Strength and Stiffness Studies of Corex Slag and Lime Stabilized expansive Soil

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Abstract. Enormous quantities of waste by-products, like fly ash, red mud, granulated blast furnace slag (GBFS), silica fume, and many more, are being produced every year all over the world from several industrial activities. These wastes are unloaded near the plants or in lagoons that conquering quite a lot of hectares of valuable land which may cause harm to environment. India is one of the primary producers of many industrial wastes, in which fly ash, and different slags are generating in massive amounts. Although the slags from the steel industry have acceptable quality to utilise for road works, their use on Indian roads construction is limited. The work is meant to determining the amount of corex slag by the weight of the mix that can be used in the subgrade layer/embankment of road construction. Strength properties of various soil-corex slag-lime mixes, namely compressive strength and stiffness in terms of flexure strength studied in the laboratory investigation for 7 and 28 days curing period. Also, relationships have been proposed to determine the flexural modulus of corex slag+lime stabilised expansive soil from its compressive strengths.

Keywords: subgrade, Stabilized, Corex slag, Flexural modulus, compressive strength

1 Introduction

In India under Pradhan Mantri Gramin Sadak Yojna (PMGSY) rural road construction works have been going on in different part of the country. The inadequacy of natural aggregate promotes the use of marginal material and industrial waste in the pavement structure construction. In recent year utilisation of industrial waste has been found promising in the construction of new roads and rehabilitation of existing pavements. The use of marginal quality of material in pavement construction would be cost-effective [1].

Expansive soil is found in about 20% land area of India, and it possesses unacceptable plasticity and strength for pavement construction [2]. However, the engineering properties of black cotton soil enhance by stabilising. Typically expansive soils are stabilised using lime, fly ash and chemical additives [3]. In recent years expansive soil properties improved by other non-conventional materials like quarry dust, ground granulated blast furnace slag (GGBFS), alkali-activated slag, rice husk, recycled basanite, calcium carbide residue, waterborne polymer etc. [4–9]. Different studies focus on the stabilising expansive soils to improve the geotechnical properties for engineering work. There is the least concentration regarding flexure strength with compare to the compressive strength of stabilised soils. The study of stabilisation of expansive soils shown the use of 25 % GGBFS would be optimum to improve engineering properties of the soils [4]. Quarry dust used up to 30% to improve only compaction characteristics of clay with different compressibility [6]. Rice husk ash also improved index and some engineering properties (California bearing ratio and shear modulus) of clayey soil to act as subgrade of flexible pavement [7]. The stability and performance of pavement subgrade having poor clay improved by recycled basanite from gypsum waste material with improving compressive strength and tensile strength [8]. The marginal materials proved to be suitable stabilisers even for clayey soil to enhance its engineering properties. However, the appropriate characterisation of slag stabilised soil is needed for subgrade construction to meet the requirement of mechanistic design input parameters like elastic modulus and Poisson's ratio [1].

Adding of optimum dosage of stabiliser could improve the plasticity and strength of the soil. Standards specifications and researchers reported the minimum strength requirement for stabilised soils. The Indian Road Congress IRC: 37, 2018 suggest to achieve 4.5-7 MPa unconfined compressive strength (UCS) value for cement stabilised soils to be used as a base layer and 0.75-1.5 MPa UCS for cement-treated soil used in subbase layer for flexible pavement. If stabilised soil used for low volume road subbase layer, the minimum UCS value should be achieved 1.7-3 MPa as per Indian specifications for rural roads IRC: SP: 72, 2015. The strength criteria for rural roads are quite lower than high volume roads.

Elastic modulus is an essential parameter for the design of flexible pavement for determining developed stress and strain at a critical location in pavement layers. Laboratory elastic modulus of cementitious materials could determine from the third point beam load test and correlate with UCS (IRC: SP: 89, Part 2, 2018). The correlation of modulus with UCS is used to determine elastic modulus as Laboratory determination of elastic modulus is a tedious process. The following equation is given in IRC: 37, 2018 to evaluate the modulus value of stabilised material from UCS:

$$E_f = 1000 \times UCS \tag{1}$$

Here E_f is flexure modus in MPa and UCS is in MPa.

