# Strength Characterisation of Nanochemical Stabilized Kuttanad Clay for Pavement Construction

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## ABSTRACT

Kuttanad clays are low strength, soft, organic clay deposits found in the Kuttanad areas of the Alappuzha district, Kerala. Lots of failures have been reported to the structures built over it due to its swelling - shrinking characteristics. To enhance the load-bearing capacity and decrease the settlement characteristics, the addition of appropriate stabilizing agents is considered the most efficient technique in soil stabilization applications. Soil stabilization techniques using traditional stabilizers in mass projects have become costly due to the increase in the cost of materials like cement, lime, fly ash, etc. Moreover, cement production also accounts for global warming due to the emission of carbon gas. Hence studies are going on regarding the effectiveness of using non-traditional materials that can react faster as stabilizing agents and thus reducing the cost of construction. This paper focuses on studying the suitability of a non-traditional nanotechnology-based organo-silane compound in the treatment of Kuttanad clay soils. Observations were made for the variation in the strength characteristics of the soil such as maximum dry density, optimum moisture content, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) strength of samples stabilized with varying dosages of nanochemical for curing periods up to 28days. Pavement design was also carried out based on the soaked CBR strength of untreated and optimum nanochemical treated samples. Observing the tremendous improvement in strength characteristics particularly in the CBR strength of soil, stabilization using this nanotechnology-based organo-silane compound may be recommended for cost-effective construction of pavement in areas with low load-bearing capacity.

**Keywords:** Nanochemical; clay soil stabilization; Kuttanad clay; Nontraditional additives; Unconfined compressive strength.

## 1 Introduction

The utilization of soil stabilization techniques has significantly increased in recent decades because of new construction sites being located in areas having poor ground conditions. Soil Stabilization is the alteration of soils to enhance their properties such as shear strength, shrinkage-swell property, load-bearing capacity etc. Stabilizing agents enhance the strength characteristics of weak soils causing reduced construction cost and improved performance. Soft ground improvement techniques involving the addition of stabilizers in small quantities to improve the strength characteristics are in practice for so many years. Due to calcium-based structure, traditional additives like cement, lime, fly ash, rice husk ash etc. in presence of water take part in chemical reactions with soil resulting in an overall enhancement of the soil's physicochemical characteristics (Buazar 2019). Production of traditional additives involves calcination of calcium carbonate which results in a high carbon footprint or high energy demand, leading to global warming (Eujine *et al.* 2016, Ewa *et al.* 2016, Maddalena et al. 2018, Taha 2013). Hence high energy demand, carbon footprint and leaching away during monsoons resulted in the reduced application of stabilization with traditional agents over the past decade.



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Hence to reduce the amount of lime, cement etc, there is an urgent need to substitute with other environmentally friendly stabilizers.

Nontraditional additives are dominant in the present era as it reacts faster, economical, eco-friendly, less energy demand in production and causes less carbon emission. The nontraditional additives include bio enzymes, nanoparticles, nanomaterials etc whose effects on the properties of soil are still being researched. Over the last few years, the application of nanomaterials in the engineering field has drawn the interest of researchers worldwide. Nano chemicals are non-cementitious materials which when introduced in soil reduces the interparticle spacing and nano reinforce it. Nanomaterials are non-toxic, biologically and chemically inert materials, and have excellent durability characteristics. Even small amounts of nano-material can make a big difference in the physical and chemical properties of the soil because of its high surface area (Zhang, 2007). Also due to its large surface area, a lot of interactions occur between soil and nano-composites which lead to an improvement in the strength of soil (Majeed et al. 2014).

Kuttanad soils are soft highly organic clay or silt deposits with higher compressibility and lower strength characteristics found in the Kuttanad areas of the Alappuzha district in Kerala, India. These soils are unstable and had caused a lot of failures to the structures built over them. Hence studies are being conducted for the effective stabilization of Kuttanad clays by imparting desired characteristics using stabilizing agents for improved performance (Yasodian et al. 2012). A detailed summary of the laboratory test program conducted for finding the effect of a nanotechnology-based organosilane compound as a chemical additive on the strength characteristics of Kuttanad soil is presented in this paper.

## 2 Materials and Methods

### 1.1 Materials

#### 2.1.1 Soil

Natural soil for the study referred to as 'virgin soil' was collected from the Champamkulam area of the Kuttanad region, Alappuzha, Kerala at 1 m depth from ground level. It is dark grey in colour. According to IS classification soil is classified as Clay of High plasticity (CH). It is having a UC strength value of 93kN/m² i.e. soil is moderately hard. Also, it is having low CBR strength. Virgin soil characteristics are given in Table 1.

