RESILIENT PERFORMANCE OF EXPANSIVE SUBGRADES STABILIZED WITH NANOSIZED AND ACTIVATED FLY ASH

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Abstract

Subgrades across arid and semi-arid region are known for its random swelling, with high plasticity due to moisture infiltration of the pavement structures. Subgrades materials are significantly influenced by the cahnges in degree of saturation, which is unavoidable. Studies in the past, have reported several positive results on the stabilization of expansive soils with additives like lime, cement, fly ash, etc. In this study, resilient performance of expansive subgrades treated with 0.5 %, 1.0 %, 1.5 % and 2.0 % of nanosized and activated fly ash (NFA and AFA) is presented. Series of cation exchange capacity tests, zero swelling tests (ZST) and resilient modulus tests were performed to study the effects of NFA and AFA on resilient modulus () and swelling index of the subgrades material respectively. Scanning electron microscopy (SEM) tests was conducted to evaluate the morphological changes in the subgrades, and compounds responsible for resilient strength development. The result showed that, NFA and AFA inclusions in the treatment of expansive subgrades caused an increase in resilient strength and decrease in swelling stress to a limiting stabilizer content of 0.5 % and 1.0 % beyond which, the resilient modulus values increased triggering a significant decrease in swelling stress. The test result revealed that the reduction was caused by the pozzolanic reaction between the stabilizers and available moisture required for full completion of pozzolanic process. Based on the test result, nano-fly ash exhibite high potential in improving resilient strength and reducing swelling stress to 58.7 % and 63 % respectively on the average compared to activated fly ash. This study suggest a feasible solution to improve the quality and performance of expansive subgrades.

Keywords: nano fly ash, activated fly ash, subgrades, resilient modulus, pavements

1 Introduction

Expansive subgrades causes frequent fatigue to the pavement, due to volumetric changes. Moreover, in arid/semi-arid regions, moderate swelling could induce major damages to pavement structures (Aneke, Mostafa, and Moubarak 2018).
The ratio of cyclic deviator stress to the resilient strain is known as and it is one of the important parameters in flexible pavement design (Sun et al. 2016; Banerjee 2017). In general, subgrade tends to swell or shrink for a given change in moisture content (Jones and Jefferson 2012). A review of the available literature indicated that increases with increase in density, despite the fact is function of stiffness (Titi et al 2015). Though, is affected by many factors, i.e. moisture, the amount and type of the clay-size particles and the minerals contained in the subgrade soils, density, matric suction and applied stress level (Azam et al. 2012). To improve the performance of expansive subgrades, variety of treatment methods have been

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developed in the recent past. Essentially, traditional chemical stabilizers such as lime, cement and fly ash are utilized to control the swelling and enhance the soil stiffness (Pei et. al 2015, Zhang 2018). The utilization of nano-technology to improve is still very sketchy (Ng et al 2014).Thus, nano-particles may generate lower total cost in practical engineering (Ren and hu 2014). There are very few attempts in using nano-particle additive to treat subgrades (Tabarsa 2018). This study rationaly investigated the resiliennt permance of subgrades using NFA and AFA with respect to their morphological changes.

2 Material and experimental program

2.1 Soils

The subgrade samples were collected from three sites in South Africa. Specifically, Soils 1, 2 and 3 were selected from Bloemfontein, Winburg and Welkom, respectively. All soil samples were disturbed, as they were collected at a depth of 0.5 to 1.2 m below the ground level. Fig. 1 shows the grain size fractions.

