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# Mechanisms of binder interactions and their role in strengthening Kuttanad clay

## Mécanismes d'interaction des liants et leur rôle dans le renforcement de l'argile de Kuttanad

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**ABSTRACT:** The present investigation is on a soft organic soil from Kuttanad region in Kerala, India wherein a detailed laboratory study was undertaken to contemplate the interaction of various components of soil with cement and cement admixtures. An attempt was made to understand the influence of cement as binder based on parameters such as Clay water/ Cement (W/C) ratio, Initial water content of clay (IW) and curing period by studying the Unconfined Compressive Strength (UCC) of stabilized soil. The results showed that the UCC strength increased with decreasing W/C ratio irrespective of the IW used. Binder combinations involving partial replacement of Cement with Lime, Fly ash and Slag were not effective in improving the strength of soil when compared to the performance of cement alone as binder. On the other hand, addition of Sodium Silicate to cement enhanced the strength of the soil significantly.

**RÉSUMÉ :** Le travail présenté porte sur un sol mou organique de la région de Kuttanad, dans le Kerala, en Inde, pour lequel une étude de laboratoire détaillée a été menée pour analyser les interactions de différents composants du sol avec le ciment et les adjuvants ajoutés. Une tentative a été faite pour comprendre l'influence du ciment en tant que liant, en se basant sur l'étude de paramètres tels que le rapport eau de l'argile / ciment (W / C), la teneur en eau initiale de l'argile (IW) et la période de cure, en étudiant la résistance à la compression simple (UCC) du sol traité. Les résultats ont montré que la résistance à la compression simple augmente avec la diminution du rapport W / C, quelle que soit la valeur de IW. Différentes formulations de liants basées sur le remplacement partiel du ciment par de la chaux, des cendres volantes et du laitier ne se sont pas avérées efficaces pour améliorer la résistance du sol par rapport au ciment seul. D'autre part, l'ajout de silicate de sodium au ciment améliore de manière significative la résistance du sol.

**KEYWORDS:** Kuttanad soil, Minerology, Binders, Organic content, Shear strength  
**MOTS-CLÉS :** sol du Kuttanad, minéralogie, liants, teneur en matière organique, résistance au cisaillement

### 1 INTRODUCTION

Soft soils are more prominently found in coastal regions and low land areas where many important cities and ports are located. And also in today's scenario of increased rate of infrastructural development to match the population growth, it has become mandatory to construct on soft grounds. Soft clays normally exist with high liquidity indices and presence of soft clay as a foundation material in any construction project demands proper engineering judgment as it is associated with inherent problems of excessive settlement and low shear strength. In addition to it presence of organic content in soft clays further worsens the ability of the deposit to support even moderate loads. Such problematic soft soil deposits with inadequate geotechnical properties are present in Kuttanad region of Kerala, India. This soft soil used in the present study also contains organic matter (Thiyyakkandi and Annex 2011) and is found to be acidic (Muralidharan et al. 1999). There are many geotechnical failures reported in Kuttanad region (Ayyar 1966) and hence improving the properties of the soil have been a matter of intense research (Bindu and Vinod 2008, Dipty and Girish 2009).

Compared to other methods of improving the soft ground, introducing deep mixed cement columns and mass stabilization with binders are rapid techniques of ground improvement. Successful case histories are reported on soft grounds improved with soil stabilization techniques (Bergado et al. 1999, Lin and Wong 1999). It is important to note that the success of the method is by the interaction of the binders with the soft clay and the extent of improvement in strength depends on factors such as the type and amount of binder, water content, soil type and curing period (Lorenzo and Bergado 2004, Horpibulsuk et al.

2005). However little is understood about the role of organic matter and clay type on the binder soil interaction. Hence in the present study an attempt is made to evaluate the mechanism of strength development with various binders along with other additives.