**Table 1. Virgin soil characteristics**

| Characteristic | Liquid limit (LL) (%) | Plastic limit (PL) (%) | Maximum Dry Density (MDD) (kN/m³) | Optimum moisture content (OMC) (%) | UC Strength (UCS) (kN/m²) | Soaked CBR Strength (%) | Unsoaked CBR strength (%) |
|---|---|---|---|---|---|---|---|
| Value | 65 | 31 | 15.2 | 21.5 | 93 | 2.9 | 4 |

#### 2.1.2 Nanochemical

Nanochemical (NC) used in the study is Terrasil, manufactured by Zydex industries, Vadodara, Gujarat. Its composition consists of hydroxyl alkyl- alkoxy alkysilyl (65-70%), Benzyl alcohol (25-70%), Ethylene glycol (3-5%) (Meeravali et al. 2020). It is an organosilane compound that is a water-soluble, ultraviolent and heat stable, reactive soil modifier to waterproof soil subgrade (Selvaraj. 2018). Nanochemical dosages selected were: 0.02%, 0.04%, 0.06%, 0.08%, 0.1%. It available in concentrated liquid form in pale yellow colour and is mixed with water quantity corresponding to optimum moisture content, before mixing with the soil.

#### 2.1.3 Cement

From trial tests, 1% Ordinary Portland cement is also added as a binder for nanochemical stabilization considering the economical aspect.

#### 2.1.4 Water

Water used in the study is potable water.

### 2.2 Sample Preparation

All samples were prepared according to IS specifications at optimum moisture content and maximum dry density of virgin soil. The virgin soil was firstly oven-dried for 24 hours, then crushed and sieved to pass through a 4.75mm IS sieve. Separate samples were prepared with different % of NC and were stored in moistened conditions to minimize the loss of moisture. Cylindrical compacted specimens of height 76 mm and diameter 38mm are prepared at the maximum dry unit weight and optimum moisture content. For each additive treated soil mixture, three similar UCS samples were prepared. A covered curing technique was adopted to study the influence of the curing period on strength characteristics. Samples with appropriate packaging in polyethylene bags were stored in airtight desiccators until the required curing time. Samples were weighed for loss of water content after each curing period and are rejected when the difference was more than 0.5%. Additive mixed samples were cured for 7 days for proctor compaction testing while liquid limit, plastic limit and UCS samples were tested after 7 to 28 days of curing. CBR strength value was determined after 7 and 28 days of curing.

### 2.3 Testing

All tests were conducted according to IS 2720 specification. The dosage of additive to prepare additive – soil mixture for each experiment is taken on a dry weight basis of soil. Characterization of untreated soil was done. Then testing was conducted on cured samples to check the effect of nanochemical addition on strength characteristics of soil such as compaction, UCS and CBR strength. UCS tests are performed according to IS 2720 (Part 10) (1973) under a constant strain rate of 1.2 mm/min. Three identical specimens of each mix were tested and peak stress values are taken from the stress-strain curve. The optimum content of nano chemical is determined from a series of UCS tests which gave maximum strength values. Samples were tested after the curing period of 7 to 28 days to study the effect of curing period on compressive strength properties.

## 3 Results and Discussions

### 3.1 Compaction Characteristics

Standard proctor compaction test as per IS 2720 Part 7 was conducted on samples treated with different dosages of nanochemical after 7 days of curing period to check the influence of NC on maximum dry density (MDD) and optimum moisture content (OMC). Figure 1 shows the variation in MDD and OMC values with different dosages of nanochemical. It can be seen that, with the increase in NC addition, MDD values increased and OMC values reduced till 0.06% of nanochemical addition. MDD value increased to 17.9kN/m$^3$ from 15.2kN/m$^3$ of untreated soil. An increase in MDD indicates improvement in soil property, whereas a reduction in OMC causes soil to be more workable. Increased MDD is due to the reduction in surface area of soil due to the reaction of nanochemical with soil particles on a molecular level and converts the soil surface hydrophobic (Meeravali et al. 2020). With the addition of more nanochemical solution it is seen that MDD values reduced and OMC values increased. At the optimum NC content, there occurs a structural adjustment which results in the development of maximum UC strength. But with further addition of NC content, the MDD values reduces which may be due to untreated excess organo-silanes that could not react thus consequently creating weak bonds.

