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Experimental Investigation on Stabilization of Silty Sand using Fly ash

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Abstract. In the present work fly ash is used as an additive for stabilization with Silty sand. Geotechnical properties of fly ash and its interaction behavior with soils can lead to a viable solution for its large scale utilization and disposal. The effect of fly ash on geotechnical properties of silty sand stabilized with the optimum percentage of fly ash has been reported. The fly ash in the rate of 5-20 % was added, at an increment of 5% and the change in the soil properties was studied. Atterberg's limits (silty sand is non-plastic), compaction, California bearing ratio and unconfined compressive strength tests were conducted on these soil fly ash mixtures. The effects of 7, 14 and 28 days of unconfined compressive strength were studied for fly ash mixtures. The results indicate that the maximum dry density increases up to 10% fly ash content, and then dry density decreases gradually with an increase in optimum moisture content. The unconfined compression strength is maximum for 15% fly ash content. The California bearing ratio value of the silty sand increases gradually with the addition of fly ash up to 15%, beyond, where a further increase in fly ash percentage is observed to cause a decreasing trend. The improvement in the California bearing ratio value of the silty sand upon the addition of fly ash suggests that it can be effectively used as a subgrade stabilizer for road construction.

Keywords: Silty sand, Fly ash, Compaction, Unconfined Compression Strength

1 Introduction

The pavement carries the wheel loads and transfers the stresses through a wider area on the soil subgrade below. Thus the stresses transferred to the subgrade soil through the pavement layers are considerably lower than the contact pressure or compressive stresses under wheel load on the pavement surface. The reduction in the wheel load stresses due to the pavement depends both on its thickness and the characteristics of the pavement layers. A pavement layer is considered more effective/superior, if it is able to distribute the wheel load stress over a larger area per unit depth of the layer.

However, there will be a small amount of temporary deformation even on good pavement surface when modified wheel loads are applied. Also, most of the methods, which use California Bearing Ratio (CBR) and Soil Support Value (SSV), do not represent the conditions of the pavement subjected to repeated traffic loading. Recognizing this deficiency, the 1986 and the subsequent 1993 American Association of State Highway and Transportation Officials (AASHTO) design guides recommended the use of resilient modulus (MR) for characterizing base and subgrade soils and also for designing flexible pavements. The resilient modulus test provides a basic relationship between stress and deformation of pavement materials for structural analysis of layered pavement systems. It also provides a means of characterizing pavement construction materials under a variety of conditions such as moisture, density, and stress states that simulate the conditions in a pavement subjected to moving wheel loads. During the past decades, the road constructions have undergone a vast and rapid development. Yet there is a major problem in providing an adequate road system, namely the scarcity of good road construction materials, which fit the adverse climate of different parts of the country and several other geological factors. In facing with probable construction damage, civil engineers efforts would aim in improving the engineering properties of the soil using different types of stabilization methods. For example, stabilization of subgrade railway soils which has traditionally relied on treatment with lime, fly ash, cement, and special additives such as pozzolanic materials [1]. Some authors [2] and [3] have shown that adding low calcium fly ash and lime to the soil gives a substantial improvement in strength than using lime alone. Reuse of waste materials, such as fly ash, in road construction has tremendous potential to reduce the volume of waste materials disposed [4] and [5]. The suitability of industrial waste i.e., bottom and fly ash mixture in highway embankment construction [6].

