Strength Properties of Alkali Activated Fly Ash

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Abstract. Fly ash is a by-product of coal fired power plants and a rich source of alumino-silicate. This paper reports the compaction, and strength properties of fly ash activated with different concentrations of lime, cement and alkali solution. The lime and cement content has been varied as 0, 2.5, 5, 7.5 and 10% of dry weight of fly ash whereas the concentration of NaOH solution is varied as 0.5M, 1M and 2M. In general an increase in stabilizer content increases the MDD value whereas the OMC decreases. The maximum UCS value of the stabilized specimens is found to be 3.5 MPa. However, stabilized specimens are found to be brittle in nature.
Keywords: Fly-ash, Activation, OMC, MDD, Unconfined Compressive Strength

1 Introduction

Industrialization and urbanization are the two major aspects of development both of which call for a scenario for high power generation. Fly ash produced from coal fired power plants poses serious disposal as well as environmental issues. On the other hand, transformation of these deleterious waste products into suitable construction material might be a more suitable alternative owing to the fact that this technique would not only alleviate the environmental issue of waste disposal but also help decreasing the cost of construction business [1]. The self-hardening property of fly ash owing to its free lime content has made fly ash a suitable for construction material [2]. However, the cementitious property of fly-ash can be further enhanced by activation [3]. The investigation of strength properties of fly ash has spurred the scientific curiosity in the past few decades. The variation of shear strength of pulverized fuel ash has been investigated by Raymond [4] and amelioration of the strength properties have been reported with progressing time. The enhancement of strength with lime stabilization at elevated temperature has also been studied by the investigators [5]. Enhancement of strength properties of class F fly ash via alkalization and gypsum addition have also been accomplished by Ghosh et al. [6]. Activation of fly ash has been attempted by various researchers [7-9]. Stimulation of the pozzolanic reactions upon the addition of lime to fly ash has been demonstrated by Mira et al. [10]. On the other hand Ryu et al. [11] has concluded based on their study that the higher the molarity of alkaline addition the better the compaction, consequently improved strength. In this paper an attempt has been made to investigate the effect of different stabilizers i.e. lime, cement and NaOH on the compaction and strength properties of fly ash under various curing conditions.

2 Materials

Fly ash used in this study was collected from Rourkela steel plant (RSP) India. The collected sample has been passed through 425 µm sieve to remove foreign and vegetative matters. The samples were mixed thoroughly to obtain the homogeneity and were oven dried at temperature of 105-1100 C. The physical and chemical properties of the fly ash have evaluated prior to the investigation and presented in Table 1 and 2 respectively. Laboratory grade lime (CaO) of 95.6% purity is used in the test program. Similarly 43 grade slag cement is used. Sodium hydroxide solution of required concentration is prepared from NaOH pellets in the laboratory.

Table 1. Physical Properties of Fly Ash

Physical Parameters	Values	Physical Parameters	Values
Colour	Light Grey	Shape	Rounded/Sub Rounded
Silt and Clay (%)	88	Uniformity Coefficient (Cu)	5.67
Fine sand (%)	12	Coefficient of Curvature (Cc)	1.25
Medium sand (%)	0	Specific Gravity	2.182
Coarse sand (%)	0	Plasticity index	Non-plastic

Table 2. Chemical Analysis of Fly Ash

Elements	Composition	Elements	Composition	Elements	Composition
MgO	1.7	K_2O	1.97	MnO	0.3
Al_2O_3	28.1	P_2O_5	1.72	TiO_2	0.85
SiO_2	53.6	CaO	2.65	LOI	6.5
Fe_2O_3	1.8	Na_2O	0.5		

3 Methodology

The experimental procedure consisted of the treatment of fly ash with varying contents of lime, cement (0, 2.5, 5, 7.5 and 10%) and NaOH solution with varying molar concentration (0.5 M, 1 M, 2 M). The specific gravity of fly-ash is found to be 2.182 [12]. Fig. 1 presents the particle size distribution for the fly ash. Based on this analysis it can be inferred that the fly ash consists of sand to silt sized particles. As apparent from the figure almost 88 percentage of the fly ash is found to pass through 75 µm sieve [13]. The uniformity coefficient (Cu) and the coefficient of curvature (Cc) of the fly ash is evaluated to be 5.67 and 1.25 respectively thus indicating uniform gradation of samples. All the tests are conducted as per Indian Standards.

