50th IGC

50th INDIAN GEOTECHNICAL CONFERENCE
17th – 19th DECEMBER 2015, Pune, Maharashtra, India
Venue: College of Engineering (Estd. 1854), Pune, India

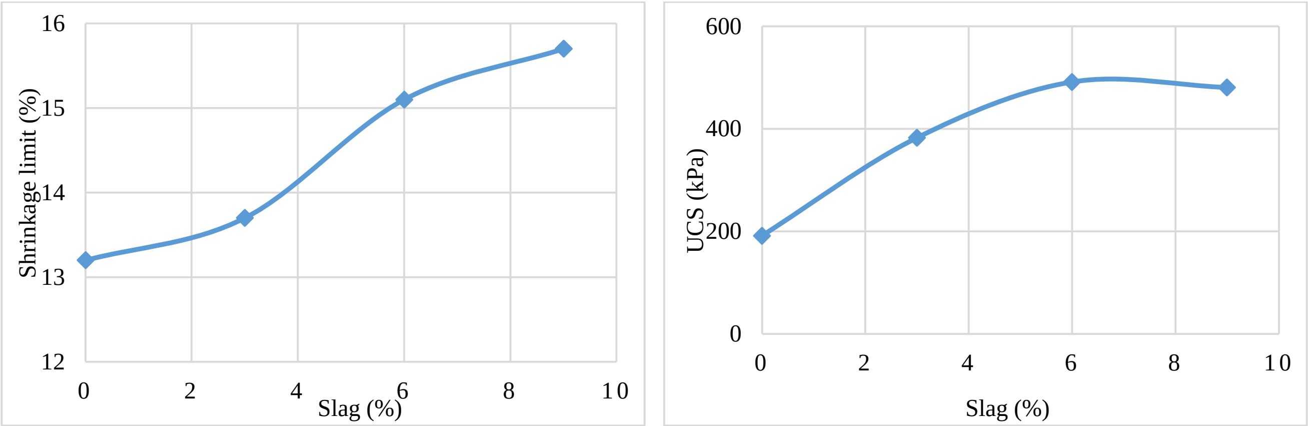
PROBLEMS AND TREATMENT OF BLACK COTTON SOIL

Rajesh Prasad Shukla[1], Niraj Singh Parihar[2], Pravar Yadav[3], Nitesh Mankotia[4]

ABSTRACT

Black cotton soil covers more than twenty percentage geographical area of India. It is spread over Madhya Pradesh, Maharashtra, Andhra Pradesh, Gujarat, Tamil Nadu, Karnataka and some other parts of India as well. Expansive soils containing high clay content are susceptible to unfavorable volumetric changes. Volume change occurs with change in the moisture content of soil. Black cotton soil shrink and swell with decrease and increase in water content respectively. This behaviour is attributed to the presence of a clay mineral called as montmorillonite. Light weight and small structures are more susceptible to damages due to relatively small overburden pressure. Uneven contraction and swelling leads to reduction in the serviceability, emergence of hairline cracks and sometimes even severe cracks which lead to collapse of the structure. Black cotton soil has proved itself as a source of damage to the property and economical loss. Appropriate remedial measures are to be considered before construction in the areas having black cotton soil. There are many solutions available to improve the workability and minimize the swelling and expansion characteristic of black cotton soil reduce or avoid the losses due to soil hazardous behaviour of soil such as, to remove the black cotton soil up to a particular depth, keep the water table constant well below foundation level, reinforce the soil, use the under reamed foundation or alter the properties with some additives. Word is producing a huge quantity of slag annually and it creating a lot of waste management problem. This article presents the outcomes of laboratory test performed on microfine slag added expansive soil. Soil characteristics are altered by mixing different amounts of slag, i.e., 3, 6 and 9 % in expansive soil. The change in the soil is evaluated by estimating the change in the soil properties, namely, unconfined compressive strength, Atterberg limit, and free swell. Mixing of microfine slag decreased the plasticity index and free swelling of soil. Microfine slag significantly increased the unconfined compressive strength and plasticity index of soil up to 6-7%, but further more addition of slag content leads to decrease in the CBR and UCS of microfine added black cotton soil. Shrinkage limit is increasing continuously with increase in the slag content. Swell potential is reduced from medium to low. The optimum quantity of microfine slag is approximately 6 to 7% by weight of soil.

