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Influence of randomly mixed coir fibres and fly ash on stabilization of clayey subgrade

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Abstract

This paper discusses the stabilization of clayey subgrade when mixed with coir fibres (CF) randomly and fly ash (FA). The tests were carried out on the locally available clay soil with different proportions of randomly mixed CF and FA. The CF and FA proportions used in the study are expressed in percentage by dry weight of soil. The CF and FA proportions used in the present study are 1%, 1.5% and 2% and 0%, 5%, 10%, 20% and 30% respectively. The tests results revealed that the clayey subgrade stabilized with FA resulted in improvement of strength and California bearing ratio (CBR). Further, it is observed that randomly mixed 1% CF and 20% FA mixture resulted in improvement of CBR of subgrade as compared to clay subgrade treated with 20% FA alone and this increase is noticed as 1.5 times. Overall, it is concluded that 20% FA + 1% CF resulted in improvement of subgrade in terms of CBR.

Keywords: Fly ash, Coir fibres, Clayey subgrade, CBR

Introduction

Soil stabilization is of an immense concern principally in the pavement construction as it results in an increase in shear strength of the soil for a given requirements of a project, as well as meeting those requirements under specific environmental and traffic conditions. It is vital to delight the soil to overcome the adverse problems. Several engineering properties of soils are beneficially modified by adding cementitious materials like lime, discrete coir fibres and fly ash. Although lime is primarily utilized to treat fine-grained soils, it can also be used to modify the characteristics of the fine fraction of granular soils. The lime proportion of 4% to 6% is effective as a stabilizing agent of black cotton soil and this proportion the soaked CBR of black cotton soil increased considerably [7]. A minimum of 3% to 5% of the lime stabilizer is necessary to gain a significant increase in the compressive and tensile strength. Although the use of lime stabilization is widespread, the reported performance of the technique is often variable [21]. The effect of fly ash and lime on red soil indicated that optimum benefits are achieved when fly ash is added to soil in combination with lime. The optimum value of additive combination was found to be 15% of fly ash and 5% of lime [1].

The high content of clay can possess shrink-swell properties brought by changes in moisture content. To conquer this negative aspect of the stabilization is to convert the soil to a rigid or granular mass by binding the soil particles sufficiently strong to resist the internal swelling pressure of the clay [25]. Alternatively, to reduce the shrink-swell

potential, the movement of moisture within the clay soil must be reduced, which can be achieved by blocking the pores. There is no appropriate conventional method of stabilization to overcome the disruptive effects of moisture in clay. Studies concerning to fly ash and lime utilization for soil stabilization have been performed by the earlier investigators [5, 15, 17]. The plasticity characteristics and swell potential of clayey soil can decrease with the increase in fly ash contents. Addition of fly ash more than 20% to clay soil are comparable with lime addition rates of 8% in reducing the plasticity and swell potential of a soil consisting of 85% kaolinite and 15% bentonite [3]. Similarly the plasticity index, activity and swelling potential of the samples decreased with the % of fly ash increases. The changes in the physical and swelling properties of clay soil are a result of the following: formation of additional silt size particles due to chemical reactions that cause immediate flocculation of clay particles, time-dependent pozzolanic actions and self-hardening properties of fly ash [3]. The physical and chemical mechanisms of short and long term reactions involved in the lime stabilization of soils or soil-fly ash mixtures have been extensively described [2, 8]. The rate of decrease in swell potential has been noticed with the increased curing period of fly ash mixed clayey soils. After curing the fly ash mixed clay samples for 7 days, the swell potential noticed are 4.8% and 3.7% respectively for fly ash proportions of 15 and 20%. Thirty days cured samples showed the swell potential nearly zero for both 15 and 20% fly ash proportions. Also, it was interesting to see that the compression and recompression index of fly ash mixed clay soils have decreased with the increased curing period and fly ash proportion [18].

