



# The geotechnical and microstructural properties of desilicated fly ash lime stabilised expansive soil

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**Abstract** This study presents the use of marginal material as a stabiliser for expansive soil and therefore provides opportunity for high volume use of waste material for low cost, low volume road construction. Desilicated fly ash (DFA) was stabilised with lime up to 40 %. The effect of composite moisture content, lime content and curing temperature was studied. A 70:30 DFA:lime composite cured at 80 °C for 96 h had the highest unconfined compressive strength (UCS) of 8.57 MPa, a 19.5 % water absorption after a 24 h soak with a corresponding 23.5 % reduction in UCS. The green composite (70:30) was then used to stabilise expansive soil. Expansive soil stabilised with 30 % 70:30 DFA: lime composite was found to have a UCS of 4.1 MPa and resulted in a 50.1 % reduction in the liquid limit and a 15.1 meq/100 g reduction in cation exchange capacity of the soil. The formation of calcium silicate hydrate and tricalcium aluminate in the expansive soil was responsible for the strength gain in the stabilised soil. The stabilised soil met the

minimum requirements for the American Concrete institute's requirements for rigid pavement layers.

**Keywords** Desilicated fly ash · Durability · Saturation coefficient · Cation exchange capacity · Hydration

## 1 Introduction

Expansive soils are found in arid and semi-arid regions because chemical weathering is less prevalent than in rainy areas leading to reduced leaching of soluble bases [39]. These conditions then favour the formation of the 2:1 lattice type of clay which contain at least 12 % smectite mineral group with the most common one being Montmorillonite. This is the mineral for bentonites which has two tetrahedron sheets combined with one octahedron sheet allowing water molecules to freely enter between the successive sheets resulting in the considerable volume change of the expansive soil in the presence or absence of moisture. This continual heave and shrinkage causes considerable damage to structures built on such soil, these soils are capable having swelling pressure of over 700 kPa (Williams and Pidgeon [43]; [36]) which is enough to damage a single or double storey house. These soils are quite common in South Africa occurring in places like Vereeniging, Pretoria Moot area, Port Elizabeth and Uitenhage to name but a few areas [40]. Repairs to

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structures built on these expansive soils are costly and may not be permanent, which may result in structures becoming redundant. It has been shown in South Africa that a new conventional brick house of 50 m<sup>2</sup>, the cost of repair associated with expansive soil can reach 20 % of the market price of the house. Various chemical stabilisation of expansive soil has been reported in literature. The use of supplementary cementitious material (SCM) which include lime, fly ash, basic oxygen furnace slag and granulated blast furnace slag for the stabilisation of soil is well reported in literature [2, 29, 44, 25, 11]. SCM afford the use of industrial products thereby allowing pollution control, this also helps in the replacement of cement in the stabilisation of soil thereby significantly reducing the CO<sub>2</sub> emissions associated with cement production. The durability and strength of stabilised soil will depend on the type of SCM used, pH of composite and curing temperature [22]. The amount of OH<sup>-</sup> ions (pH) available for the dissolution of silica and alumina in pozzolanic reaction is affected by the cation exchange capacity (CEC) of the soil [12], where a high CEC results in low OH<sup>-</sup> in pore solution. Therefore the determination of CEC becomes important indicator the mechanistic pathway formation of hydration products [12]. UCS gain in stabilised soil is mostly due to pozzolanic reaction, which results in the formation of calcium silicate hydrate (CSH), calcium aluminate hydrates (CAH) and calcium aluminosilicate hydrates (CASH) [14] and the type of hydration product is also dependent on the SCM used [27]. The 28 day UCS of treated soils has ranged between 711–12000 kPa [25, 19, 26]. There is no literature on the use of desilicated fly ash (DFA) as a soil stabiliser. DFA is the residue from silica leaching of fly ash using KOH. This research investigated the effect of DFA lime composites on the physical, microstructural and durability properties of stabilised soil. The aim is to evaluate the potential application of high volume DFA in low cost infrastructure development.

## 2 Materials

Desilicated fly ash (DFA) was obtained through desilication of ash from the Camden power station in South Africa. Commercially available hydrated Lime was supplied by Home Builders. The expansive soil used was made in the laboratory by mixing

commercially available bentonite, kaolin and sand in the ratio of 20:40:40. Tables 1 and 2 show the properties of DFA/Fly ash (FA) and the expansive soil respectively.