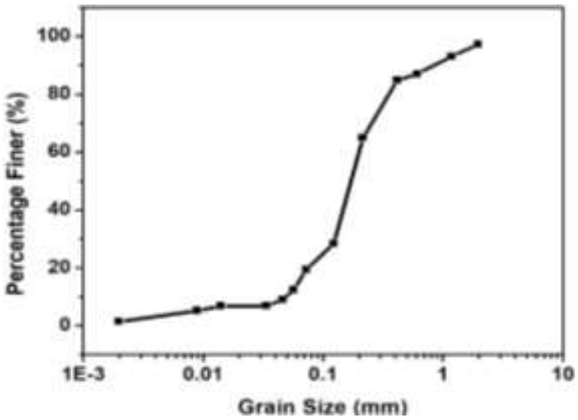

Fig. 1. Grain size distribution of Fly ash

4 Results and discussions

4.1 Compaction Characteristics

The light and heavy compaction tests are carried out in order to determine the relationship between the dry density and moisture content of the fly ash amended with different concentrations of the stabilizers. Fig. 2(a) shows the relationship between dry density and water content at compactive effort of 595 kJ/m3 [14] whereas Fig. 2(b) gives for compaction effort of 2674 kJ/m3 [15]. The curves of dry density and moisture content for different lime content are present in Fig. 2(c) and 2(d) respectively. It can be inferred that as the compactive energy increases the MDD of the increases and the moisture required to achieve this density decreases. Furthermore, it is seen that the nature of compaction curve fairly flat. Such a slight variation of compaction properties with moisture content is desirable from the aspect of field application. Under such a circumstance, the variation of field moisture content may not alter the dry density of the compacted layer appreciably. Similar kinds of observations have also been reported for fly ash amended with lime in the literature [6, 16]. The variation of dry density with water content for cement amended fly ash subjected to light compaction energy, heavy compaction energy, are represented in Fig. 3(a), 3(b), 3(c) and 3(d) respectively. Cement amended fly ash also show a similar behavior. However, under heavy energy compaction, a steady decrement in the moisture content values can be observed. The decrement in dry density values at higher cement content and an insignificant rise in the moisture content values are attributed to plasticity of the specimen imparted by cement. Fig. 4(a) and Fig. 4(b) show the variation of dry density

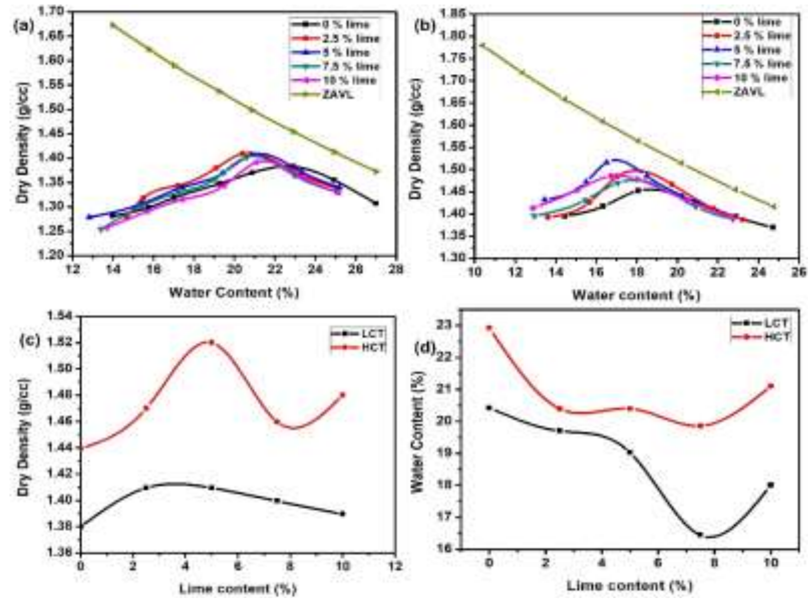

Fig 2 Compaction curves for lime amended fly ash at compactive effort of (a) 595 kJ/m3 (b) 2674 kJ/m3, Variation of (c) MDD (d) OMC with lime content