The soil is heterogeneous mixture consisting of different percentage of coarse and fine grained fractions. There is a wide variation in the behavior owing to the complex geological process during the formation. In geotechnical engineering application, the mechanical behavior of soil namely strength and compressibility plays major role. Fine grained soils containing large amount of silt and clay under high moisture content show low strength and high compressibility and are generally problematic in nature. One such problematic Silty-sand locally called Suddha soil is present in southern parts of Karnataka and is chosen for the present investigation. Silty-sand is wide spread below a depth of 1.5m from the ground level and extends to depth greater than 10m. It possesses good strength in dry condition and upon increase in moisture content it loses strength. Many failures have been observed along canal slopes, road bases, and foundation sites where silty-sand is present. This soil is considered as a problematic soil in view of wide spread damage under saturated conditions. It is necessary to improve the strength of Silty-sand. Conventional stabilization techniques are not effective when the water content is high. Therefore, different additives such as cement, lime and fly ash may be used. It is necessary to have a basic understanding of the mechanical behavior of soil, in particular during the development of strength and durability aspects in the laboratory due to the effect of additives. In the present work, laboratory investigations are carried out to find the effectiveness of fly ash stabilization to improve the mechanical behavior of Silty-sand for pavement applications.

2 Materials and Experiments

Silty sand sample locally called Suddha soil has been collected from a local site in Tumkur District, Karnataka and fly ash from the locally available supplier. Laboratory investigations were carried out to determine the index properties, compaction, strength properties and physico-chemical properties of silty sand. The grain size distribution of the soil sample was evaluated as per IS 2720- Part IV (1985). The geotechnical properties of silty sand are tabulated in Table 1. The silty sand consists of 3% Gravel, 77% Sand and 20% Silt and it is classified silty sand with the group symbol SM according to the IS soil classification system. The soil is non-plastic and predominantly consists of sand. It possesses good compaction properties from the subgrade point of view. The unconfined compressive strength under unsoaked condition is 38 kPa and under soaked conditions, the sample collapsed. It has good CBR value under OMC conditions but the soaked CBR is very low. Physico-chemical properties of silty sand and fly ash are tabulated in Table 2. The soil mainly consists of silica. It possesses 89.53% silica, 2.98% Iron, 2.33% Aluminum, 2.38% Calcium, 1.87% Magnesium and other compounds constitute 0.91%. It contains an organic matter of 1.58 [7].

Table 1. Geotechnical Properties of Silty sand.

Engineering property	Laboratory Test Results
	Silty sand (Suddha Soil)
Specific gravity	2.65
Grain Size Analysis	
Gravel, %	3
Sand, %	77
Silt, %	20
Clay, %	--
Liquid Limit, %	38
Plastic Limit, %	NP
Plasticity Index	NP
Shrinkage Limit, %	24
IS classification	SM
MDD, kN/m^3	19.22
OMC	15
Free Swell Index	37
CBR Values	
Unsoaked (%)	4.39
Soaked (%)	2.18

Table 2. Physico-Chemical Properties of Silty sand and Fly ash

Parameter	Laboratory Test Results	
	Suddha Soil (Silty sand), %	Fly ash, %
SiO_2	89.53	39.3
Fe2O3	2.98	2.38
Al2O3	2.33	6.44
CaO	2.38	8.90
MgO	1.87	0.50
pH	7.92	9.72
Organic Matters	1.58	--
Others	0.91	--

3 Results and Discussions

The wetting and drying process of a subgrade layer composed of soft soil results in failure of pavements in the form of settlement and cracking. Therefore, priority should be given to the construction of a road on such a subgrade, it is important either to remove the existing soil and replace it with silty sand or to improve the engineering properties of the existing soil by stabilization. Replacing the existing soil might not be a feasible option; therefore, the best available approach is to stabilize the soil with suitable stabilizers. Various types of soil stabilizers are being used for the stabilization of soil. However, the selection of a particular type of stabilizer depends upon the type of subgrade soil and the availability of stabilizers. Several researchers have reported the benefits of stabilizers for modifying the engineering properties of soil.

