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Characteristic Properties of Bentonite Clay and use of Nanomaterials in Stabilizing its Expansive Behavior

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Abstract: ***This paper represents the study done on expansive soil, i.e., Bentonite Clay to study and improve its shrinkage and swelling properties using the nanomaterial.The expansion and shrinkage tests were conducted to study the effect of TerraSil (nanomaterial) on the soil when mixed with different percentages of nanomaterial. The soil samples were compacted at optimum moisture content and maximum dry density as obtained from the Standard Proctor Test. The results of various tests were compared of the specimens with and without nanomaterial. The results show that on adding the nanomaterial in optimum percentage to the soil sample, the compressive strength of the sample improves, and the desiccation crack density reduces.***

Keywords: Bentonite clay, nanomaterial, expansion, shrinkage, desiccation crack

1. Introduction

This project aims to study the modified engineering properties of soil on addition of nanomaterials to it, primarily focusing on controlling the shrinkage and swelling behavior of the expansive soils with the help of nanomaterials.

Suitability of a site for every projects depends on soil conditions at the site and the design requirements of each project. In some cases, soil conditions at the given site is not good enough to meet the design requirements from engineering perspective. Such sites need to be modified or improved using suitable ground modification techniques. One of the methods in this regard is adding cement or chemical additives to the soils. Some of the additives which have been used to be applied are lime, cement, tar, volcano ashes, and so on. Addition of them to soil reduces the plasticity and swelling and improves its density, resistance and consistency after stabilization. Most of these materials are used for stabilizing of fine grained soil and if they can be applied for coarse grained soil, reduces penetration and erosion while increase durability (Kadivar et al. 2011). One of the main problems in such additives to soil is contamination. Nevertheless, application of nanoparticles reduces such impact. Moreover, application of them in soil improvement result in controlling its resistance, reducing application of cements and consequently gaining economic advantages (Michael and Hochella 2002).

The main problem which occurs in case of soils is the structural damages caused by the shrinking and expanding behavior of clays (See Fig.1). Construction of civil engineering structures on expansive soil is highly risky because such soil is susceptible to differential settlements, poor shear strength and high compressibility. Soils having high content of expansive minerals can form deep cracks in drier seasons. It can lead to cracks in lightly-loaded buildings, pavements and embankments etc. According to the hazard mitigation plan (Wyoming Office of Homeland Security, 2011), United States of America suffers a loss of $3.2 billion per annum due to expansive nature of the soils whereas China's experience $1 billion annually (Yanjun Du, 1999). India has 20 % of its land covered with expansive soils (Soundara and Robinson, 2009). Damage to various structures were reported in India also that are attributed to swelling and shrinkage of soils. The most important problems encountered by geotechnical and geo-environmental engineers in particular are consolidation settlement, volumetric change (shrink/swell), hydraulic conductivity and desiccation cracking of clays.

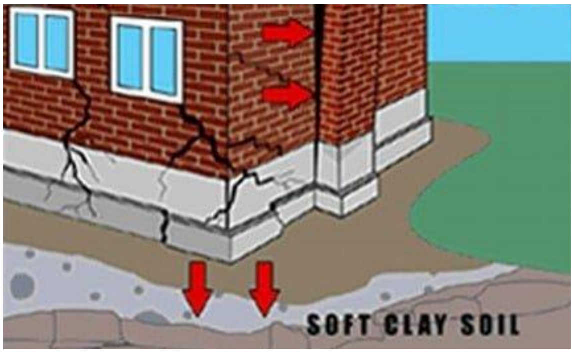


Figure 1: Structural damage due to soft clay soil (Source: https://theconstructor.org/geotechnical/types-of-foundation-failure-on-soils-and-remedies/8723/ ; Accessed on24/02/2018)

1.1 Expansive Soils

Expansive soils expand when water is added, and shrink when they dry out. These clays are primarily montmorillonite. Sodium montmorillonite (commonly known as bentonite), is especially prone to shrinking and swelling. Calcium montmorillonite, also shows some shrink-swell capabilities.

