Strength enhancement studies on expansive soil by utilization of unburnt agricultural waste.

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Abstract. In order to determine stability and to support any structure underlying soil bearing strength is necessary. Of all the soils available in India black cotton soils rich in montmorillonite is one of the most problematic and expansive soils as they are every dangerous for construction because of its swelling and shrinkage properties. Such types of soils can be stabilized using locally available waste materials either agricultural or industrial. The waste materials can be used to improve the bearing strength of the soil and decrease in cost of construction. This paper focuses on improvement of strength and stability of lime treated expansive soil by using rice husk ash as additive. Compaction, Unconfined strength test, and California bearing ratio tests were performed on soil by adding lime in increments of 2 to 12% and then optimum lime was determined. To the optimum lime soil mix rice husk ash an agricultural waste was added in increments of 2 to 12 % and optimum RHA was determined.

Keywords: Expansive soils, scanning electron microscopy, rice husk ash, strength, curing periods

1. Introduction
A pavement main function is to support wheel loads. Rural roads in developing countries like India are in devastating condition. At the initial stage deterioration of the roads only leads to increased transport costs marginally, later when the traffic conditions, composition and patterns change and as the road becomes increasingly known trafficable, then the cost of transportation rises drastically. In this context, many researchers have conducted studies by adding rice husk to expansive soil stabilized with lime in terms of strength enhancement and variation of index properties. When various researchers studies were observed it has been notice that the focus on actual mineralogy changes that led to strength enhancement were missing. Hence research was made to study the clay mineralogy changes of lime stabilized expansive soil using rice husk ash as additive along with identification of optimum in different proportions in terms of clay mineralogy changes during strength enhancement and variation of strength under different curing periods on rice husk ash mixed expansive soil using UCS, CBR and scanning electron microscopy.

2. Literature Review
In the recent years rice husk ash (RHA) has been used in soil treatment especially expansive soils after proper incineration. But in rural economy usage of RHA industrial by product is only 20% due to lack of proper treatment facilities and proper knowledge. While the remaining is left out as waste material
and dumped in open creates lot of havoc. Numerous studies have been carried out by researchers in view of lime light of usage of lime and RHA. Satyanararayana et al. (2016) [1], in his study on the feasibility of RHA and sand as fill and subgrade material by conducting compaction and shear strength of RHA and sand as fill and subgrade material by testing them for compaction, shear strength and CBR. reported that angle of shearing resistance and CBR increased by 11%. Iloje-Amechi Francis and Anaigo-Venantus. (2013) [2], studied expansive soils remoulded with RHA to examine the effect of OMC and CBR by adding RHA in different proportions. They also developed models based on scheffe’s model and they concluded that OMC varies from, 15 to 33% for Eke Obinagu (A-7-5) and 14 to 25% for Agbede (A-6) and 15-31% for Ugwuaji (A-2-7) soils, while CBR varies from 5-29%, 7-13%, 5-23% for the same set of soils. They also concluded that models showed a good correlation for the A-7-5 and A-6 soils. Musa Alhassan and Alhaji Mohammed Mustapha (2007) [3], in their studies on the effect of RHA on laterite soil stabilized with cement varying the proportion of cement from 2 to 8% in terms of compaction, CBR and UCs studies. Their studies revealed that RHA content 4-6% was responsible for tremendous improvement in strength. Surya Manikanta et al. (2016) [4], in his study observed that addition of RHA and lime admixtures makes montmortillomite rich black cotton soils to be non plastic and non swelling, also observed that the California bearing ratio reached its higher value at 10% lime mixed with 20% RHA and 30% RHA separately. Subrahmanyam et al. (1981) [5], investigated the impact of blending RHA and lime by conducting a series of experimental studies for different curing periods. Their studies revealed that maximum dry density decreases and optimum moisture content increase due to blending of RHA. Plasticity index decreased and they have found that the effect was more when the curing period was 28 days. Optimum RHA identified from the study was 10%. Bagheri.Y et al. (2014) [6], studied the mechanical and physical behaviour by conducting undrained tri axial studies and Unconfined compressive strength test by varying dosage of RHA between 2.5 to 12.5% to lime and cement stabilized soil and these mixes were observed for curing periods of three, seven and twenty eight and sixty days. Their studies concluded that maximum strength was at the end of 28 days and the strength development from 28 to 60 days was meagre compared from 7 to 28 days. Deepak Gupta and Arvind Kumar. (2018) [7], from their morphology studies on crystallization characteristics of cement stabilized pond ash - RHA. Their findings strengthened the usage of RHA as partial replacement of cement. Mrityunjau Jaiswal and Bindhu Lal. (2016) [8], conducted a study on impact or RHA on soil stability and from SEM analysis, he found out that the decrease in void ratio and breaking montmorillonite was the main reason of drastic strength gain of the mix. Manisha and Srinivasa Reddy (2017) [9], in their investigation of effect of adding chemical additive RBI grade 81 by scanning electron microscopy found that surface morphology indicated a change in failure pattern along with reduction of void ratio at different curing periods. They also reported that the formation of hydration products from calcium rich additive led to decrease in Si, Al and CA percentages. Pranshoo Solanki and Musharraf Zaman. (2012) [10], in their study of Micro structural characterization of clayey soil stabilized with calcium based fly ash and calcium based kiln dust induced stiffness. This stiffness was mainly attributed to formation of reaction products and ettringite. Mogili, S et.al (2021) [11], studied behaviour of soil pond ash mixtures modified with due to cyclic stress application and number of load cycles. Their study revealed that optimum lime content is 8 %, M_r values of the lime mixed pond ash significantly changed due to the addition of lime compared to only pond ash mixtures. Noolu et.al (2021) [12], in their study evaluated permanent strain behaviour of natural and calcium carbide residue soils and suggested that calcium carbide residue addition to red soil shifted incremental collapse from a stress level of 60 to 70%. Sudhakar Mogili et.al [13], in their study on effect of lime addition to pond ash on various curing periods concluded that there is substantial increase in strength when lime was increased from 6 to 8% particularly at the end of 28 days. Sudhakar Mogili et.al [14] conducted a study to investigate the performance of pond ash mixed with lime and fibre. They observed that pond ash mixed with 8% lime and 1% fibre individually yielded better results in terms of strength enhancement.