[1]Research Scholar, Dept. of Earthquake Engg., IIT Roorkee, India shuklarajesh4687@gmail.com
[2]Assistant Professor, Department of Civil Engineering., JUIT, Solan, (H.P), singhpariharniraj@gmail.com
[3]Undergraduate student, Department of Civil Engineering., JUIT, Solan, (H.P), pravaryadav@gmail.com
[4]Undergraduate student, Department of Civil Engineering., JUIT, Solan, (H.P), nitesh.mankotia@gmail.com



(a) (b)

Fig. 1 Effect of potassium chloride of characteristic of black cotton soil (a) on shrinkage limit (b) on UCS

Keywords: black cotton, potassium chloride, Atterberg limit, UCS

PROBLEMS AND TREATMENT OF BLACK COTTON SOIL

Rajesh Prasad Shukla, Dept. of Earthquake Engg., IIT Roorkee, India, shuklarajesh4687@gmail.com
Niraj Singh, Department of Civil Engineering., JUIT, Solan, (H.P), singhpariharniraj@gmail.com
Pravar Yadav, Department of Civil Engineering., JUIT, Solan, (H.P), pravaryadav@gmail.com
Nitesh Mankotia, Dept. of Civil Engineering., JUIT, Solan, (H.P), nitesh.mankotia@gmail.com

ABSTRACT: Expansive soils containing high clay content are susceptible to detrimental volumetric changes. Volume change occurs with change in the moisture content of soil. This behaviour is attributed to the presence of a clay mineral called as montmorillonite. This article presents the outcomes of laboratory test performed on microfine slag added expansive soil. Soil characteristics are altered by mixing different amounts of slag, i.e., 3, 6 and 9 % in the expansive soil. The change in the soil is evaluated by estimating the change in the soil properties, namely, unconfined compressive strength, Atterberg limit, and free swell. Mixing of microfine slag decreased the plasticity index and liquid limit. Microfine slag significantly increased the unconfined compressive strength and plasticity limit of soil up to 6-7%, but further more addition of slag content leads to decrease in the UCS of microfine mixed soil. Shrinkage limit is increased continuously with increase in the slag content. Swell potential is reduced from medium to low. The optimum quantity of microfine slag is approximately 6 to 7% by weight of soil.

INTRODUCTION

Soils susceptible to expansion in volume are known as expansive soils. Such soils usually have high clay content. Such soils are called expansive soils and are usually found in larger parts of India. It's called as black cotton soil due to its black colour which is a result of high iron and magnesium minerals derived from basalt [1]. Black cotton soil has shown quite significant volumetric change upon absorption of moisture which causes problems to geotechnical engineers during construction. Primary problem associated with such soils is that deformations associated are more significant than elastic deformations. Montmorillonite clay mineral is the main reason behind such destructive swelling in expansive soils [2].

The damage caused by expansive soils to roads, canals, buildings and life line is of the order of 2255 million dollars per annum as estimated by [3]. It was reported that this loss exceeds the loss caused by combined effects of floods, earthquakes and hurricanes. A sub grade made of expansive soils is problematic due to its tendency undergo shrinkage and swelling. It is very hard when dry but loses its stability when wet. On drying such soils develop cracks of up to 15 cm dry and 3 meters depth. Therefore some points must be taken consideration such as shrinkage and swelling characteristics, liquid and plastic limit, changes in strength with change in moisture content.