Studies carried out by Emilliani Anak and Dygku Salma [6] presented that the shear strength of sample mixtures cured for 7 days is decreasing when the amount of fly ash governed is 80% of the total weight of the mixture. Besides this, the clay soil mixed with 60% fly ash by weight showed the highest compressive stress. Fly ash alone cannot perform as a better construction material due to its lightweight behaviour, but, a suitable amount of fly ash 50 to 60%, when added to clay soil by dry weight, would perform as a suitable construction material. Prasanna Kumar [22] reported that the maximum dry density (MDD) of black cotton (BC) soil has increased from 13.6 to 15.2 kN/m³ for the addition of 40% Nyveli fly ash (NFA) and for red earth soil, it was seen that the MDD increased from 14.6 to 17.8 kN/m³. Also, considerable improvement in compressive strength has been noticed and its improvement is from 310 to 1393 kPa for BC soil and from 590 to 2342 kPa for red earth soil when NFA proportion of 30% is added. A series of investigations were reported on Cement Kiln Dust (CKD) and fly ash mixtures for producing sub-base materials with different aggregates. CKD was used up to 16% by dry weight of the mixture, producing a durable mass by reacting with water at ambient temperatures [19, 20]. It was pointed out that the use of any particular CKD—fly ash combination would require a performance appraisal of the mix based on the chemical and strength behaviour to establish the optimum mix [16]. The CKD-treated fly ash and aggregate mixtures showed comparable behaviour in strength, durability, dimensional stability, and other engineering properties, to those of the conventional lime-fly ash-aggregate mixtures [4].

As reported by Senol et al. [24], it is interesting to note that the low CBR of black cotton soil is attributed to the inherent low strength of which due to the dominance of clay fraction. The addition of fly ash to black cotton soil increased the CBR of the mix

up to the first optimum level due to the frictional resistance from fly ash in addition to the cohesion from black cotton soil. Further addition of fly ash beyond the optimum level caused a decrease in CBR up to 60%. Unconfined compression stress (UCS) and CBR of low plasticity clay with 20% fly ash decreased after a 2-h compaction delay and the strength can be maximized by stabilizing at mixture-specific moisture content and minimizing compaction delays. Ash blended expansive soil with fly ash contents of 0%, 5%, 10%, 15% and 20% on a dry weight basis inferred that the increased fly ash content decreased the plasticity characteristics of the soil. Free swell index (FSI) of soil was reduced to 50% when expansive soil was blended with 20% fly ash. The undrained shear strength of the expansive soil blended with fly ash increased with the increase in the fly ash content [23].

From the aforementioned literature review, it is evident that numerous works have been carried out relevant to the stabilization of pavements especially on clayey subgrade using various admixtures such as fly ash, stone dust, granulated blast furnace slag, lime, cement kiln dust and cement. There are few studies reported on the utilization of randomly mixed coir fibre along with fly ash in the pavement construction. In this paper, the results of a laboratory study carried out to understand the behaviour of fly ash + fibre mixtures for use in pavement construction in the clayey subgrade are presented and discussed. The fly ash proportions in percentage by dry weight of soil adopted are 0, 5, 10, 20 and 30. The coir fibre proportions in percentage used are 0, 1, 1.5 and 2 by dry weight of soil. The details of the experimental program and materials used and their physical properties are presented in the following sections.

Experimental investigation

Materials used

Soil

The soil was collected from open pits near Patancheru area, Rangareddy District, Telangana, India. The soil is in black colour. The soil collected from the site was processed and stored in an airtight container in the laboratory. The basic tests were conducted according to the Indian Standard Code of Practice of testing of soils and basic properties of soil are presented in Table 1. From the grain size distribution curve presented in Fig. 1, it is noticed that the soil consists of 3% gravel, 4% fine sand, 18% medium sand, 22.5% coarse sand and rest is fines content (soil fraction passing through 0.075 mm sieve) 52.5%. Overall the soil is dominated by a fine fraction and fine sand.

