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Durability of Active Soil Stabilized with Nanomaterial

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Abstract— *Several efforts are being put forward to manage the swell-shrink characteristics of active soils in Nigeria's Niger Delta. These dynamic or expanding soils have an impact on all types of infrastructure, including roads built with or put on them. The wetting-drying durability of active soil stabilized using nanomaterial, an organo-silane compound containing nonfunctional organic trialkoxy groups and R, (alkyl) group is investigated in this article. This research focuses on more efficient exploitation of the region's abundant active soils for sustainable civil engineering practice. The influence of soil modification on the strength behavior and durability of active soil improves with nanomaterial combination throughout wetting-drying cycles is of special interest. Different cylindrical stabilized soil samples were constructed in nanomaterial water ratios of 1:250, 1:200, 1:150, 1:100, and 1:50. Unconfined compressive strength tests were performed on samples that had been untreated and treated with nanomaterial and cured for a minimum of 1 day and 7 days. The results reveal that as the nanomaterial content and cure period increased, so did the compressive strength. Compressive strength values were higher in 7-day cure specimens than in 1-day cure specimens. UCS values increased from 6.90 kN/m2 to 185.9 kN/m2 with the application of the stabilizer, the durability improved significantly from low values in excess of 37.1 percent at low content to extremely high values in excess of 80 percent with greater nanomaterial content. Statistical tests on effects on nanomaterial performed at 95% confidence limit on the addition of different proportions of nanomaterial to the soil have a significant effect on 7-day cure, samples only from nanomaterial content greater than or equal to 1:50.*

Keywords— *Wetting – drying, Active Soils, Strength, Durability, Stabilization, Nanomaterial.*

I. INTRODUCTION

In the southern region of Nigeria, active soils damage and, to large extent, virtually affect infrastructural development. They are expansive soils that swell significantly during the wet season and shrink substantially during the dry seasons, which affect any technical structures required for society's operation, such as buildings, roads, electrical grids, and telecom communications, which are built on them (Ugwu et al., 2014., Okagbue, 2014, and Omotosho and Ogboin, 2009). Civil engineers face a variety of issues when dealing with active or expanding soils. They are regarded as a possible natural threat that, if not properly addressed, can cause considerable damage to infrastructure (Al-Rawas et al., 2002).

In several locations in Nigeria, active soil deposits have been found and reported. The most common clay mineral in Nigeria's active soils is Montmorillonite. In most soil samples, chemical (X-ray) examination revealed a montmorillonite to kaolinite ratio of roughly 7:3 (Ola, 1983a and Ola, 1983b). In fact, during a tropical rainy season in the Niger Delta, there are abundant water molecules (combined with the high specific surface of fine montmorillonite tiny grains) exert immense pressure at the interface, separating and pulling apart from each crystal plate, resulting in a large swelling. However, during the dry seasons, the infiltrating water evaporates through capillary holes, causing the crystal sheet to shrink or collapse, as seen in Figure 1.

Figure 1. Alluvial Clay within Area of Studies (Source: Research Field Survey Data)

Civil infrastructures constructed on active soils are often prone to large uplift forces during wet seasons. This causes heaving, cracking, and possibly catastrophic collapse. However, in the dry season when the soil shrinks, such structures often break down or collapse together. This explains why the cracks on building walls at Isiebu-Umuduru in Imo State were even visually observed to open wider in the wet season but close noticeably in the dry season (Omotosho, 1990). Thus, in its natural state and because of the cycle of seasonal swelling and shrinking, an active soil is not a reliable foundation or construction, material. This also explains why even the natives in the Niger Delta hinterland could not use the active soils for local building construction. Instead, the soil is used only as molded filler for a wooden skeleton as shown in Figure 2.

More specially, road construction on and/or with active soils has also been highly problematic. First such roads often act like a dam that retains back swamp flood on both sides of the embankment in the rainy season and as such water accumulates. All these cumulatively result in further aggregation of the embankment fill material activity thereby causing further soil softening and swelling. As a result, the entire road pavement gets lifted up destructively to collapse under traffic loading. Moreover, as the water evaporates through the capillary pores in the dry seasons; whatever remains of the road pavement structure finally capitulates.

