Engineering and resilient properties of local clayey soil improved by fly ash and cement for pavement subgrade

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ABSTRACT: Soil for the subgrade of a pavement as represented by satisfactory engineering and strength properties, is usually preferred. Generally, poor soil for subgrade is improved by use of additives like lime, cement, etc. However, cost being a concern, locally available or waste materials like fly ash are chosen for soil improvement in the subgrade layer. This also helps in minimizing the concerns of pollution, besides reducing the cost. This motivates the authors to use fly ash with clayey soil, each locally available to reduce the plasticity and make it suitable for subgrade. This paper encompasses a systematic laboratory study of use of fly ash and ordinary Portland cement (OPC), from improvement of consistency properties to strength characteristics including resilient modulus. The present study concluded that the clayey soil modified with 30% fly ash and 2% cement (each material available locally) results in a considerably improved soil for use in the subgrade of a pavement subjected to high volume traffic.

1. INTRODUCTION

For most part of the world the presence of soft sub grades is one of the most frequently occurring problem in pavement construction. Usually solution to this includes two approaches. The conventional method includes removal of softer soil and replacing it by stronger material like crushed stone or sand. Cost associated with conventional method for removal of soil, collection and transportation of better soil makes it uneconomical in many locations. This approach is many a times not economical particularly when long distances are involved. As a result, construction agencies resort to less expensive method of soil modification using locally available soil. Hence, the alternative procedure considered is improvement of local soil by stabilization (including modification). Soil modification refers to enhancement of geotechnical properties of soil while maintaining its stability. For this several chemical additives are used, which may also substantially increase the cost of construction.

This research work intends to obtain an economic and suitable procedure to improve existing poor quality soil while optimally utilizing the additional and alternate materials used. Fly ash, an industrial waste product which is available abundantly in the locality where this research work, has been utilised. Moreover, considerable research has already been taken up to justify the beneficial effects of use of fly ash for improvement of poor soil. For instance, Sezer et al (2006) investigated on soil modification for soft subgrade with fly ash of high lime content. Soil was replaced by fly ash to the extent of 20%. The engineering properties like cohesion, friction angle, shear parameters and compressive strength of soil were determined at an interval of 0, 7, 14, 28 and 90 days. The improvements observed were attributed to pore refinement property and reaction of fly ash to siliceous material present in soil. High concentration of lime was also a key factor towards gain of strength in soil. Senol et al [2002] utilized fly ash in various contents ranging

from 10 to 20%. Soil mixture was prepared at 7% wetter than optimum, and compacted after 2 hours of mixing with water. California bearing ratio (CBR) samples were cured for 7 days at room temperature and then inside humidity chamber with 100% humidity before testing. Delay in compaction was done to study effects of the delay in compaction that usually occur during construction in field. They concluded that stabilizing the soil at near required moisture content, and diminishing compaction delay results in maximum strength for modified soil. Bin-Shafique et al [2010] investigated on long term strength characteristics of two fine grained soil sub bases stabilised using fly ash varying from 0 to 20%. They concluded that the effect of wet–dry cycles on stabilised soils was essentially insignificant. Sariosseiri and Muhunthan (2009) used Portland cement for modification and stabilisation of soils. Cement was added at 2.5%, 5%, 7.5% and 10% of dry weight of the soil. They observed that the unconfined compressive strength (UCS), workability, drying rate of soil and shear strength improved. At 10% cement content, the failures were treated as ductile, planar and splitting type. Titi et al (2006) developed correlations for estimation of resilient modulus of various Wisconsin soil subgrade by using the basic properties of soil. The resilient modulus (RM) of soil was determined from the repeated load triaxial test following AASTHO T 307 procedure. The constitutive equation of resilient modulus adopted by the NCHRP Project 1-37A, was selected for this study to develop correlations between the basic soil properties and resilient modulus model parameters. It is observed that while fly ash improves the plasticity characteristics of poor clayey soil, the cohesive characteristics are reduced.
Considering some observations on related topic, this research has been taken up to improve the local clayey soil by using abundantly and freely available fly ash (class F type with low concentration of CaO) in the locality, in possible combination of cement, so that cost effective and environmentally sustainable solution of pavement subgrade construction may be achieved. To achieve this broad objective the important scope of work in the present study involves the following.

