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[1.]Jijo JAMES, [2.]P. Kasinatha PANDIAN

DEVELOPMENT OF EARLY STRENGTH OF LIME STABILIZED EXPANSIVE SOIL: EFFECT OF RED MUD AND EGG SHELL ASH

[1-2.]Tagore Engineering College, Rathinamangalam, Melakottaiyur P.O., Chennai, INDIA

Abstract: The present study evaluated the effect of two solid wastes, Red Mud (RM) and Egg Shell Ash (ESA), in the enhancement of early strength of lime stabilized soil. Quick strength development is significant in highway projects longer wherein curing periods may lead to delay in completion of the work. In order to study the influence of the two waste materials, they were admixed with two lime contents chosen for stabilization of an expansive soil and their unconfined compressive strengths were evaluated over three curing periods of 0 (2 hours), 3 and 7 days of curing. The test samples were prepared in a split mould of 38 mm x 76 mm at a fixed density and moisture content. The results of the test revealed that ESA performed better that RM in enhancing the early strength of lime stabilized soil. ESA produced significant strength gain at low lime content and noteworthy gain at higher lime content whereas RM could produce only marginal strength gain at low lime content but noteworthy strength gain at higher lime content.
Keywords: Expansive Soil, Lime Stabilization, Red Mud, Egg Shell Ash, Early Strength

INTRODUCTION

Lime stabilization has been one of the most common techniques adopted for stabilization of expansive soils. Expansive soils have been known for being disastrous on the structures constructed on them and their effects are only too well documented [1–5]. The primary reason for such problems is because of the volume change behavior of the soil [6] arising from the presence of montmorillonite group of minerals [7,8]. However, even such lime stabilized soil seems to be ineffective under certain conditions like sulphate rich soils resulting in the formation of minerals like ettringite [9,10]which render the soil even poorer than before. In order to reduce such damaging effects under adverse conditions, researchers have tried to use auxiliary additives to lime in soil stabilization to mitigate the damaging effects. A lot of industrial wastes have been adopted by researchers in finding a solution to such problems as well as augmenting the performance of lime. Wild et al. [11] studied the effect of GGBS in suppressing the swelling behavior of lime in sulphate rich environments. James et al. [12] studied the effect of lime and RHA on the index properties of stabilized soil. McCarthy et al. [13] investigated the effect of flyash on lime stabilized sulphate rich soils. Moayed et al. [14] studied the performance of micro silica addition to lime stabilization of saline silty soil. James and Pandian [15] studied the effect of phosphogypsum on the development of early and late strength of lime stabilized soil. Sharma et al. [16] explored the behavior of remoulded clays blended with lime, calcium chloride and rice husk ash. Manikandan and Moganraj [17] evaluated the consolidation and rebound properties of lime stabilized soil admixed with bagasse ash. Shah et al. [18] examined the adverse effects of fuel oil contamination on the geotechnical properties of the soil and its stabilization with lime, cement, flyash and also their combinations. A lot of work on stabilization of soil with lime and industrial wastes mostly deal with the development of delayed strength of the stabilized soil. However, in certain cases the development of early strength assumes significance as in the case of subgrade stabilization of pavements and highway embankments wherein increased curing periods results in delayed projects. Okonwo et al. [19] state that during peak rainy seasons, construction work gets interrupted and hence it is desirable to reduce the setting time of the stabilized matrix. A few researchers have however, studied stabilization from the point of view of early strength development. James and Pandian [20] had earlier carried out a similar study on the early strength development of cement stabilized expansive soil admixed with ceramic dust and lime stabilized expansive soil admixed with press mud. Zhe et al. [21] studied the early strength and shrinkage of cement and lime stabilized soil. The primary objective of this work is to study the effect of Egg Shell Ash (ESA) and Red Mud (RM) on the development of the early strength of lime stabilized soil.

MATERIALS AND METHODS

The materials adopted in this study include the virgin expansive soil, lime, ESA and RM.

Virgin Soil

The virgin soil was obtained from Thiruvallur district of Tamil Nadu, India. It was tested in the laboratory and its geotechnical properties were determined and classified. Table 1 shows the geotechnical properties of the virgin soil. The geotechnical properties were all determined in accordance with Bureau of Indian Standards (BIS) codes.