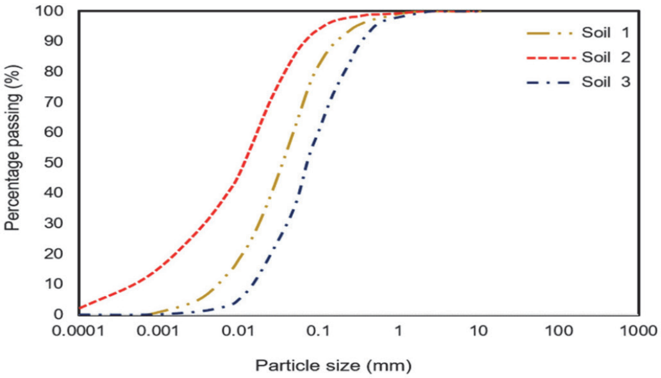

Figure 1 Soils grain-size curve

The collected subgrade materials are categorized as fat clay (CH) soils according to the Unified Soil Classification System(USCS). The cumulative percentages of the soils passing through ASTM sieve size of #200 vary between 50 % and 100 %. Table 1 present the mechanical properties of the investigated subgrade soils.

Table 1 Properties of soils

Number	Measurements results					Rail-to-earth conductance [S/km]			
						Based on standard		Based on Ohm's law	
	I1 [A]	I3 [A]	Ure1 [V]	Ure2 [V]	Ure3 [V]	G're 1	G're 2	G're 3	G're
1	256	291	3.5	5.4	8.9	0.077	0.418	0.561	4.424
2	248	286	4.0	5.9	9.3	0.082	0.375	0.564	4.474
3	458	536	6.6	10.2	16.5	0.075	0.377	0.540	5.173
4	323	369	3.5	6.0	10.3	0.080	0.376	0.547	5.136
5	349	398	3.9	6.6	11.3	0.077	0.368	0.554	5.021
6	251	294	4.4	6.3	9.8	0.075	0.407	0.540	4.684
7	461	528	7.8	11.5	18.0	0.063	0.398	0.535	4.062
8	439	507	4.3	7.7	13.7	0.063	0.390	0.542	5.903
9	459	531	4.6	8.1	14.3	0.067	0.385	0.547	5.925
10	570	666	6.1	10.6	18.5	0.059	0.393	0.542	6.100

*USCS: Unified Soil Classification System * S1, 2, and 3: Soil 1, 2 and 3 * P_s: Swelling stress

2.2 Fly ash and lime

The fly ash used herein are sampled from Lethabo power station in South Africa. The classification of this materials, were achieved in accordance with the standard specification for coal fly ash (ASTM C6 2018) .The classes of fly ash are class “C” and “F”. fly ash. The chemical compositions of the soil, fly ash and lime used in this study are summarised in Table 2, as obtained from XRF test..

Table 2 Materials chemical composition

Chemical oxides	S 1 mass [%]	S 2 Mass [%]	S 3 Mass [%]	FA “C” mass [%]	FA “F” mass [%]	Lime Mass [%]
SiO_2	58.16	62.40	59.65	41.20	56.34	10.69
Al_2O_3	21.41	13.36	14.11	16	37.1	0.33
Fe_2O_3	12.09	4.32	12.34	6	1.95	0.39
CaO	1.75	0.67	2.11	26	3.69	78.88
LOI (%)	0.23	1.23	2.54	2.33	0.38	0.67
pH	7.12	6.78	6.35	10.13	9.67	11.54

3 Material preparations

3.1 Nano fly ash (NFA) and AFA preparations

The NFA was prepared using top down method, the bulk fly ash material was reduced into nanostructures by the means of mechanical processes i.e. mechanical ball-milling and grinding. The milling process was done using planetary ball milling and measured quantity of class “C’ fly ash was subjected to milling for 18hrs. Subsequently, the surface area of the nanosized fly ash increased from 0.228 m^2/gm 28.40 m^2/gm. Whereas, the activated fly ash (AFA) was prepared in accordance with activated analytical procedure by (Aneke et. Al 2019).

