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Environmental Benefits of Cement and Areca Nut Husk Ash on Behavior of Clay and Red Clay

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Abstract*: *The swelling and shrinkage characteristics of clay soil types cause many problems in civil engineering works like Laying, buildings and roads constructions. These soil types tend to put challenges to civil engineers as their shearing strength and bearing capacity are extremely low. Many studies have been made to rectify these challenges by using different materials and various innovative ways that could possibly improve the soil engineering properties, as well as reduce environmental hazards in a cost-effective way. This study focuses on the use of areca nut husk ash and cement as admixture to improve the stabilization properties of clay and red clay soil types. The stabilization of soil was tested by adopting the standard methods such as Atterberg's limit test, Standard proctor test and unconfined compressive strength test by mixing equal proportion of admixture to both soil types with varying percentages of clay (0%, 3%, 4%, 6% and 8%) and red clay (0%, 2%, 3% and 4%) soils. From the results, it was observed that clay soil with 6% of admixture and red clay with 3% admixture were optimum and the findings clearly showed that the stability of clay and red clay soil, can be improved by admixture containing areca nut husk ash and cement and this can be used as a good ground improvement technique in engineering projects.

Index Terms*: *Arecanut Husk Ash (AHA), Unconfined compressive strength, Maximum dry Density (MDD), Optimum Moisture Content (OMC), Free swell value.

I. INTRODUCTION

Soil stabilization is the process which is used to improve the engineering properties of the soil and thus making it more stable. Soil stabilization is required when the soil available for construction is not suitable for the intended purpose. Virtually all civil engineering structures have their foundation on the soil. Thus there is a need for study on the engineering properties of soil in the proposed site of construction. The soil may not be suitable in the existing form for any type of construction due to their poor workability for compaction, high compressibility and inadequate shear strength [1]. The construction schedule becomes critical during monsoon when optimum moisture content cannot be achieved. These soil types have higher strength in dry state and become softer with saturation of water. Filling up of water into fissures and cracks, initiates the process of softening, leading to the reduction of shear strength and low bearing capacity. To overcome these issues in the soil, it should be treated and stabilized by some way or the other including the addition of solid wastes. Solid wastes are broadly classified in to three main groups namely (i) industrial waste [2], (ii) agricultural waste [3], [4] and (iii) chemical waste [5] apart from other wastes. Generally cement [6] and lime [7] are the two main materials used for the stabilization of the soil. In the present study, areca nut husk ash, a solid agri waste along with cement was used to stabilize the weaker soil types (i.e.) clay and red clay. A series of laboratory tests were conducted on clay and red clay mixed with equal proportions of AHA and cement in various percentages by weight of dry soil. Previous researchers worked on the use of various agricultural wastes on behavior of expansive soil [8-10]. However, no detailed study has been reported on the usage of areca nut husk ash and cement as admixture for soil stabilization. Hence the present study. In general, natural fibres are preferred over synthetic for their physical properties as well as economic feasibility. Fiber reinforced cement composites are useful in all types of constructions like bridges, buildings, dams, road, etc [11] and also in bituminous mixes [12]. The role of fibres in soil stabilization had been reported by many researchers [13]. Chauhan et al., [14] evaluated role of fly ash and fiber with silty sand for subgrade reinforcement. Karthikeyan et al., [15] tried ash and coir fibre to improve subgrade soil. Kumar and Gupta [16] worked on rice husk ash, pond ash, cement and fibre on the behavior of clay. Kumar et al., [17] did similar work using fly ash, lime and polyester fibre on compaction and strength of expansive soil. Fly ash had been tried by many. However on natural fibres especially the areca nut fibre was not tried by many. This kind of study addresses the environmental improvement also, as raw materials used for the manufacturing of Portland cement contribute 7-10% of CO_2 emission globally [12]. Using cement alone is not cost effective beyond its environmental burden. Hence alternative materials supplementing the Portland cement is given a thought by researchers especially civil and structural engineers. Various artificial and natural fibres, ash of biomass, egg shell powder, microsilica etc., were tried off without compromising the compressive strength of conventional cement [18-21]. This study is also of it's kind with a new natural fibre, Areca nut.