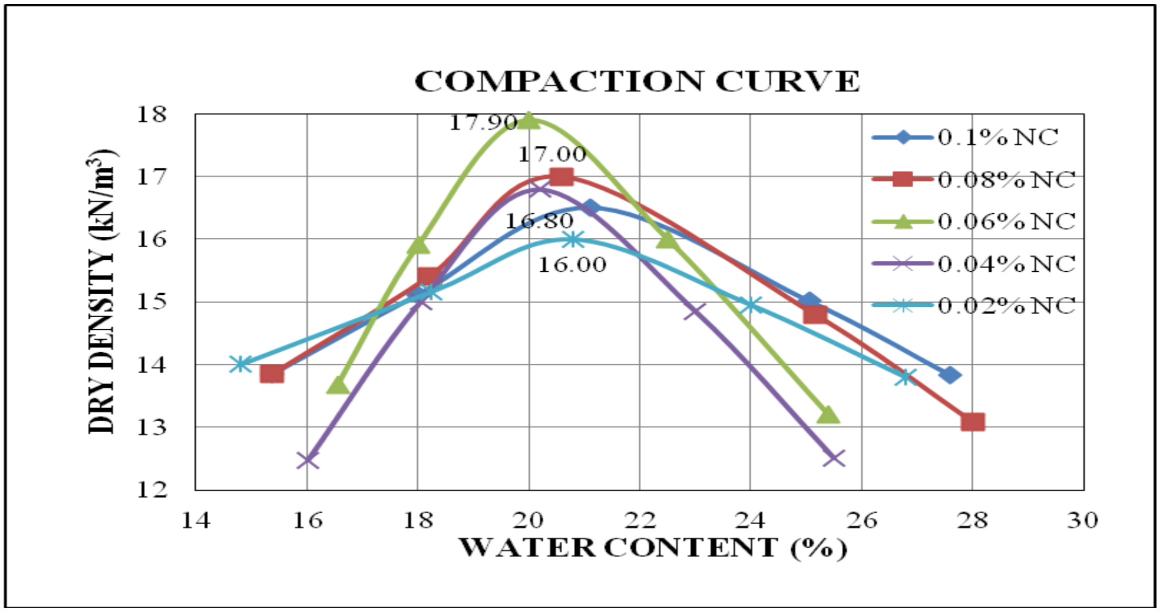


**Figure 1. Variation in compaction characteristics with varying NC content**

An increase in OMC after optimum point may be due to the addition of nanochemical that reduces the amount of silt and clay particles and resulting in formation of coarser materials with large surface areas (Aderinola and Nnochiri 2017).

### 3.2 Unconfined Compressive Strength

UCS tests were performed according to IS 2720: Part 10 on all combinations of soil- additive mixture at different curing periods. For each mix, three samples were tested and the average UCS value is taken. UCS values of samples treated with varying dosages of NC for curing periods of 7, 14, and 28 days are given in Figure 2. In Figure 2, the notations NC7, NC14 and NC28 represents variation in UCS values for varying nano chemical contents after 7, 14 and 28-day curing period respectively.

