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Effect of Combination of Nanomaterials on Performance of Black Cotton Soil

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Abstract: **-- Soil stabilization has become useful solution to treat the weak soil to achieve the required engineering properties. Soil stabilization by adding materials such as cement, lime, bitumen, etc. is the effective method for improving the geotechnical properties of soil which have been applied for many years now. This research is intended to study the effect of adding nanomaterials (nano-copper and nano-silica) on geotechnical properties of soil especially Atterbergs limit, compaction characteristics, unconfined compressive strength, CBR value and swelling pressure. Nanomaterials were mixed with soil in three different percentages (i.e. 1, 1.5, 2.5 % and 0.3, 0.6, 0.9 % by weight of soil). Based on obtained results, in order to reach the maximum increase in strength parameters, the optimum nano-copper and nano-silica content occur at 1.5 % and 0.6 %.**

Keywords: **- Stabilization, Geotechnical Properties,Nano-Cu, Nano-Si, CBR, Swelling Pressure.**

I. INTRODUCTION

The black cotton soil is one of the major soil deposit in India and its spread 300000 km2. The black cotton soil extends over the states of Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh, Tamilnadu and Uttar Pradesh. These soils are expansive in nature due to presence of Montmorillonite and Illite clay minerals. The soil surface is hard in nature in summer season but becomes slushy and loses its strength substantially during rainy season. The volume change up to a depth of 1.5 m generally occurs due to seasonal moisture changes. The highly loaded structures are most susceptible to damages as a result of volume changes. Because of the swelling and shrinkage characteristics of soil, special treatment of the soil or special design needs to be adopted. To enhance the properties of the weak soil, many methods like soil stabilization, soil reinforcement, grouting, addition of admixtures etc. are being adopted. Addition of admixtures like lime, fly ash, bitumen based on type of soil improves the properties of soil to some extent. Use of industrial waste as additives is recently under study, but it arises a question of toxicity. So there is a need for finding a new innovative material. One of the new innovative fields recently introduced to soil is Nanotechnology. Nanotechnology is the science that deals with the particles which are in nonmetric scale, play a crucial role in the behaviour of soil exhibiting different properties. This technology is already being used in various fields of civil engineering, but it is recently introduced to soil stabilization. Use of these nano particles (in order of 10-9) in stabilization influences the shear strength, dry density, CBR value, permeability and bearing capacity of the soil and makes more reactive to soil because of its high specific surface area. The Fig.1.1 shows the soil and nanomaterials interaction phenomenon.

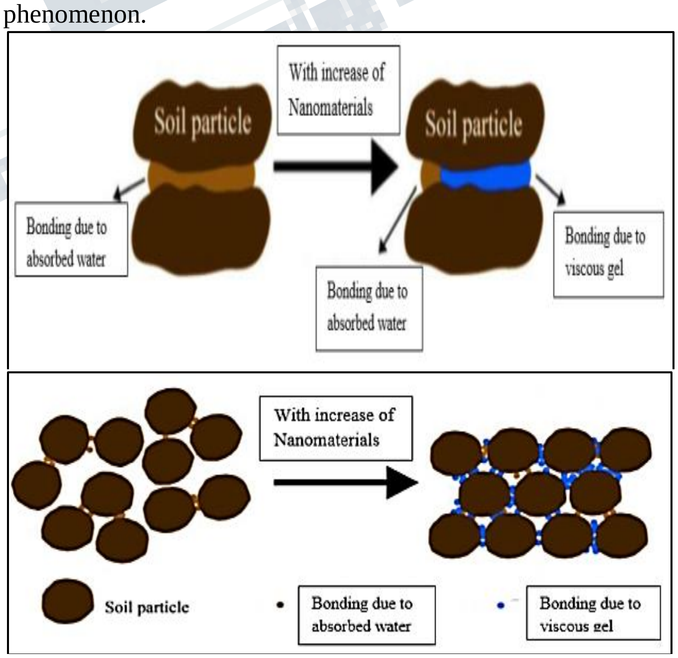

Fig. 1.1: Interaction of Soil and Nanomaterial Particle

In this investigation, an attempt is made to investigate the influence of nanoparticles in the improvement of black cotton soil. The nanomaterial used in the project work is nano-copper and nano-silica powder.