3.1 Effect on Compaction Characteristics

The variation of dry density-moisture content relationship for Silty sand with various percentages of fly ash [8] (See Fig. 1). It is seen that the density-moisture content relation is affected by the addition of fly ash and it varies upon the percentage of fly ash. It is observed from Fig. 1 that, increase in MDD with an increase in the percentage of fly ash, reaches a maximum dry density of 17.80 kN/m^3 at 10% fly ash content and is also observed that with further increase in the fly ash percentage, there is a decrease in MDD and an increase in OMC. The above observations in the variation of MDD and OMC values with the varying percentages of fly ash suggest an optimum percentage of fly ash to achieve a higher value of MDD and lower value of OMC for any particular soil. The addition of fly ash in small percentage results in the decrease of repulsive forces of soil particles. This in turn reduces the resistance to compactive effort and the mix gets compacted to relatively higher densities. Though there will be flocculation due to free lime in the fly ash, this effect is dominated when the fly ash percentage is low. Hence a marginal increase in dry density is observed. Further, the addition of fly ash beyond the optimum results in increased flocculation due to increased availability of free lime content in fly ash. This would increase the repulsive forces of soil particles, thereby increasing the resistance to compactive effort and hence the density of the mix starts decreasing.

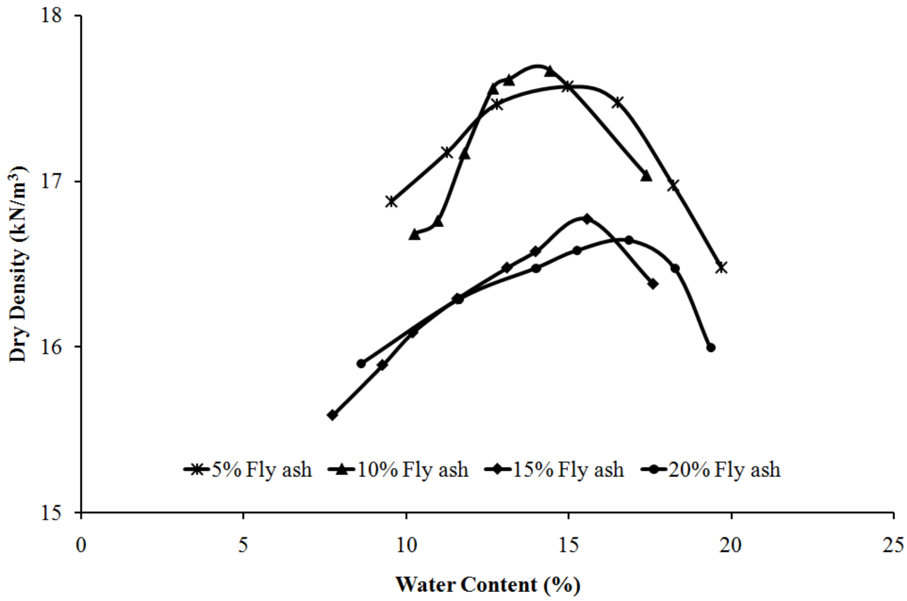

Fig. 1. Compaction curve of Silty sand treated with fly ash

3.2 Effect of Unconfined Compressive Strength

The silty sand (Sudha Soil) was mixed with 5, 10, 15 and 20 percent of fly ash as an additive and the laboratory tests related to strength were conducted to ascertain the effectiveness of the additive. For fly ash, a strength test was conducted under un-soaked and soaked conditions. The samples for unconfined compressive strength tests were cured for 7, 14 and 28 days in desiccators at 100 percent relative humidity. In the case of soaked conditions, the samples were soaked for one day after curing. Samples were covered by a membrane with porous stones at top and bottom and then soaked by immersing in water such that water enters through porous stones but not from sides (capillary saturation). The soaked samples were kept in air for drying for about one hour and then subjected to an unconfined compressive strength test

The variation of unconfined compressive strength with the curing period for varying percentage of fly ash (See Fig. 2 (a)).With the addition of 5% fly ash unconfined compressive strength increases from 42 kPa to 73 kPa, with 10% fly ash unconfined compressive strength increases from 46 kPa to 94 kPa, with 15% fly ash unconfined compressive strength increases from 109 kPa to 135 kPa and with 20% fly ash unconfined compressive strength increases from 61 kPa to 79 kPa with a curing period of 0 to 28 days.