The clay minerals are basically hydrated aluminium silicates in a crystalline form. The behavior of the clay particles is strongly influenced by the electrical forces acting on the particle surface rather than the gravitational forces. These electrical forces are in turn influenced by the type and concentration of ions present in the pore water. Therefore, some clay minerals experience appreciable swell and shrink upon exposure to wetting and drying respectively.

The natural tendency for a water-ion system is for the ions to be fully diffused with time. The balance of electrical attraction and ions diffusion leads to a diffuse layer of cations surrounding the particle. This layer is termed as double layer. The double layer thickness, as defined by [4], is the distance from the surface required to neutralize the net charge on the particle i.e., the distance over which there is an electrical potential. Therefore, the thickness of the double layer is significantly influenced by the concentration of the cations and is decreased by an increase of this concentration. The cation exchange capacity defined as the ability of a clay mineral to exchange the cations with other cations plays an important role in the process of clay expansion due to wetting [5]. The exchangeable ions are held around the outside of the silica alumina clay mineral structural units. The exchange reaction results in a reduction of thickness of the double layer around the soil particle, which change the properties of the mass of particles. In clay minerals, the most common exchangeable cations are Ca^{++}, Mg^{++}, H^+, K^+, NH_4^+ and Na^+, frequently in about that order of general relative abundance [2]. The montmorillonite is about 10 times as active in absorbing cations as kaolinite. This is caused by the large net negative charge carried by the montmorillonite particle and its greater specific surface as compared with kaolinite and illite [2].

In real practice, plasticity index is frequently considered as an indicator of the swelling potential and it significantly affected by the strength and characteristic of adsorbed cations [6]. Reference [7] found that diffusion of water can be a main cause of swelling. The inter-layer solution in a clay mineral has a higher concentration of dissolved electrolyte than the external solution leading water to drawn in and reducing the ion concentration Based on the above review, it may be concluded that there are two phases of swell, the first is an expansion in the particle itself and the second is an increase in the volume of voids. In nature soil continuously undergoes wetting and drying due to seasonal fluctuation of the environmental conditions [8]. Consequently cycles of swell and shrink would take place. Most researchers have dealt with the first full cycle of swell. However, many others performed wetting-drying tests. The main findings obtained from such cyclic tests were concentrated on the shape of the relation between sample height and the number of wetting or drying cycle. It was generally agreed that the sample can never shrink down to its original height and also a stable swell-shrink band will be attained after a certain number of cycles [6-8].

TREATMENT OF EXPANSIVE SOILS

Reference [8] estimated the annual cost of damage from expansive soil in the United States to be 9$ billion. Expansive soils are spread in the middle and north of Iraq causing damages to structures. Actually, the problem is worldwide as expansive clay is spread in many regions like Africa, Australia, India, South America and Sudan. Methods of treatment involve pre-wetting, maintaining constant water content, compaction control, soil replacement and electro–osmotic stabilization [9]. Reference [10] reported the success of using high strength geogrids to resist the swell. Thermal stabilization can be used to stabilize the black cotton soil [11-12]. Chemical stabilization using materials like lime, cement and chlorides is one of the available options for geotechnical engineers.

A good number of work are published on chemical added black cotton soil and it was found that chemicals are useful in stabilization of black cotton soil [13-17]. However, low solubility of chemicals pose problems on soil stabilization [18].

Furnace slags obtained from steel and iron manufacturing industries have cementations reactivity and various studies have used slag as additive to change the soil characteristics. Using slag as a soil stabilizing material minimize the problem of waste management. [19] used lime-GGBS and found that it increased the strength of soil. [20] found that plastic limit and liquid limit were reduced, while, strength was improved GGBS mixing amount up to 10%. The angle of internal friction was reduced with increase in the GGBS content. Addition of finer GGBS can decrease the corrosion and time to attain peak strength [21]. [22] observed that GGBS has reduced the swelling of lime stabilized kaolinite which is exposed to water. Strength was increased by a great amount but density was increased by a small amount. [23] conducted tests on site and found that diversion road which was treated with lime activated GGBS worked adequately over a year whereas untreated road was worked only for few months only. [24] stabilized subgrade of flexible pavements by various industrial wastes such as GGBS, lime, RHA and FA. It was stated that maximum improvement in the soil properties occurred with adding of FA up to 20%, RHA and GGBS up to 15%, and lime up to 5%. Effectiveness of additive depends more on the amount of GGBS as compared curing period [25]. Initial tangent modulus improved with increase in GGBS quantity. Significant improvement in the Plasticity index, swelling pressure and OMC of soil decreased with addition of granulated blast furnace slag (GBFS). UCS and CBR were increased up to 9% GBFS and mixing more GBFS decreased the UCS, CBR and MDD value [26].

