimum and wet of optimum corresponding to the same dry density, sample A failed at a stress of 91 kPa and sample C at 93 kPa. The stress-strain curve for sample B is above the stress-strain curves for samples A and C for all the strains. Similarly, the stress-strain curve for the sample A (compacted at lesser water content) lies above the stress-strain curve for the sample C (compacted at higher water content) for all strains. This shows that the stress for sample A at all strains was higher than for sample C. Though the peak stress for sample A and C was nearly the same, sample A failed at a lower strain of 4% than sample C which failed at 6%. Figure 3 shows the stress-strain characteristics of lime-fly ash blends for varying lime content for 0 days curing. The peak stress or failure stress increased with increasing lime content. However, this trend was observed only up to a lime content of 4%. The peak stress decreased after 4% lime content. The data pertain to the lime-fly ash blends prepared at their respective OMC and MDD values. Fly ash blended with 4% lime showed the highest failure stress at 218 kPa. The peak stress up to 8% lime content was more than that for fly ash alone (0% lime content). However, when the lime content was increased to 12% and 16%, the peak stress became lower than for fly ash alone (0% lime). As flocculation and cementation take place in the lime-fly ash blends, the resistance offered by the lime-blended fly ash sample to the applied load increased compared to the unblended fly ash sample. However, as OMC increased at higher lime contents, the peak stress at which the blends failed decreased with increasing lime content. A lime content of 4% is the optimum lime content with reference to shear strength for the fly ash used. Table 4 shows the failure stress (kPa) and the corresponding % failure strains for different lime-fly ash blends.

Effect of curing: Figures 4 and 5 show stress-strain characteristics for lime-fly ash blends at different lime contents for 7 days curing and 21 days curing. The peak stress at which failure occurred increased with increasing lime content up to 16% lime, which was the maximum lime content used in the test programme. This was true for both when curing period was increased to 7 days to 21 days. The data shown in Figures 4 and 5 show the conspicuous effect of curing on the peak stress of the samples; for, the lime-fly ash blends cured for 0 days increased in their peak stress only up to 8% lime content , and thereafter decreased at 12% and 16% lime contents (Figure 3). However, when the curing period was increased from 0 to 7 days and 21 days, peak stress increased. As

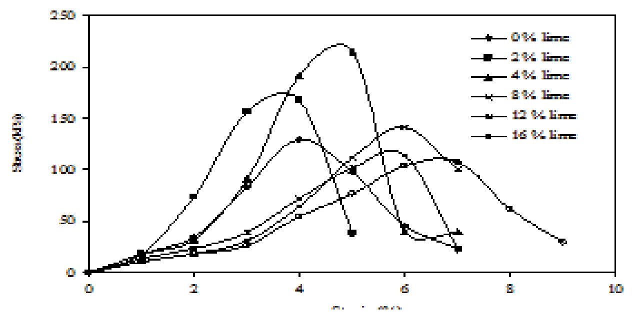

Figure 3: Stress-strain characteristics of lime-fly ash blends (0 days cuing).

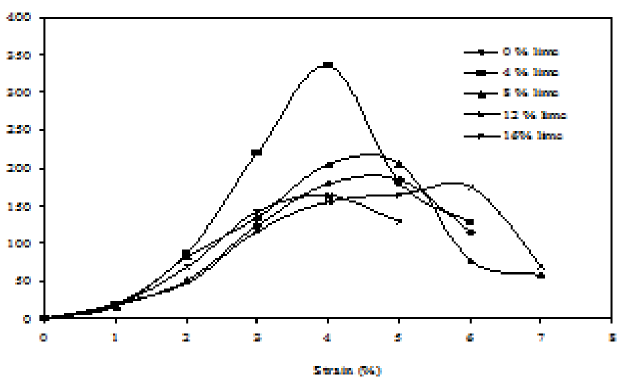

Figure 4: Stress-strain characteristics of lime-fly ash blends (7 days cuing).

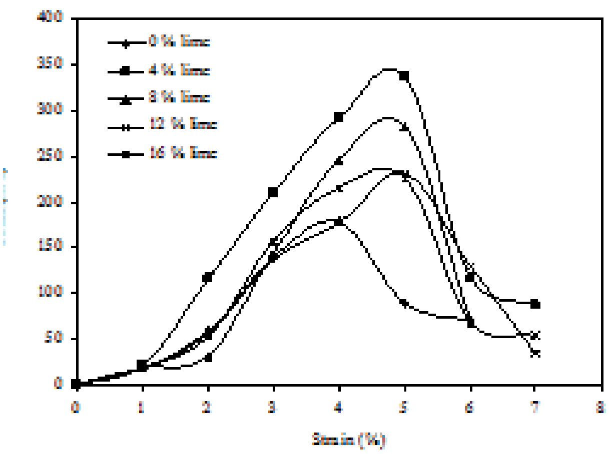

Figure 5: Stress-strain characteristics of lime-fly ash blends (21 days cuing).