Table 1. Properties of Virgin Soil

Property	Value
Liquid Limit [22]	68%
Plastic Limit [22]	27%
Plasticity Index	41%
Shrinkage Limit [23]	10%
Specific Gravity [24]	2.76
% Gravel [25]	0
% Sand [25]	2.5
% Silt [25]	60.5
% Clay [25]	37
Maximum Dry Density [26]	15.3 kN/m^3
Optimum Moisture Content [26]	25%
UCC Strength [27]	115.8 kPa
pH [28]	6.53
Soil classification [29]	CH

Lime

Laboratory grade hydrated lime was adopted in this study. The lime adopted in the study was sourced from Nice Chemicals India Pvt. Ltd. The composition of lime used in the study as given by the manufacturer is tabulated in table 2.

Table 2. Composition of Lime

Component	Content (%)
Acidimetric	90
Chloride(Cl)	0.04
Sulphate(SO4)	0.4
Aluminium, Iron and insoluble matter	1
Arsenic(AS)	0.0004
Lead	0.04

RM

RM is generated as a by-product during the production of alumina. Depending on the raw material processed, 1–2.5 tons of RM is generated per ton of alumina produced. The worldwide production of RM is in the range of 70 -120 million tons per annum [30–32]. In India, about 4.71 million tons/annum of RM is produced which is 6.25% of world's total digestion with sodium hydroxide at elevated temperature and pressure [33]. It is a mixture of compounds originally present in the parent mineral bauxite and of compounds formed or introduced during the Bayer cycle. It is disposed as slurry having a solid concentration in the range of 10-30%, pH in the range of 10-13 and high ionic strength. Less than 5% of RM is utilized worldwide [33]. RM has been investigated in earlier research works for various purposes. Kalkan [34] investigated the utilization of RM in stabilization of clay liners. Dass and Malhotra [35] had adopted lime for stabilization of RM bricks. Rai et al. [32] investigated the potential of sintered RM as an alternative clay as building material. The RM adopted in this study was obtained from MALCO aluminium industry, Salem district, Tamil Nadu, India. The RM was crushed and pulverized to a powder form and was sieved through 75 micron BIS sieve for use in the study. The typical composition of RM from MALCO is given in table 3.

Table 3. Typical composition of MALCO RM [33]

Component	Content (%)
FE_2O_3	45.17
Al_2O_3	27
TiO_2	5.12
SiO_2	5.7
Na_2O	3.64

ESA

ESA is the residue obtained on incineration of egg shells of poultry birds. The primary component of egg shell powder is calcium carbonate. A lot of work has been done on use of egg shell powder in construction industry including its use in concrete and in soil stabilization. Amu et al. [36] adopted egg shell powder as replacement for lime in soil stabilization and found that replacement of lime with egg shell powder produced marginally lesser strength than lime stabilized soil. James and Pandian [37] had earlier adopted egg shell powder in soil stabilization and found that it improved the soil properties albeit by physical interaction as calcium carbonate is a stable component and does not react in the presence of water. However, on incineration the calcium carbonate in egg shell powder decomposes to calcium oxide at high temperature [19]. Very few investigations have been carried out with ESA in soil stabilization. Okonkwo et al. [19] adopted ESA as additive to cement stabilization of lateritic soil. The ESA adopted in this study was prepared by controlled combustion of egg shell powder, obtained from a commercial manufacturer of egg products, in a muffle furnace at a temperature of 500°C and the resultant ash was allowed to cool down and then sieved through 75 micron BIS sieve.

METHODS

The soil sample was prepared for the investigation in accordance with BIS code [38]. The stabilization of expansive soil was done at two lime contents, one at Initial Consumption of Lime (ICL) and the other at Less than ICL (LICL). The basis for selection of lime contents for stabilization is founded on the work done by Nazrizar et al. [39]. The determination of ICL is described in a similar earlier work by the authors [20]. The LICL content was randomly assumed below the determined value of ICL. The auxiliary additive contents were randomly assumed on trial and error basis but limited to low doses. The determination of uniaxial strength of the stabilized samples were done by casting cylindrical specimens of dimensions 38mm x 76mm in s split mould, cast at a density of 14.3 kN/m^3 and 25% water content. The density and the water content of the specimens were fixed by performing compaction tests on lime stabilized soil using a Jodhpur mini compactor in accordance with BIS 4332 [40].