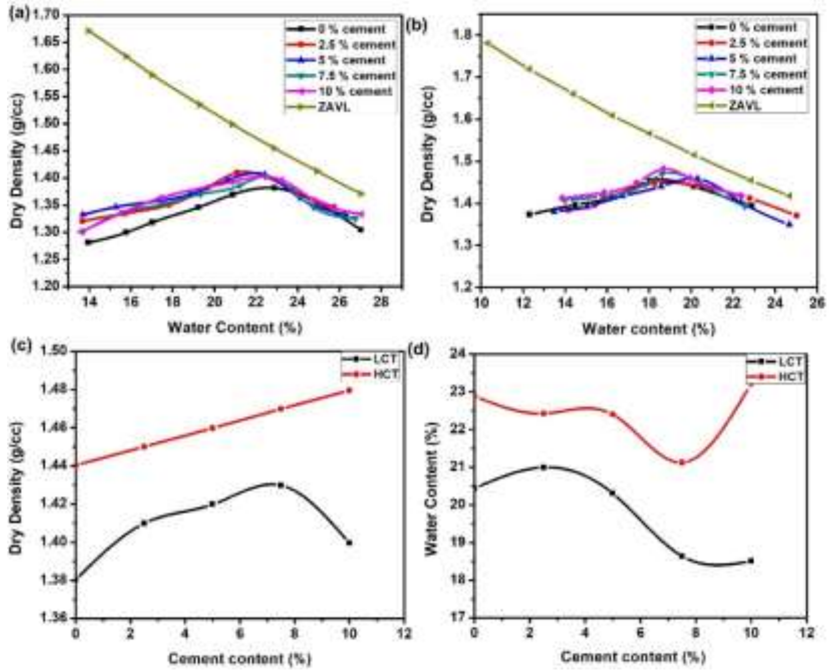

Fig. 3. Compaction curves for cement amended fly ash at compactive effort of (a) 595 kJ/m3 (b) 2674 kJ/m3, Variation of (c) MDD (d) OMC with cement content

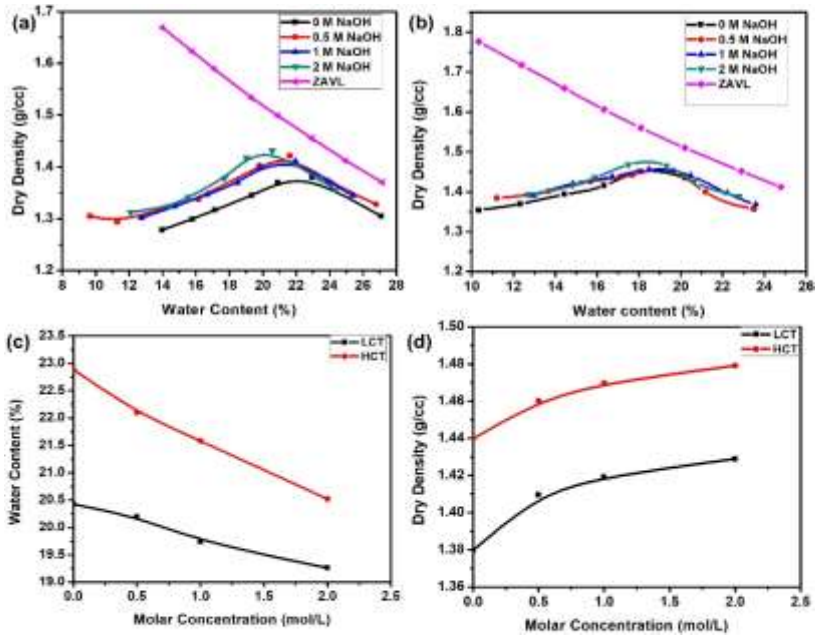

Fig. 4. Compaction curves for NaOH treated fly ash at compactive effort of (a) 595 kJ/m3 (b) 2674 kJ/m3, Variation of (c) MDD (d) OMC with NaOH concentration

with moisture content of the NaOH treated fly ash specimen. Fig. 4(c) and Fig. 4(d) shows the variation of OMC and MDD of the NaOH treated fly ash specimen. It can be observed that with increase in NaOH content and increase in compaction energy the dry density of the specimen exhibits a steady enhancement. On the other hand, the OMC of the specimen decrease as the NaOH molar concentration increase. NaOH is viscous and much lubricating than normal water. During compaction when the load is applied the coated fly ash particles shear along each other surface, resulting in a dense packing. Consequently, water, which is in between the particles, expels out. Hence, the maximum dry density increases and optimum water content decreases.