- Improving strength of clayey sub-grade soil through addition of fly ash and cement in terms of basic physical properties.
- Determining the optimal use of fly ash and cement in local clayey soil.
- Evaluating performance of improved soil in terms of engineering and resilient properties.

2. EXPERIMENTAL WORKS

2.1 Materials Used

The present research revolves around the following three materials used in the study.

Clayey soil: Locally procured clayey soil has been used in the present study. The particle size distribution of this soil as determined as per the IS 2720 (Part 4) (1985) is presented in Figure 1.

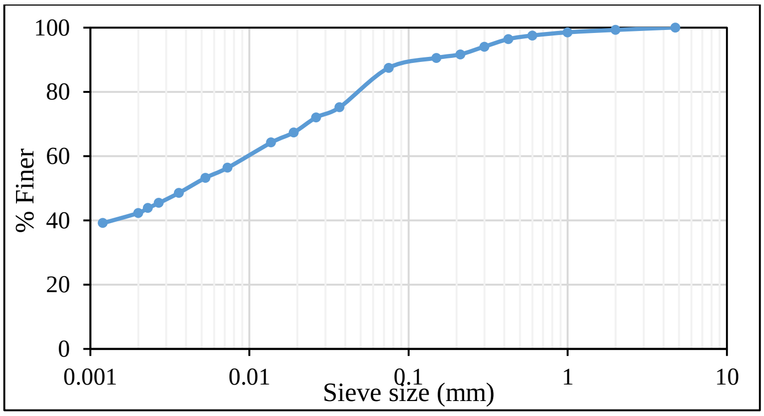

Figure 1 Particle size distribution curve of clayey soil used

The basic properties of clayey soil used in the present study and determined as per relevant IS codes are presented in Table 1.

Table 1. Basic properties of clayey soil used

Property of soil	Test result	IS Code/other procedure followed
Specific Gravity	2.73	IS 2720: Part 3
Liquid Limit	45.35 %	IS 2720: Part 5
Plastic Limit	24.02 %	IS 2720: Part 5
Plasticity Index	21.33 %	IS 2720: Part 5
DFS Index	51.2%	IS 2720: Part 40
Proportion of particles	Gravel (0%), Sand (12.55%) Silt (45.16%), Clay (42.29%)	IS 1498
Soil Classification	CI (Intermediate Clay)	IS 1498

Fly ash: Fly ash collected from a nearby coal based thermal power station was used in the present study. Its specific gravity was found to be 2.3.

Cement: Ordinary Portland cement (OPC) of 43 grade procured through a local supplier was used. Its specific gravity was found to be 3.03.

2.2 Other experimental works involved

Having determined the basic properties of materials used, the next step was to use the ingredient materials in suitable proportions and consider the selected composition in determining the strength characteristics of improved soils so as to assess their suitability as pavement subgrade material. Accordingly, the processes involved subsequently are as follows.

- Preparation of different stabilized mixes with varying composition of local soil, fly ash and OPC.
- Determination of optimum moisture content (OMC) and maximum dry density (MDD) of soil combinations through compaction test.
- Determination of soaked California bearing ratio (CBR) value.
- Determination of unconfined compressive strength (UCS).
- Determination of resilient modulus (M_r)

This research is aimed at studying and understanding the beneficial effects of fly ash and cement in improving the engineering properties of locally available poor clayey soil for subgrade. Initially, fly ash was mixed with soil to the extent of 40% at an increment of 10% (each per cent by weight of total mix). Heavy Proctor compaction tests were undertaken to determine the optimum moisture content (OMC) and maximum dry density (MDD) of each mix sample (IS 2720: Part 8). These OMC and MDD test results were used subsequently for next round of tests. Soaked CBR tests were then conducted to assess the benefits as per IS 2720: Part 16. This is followed by conduct of UCS tests of samples cured at various periods as per IS 2720: Part 10. Based on the preceding test results, the most suitable fly ash content was decided. Then cement was added to the selected soil-fly ash mix to the extent of 6% at an interval of 2% (by weight). Heavy proctor compaction tests were conducted on such mix sample to assess the OMC and MDD for subsequent strength tests. CBR and UCS tests were next carried out. Based on the selected cement content, the resilient modulus test is conducted on the mix.