Figure 2. Typical Reinforced (Active Soil) mud house in Niger Delta (Source: Research Field Data)

It is, therefore, necessary to characterize the active soils of the Niger Delta. Although, there are several ways to characterize active soils and since there is no full-proof method, geotechnical Engineers adopt a systematic method for identification. The characterization is based on the index properties such as Particle Size Distribution, Plasticity Index, Shrinkage Units, Linear Shrinkage, Clay Content, and Potential Swell, and in summary, characterizations are based generally on a combination of mineralogical and particularly physic-chemical properties. This will be followed to classify the Niger Delta active soils for proper identification of them.

The active soils in the natural state pose enormous limitations on the engineering application and predominate in the Niger Delta area (George, et al., 2006).

The authors intend to explore the effect of a moist climate on stabilized active soil of the Niger Delta environment, which is characterized by wetting-drying cycles. Therefore, 1 and 7-day cured stabilized active soil samples were examined for unconfined compressive strength after undergoing various numbers of wetting-drying cycles.

Damages to building foundations, pavement roadways, slab-on-grade members, irrigation systems, channels, water lines, and sewer lines caused by swelling action were formerly thought to be a problem exclusively in arid and semi-arid sections of the world (Cokca, 2001). However, in the Niger Delta's freshwater zone, active or expansive soil degradation has become a widespread, costly, and little-publicized geotechnical concern. The soil-moisture variation caused by the 2012 flood amplified and demonstrated its negative impact. Several roads were cut and destroyed, causing them to fail completely. Electrical grids and telecommunications systems collapsed, and numerous buildings were washed away, resulting in billions of naira in infrastructure losses (Bariwen et al., 2012.).

Akokodje and Arumala, (1987) proposed that a pavement design comprising of properly cement stabilized base course, compacted sub-grade/sub-base, paved shoulders, and efficient drainage would provide good performance while avoiding the costly hauling of better base materials from long distances. In connection to the area's geotechnical issues, Olorunfemi, (1983) suggested the use of lime-cement, lime stabilization and combinations, tree sap, and reforestation.

Arizona, (2011) reported that in the Niger Delta region, the problem of substandard roads has become an embarrassment. Bad roads have hampered regular contact in many parts of this region. This circumstance has a direct negative impact on infrastructural development, causing major decay as well as other issues related to durability and maintenance. As a result, there is a projected infrastructural deficit of billions of dollars (Ugwu et al., (2014).

The Niger Delta's active soils are unique and irreplaceable (both vertically and laterally). It is vital to enhance the engineering characteristics of the active soil by improving it with stabilizing substances that re-engineer the active soil for improved engineering applications. Nanomaterials, which are by-products of nanotechnology, may offer a novel solution to this age-old problem (Ugwu et al., (2014). Such an important technique would increase the Niger Delta environment's durability, stability, and soil waterproofing criteria. In general, multiple researchers have looked at the use of various types of stabilizers to improve the engineering properties of expansive soil.

There is a lot of information available on soil enhancement by the use of additives, particularly lime and cement. Many studies have recently reported on supplements that might potentially replace lime as a soil modifier. Such supplements include fly (Kolias and Kasselour, 2005), rice husk (Muntohar, 1999); (Mountohar and Hantoro, 2000), marble dust (Okagbue and Onyeobi, 1999), limestone ash (Okagbue and Yakubu, 2000) (cited in (Okagbue, 2007) marble waste, (Celik and Sabah 2008) and Nanomaterial (19 Taha, 2009; Ugwu, 2013, Ugwu et al., 2014).

However, Ola, (1983a) investigated the durability and strength of expansive soils in Nigeria. With the percentages employed, unconfined compressive lab tests did not attain the seven-day strength of 1,723.75 kN/m^2 specified as a criterion for satisfactory cement stabilization. The durability test was performed utilizing the 12th cycle of soaking and drying to assess the adequacy of the soil stabilization. The results were determined to be less than the maximum weight loss and volume gain of 1.5 percent each. In general, he suggested analyzing the three criteria for establishing the appropriateness of soil stabilization, namely CBR, durability, and unconfined compressive strength test, while keeping economic feasibility in mind.

II. MATERIALS AND METHOD

The Active Soil used in this investigation was sourced from the Niger Delta area, while the Nanomaterial was sourced from manufacturers and distributors (VXL Nig. Ltd.).