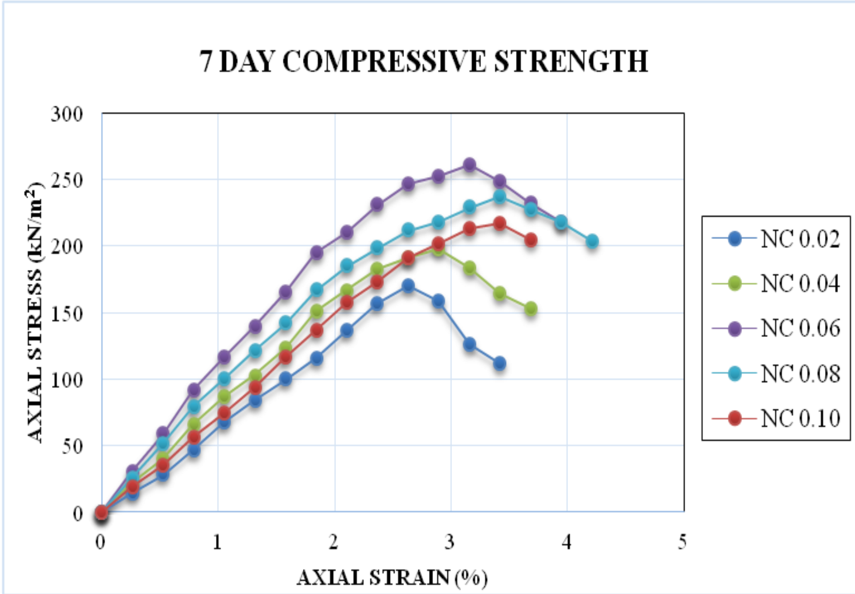


**Figure 2. Variation in 7 days UCS value with varying NC content**

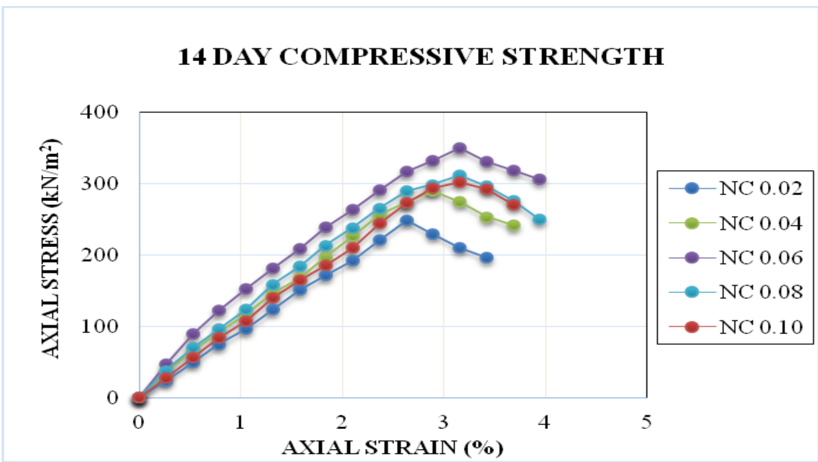


**Figure 3. Variation in 14 days UCS value with varying NC content**

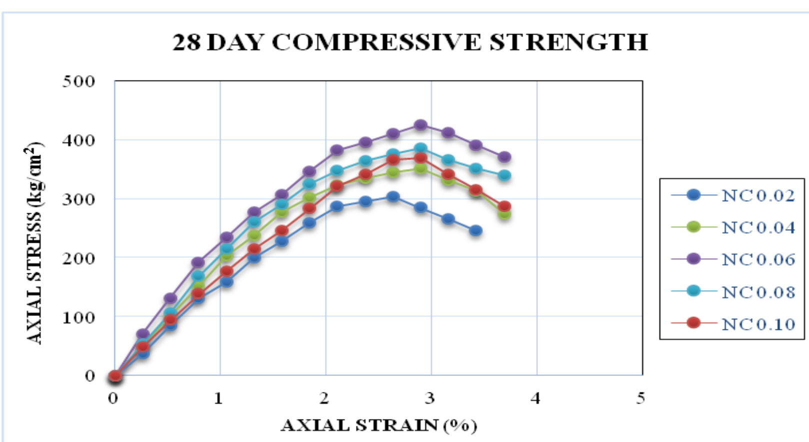


**Figure 4. Variation in 28 days UCS value with varying NC content**

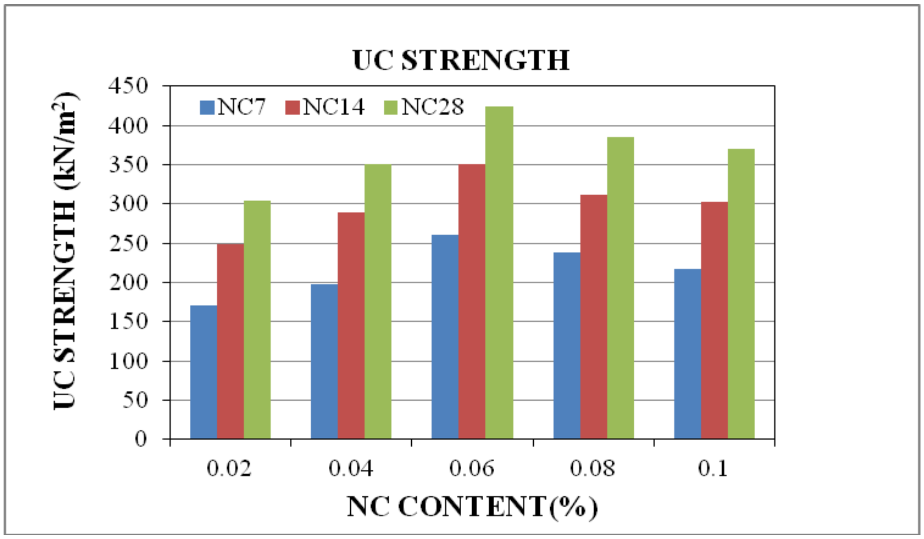


**Figure 5. Variation in 28 days UCS value with varying NC content**

It can be seen from Figure 5, that there is a considerable enhancement in compressive strength values with an increase in the dosage of NC till 0.06% dosage. After that, the rate of increase of strength decreased with the further addition of NC. This trend is repeated for curing periods of 7, 14 and 28 days. Hence 0.06% nano chemical content can be considered as the optimum dosage of NC which gave the highest compressive strength values at all curing periods. After 28 days of curing, the UC strength value of soil increased to 424.73kN/m$^2$ for the optimum dosage of NC i.e. 4.4 times the UC strength of untreated soil. This enhancement in UCS is due to the reaction of the NC with the silanol groups of soil particles, converts it to highly stable water repellent alkyl siloxane bonds and as a result, it waterproofs the surfaces permanently with the formation of a breathable in-situ membrane (Meeravali et al. 2020). The reduction in strength after the optimum dosage is due to the presence of excess organo-silanes which was not mobilized making the solution to be less reactive and forming weak bonds (Aderinola and Nnochiri 2017).

