Stabilization of Kuttanad soil using Calcium and Sodium Lignin Compounds

Sabitha B. S.[1] and Sheela Evangeline Y.[2]

[1] College of engineering, Trivandrum, India
sabithabs1994@gmail.com
[2] College of engineering, Trivandrum, India
sheelabala2000@gmail.com

Abstract. Kuttanad region in Kerala is the lowest lying area in India with an elevation of one meter above mean sea level. Soil in this region is characterized by low bearing capacity hence construction works on Kuttanad soil is often problematic and expensive. Traditionally stabilization in Kuttanad soil is done by hydrated lime, Portland cement, fly ash etc. Stabilization of weak soil with industrial by products are commonly adopted nowadays because of its economical as well as environmental benefits. One such material is lignin; chemically called as lignosulphonates produced as a byproduct in paper pulping industry. Lignin compounds are available in different chemical composition based on the cellulose separator used during pulping process. This paper presents in detail the effectiveness of stabilizing Kuttanad soil using sodium as well as calcium forms of lignin. The effect of lignin on compaction characteristics, consistency limits, unconfined compressive strength and CBR were studied using a series of laboratory tests and the optimum percentage of additive was found out. A comparative study has also been done with the two compounds to identify which one has the best stabilization capacity.
Keywords: Kuttanad soil; Lignosulphonate; Wood Pulp; CBR

1 Introduction

In a developing country like India rural roads play an important role by increasing access to economic and social services and thereby increasing agricultural income. The major problems faced by roads across the country are, they are built in poor subgrade. India being a developing country produce tonnes of industrial and agro based by- products, most of them are found to have excellent stabilisation capabilities. Stabilisation with industrial by-products are commonly adopted nowadays as it is an effective way of disposing the huge piles of such waste products which would otherwise became a pollutant due to improper disposal. Hence stabilisation with industrial by products are found to have economic, environmental as well as social benefits.

Kuttanad is a low lying region comprising an area of about 900 sq. km in the Alappuzha district of South Kerala. Kuttanad soil is a black marine soil deposited by backwater tract characterized by low bearing capacity hence construction works on Kuttanad soil is often problematic and expensive. In this study an attempt was made to investigate the ability of lignosulphonate by products in stabilising Kuttanad soil. Lignin is the second richest renewable natural resource after cellulose. About 50 million tonnes of lignin is produced worldwide every year (Varanasi et al, 2013). Commercial lignin is produced as a by-product of the paper pulping industry. It is separated from trees by a chemical pulping process. Subgrade stabilisation has been identified as one of the viable answers to consume huge quantities of lignin produced per annum (Zhang et al, 2018).

Laboratory investigations conducted to find the effect of lignin on geotechnical properties suggest that lignin has a considerable influence on the mechanical properties, particle size distribution and consistency limits of soil (Zhang et al, 2018). Stabilising expansive soil with lignin reduced the swelling potential and improved the resistance to alternate wet and dry cycles. The swell potential of lignin stabilised soil decreased by about 23 %. Shrinkage limit of stabilised soil also improved but little change was only observed in compaction and permeability characteristics (Alazigha et al, 2018). Micro-chemical analysis on lignin stabilised soil revealed that the improvement of soil properties is due to the cation exchange between the soil and lignin hence forming a cementing substance which holds the soil particles together. It is found that the lignin based stabilizers have a great potential to enhance the engineering properties of soil (Cai et al, 2016). Lignin stabilised soil have better thermal resistivity and mechanical properties. Curing time has great influence in enhancing the properties of soil (Zhang et al, 2015).From the literatures it could be concluded that lignin is effective in stabilizing weak soil. In this study the suitability of using lignosulphonates for stabilizing Kuttanad soil is explored.

2 Materials used

2.1 Soil

The soil used in the study is collected from the Edathua region of Kuttanad, Alappuzha district. The soil had been collected from a depth of 2.5 m from the ground surface. The properties of soil sample is presented in table 1. From the plasticity characteristics as per IS specification the soil is found to have intermediate plasticity.

Table 1. Properties of Kuttanad soil

Property	Value
Specific gravity	2.20
Natural water content (%)	90.6
Clay content (%)	22.0
Silt content (%)	76.0
Sand content (%)	2.0
Liquid limit (%)	49.0
Plastic limit (%)	18.0
Shrinkage limit (%)	13.7
MDD (g/cm^3)	1.6
OMC (%)	27.0
UCC (kPa)	12.8

Unsoaked CBR (%)	0.9

2.2 Sodium and Calcium lignosulphonate

Commercially produced lignosulphonates are used for the study. The properties of lignosulphonates used in the study are shown in table 2.