TABLE 1. Samples location and state

Location No.	State in Niger Delta/Town
Loc 1-R	Rivers-Atese
Loc 2-R	Rivers-Mbiama
Loc 3-B	Bayelsa-Opokuma
Loc 4-B	Bayelsa-Kiama
Loc 5-D	Delta-Patani

The active soil samples were collected from five different locations within the Niger Flood Zone in Southern Nigeria. As stated in Table 1, they are; two sites in Rivers State, two sites in Bayelsa State, and one in Delta State.

Generally, the freshwater alluvial or active soil covers the Niger Delta Zone from the relatively low-lying board and more gently sloping portion of the Niger Delta Basin. They comprise small meander oxbow lakes, flooded plains, alluvial cones, alluvial fans, natural levees of rivers, creeks, and black swamps.

It is commonly recognized that the active soil makes up a significant component of the Niger Delta's freshwater zone. The annual rainfall in these locations exceeds 2000mm, yet the topography is nearly flat, resulting in hindered drainage and (as a result) inadequate laterization.

The zone defined by Akokodje and Arumala, (1987) is characterized by particularly active (montmorillonite) silty clay on the surface. However, active soils stand out better for now as the most viable slope stability materials in the freshwater or (Niger Flood) zone in the Niger Delta. Disturbed samples of these soils were collected from depths between 0.5 – 0.75 meters with diggers and shovels.

The nanomaterial is an organosilane compound with the following chemical composition: Oxygen – O (46.7%), Silicon – Si (27.0%). Aluminum – Al (8,1%), Iron – Fe (5.0%), Carbon – C (3.0%), Calcium – Ca (6.7%), Magnesium –Mg (1.4%), all others (approx. 2.1%). The ensuing section discusses the effect of the nanomaterial chemistry on the observed changes in soil geotechnical properties.

All specimens were air-dried in the laboratory, ground to pass through a 4.75mm sieve, and labeled as treated or untreated. Following air drying, samples were submitted to conventional classification tests in line with British Standard 1377 of 1990. Example sample combinations for Loc 1-R are shown in Table 2.

This was done similarly for all sites. The approach for measuring soil losses, moisture changes, and volume changes is covered in the measurement technique (swell and shrinkage). ASTM 599 approach was used to conduct this wet and dry test. Samples were prepared and then soaked in water at room temperature for 5 hours after a 7-day curing period, then placed in a 600°C oven for 42 hours, and then removed. Wire brushes the whole surface area to remove any loosened material from the soaking and drying process. On each section of the surface, two hard strokes were employed. These strokes were applied at full height, and the procedure took 5 hours of immersion in water, 42 hours of drying, and 1 hour of handling.

TABLE 2. Mixtures for experimental study.

Sample	Active soil (%)	Water nanomaterial ratio
Sample Loc 1-R	100	-
1:250	100	1:250
1:200	100	1:200
1:150	100	1:150
1:100	100	1:100
1:50	**100**	**1:50**

A total of 12 cycles makes up a whole operation. The test samples are dried to a constant weight of 1100C after 12 cycles, then weighed to ascertain the oven-dry weights.

For the measurement of the UCS, cylindrical samples were constructed. The split type mold was employed, with two semi-circular portions with a pipe circumference of 100mm and an area of 78.53 mm^2. In line with BS 1924, samples were examined for dry unconfined compressive strength.

III. RESULTS AND DISCUSSION

A summary of the preliminary investigation of the untreated specimens (natural state) is shown in Table 3.

TABLE 3. Physical properties of studied soils

Samples No.	Location Name	NMC (%)	LL (%)	PI (%)	C (%)	A (%)	Soil Classification	
							USCS	AASHO
Loc 1-R	Atese Rivers State	26	63.2	42.6	31.6	1.35	CH	A-7
Loc 2-R	Mbiama Rivers State	27	67.9	42.2	30.1	1.34	CH	A-7
Loc 3-B	Opokuma Bayelsa	23	56.0	38.9	28.2	1.38	CH	A-7
Loc 4-B	Kiama Bayelsa State	24	61.0	26.2	26.2	1.43	CH	A-7
Loc 5-D	Patani Delta State	19	51.0	24.9	24.9	1.28	CH	A-7

The clay concentration of the specimens taken from the five sites ranged from 25 to 32 percent. They are categorized as CH by the USCS, with activity levels ranging from 1.3 to 1.4, and are thus categorized as active calcium montmorillonite soils. All soil samples are characterized as having a high swelling potential (After Seed, et al; 1962).