The pH of DFA was found to be 12.28. The pH was higher than that typical FA because DFA has more basic oxides (especially K<sub>2</sub>O) than FA which then contribute to the high alkalinity. DFA was also characterised by low silica content due to leaching of silica. The expansive soil was basic as it had an alkaline pH. The soil was a fine grained soil classified as CH according to ASTM D2487 [6] making it unsuitable for road construction. Within the CH category the expansive soil could also be classified as sandy fat clay soil. The presence of bentonite in the

**Table 1** Some physical and chemical properties DFA and FA

Parameter	DFA	FA
pH	12.28	10.28
Specific gravity	2.32	2.40
% CaO	4.25	6.40
% Al <sub>2</sub> O <sub>3</sub>	38.7	23.28
% SiO <sub>2</sub>	19.6	45.06
% K <sub>2</sub> O	25.2	5.93
% Fe <sub>2</sub> O <sub>3</sub>	4.25	9.40
% Sand	67	45
% Fine	33	55
% Silt	17	54.7
% Clay	16	0.30

**Table 2** Expansive soil properties

Parameter	Specification
pH	10.25
G <sub>s</sub>	2.6303
CEC	36.3 meq/100 g
Liquid limit	97.5 %
Plastic limit	20.7 %
Plasticity index	76.8 %
Swell index	15 ml/2 g
Gravel	5 %
Sand	35 %
Silt	12 %
Clay	48 %
Bentonite	20 %
Kaolin	40 %



expansive soil makes it undesirable as a construction material. This is because the principal mineral in bentonites is montmorillonite. Its structure is made of an alumina sheet held between two silica sheets to form a weakly bonded, three sheet layer. The structure is also called 2:1. The interchange between elements within each sheet makes bentonite layers to exhibit the characteristic of undergoing considerable change in volume in the presence of moisture. The soil had medium swell index of 15 ml/2 g as bentonite has an average swell index of 30 ml/2 g [23].

### 3 Experimental methods

#### 3.1 Lime stabilisation of DFA

Oven dry DFA and lime were dry mixed at ratios of 90:10, 80:20, 70:30 and 60:40. Water was then quantitatively added at 27.5, 30 and 32.5 % to each ratio mix of the total dry components. 30 % water content represented optimum moisture content (OMC). The DFA-lime-water mixture was then mixed thoroughly and then into 100\*100\*100 mm<sup>3</sup> mould in triplicates and pressure molded from one end using a moulding load of 5 kN. The specimens were then cured at 40, 80 and 100 °C for 4 days.

#### 3.2 Expansive soil stabilisation

Oven dried (105 °C) 70:30 DFA:lime was mixed with the expansive soil in the ratio of 1:9, 2:8, 3:7, 4:6 and 1:1 respectively. Water at the optimum moisture content (OMC) of each ratio was then added and the mixture was thoroughly mixed. The mixed DFA-lime-soil-water mixture was then cast into a 100\*100\*100 mm<sup>3</sup> mould in triplicates and pressure molded from one end using a moulding load of 5 kN. When the mould had obtained sufficient strength it was demoulded and subsequently sealed in a plastic bag. Specimens which showed uneven surfaces due to demoulding or pressure casting were rejected. Curing was done in accordance with ASTM D5102 [8] where the moulded stabilised soils were sealed in a plastic bag and were then cured for 7 days at 40 °C. After 7 days the specimens were removed from the oven and allowed to cool to room temperature before further test work.

#### 3.3 Characterisation of composites

ASTM B822 [5] was used to determine particle size distribution of material below 300 µm. ASTM D5550 [9] was used to determine relative density. Compaction tests were carried out in accordance with ASTM method ASTM D698. The UCS was determined in accordance with ASTM D2166 on the specimens that had no visible signs of failure and dimensions had not changed by more than 10 % using a UCS machine with a loading rate of 15 kN/min. The results were an average of three specimens. The swell index, Atterberg limits and saturation coefficient were determined using ASTM D5890 [10], D4318 [7] and C67 [4] respectively. The X-ray fluorescence (XRF), laser diffraction and scanning electron microscope (SEM) were used to study the microstructure of the composites.

The copper bis-ethylenediamine complex method was used to estimate the cation exchange capacity (CEC) of the expansive soil. A quantity of 50 ml of 1 M CuCl<sub>2</sub> solution was mixed with 102 ml of 1 M ethylenediamine solution to allow the formation of the [Cu(en)<sub>2</sub>]<sup>2+</sup> complex. A slight excess of the amine ensured complete formation of the complex. The solution was diluted with water to 1 l to give a 0.05 M solution of the complex. A quantity of 0.5 g of expansive soil or stabilised soil was mixed with 5 ml of the complex solution in a 100-ml flask and diluted with distilled water to 25 ml and the mixture was agitated for 30 min in a thermostatic shaker at 200 rpm and 25 °C and centrifuged.

The concentration of the complex remaining in the supernatant was determined by mixing 5 ml of the liquid with 5 ml of 0.1 M HCl to destroy the [Cu(en)<sub>2</sub>]<sup>2+</sup> complex, followed by adding 0.5 g KI per ml and then titrating iodometrically with 0.02 M Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> in the presence of starch as an indicator. The CEC was calculated from formula 1.

$$\text{CEC}(\text{meq}/100\text{g}) = \text{MSV} (x - y)/1000m \quad (1)$$

where  $M$  is the molar mass of the complex,  $S$  the concentration of the thio solution,  $V$  the volume (ml) of the complex taken for iodometric titration,  $m$  the mass of adsorbent taken (g),  $x$  is the volume (ml) of thio required for blank titration (without the adsorbent), and  $y$  is the volume (ml) of thio required for the titration (with the adsorbent).