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II. LITERATURE REVIEW

Muthyalu1et al. (2012) carried out the experimentation to investigate the influence of electrolytes i.e., potassium chloride, calcium chloride and ferric chloride on the properties of expansive soil. Electrolytes like KCl, $CaCl_2$ and $FeCl_3$ were mixed in different proportions to the expansive soil and the physical properties like liquid limit, plastic limit, shrinkage limit and DFS of the stabilized expansive soil were determined to study the influence of electrolytes on the physical properties of the expansive soil. It was observed that plasticity index and differential free swell index was decreased. The CBR and UCS values were increased for a curing period of 14 days.
Kenawi and Kamel2 (2013) carried out the experimental investigation on expansive soil. The soil was treated with chemical additives (Addicrete P) 0.5%, 1% and 2% by dry weight of soil. As the amount of additives was increased, there were apparent reductions in optimum moisture content, unconfined compressive strength, and free swell, swelling potential and swelling pressure, and a corresponding increase in maximum dry density and continued to increase or decrease over time. Based on the results obtained, it was concluded that the expansive soil can be successfully improved by Addicrete P. Mishra3 (2013) carried out the experimental investigation on engineering behavior of black cotton soil and its stabilization by use of lime. Lime (3% and 5%) was added to black cotton soil and stabilization took place by virtue of pozzolanic reaction. A reaction took place between hydrated lime and clay particles and resulted in formation of permanent strong cementation matrix. The basic properties of soil were determined. Changes in various soil properties like liquid limit, plastic limit, California Bearing Ratio (CBR) and maximum dry density were analyzed. The properties of black cotton soil were effectively improved by use of different percentage of lime content. Raut4et al. (2014) carried the experimental investigation to check out the improvements in the properties of expansive soil with fly ash, murrum in varying percentages. The laboratory tests had been carried out and results were presented. The work consists results of index properties, compaction characteristics (optimum moisture content and maximum dry density) and shear strength parameters (cohesion and angle of shearing resistance) for the murrum blended with varying percentages of sand, clay, and combination of both sand and clay mixtures. Neethu and Remya5 (2013) carried out the experimental investigation on the engineering behavior of soil treated with different percentages of nanomaterial. An experimental program was conducted to study the effect of nanomaterial on compaction characteristics, consolidation parameters, permeability and unconfined compressive strength for both soils. Soils were mixed with different concentrations of nanoclay (0.25%, 0.5%, 1%, 1.5% and 2%) and the entire tests were carried out. By the addition of nanomaterial, unconfined compressive strength got increased for lateritic soil and kaolinite clay.
Mohammadi and Niazian6 (2013) carried out the experimental investigation oneffect of nano-material on geotechnical properties of Rasht clay. A different percent of nano-clay Montmorillonite had been used in order to check out created changes in soil characteristics with increasing percent of Nano-clay. The Atterberg limit tests were used to study the effect of mentioned Nano-particle on plastic features of soil. Two different weight percent of Nano-clay is applied in soil (1% and 2% Nano-clay). Unconfined pressure test, direct shear test and CBR test are used as strength tests to study the influence of Nano-clay on features of soil strength. In these tests four different weight percent of Nano-clay (0.5%, 1%, 1.5% and 2% Nano-clay) used to study created changes by increasing of Nano-clay percent.
Priyadharshini and Arumairaj7 (2015) carried out the experimental investigation on improvement of bearing capacity of soft clay using nanomaterials. Theeffect of three types of nanomaterials (nano clay, nanoMgO and nano Al_2O_3) on Atterberg's limits, compaction characteristics, unconfinedcompressive strength, consolidation parameters and model plate load test were investigated. The nanomaterial was mixed with soft clay at variouspercentages to study the geotechnical properties. The optimum percentage of nanomaterial was obtained. The consolidation settlement behaviorwas studied at the optimum dosage of nanomaterial.
Hareesh and Vinothkumar8 (2016) carried out the experimental investigation on assessment of nano materials on geotechnical properties of clayey soils.The effect of Nano materials (nano silica and nano zeolite) on differential free swell, Atterberg's limits, compaction characteristics and unconfined compressive strength were investigated. The Nano materials were mixed with two soil samples (CH & CI) in varying proportions of nanosilica (0.2%, 0.4%, 0.6%, 0.8% and 1.0%) and nanozeolite (0.4%, 0.8%, 1.2%, 1.6% and 2%) to study the geotechnical properties of soil. The results showed the expansive nature of soil got decreased and Atterberg's limits and shear strength characteristics of soils got increased with increase in percentages of nanomaterials.
The work carried out by various author shows that the study on black cotton soil is lagging for combinations of different nanomaterials. There is a need to study the effect of different combinations of nanomaterials on the performance of black cotton soil.

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III. MATERIALS

3.1. Soil

Soil used in experimental investigation is a locally available black cotton soil. The soil was selected by conducting DFS test.Table 1 shows the index properties of soil. The soil is classified as CH type and based on FSI value the soil gets high swell classification. From Unconfined compression test, it was found that the shear strength of the untreated soil is 151.15 kN/m2 at optimum moisture content. The Table 3.1 shows the index properties of soil.

Table 3.1: Index Properties of Soil

Sr. No.	Properties of Clay	Value
1.	Atterberg's Limits	
	Liquid Limit (%)	49.80
	Plastic Limit (%)	18.35
	Plasticity Index (%)	31.36
	Shrinkage Limit (%)	13.39
2.	IS-Classification	CH(clay of high plasticity)
3.	Free Swell Index (%)	60.00

3.2. Nanomaterials

The nanomaterials which were used in the experimental investigation were described here.The nano-copper powder which was used in the experimental investigation for stabilizing the black cotton soil was procured from Ladhani Metal Corporation, Mumbai having size 325μ. The nano-silica powder which was used in the experimental investigation for stabilizing the black cotton soil was procured from Adinath Industries, Rajasthan having size 250μ. The nano-copper and nano-silica powder is as shown in Fig. 3.1.