The variation of unconfined compressive strength versus fly ash (%) at 7, 14 and 28 days curing period (See Fig. 2 (b)). Maximum UCS strength is achieved at 15% fly ash content and the optimum fly ash content for strength attainment is 15%. The strength increases with an increase in the curing period.

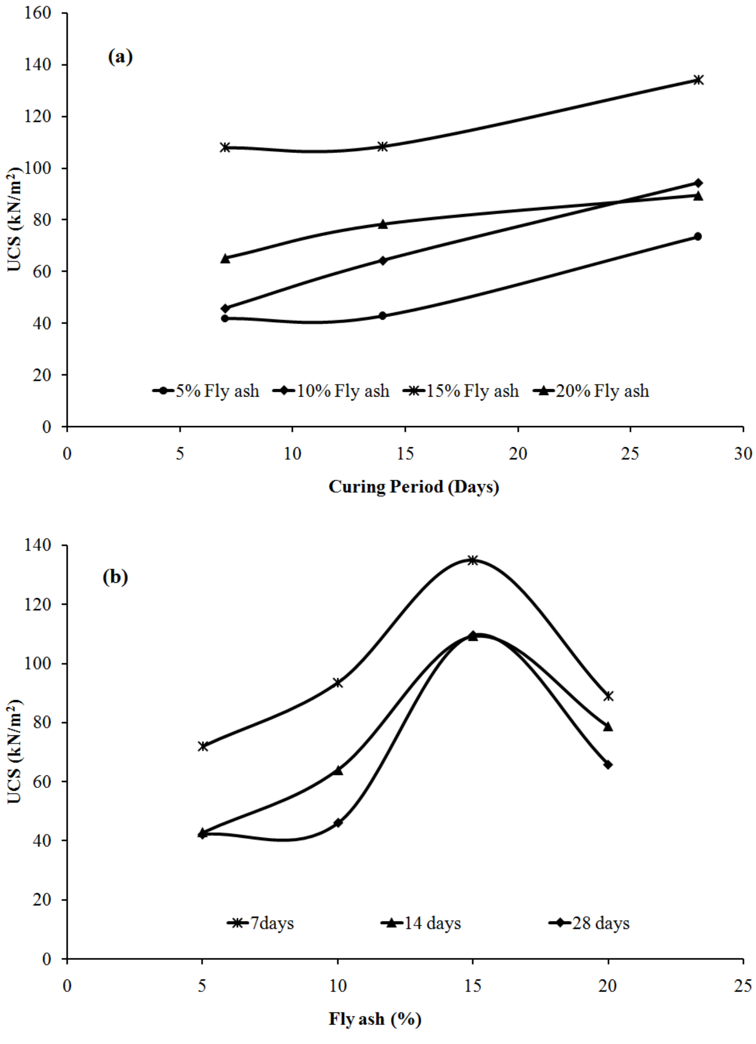

Fig. 2. Effect of curing period and fly ash content on unconfined compressive strength of silty sand- fly ash mixture under the unsoaked condition

The variation of unconfined compressive strength with the curing period for varying percentage of fly ash (See Fig. 3 (a)).With the addition of 5% fly ash unconfined compressive strength increases from 28 kPa to 62 kPa, with 10% fly ash unconfined compressive strength increases from 35 kPa to 69 kPa, with 15% fly ash unconfined compressive strength increases from 72 kPa to 89 kPa and with 20% fly ash unconfined compressive strength increases from 84 kPa to 87 kPa with a curing period of 0 to 28 days.

The variation of unconfined compressive strength versus fly ash (%) at 7, 14 and 28 days curing period (See Fig. 3 (b)). In this case, also, the optimum fly ash content is 15%, in general, strength reduction due to soaking is 50% and strength increases with an increase in the curing period.