Equation 1 cannot commonly be used for expansive soil stabilised with industrial waste or with marginal material. Thus present study focus on the relation between UCS and flexure modulus values for stabilised expansive soil with corex slag and lime. The study carried out to find strength properties of stabilised expansive soil using local industrial waste corex slag with lime. The strength in terms of UCS and Indirect Tensile Strength (ITS) has been studied in the laboratory.

2 Materials and method

2.1 Materials

Soil. The expansive soil is found common in south Gujarat region in India. The soil is collected form Suvali town of Surat district in Gujarat, India. Mainly intermediate to highly compressible clay found in south Gujarat region. The grain size distribution of the soil is given in Figure 1. The index and engineering properties of the collected soil are tabulated in Table 1.

Corex slag. The Corex slag acquired from the Essar Steel Ltd. Hazira, Surat, Gujarat, India. It has been confirming that material is nonhazardous and harmless to the environment. The corex slag is stockpile near the plant, found black in colour with 2.91 specific gravity and 9.6 pH value. It mainly contains Alumina (Al_2O_3, 55.31%), Cao (32.69%), Silica (SiO_2, 3.91%) and Ferric Oxide (Fe_2O_3, 3.15%). The Corex slag can be classified well-graded sand and could categorise in zone III of sand classification given in IS: 383, 2016. The gradation curve of slag is plotted in Figure 1.

Lime. Lime is collected from the local supplier of Surat city. The hydrated lime with calcium oxide (CaO) more than 70% have been used in the experiment work.

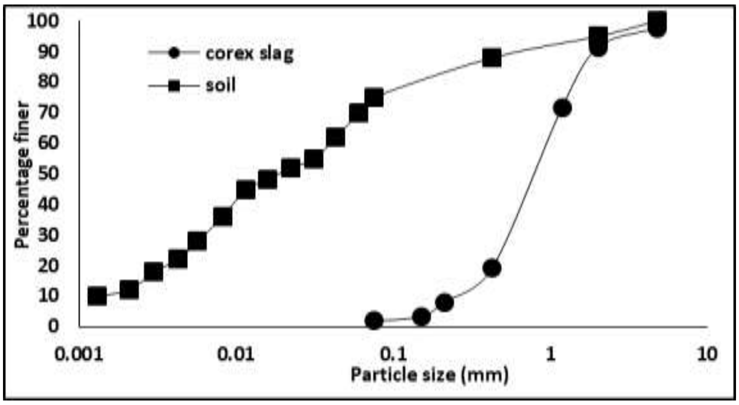

Fig. 1. Grain size distribution curve for corex slag and expansive soil

Table 1. Index and engineering properties of soil

Properties	Soil
Liquid Limit (%)	62
Plastic Limit (%)	23
Plasticity Index (%)	39
Specific Gravity	2.55
Free Swell Index (%)	70.59
Coarser (%) 4.75 mm & above	0
Sand (%), 0.075 mm to 4.75 mm	5

Silt and clay content< 0.075 mm (%)	95
OMC (%)	17.5
MDD (gm/cc)	1.66
IS Classification	CH
CBR (%)	1.86
UCS (MPa)	0.24
AASHTO soil classification	A-7-6

2.2 Methods

The mechanical properties of the stabilised mix were evaluated in the laboratory. The mixes were prepared by adding Corex slag (10, 15, 20, 25, 30 and 35 %) and lime (2, 4 and 6 %) to the soil in different percentage of by dry mass of total mix. The percentage of mixes were fixed form the previous studies. The compaction characteristics were determined according to the heavy compaction test as per IS: 2720 (Part-8), 1983 for soil+Corex Slag+lime mix. The test samples of UCS and IDT were compacted at the optimum moisture content (OMC) to reach maximum dry density (MDD). All tests were performed according to Indian Standards code of practice.

Unconfined compressive strength (UCS) test. The IS: 2720 (Part- 10), 1991 used to perform UCS test on 7 and 28 days cured samples. These samples were cast by ensuring the L/D ratio as 2 with 50 mm diameter and 100 mm height. All the samples were covered with a thin plastic film to maintain moisture content and left at ambient temperature and humidity conditions. During testing, loads were recorded at an interval of 0.1 mm deformation.