Fly ash (FA)

Fly ash (FA) was collected from the Vijayawada Thermal Power Station (VTPS), Vijayawada, Andhra Pradesh, India. It contains the majority of fine sand fractions around 97.5% and the remaining fractions are about 2.5% of silt range. Figures 2 and 3 present the photograph of FA and its grain size distribution curve. The physical and chemical properties of FA are presented in Table 2.

Coir fibre (CF)

Coir fibre (CF) was collected locally and used as a stabilizing agent in combination with FA to the clayey subgrade. The CF was cut into 6 mm length and stored in airtight

Table 1 Basic properties of soil

S. no.	Soil property	Value
1	Atterberg's limits	
	Liquid Limit (LL)	48
	Plastic Limit (PL)	24
	Plasticity Index (PI)	24
2	Compaction properties	
	MDD (kN/m ³)	17.5
	OMC (%)	17.0
3	CBR and strength properties	
	Unsoaked CBR (%)	2
	UCS (kN/m ²)	150
4	Soil classification	CI
5	Specific gravity	2.67

Fig. 1 Grain size distribution curve for soil

Fig. 2 Fly ash used in the study

Table 2 Physical and chemical properties of FA [Source: Vijayawada Thermal Power Station (VTPS)]

Property	Value
Specific gravity	1.97
Grain size distribution	
% Gravel	0
% Coarse sand	0
% Medium sand	0
% Fine sand	97.5
% Silt and clay	2.5
Effective diameter, D_{10} (mm)	0.085
Coefficient of uniformity, C_u	2.2
Coefficient of curvature, C_c	1.2
Chemical composition	
% SiO_2	60.5
% Al_2O_3	30.8
% Fe_2O_3	3.6
% Cao	1.4
% Mgo	0.91
% SO_3	0.14
% $\text{K}_2\text{O} + \text{Na}_2\text{O}$	1.1

container in the laboratory. Care has been taken during preparation of standard length of each fibre. Figure 4 presents the photography of CF.

Tests conducted

Diverse tests were conducted on the soil as per the Indian Standard Code of Practice of Testing Soils as specified below. The liquid limit and plastic limit tests were conducted as per IS: 2720 (Part 5)—[11]. Grain size distribution is as per IS: 2720 (Part 4)—[10]. Standard Proctor Compaction test was carried out according to IS: 2720 (Part 8)—1983 [12]. The California Bearing Ratio (CBR) test was carried out as per the IS: 2720 (Part 16)—1987 [14]. The Unconfined Compressive Strength (UCS) test

Fig. 4 Photograph of coir fibre (CF)

Fig. 5 Variation of LL, PL and PI with % of FA

was carried out as per the IS: 2720 (Part 10)—[13]. The specific gravity test of soil was carried out as per the IS: 2720 (Part 3/Set I)—[9].

Results and discussions

Atterberg's limits

The variation of Atterberg's limits such as liquid limit (LL), plastic limit (PL) and plasticity index (PI) with percentage FA is presented in Fig. 5. From this figure, it can be observed that as the percentage of FA increases from 0 to 30, the LL of soil decreasing linearly. At 30% FA, the LL of soil-FA mixture is 39% and at 30% FA this value is 36%.

Addition of FA to soil does show a minimal change in PL. There is a hardly modest increase in PL of soil.

The variation in plasticity index (PI) with the percentage of FA is presented in the same figure and from this, it can be seen that, as the % of FA increases, the PI of soil is decreasing linearly and this decrease is at a lower rate, from 20% FA onwards. The PI of soil has decreased to 50% at the FA content of 20%. Lowering of PI is always advantageous to avoid the construction problems associated with clay subgrade soil.