Most of earlier studies determined the effect of slag on concrete roads, and a few studies studied the effect of GGBS on expansive soil. This this study micro fine slag is used to modify the properties of expansive soil. The enhancement in the soil characteristic was assessed by determining the change in the soil properties, California bearing ratio, Atterberg limit, free swelling, unconfined compressive strength and compaction parameters

MATERIAL USED IN LABORATORY TEST

The soil is collected from Guna, M.P., India. Soil properties are presented in Table 1. Swelling potential of soil can be evaluated based on soil plasticity index and based on their classification [27-29], this soil has medium or intermediate swelling potential.

Table 1 Properties of soil used in study

Soil Properties	**Value**
Sand	26-30%
Silt +clay	70-74%
Specific gravity	2.67
Density	16.47kN/m^3
Shrinkage limit	12.2%
Plastic limit	43.50%
Liquid limit	66.70%
Plasticity index	23.20%

ALCCOFINE 1203, a fine cementitious material was used as additives. It is bought from Counto Microfine Product Private limited, Goa, India. Physical properties and chemical constituents are shown in table 2.

Table 2. Physical properties of microfine slag

Physical properties	Amount
Bulk Density (kg/m3)	700-900
Particle mean diameter (μm)	1.5
D90 (μm)	9.0
D50 (μm)	5
Fineness (cm2/gm)	12000
Plasticity	Non plastic

Table 3. Chemical constituents

Chemical constituent	Amount (%)
Al_2O_3	5.2
Fe_2O_3	4.25
SO_3	2.25
CaO	62.5
SiO_2	22
MgO	1.2

METHOD

Index properties; Atterberg limit , in -situ moisture content, grain size distribution curve and maximum dry density of all soil samples were determined in laboratory as per the Indian standard codes. Amount of slag was varied from 3 to 15 % of weight of soil. The standard proctor tests were conducted as per on Indian standard [30]. Water was added with microfine slag mixed soil as required to enable smooth mixing and compaction process. Samples for unconfined compressive strength test were prepared using a mould of 38 mm diameter and 76 mm length. Sample were prepared for optimum moisture content.

Casagrande percussion method and thread rolling method were used to determine the plastic limit and liquid limit of microfine slag. Free swelling was determined using consolidation test. UCS and Atterberg limits were determined respectively, as per Indian standard codes namely [31-32]. All tests were conducted first on virgin soil and repeated for different amount of microfine slag. Swell potential of expansive soil can be evaluated based on Atterberg limit of soil. Swell potential of soil was determined as per chart and relationship developed by [27-29, 35-36] and was found that soil have swelling potential medium.