Unconfined compressive strength tests were performed on samples that had not been treated and samples that had been treated with nanomaterial and cured for 1 and 7-days. Table 4 shows the results, while Figures 2 and 3 show the effect of adding the nanomaterial stabilizer. According to the findings, 7-day cure samples showed compressive strength values that were greater than 1-day cure samples, and UCS values rose as stabilizer concentration increased. The UCS values increased from 6.9kN/m^2 to 185.9kN/m^2, and statistical tests were performed to see if the changes in engineering properties were due to the use of the nanomaterial as a stabilizing agent.

The statistical data analysis compares the text values of the soil properties before and after treatment comparing the level of significance of the changes after treatment. As a result, 95 percent confidence intervals were used for the analysis of variance (ANOVA) testing.

Comment: since the value of F (0.4) is less than $F_{critical}$ (2.62), then the addition of different proportions of nanomaterials to the soil has **NO** significant effect on one-day unconfined compressive strength at 95% confidence limit. Hence, the analysis was repeated between the natural soil and soils amended with different proportions of nanomaterials. However, even at the maximum nanomaterial content of 1/50, there was no significant improvement in the 1-day compressive strength (see next Tables 7 and 8)

TABLE 4. Unconfined Compressive Strength Results

Loc	Mix	Weight Before Curing (kg)	Weight After Curing (kg)	Crushing Load (kg)		Compressive Strength (kN/m^2	
				1-day	7-day	1-day	7-day
1	0.0	1.732	1.601	14	45	21.1	69.0
	1:250	1.612	1.550	18	53	27.8	80.5
	1:200	1.772	1.566	27	85	41.2	129.3
	1:150	1.785	1.678	31	99	46.9	151.4
	1:100	1.742	1.609	38	118	58.4	180.1
	1:50	1.742	1.600	35	122	53.7	185.9
2	0	1.698	1.575	15	54	23.0	82.4
	1:250	1.709	1.614	23	76	35.5	115.9
	1:200	1.694	1.639	36	114	54.6	173.4
	1:150	1.723	1.629	39	116	59.4	177.2
	1:100	1.754	1.667	37	117	56.5	178.2
	1:50	1.750	1.640	41	120	62.3	180.3
3	0	1.765	1.624	23	85	35.5	129.3
	1:250	1.760	1.604	33	106	50.8	161.9
	1:200	1.714	1.538	41	130	62.3	198.3
	1:150	1.728	1.571	37	133	56.5	203.1
	1:100	1.733	1.580	40	135	61.3	205.0
	1:50	1.757	1.616	45	154	69.0	221.3
4	0	1.736	1.552	15	40	23.0	61.3
	1:250	1.747	1.563	20	62	30.7	94.8
	1:200	1.760	1.592	32	102	48.9	155.2
	1:150	1.749	1.600	36	105	54.6	160.0
	1:100	1.766	1.609	40	124	61.3	188.7
	1:50	1.760	1.578	44	140	67.1	213.6
5	0	1.799	1.669	28	92	43.1	139.9
	1:250	1.739	1.620	35	112	53.7	170.5
	1:200	1.081	1.652	31	117	46.9	178.2
	1:150	1.783	1.662	39	125	59.4	149.5
	1:100	1.792	1.675	43	130	65.1	198.3
	1:50	1.799	1.637	45	142	69.0	216.5

TABLE 5. ANOVA (UCS7)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	33298.75	5	6659.751	2.403133	0.068186	2.639999
Within Groups	63739.41	23	2771.279			
Total	97038.17	28				

TABLE 6. ANOVA (7- days UCS, 0 & 1/150)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	13395.6	1	13395.6	6.658814	0.032593	5.317655
Within Groups	16093.68	8	2011.71			
Total	29489.28	9				

TABLE 7. ANOVA (1-day UCS)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6707.035	5	1341.407	0.401834	0.842673	2.620654
Within Groups	80117.11	24	3338.213			
Total	86824.15	29				

TABLE 8. ANOVA (UCS1, 0 & 1/50)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5112.121	1	5112.121	1.383633	0.273297	5.317655
Within Groups	29557.67	8	3694.709			
Total	34669.79	9				

The findings of durability tests undertaken to evaluate the durability of stabilized active soil exposed to weathering conditions are presented in Table 9. The results show that increasing the stabilizing content reduces the likelihood of degradation. According to ASTMD 4644-08, the durability index was calculated after two drying and wetting cycles with absorption. Figure 4 shows a reduction in the durability index for sites Loc 1-R and Loc 5-D, from 65-20% and 55-13%, respectively.