### 2 MATERIALS AND METHODS

#### 2.1 Soil Sample

Clay collected from Kuttanad region, Kerala from a depth of 2 m was used in experimental investigation. The clay is classified as organic clay of high plasticity (OH) according to IS 1498 (Part 1) - 1987. The specific gravity of the soil was determined based on the code IS 2720 (part 3) – 1980. The Cation Exchange Capacity (CEC) of the Kuttanad clay was measured as per the guidelines of ASTM D7503. Organic content of the soil was determined as per the code, ASTM D2974. Unconfined compressive strength of the soil at a water content of 125 % was found to be 10 kPa. The properties of the clay used in the study are given in Table 1.

Table 1. Properties of Kuttanad clay.

|                       |              |
|-----------------------|--------------|
| Colour                | Black        |
| Specific gravity      | 2.48         |
| Soil classification   | OH           |
| Organic content       | 17 %         |
| Natural water content | 100 to 200 % |
| CEC                   | 17 meq/100 g |
| pH                    | 3.6          |

2.2 Soil Mineralogy

2.2.1 X-Ray Diffraction (XRD) Studies

XRD analysis was carried out using Bruker D8 Advance system on powder samples. Samples were scanned using copper K alpha ( $\lambda = 1.54 \text{ \AA}$ ) radiation at a scanning rate of 1°/minute. Identification of minerals was done by comparing the XRD patterns got from the soil with the standard data sets of the known minerals (JCPDF, Powder Diffraction File, 1990). The peaks for the Kuttanad soil and its corresponding minerals are shown in Fig. 1.

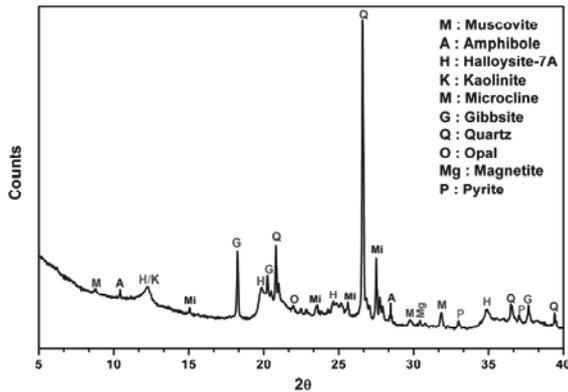


Figure 1. XRD of Kuttanad clay

2.2.2 Scanning Electron Microscopy (SEM)

The Quanta Environmental Scanning Electron Microscope (ESEM) was used in analyzing the fabric of the uncemented and cemented clay. A study of the micrographs of uncemented Kuttanad soil sample prepared by freeze drying technique indicates an open honeycomb type of fabric arrangement, as shown in Fig. 2(a). The fabric shows the presence of frustules, Fig. 2(b & c), which are skeletal remains of diatoms, composed of amorphous silica (opal, presence also verified by XRD analysis). Diatomaceous frustules in marine sediments are known to play a significant role in controlling the geotechnical properties of the soil (Rajasekaran 2006) and this study tries to throw some light on the ability of this amorphous form of silica to participate in the strengthening reactions with binders.

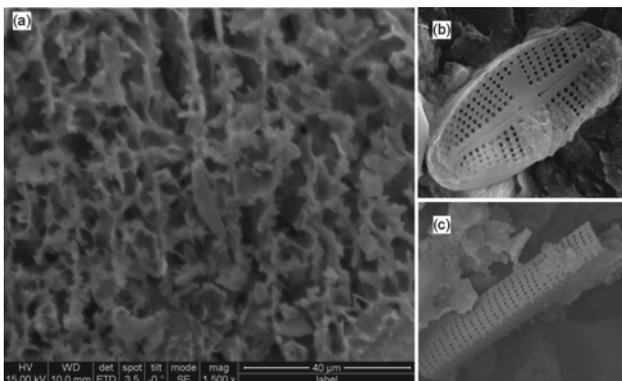


Figure 2. (a) Open fabric of Kuttanad marine clay and (b) & (c) Diatom frustules in Kuttanad clay

2.3 Binders

In the current study ordinary Portland cement of 43 grade was used as the binder. Initially the effect of cement stabilization was evaluated by varying parameters such as IW, W/C and curing period. And then the effect of different composite binder combinations with mineral admixtures and puzzolonic materials such as quick lime (CaO), Ground granulated blast furnace slag

(GGBS) and Fly ash (FA) on Kuttanad soil stabilization was studied. Further for W/C ratio of 3.33 addition of FA, GGBS, Silica fume (SF), Sodium Silicate (SS) and Fine sand to cement on the strength of Kuttanad clay was evaluated.