## 4 Results and discussion

### 4.1 Lime stabilisation of DFA

Figure 1 shows the variation in UCS with DFA:lime combination and moisture content.

For any DFA:lime, ratio there was an increase in the UCS from 27.5 % to the UCS at 30 % moisture content followed by a drop in the UCS of the composite with 32.5 % moisture. Compaction tests had shown that 30 % moisture content as OMC. Pre OMC moisture has less moisture hence hydration reaction may not go to completion and also pre OMC moisture mixtures were too dry and were not easily compactable. Post OMC moisture has excess water which might not be used in the hydration reaction and this results in the excess water being lost via evaporation which then left voids creating weak points which reduce the strengths of composites. At the same moisture content with varying DFA:lime ratios there was an increase in UCS as the lime content was increased. This can be explained by the increase in lime consumption with increasing lime content leading to more hydration products being formed hence the higher the UCS. The 70:30 DFA:lime composite was then cured at 40 °C, 80 and 100 °C. Figure 2 shows the variation in UCS with curing temperature.

A change in temperature from 40 to 80 °C brought about at least 140 % increase in UCS of the DFA:lime composite showing that the initial temperature increase accelerated pozzolanic/hydration reaction which is in line with literature [37]. The increase from 80 to 100 °C brought about an appreciable increase (33 % for 70:30) only after 24 h, there after

the increase in UCS was not significant with the difference at 3 days being 3 %. After 4 days the UCS of composites cured at 80 °C were higher than the one at 100 °C. This could be explained using SEM (Fig. 3) micrographs of the 70:30 DFA:Lime composites cured at 80 and 100 °C.

## 5 Materials and methods

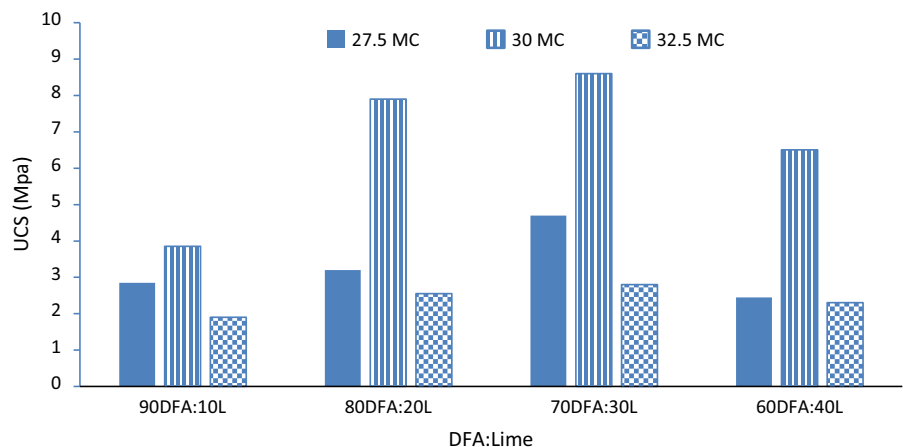
The extensive covering of DFA particles with lime and hydration products after 1 day of curing for the composite cured at 100 °C would be the reason for the early development of high strength as compared to the one cured at 80 °C (Figs. 3a, b respectively). The extensive covering also acts as a barrier for the further hydration of DFA particles as by the third day DFA particles were completely covered by hydration products (Fig. 3c). The composite cured at 80 °C was still fairly covered by hydration products at day four allowing for further hydration to take place. Though DFA has low silica content hydration reactions take place as has been shown with high alumina low silica fly ashes [24].

The 70:30 (DFA:lime) composite showed 19.5 % water absorption after a 24 h soak with a corresponding 23.5 % reduction in UCS. The composite met the minimum requirement of ASTM C34 13 and was subsequently used to stabilise expansive soil.