Fig. 3.1: Nano-copper Powder and Nano-silica Powder

IV. METHODOLOGY

The series of experimental investigation were conducted on untreated and treated soil to evaluate the effectof nano-copper and nano-silica powder on black cotton soil. In this, the soil was mixed with combinations (1% + 0.3%, 1.5% + 0.6%) of various percentages of nano-copper and nano-silica. The stabilizers were thoroughly mixed with soil and standard proctor test was then conducted to determine OMC and MDD. The soil samples were then prepared for UCS test using water content corresponding to OMC as determined from the Standard Proctor Test. UCS test was then conducted and UCS was determined. The swelling pressure test, CBR (unsoaked) and CBR (soaked) were also conducted on soil mixed with the same combination of stabilizers.

4.1 Test Adopted

The various tests which were performed in the experimental investigation are

i. Free Swell Index
ii. Atterbergs Limit
iii. Standard Proctor Test
iv. Unconfined Compression Strength Test
v. California Bearing Ratio Test (Unsoaked and Soaked)
vi. Swelling Pressure

The free swell index tests were conducted on treated soil specimens according to IS: 2720 (Part 40) 1977. The Atterbergs limit were found out according to IS: 2720 (Part 5) 1985. The smooth paste of soil from 425μ was made by adding different percentage of nano-copper and nano-silica and allow for drying which forms the dry paste. After that the dry paste was broke down into a fine powder and then tested.

The standard proctor tests were conducted according to IS: 2720 (Part VII) 1980 on untreated treated soil. The MDD and OMC was determined for various combinations of nano-copper and nano-silica. The soil samples were then prepared for UCS test using water content corresponding to OMC which were determined from the Standard Proctor test. The effect of curing on treated soil specimens were find out. The specimens were wrapped in polythene bags and then kept in desiccator for curing period of 7 and 28 days as shown in Fig. 4.1.1.

The CBR tests were conducted on soil mixed with nano-copper and nano-silica for both soaked and unsoaked conditions. The soil samples were kept for curing after preparing the mould by covering it with polythene bag for 7 days and then test were conducted, as shown in Fig. 4.1.2. In case of soaked CBR the samples were again kept for soaking for 4 days then tests were conducted.

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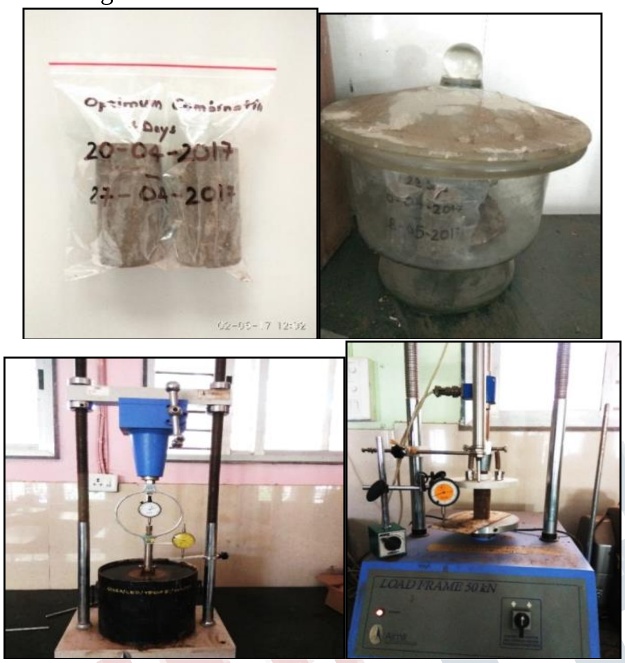
For different combination of nano-copper and nano-silica the quantity corresponding to the percentage was mixed to the oven dried sample of soil and Swelling pressure tests were conducted. The test set up for swelling pressure test is as shown in Fig. 4.1.3.



(a) Sample Wrapped in Polythene Bag (b) Desiccator (c) UCS Test Set up

Fig.4.1.1: Procedure of Unconfined Compressive Strength Test

Fig. 4.1.2: CBR Samples Kept for Curing and CBR Test Set up

Fig. 4.1.3: Set up for Swelling Pressure Test

V. RESULT AND DISCUSSION

The laboratory tests were conducted on original black cotton soil as obtained from field. The various properties of soil were determined in the laboratory as per ISand presented in Table 5.1.

Table 5.1: Properties of Untreated Black Cotton Soil

Sr. No.	Properties of Clay	Value
1.	Liquid Limit (%)	49.80
2.	Plastic Limit (%)	18.35
3.	Shrinkage Limit (%)	13.39
4.	Optimum Moisture Content (%)	28.50
5.	Maximum Dry Density (kN/m³)	15.30
6.	Swelling Pressure (kN/m²)	122.23
7.	Free Swell Index (%)	60.00
8.	UCS (kN/m²)	151.15
9.	CBR (Soaked %) (Unsoaked %)	1.45 7.44

5.1For Combination of 1% Nano-copper and 0.3% Nano-silica

The tests were conducted on soil mixed with combination of 1 % nano-copper and 0.3 % nano-silica and the Table 5.1.1 shows the results obtained from the free swell index test.