2.4 Sample Preparation

The clay was thoroughly hand mixed and IW was increased to 165 % and 200 %. The intentional increase in the initial water content before stabilizing was done to simulate the field conditions where there is a raise in the insitu water content because of wet binder dispensing methods adopted during deep mixing (Horpibulsuk et al. 2004). Cement quantity to be added for preparing the mixes was calculated based on W/C ratio. In the present investigation three W/C ratios were used namely 6.5, 5 and 3.33. Cement was added to the soil and mixed thoroughly for about 10 minutes as suggested by Miura et al. 2001. Split moulds having diameter 38 mm and height 76 mm (Length/Diameter = 2) with sides slightly lubricated with oil were used for casting and curing the stabilized mixes. The well mixed paste was transferred to the split mould in three layers. Spreading of the paste into the mould and removal of air entrapped during casting was done by giving mild tamping for each layer. The samples caste in the split moulds were cured for 7, 14 and 28 days in desiccators maintained at 100 % relative humidity. Similar methodology of making samples was adopted for different composite binder combinations adopted in this study.

3 RESULTS AND DICUSSION

3.1 Cement as binder

Figure 3 presents the UCC strength of cement stabilized samples at different W/C ratio with varying IW and Cement Content (CC) with curing period.

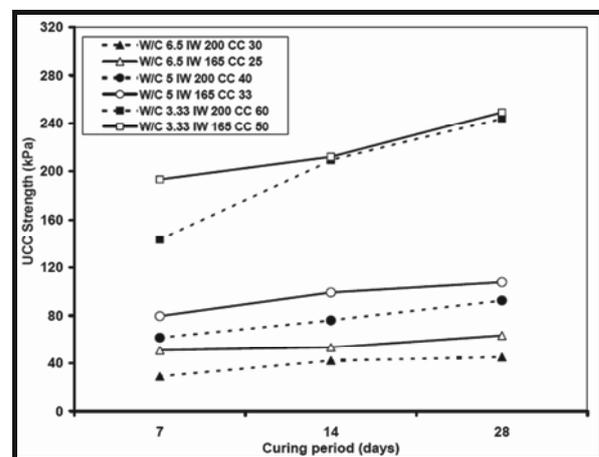


Figure 3. Unconfined compressive strength (UCC) of cement stabilized samples

It can be seen from Figure 3 that with reducing W/C ratio there is an increase in the strength developed. Even though the cement percentage corresponding to the W/C ratios used in the study is high (more than 25 %) the strength attained is very low. This might be due to the organic content present in the soil hindering the cement hydrolysis and subsequent strength development. It can also be inferred that up to W/C ratio of 5 there is a marginal improvement in the UCC strength but when the W/C ratio further reduces to 3.33 the strength gained is significant. This is because the organic components gets enough calcium at lower water cement ratios so that surplus calcium is available in solution to aid the cement hydration and hardening reactions contributing to better strength development. From (Figure 4) the fabric changes happening over reduction in W/C

ratio it can be concluded that the cementation compounds are still insufficient to bind the clay fabric in case of high W/C ratio whereas at the lowest W/C ratio the cement matrix is continuous binding the clay aggregates contributing to a significant strength gain.

It can be seen from Figure 3 that the effect of curing is almost negligible and this is mainly because the organics tending to coat the surface of the soil particles impeding the interaction between clay minerals and the cement hydration products harming the long term strength gain contributed by secondary reactions (Chen & Wang 2006). Results indicate that for the same W/C ratio the variation in initial water content has very little influence on the long term strength gain thus confirming the critical role played by W/C ratio in strength development of cemented clays as suggested by Miura et al. (2001).