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II. MATERIALS AND METHODS

A. *Collection of soil samples*

The clay and red soil used in this work were collected respectively from Pachapalayam and kuniamuthur, Coimbatore district, after removing the top soil upto 0.9m. Samples collected were air-dried and then pulverized using a pulverizer. Soil passing through the 4.75 mm sieve was used for Proctor compaction and that of 425 micron was used for Atterberg's limit and UCC tests.

B. *Areca Nut Husk Ash*

Areca nut is an important commercial crop in India. India ranks first in the areca nut production in the world having around 4.78 hundred thousand tones of production per year. Areca nut husk were collected from areca nut gardens of Pollachi, Coimbatore district. The husk were cleaned with water, dried in sunlight and incinerated in open furnace at a rate of 10˚C per min up to 500˚C for 6 hours to remove volatiles, then cooled for 10 hours and sieved through a 75 micron sieve for the test purpose.

C. *Cement*

Cement is a fine powder, when mixed with water and allowed to set and hardened components or ingredients together to give a mechanically strong structure. 43 grade cement (i.e) which is capable of attaining compression strength of 43mpa (megapascals) in 28 days of setting was used in the present investigation. It is capable of attaining 23 mpa in7 days. It is commonly used for plastering works, non-RCC structures, pathways, etc, where initial settling time is not so important as in RCC. As in the present work, construction of pavement and roads was the target, 43 grade was used.

D. *Physical and Chemical analysis of ANA*

The material composition of ANA was determined by – XRD available in the chemistry dept. of Annamalai University. Physical properties were determined as per IS: 1727-1967 [22] in department of Physics and Earth Sciences of Annamalai University.

E. *Determination of Free Swell Index*

Free well index is the increase in volume, without any external constrains, on submergence in water. ASTM D4546-96 method using odometer was done in the present investigation. The percent of free swell was calculated using the formula given below.

$$S_w \text{ (free) } \% = (\Delta H / H) \times 100$$

Where,

ΔH = Ht. of swell due to the saturation

H = Original height of the specimen

Change in free swell was noted by adding varying % of admixture.

Determination of index properties related to construction Liquid limit and plastic limit were calculated as per IS: 2720 Part 6 method [23]. Compaction tests were done as per IS: 2720 Part 7 method [24].

III. RESULTS AND DISCUSSION

A. *Natural soil test*

Based on the liquid limit and plasticity index results, clay soil was classified as Highly Compressible Clay (CH) and red soil classified as an Intermediate compressible Clay (IH) according to Indian Standard Classification. Properties of both the soil samples tested are given in Table 1. UCS tests was conducted in accordance with IS: 2720 Part 10 [25].

Table 1: Soil properties

Description		Clay soil	Red clay
Free swell index		90%	30%
Specific gravity		2.04	1.99
Liquid limit		64%	39%
Plastic limit		10%	20%
Plasticity Index		54%	19%
Standard proctor test	MDD	1.68 g/cc	1.85 g/cc
	OMC	16%	13%
Unconfined Compressive strength		9.598×10^{-3} N/mm^2	11.075×10^{-3} N/mm^2

The properties of soil types selected for the study showed that they were not suitable for any construction. The nature of the soil decides the construction process over it. Weaker soil types such as clay and red clay need proper ground improvement technique before starting the projects. Clay soil showed 90% of free swell index which seemed to be very high. The specific gravity of clay and red clay soil types were 2.04 and 1.99 respectively. The other index parameters also were not in limit as per IS standard.

When the soil type is not supportive for the intended construction, it results in failure leading to development of large number of cracks which may shorten the life of the structure [26]. Recently the use of many synthetic and natural biomaterials including fibers are tried to make reinforced concrete. According to Jiang et al., [27], steel, fibers, class fibers, polythene fibers, polypropylene fibers, poly vinyl alcoholic fibers, polyester fiber, basalt fiber and many natural fibers are so far tried as fiber reinforced concrete materials. The admixture used in the present study contained cement areca nut husk ash.

B. *Characteristics of Areca nut husk ash*

Physicochemical characteristic features of areca nut husk ash were analyzed using standard procedures and the results are given below.