The results of the Jodhpur mini compaction test and standard proctor test are very close within the limits of experimental error [41]. To achieve the fixed density, carefully calculated weights of soil, lime and additive were weighed and packed in dry condition. At the time of preparing the specimen, the required quantity of water was added and statically compacted to the aforementioned dimensions. The prepared specimens were de-moulded immediately after casting and placed in sealable polythene covers to prevent loss of moisture and cured for periods of 2 hours, 3 days and 7 days for understanding the course of development of early strength of the stabilized soil. After the end of the curing periods, the samples were removed from the covers and strained axially until the failure of the specimen, at a strain rate of 0.625mm/min which is within the strain rate prescribed by BIS code [27].

RESULTS AND DISCUSSION

The ICL was determined from the Eades and Grim pH test as 5.5%. The LICL content was assumed to be 3%. Four trial values of auxiliary additives were assumed as 0.25%, 0.5%, 1% and 2%. The early strength development of ESA and RM admixed lime stabilized soils have been discussed in subsequent sections.

Early Strength of RM Admixed Lime Stabilized Soil

The addition of RM to lime stabilized soil at LICL content is shown in figure 1. It can be seen that the addition of RM to LICL stabilized soil affects the strength of the soil. It can be noticed that the addition of RM results in an increase in the early strength of LICL stabilized soil at 7 days of curing. The addition has no positive effect on the immediate and 3 day strength of the stabilized soil.

Looking at the effect of additive content, it can be seen that there is an initial dip in the performance of the stabilized soil at 0.25% RM content but performance increases on further addition of RM until 2% RM addition which is the limit of auxiliary content studied in this investigation. The trends of strength development are similar across curing periods. It can be seen that the maximum strength is achieved at 2% RM. The strength of the soil increases from 517.69 kPa for pure lime stabilized soil to 563.73 kPa for 2% RM addition at 7 days of curing. In an earlier study, James and Pandian [15] found that phosphogypsum was capable of raising the strength of LICL stabilized soil at a dosage of 0.25% addition.

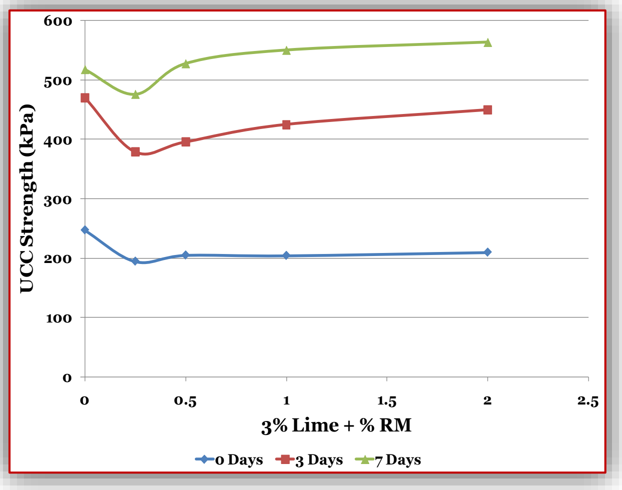

Figure 1. Early Strength of LICL Stabilized Soil admixed with RM

Figure 2 shows the early strength development of ICL stabilized soil admixed with RM. The addition of RM to lime stabilized soil at ICL content shows a different result as addition of RM does not produce significant gains in early strength. There is a dip in performance on addition of RM at 0.25% addition. However, on increasing the content, there is an increase in the strength gain but at 2% addition, the gain is still marginal. As in the earlier case, the trends are similar across curing periods. The strength increases marginally from 981.32 kPa to 992.44 kPa at 7 days of curing. A similar outcome, at ICL admixed with 2% press mud resulting in strength gain at 7 days of curing has been recorded. [20].