3.2 Specimens preparation

The maximum dry densities and optimum moisture contents of subgrades were initially determined, by conducting standard Proctor compaction test according to (ASTM D698 2007). Subsequently, the prescribed NFA and AFA contents for the specimens were determined by the percentage dry mass of soil, given by Eq. (1). in a mould, having a volume of 23.05 x 10-4 m^3.

$$M_{stab} = M_s \cdot \beta \,(\%) \tag{1}$$

where is mass of stabilizers in kg, and is mass of the soil in kg and the is the percentage of stabilizers. The stabilizer dosages used herein were 0.5 %, 1 %, 1.5 % and 2 %, this percentages were selected to ensure easy mixing of soil with the stabilizer and also to provide full reactivity for pozzolanic reaction based on the pH results.

4 Experimental testing procedures

The experimental procedures followed to directly pursue the objective of this investigation are listed Table 3.

Table 3 Tests and specifications

Tests	Specifications
Cation exchange capacity	Indian standard 2720 XL
Zero swelling	Indian standard part 41
Repeated load triaxial	AASHTO T 307

5 Result and discussions

5.1 Effects of stabilizer inclusion on CEC

The variation of CEC with stabilizers inclusions at optimum moisture content is shown in Fig. 2. It is clearly noted that, CEC values of the soil increased as the percentage of NFA and AFA increases. The specimens stabilized with NFA, increased from initial CEC values of 118.12,120.32 and 42.51 meq/100 g to 286.24, 341 and 290 meq/100 g for soil 1, 2 and 3 respectively.

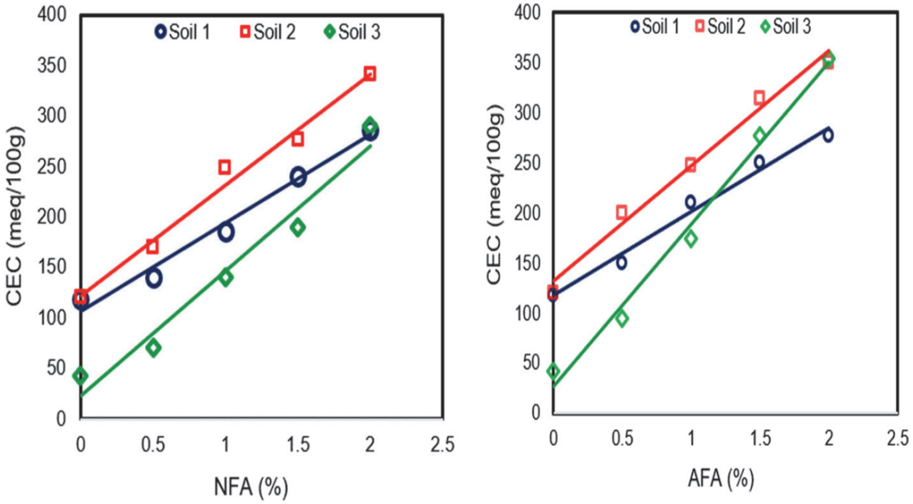

Figure 2 Variation of CEC with stabilizer contents

5.2 Effect of stabilizers inclusion on swelling stress

The variation of swelling stress with stabilizers inclusion is shown in Fig. 3. It can be interpreted from the curve that, the addition of NFA and AFA, demonstrate significant decrease in swelling stress values. It is evident that is not only relative to moisture content, thus void ratio and stiffness of the soil significantly influence the swelling behaviour of the subgrades. The initial values of Soil 1, 2 and 3 are 760 kPa, 850 kPa and 630 kPa. The result demonstrate drastic decrease in swelling stress with decrease in void ratio due to stabilizer inclusion. This imply that the dry density of the investigated soils increases, as the voids within the soil particles are filled with stabilizer.