2.3 Determination of Resilient modulus of selected soil-fly ash-cement mix

Resilient modulus is considered to be a measure of elastic modulus of unbound base, subbase or subgrade soils, and has been determined in this study as per AASHTO T 307 (2003) guideline. A repeated cyclic axial stress of fixed magnitude with load duration 0.1 second, cycle duration 1 second has been applied to the cylindrical specimen. During the time of testing the sample was subjected to dynamic axial cyclic stress and static confining pressure. The total resilient or recoverable axial deformation responses of specimen were measured and used to calculate the resilient modulus.

Before testing, moulds of 71mm diameter with height of 174 mm were used for subgrade soil, in which compaction was done in 5 equal layers with sufficient number of blows. The extracted specimen was covered with polyethylene to prevent moisture loss, and was cured in a humidity chamber at 27±2^{0}C, and at humidity of not less than 98% for a period of 7 days and 28 days.

3. RESULTS AND DISCUSSIONS

3.1 General

The steps as mentioned above were followed with the objective of selecting the best soil-fly ash-cement composition which may possibly be best suitable for a pavement subgrade.

3.2 Soil-fly ash mix

3.2.1 Compaction test

Heavy Proctor compaction tests were conducted on soil-fly ash mix. The results of the heavy compaction tests are represented through the compaction curves as presented in Figure 2. The OMC and MDD parameters are represented in Table 2. It is observed from the table that with increase in fly ash content, OMC increases and MDD decreases.

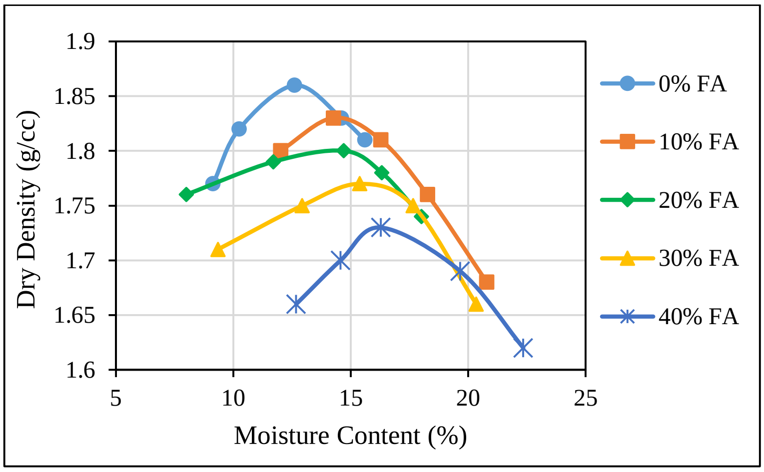

Figure 2 Compaction curves for soil-fly ash mix

Table 2. Compaction test results of soil-fly ash mix

Fly Ash content (%)	OMC (%)	MDD (gm/cc)
0	12.61	1.86
10	14.27	1.83
20	14.71	1.8
30	15.39	1.77
40	16.29	1.73

3.2.2 Soaked CBR test

The results of soaked CBR test for soils with varying fly ash contents in the mix are presented in Table 3. It is seen that with increase in fly ash content up to 30%, there is an increase in CBR value, after which there is a substantial decrease. This is because of decreased cohesion in the mix beyond certain fly ash content. Hence, for subsequent tests it has been decided to take fly ash to the extent of 30% (by weight).

Table 3. Soaked CBR values of soil-fly ash mix

Fly ash content (%)	Soaked CBR (%)
0	3.16
10	3.8
20	5.1
30	7.1
40	5.4

3.2.3 UCS test

The results of the UCS tests for soil-fly ash mix samples are presented in Table 4. In general, it is observed that there is a small decrease in UCS value with fly ash content. This is because of reduced cohesion in the modified soil. As the objective is to modify the plasticity and other strength characteristics by using fly ash to a maximum extent, 30% fly ash in the mix was selected as optimum. In view of reduced cohesion, the next step was to try with addition of cement which causes cementing action in the mix, thus improving the strength properties of soil-fly ash mixes.