Table 2: Physicochemical characteristic features of areca nut husk ash

Physicochemical Test	Quantity (%)
Specific gravity	2.99
Silica	29.01
Potassium oxide	27.1
Iron oxide	2.01
Calcium oxide	2.92
Sodium oxide	0.03
Sulphur oxide	5.9
Alumina	3.2
Magnesium oxide	4.0
Loss of ignition	25
Fineness (Residue on 75 µm sieve)	75

From each hectare of areca nut approximately 5.5 – 6 metric tonnes of husk is produced and India stood first in areca production [28]. About 50 – 70 % of total weight of the fruit is of husk. The husk results in 2.50 – 2.75 g of areca fiber from each husk. Areca fibers have 53.20% of alpha cellulose, 30 - 64.8% of hemicellulose, 7-24.8% of lignin and 4.4 – 4.85of ash, 11.7% of moisture and negligible % of pectin and wax [11]. Large waste of unutilized biomass is resulted which needs an alternative application to tide over the problem related to its disposal. Apart from availability the physicochemical analysis of areca nut husk showed the possibility for using it as an additive with cement for stabilizing of expansive soil types. The analysis of physicochemical characters of ANA revealed that its high content of silica (29.01%) and potassium oxide (27.1%) along with other alkali can act as a good supplementary cementing agent as well as it seems to be compatible with Portland cement. From chemical composition it was evident that water absorbing capacity (or) sorpticity during curing also might be appreciable and might be helpful in reducing the settling time also.

The specific gravity observed in the present study for ANA was 2.99. This value is closer to 3.15 of Portland cement, which is advantageous and this value was higher to that of groundnut husk ash (1.85) reported by Adole et al., [29] and 1.9 with pulverized fuel ash [30]. As calcium oxide and silica were present there is a possibility of formation of carbonate silicate hydrate (CSH) gel. This kind of gel may block the pores and alter the pore structure that might result in improved strength and impermeability. Adole et al., [29] also observed similar reactions in ground nut husk ash blended cement.

C. *Liquid limit test*

The liquid limit and plastic limit value of treated and untreated soil were studied to classify the soil type as per IS classification system. The Atterberg's test was carried out in clay soil mixed with 3%, 4%, 6% (i.e) equal proportion of AHA and cement by weight of soil. For red clay soil it was 2%, 3%, 4% of equal proportion of AHA and cement by weight. From the results of test, it was observed that with the increasing percentage of admixtures, there was a decrease in the liquid limit value. The liquid limit value of red clay was 39% which was reduced to 33% by adding 2% areca nut husk ash containing admixture. Similarly in clay soil it was reduced to 48% from the value of 64% (i.e) the % increase was 16% for clay and 6% for red clay. It is because of arecanut husk ash which has more silica and potassium oxide content which enhances the water holding capacity of soil. In general, reduction in the liquid limit is the indicative of reduction in the compressibility and swelling characteristics. From the change in liquid limit, it may be inferred that there is an overall improvement in the behavior of problematic clay and red soil on the addition of AHA. The percentage of ANA corresponding to liquid limit value is shown in Fig.1.

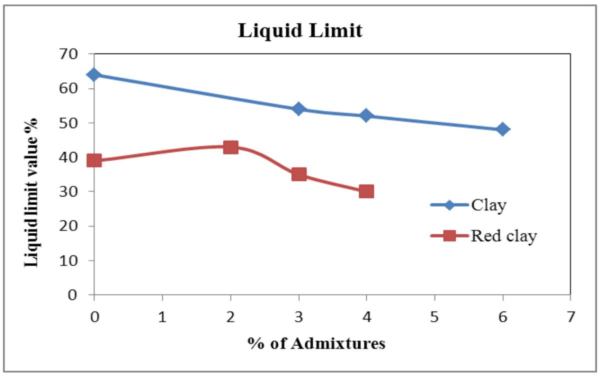

Fig.1: Liquid limit value with admixture

D. *Plastic limit test*

Plastic limit is defined as the moisture content of a solid, at which a soil changes from a plastic state to a semisolid state. The plastic limit value of the red clay soil was increased upto 3% addition of admixture and the increase was upto 2% in the case of clay soil. The percentage increase in plastic limit was upto 15% for clay and upto 5% for red clay soil (i.e.) plastic limit value was improved by the addition of areca nut containing admixture. The admixture had increased the binding action or attraction of the clay platelets. From lower plasticity it had improved to avoid shift (or) sink of concrete structures, laid over them.