Many researchers have reported in terms of strength enhancement whether UCS or index properties variation by using treated RHA. Micro-level investigation of the samples is also required to understand the clear path of mineralogical studies that are responsible for the enhancement of strength. As a result, a research to identify the appropriate percentage of lime and RHA for soil strength
increase, as well as a complete grasp of the mineralogical studies that are responsible for strength enhancement was conducted.

3. Methodology of study

The basic properties of expansive soil are determined as per Indian standard procedures [15-22]. Then optimum lime was decided based on conducting the unconfined compressive strength (UCS) test and pH test. Optimum lime determination. Optimum lime is taken as that percentage of lime where UCS is maximum and pH>12.4 or nearing to 12.4 as mentioned in IRC: 51-1992 [23]. Then Influence on CBR [20], UCS [21], Atterberg’s Limits [17], Differential free swell index [18] and pH Variation of soil-lime-RHA, with the support of SEM by varying rice husk increments of 2% (RHA are starting from 2% since many studies RHA mixed with lime was considered varying RHA 4 to 18 %). Hence, these proportions were considered from 2%) UCS test is performed on all the mixes after 7 days, 14 days, 28 days and 56 days, variation of strength on various curing periods was studied. The main reason for the strength development on a borderline was due to the formation of various cementitious bonds or either formation of flocs that led a dispersed structure to form into a flocculated structure. SEM Analysis was performed on the necessary mixes at all the stages to study mineral composition, surface morphology, changes in crystalline structures etc.

4. Results and discussions

4.1. Properties of raw materials

The physical and engineering properties of soil are as given in Table 1. In the current study, expansive soil was procured from Nurukullapu Village, Andhra Pradesh. Lime was collected from lime stone quarry at Pidugurala. It was hydrated lime and with a purity of about 95%. Chemical composition of RHA has been collected from an open dump yard connected to twelve local small power stations. The RHA thus collected is unburnt and was used without any treatment after obtaining its chemical composition from Indian Institute of Chemical Technology (ICT), Hyderabad. All the Scanning electron Microscopy analysis was done at ICT Hyderabad. Physical properties of RHA were determined.

Table 1. Properties of expansive soil.

| Name of the Property                  | Value   |
|--------------------------------------|---------|
| Specific gravity                     | 2.5     |
| Particle size distribution           |         |
| a) Sand (%)                          | 24      |
| b) Silt (%)                          | 3.2     |
| c) Clay (%)                          | 72.8    |
| Liquid limit (%)                     | 86      |
| Plastic limit (%)                    | 36      |
| Plasticity Index (%)                 | 50      |
| IS Classification of soil            | CH      |
| Maximum Dry Density (kN/ m³)         | 14.4    |
| Optimum Moisture Content             | 23      |
| Soaked CBR value (Compacted at OMC) (%) | 0.85  |
| Differential free swell index (%)    | 140     |

From the value of Liquid limit value, plasticity index and free swell index the soil showed higher degree of expansiveness (Table 1)
From the SEM image of soil (Figure. 1), it can be observed that the texture of soil contains dispersed fabric in natural state and flaky like structure. In general, soil that has flaky structure possesses less strength.