4.2 Unconfined Compressive Strength

Cylindrical specimens have been prepared with dimension 50 mm×100mm for each combination of stabilizers compacted to their respective MDD at OMC. These specimens are coated with wax and cured for 0, 7, 15, 30, and 60 days at 30^0 C. The cylindrical specimen has been sheared at an axial strain rate of 1.25 mm/min till failure of the sample. For each lime, cement and NaOH content and curing period three identical specimens were tested and then the average compressive strength value has been reported. The stress-strain relationships of compacted lime-treated fly ash for varying curing periods are presented in Fig. 5 and Fig. 6 corresponding to light and heavy compaction energy levels respectively. From these plots it is envisaged that the failure stress are higher when subjected to higher compaction energy than that of compacted with lower compaction energy.

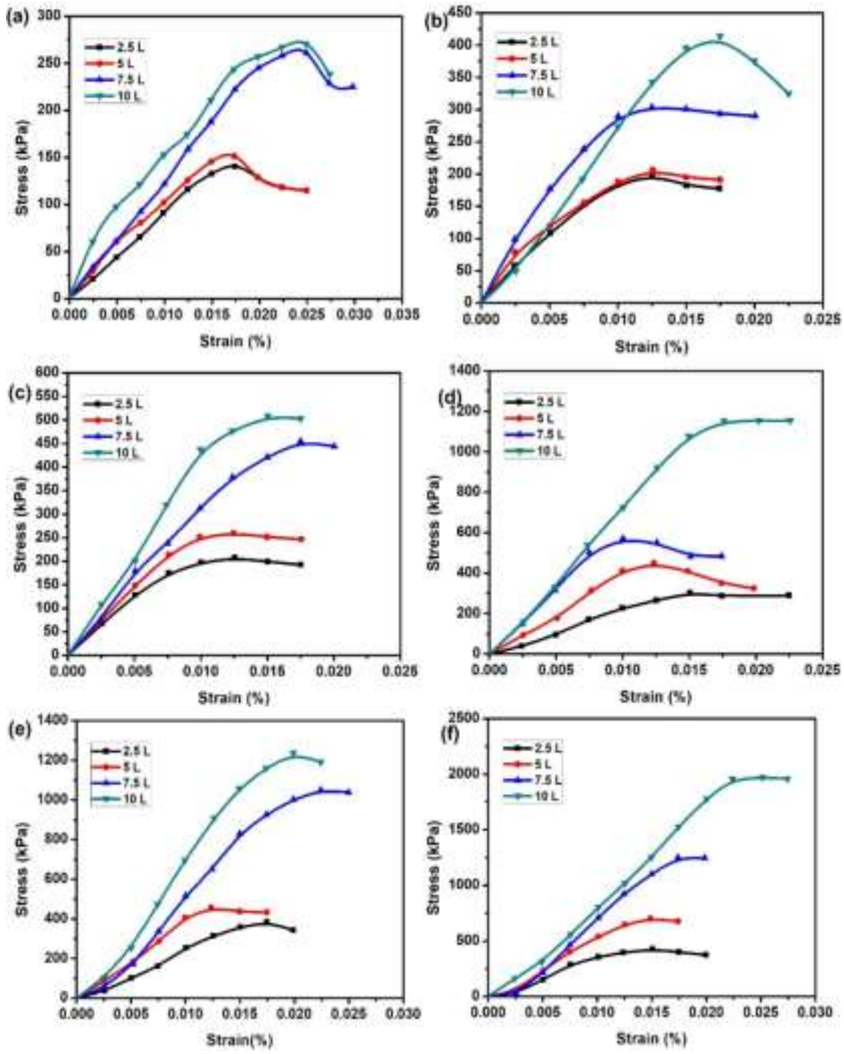

Fig. 5. Stress-strain curves for lime treated fly ash compacted with low compaction energy and cured for (a) 0 day (b) 3 day (c) 7 day (d) 15 day (e) 30 day (f) 60 day

However, with increasing curing time the unconfined compressive strength of the specimen increases appreciably. However, in general the failure strains are found to be lower for samples compacted with higher energies. The failure strains vary from a value of 1.5% to 2.75%, indicating brittle failure in the specimens with increasing lime content. The increase in unconfined strength of specimens with increased compactive effort is attributed to the closer packing of particles, resulting in the increased interlocking among particles. A closer packing is also responsible in increasing the cohesion component in the sample. With increasing curing period of lime treated fly ash specimen shows improvement in UCS values.