Indirect Tensile strength (ITS) test. The cracking behaviour of the stabilised material for pavements and earth structures is determined by the tensile strength test. In the present work, ITS test was performed according to IS: 5816, 1999 on the stabilised samples. The cylindrical specimen of 50 mm diameter and 100 mm height were subjected to loading condition along a line on the surface of the specimen. Samples were cured for the same as UCS testing conditions for 7 and 28 days curing period before testing. For ITS (S_t in kPa) was calculated as per equation 2:

$$S_t = 2P/\pi tD \tag{2}$$

P = Ultimate load at which failure of sample occurred in N, t = Thickness of specimen =100 mm, D = Diameter of specimen = 50 mm.
As per IRC: 37, 2018 the flexural strength of the stabilised material can be taken as 1.5 times of the ITS value. The values of flexural strength also may take as 20 per cent of the 28-day UCS value (MPa) subject to limiting (maximum) value of 0.7 MPa for cement stabilised the soil. In the present study, flexural strength is calculated by IRC: 37, 2018.

3 Results and Discussions

From the UCS values strength of stabilised material determined. Minimum requirement of UCS value is specified for stabilised material used for pavement layers in a different standard, including Indian specifications. The OMC and MDD with 7 and 28 days UCS and ITS test values are given in Table 2.

Table 2. OMC, MDD, UCS and ITS values for different combinations

			UCS (kPa)		ITS (kPa)	
Combinations	OMC (%)	MDD (gm/cc)	**7 days**	**28 days**	**7 days**	**28 days**
88S+10CS+2L	18.84	1.88	317.98	390.53	20.25	35.43
83S+15CS+2L	16.88	1.89	350.00	410.00	23.95	44.41
78S+20CS+2L	16.57	1.9	386.75	483.50	28.64	55.80
73S+25CS+2L	15.4	1.91	394.35	520.00	34.94	69.60
68S+30CS+2L	14.51	1.93	422.00	580.00	36.70	87.31
63S+35CS+2L	13.48	1.96	482.00	648.79	42.10	98.70
86S+10CS+4L	17.27	1.82	302.00	480.24	28.47	50.62
81S+15CS+4L	16.45	1.86	336.34	589.00	34.17	68.70
76S+20CS+4L	15.66	1.89	457.39	682.00	39.23	93.76
71S+25CS+4L	14.36	1.92	527.55	787.04	51.00	110.09
66S+30CS+4L	13.18	1.95	587.00	839.00	64.54	156.42
61S+35CS+4L	12.57	1.96	612.00	989.00	74.03	199.30
84S+10CS+6L	17.5	1.81	347.00	518.00	40.49	146.79
79S+15CS+6L	16.23	1.83	384.00	555.69	52.00	163.24
74S+20CS+6L	15.23	1.86	418.00	618.00	61.00	177.03
69S+25CS+6L	14.66	1.89	452.00	707.00	68.00	189.81
64S+30CS+6L	13.68	1.92	479.00	846.53	76.00	204.99
59S+35CS+6L	13.5	1.93	513.00	970.00	87.31	218.78

The ITS values multiplied with 1.5 to get flexural strength as given in IRC: 37, 2018. The relation between flexural strength and UCS is given in Figure 2 for 28 days of cured samples. For a given set of data, the flexural strength of expansive soil stabilised with Corex slag and lime could be given by equation 3 (in kPa). The flexure modulus of Corex slag lime stabilised samples varies between 50 to 350 kPa for different combinations. The report by the National Cooperative Highway Research Program (NCHRP report 789) also suggests the equation to find Flexural strength form UCS as given in equation 4 (in psi).

$$Flexural\ strength = 0.285 \times UCS,\ R^2 = 0.7926 \quad (3)$$

$$Flexural\ strength = 0.14 \times UCS \quad (4)$$

In Figure 3, the comparison of the predicted value of flexure strength with equation 3 and 4 is given. The values obtained by equation 3 are near to flexure strength by equation 4. The limiting flexural value to be adopted for the design is 0.7 MPa for cement stabilised soil as per IRC: 37, 2018. Most of the studied combinations satisfied the criteria given by the Indian code provision for stabilised soils for flexure strength.