This continuous expansion and shrinkage in soil volume can cause homes built on this soil to move unevenly and crack. They can damage structures and disrupt supply lines (i.e. roads, power lines, railways, and bridges). The process of uneven expansion leading to cracking of structures is shown in Fig. 2. Expansive soils changes slowly. Observing damage in real-time can be difficult usually. Although damage may not occur in a matter of minutes, it still has potential to severely damage structures and roads over time if not sufficiently mitigated.

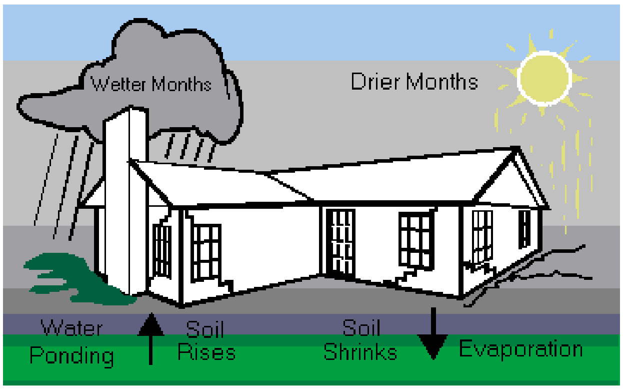


Figure 2: Cracking in buildings due to expansion and shrinkage in soil
(Source: https://dualpier.com/basic-causes.html , accessed on 22-02-2018)

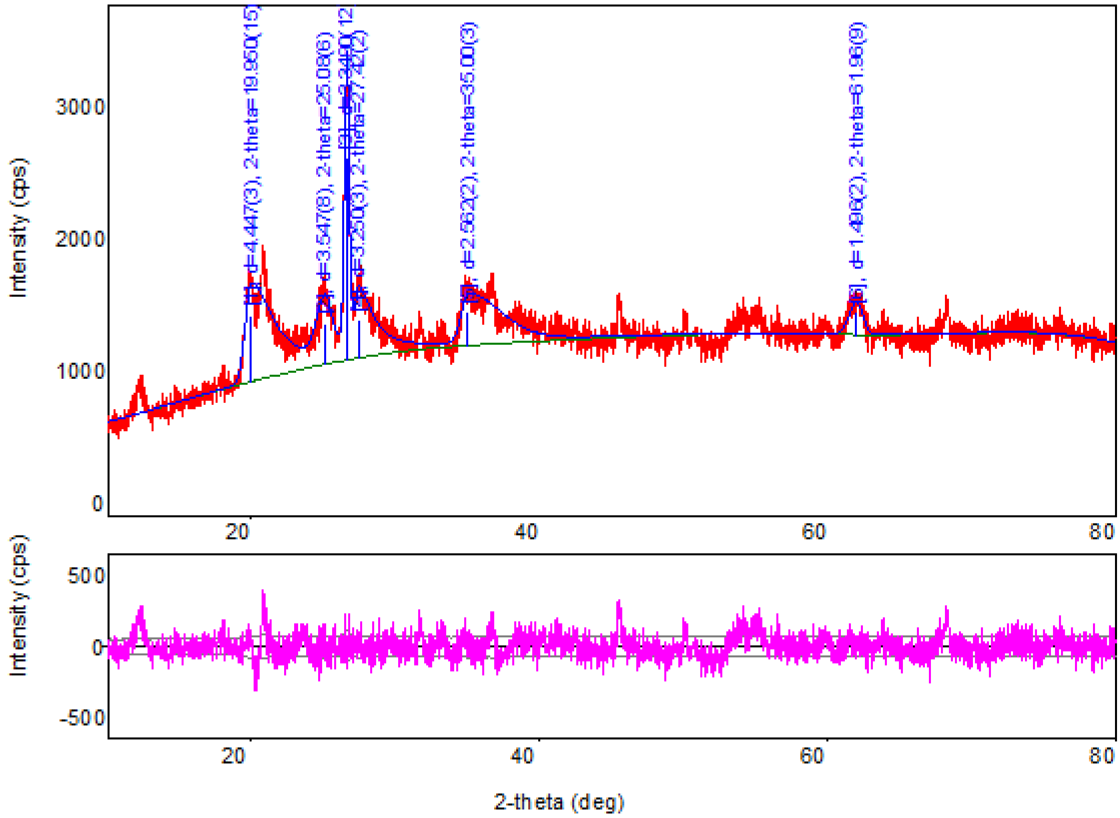
Desiccation causes clayey soils to shrink. This occurs due to the loss of soil water content which developed matric suction in soil that increases the shrinkage strain in the soil and normally followed by cracks (Nahlawi and Kodikara 2006). The expansive and shrinkage strains in the soil causes cracks (Fig. 3) which increase the permeability of soil, and the soils with high permeability has less strength to resist sliding.