Table 5.1.1: Variation of FSI for combination of 1 % Nano-copper and 0.3 % Nano-silica

Test	Combination of 1 % Nano-copper and 0.3 % Nano-silica	
	Sample 1	Sample 2
FSI (%)	30	28

The tests were conducted on soil mixed with combination of 1 % nano-copper and 0.3 % nano-silica. The Table 5.1.2 shows the results obtained from the liquid limit, plastic limit, plasticity index and shrinkage limit for combination of 1 % nano-copper and 0.3 % nano-silica. The standard proctor tests were conducted on soil mixed with combination of 1 % nano-copper and 0.3 % nano-silica.

Table 5.1.2: Atterbergs Limit for combination of 1 % Nano-copper and 0.3 % Nano-silica

Tests	Combination of 1 % Nano-copper and 0.3 % Nano-silica	
	Sample 1	Sample 2
Liquid Limit	47.00	49.10
Plastic Limit	19.22	21.00
Plasticity Index	27.78	28.10
Shrinkage Limit	11.90	13.00

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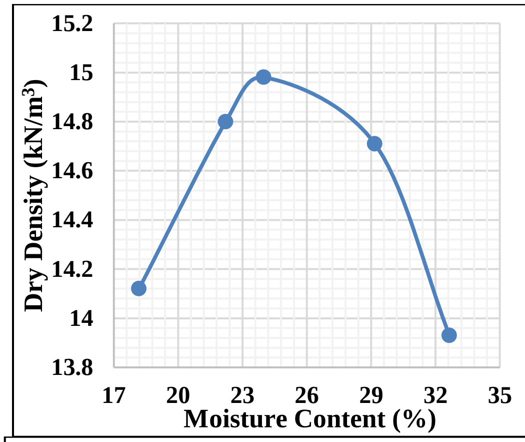
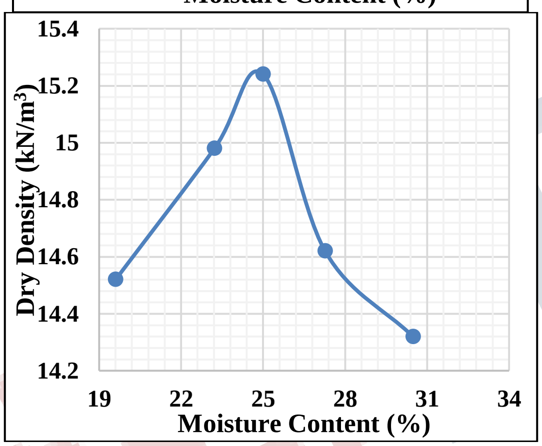
The Table 5.1.3 and Fig. 5.1.1 shows the results obtained from the standard proctor test for the combination of 1 % nano-copper and 0.3 % nano-silica.





Sample-1 (b) Sample-2

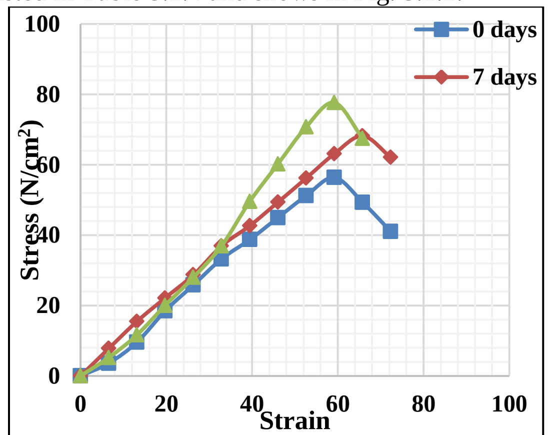
Fig. 5.1.1: Compaction Curves for Combination of 1 % Nano-copper and 0.3 % Nano-silica

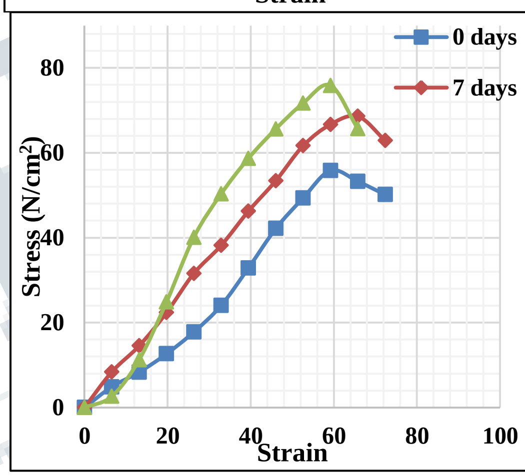
The unconfined compressive strength of treated specimen with combination of 1 % nano-copper and 0.3 % nano-silica was obtained by conducting UCS test for combination of 1 % nano-copper, 0.3 % nano-silica and curing period.