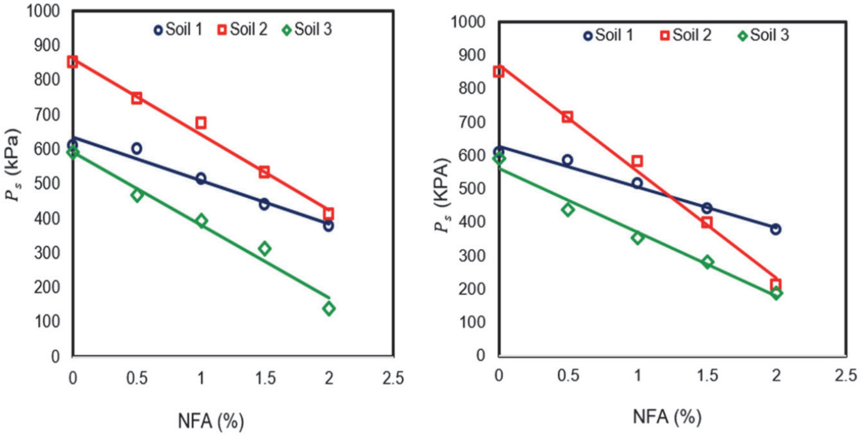

Figure 3 Variation of stabilizer contents on swelling stress

For NFA stabilized specimens, swelling stress is reduced by 63 % at stabilizer content of 1.5 % as compared to 47 % of AFA stabilized specimens with the same percentage. Generally, the NFA and AFA strikingly restrain the expansive activities of the investigated subgrades without with altering the mineralogical properties of the subgrades, as evidenced under SEM analysis (Judy et al 2016).

5.3 Effect of stabilizers inclusion on resilient modulus

The stress induced by traffic load, is represented by resilint response of subgrades under cyclic stress analysis. Figs. 4 and 5 presents the behaviour of unstabilized subgrades at OMC. It is evident that untreated subgrades exhibits considerable ductility, yielding low values with increasing deviatoric stress due to stress softening (Rahman and Tarefder 2015). It is noted that the differences in values due to change in confining pressures are small. The results revealed that average difference in values relative to deviator stress is ›4.41 % in all tested subgrade. It is observed that in at constant confining stress gradually decreased with an increase in deviator stress irrespective of subgrade type. The decreasing rate at the low deviator stress is more pronounced at high deviator stress. Soil 3 recorded the highest value, followed by soil 1 and 2. Based on the particle size distribution analysis, soil 3 is composed of 52.57 % amount of fines. Whereas, soil 1 and 2 content 75.52 % and 91.38 % amount of fine content respectively.