Figure 3: Cracks in soil as a result of expansion and shrinkage
(Source: http://www.e-ca.us/ , accessed on 22-02-2018)

2. Materials& Experimental Methods

2.1 Materials

Bentonite Clay: Bentonite used in the present investigation is a high swell sodium bentonite (XRD Results plotted in Graph 1) containing sodium montmorillonite and its properties are listed in Table 1. In general, it has a specific gravity of 2.86, plasticity index of 192.08.



Graph 1: XRD Results

Table 1: Physical properties of Bentonite Clay used in investigation

Physical Properties	Value
% Sand	19.8%
Specific gravity	2.703
Liquid Limit	240.3%
Plastic Limit	48.23%
Shrinkage Limit	25.5 %
Differential Free Swell Index	592.31%
M.D.D	17.70 g/cc
O.M.C	25.1%

TerraSil

TerraSil is a nanotechnology based material. It is made of 100% organo-silane molecules.

TerraSil forms Si-O-Si bonded nano-siliconize surfaces and converting water loving Silanol groups to water repellent Alkyl Siloxane groups in soil. TerraSil is highly water-soluble, UV stable, heat stable and active soil stabilizer which is used for subgrade stabilization till yet. The chemical properties of TerraSil are listed in Table 2.

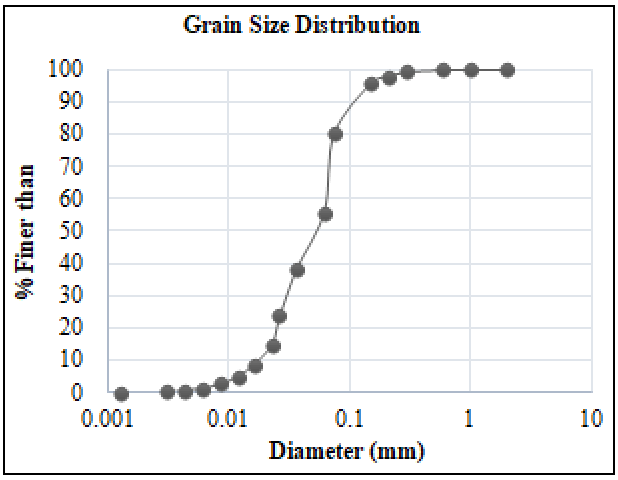
Table 2: Chemical Composition of TerraSil

Chemical compound	Value in range
Hydroxyalkyl-alkoxy-alkylsilyl	65 –70 %
Benzyl alcohol	25 –27 %
Ethylene glycol	3 –5 %

2.2 Experimental Methods

2.2.1 Without Terrasil

Grain Size Distribution: Grain Size Distribution and hydrometer analysis was done to ensure the clayey nature of the sample. The soil used in the test is 80.2 % clay. The Grain Size Distribution curve is as shown in Graph 2.



Graph 2: Grain Size Distribution

Atterberg Limits: Liquid Limit and Plastic Limit is determined as per IS 2720 (Part 5) – 1985. Five samples with different moisture content was made and kept moisture tight for seven days. It was then tested after thorough mixing. To confirm the result, liquid limit was also determined using cone penetrometer as per IS 2720 (Part 5) – 1985. The results were consistent with a minor deviation. Shrinkage Limit was also determined as per the code and is mentioned in Table 1.