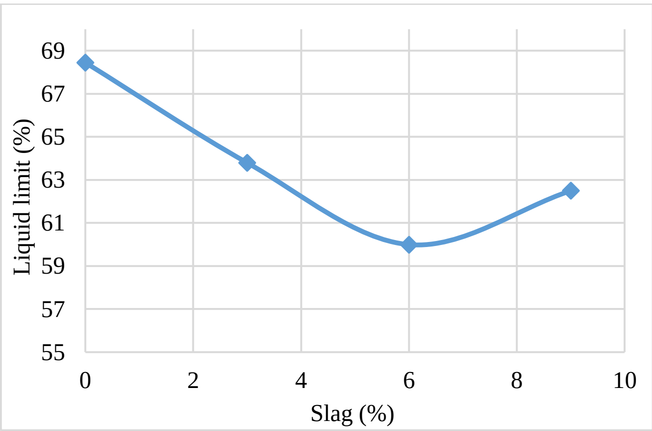
EXPERIMENTAL RESULTS

Atterberg Limits

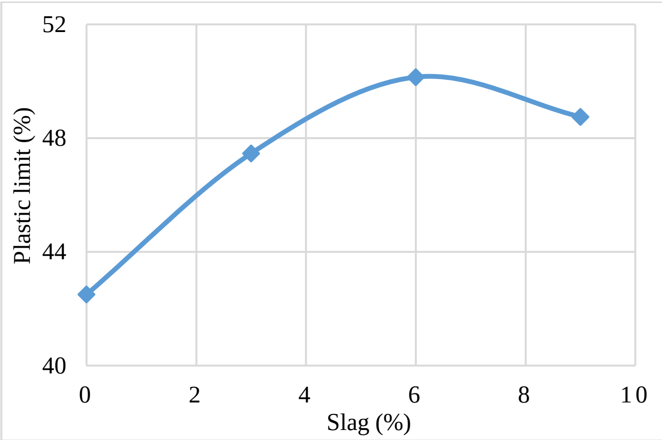
Tests were conducted on black cotton soil with and without addition of microfine slag. Slag contents were varied from 0% to 9%. The effect of microfine on liquid limit is shown in Fig 1a. It is observed from test result that addition of microfine slag has decreased the liquid limit of soil by a considerable magnitude. Effect of microfine slag is more prominent at 6% means that effectiveness of potassium chloride is decreasing with increase in the content of additives.

Plastic limit increased with increase in the slag content up to 6%, additional mixing of slag in the black cotton soil causes the decrease in plastic limit. Variation in the plastic limit with microfine slag content is shown in Fig 1b.

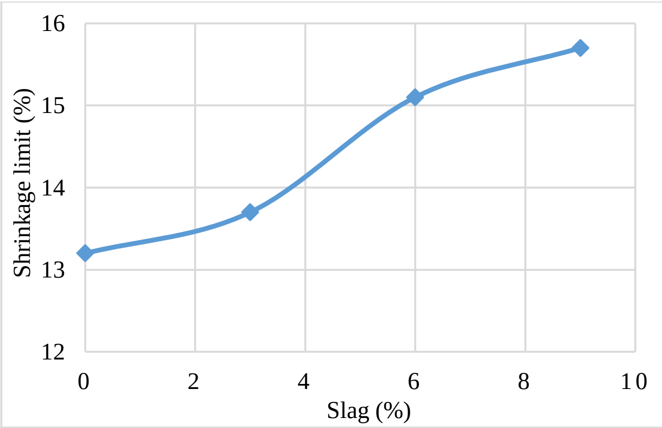
The shrinkage limit is a very valuable parameters for the soil which undergo large volume changes with change in moisture content. Shrinkage limit is increasing with increase in the quantity of added potassium chloride. Increase in the shrinkage limit after addition of indicates that volume of soil mass cannot reduces for a water content equal to or less than 15.8%.



(a)



(b)



(c)

Fig. 1 Effect of microfine slag on Atterberg limit; (a) on liquid limit, (b) plastic limit, (c) shrinkage limit

Shearing resistance can increase with increase in the concentration of electrolyte and it causes the reduction in the thickness of the double layer, which further leads to increase in the shearing resistance between soil particles [37-39]. Increase in the shearing resistance between particles had caused the decrease in the plasticity index and liquid limit. But after a certain amount of slag (6-7%) there are increase in the plasticity index and liquid limit which shows that cation exchange capacity is reducing with addition of excessive slag. Change in plasticity index with the addition of fine slag is shown in Fig 2.