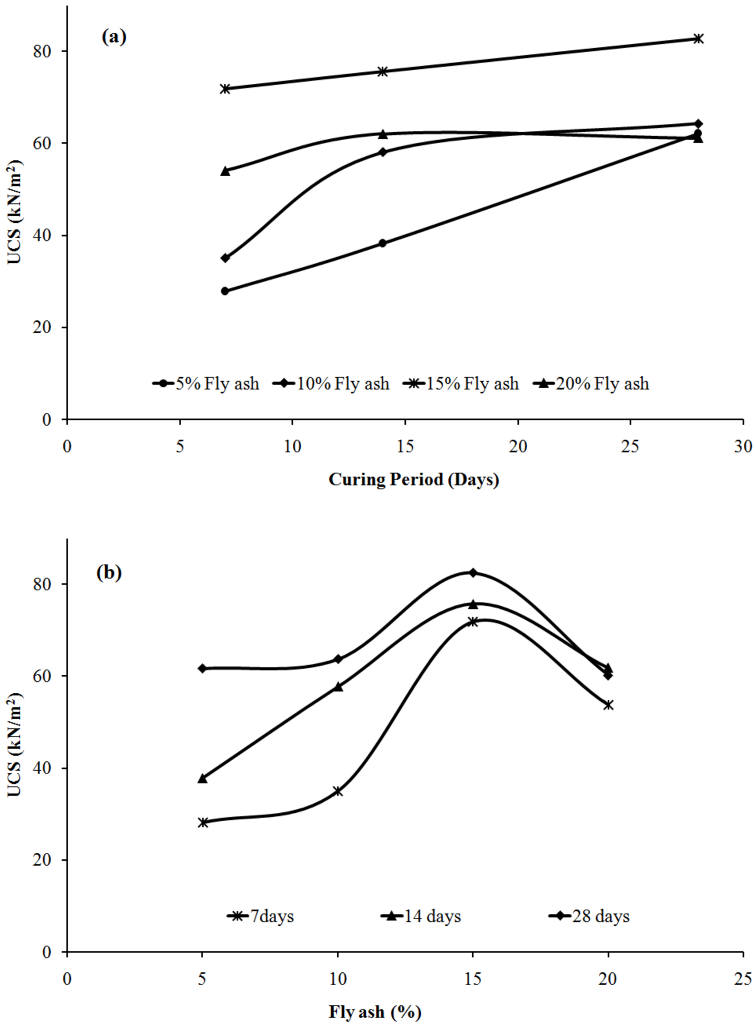

Fig. 3. Effect of curing period and fly ash content on unconfined compressive strength of silty sand- fly ash mixture under the soaked condition

Based on the results it can be observed that the strength generally increases with the curing period under both unsoaked and soaked conditions for all the fly ash content. The strength development at 5% fly ash is low when compared to 10%, 15% and 20%

fly ash. At 5%, 10%, 15% and 20% fly ash soaked strength is less than the unsoaked strength. In general, soaked strength is less than the unsoaked strength. The rate of strength is rapid up to 7 days and gradual beyond 14 days for 5%, 10%, 15% and 20% fly ash. In general, the rate of strength development is very similar for all four percentage of fly ash content. From the data, 15% additive is optimum from the point of rate of strength development. Table 3 gives the details of strength gain between 0 to 28 days for unsoaked and soaked conditions