Table 5.1.3: Variation of Compaction Characteristics for Combination of 1 % Nano-copper and 0.3 %Nano-silica

Tests	Combination of 1 % Nano-copper and 0.3 % Nano-silica	
	Sample 1	Sample 2
OMC (%)	24.00	25.00
MDD (kN/m3)	14.98	15.24

The unconfined compressive strength of treated soil samples was listed in Table 5.1.4 and shows in Fig. 5.1.2.





Sample-1 (b) Sample-2 Fig. 5.1.2: Unconfined Compressive Strength for Combination of 1 % Nano-copper and 0.3 % Nano- silica and Curing Period

Table 5.1.4: Unconfined Compressive Strength for Combination of 1.5 % Nano-copper and 0.3 % Nano-silica and Curing Period

Test	Curing Period	Combination of 1 % Nano-copper and 0.3 % Nano-silica	
		Sample 1	Sample 2
Unconfined Compressive Stress (kN/m2)	0 days	547.70	552.8
	7 days	672.55	668.75
	28 days	744.28	761.55

CBR tests were carried out on treated soil for soaked and unsoaked condition. Soil sample were kept for maturing for 7 days in unsoaked condition and then tested in case of unsoaked condition while again soaked for 4 days in soaked condition and then tests were performed. The CBR values for

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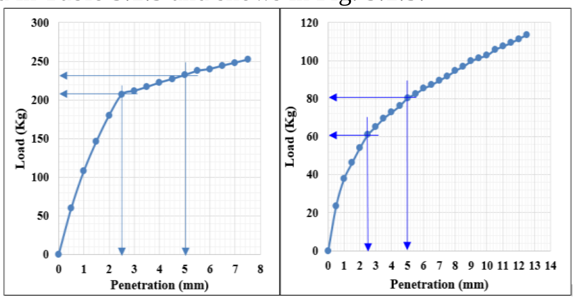
combination of 1 % nano-copper and 0.3 % nano-silica were listed in Table 5.1.5 and shows in Fig. 5.1.3.



(a) Sample – 1 (Unsoaked) (b) Sample – 1 (Soaked)
(c) Sample – 2 (Unsoaked) (d) Sample – 2 (Soaked)

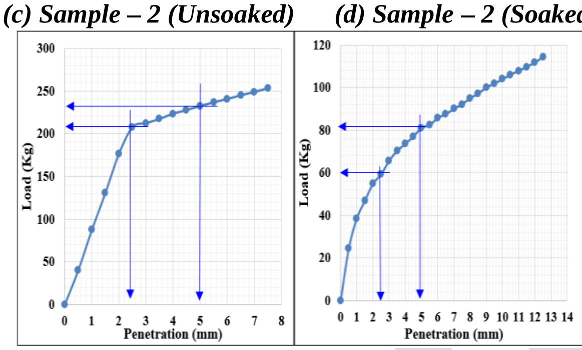


Fig. 5.1.3: CBR Values for Combination of 1 % Nano-copper and 0.3 % Nano-silica

The swelling pressure test was conducted on the combination of 1 % nano-copper and 0.3 % nano-silica. The results showed that for the combination of 1 % nano-copper and 0.3 % nano-silica the swelling pressure was 90.35 kN/m2.

Table 5.1.6: CBR Values for Combination of 1 % Nano-copper and 0.3 % Nano-silica

Test	Combination of 1 % Nano-copper and 0.3 % Nano-silica	
	Sample 1	Sample 2
CBR (Soaked)	4.45	4.32
CBR (Unsoaked)	15.08	15.16

5.2For Combination of 1.5% nano-copper and 0.6% nano-silica

The tests were conducted on soil mixed with combination of 1.5 % nano-copper and 0.6 % nano-silica.

Table 5.2.1 shows the results obtained from the free swell index test for combination of 1.5 % nano-copperand 0.6% nano-silica.

Table 5.2.1: Variation of FSI for combination of 1.5 % nano-copper and 0.6 % nano-silica

Test	combination of 1.5 % nano-copper and 0.6 % nano-silica	
FSI (%)	Sample 1	Sample 2
	10	13

The tests were conducted on soil mixed with combination of 1.5 % nano-copper and 0.6 % nano-silica. The Table 5.2.2 shows the results obtained from the liquid limit, plastic limit, plasticity index and shrinkage limit for combination of nano-copper and nano-silica.

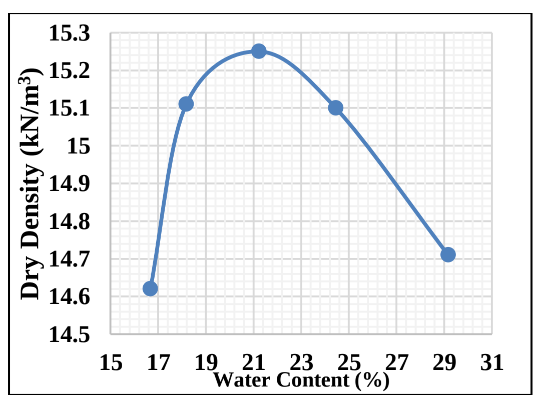
Table 5.2.2: Atterbergs Limit for combination of 1.5 % nano-copper and 0.6 % nano-silica

Tests	combination of 1.5 % nano-copper and 0.6 % nano-silica	
	Sample 1	Sample 2
Liquid Limit	46.00	45.00
Plastic Limit	21.50	23.50
Plasticity Index	24.50	21.50
Shrinkage Limit	7.74	10.88

The standard proctor tests were conducted on soil mixed with combination of 1.5 % nano-copper and 0.6 % nano-silica. The Table 5.2.3 and Fig. 5.2.1 shows the results obtained from the standard proctor test for the combination of 1.5 % nano-copper and 0.6 % nano-silica.