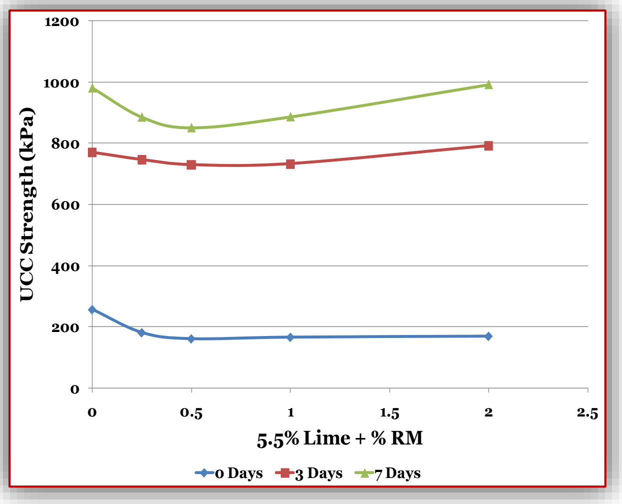

Figure 2. Early Strength of ICL Stabilized Soil admixed with RM

Early Strength of Egg Shell Ash Admixed Lime Stabilized Soil

The effect of the addition of ESA on the early strength of LICL stabilized soil is shown in figure 3. The addition of ESA results in the increase in the early strength of the stabilized soil. The general trends indicate that addition of increasing contents of ESA results in the increase in the early strength of the stabilized soil. The trends are more of less similar across various curing periods.

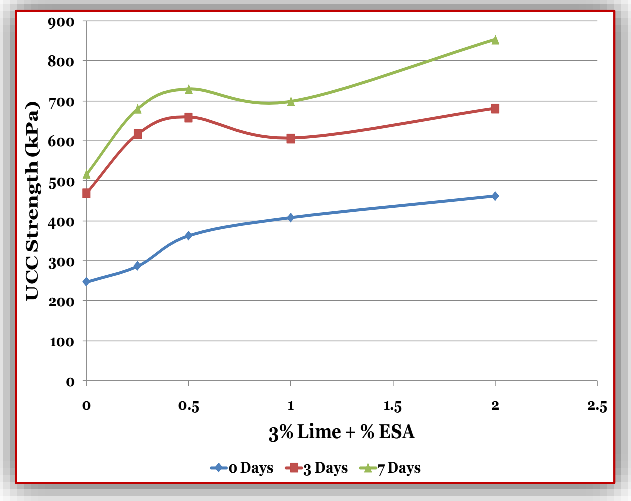

Figure 3. Early Strength of LICL Stabilized Soil admixed with ESA

Similar to RM admixed lime stabilized soil, the addition of ESA also produces maximum strength at 2% addition of ESA. The strength of the stabilized soil increases from 517.69 kPa to 853.66 kPa. Thus it can be seen that the strength gain achieved by ESA is tremendous when compared to RM. Okonkwo et al. [19] found that addition of 10% ESA to 6% cement stabilized lateritic soil raised the strength from 370 kPa to 614 kPa at 7 days of curing. In the present study, lime with ESA produced even higher strength. However, it should be noted that early strength gain is dependent on initial water content, stabilizer content and curing period [21].

Figure 4 represents the development of early strength of ICL stabilized expansive soil admixed with ESA. The immediate difference that is noticed is that the addition of ESA to ICL stabilized soil produced strength addition but peaks at a different ESA content when compared to LICL content. The addition of ESA to ICL stabilized soil results in peak strength at 0.5% addition of ESA. The strength of ICL stabilized soil increases from 981.31 kPa to 1081.65 kPa upon addition of 0.5% ESA.

In comparison, there was no change in the RM content that produced peak strengths in both LICL as well as ICL stabilized soil. This behavior, in the case of ESA, was unexpected and needs further investigation to determine the reason behind a shift in the optimal content of ESA for higher lime content. However, both the cases reinforce the fact that addition of ESA can enhance the early strength of the stabilized soil. Okonkwo et al. [19] found that 8% cement stabilized lateritic soil admixed with 10% ESA raised the strength from 471 kPa to 687 kPa at 7 days of curing. As in LICL content, here as well ESA admixed ICL stabilized soil produced higher strength than cement with ESA.