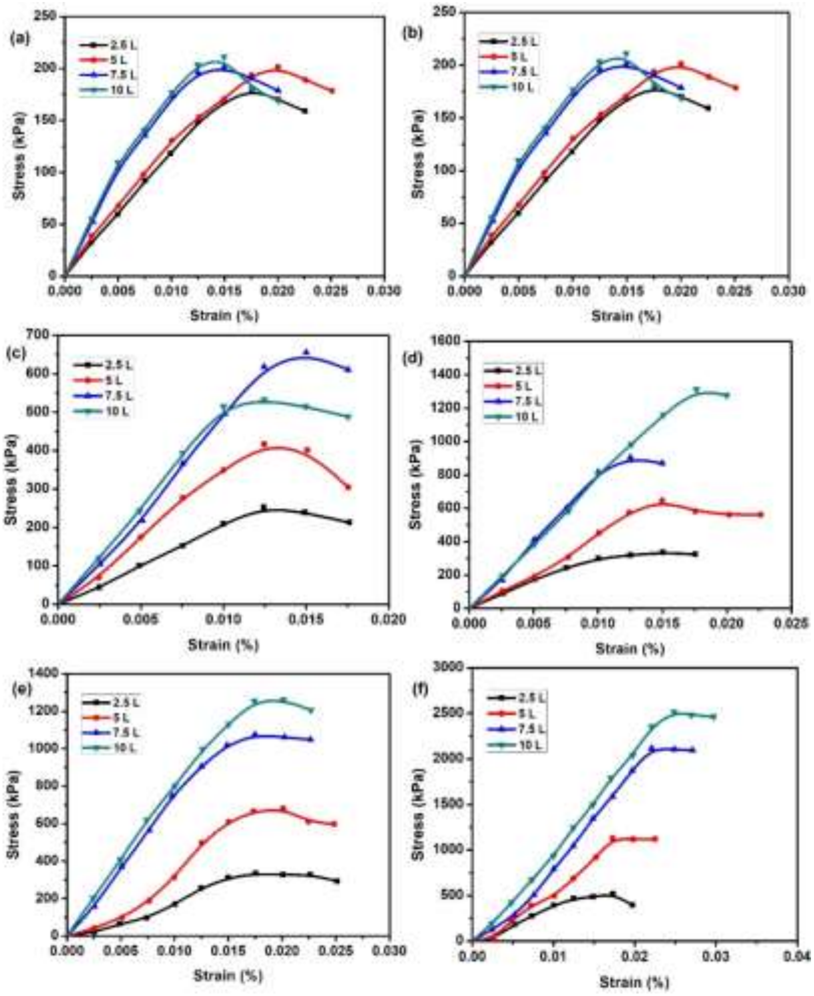

Fig. 6. Stress-strain curves for lime treated fly ash compacted with heavy compaction energy and cured for (a) 0 day (b) 3 day (c) 7 day (d) 15 day (e) 30 day (f) 60 day

Fig. 7 and Fig. 8 show the stress-strain behavior of compacted cement-treated fly ash for varying curing periods corresponding to low compaction energy and high compaction energy respectively. From these plots it can be envisaged that the failure stress as well as failure strain of samples compacted with greater compaction energy, are higher than the samples compacted with lower compaction energy However, in general the failure strains are found to be lower for samples compacted with higher energies. The failure strains vary from a value of 1.5% to 2.5%, indicating brittle failure in the specimens. Fly ash has alumina and silica both of which are available for reactions leading to cementation process. Under such circumstance, the cement stabilized fly ash imparts higher strength values. The variation in stress-strain behavior of the NaOH-treated fly-ash specimen with increasing curing period have been illustrated in Fig. 9 and Fig. 10 for low compaction energy and high compaction energy respectively. The variation is similar to previous two cases i.e. lime treated and cement treated fly-ash specimens.