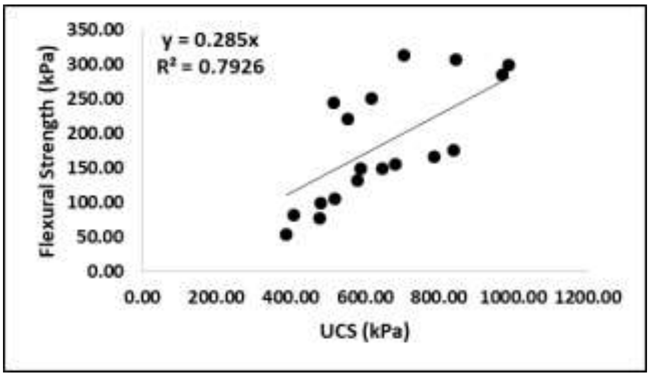

Fig. 2. Relation between UCS and Flexural strength

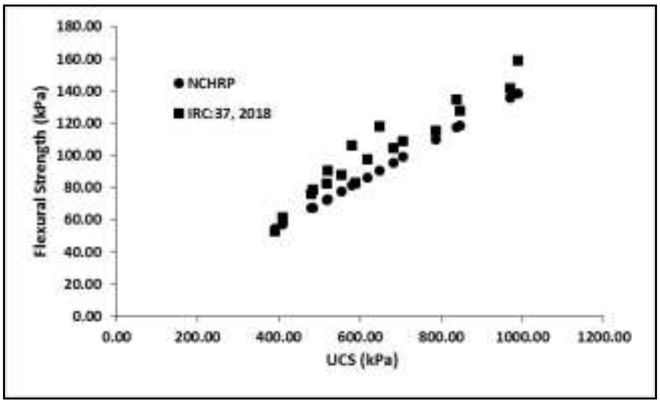

Fig. 3. Flexural strength prediction form UCS using different correlation

The comparison also made to calculate flexure strength from UCS vales and ITS value. The results of the comparison are presented in Figure 4. It has been observed that both calculated values not differ significantly and have been proved by the t-test. The t-test (two samples assuming unequal variance) has been performed between calculated values of flexural strength form UCS and ITS test. From the t-test results, it has been observed that, t Stat < -t Critical two-tail or t Stat > t Critical two-tail (-2.074 < 2.22 < 2.074) is not the possible and null hypothesis is rejected. The difference between the sample means (129 - 181) is not conclusive enough to say that the Flexural strength values derived from UCS and ITS tests differ significantly.

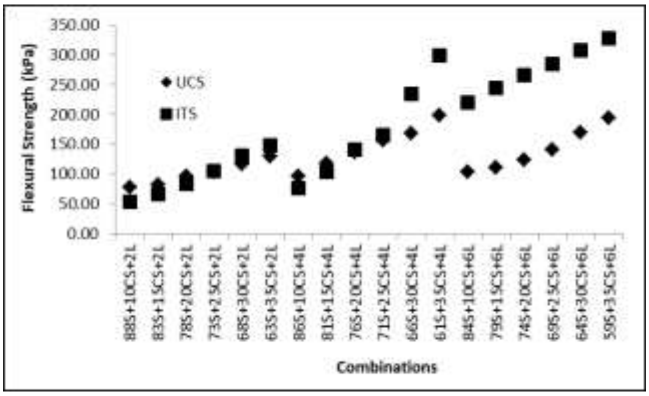

Fig. 4. Comparison between Flexure strength values

4 Conclusions

Laboratory investigations have been carried out to stabilise expansive soil with Corex slag and lime in different combination to find UCS, ITS and Flexural Strength values.

- The combinations 4% lime with Corex slag more than 20 % satisfied the criteria of subgrade and embankment construction with expansive soil.
- The relations between UCS and Flexure strength have been observed in the study for Corex slag and lime stabilised expansive soil and compared with the NCHRP and IRC:37, 2018 equation.
- The Flexure strength value for the stabilised soil found close to the standardise equation determined to form the study.

However, more study is required with different soil stabilised with corex slag and lime to get good correlation to get flexural strength from the UCS test.

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