## 3.3 California Bearing Ratio strength

CBR strength testing was performed following IS 2720: Part 31 in NC-treated samples under both soaked and unsoaked conditions after 7 and 28 days of curing. Figure 6 represents the CBR strength values of soaked and unsoaked NCS samples with varying NC content after 7and 28 days of curing.

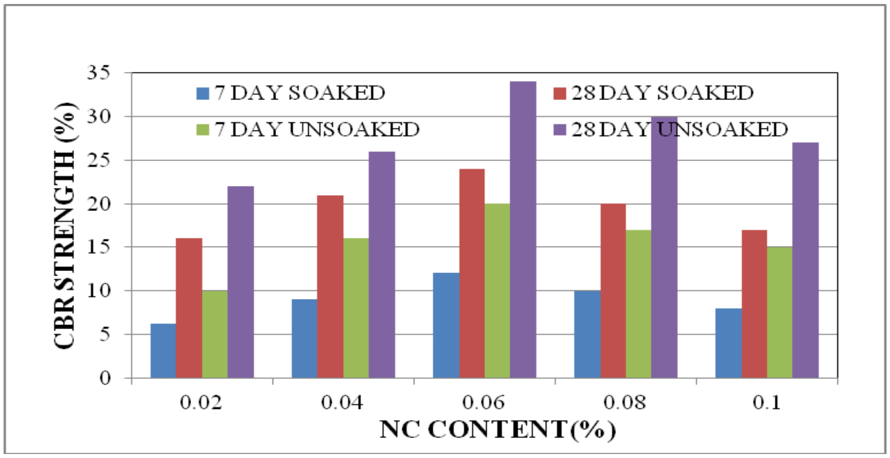


**Figure 6. Variation in CBR strength value with NC content**

From Figure 6, it is seen that CBR strength increases with an increase in NC dosage till optimum dosage which gave the maximum CBR strength value for both soaked and unsoaked conditions. After 28 day curing period, the soaked and unsoaked CBR strength of NC stabilized soil improved by about 8 times the respective CBR strength of untreated soil. With the further addition of NC dosage after optimum, CBR strength decreased.

## 4 Flexible Pavement Design as Per IRC 37:2012

After finding the soaked, as well as unsoaked CBR strength values of optimum NC, treated specimens, design of flexible pavement is carried out as per IRC: 37- 2012 based on CBR values. The design of pavement is done with the soaked CBR strength value of untreated soil specimen as well as with improved CBR strength value of optimum NC content (0.6%) treated specimen after 28 days of curing. The pavement is designed considering it as conventional layered flexible pavement. Based on the traffic and material properties, pavement compositions are suggested by design catalogs in the form of simple design charts presented in plates in IRC 37 code for subgrade CBR values ranging from 3% to 15% and design traffic ranging from 2 msa to 150 msa.