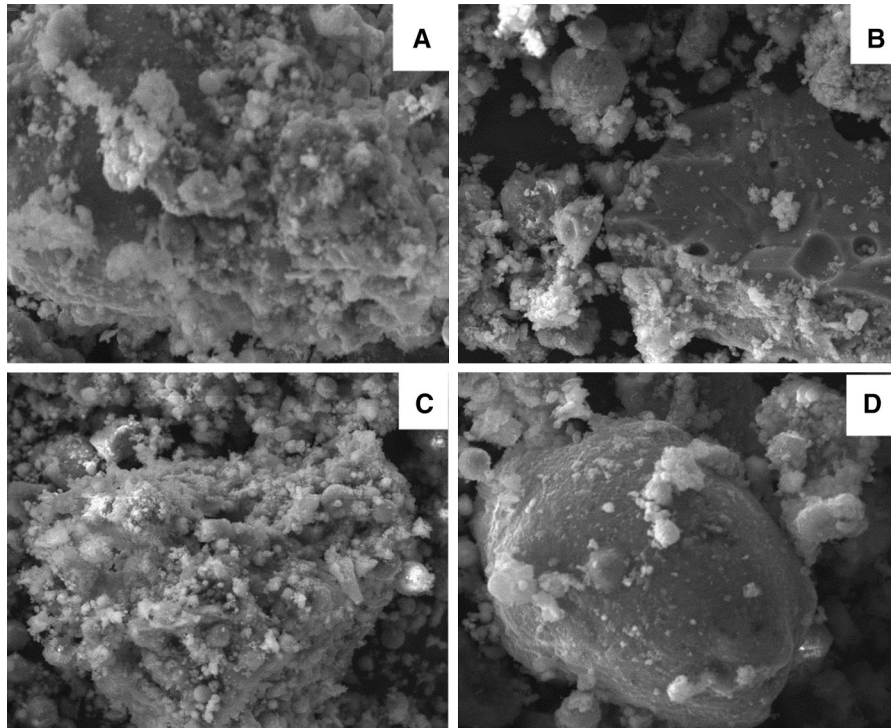
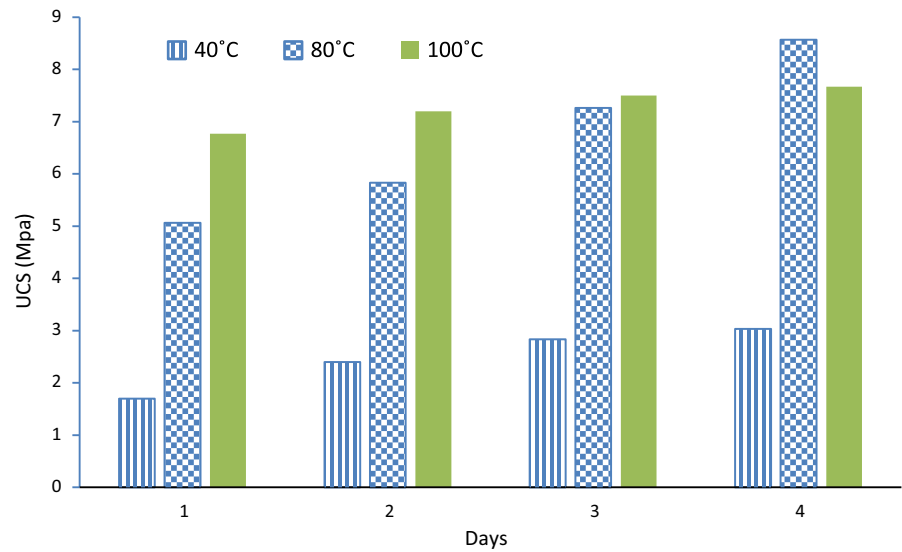
### 5.1 Kinetics of DFA lime consumption

Lime consumption over the duration of the curing period was measured using a method proposed by

**Fig. 1** Variation in UCS with DFA:lime ratio and moisture content of composites cured at 80 °C for 96 h



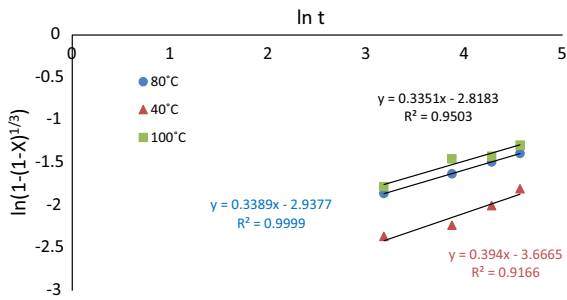
**Fig. 2** Variation of UCS with temperature and curing period for 70:30 DFA:lime composites



**Fig. 3** SEM Micrographs of 70: 30 DFA:lime composite: a 100 °C after 1 day; b 80 °C after 1 day; c 100 °C after 3 days; d 80 °C after 4 days

[Rao and Asha [34]]. Lime consumption fitted the modified Jander kinetics at all curing temperatures (Fig. 4) as the correlation coefficient was greater than 0.92. The original Jander equation was modified by

incorporation of the term  $N$  (reaction grade) so that it can apply to broad reactions including consecutive and overlapping reactions [13] which suited the hydration reaction of DFA since dissolution and hydration



**Fig. 4** Plot of the modified Jander equation at various temperatures of the 70:30 DFA:lime composite

reactions are involved. The calculated  $N$  values at 40, 80 and 100 °C were 2.6, 3.0 and 3.0 respectively. This therefore meant that lime consumption by DFA is controlled by diffusion of reactants through a dense layer of reaction products [13] which was also supported by the SEM micrograph analysis of DFA-lime composites (Fig. 3).