Compaction characteristics of soil

The compaction characteristics of the soil are the important parameters to ascertain strength and durability aspects of pavements constructed on clayey subgrades. Any subgrade soil prepared at optimum moisture content (OMC) can have sufficient stability during its existence. It is evident that to achieve the required sustainability of pavement, it is utmost important to follow the compaction specifications [26, 27]. The soil-FA mixtures are tested for compaction characteristics as per the standard compaction test procedure. Figure 6 presents the compaction curves of soil FA mixtures, where FA content was varied from 0 to 30% at 5% increment. From these curves, it is clearly noticed that as the percentage of FA increases from 0 to 30%, the peaks of compaction curves are moving down. The behaviour of compacted soil-FA mixtures is rigid till the peak condition and once the peak is attained further addition of water to the mixture is causing a drastic reduction in dry unit weight of soil-FA mixtures. The compaction curve of untreated soil is riding on top as compared to compaction curves of FA treated soil. All the compaction curves are showing the typical clay behaviour to silt behaviour and following a similar kind of trend.

The variation of MDD and OMC with the percentage of FA is presented in Fig. 7. From this figure, it can be seen that as the percentage of FA increases, the MDD of soil-FA mixtures is decreasing from 17.5 to 15.8 kN/m³. About 10% of FA addition to soil does not show any change in MDD of soil, but FA of above 10%, the variation in MDD of mixtures is seen drastic. This can be attributed that the FA is a lightweight material and

replacing the soil, which caused the reduced densities of the mixture. Likewise, as the percentage of FA increases from 0 to 30%, the OMC of the mixture is increasing gradually and this increase is observed about 20% at 30% FA proportion. When a clay soil is blended with higher proportions of FA causes an increase of diffuse double layer thickness. The decrease in MDD and increase in OMC are noticed in the clay soil-FA mixtures as percentage FA increases.

Unconfined compression stress (UCS)

The results pertinent to unconfined compression stress (UCS) are presented in Figs. 8 and 9. The samples for UCS were prepared at the OMC. Figure 8 presents the stress-strain plots of soil samples blended with different percentages of FA. From this figure, it is observed that as the strain increases from 0 to 2% the stiffness of the FA soil mixtures is almost constant and thereafter for any small increase in the strain, the behaviour of the mixture is changing from linear to curvilinear. The untreated sample is showing lower compression stress as compared to the soil samples treated with FA corresponding to a particular strain level. The compression stress levels are gradually increasing for the

samples blended with FA. The soil samples blended with 20 and 30% of FA are showing higher levels of compression stress compared to lower proportions of FA blended soil mixtures.

From the peak values of stress–strain curves, UCS values are derived and these values with the percentage of FA are presented in Fig. 9. From this figure, it can be seen that up to about 20% of FA soil mixtures, the UCS is increasing and thereafter and for 30% of FA the strength has reduced slightly compared to soil blended with 20% FA. The UCS is increased about 50% for the soil blended with 20% FA as compared to the untreated soil. Similarly, the increase in strength is noticed as 40% for the soil blended with 10% FA. This increase in strength is attributed to the flocculation of grains and improved frictional resistance in the mixture. Especially in the pavement construction, the stable subgrade and its strength considerations play a vital role. From the above discussion, it can be noticed that FA proportion, when blended even up to 30% to the soil, can result in a stronger subgrade. FA about 30% can be effectively utilized in the clayey subgrade towards effective stabilization of clay subgrade soil. Further to analyze the strength of FA blended clay with respect to CF mix, an optimum FA proportion has been considered as 20%.

California bearing ratio (CBR)

The California bearing ratio (CBR) of the subgrade is an important strength parameter to estimate the thickness of flexible pavement. Majority of the clay subgrade have lower CBR. It is required to improve the CBR of clay subgrade by using different admixtures. The CBR results presented herein are corresponding to the unsoaked conditions. The CBR tests are conducted for the mixtures of soil + % FA and soil + 20% FA + %CF. The CF proportions adopted are 1, 1.5 and 2% by dry weight of soil. Figure 10 presents the load–penetration curves of FA blended clay soil. From this figure, it can be noticed that up to about 4 mm penetration, the stiffness of the load penetration curves is constant and high, and from 4 mm penetration onwards, the stiffness of mixtures are becoming linear to curvilinear. The failure can be expected from 4 mm penetration onwards as per

Fig. 10 Load-penetration relationship of soil for various % of FA

Fig. 11 Relationship of CBR of soil with % of FA

the trend of the curves presented. The curves belonging to 20% and 30% of FA are moving parallel and at a high level compared to the curves of other percentages of FA. Addition of FA to the clay soil imparting more rigid behaviour to the mixture and hence it is noticed that for the same penetration levels the loads observed are high as the percentage of FA increases.