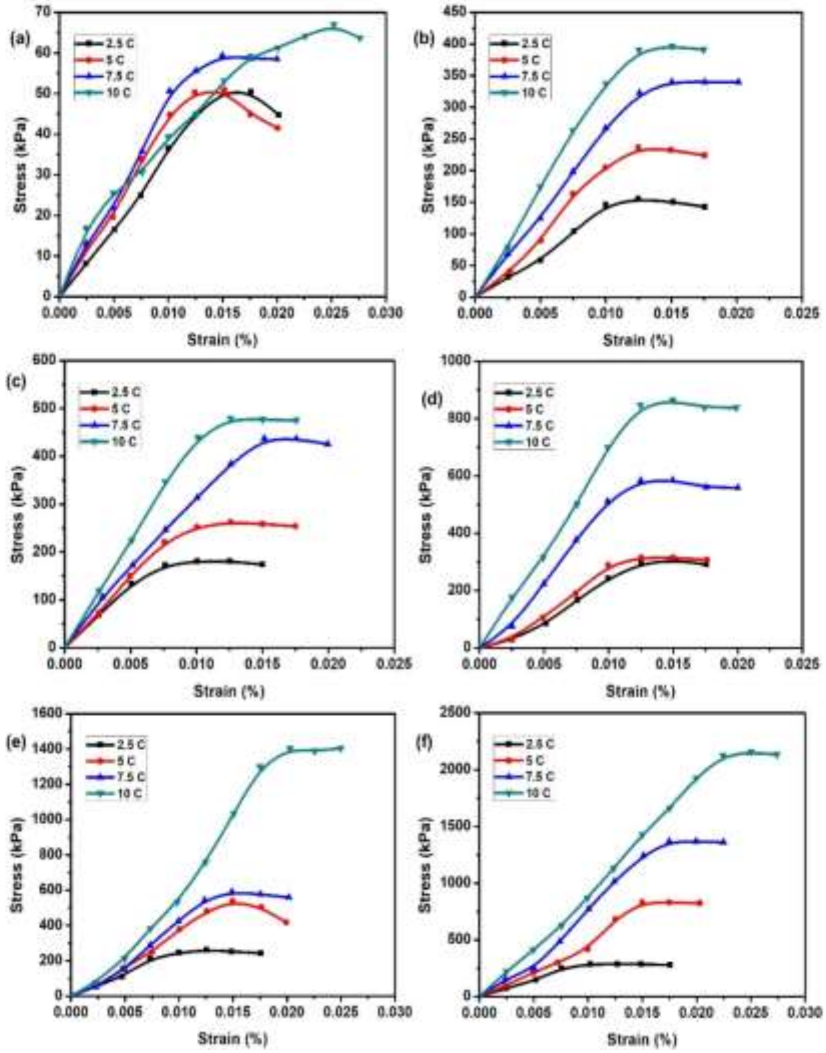

Fig. 7. Stress-strain curves for cement treated fly ash compacted with low compaction energy and cured for (a) 0 day (b) 3 day (c) 7 day (d) 15 day (e) 30 day (f) 60 day