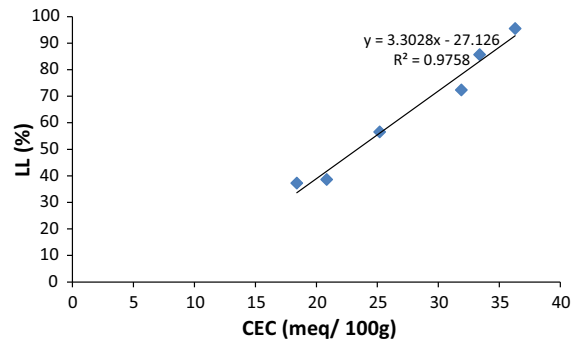
An Arrhenius plot of the lime consumption was found to give an activation energy of 16 kJ/mol which further supported that the consumption of lime using DFA is a diffusion based process [33].

## 5.2 Stabilised soil physical properties

Table 3 shows the variation in physical properties of stabilised soil with stabiliser addition.

The pH of expansive soil increased with the addition of stabiliser (Table 3). The  $\text{OH}^-$  ions from lime and basic oxides ( $\text{K}_2\text{O}$ ) from DFA accounted for the rise in pH although no appreciable pH change was observed after 30 % stabiliser addition.

There was a decrease in specific gravity of the soil as the % stabiliser was increased from 10 to 50 % due to that both DFA and lime had a combined specific gravity of 2.4231. Therefore the decrease in specific gravity is due to dilution effect by the stabiliser. Ion



**Fig. 5** Variation in liquid limit with cation exchange capacity of the stabilised soils

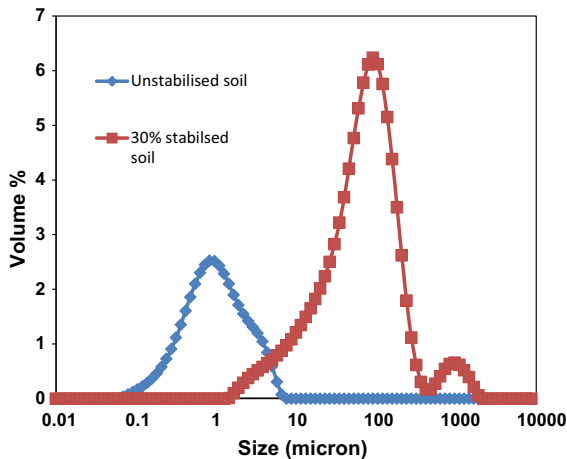
exchange between  $\text{Ca}^{2+}$  (from lime and DFA) and exchangeable cations on the surface of the expansive soil resulted in a high charge on the expansive soil surface [41] leading to particle flocculation resulting in larger sized particles being formed. The larger sized particles have less packing as compared to clay particles hence the reduction in SG.

The addition of stabiliser resulted in reduction of CEC of the soil (Table 3). This was because lime and DFA supplied divalent cations which replaced monovalent cations in the soil. The reduction of CEC is known to directly affect the index properties of soil. Figure 4 shows the correlation in CEC reduction with LL reduction.

From Fig. 5, it can be seen that there was a direct proportionality in the reduction of LL with a reduction of CEC. The correlation coefficient of 0.98 shows a good linear correlation therefore it can be concluded that CEC is one of the main factors which affect the index properties of soil. A 30 % stabiliser addition resulted in a 39 % decrease in LL and a corresponding decrease by 50.7 % in PI. Beyond 30 % the decrease in LL became insignificant with the stabilised soil passing onto being non-plastic. The 30 % stabiliser content therefore provides the initial lime

**Table 3** Physical properties of stabilised soils

%Stabiliser	PH	Gs	CEC meq/100 g	LL (%)	PL (%)	PI (%)	SI (ml/2 g)
0	10.25	2.6303	36.3	95.5	20.7	76.8	15
10	10.81	2.6064	33.4	85.6	22.3	63.3	12
20	11.25	2.6156	31.9	72.3	25.4	46.9	9
30	12.65	2.5633	25.2	56.5	30.4	26.1	8
40	12.8	2.5238	20.9	38.6	NP	N/A	7
50	12.9	2.5139	18.4	37.2	NP	N/A	5



**Fig. 6** Laser volume distribution of unstabilised and 30 % (70:30 DFA:lime) stabilised soil

consumption value of 6 % [15, 18]. The reduction in LL and PI was due to agglomeration of particles leading to reduction of clay sized particles. With 30 % stabilisation the soil became a medium plastic soil from a high plastic soil [6]. The increase in ion concentration led (caused by increase in  $\text{Ca}^{2+}$ ) to increase in inter-particle shear resistance resulting in increase in PL [30].

30 % stabilisation of expansive soil resulted in increase in particle size to a modal value of 91  $\mu\text{m}$  from 1  $\mu\text{m}$  in unstabilised soil (Fig. 6). 30 % stabilisation also resulted in a bimodal volume distribution which is evidence of particle growth by agglomeration during stabilisation [32].