Liquid Limit Test | Shrinkage Limit Test | Liquid Limit Test

Figure 4: Atterberg Limit Test

Differential Free Swell Index: Free Swell Index of the clay is determined as per IS 2720 (Part 40) – 1977. Due to highly expansive nature of the clay, proper care was taken and lesser quantity of clay (10 g) was taken, the results were consistent for three samples. Results are mentioned in Table 1.

Figure 5: Free Swell Index Test

Specific Gravity: Specific gravity determination of Bentonite Clay is very important to determine and requires considerable practice. It was done in accordance with IS 2720 (Part 3/Sec 1) – 1980 and relatively lesser amount (5 g) of clay was taken to account for swelling. Results are tabulated in Table1.

Figure 6: Determination of Specific Gravity

Standard Proctor Compaction Test: Optimum water content for the clay was determined by Light Compaction Test as per IS 2720 – Part VII – 1987 which is similar to Standard Proctor Compaction Test. Samples at different water content were prepared and kept sealed for 24 hours before testing. Results are tabulated in Table 1.

Figure 7: Standard Proctor mould and rammer

Unconfined Compressive Strength (UCS) Test: UCS Test was done at the maximum dry density, the sample was prepared at optimum moisture content and kept moisture tight for 24 hours before testing as per IS: 2720 (Part 10) – 1973. The results are shown in Graph 3.

(a) (b)

Figure 8: UCS Test (a) Triaxial Loading Apparatus (b) Specimen

Desiccation Cracking: Soil samples at a water content more than liquid limit (250 %) was added to oven dried soil, was mixed thoroughly and then kept moisture tight for 24 hours. The soil was poured in three layers in a well-greased mould of specification 10 cm × 10 cm × 2 cm upto 1.1 cm depth (the depth was estimated after conducting the same procedure at different depths) ensuring no air voids are entrapped in it. It was kept to be air dried for a few hours and due to rainy season, it was kept in oven for another 24 hours. The desiccation cracking pattern at different contents of hair fibres and TerraSil are observed. We did this with a variety of combination of thickness and content of Human Hair Fibres in absence of nanomaterials. Results are discussed in Appendix.

(a) (b) (c)

Figure 9: Desiccation Cracking pattern (a) Without TerraSil (b) With 0.5 % HHF (c) With 0.1% TerraSil

2.2.2 With Terrasil

Shrinkage limit, UCS and desiccation cracking was conducted with TerraSil. Standard practices for dosage and procedure of sample formation was adopted. We adopted the methods adopted by Vimla Sharma (2016). TerraSil was diluted at 150% of OMC in water and then mixed with soil, mixed thoroughly and left for 24 hours to air dry. It was then again mixed and used for sample preparation, some sample was kept for determining the moisture content to keep a check on sample moisture content. We performed the UCS Test at three percentages (0.7 %, 1.0 %, 1.2 %) of TerraSil. The usual dosage of TerraSil is 1 litre to 1000 kg of soil, and the dosage was varied from 700 ml to 1200 ml per 1000 kg. It is tabulated under Table 3.

Table 3: Dosage of TerraSil

Sl. No.	Dilution %	Amount of chemical per 200 g of soil
1	0.7 %	0.14 ml
2	1.0 %	0.20 ml
3	1.2 %	0.24 ml

3. Results and Discussion

3.1 Characterisation of Bentonite Clay

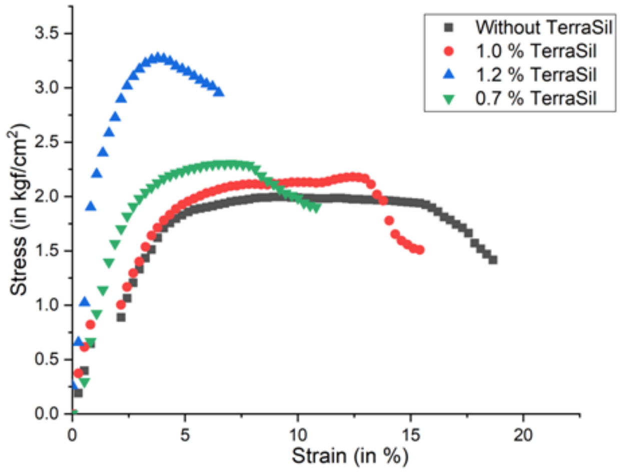
The observations from the physical characterisation of Bentonite Clay and the typical values obtained by other researchers on similar expansive clay is tabulated in Table 4. The observed and reported values are in accordance.