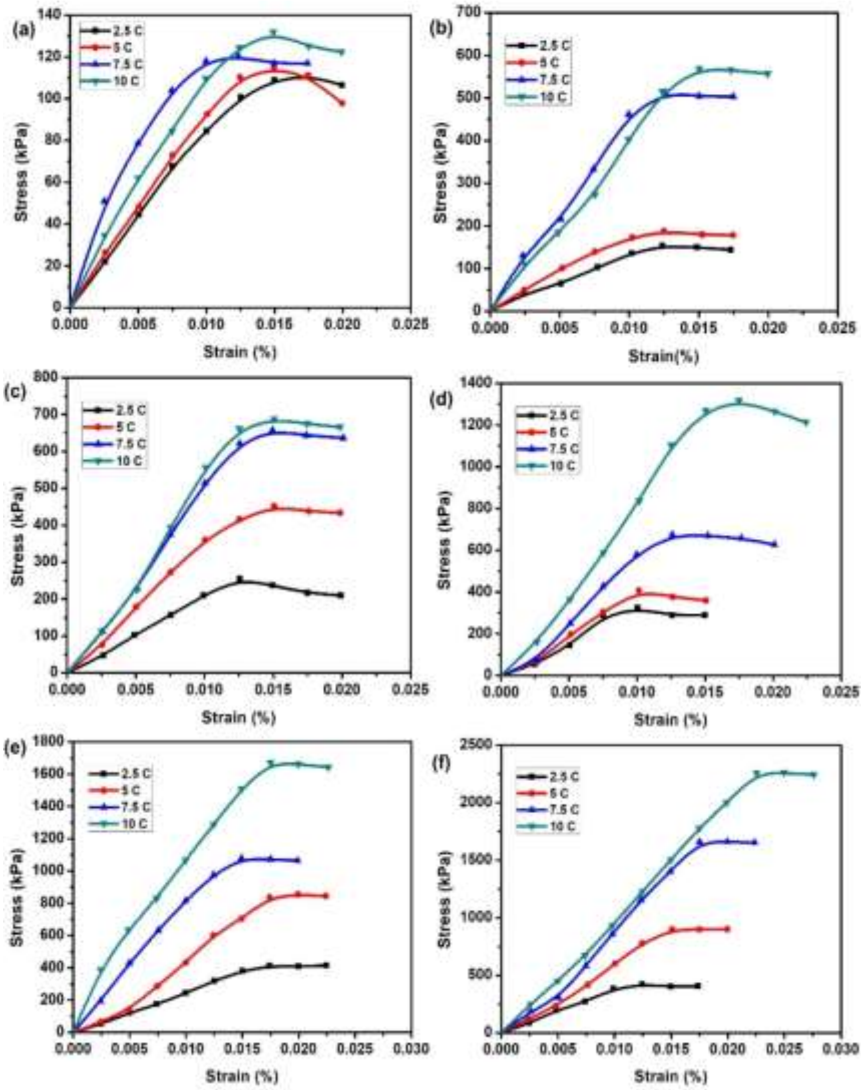

Fig. 8. Stress-strain curves for cement treated fly ash compacted with heavy compaction energy and cured for (a) 0 day (b) 3 day (c) 7 day (d) 15 day (e) 30 day (f) 60 day

Additionally, it is observed that the failure strains vary from a value of 1.25% to 2.5%, indicating brittle failure in the specimens. As NaOH reacts with silica and alumina present in fly ash during the curing period and formed a gel like material called sodium alumino-silicate gel with a general formula $Na_n\{ -(SiO_2)_z -AlO_2 - \}_n$. This gel filled the pore space in the specimens and developed strength. At lower NaOH content the amount of sodium available for the sodium alumina-silicate gel is not adequate thus the gel formation is unsubstantial thereby the strength properties do not show a significant enhancement. Although they exhibit appreciable plasticity, at higher alkali content the gel formation is adequate imparting high strength values. However, at higher alkali content and extended curing period excessive formation of gel eventuates.