The decrease in SI with increasing amount of stabiliser due to the compression of the interlayer region was due to the increase in lime concentration which supplies  $\text{Ca}^{2+}$  ions [38, 20]. The replacement of single valence ions on the soil with divalent  $\text{Ca}^{2+}$  has also been shown to reduce water absorption by soil particles [21]. This decrease in Montmorillonite peak (Fig. 8) is also responsible for the decrease in SI of the soil as the 2:1 structure of bentonite is known to have a high swell potential [42].

There was decrease in MDD and a corresponding increase in OMC with increase in stabiliser content (Table 4). The decrease in MDD was due to dilution effect as expansive soil had an MDD of 1780  $\text{kg}/\text{m}^3$  whereas the stabiliser had an MDD of 1300  $\text{kg}/\text{m}^3$ . The voids also left by water and particle agglomeration are said to be responsible for the decrease in MDD

**Table 4** Variation in MDD and OMC with stabiliser addition

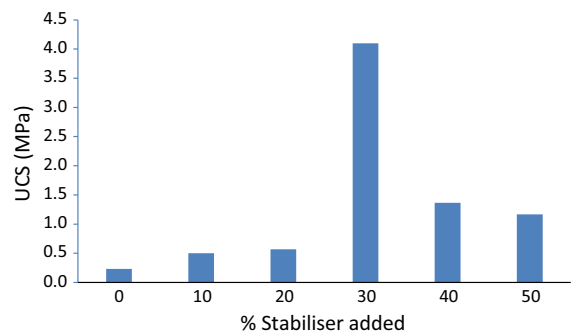
% Stabiliser	0	10	20	30	40	50
MDD ( $\text{kg}/\text{m}^3$ )	1780	1678	1616	1507	1421	1376
OMC	14.1	15.5	20.6	22.4	22.6	23.5

[35]. The increase in OMC was due to increase in DFA content in the soil. DFA like FA is hydrophilic and hence its presence led to adsorption of more water [3]. The increase in lime content which has a high affinity for water was also responsible for the increase in OMC [28]. The increase  $\text{Ca}^{2+}$  cations caused dispersion of particles which results in a decrease in MDD and increase in OMC.

### 5.3 UCS

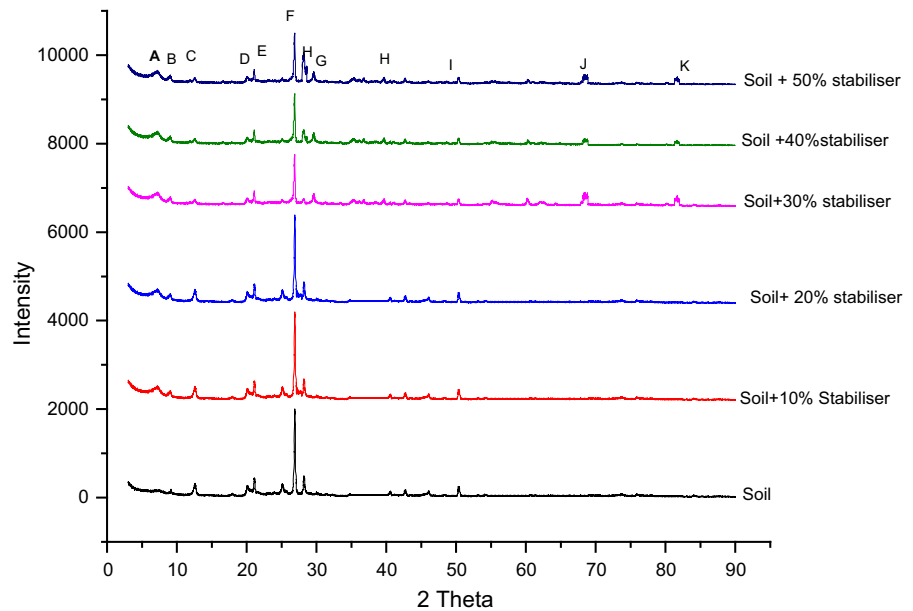
Figure 7 shows the variation in 7 day 40 °C UCS.

There was an increase in UCS with an increase in % stabiliser added up to 30 % addition followed by a UCS decrease up to 50 % stabiliser addition. Strength development of lime-DFA stabilised soil is due to hydration reactions [2]. The hydration reaction only occurs if pH of soil is above 12.4 [15]. Unstabilised soil and soil stabilised with 10 and 20 % stabiliser had a pH less than 12.5 therefore hydration reaction did not take place and hence a UCS less than 400 kPa. The apparent strength gain at 10 and 20 % stabilisation is due to reduction in plasticity thereby facilitating better compaction of the stabilised soil (Table 2). The strength gain from unstabilised soil to 20 % stabilised soil is less than 345 kPa and therefore deemed insignificant (ASTM D4609-08). The optimum



**Fig. 7** Variation in UCS of expansive soil specimens that were stabilised with different percentage of 30:70 DFA:lime composite and cured for 7 days