Table 4: Observed vis-à-vis reported values

Sl. No.	Property	Observed	Reported		
			M.Y. Fattah, (2016)	Rao, Sudhakar M., et al. (2008)	
				Hamla bentonite	Barmer-2 bentonite
1	% sand	19.8 %	22 %	8%	27%
2	Liquid Limit	240.3 %	145 %	243%	317%
3	Plastic Limit	48.23 %	50 %	50%	35%
4	Shrinkage Limit	25.5 %	Not Determined	11%	10%
5	Specific Gravity	2.70 g/cc	2.86 g/cc	2.82 g/cc	2.74g/cc
6	Free Swell Index	592.31 %	Not Determined	Not Determined	Not Determined
7	Optimum water Content	25.1 %	37 %	Not Determined	Not Determined

3.2 Engineering Properties

The results of UCS Test are plotted in Graph 3. The values with and without TerraSil are compared and it is found that TerraSil improved the strength of the soil. The sample without TerraSil showed less strength as comparison to the ones with TerraSil, and the strength increased with increasing percentage of TerraSil.



Graph 3: UCS Test Results

4. Conclusion

The results of the tests indicate that the use of TerraSil has modified the properties of the clay and can be used to stabilise expansive clays. It will be helpful in controlling the shrinkage and expansive behaviour of the clay. The following can be concluded from the results:

1) The Unconfined Compressive Strength of the soil showed considerable improvement on addition of TerraSil. The strength without TerraSil was close to 2 kgf/cm^2 and with increasing percentage of TerraSilthe Unconfined Compressive Strength increased.
2) The desiccation cracking also showed significant improvement on addition of TerraSil. The number of cracks per unit area also decreased on addition of TerraSil.
3) Number of cracks per unit area was qualitatively much less in case of TerraSil in comparison to that of Human Hair Fibres.

5. Future Scope

a) Study of other engineering properties like California Bearing Ratio, Swell Pressure, etc needs to be studied to comment on the suitability of using nanomaterial-based chemicals in soil stabilisation.
b) Study in a wide range of percentages of nanomaterial and with a variety of non-polluting nanomaterials is required to generate a pool of nanomaterials to use them viably in practice.
c) A collection of acceptable practices based on experience should be made to consolidate the experimental methods incorporated to conduct tests on Bentonite Clay.

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Appendix (Desiccation Cracking Control by Human Hair Fibres (HHF))

We tried preparing samples of varying depths to understand the effect of thickness on cracking pattern. We observed that at too low thickness (~0.5 cm), the cracking pattern was not as desired as it was quite segregated, and it tended to stick to walls and separated into very minute parts (Fig 10 (a)). At very high thickness (~ 1.5 cm), the cracking pattern was good (Fig 10 (b)) but the fractured parts showed bending due to differential heating at top and bottom as shown in Fig 10 (c). The optimum depth at which there was no bending and good cracking was nearly 1.2 cm which is shown in Fig 10 (d).