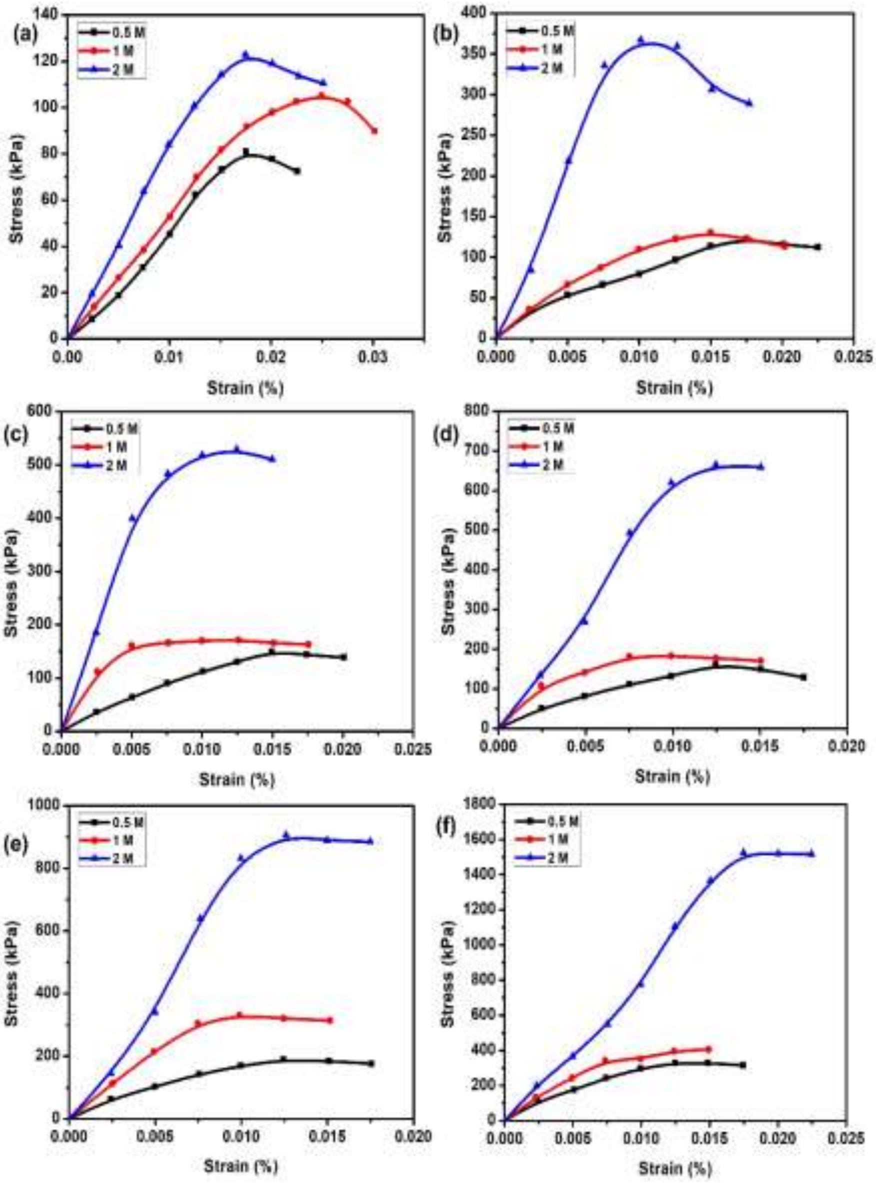

Fig. 9. Stress-strain curves for NaOH treated fly ash compacted with low compaction energy and cured for (a) 0 day (b) 3 day (c) 7 day (d) 15 day (e) 30 day (f) 60 day

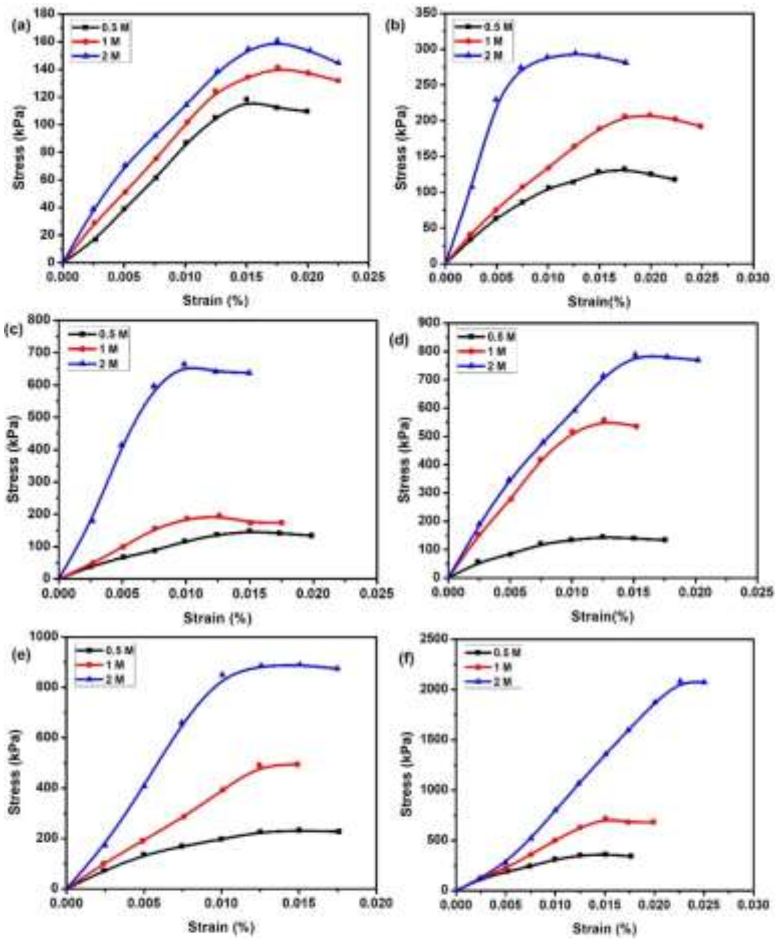

Fig. 10. Stress-strain curves for NaOH treated fly ash compacted with heavy energy and cured for (a) 0 day (b) 3 day (c) 7 day (d) 15 day (e) 30 day (f) 60 day

5 Conclusions

A comparative assessment on the stabilizing efficiency of lime, cement and NaOH is made. In general the MDD increases and OMC decreases with increase of stabilizer content or compaction energy. The enhancement in UCS for lime stabilized and cement stabilized fly ash specimen is attributed to the formation of pozzolanic products whereas for NaOH stabilized fly ash specimen it is due to the formation of sodium alumino-silicate gel with a general formula Nan{-(SiO2)z-AlO_2-}n. NaOH activated fly ash gains strength much faster followed by cement and lime. An addition of 2M NaOH solution to fly ash exhibit similar strength as obtained with 10% of cement addition. A maximum failure stress of 2.5 MPa is obtained. However, the failure strains reduce as the compaction energy or stabilizer content increases.

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