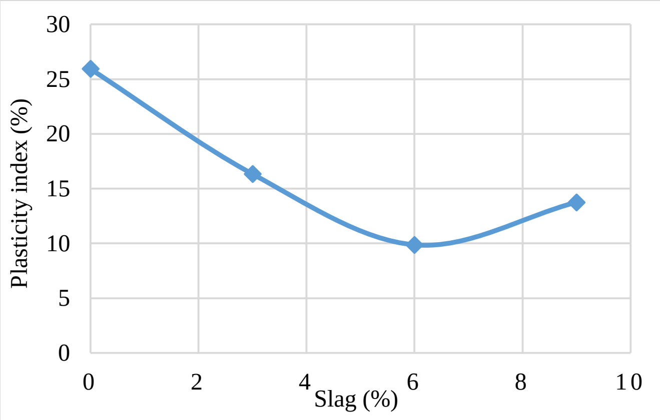


Fig. 2 Change in the plasticity index with microfine slag content

Unconfined compressive strength

Fig 3 shows that unconfined compressive strength of black cotton soil increase with increase in the microfine slag, but it started reducing when amount of added microfine is more than 6%. Change in the UCS for three days curing is shown in figure. Unoppressive strength of soil is increased by 2.5 for 6% of microfine slag.

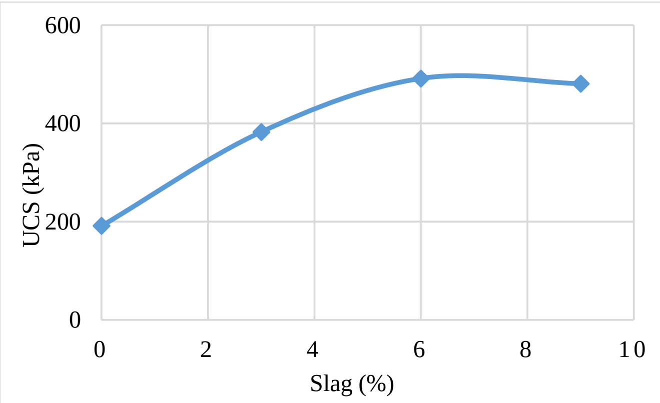


Fig.3 Change in the UCS of soil with slag content

Swelling Characteristics

Fig 4 shows that free swell is reducing continuously with increase in the amount of microfine slag. As per [27], the degree of expansion of soil used in present study is medium and addition of micro fine slag changed the swell potential from medium to low.

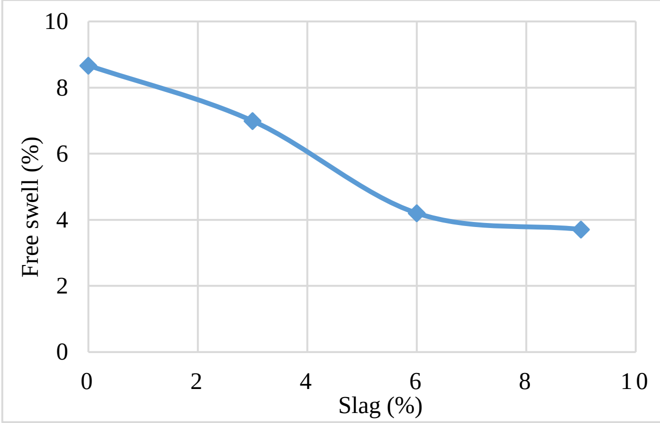


Fig. 4 Change in the free swell with slag content

CONCLUSIONS

Effects of micro fine slag is depends upon the quantity of micro-fine slag mixed with the black cotton soil. Free swell of soil is reduced to half of the virgin soil due to incorporation of micro fine slag. Addition of micro fine slag changed the swell potential from medium to low. Liquid limit and plasticity index contents decreased with mixing of microfine slag. Shrinkage limit is increasing continuously with increase in the slag content. Plastic limit and unconfined compressive strength of soil are increasing up to 6-7% of soil weight and adding more slag causes the reduction in the plasticity and UCS of micro fine slag added soil. Unconfined compressive strength of soil is increased 2.5 time of initial UCS. The optimum amount of microfine slag is approximately 6 to 7% by weight of soil.