Table 5.2.3: Variation of Compaction Characteristics for combination of 1.5 % nano copper and 0.6 % nano-silica

Tests	combination of 1.5 % nano-copper and 0.6 % nano-silica	
	Sample 1	Sample 2
OMC (%)	21.00	23.44
MDD (kN/m3)	15.25	15.35



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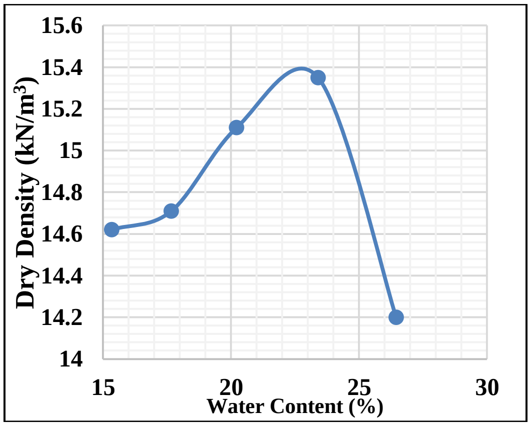
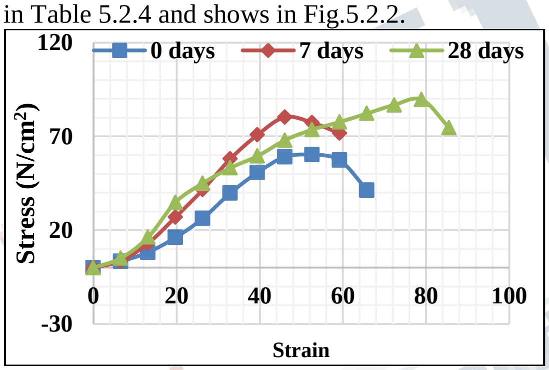


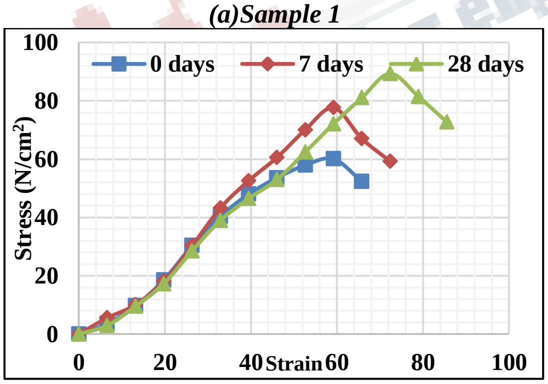
(a) Sample 1 (b) Sample 2

Fig. 5.2.1: Compaction Curves forcombination of 1.5 % nano-copper and 0.6 % nano-silica.

The unconfined compressive strength of treated specimen withcombination of 1.5 % nano-copper and 0.6 % nano-silica was obtained by conducting UCS test with curing period. The unconfined compressive strength of treated soil samples was listed in Table 5.2.4 and shows in Fig.5.2.2.



(a)Sample 1



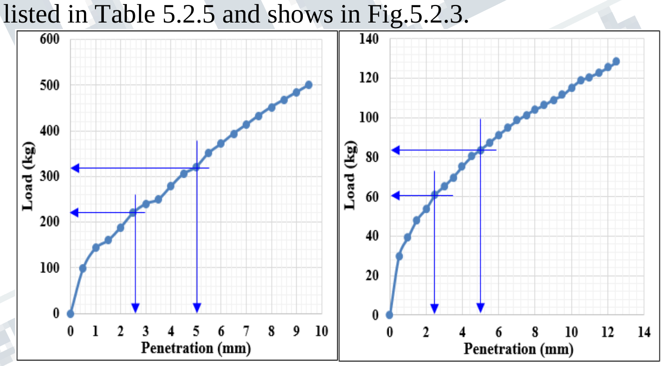
(b) Sample 2

Fig. 5.2.2: Unconfined Compressive Strength for combination of 1.5 % nano-copper and 0.6 % nano-silicaand Curing Period

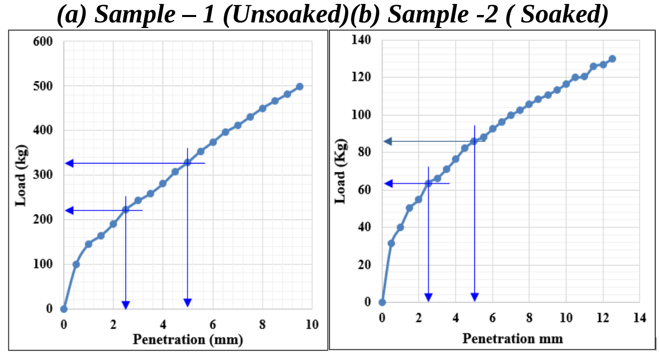
Table 5.2.4: Unconfined Compressive Strength for combination of 1.5 % nano-copper and 0.6 % nano-silica and Curing Period.