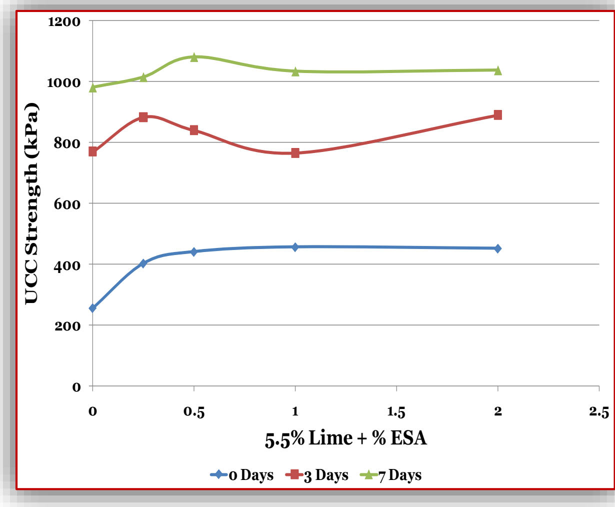

Figure 4. Early Strength of ICL Stabilized Soil admixed with ESA

Percentage Early Strength Gain of Lime Stabilized Soil Admixed with RM and ESA

The percentage early strength gain is calculated by comparing the strength of pure lime stabilized soil admixed with RM and ESA against the strength developed by pure lime stabilized soil at 7 days of curing, expressed in percentage. Bhuvaneshwari et al. [6] also performed a strength gain analysis for cured expansive soil-lime composites; however it was performed for subsequent curing periods.

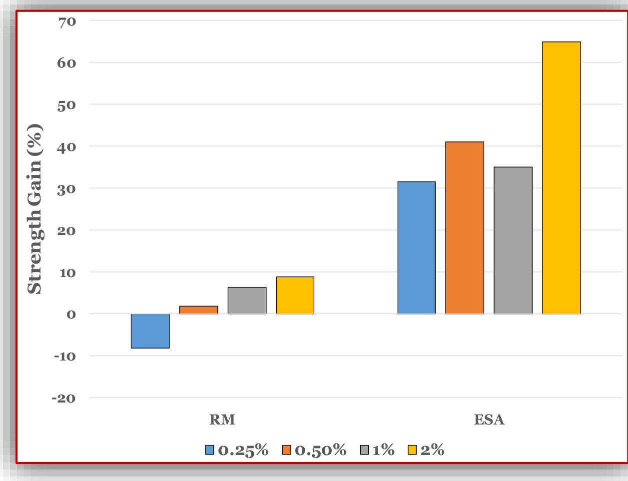

Figure 5. Percentage Early Strength Gain of LICL Stabilized Soil admixed with RM and ESA

Figure 5 displays the strength gain achieved due to the addition of RM and ESA to lime stabilization of expansive soil. It can be seen that the addition of ESA to LICL stabilized soil produces better strength gain when compared to RM. Addition of red mud produces a steady increase in the early strength of the stabilized soil. Addition of 0.25% RM results in a loss in strength of lime stabilized soil, however, further increase in the RM content steadily results in strength gain. The gain in early strength increases from ~ 8.12% to 8.89% for 0.25% to 2% increase in addition of RM.

In comparison, the addition of ESA results in a significant gain in early strength of the stabilized soil. For LICL stabilized soil, the addition of 2% ESA results in a tremendous strength gain of 64.9%. The addition of all combinations of ESA produces positive strength gain with a minimum percentage gain of 31.5% at 0.25% addition of ESA. James and Pandian [15] found that addition of phophogypsum to LICL stabilized soil could not produce a significant strength gain. It can be seen that ESA produces a better performance when compared to phosphogypsum in enhancing the early strength at LICL stabilization.