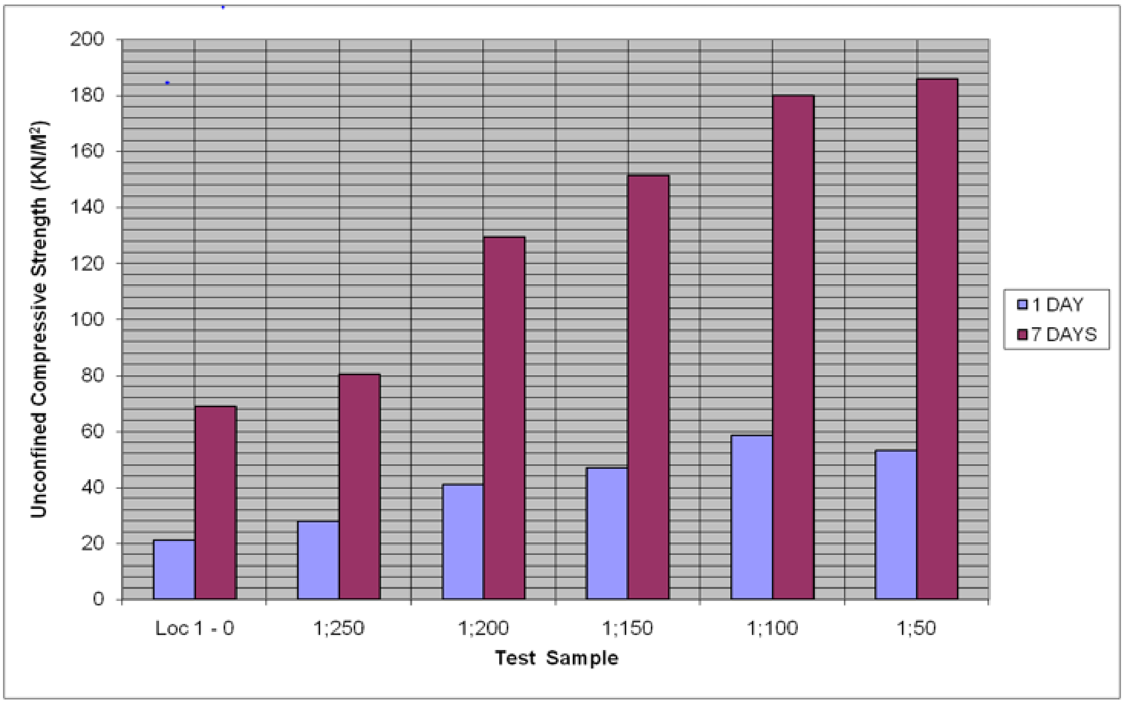

Figure 3. Effect of Application of Nanomaterial on the Unconfined Compressive Strength of the Sample

TABLE 9. Durability Test

SAMPLE	Weight before test (g)	Weight (g) after test				Percentage Weight Loss After 4 Cycles %
		1	2	3	4	
LOC 1- R	1762	0	0	0	0	100
1:250	1716	1026	620	25	0.629	62.9
1:200	1777	1126	596	106	0.551	55.1
1:150	1785	1272	623	36	0.559	44.1
1:100	1756	1632	1260	826	0.250	25.0
1:50	1743	1608	1461	890	0.196	19.6
LOC 2-R	1698	0	0	0	0	100
1:250	1710	1111	520	180	0.470	47.0
1:200	1717	1201	580	96	0.454	45.4
1:150	1732	1062	796	126	0.289	28.9
1:100	1754	1621	1201	620	0.241	24.1
1:50	1767	1682	1362	300	0.210	21.0
LOC 3-B	1745	0	0	0	0	100
1:250	1752	1216	720	123	0.519	51.9
1:200	1732	1086	680	204	0.510	51.0
1:150	1750	1080	962	360	0.470	47.0
1:100	1745	1460	1160	820	0.438	43.8
1:50	1765	1621	1262	980	0.286	28.6
LOC 4-B	1736	0	0	0	0	100
1:250	1747	1029	420	33	0.541	541
1:200	1756	1121	660	76	0.525	52.5
1:150	1745	1421	820	200	0.350	350
1:100	1760	1621	1226	820	0210	21.9
1:50	1768	1600	1321	1001	0.179	17.9
LOC 5-D	1717	0	0	0	0	100
1:250	1720	1212	786	46	0.544	54.4
1:200	1738	1306	840	201	0.481	48.1
1:150	1791	1436	1021	562	0.461	46.1
1:100	1782	1686	1314	1060	0.205	20.5
1:50	1796	1731	1456	1123	0.338	13.5