“Figure 1. SEM image of expansive soil without treatment”

From SEM images it is often seen that RHA particles were angular and uneven in shape, with rough, gritty surface textures, as shown within the SEM pictures below (Figure 2. (Magnification 1 mm), Figure 3. (Magnification 20 m). additionally, very small particles to a size of millimetre or less with pores of variable sizes within the particles were observed under different magnifications.

“Figure 2. SEM image of RHA 1mm magnification Figure 3: SEM images RHA 20 µm magnification

4.2. Identification of optimum lime
As on percentage of lime increases (Table 2) OMC increases and MDD decreases. The increase in OMC can be attributed to water affinity of lime and decrease in MDD may be attributed due to the mineralogy changes due to development of flocculation bonds. Even the increases in pH states that as a result of high alkaline condition generated pozzolonic reaction occur between Ca²⁺resulting in dissolution of Si⁴⁺ ions and Al⁺³ions forming calcium silicate and calcium aluminate ions and in later stage transforms to hydrates to form cementetious compounds. As on lime percentage increases till 8%, there was increase in UCS this may be ascribed to growth of a flocculated structure due to cementitious bonds developed between lime and soil particles, further slight reduction in UCS is due to segregation of excess lime available in powder form. Hence, optimum lime was considered to be from Table 2.
Table 2. OMC, MDD, UCS and pH values of soil-lime mixes

| S.No | Percentage of lime added to soil (%) | OMC (%) | MDD (kN/m$^3$) | UCS (kN/m$^2$) | pH  |
|------|-------------------------------------|---------|----------------|----------------|-----|
| 1    | 2                                   | 24      | 14.35          | 37.69          | 5.7 |
| 2    | 4                                   | 25      | 14.26          | 46.1           | 6.8 |
| 3    | 6                                   | 25.92   | 14.21          | 65.63          | 9.2 |
| 4    | 8                                   | 24.62   | 14.44          | 89.21          | 12.6|
| 5    | 10                                  | 24      | 14.5           | 78.45          | 12.6|
| 6    | 12                                  | 23.92   | 15.1           | 61.2619        | 12.6|

4.3. Identification of optimum RHA

4.3.1. Variation of physical and engineering properties of soil with different percentages of RHA and optimum lime

Table 3. Variation of physical and engineering properties of soil with different percentages of RHA and optimum lime

| S.No | % of RHA | L.L (%) | P.L (%) | P.I (%) | S.L (%) | F.S.I (%) | pH | OMC (%) | MDD (kN/m$^3$) | UCS (kN/m$^2$) | CBR (%) |
|------|----------|---------|---------|---------|---------|-----------|-----|---------|----------------|----------------|---------|
| 1    | Soil+8%lime+2%RHA | 74      | 35      | 39      | 24      | 70        | 13  | 28      | 14.1           | 47.9           | 6.4     |
| 2    | Soil+8%lime+4%RHA | 65      | 37      | 28      | 28      | 63        | 13.3| 30      | 14.1           | 68.9           | 10.8    |
| 3    | Soil+8%lime+6%RHA | 59      | 40      | 19      | 29      | 55        | 13.4| 30      | 14.1           | 91.9           | 15.8    |
| 4    | Soil+8%lime+8%RHA | 52      | 45      | 7       | 32      | 52        | 13.5| 30      | 14.0           | 99.5           | 18.7    |
| 5    | Soil+8%lime+10%RHA| 45      | N.P     | 33      | 47      | 13.5      | 13.5| 30.2    | 13.64          | 110.5          | 22.7    |
| 6    | Soil+8%lime+12%RHA| 44      | N.P     | 31      | 46      | 13.5      | 13.5| 28      | 13.54          | 90             | 17.7    |

The pozzolanic reaction between lime and RHA may be responsible for the drop in free swell index and increase in pH as listed in Table 3. The creation of cementitious compounds as a result of the reaction between lime soil and RHA may have resulted in a decrease in liquid limit from 74 percent to 44 percent, an increase in plastic limit from 35 percent to 45 percent, and eventually a non-plastic condition. The increase in shrinkage limit from 24 to 31 percent may be due to primarily to the physio-chemical interaction between soil particles and RHA. In the early stages, there was a slight decrease in dry density, it is attributed to RHA's low specific gravity, and an increase in OMC, which could be attributed to RHA's increased water requirement for pozzolanic action. The upsurge in UCS and CBR is because of the development of cementitious compounds, and the decrease after 10% is due to RHA occupying spaces on the soil sample, reducing bond strength.