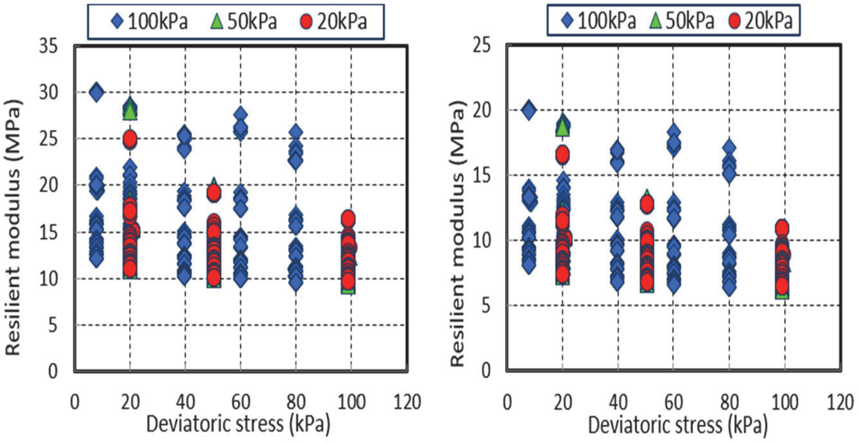

Figure 4 Soil 1 and 2 at varying deviatoric stress

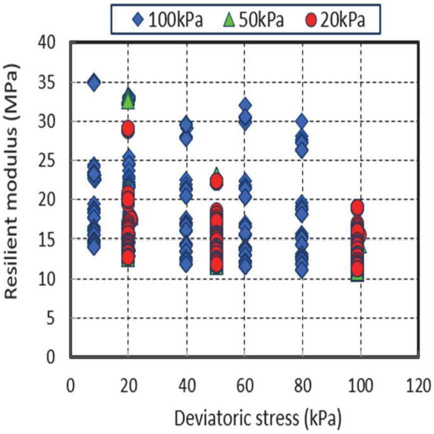

Figure 5 Soil 3 at varying deviatoric stress

Extensive tests were performed in the laboratory using the RLT machine on the stabilized soil specimens prepared at OMC with 1.5 % inclusion of stabilizer content. The variation of with stabilizer contents are shown in Figs. 6 through 9. It is indicated that increasing stabilizers content cause an increase in values. At stabilizer contents of 1.5 % for NFA improved to 46 %, 60 % and 70 % for soil 1, 2 and 3 respectively. The indicated behaviour of the nano-fly ash stabilized subgrade are in agreement with the findings reported elsewhere (Ozel 2001). The nonlinear trend of to deviator stress is similar to all treated subgrades and this result is in agreement the report published elsewhere by (Masada and Sargand 2002). based on curves slope, it can be inferred that the influence deviatoric stress is more exhibited at lower stress values irrespective of the confining stress level. The of the stabilized soils were less influenced by the deviator stress compared to unsatbilized soils. Thus, stabilized subgrades, decreases in values at low rate with deviator stress increase, which typically indicates strain hardening due to the stabilizer and denser state of grains soil particles (Maher et al. 2000).