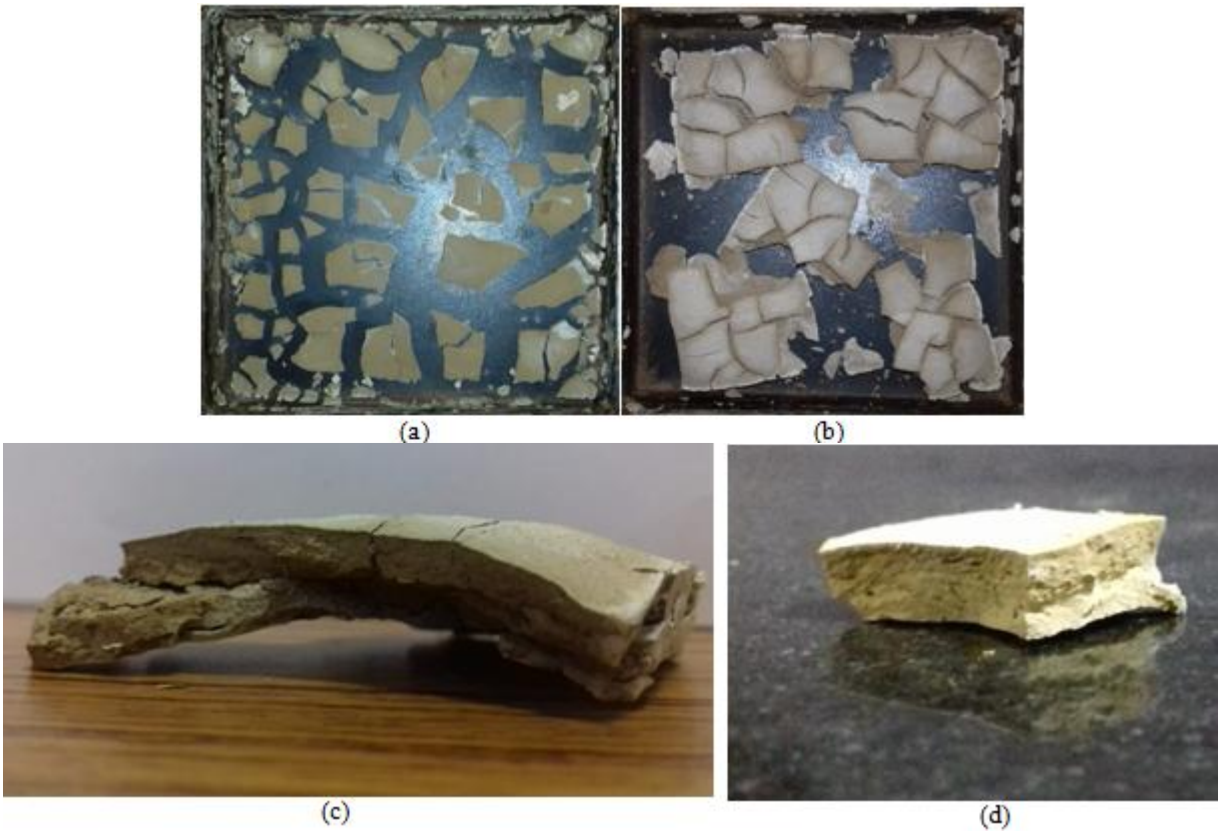

Figure 10: Desiccation cracking pattern (a) at thickness 0.5 cm (b) at thickness 1.5 cm and (c) bendingof fractured part at high thickness (~1.5 cm) (d) No bending at thickness 1.2 cm

The samples were further prepared of thickness of 1.2 cm and of varying quantity of Human Hair Fibre (HHF) with fibres of size about 10 mm.The samples with 0.25 %, 0.50 %, 0.75 %, 1.00 %, 1.50 %, 2.00 %, 2.50 % and 3.00 % HHF were made. The samples were then kept for drying for 24 hours in oven at 100°C, because of absence of clear weather outside. The photographs at same focus was taken to compare. The pictures are shown in Fig 11. Qualitatively, the cracks showed improvement with increasing percentage of HHF, however requires great amount of care while mixing higher quantity of HHF. The improvement using HHF are quite satisfactory and suggested to be used for stabilisation of expansive clays.

Figure 11: Desiccation Cracking patterns at (a) 0.25 % HHF (b) 0.50 % HHF (c) 0.75 % HHF (d) 1.00 % HHF (e) 1.50 % HHF (f) 2.00 % HHF (g) 2.50 % HHF (h) 3.00 % HHF