**Fig. 8** XRD analysis of unstabilised and stabilised soils. **a** Phillipsite K, **b** montmorillonite, **c** kaolin, **d** kaolin, **e** kaolin, **f** quartz, **h** lime, **g** feldspar, **h** mullite, **i** kaolin, **j** calcium silicate hydrate, **k** tricalcium aluminate hydrate



stabilisation was at 30 % with a UCS of 4.1 MPa. The 4.1 MPa met the minimum requirements of the American Concrete Institute for base course for a rigid road and the stabilised material could be classified as C2 by South African standards [1, 17]. This stabilised soil had pH of 12.65 therefore lime hydration reactions could take place. The high UCS is also due to the soil having the lowest PI hence easier workability and high compatibility. The interesting and odd trend of a decrease in UCS at 40 and 50 % stabilisation is due to excess lime which then is not involved in hydration reaction and also becomes a weak filler. The increase in low density DFA content at 40 and 50 % also reduces the strength of the stabilised soil.

#### 5.4 Development of hydration products

Figure 8 shows the development of hydration products of the unstabilised and stabilised soils.

XRD analysis indicated the formation of calcium silicate hydrate and tricalcium aluminate hydrate as the hydration products during curing. Expansive soil and soil stabilised with 10 and 20 % stabiliser did not show any hydration products. This is because these soil had a pH less than 12.4 (Table 3) hence no pozzolanic activity took place. This is further supported by the UCS of these soils which was less than 600 kPa (Fig. 7). The only difference between the

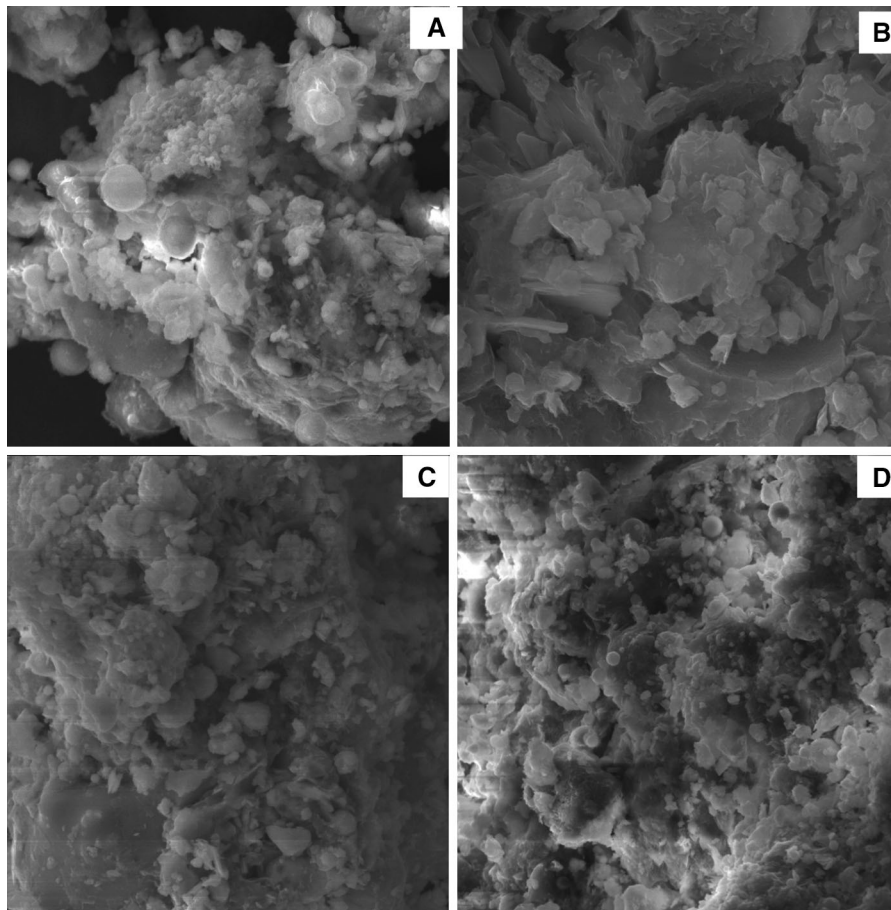
expansive soil and soil stabilised with 10 and 20 % stabiliser is the appearance of the peak for Phillipsite K at around  $9^{\circ}$  which is a component of desilicated fly ash [16]. The formation of hydration products resulted in the decrease in intensity of the Montmorillonite and Kaolin peaks from the stabilised soil (Fig. 8). The intensity of the lime peak for soil stabilised with 40 and 50 % stabiliser was higher than the one stabilised at 30 % showing the presence of unused lime at 40 and 50 % stabilisation leading to reduction of UCS. The intensity also of hydration products peaks are also lower at 40 and 50 % stabilisation.

#### 5.5 Particle morphology of cured stabilised soil

Figure 9 shows the SEM micrographs of various 7 day cured stabilised soil.