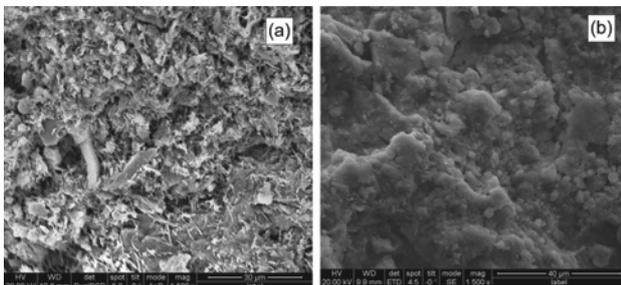


Figure 4. Fabric of Cemented Kuttanad clay (a) W/C 6.5 (b) W/C 3.33

### 3.2 Cement Composite binder combination

With an effort to economize and reduce the carbon foot print of the proposed ground improvement technique, composite binder combinations such as cement – Lime, Cement – FA and Cement – GGBS were tried.

#### 3.2.1 Cement-Lime

Quick lime as reported in literature (Åhnberg and Johansson 2005) as a possible replacement for cement was tried in different proportion with cement and the UCC tests were done on stabilized soil samples. For IW 165 % and W/C ratio 5, Cement(C) - Quick Lime (L) binder combinations of 75C-25L and 50C-50L were tried and the UCC strength at the end of 14 days curing was found. UCC strength of the sample with only cement as binder was 99 kPa where as with lime replacement the strengths significantly reduced to 33 kPa (75C-25L) and 25 kPa (50C-50L). Development of strength happens when the added lime reacts with the clay minerals. As soon as lime is added, pH increases and there is De-flocculation of soil fabric and removal of organics adsorbed on to the minerals. The organic matter hinders the reactions between added lime and the clay minerals present in the soil hence there is no beneficial effect of lime replacement observed. Diatom silica is also found not reacting with the added lime confirming the role of components such as organic content and sesquioxides (Van Capellen et al. 2001) present in the soil inhibiting its solubility, finally retarding the pozzolonic reactions responsible for strength development.

#### 3.2.2 Cement - Mineral admixtures

Figure 5, shows the stress – strain characteristics of cement with GGBS and Fly ash binder combination with and with out lime. It can be clearly seen that the effect of replacing a portion of cement with either of the mineral admixtures (GGBS / FA) results in strength loss when compared to the cement alone case. Hence it reinforces the fact that the positive effect of pozzolonic reactions is not enough to offset the role of cement which is replaced. Both lime released and lime added have insignificant

role to play in enhancing the strength of the Cement - Mineral admixture stabilized Kuttanad soil.

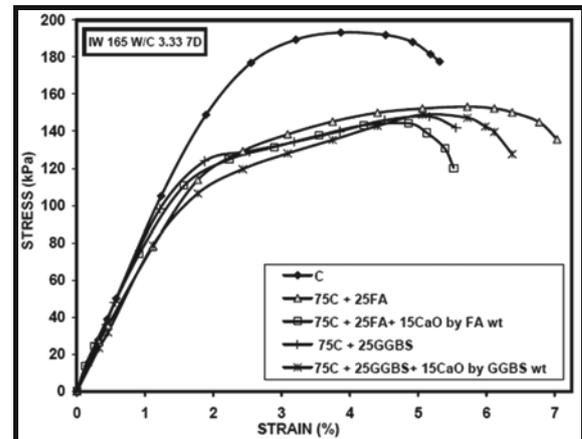


Figure 5. Stress Vs Strain for cement- mineral admixture combination

### 3.3 Role of Admixtures

To further enhance the strength of soil with cement as binder different additives with varying reactive silica content were considered. Results from UCC tests of different additives such as Fine sand, Fly ash, Silica fume, GGBS and Sodium silicate used along with cement are shown in Figure 6.