Table 4. UCS test results of soil-fly ash mix at various curing periods

Fly ash content (%)	UCS value (MPa) at curing periods		
	0 day	7 days	28 days
0	0.65	-	-
10	0.62	0.673	0.808
20	0.568	0.576	0.675
30	0.508	0.521	0.543

3.3 Soil-fly ash-cement mix

3.3.1 Compaction Test

The results of the heavy Proctor compaction tests in respect of soil modified with 30% fly ash and varying cement content, are presented through the compaction curves in Figure 3. The OMC and MDD results of the said mixes are represented in Table 5. It is observed that with increase in cement content, both OMC and MDD increase.

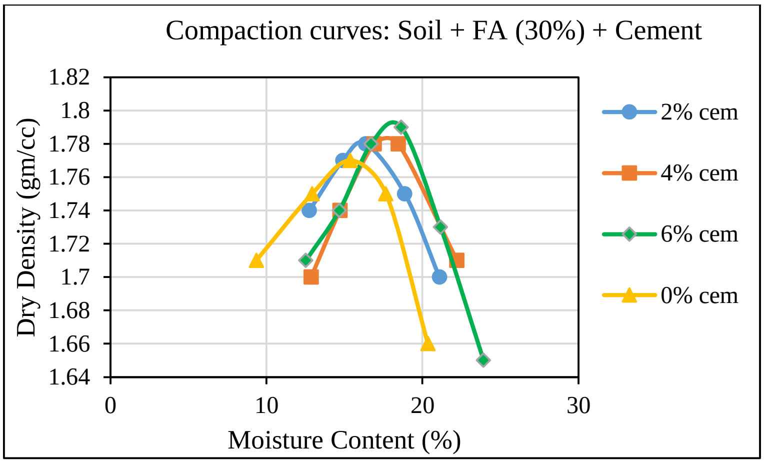

Figure 3 Compaction curves for soil-fly ash-cement mixes

Table 5. OMC and MDD parameters for soil-fly ash-cement mixes

Cement content (%)	OMC (%)	MDD (gm/cc)
0	15.39	1.77
2	16.35	1.78
4	17.48	1.785
6	18.63	1.79

3.3.2 Soaked CBR test

The results of soaked CBR tests of above mixes with varying cement contents in the soil-fly ash-cement mixes are presented in Table 6. It is seen that with a small increase in cement content, there is substantial increase in soaked CBR value because of good cementing action.

Table 6. Soaked CBR values soil-fly ash mix treated with cement

Cement content (%)	Soaked CBR Value (%)
0	7.1
2	26.18
4	61.49
6	175.27

3.3.3 UCS test

The results of the UCS tests for the soil-fly ash mixes treated with varying cement contents are presented in Table 7. In general, it is observed that there is a substantial increase in UCS value with cement content. As per IRC 37 (2018) satisfactory results are observed with 2% cement content, it has been decided to adopt this cement content as further increase in cement content would unnecessarily cause increased cost of construction.

Table 7 Results of UCS tests of soil-fly ash mix treated with cement contents at various curing periods

Cement content (%)	UCS value (MPa) at various curing periods		
	0 day	7 days	28 days
0	0.508	0.521	0.543
2	0.544	1.379	1.546
4	0.645	2.28	2.44
6	0.724	3.758	4.17

3.4 Resilient modulus test

From the results of the tests conducted, the tests for resilient moduli of selected soil mix (clayey soil+30% fly ash + 2% cement) conducted and the resilient moduli of these mixes at 7 days and 28 days of curing were determined with respect to different deviator stresses as per the AASHTO protocol. The related models with respect to resilient modulus vs deviator stress were developed. It is observed that for a particular deviator stress, the resilient modulus of stabilised soil at 28 days curing is found to be more than that at 7 days curing.

4. CONCLUSIONS

From the results of various tests conducted, the following major conclusions are drawn.

- Fly ash substantially improves most of the basic strength characteristics of clayey soil except the unconfined compressive strength.
- To improve the cohesion and strength characterises of the soil-fly ash mix, cement was added.
- It is observed that local clayey soil modified with 30% fly ash and 2% cement (each by weight) results in most satisfactory engineering properties of the stabilised soil for pavement subgrade applications.
- The resilient modulus of the stabilised soil as above is found to be substantially higher as compared with normally observed values of soil (at a specific deviator stress) used in pavement subgrade.
- Therefore, the results presented in this research work justify the need for utilising locally and abundantly available industrial waste like fly ash in improving the poor clayey soil for use in pavement subgrade.

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