30 % stabilisation (Fig. 9b) resulted in the formation of thin irregular shaped flakes with very little visibility of spherical DFA particles which accounted for the high UCS at 30 % stabilisation due to more packing. At 40 and 50 % stabilisation (Fig. 9c, d) the spherical particles of DFA can be seen showing that DFA was still part of the dominant constituents. DFA is a light material which then explains the reduction in UCS at 40 and 50 % stabilisation. At 20 % stabilisation lime and DFA can be seen. There was also no evidence of the formation of irregular shaped flakes further supporting that at 20 % or less stabilisation no





**Fig. 9** SEM micrographs of 7 day cured stabilised soil. **a** 20 % stabilised soil; **b** 30 % stabilised soil, **c** 40 % stabilised soil, **d** 50 % stabilised soil

**Table 5** Durability of 30 % stabilised soil

Cast	1	2	3	4	5
Mass of cast (kg)	1.859	1.987	1.988	1.949	1.901
Mass of cast after 24 h soak (kg)	1.951	2.0158	2.128	2.028	2.215
Mass of cast after 5 h boiling (kg)	2.127	2.073	2.382	2.175	2.722
Saturation coefficient	0.34	0.33	0.36	0.35	0.38
UCS (Mpa)	3.80	4.00	4.20	4.00	4.20
UCS (Mpa) after 24 h soak	3.28	3.36	3.68	3.55	3.44

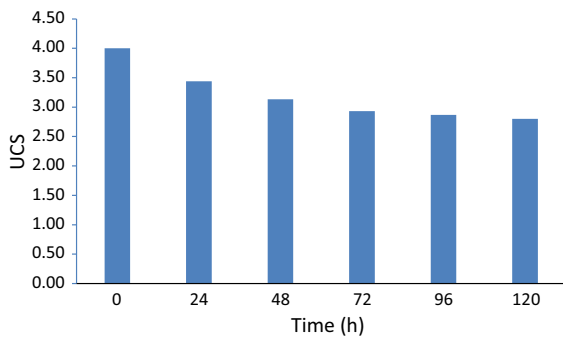
hydration products were formed hence a low UCS of the material.

### 5.6 Wet compressive strength

The 30 % stabilised soil was moulded and cured for 7 days at 40 °C. The cured stabilised soil was then

soaked in a water bath for 24 h [31]. Table 5 shows the variation in UCS and mas after a 24 h soak.

A 24 h soak resulted in 12–18 % loss in UCS with a corresponding 5–16 % gain in cast mass due to water absorption. These figures indicate that the stabilised material has adequate strength and can be used subbase or base material [31]. The stabilised soil also had a saturation coefficient of 0.35. The lower the



**Fig. 10** Variation in UCS with soak time of the 30 % stabilised soil using 70:30 DFA:lime and cured for 7 days at 40 °C

figure the more resistant the material to frost action. Therefore the stabilised soil had a good resistance to freezing and thawing. Figure 10 shows the variation of UCS with time of soaking.

The drop in UCS reaches an equilibrium at after 72 h. The drop in UCS after 72 h was statistically insignificant as the ANOVA  $F$  values for the difference were lower than the  $F_{critic}$  value of 7.71. After 72 h the loss in strength was 26 %, which was still satisfactory. A correlation between the UCS and saturation coefficient was also established. A maximum saturation coefficient of 0.74 was achieved after 5 days showing that the stabilised soil was still stable even after 5 days of being soaked in water.

## 6 Conclusion

A 30 % lime stabilisation of DFA resulted in a composite with a UCS of 8.57, a 19.5 % water absorption a 24 h soak with a corresponding 23.5 % reduction in UCS. A curing temperature of 80 °C was found to be the optimum together with a composite moisture content of 30 %. The rate of covering of the DFA particles with hydration products affected the final strength of the composite. Lime consumption by DFA was seen to fit modified Jander kinetics with an activation energy 16 kJ/mol. The green 70:30 DFA:-lime composite was seen as an effective stabiliser of expansive soil. Additions of the composite to the expansive soil resulted in the reduction of liquid limit and plasticity index, this is due to reduction in specific surface and diffuse double layer. There was also an increase in soil pH and OMC, reduction in CEC and MDD. All these property changes assisted in

transforming the soil to a medium plastic soil from a high plastic soil and thus improve the short term strength of the stabilised expansive soil. The stabilisation resulted in the formation of new crystalline structure in the expansive soil. Long term strength was due to presence of hydration products which were calcium silicate hydrate and tricalcium aluminate though the presence of Philipsite K also added apparent strength to the expansive soil. The 30 % (using 70:30 DFA:lime) stabilised expansive soil met the minimum requirements of American Concrete Institute for soil stabilisation with a 7 day strength of 4.1 MPa, 14 % reduction in UCS after a 24 h soak and saturation coefficient of 0.36 meaning that the stabilised soil has resistance to frost. The use of DFA and lime in soil stabilisation therefore presents an attractive cheap alternative for countries like south Africa which has vast tracts of land with problematic expansive soil. The use of DFA for stabilising soil also presents high volume use of a waste product which currently has no use and is stored in dams which affect the environment.

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