Test	Curing Period	Combination of 1.5 % nano-copper and 0.6 % nano-silica	
		Sample 1	Sample 2
Unconfined Compressive Stress (kN/m2)	0 days	590.07	589.28
	7 days	787.06	761.55
	28 days	878.87	877.60

CBR tests were carried out on treated soil for soaked and unsoaked condition. Soil sample were kept for maturing for 7 days in unsoaked condition and then tested in case of unsoaked condition while again soaked for 4 days in soaked condition and then tests were performed. The CBR values for combination of 1.5 % nano-copper and 0.6 % nano-silica were listed in Table 5.2.5 and shows in Fig.5.2.3.



(a) Sample – 1 (Unsoaked)(b) Sample -2 (Soaked)



(c) Sample – 2(Unsoaked)(d) Sample – 2 (Soaked)

Fig. 5.2.3: CBR Values for combination of 1.5 % nano-copper and 0.6 % nano-silica.

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Table 5.2.5: CBR Values for Combination of Nano-copper and Nano-silica

Test	combination of 1.5 % nano-copper and 0.6 % nano-silica.	
	Sample 1	Sample 2
CBR (Soaked)	4.45	4.63
CBR (Unsoaked)	16.11	16.56

The swelling pressure test was conducted with the combination of 1.5 % nano-copper and 0.6 % nano-silica. The results showed that for the combination of nano-copper and nano-silica the swelling pressure was 85.23 kN/m2.

VI. DISCUSSION

The Fig. 5.3.1 shows the variation of free swell index for 0 %, 0.3 % nano-silica + 1 % nano-copper and 0.6 % nano-silica + 1.5 % nano-copper. From Fig. 5.3.1 it was observed that combination of0.6 % nano-silica + 1.5 % nano-copper was most effective for reducing free swell index of soil.

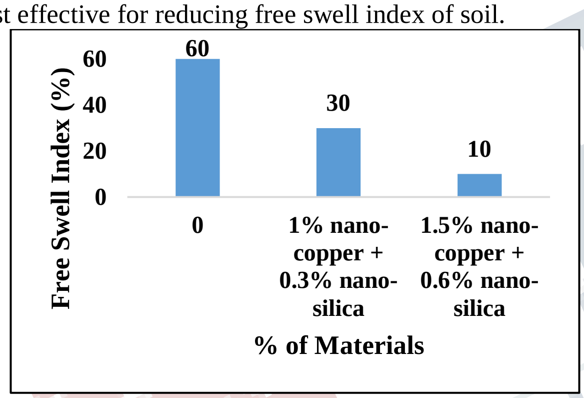

Fig. 5.3.1: Variation in Free Swell Index

The variation in Atterbergs limit were shown in Fig. 5.3.2.

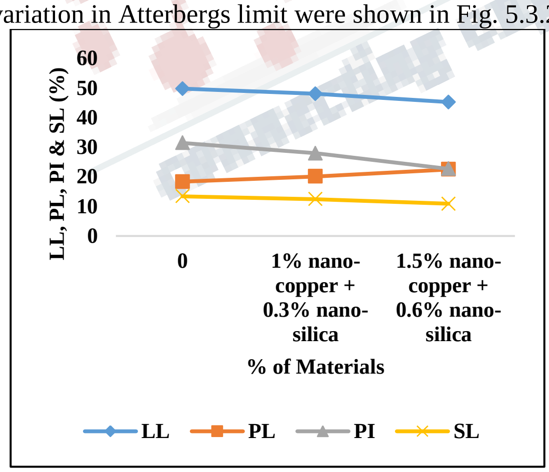

Fig. 5.3.2: Variation in Atterbergs Limit

Fig. 5.3.3 shows the variation in optimum moisture content and maximum dry density according to various percentages of nano-copper and nano-silica. It was observed that the optimum percentage for increased in dry density and decreased in moisture content was combination of 0.6 % nano-silica + 1.5 % nano-copper.

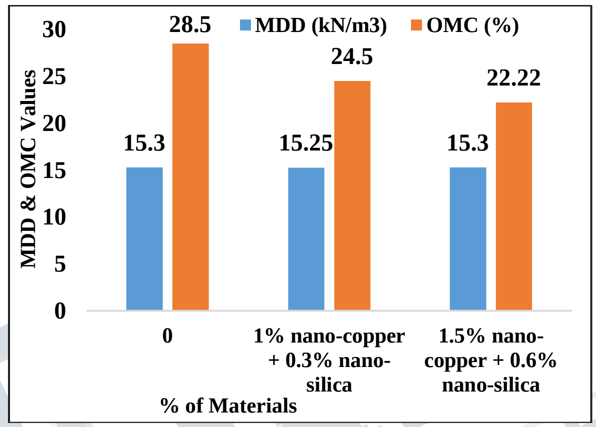

Fig. 5.3.3: Variation of MDD and OMC

The unconfined compressive strength of treated soil for 0, 7 and 28 days were shown in Fig. 5.3.4. The maximum strength was achieved after 28 days of curing for combination of 0.6 % nano-silica and 1.5 % nano-copper.