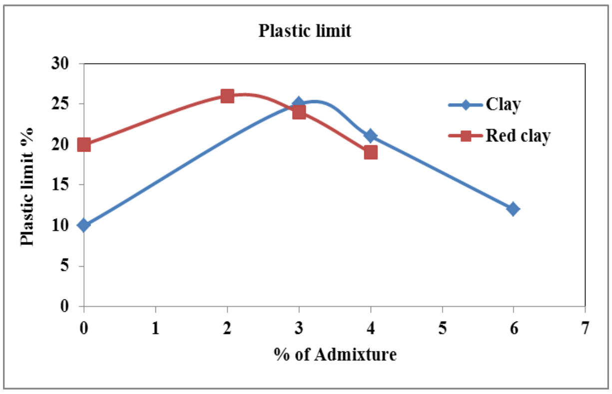

Fig. 2: Plastic limit value with admixture

E. *Standard Proctor Compaction Test*

The compaction characteristics of soil claim to be its initial and final density achieved after compaction at its optimum moisture content. The compaction delivered at standard energy preferred to be light compaction with uniformity. A series of compaction tests were conducted for natural clay soil and red clay soil and soil treated with equal proportions of ANA and cement at different proportions (i.e.) 3%, 4%, 6%, 8% for clay soil and for red clay 2%, 3%, 4%. The Dry Density was determined and plotted against the water content to find the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD). With the exponential increase in the percentages of ANA and cement, there was a decrease in the MDD and increase in the OMC for both clay and for red clay soil OMC increased and MDD were in increasing trend up to an addition of 3% admixture after which it decreased. The MDD value was found to be reduced from 1.68 to 1.56 g/cc and OMC increased from 16% to 20% and for red soil MDD value increased from 1.85 to 1.79 g/cc and OMC increased from 13% to 16%. The tendency of AHA and cement is to be very responsive for variation in the moisture content and dry density which helps in betterment of soil properties. The increase in OMC may be due to more absorption of water by the additive to carry out chemical reaction, and the decrease in MDD may be due to the lower specific gravity of additive compared to soil.

Dry density corresponding to the moisture content for both the soil with an increase in the percentages of admixture is shown in Fig. 3(a & b). Variation of MDD and OMC is shown in Fig. 4(a & b).

Areca nut ash being a light weight material and of low specific gravity compared to clay or red clay soil, it acted as filler material occupying the voids. Flocculation might have happened by the addition of ANA.