Table 2. Properties of lignosulphonates used in the study

Property	Value	
	Sodium lignosulphonate	Calcium lignosulphonate
Sodium (%)	9	-
Calcium (%)	-	6.3
Dry solids (%)	95	93
pH	6	7
Bulk density	500 kg/m^3	500 kg/m^3
Particle size	<300 nm	<300 nm

3 Methodology

Suitability of using sodium and calcium lignin compounds as a subgrade stabiliser is evaluated by studying the strength characteristics and plasticity characteristics. To find the stabilisation capacity of the two lignin compounds, a series of laboratory tests are done by varying amount of lignosulphonates. In the case of sodium lignosulphonate the content is varied as 2, 5, 8,12 and 14 % whereas in the case of calcium lignosulphonate the content is varied as 0.5, 1, 1.5, 2 and 2.5 % .The dosage range of the additives were selected by trial and error method. The optimum amount of sodium lignosulphonate and calcium lignosulphonates required to stabilize Kuttanad soil is also found out.

3.1 Sample preparation

The collected soil is air dried and broken down before passing it through sieve with 4.75 mm opening size for standard Proctor compaction test and Unsoaked CBR test. For UCC, Atterberg limits and other soil properties the soil is sieved through 425 micron sieve. Required amount of lignin and water (OMC of the soil stabiliser mix as given in table 4 and table 5) is thoroughly mixed with the air-dried soil to conduct the tests.

3.2 Curing

Stabiliser-soil samples are sealed by vinyl bag and placed in water for curing before conducting all the tests. The curing period for different tests are presented in table 3. Compaction tests were conducted just after mixing without any curing as done in the field so as to improve the strength characteristics for long term.

Table 3. Curing given for various tests

Property	Curing (days)
Atterberg limits	28
Compaction tests	0
Unconfined compressive strength test	1,7,14 and 28
Unsoaked California Bearing Ratio test	7 and 28

3.3 Testing procedure

All the tests are conducted as per IS specifications.

- Liquid & Plastic limit test: IS 2720 (Part 5) – 1985
- Shrinkage limit test: IS 2720 (Part 6)-1972
- Compaction test: IS 2720 (Part 7) - 1980
- Unconfined compression test: IS 2720 (Part 10) – 1991
- Unsoaked California bearing ratio test: IS 2720 (Part 16) - 1987

4 Results and discussion

4.1 Compaction characteristics

Standard Proctor Compaction tests were conducted to study the effect of lignosulphonates on compaction characteristics of Kuttanad soil. From Fig. 1 it can be seen that with increase in the percentage of sodium lignosulphonate (SL) Maximum Dry Density (MDD) increased from 1.6 g/cm^3 to 1.7 g/cm^3 at 5 % SL content, this is due to the cementing ability of lignosulphonates which not only binds the particles but also fills the pores. After 5 % with further increase in SL content MDD decreased this may be because more soil is replaced by finer lignosulphonate. Similar trend was shown by calcium lignosulphonate stabilised soil. Fig. 2 shows the compaction characteristics of calcium lignosulphonate (CL) stabilised soil. Stabilisation by CL increased the MDD from 1.6 g/cm^3 to 1.63 g/cm^3 at 1.5 % CL content. Table 4 and table 5 shows the MDD and OMC values corresponding to each dosage of sodium lignosulphonate and calcium lignosulphonate respectively.

Table 4. MDD and OMC values of SL stabilised soil

SL content (%)	MDD (g/cc)	OMC (%)
0	1.6	27.0
2	1.7	23.0
5	1.7	19.7
8	1.7	18.5
12	1.7	18.0
14	1.7	17.0

Table 5. MDD and OMC values of CL stabilised soil

CL dosage (%)	MDD (g/cc)	OMC (%)
0	1.60	27.0
0.5	1.61	22.7
1	1.61	20.9
1.5	1.63	22.4
2	1.60	17.4
2.5	1.61	18.7