Lime content (%)	Failure strain (%)	Peak stress (kPa)	% increase in peak stress	% decrease in peak stress
0	4.05	129.5	---	---
2	3.8	170.5	31.67	---
4	4.85	218	68.34	---
8	6	141.7	9.42	---
12	5.8	116	---	10.42
16	6.7	110	---	15.05

Table 4: Stress-strain characteristics of lime-fly ash blends (0-days curing).

the samples were cured for 7 and 21 days, cementation took place, leading to increase in the peak stress at all lime contents (Figures 4 and 5). Moreover, the peak stress increased for all lime contents with increasing curing period. For example, the peak stress increased by 50% at 0% lime content and 100% at 16% lime content as curing period increased from 0 days to 21 days. Figures 6 and 7 show the stress-strain characteristics of fly ash alone (0% lime) and lime-fly ash blends (at 4% lime) respectively for different curing periods. The stress-strain curves are similar for both 0% and 4% lime at different curing periods; but, they show that the peak stress increased with increasing curing period. The increase in peak stress could be attributed to the development of cementitious products in the blend with increasing curing period. Figure 8 shows the variation of peak stress with lime content at different curing periods. For all curing periods, peak stress increased up to 4% lime and thereafter decreased with increasing lime content. Hence, 4% lime may be referred to as the optimum lime content irrespective of the curing period. Further, the peak stress increased with increasing curing period for all lime contents. It is interesting to find that there was a significant increase in the peak stress when the curing period increased from 0 to 7 days; the increase in the peak stress was not significant when the curing period increased from 7 days to 21 days. However, this phenomenon of change in the peak stress was predominant only up to 4% lime content. Beyond 4% lime content the change in the peak stress was uniform when the curing period changed from 0 to 7 days and from 7 days to 21 days.

Penetration resistance

Penetration resistance of lime-fly ash blends was measured (0 days curing) using Proctor needle to which a shoe of diameter 5 mm was attached. Figure 9 shows the effect of water content on penetration resistance. The data shown in figure pertain to tests done on samples A, B and C mentioned in the previous section. Of them, B was compacted

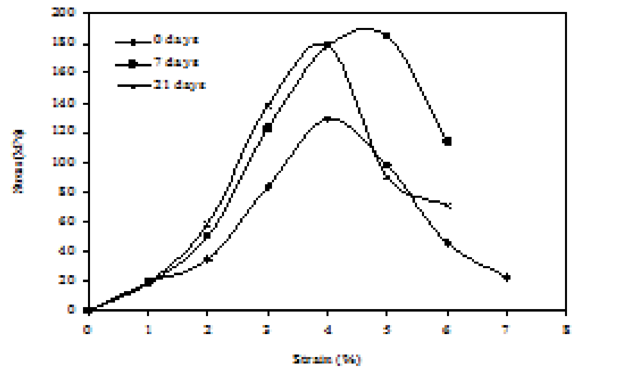

Figure 6: Stress-strain characteristics of lime-fly ash blends for different curing periods (0% lime).

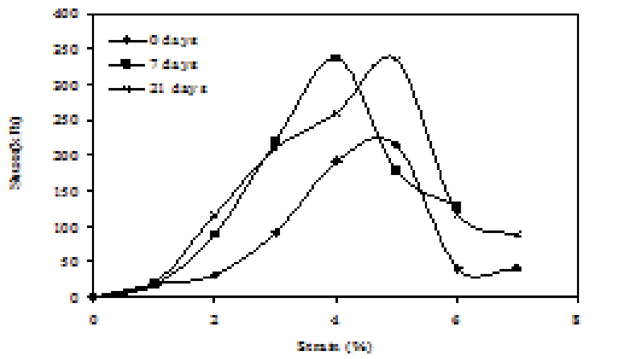

Figure 7: Stress-strain characteristics of lime-fly ash blends for different curing periods (4% lime).