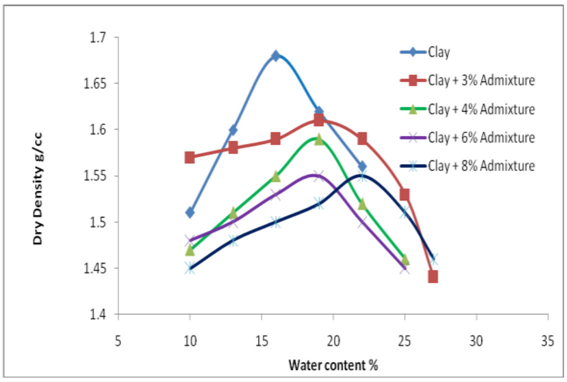

Fig. 3(a): Compaction curve for clay soil

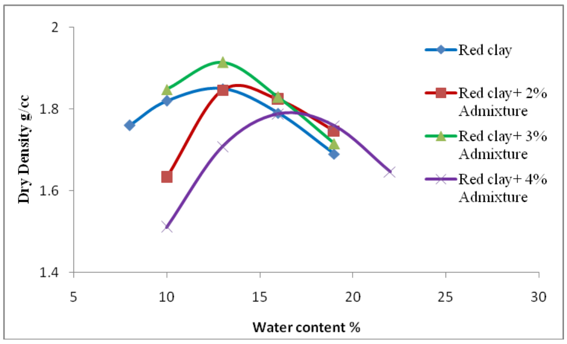

Fig. 3(b): Compaction curve for red clay

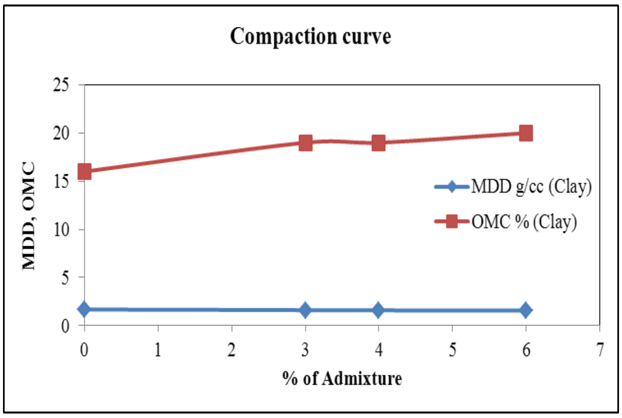

Fig. 4(a): Compaction characteristics value of clay soil with admixture

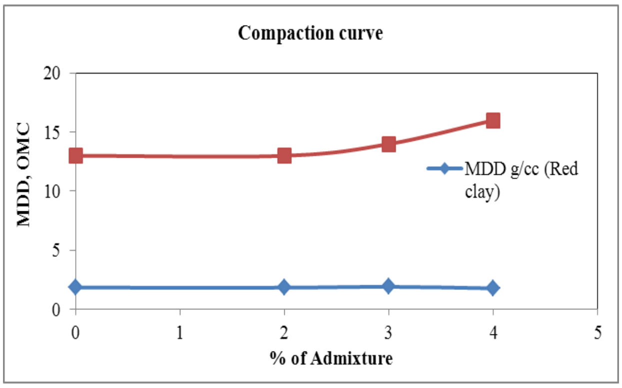

Fig. 4(b): Compaction characteristics value of red clay soil with admixture

F. *Effect of admixtures on Unconfined Compression Test*

The addition of admixture increased the UCS value in clay soil from 9.6 N/mm^2 kPa to 15 N/mm^2 which showed maximum with 4% after which it decreased and reached 5 N/mm^2 by the addition of 8% admixture. In red clay soil the increased in strength was from 11 N/mm^2 kPa to 22 N/mm^2 which showed the maximum at 3% admixture which there after decreased (Fig. 6). Stress and strain curve also revealed the same and it is shown in Fig. 5(a & b).

This material contains amorphous silica which is indication of cementing properties, which can develop good bonding between soil grains in case of weak soil. Thus, from the results, it was concluded that increase in the percentages of admixture increases the strength characteristics. Compared to fibres, the ash which becomes paste might have a better consistency and influence the setting time of blended cement. Anwar et al., [31] used burned rice husk as a cement replacement material in concrete. According to Grith et al., [32] insulating blocks also can be made with cement and husk ash.