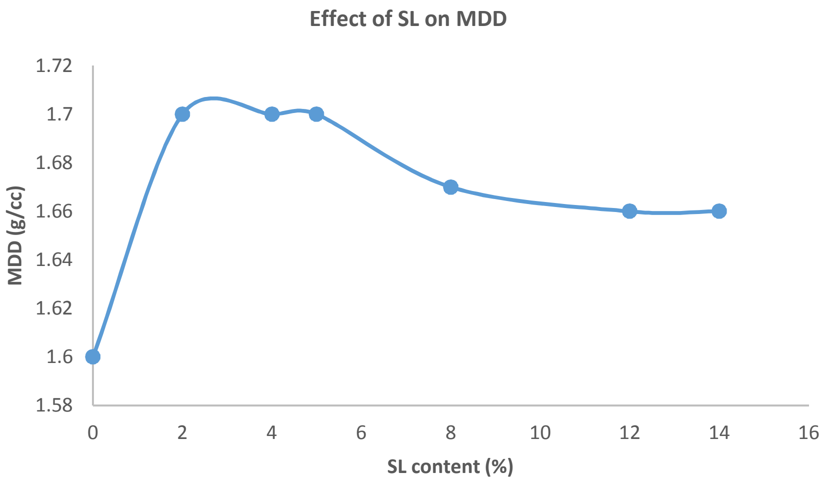

Fig. 1. Compaction characteristics of SL stabilised soil

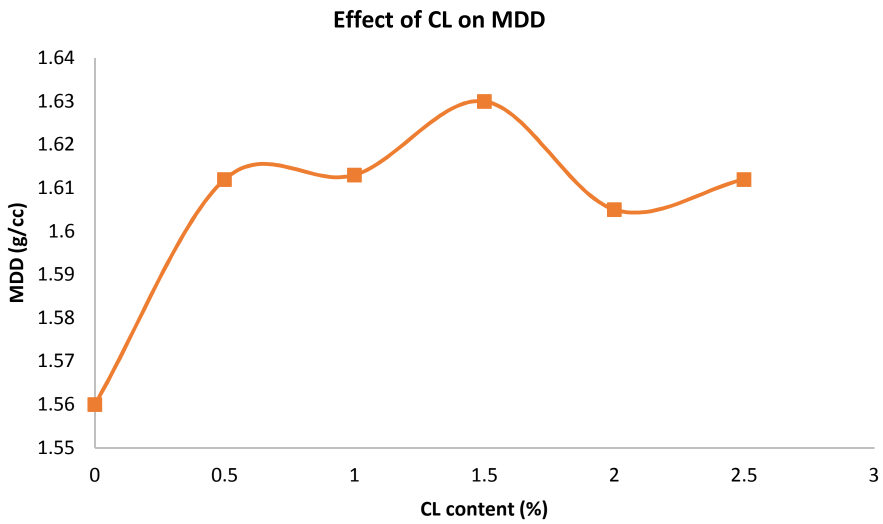

Fig. 2. Compaction characteristics of CL stabilised soil

4.2 Effect on consistency limits

Fig. 3 and 4 shows the effect of sodium and calcium lignosulphonate on the plasticity and shrinkage characteristics of Kuttanad soil. It can be observed that addition of SL decreased the liquid limit by 20 % and increased the plastic limit by 8 % .It increased the shrinkage limit by 55 %. In the case of CL stabilisation the liquid limit of stabilised soil decreased by 17 % and plastic limit increased by 50 %. Shrinkage limit of CL stabilised soil increased drastically over 100 %. Maximum improvement in consistency limits are obtained at 5 % in the case of sodium lignosulphonate and 1.5 % in the case of calcium lignosulphonate. The improvement in consistency limits may be due to the change in the particle size distribution. Table 6 shows the particle size distribution of stabilised soil determined by conducting hydrometer test on 28 day cured samples. Shrinkage limit of stabilised soil is found to be more than the plastic limit, such anomalous behavior of soil is shown by soils were clay fraction is very low, and soils with relatively uniform or poor gradation that does not lead to denser packing and, hence, higher shrinkage limit results. The shrinkage limit obtained for such soils does not represent the boundary between semi-solid and solid states of consistency (Sridharan and Prakash, 1998). In lignosulphonate stabilised soil the clay fraction got reduced and silt fraction was high compared to sand and clay fraction, thus leading to a loose packing and shrinkage limit increased compared to plastic limit.