REFERENCES

1. Lal R. (2007) Encyclopedia of Soil Science, Volume 1. CRC Press, Boca Raton.
2. Chen, F. H. (1975). Foundation on expansive soils, Elsevier Scientific Publishing Company, Amsterdam.
3. D. E.Jones, and W. G. Holtz, “Expansive Soils - The Hidden Disaster,” Civil Engineering, ASCE, vol. 43(8), pp. 49-51, 1973.
4. Lambe, T.W., and Whitman, R. V. (1969). Soil mechanics, John Wiley and Sons Inc., NY.

5. Barnes, G. E. (2000). Soil Mechanics: Principles and Practice, 2nd ed. Hampshire, UK: Palgrave Macmillan.
6. Al-Omari, R. R., and Oraibi, W. K. (2000). “Cyclic behavior of reinforced expansive clay.” Soils and Foundations, 40(2), 1–8.
7. Krebs, R. D., and Walker, R. D. (1971). Highway materials, McGraw-Hill Book Company, New York.
8. Jones, D., and Jones, K. (1987). “Treating expansive soils.” Civil Eng., ASCE, 62–65.
9. Gromko, G. J. (1974). “Review of expansive soils,” Journal of Geotechnical Engineering Division, GT6, 667–687.
10. Al-Omari, R. R., and Hamodi, F. J. (1991). “Swelling resistant geogrid–A new approach for the treatment of expansive soils.” Geotextiles and Geomembranes, 10, 295–317.
11. Jha, J., and Sinha, S. K. (1981). Construction and foundation engineering, Khanna Publishers, Delhi.
12. Al-Qaragholy, A. D. (2007). Effect of temperature on engineering properties of expansive soil, M.Sc. thesis, Nahrain University, Iraq.
13. Al-Omari, R. R., Dalaly, N. K. and Al-Dahlaggi M. H. (2004). “Effect of calcium chloride on cyclic behavior of expansive clays.” Proceedings of the International Conference on Geotechnical Engineering, Beyrouth, 423-429.
14. Rao, A. S., and Rao, M. R. (2008). “Swell-shrink behavior of expansive soils under stabilized fly ash cushions.” 12th Int. Conf. of Int. Association for Computer Methods and Advances in Geomechanics, Goa, India.
15. Katti R. K., Kulkarni R. R. and Radhakrishnan (1966) “Research on Expansive soils without and with Inorganic Additives” IRC Road Research Bulletin No. 10. PP 1-97.
16. Al-Ashou, O., and Al-Khashab, M. N. (1993). “Treatment of expansive clay soil with potassium chloride.” Al-Rafidian Engineering Journal, 1(2), 17–31.
17. Ramana Sastry, M.V.B., Srinivasulu Reddy, M. and Gangaraju, Ch.P. (1986). Comparitive Study of the effect of addition of Rice-Husk-Ash and Cinder-Ash to Soil-Lime mixtures, Indian Highways, Vol. 14, No. 8, pp 5-14.
18. Prasada Raju, G.V.R. (2001). Evaluation of flexible pavement performance with reinforced and chemical stabilization of expansive soil subgrades, Ph.D thesis, Kakatiya University, REC, Warangal.
19. Gupta, S., and Seehra, S. S., 1989, "Studies on Lime-Granulated Blast Furnace Slag as an Alternative Binder to Cement", Highways Research Board, Bulletin, No. 38, pp. 81-97.
20. Akinmusuru, J. O., 1991, "Potential Beneficial Uses of Steel Slag Wastes for Civil Engineering Purposes", Resources Conservation and Recycling, Vol. 5, PT1, pp. 73-80.
21. Wong, R. C. K. (1998). “Swelling and softening behavior of La Biche Shale.” Canadian Geotechnical Journal, 35(2), 206 –221.
22. Wild, S., Kinuthia, J.S., Robinson, R.B., and Humpreyas, I., 1996, “Effects of Ground Granulated Blast Furnace Slag (GGBS) on the Strength and Swelling propertiesof Lime-Stabilized Kaolinite in the presence of Sulphates,Clay Minerals, 31,423-433.
23. Higgins, D. D and Kennedy, J., 1999, "Lime + Ground Granulated Blast Furnace Slag Stabilisation of Boulder Clay on the "A421" Tingewick Bypass", Proc. 3'd European Symposium on The Performance and Durabilityof Bituminous Materials and Hydraulic Stabilised Composites, Leeds, U. K.
24. Neeraja D., and Rao Narsimha A.V., 2010, “Use Of Certain Admixtures In The Construction Of Pavement On Expansive Clayey Subgrade” International Journal of Engineering Science and Technology, Vol. 2(11), 2010, 6108-6114.
25. Sharma A.K. and Sivapullaiah P.V. 2012, “Improvement of Strength of Expansive Soil with Waste Granulated Blast Furnace Slag” Geo Congress 2012.
26. Yadua, Laxmikant and R.K. Tripathi (2013) Effects of Granulated Blast Furnace Slag in the Engineering Behaviour of Stabilized Soft Soil, Procedia Engineering, Volume 51, 2013, Pages 125–131.
27. Holtz W.G., & Gibbs H.J. (1956). “Engineering properties of expansive soils.” Trans of ASCE, 121, 641-679.
28. Seed, H. B., Mitchell, J. K. and Chan, C. K. (1960) The Strength of Compacted Cohesive