### 4.1 Design Parameters

Initial traffic volume in terms of commercial vehicles per day (cvpd) (A) = $P (1+r)^x$

No. of commercial vehicles as per last count (P) = 1200 nos. (assumed value)

No. of years between the last count and the year of completion of construction (x) = 2 years (assumed value)

Traffic growth rate per annum (r) =5.0% (as per IRC: 37- 2012 clause 4.2.2)

Calculating, Initial traffic volume (A) = 1323 cvpd

Design life (n) =15 years (as per IRC: 37- 2012 clause 4.3.2)

Vehicle Damage Factor (F) = 3.5 (as per IRC: 37- 2012 clause 4.4.6 Table 2)

Lane Distribution Factor (D) = 50% for two - lane single carriage way (as per IRC: 37- 2012 clause 4.5.1 ii)

#### 4.1.1 Calculation of Design Traffic

The design traffic is considered regarding the cumulative number of standard axles to be carried during the design life of the road. According to IRC: 37- 2012 clause 4.6.1, Cumulative number of standard axles (N) in million standard axles (msa):

$$N = (365\{(1+r)^n-1\} \text{ x } A \text{ x } D \text{ x } F)/r \qquad \text{(Eqn 1)}$$

The value of N is obtained from Eqn.1 as 17.32 msa which is round off as 20 msa. According to the respective CBR value, suitable plates from IRC: 37 2012 is selected for both the untreated and optimum biopolymer treated specimens.

#### 4.1.2 Thickness Design

For the N value of 20 msa, thickness composition is selected from the respective plates for untreated and optimum NC treated specimens. The details of the design are given in Table 2. From Table 2, it is noted that there is a thickness reduction of 240 mm in total pavement thickness. Comparing the Dense Bituminous Macadam (DBM) layer of untreated soil and biopolymer treated soil; there is a thickness reduction of 60mm. Also, there is a thickness difference of 180mm in the granular sub-base layer between the above two specimens. Thus the reduction in total pavement, granular sub-base layer, and DBM layer shows cost-effectiveness of Nanochemical application for pavement construction.

**Table 2. Design of Pavement in Untreated and optimum NC Treated Subgrade**

| Property | Design characteristics of untreated subgrade | Design characteristics of treated subgrade |
|---|---|---|
| Soaked CBR value (%) | 2.9% | 24% |
| IRC: 37-2012 – PLATE No | Plate 1 | Plate 8 |
| Total pavement thickness (mm) | 790 | 550 |
| Thickness of granular sub-base (mm) | 380 | 200 |
| Thickness of granular base (mm) | 250 | 250 |
| The thickness of dense bituminous macadam (mm) | 120 | 60 |
| Thickness of binder coarse (mm) | 40 | 40 |

## 5 Conclusion

This study investigated the effect of nanotechnology-based organosilane compound addition on geotechnical characteristics of virgin soil like compaction, UC strength, and CBR strength of weak Kuttanad soil through a set of laboratory experiments. The study also examined the influence of the curing period on the strength characteristics of the soil.

The following conclusions were drawn from the study:

- According to IS classification, soil collected for the study from Champamkulam of Kuttanad region, Alappuzha is of CH i.e. clay of high compressibility
- Untreated soil is having a high liquid limit, low UC strength, and CBR strength characteristics; which makes it unsuitable for load-bearing constructions.
- The optimum dosage of nano chemical is 0.06% of the dry weight of soil.
- With the addition of nano chemical, maximum dry density increases and OMC decreases till optimum dosage.
- Unconfined compressive strength and CBR strength of nanochemical stabilized soil increase considerably with the increase in additive dosages till optimum content is reached.
- With the increase in curing period, UC strength and CBR strength improved considerably for NC stabilized soil.
- With the application of optimum nanochemical content in subgrade soil, there is a reduction in the total pavement, granular sub-base layer and DBM layers which show the cost-effectiveness of nanochemical application for pavement construction.

Thus, Mechanical strength characteristics of the sample show a considerable increase in strength when stabilized with an optimum dosage of nanochemical compared to untreated soil at all curing periods. Hence it can be concluded from the study that the addition of nanochemical as a stabilizer has a significant influence on the strength characteristics of low strength soils. The application of nano technological stabilization for ground improvement works enables the usage of local soil as much as possible in the field. And thus the cost of soil replacement, digging and transportation can be avoided. Thus, it has the added advantage of savings in the cost and construction time.

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