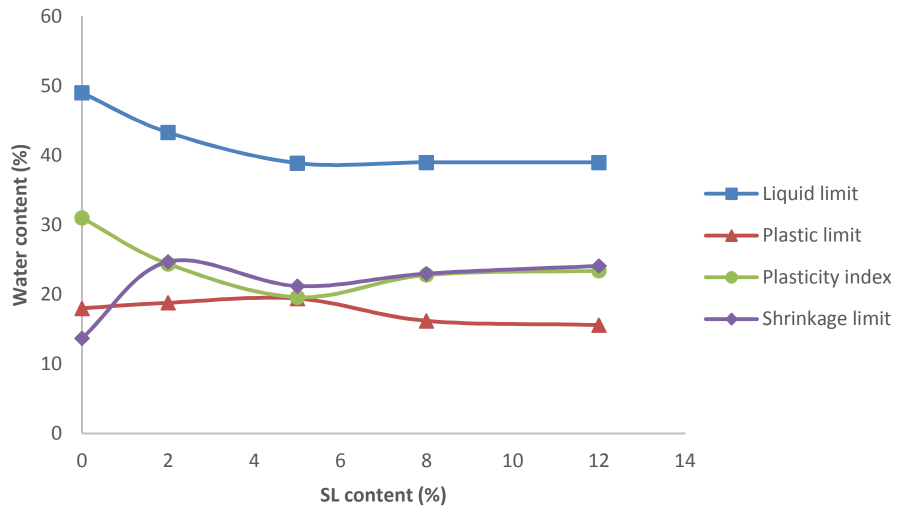

Fig 3. Plasticity characteristics of SL stabilised soil

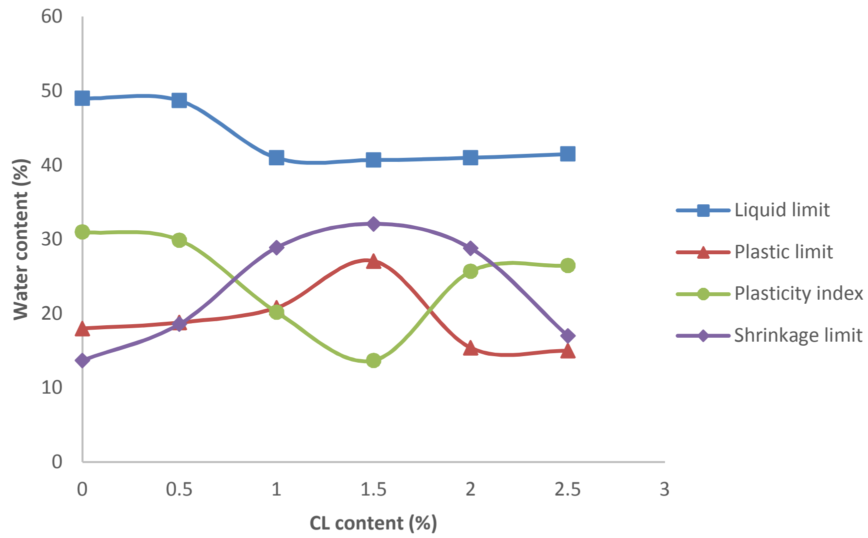

Fig 4. Plasticity characteristics of CL stabilised soil

Table 6. Results of hydrometer analysis

Fraction	Kuttanad soil	CL stabilised soil	SL stabilised soil
Clay (%)	22	11	15
Silt (%)	76	71	77
Sand (%)	2	18	8

4.3 Unconfined compression strength test

Fig. 5 and Fig. 6 shows the effect of curing on unconfined compressive strength (UCS) of sodium and calcium lignosulphonate stabilised soil. From the figure it is clear that curing has a significant influence on the strength mobilization. Lignosulphonate stabilisation increased the strength 10 times as that of untreated soil after 28 day curing. The maximum strength is obtained at 5 % SL content conforming that the optimum sodium lignosulphonate for stabilizing Kuttanad soil is 5 % and the optimum CL content required for stabilizing Kuttanad soil is 1.5 %. The increase in UCS may be due to the formation of lignin based cementitious compounds which coats the soil particles and bind them together. (Indraratna et al, 2008).