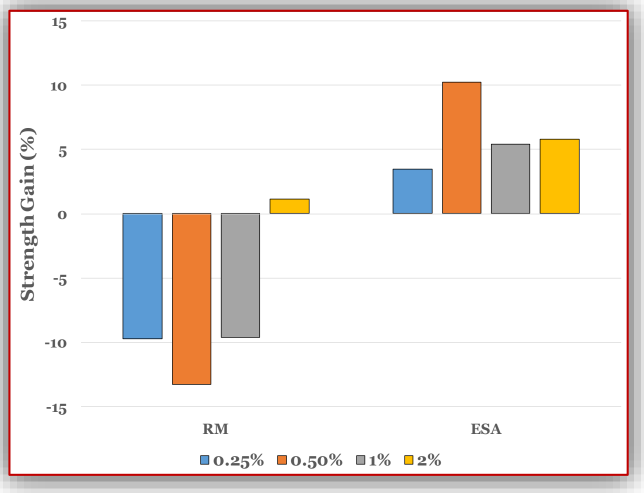

Figure 6. Percentage Early Strength Gain of ICL Stabilized Soil admixed with RM and ESA

Figure 6 reveals the percentage early strength gain of ICL stabilized expansive soil admixed with RM and ESA. A clear indication at the outset is that, in comparison with LICL stabilization, the effect of strength addition of both the additives is much lesser when stabilization takes place at ICL. In the case of RM, there is almost no gain in early strength with strength loss in all doses of RM addition, with the exception of 2% RM wherein the gain in strength is a meager 1.1%. In the case of ESA, despite no comparable strength gain as in the case of LICL stabilization, the percentage strength gain is a noteworthy 10.2% at 0.5% addition of ESA. The strength gain in all other doses is positive, but lies in the range of 3 to 6%. In an earlier study, at ICL, addition of phosphogypsum produced a comparable early strength gain of 14% [15]. At ICL stabilization, the performance of ESA drops below that of phosphogypsum, despite the optimal content in both cases being 0.5%. But the difference in their strength gains is not huge and is still at comparable levels.

Early Strength Development with Curing

Curing period is an important parameter that influences strength development. In order to understand the strength development over curing period, a comparison of strength versus curing period has been done for the two additives. Figure 7 shows the development of early strength for LICL stabilized soil. However, the comparison has been made only for the optimal dosages of the additives to lime. The figure reveals that the strength development of RM admixed LICL stabilized soil is very much similar to pure lime stabilized soil. The addition of RM to LICL stabilized soil results in lesser strength at 2 hours of curing itself. With curing however, the strength develops, but at 3 days of curing it is still lesser than the strength of pure lime stabilized soil. The effect of addition of RM can be seen only at 7 days of curing wherein it produces higher strength than that of pure lime stabilization.

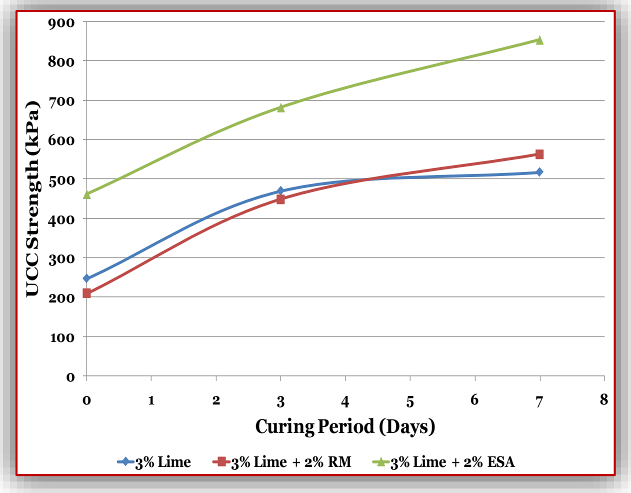

Figure 7. Development of Early Strength with Curing Period of LICL Stabilized Soil admixed with RM and ESA

In the case of ESA, the strength curve is significantly higher above both LICL strength curve as well the RM admixed LICL strength curve. This is due to the fact that, addition of ESA leads to a significantly higher strength at 2 hours of curing itself. With increasing curing period, the strength also develops proportionately and hence the curve stays significantly above the rest. Press mud when added to optimum lime content for soil stabilization produced a significant strength gain with curing in an earlier study [20]. However, in the present case, the effect of ESA was prominent at LICL that is at comparatively lower lime content.