4.3.2. Micro Level Analysis of Soil-Lime RHA Mixes

In order to understand the reason for strength gain, SEM analysis of various mixes carried out and then compared with SEM image of Calcium Silicate Hydrate (CSH) gel available from the literature [24]. The figure 3 shows the common fibrous type which indicates the structure of C-S-H.
Figure 3 SEM image of CSH gel taken from literature

(a) Soil +8% lime +2% RHA  (b) Soil +8% lime +4% RHA

c) Soil +8% lime +6% RHA  (d) Soil +8% lime +8% RHA

e) Soil +8% lime +10% RHA  (f) Soil +8% lime +12% RHA

Figure 4 (a-f): SEM Images of Soil-Lime-RHA mixes
4.3.3. UCS analysis of Soil-Lime-RiceHuskAsh Mixtures for different curing periods

Different mixtures have been tested for various curing times (7, 14, 28, and 56 days). The obtained results are shown below. Figure 5 shows that as the curing time increases, so does the strength, and the increase in strength until 28 days can be attributed to the increased pozzolanic reactivity with time between the lime and the siliceous pozzolonic materials from RHA and soil. Because of the hydration reaction, the volume of pores decreases during the curing period. As a result, as the curing period lengthens, so does the strength gain. As a result, as the cure duration grows, so does the strength gain. To the fact that cementitious products are created as soon as flocculation has taken place, a significant increase in UCS from 0 to 7 days may be attributable to this fact. An increase in strength from 7 to 28 days may be a result of cementitious products, while a modest rise in strength from 28 to 56 days may be a result of the time-dependent pozzolanic compounds created later in the process of cementation. SEM analysis of Soil-lime-RHA Mixtures for different curing periods.

Following mixtures stated in Table 4 have been tested for morphology changes for curing periods of 7, 14, 28 and 56 days.

Table. 4 Soil-lime-RHA Mixtures tested for SEM analysis.

| Sl.no | Name of the mix         |
|------|-------------------------|
| 1a   | soil-8%lime-2%RHA       |
| 1b   | soil-8%lime-10%RHA      |
| 1c   | soil-8%lime-12%RHA      |

According to the SEM images (Figure 6, 7 & 8), the crystal growth emerges column-like structures after 28 days, as contrasted with all of the mixtures' acicular structures that are detected after 7 days. These photos from a scanning electron microscope reveal that crystal formation is complete by 28 days, and hence the mixtures are stronger at 28 days than at 7 days.
Figure 6 (a-d): Scanning Electron Microscopy Images of mix 1a for 7, 14, 28 and 56 days.
Figure 7 (a-d) Scanning Electron Microscopy Images of mix 1b for 7, 14, 28 and 56 days.
5. Conclusion

1. RHA particles were angular and irregular in shape, with rough, gritty surface textures. The ideal lime obtained was 8%, and the RHA for the optimum lime was 10%.
2. SEM images studied to understand the morphology changes as part of the identification of optimum RHA for optimum lime and as on RHA increases up to 10%. The presence of foil-like leafy structures dispersed in a random direction indicated destroying of platy clay particles and formation of new reaction compounds with formation of more cementitious connectors resulting in well-developed flocules.
3. Studies on three mixes to determine the effect of curing periods (7, 14, 28, and 56) days revealed a slow rate of increase in strength until 7 and 14 days, followed by a steeper increase that extends to 28...
11 days. Since strength gain is 97 percent at the end of 28 days, the strength development is less as it reaches 56 days, which was attributed to the fact that the soil gains strength as the curing period increases because the pozzolanic reactions are time dependent and the maximum strength is achieved by 28 days.

5. The crystal growth reveals column-like structures after 28 days, contrasted to the acicular structure found after 7 days in all three mixes, and is more evident in the optimum mixes after 28 days, as determined by SEM pictures of the three mixes.

6. Future work
Study performed in the present paper can be extended to other problematic soil in rural road network using RHA and can be extended to other problematic soil in rural road network using other waste materials.

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