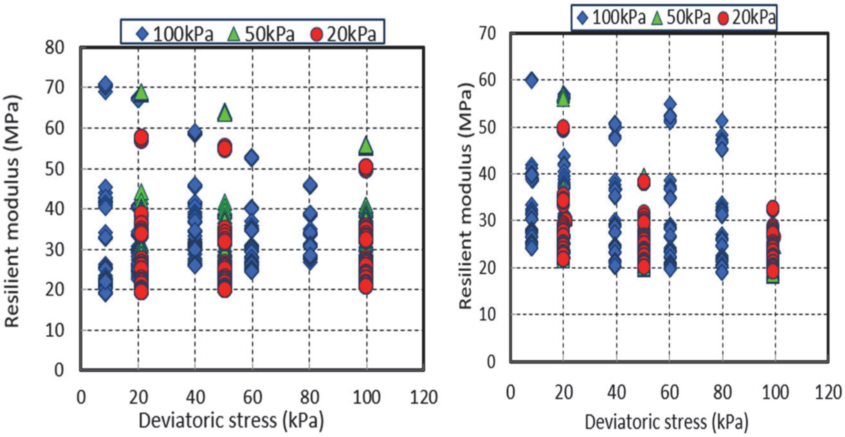

Figure 6 of 1.5 % NFA for soil 1 and 2 at varying deviatoric stress

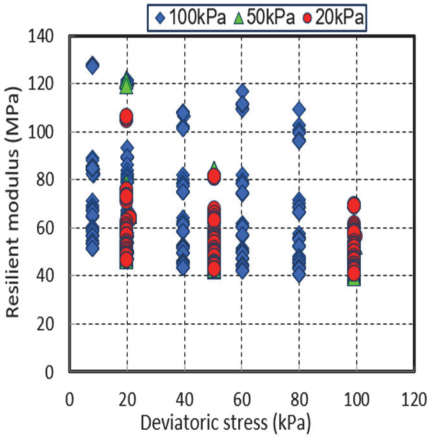

Figure 7 of 1.5 % NFA for soil 3 at varying deviatoric stress

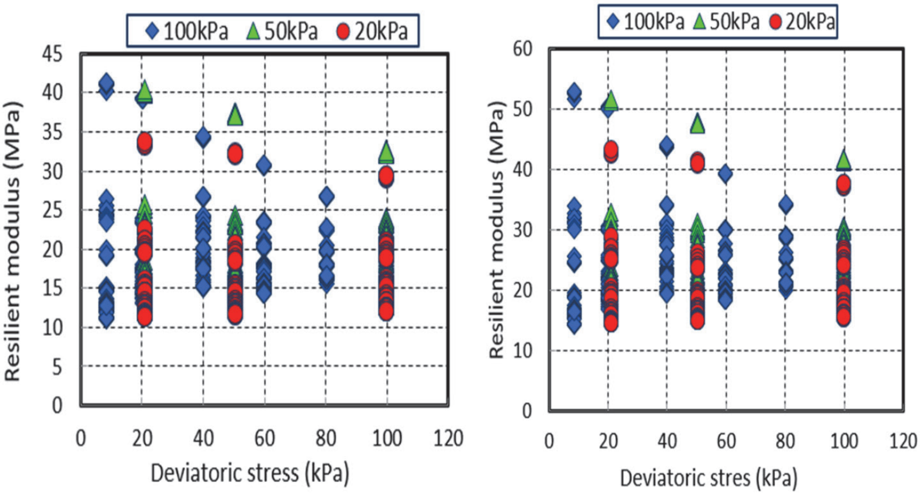

Figure 8 of 1.5 % AFA for soil 1 and 2 at varying deviatoric stress

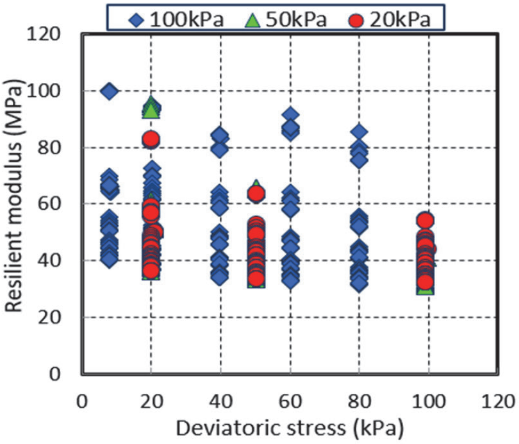

Figure 9 of 1.5 % AFA for soil 3 at varying deviatoric stress

5.4 Morphological analysis

The specimens stabilized with 1.5 % of NFA and AFA cured for 28 day period, using SEM apparatus VEGA3 TESCAN-6480 scanning electron microscope operated at 20kV are presented in Figs. 10 through 12. The specimens with 1.5 % stabilizer content were selected for the microstructure analysis, due to higher recorfed by specimens. The morphology were at magnification factor of 50µm. It is evidence that the inclusion of nano-fly ash and activated fly ash caused microstructural evolution within subgrade soils particle structures. The NFA and AFA inclusion, first produced an observed filled effect in pores between particles, which contribute to a decrease in porosity and an increase in the density of the treated subgrades. The addition of stabilizer contents propergated more clustered effect on the treated subgrades, which resulted in the formation of stronger knitted soil matrix. Whereas, the unstabilizer subgrades, appeared in a state of lose pack with larger pore.