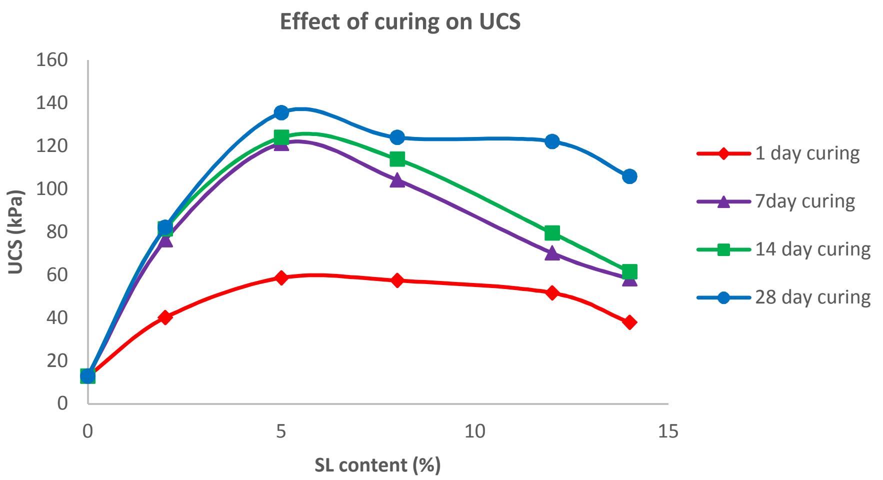

Fig 5. Effect of curing on UCS of SL stabilised soil

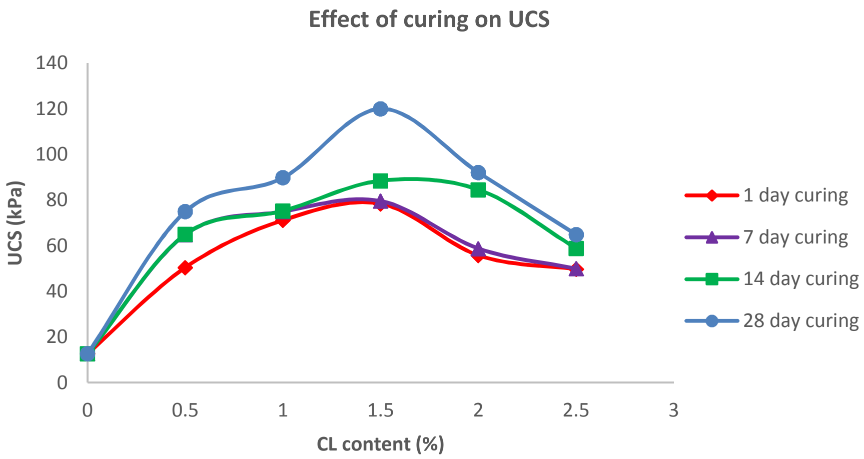

Fig 6. Effect of curing on UCS of CL stabilised soil

4.4 California bearing ratio test

Lignosulphonate stabilisation improved the load penetration behavior of stabilised soil thus increasing the CBR value, thus making it ideal for subgrade stabilisation. Curing period has a great influence on the CBR value. Fig. 7 and Fig. 8 shows the variation in CBR values after stabilisation with sodium and calcium lignosulphonates respectively.