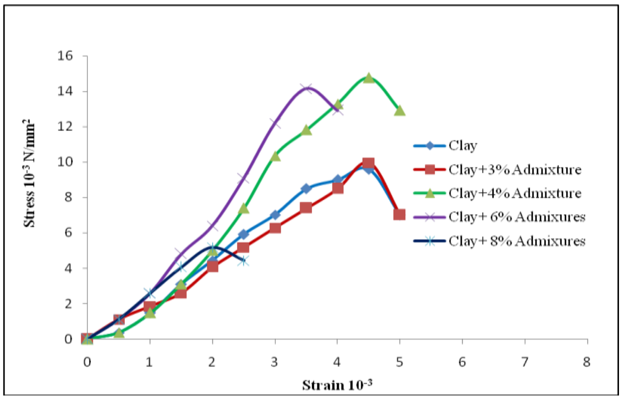

Fig. 5(a): Stress strain curve for Clay soil

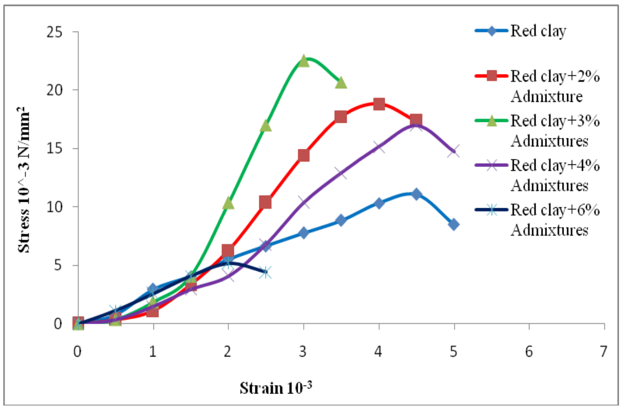

Fig. 5(b): Stress strain curve for red clay

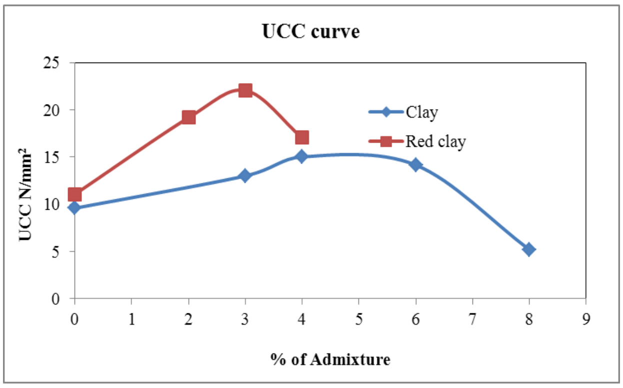

Fig. 6: UCC value of soil with varying percentages of admixture

G. *Effects of swelling behavior of treated soil*

The free swell test (FSI) is a laboratory method to detect the swelling behavior of soil samples. Free swell is the increase in volume of a soil on submergence in water. FSI value of clay and red clay sample was found to be 90% and 30% respectively. The swelling performance of soil treated using equal proportion of cement and AHA is tabulated below. There was a drastic reduction of swelling from 90% to 30% for clay and 40% to 15% for red soil with an increase in percentage of admixture and the details are given in table 3 (a & b). The decrease in the swelling behavior indicated the regulation of the permeability of soil in turn which reduce the compressibility of soil, by the admixture.

Table 3a: Free swell value for clay soil

Description	Free Swell Index %
Soil	90
Soil + 3% Admixture	75
Soil + 4% Admixture	60
Soil + 6% Admixture	40
Soil +8% Admixture	30

Table 3b: Free swell value for red clay

Description	Free Swell Index %
Soil	40
Soil + 2% Admixture	30
Soil + 3% Admixture	25
Soil + 4% Admixture	15

The free swell is defined as the % increase in volume compared to the original volume of the soil. Soil with 100% (or) more free swell causes damage to the lightly loaded structures. The reduction in swelling by the addition of admixture had clearly indicated the suitability of the soil state for construction. The reduction of free swell % by admixture might be due to increased cohesion among the soil particles.

Apart from stabilization, various other benefits also been expected from this kind of admixture. The cement hydrate might also prevent the existence of free chlorides and hence in turn reduce corrosion of concrete structures [30], [33]. Compared to fibres, ash seems to be more potent in providing corrosion resistance. Work done by many researchers has proved reduction of acid attack on concretes [29], [34], [35]. They opined that ash with its ultra-fine filling capacity can control acid attack due to its low porosity, dense packing and high silica content.

Various tests conducted revealed that the areca nut ash and cement admixture increased, liquid limit, plastic limit, OMC value, UCC value of expansive soils under study where as it decreased MDD value as well as swell percentage. These modifications might improve the workability of clay and red clay soil types for construction purposes.

IV. CONCLUSION

From the results it is concluded that clay and red clay with AHA and cement can be considered to be a good ground improvement technique especially in engineering projects on weak soils, where it can act as a substitute to deep/raft foundations and thus, control the swelling potential, increase the bearing capacity and reducing the cost as well as energy. The study clearly indicated ANA can be used as an alternative pozzolan to partially replace conventional cement, and thus effectively reduce CO_2 emission related to cement industries. Besides, it may reduce the pollution issues related to disposal of ANH, especially methane emission, a deadly green house gas.

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