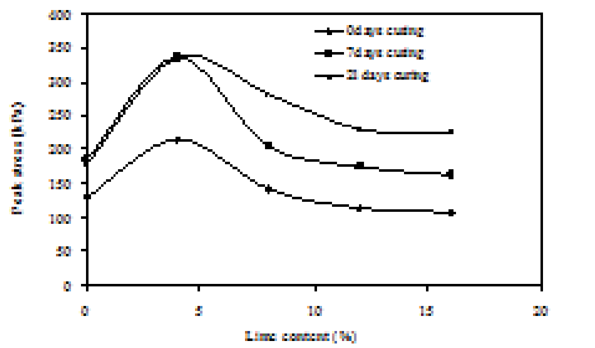

Figure 8: Effect of curing period on peak stress.

at OMC and MDD and the other two at some arbitrary density, one dry of optimum and the other wet of optimum. The penetration resistance (N) of the sample B was the highest at 127 N. The penetration resistance of sample B was high because the sample was stiff having been compacted at its maximum dry density. The penetration resistance of sample C, compacted wet of optimum was the least at 34 N, and that of sample A, compacted dry of optimum was 120 N. The figure shows that penetration resistance decreased significantly with increasing water content as the sample became soft at higher water contents. Figure 10 shows, by comparison, the variation of peak stress and penetration resistance with lime content. That data refer to 0 days curing. Both peak stress and penetration resistance increased with increasing lime content. Both peak stress and penetration resistance reached their

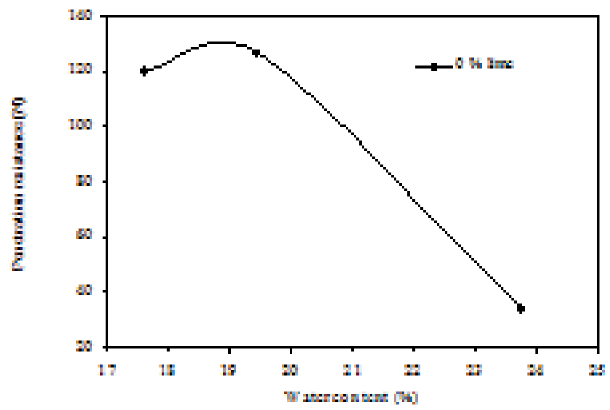

Figure 9: Effect of water content on penetration resistance of fly ash alone (0% lime).

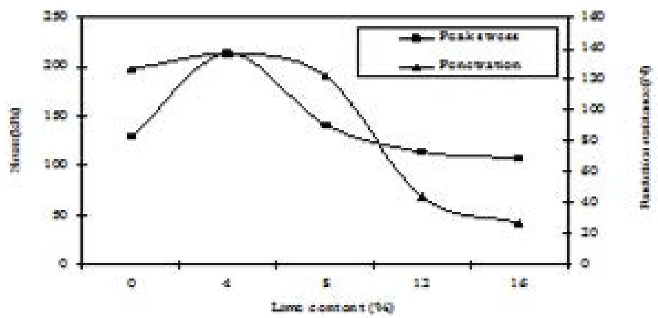

Figure 10: variation of peak stress and penetration resistance with lime content.

maximum values at 4% lime and thereafter decreased significantly with increasing lime content.

Conclusion

Engineering characteristics of fly ash are reported on from a laboratory test programme. Lime was added in different amounts to fly ash to study its effect on some of the engineering properties of fly ash. Compaction characteristics, unconfined compressive strength and Proctor needle penetration resistance were studied through experiments on lime-fly ash blends. The results would be useful for geotechnical practice wherein fly ash is used as a construction material with lime as an admixture. The following are the chief conclusions that can be drawn from the experimental study:

1. The maximum dry density (MDD) decreased and optimum moisture content (OMC) increased with increasing lime contents. Neither OMC nor MDD reached an optimum value within the range of lime content of 0% to 16% used in the test programme.

2. Unconfined compressive strength (UCC) increased with increasing density but decreased with increasing water content. Unconfined compressive strength (UCC) increased with increasing lime content. Strength was maximum at 4% lime and it decreased at higher lime contents. UCC at 8% lime content was more than that for fly ash alone (0% lime content). When the lime content was increased to 12% and 16%, UCC became lower than for fly ash alone (0% lime).

3. Lime-fly ash blends cured for 0 days resulted in increased UCC only up to 8% lime content and thereafter decreased at 12% and 16% lime contents. However, when the curing period was increased from 0 to 7 days and 21 days, peak stress increased. For all curing periods, UCC increased up to 4% lime and thereafter decreased with increasing lime content.

4. The penetration resistance of the lime-fly ash blends increased with increasing lime content. The penetration resistance was highest at 4% lime and thereafter decreased with increasing lime content. Both peak stress and penetration resistance reached their maximum values at 4% lime and thereafter decreased with increasing lime content.

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