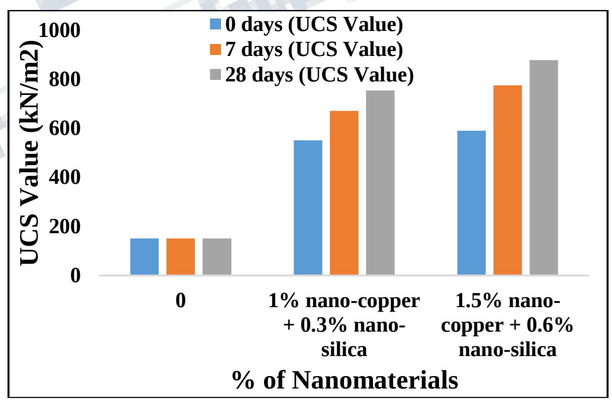

Fig. 5.3.4: Variation inUnconfined Compressive Strength for 0, 7 and 28 days of Curing

The Fig. 5.3.5 shows the CBR value for soaked and unsoaked condition for different percentage of nano-copper and nano-silica. The CBR value was maximum in case of combination of 0.6 % nano-silica + 1.5 % nano-copper.

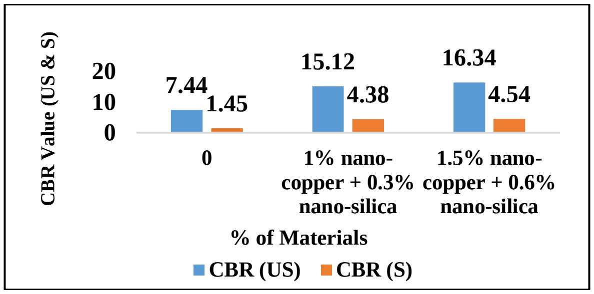

Fig. 5.3.5: Variation in CBR Value for Soaked and Unsoaked Condition

The swelling pressure for different percentage of materials were shown in Fig. 5.3.6. The swelling pressure was minimum in case of combination of 1.5% nano-copper and 0.6% nano-silica.

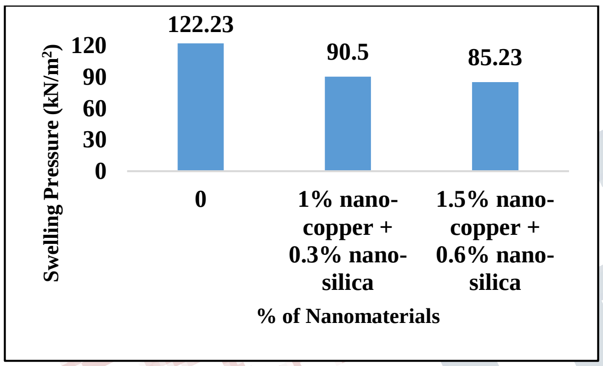

Fig. 5.3.6: Variation in Swelling Pressure

VI. CONCLUSIONS

1. The liquid limit, plasticity index and shrinkage limit of soil decreases, due to addition of optimum percentage of nano-copper (1.5 %) and nano-silica (0.6 %) powder.
2. The optimum moisture content of soil significantly decreases, due to addition of optimum percentage of nano-copper (1.5 %) and nano-silica (0.6 %) powder.
3. The unconfined compressive strength of soil increases due to addition of optimum percentage of nano-copper (1.5 %) and nano-silica (0.6 %) powder. It also increases with curing period and it is greater than corresponding values for nano-copper and nano-silica powder separately.
4. The CBR value of soil increases, for both soaked and unsoaked condition, due to addition of optimum percentage of nano-copper (1.5 %) and nano-silica (0.6 %) powder.
5. The swelling pressure of soil reduces significantly with the addition of optimum percentage of nano-copper (1.5 %) and nano-silica (0.6 %) powder.
6. The liquid limit, plasticity index and shrinkage limit of soil decreases, with the addition of nano-copper (1 %) and nano-silica (0.3 %) powder.
7. The optimum moisture content of soil decreases and maximum dry density increases, with the addition of nano-copper (1%) and nano-silica (0.3 %) powder.
8. The unconfined compressive strength of soil increases with the addition of nano-copper (1 %) and nano-silica (0.3 %) powder. It also increases with curing period, and it is greater than corresponding values of nano-copper and nano-silica powder separately.
9. The CBR value of soil increases, for both soaked and unsoaked condition, due to addition of nano-copper (1 %) and nano-silica (0.3 %) powder.
10. The swelling pressure of soil reduces due to addition of nano-copper (1 %) and nano-silica (0.3 %) powder.

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