Soils. Proc., ASCE Research Conference on Cohesive soils, Boulder, American Society of Civil Engineers, New York, 877-964.
29. Snethen, D. R and Others (1975), A review of engineering experience with Expansive Soils in Highway Sub-grades, Interim Report, Federal Highway Administration Office of Research and development, Washington, D.C. 20590.
30. IS: 2720 (Part VII)—1980, Indian Standard, “Determination of Compaction parameters.”
31. IS: 2720 (Part XVI) – 1987 Indian Standard Methods of Test for Soil. Part 16 Laboratory Determination of CBR.
32. IS 2720 (Part XI):1983 Indian Standard Methods of test for soils, Part XI: Determination of shear strength parameters of soil from unconsolidated undrained triaxial compression test without measurement of pore water pressure.
33. Casagrande, A. (1932), Research on the Atterberg limits of soil, Public Roads, vol. 13, No 3, pp. 121-130, 136.
34. Skempton, A. W. (1953), “The colloidal activity" of clays,” Proc., 3rd Int. Conf. on Soil Mechanics and Foundation Engineering, Zurich, 1, 57-61.
35. Van Der Merwe, D. H. (1964) “The prediction of heave from the plasticity index and percentage clay fraction of soil,” South African Inst. of Civil Eng, 6, 103-107.
36. Carter, M. and Bentley, S. P. (1991) “Correlation of soil properties,” Pentech Press, London.
37. R.P. Shukla, Parihar, N., Tiwari, R.P., Agrawal, B.K. “Black Cotton Soil Modification using Sea Salt,” Electronic Journal of Geotechnical Engineering, Vol. 19, Bundle Y, pp 8807-8816, 2014.
38. S. Frydman, Ravina, I., and Ehrenreich, T. “Stabilization of heavy clay with potassium chloride,” Geotechnical Engineering, Southeast Asian Society of Soil Engineering, Vol. 8, pp. 95–108, 1977.
39. R.R. Al-Omari, Saad F. Ibrahim, Ishraq K. Al-Bayati, “Effect of potassium chloride on cyclic behavior of expansive clays,” Int. Journal of Geotechnical Eng., Vol. 4, pp. 231-239, 2010.