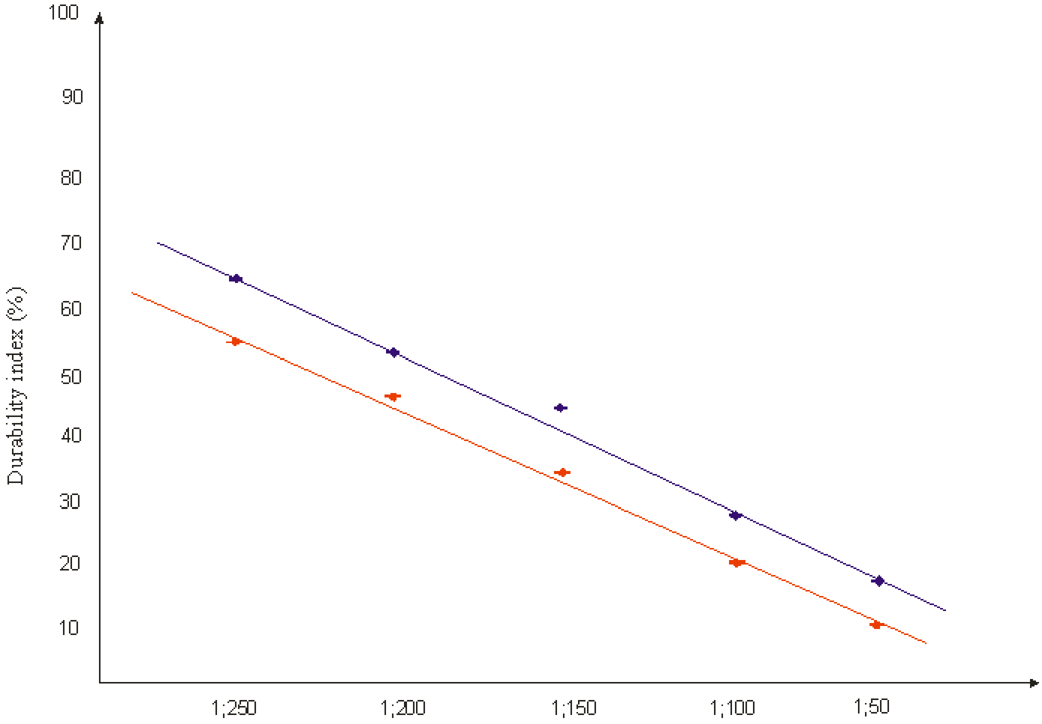

Figure 4. Stabilizer Content (Nanomaterial: Water dilution)

IV. Conclusion

The soils in the Niger Delta's freshwater zone are active, and adding nanomaterial as a stabilizer to the active soil improved its durability and strength in a wet-dry climate. The following are the key findings obtained from the test results:

1. All studied soils are dark brown with bluish-grey mottling. They are predominantly of soft to stiff silty clays interceded with seams of fine sand. Their activity range between 1.3-1.5 and by this they are composed of calcium montmorillonite. They are active soils that are classified as CH and CL by USCS. All locations samples were classified as high swelling potential soils
2. With the application of the nanomaterial, UCS values improved from 6.90 kN/m^2 to 185.9kN/m^2, and durability increased significantly from lows of over 37.1 percent at low nanomaterial content to extreme highs of over 80 percent at higher nanomaterial content.
3. The addition of different proportions of nanomaterial to the soil has no significant effect on 7-day unconfined compressive strength of 95% confidence limit up to nanomaterial content of 1:50 at which point a significant difference was observed. It is therefore recommended that to improve compressive strength nanomaterial content should be greater than or equal to 1:50.
4. For increased performance characteristics, a thorough understanding of the microstructure, basic physics, and chemistry behind material behavior at the nanoscale in relation to material transformation is required.

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