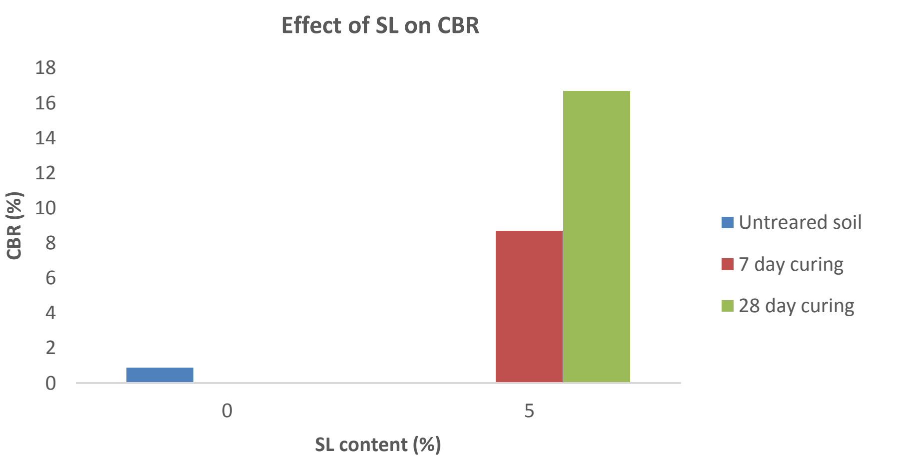

Fig. 7. Variation in CBR of soil treated with SL

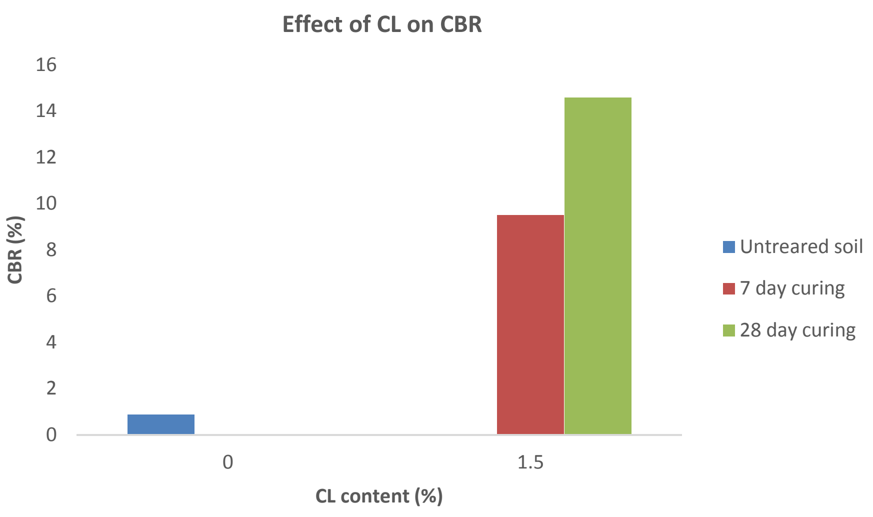

Fig. 8. Variation in CBR of soil treated with CL

5 Comparison

- Calcium lignosulphonate improved the consistency limits better when compared to Sodium lignosulphonate.

- Sodium lignosulphonate improved the strength characteristics of Kuttanad soil more when compared to calcium lignosulphonate

6 Conclusion

- The improvement in strength characteristics of the lignin stabilised soil is due to the cementing ability of lignosulphonates which binds the soil particles together and reducing the void space.
- Curing plays an important role in the strength improvement of lignin stabilised soil.
- The change in Atterberg limit is attributed due to the decrease in clay fraction of lignin stabilised soil.
- For different parameters calcium and sodium lignosulphonates performed better. But since both the additives meet the basic requirements of a stabilizer, both could be effectively used in soil stabilisation.

7 Reference

1. Alazigha, D. P., Vinod, S. J., Indraratna, B., Heitor, A.: Potential Use of Lignosulfonate for Expansive Soil Stabilisation. J. Geosynthetics International, Volume 25, Issue 3, Pg: 304–321 (2018).
2. Cai, G., Zhang, T., Liu, S., Li, J., Jie, D.: Stabilisation Mechanism and Effect Evaluation of Stabilised Silt with Lignin Based on Laboratory Data. Journal of Marine Georesources & Geotechnology, Volume 34, Issue 4 (2016).
3. Indraratna, B., Muttuvel, T., Khabbaz, H., Armstrong, R.: Predicting the erosion rate of chemically treated soil using a process simulation apparatus for internal crack erosion. J. Geotech. Geoenviron. Eng., Volume 134, Issue 6, pg 837–844 (2008).
4. Sridharan, A., Prakash, K.: Mechanism Controlling the Shrinkage Limit of Soils. Geotechnical Testing Journal, Volume 21, No. 3, pp. 240-250 (1998).
5. Varanasi P., Singh P., Auer M., Adams P., D., Simmons B. A., Singh S.: Survey of renewable chemicals produced from lignocellulosic biomass during ionic liquid pretreatment. J. Biotechnol biofuels, Volume 6, No 14 (2013).
6. Zhang, T., Cai, G., Liu, S.: Application of Lignin-Stabilised Silty Soil in Highway Subgrade: A Macroscale Laboratory Study. J. Materials in Civil Engineering, © ASCE, ISSN 0899-1561 (2018).
7. Zhang, T., Liu, S., Cai, G. Puppala, J. .: Experimental investigation of thermal and mechanical properties of lignin treated silt. J. Engineering Geology Volume 196, Pages 1-11. (2015)