The CBR variation with the percentage of FA is presented in Fig. 11 and it can be noticed that, as the percentage of FA increases from 0 to 30%, the CBR is increasing linearly. The soil blended at 20% of FA showed 2.5 times of CBR of untreated soil. The CBR of FA alone at its OMC is 18%. Though, FA alone showing required CBR, it alone cannot be used in the road construction due to its instability and unfriendly nature to the environment. In general, the CBR values of clay subgrade may range between 1 and 2% and hence, construction of pavement of different layers on pure clayey subgrade results in high cost. It may be out of the sanctioned budget in majority instances. Hence, improved values of CBR of the subgrade is aimed always. Addition of FA of 20% to the clay soil has

resulted in CBR value of about 6% and it is obviously a good improvement as per the road construction on clayey subgrade is concerned.

The influence of the CF on the CBR of FA blended clay subgrade has been further studied. The CBR tests were conducted by varying the CF as 1, 1.5 and 2%. The optimum FA content of 20% is considered along with the CF. The test specimens were prepared corresponding to OMC of 20% of FA and are subjected to CBR testing. Figure 12 presents the load penetration curves of soil + 20% of FA and CF content varying from 1 to 2% at an increment of 0.5%. From the curves, it can be clearly observed that as the random inclusion of CF along with the soil and FA, the load levels required are increasing for the same penetration corresponding to the samples without CF. Addition of CF ensuring more stiffness and increased friction content to FA soil sample. The load penetration curves of CF reinforced FA soil mixtures are behaving same as that of FA soil mixture samples. Up to about 3 mm penetration, there is a linear relationship between the load and penetration response of CF reinforced samples and thereafter there is gradual curvilinear load-penetration behaviour in the samples.

Furthermore, the CBR of CF reinforced and 20% FA blended soil sample is presented in Fig. 13. From this figure, it can be observed that when 1% CF + 20% FA is added to the soil, the CBR value has increased to 9% and for CF content of 1.5% and 2%, the CBR is noticed as 7.5 and 7% respectively. From this behaviour, it can be seen that as the addition of CF to the soil + 20% FA, there is no reduction in the CBR and the CBR has increased from 6 to 9% at CF content of 1%. For the clay soil used in the study, the addition of 20% FA and 1% CF gives an improved CBR soil + 20% FA + 1% CF is an optimum combination at which the strength and CBR values noticed are high and it results in a reduced thickness of the pavement to be provided and overall it leads to the reduced cost of the project.

Conclusions

From the above discussion of results, the following conclusions are drawn. The higher proportions of FA are resulting in the reduced plasticity behaviour of soil as confirmed

from the LL and PL variations of FA blended soil. PI of soil is decreasing linearly as the percentage of FA increases and this decrease is at a lower rate beyond the FA percentage of 20. Peaks of compaction curves are falling down as the percentage FA increased from 0 to 30%. The MDD of clay FA mixtures is decreased from 17.5 to 15.8 kN/m³ as the percentage FA increased from 0 to 30%. The UCS is increased about 50% for the soil blended with 20% FA as compared to the untreated soil. Addition of 20% of FA to the clay soil has resulted in an increase of CBR to 6%. Further increase in CBR is noticed as 9% when additionally 1% of CF is added to the soil blended with 20% FA. It is suggested that 20% FA + 1% CF blended to the clayey soil would result in improved strength and CBR of the clay subgrade.

Authors' contributions

Both authors involved in compiling and write-up of the whole manuscript. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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