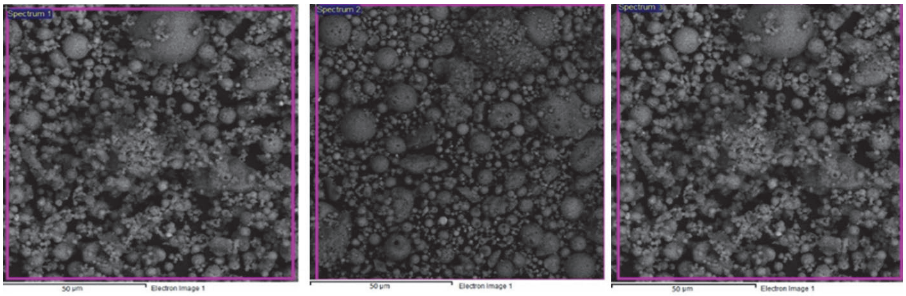

Figure 10 SEM of soil 1, 2 and 3

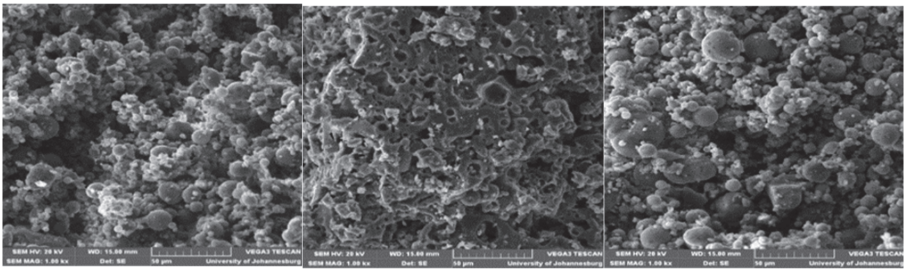

Figure 11 SEM of 1.5 % NFA stabilized specimens for soil 1, 2 and 3

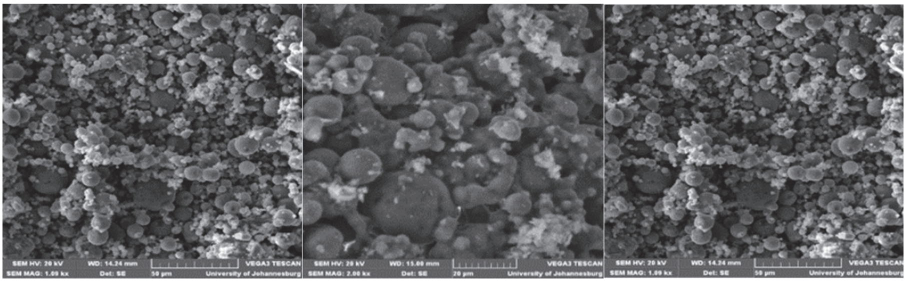

Figure 12 SEM of 1.5 % AFA stabilized specimens for soil 1, 2 and 3

Basically, micrograph of the stabilized soils depict hardened surface of pozzolanic paste. The reactive compounds of NFA and AFA compounds, such as C_3S, CASH and C_3A are more dominant on 1.5 % in NFA and AFA stabilized specimens respectively. From the above micrograph these chemicals responsible for morphological changes were traced within the capillary spaces of the stabilized soils. Based on the SEM micrograph, the pozzolanic reactions in the stabilized soil system, dissolved calcium ions from C_3S and it moves about freely in presences of moisture thus adsorbed within the surfaces of pozzolanic particles in soil. The formation of C–S–H formed by the pozzolanic effect of C_3S precipitate as the hydrates of high Ca/Si ratio on the surface of soil. The pozzolan reaction within the soil surface brings about gradual dissolution of Ca^+ causing Si and Al rich amorphous structure within soil pores. The stabilized soils with 1.5 % AFA formed predominantly amorphous phases of $3CaOSiO_2$, $CaSi_6O_{16}(OH)$, $3CaOAl_2O_3$, $3CaOAl_2O_3(OH)6$ gel within the soil pores compared with unstabilized soils.

6 Conclusions

Based on the acquired test results, the following key conclusions were drawn:

- The NFA and AFA inclusions reduced swelling stress of the stabilized soils due to an improved resistance of the specimens to swelling. An increase in stabilizer content caused increased CEC and pH properties.
- The stabilisers inclusion caused increase in for stabilizer content of 1.5 % below which reduced. The increase was attributed to the gain of stiffness of the stabilized soils due to low amount voids. The was improved by increasing level of confining pressure.
- Pozzolanic reactions were more dominant in NFA stabilized specimens, compare to AFA specimens, due to the nano size of NFA. This resulted in increasing values up to 58.67 % on the average compare to 45.32 % increase of specimens stabilized with AFA.
- Basically, this investigation revealed that NFA is more effective for stabilization compare to AFA. Though, specimens treated with both stabilizers significantly improvement the of the expansive subgrades among other geotechnical properties soil. This is expected due to the specific surface area, nano-size and higher reactivity of NFA.
- As expected, strain-softening behavior were observed as the subgrades recorded higher resilient moduli for higher confining stresses and decreased with an increase in the deviatoric stress under identical confinement.

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