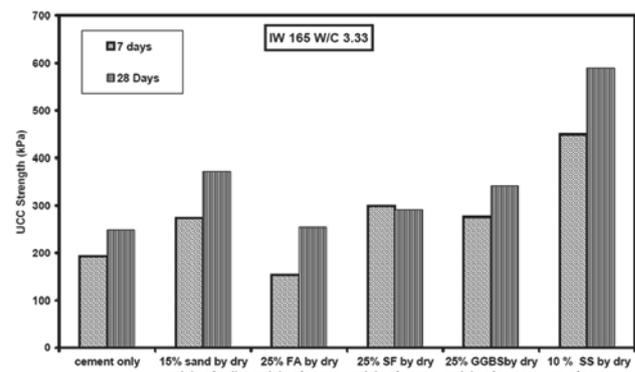


Figure 6. Effect of various additives on UCC strength of cemented soil

It is evident from Figure 6, that addition of fine sand to the mix has enhanced the shear strength of the cement stabilized soil. The mechanism of strength enhancement in this case can be attributed to the matrix of cemented sand supporting the weak soil within it. It is well known that the cement can bind very effectively the coarser sand particles involving lesser contact points than the fine organic soil.

The addition of fly ash resulting in no strength improvement can also be due to the interaction of the strengthening matrix of both soil cement and fly ash cement system leading to a weaker framework.

Silica fume as an additive with cement resulted in 17 % strength increment in case of 28 days cured samples (Figure 7). The strength increment is marginal and can be attributed to the participation of silica fume in the pozzolonic reactions, involving lime liberated from cement hydrolysis.

Adding 25 % GGBS by weight of cement resulted in a strength increase of about 37 % at the end of 28 days curing (Figure 7). The strength increase is due to the formation of cementation products because of the alkali activation of GGBS caused by cement hydrolysis (Taylor 1997). GGBS is coarser and accommodates soil in its matrix and the subsequent production of cementitious products by itself results in effective binding giving an enhanced strength.

Compared to other additives tried along with cement to improve the strength of the stabilized soil, Sodium Silicate added about 10 % by dry weight of cement resulted in maximum increase of UCC strength. From Figure 7 it can be seen that the strength increase compared to cement alone at 28 days curing was about 137 %. Initially when sodium silicate is added to the soil, the negative silicate ions go and sit in the positive edges of the clay and makes the clay completely negative resulting in thorough dispersion of the clay. Then when cement is mixed with soil the calcium ions released as a by-product of cement hydrolysis is utilized by the silicate ions leading to the formation of calcium silicate hydrate which eventually binds the clay minerals together (Moayed et al. 2011). This is expected to be the mechanism behind enormous strength gain in the presence of small percentage of SS with cement.

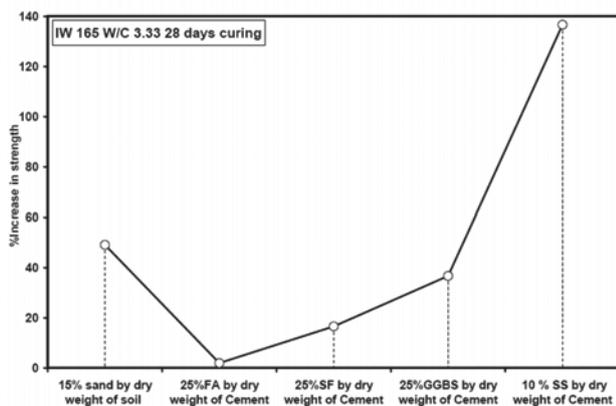


Figure 7. Percentage increase in UCC strength of cement stabilized soil upon adding various additives

#### 4 CONCLUSIONS

The following conclusions can be drawn from the present study

- In case of cement stabilization W/C ratio is the key parameter controlling the strength of the treated soil samples. Higher initial water content requires more cement content to attain desired strength as compared to the soil treated at lower initial water content for the same water cement ratio. Effect of curing is almost negligible because of the organic constituents present in the soil.
- Replacement of cement by quick lime is found to be ineffective as the organic component of the soil inhibits lime from reacting with the clay minerals. Hence lime and lime substitutes will not work in case of stabilizing Kuttanad clay.
- The solubility of Diatom silica is affected by the organic matter and sesquioxides present in the soil making the soil less responsive to lime. Thus supplying reactive silica by other additives along with cement is necessary for improving the strength of the soil.
- Among the additives used with varying quantities of reactive silica, small percentage of Sodium Silicate with cement is found to be most effective in enhancing the strength of cement stabilized Kuttanad soil.

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