Figure 8 represents the strength development of ICL stabilized soil admixed with RM and ESA. As in the case of LICL, the strength development curve of RM admixed ICL stabilized soil is very similar to that of pure lime stabilized soil. The only difference being the effect of RM addition can be seen at 3 days of curing itself albeit very marginally.

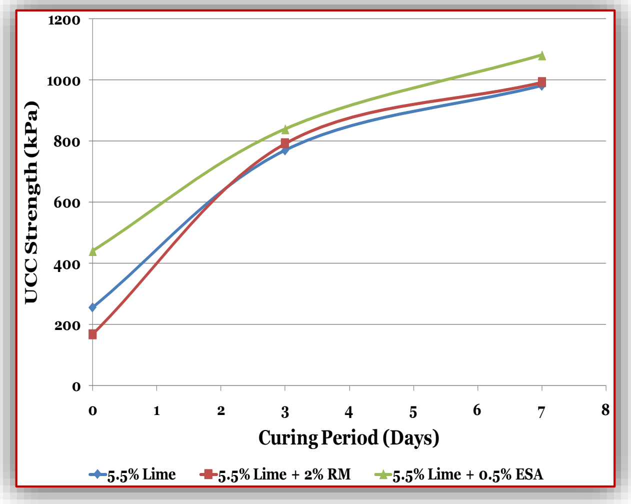

Figure 8. Development of Early Strength with Curing Period of ICL Stabilized Soil admixed with RM and ESA

In the case of ESA, the strength development curve is significantly above the other strength curves but not as high as in the case of LICL stabilized soil. One more point to be noted is that at higher lime content, the addition of ESA results in lesser strength development with curing as seen from the convergence of the curves at higher curing period. At a comparable lime content of ICL, press mud could not produce a significant strength gain [20] as produced by ESA with curing in the case of present study. However, in the case of RM, a similar status exists, wherein it was unable to produce notable strength gain with curing.

CONCLUSIONS

Development of early strength of stabilized soil particularly assumes significance in the area of stabilization of subgrade for highway embankments and pavements wherein the constructed pavements need to opened for traffic at the earliest. In such cases long curing periods may result in delay of projects and hence early strength development becomes a necessity for quick completion of projects in such cases. This study was performed with this in mind. Based on the experimental investigation, the following points can be concluded.

(i) Addition of RM and ESA can enhance the early strength of lime stabilized soil. However, between the two, ESA produces better performance when compared to RM.
(ii) At lower lime content of 3%, the effect of additives RM and ESA is more pronounced when compared to higher lime content of 5.5%.
(iii) 2% RM was found to be the optimal dosage irrespective of lime content, whereas 2% ESA was found to be optimal at LICL stabilization whereas at higher lime content of ICL, 0.5% ESA was found to be the optimal dosage. However, this behavior needs to be investigated further through more detailed investigations.
(iv) With increasing RM dosage, the strength of LICL stabilized soil steadily increased, whereas only 2% RM dosage produced strength gain at ICL stabilization. Hence, further studies involving higher percentages of RM with lime need to be evaluated to clearly define the optimal dosage.
(v) Results of strength development with curing indicate that ESA performs better than RM in both the lime contents and hence, ESA as an additive to lime stabilization can be provisionally recommended for enhancing the early strength of lime stabilized soil.
(vi) This study limits itself with only lime contents below and at ICL. The effect of solid waste additives on stabilization with lime content above ICL and corresponding strength development can also be studied to identify efficient combinations for soil stabilization.
(vii) This study limits itself to evaluating the unconfined compressive strength of the stabilized soil. The California Bearing Ratio of the said combinations should be evaluated to study their effectiveness for their application in subgrade stabilization for highway embankments and pavements.

Recommendations for Future Work

(i) Investigations performed at optimum lime content admixed with aforementioned solid wastes.
(ii) Evaluation of CBR of the lime stabilized soil with solid waste additives for applications in pavement engineering.
(iii) Investigations at longer curing periods to study the effect of the aforementioned solid waste additives in the long term stability and durability of lime stabilized soil.

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