Table 3. Strength gain between 0-28 days for an unsoaked and soaked conditions

Test Condition	Curing Period	Silty sand and fly ash mixtures											
		Fly ash content (%)											
		5	10	15	20	5	10	15	20	5	10	15	20
		Strength Gain											
Unsoaked	0-7	0.57	1.14	10.14	3.28	1.14	3	10.42	7.28	4.42	6.57	7	4.85
	7-14	0.14	2.57	0.14	0.71	0.42	3.42	2	0.14	3.57	6.28	8.71	8.74
	14.-28	2.14	2.14	1.78	0.92	4.07	2.85	1.92	2.28	3.57	2.57	2.71	2.57
Soaked	0-7	4	5	10.28	12	3.85	4.14	6.85	6.57	3.28	4.14	6.57	6.14
	7-14	1.42	3.28	0.57	0.28	1.42	2.28	0.85	0.57	1.57	0.85	0.42	0.57
	14.-28	1.71	0.78	0.92	0.07	0.64	1	0.57	0.5	0.64	0.92	0.35	0.5

3.3 California Bearing Ratio (CBR)

In the present study soaked and unsoaked CBR tests are conducted on silty sand stabilized with fly ash. The soaked CBR tests have been conducted on samples compacted to the specified densities at OMC. Often these samples are soaked for four days (96 hours) before testing in accordance with IS: 2720 (Part 16) – 1987. Variation of the soaked and unsoaked CBR values for silty sand mixed with different percentages of fly ash is studied and reported.

Table 4 shows the CBR values of unsoaked and soaked conditions using different percentages of fly ash. California bearing ratio value of the silty sand increases gradually with the addition of fly ash up to 15% further increase in fly ash percentage it is observed to cause a decreasing trend both in soaked and unsoaked condition. The improvement in the CBR value of the silty sand upon the addition of fly ash suggests that it can be effectively used as a subgrade stabilizer for the road construction works.

Table 4. Shows CBR values of unsoaked and soaked conditions using different percentages of fly ash

Fly ash, %	MDD, kN/m^3	Unsoaked CBR Values	Soaked CBR Values
0	19.22	4.39	2.18
5	17.57	4.56	2.9
10	17.80	4.70	3.5
15	16.77	4.85	3.6
20	16.64	4.40	3.2

An attempt is made to find the correlation between CBR and UCS at 28 days curing period under soaked and unsoaked conditions with varying percentages of fly ash (See Fig. 4). The R^2 values of 0.839 and 0.795 were obtained for soaked and unsoaked condition.

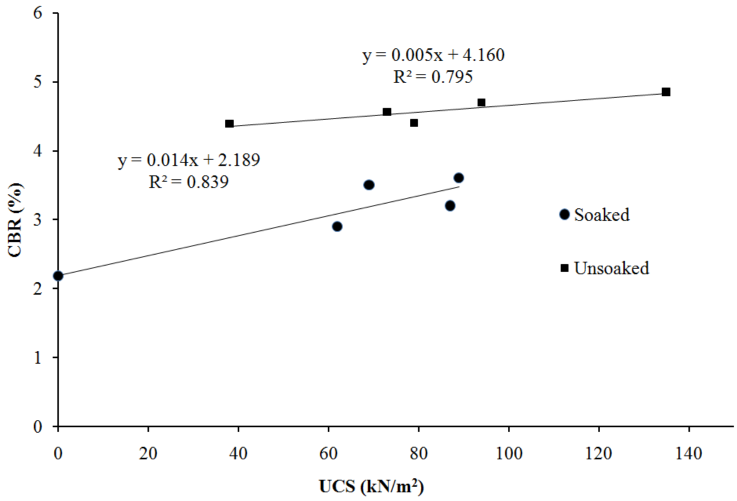

Fig. 4. Correlation between CBR and UCS

4 Conclusions

Based on the experimental test results the following conclusions have been made

1. Unconfined compressive strength of the silty sand (unsoaked & soaked condition) increases with the addition of fly ash content, and 15% fly ash content is optimum.
2. The strength increases with an increase in the curing period. The rate of strength gain between 14 to 28 days is significant. In general, the strength reduces by 50% under the soaked condition for stabilized soils for all the additives.
3. The CBR values of Silty-sand fly ash mixtures are maximum at 15% fly ash content for both unsoaked and soaked conditions.

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