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**Original Research Article**

# Effect of Granular Materials Inclusion on Shrinkage Behaviour of Compacted Lateritic Soils

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## ABSTRACT

*The effect of granular materials inclusion on shrinkage behavior of compacted lateritic soils was carried out in this study. Specimens prepared from three lateritic samples were admixed with varying percentages of sand and quarry dust independently and subsequently compacted using British Standard light (BSL) and British Standard Heavy (BSH) compaction energies. The optimum moisture contents from the compactions were obtained and then the volumetric shrinkage strain measured after drying for ten (10) days under laboratory conditions. Results of this study indicated that for the lateritic soils tested, volumetric shrinkage strain is influenced by soil composition, moulding water content relative to optimum moisture content and compaction energy. Volumetric shrinkage strain decreased with addition of sand or quarry dust for all specimens. The general trend for the natural and admixed soils shows that as compaction energy increases, volumetric shrinkage strain decreases. Specimens compacted with a higher compaction energy (BSH) at -2%OMC and OMC had a volumetric shrinkage below 4% while those compacted on the wet (+2%OMC) of optimum had a maximum volumetric strain of 5.85%. However, specimens compacted with BSL had volumetric values of over 6.2% at -2%OMC and OMC, and over 12.12% on the wet side (+2%OMC) of optimum moisture content. Volumetric shrinkage in compacted lateritic soils is reduced by inclusion of granular materials, however, the extent to which the volumetric shrinkage strain is reduced is dependent on the compaction energy and moulding water content.*

## 1. INTRODUCTION

Laterite soils are rich in iron and aluminum and are formed in tropical areas with an annual rainfall of about 750 mm to 3000 mm (mostly in areas with a significant dry season) on different types of rocks (David et al., 2004; Bello and Adegoke 2010; Oyelami and Van Rooy, 2016). Lateritic soils are used as filling materials for a number of constructions such as fill materials and flexible pavement foundations (Ojo et al., 2016). Lateritic soils are weathered under certain conditions which include high temperatures and humidity and alternating wet and dry seasons which result in poor engineering properties such as high plasticity, low workability, low strength, high permeability and high natural moisture content (Amadi, 2010). The effective use of these soils is thus often made difficult by poor handling mostly under wet conditions typical of tropical regions and can only be utilized effectively after improvement. These soils pose problems during construction and are termed problematic laterites (Osula, 1991; Oyediran, 2001). These problematic laterites can be encountered in highway pavement where they are used as sub-base materials, resulting in swelling, depression or lateral movements of the pavement having come in contact with water or even under wheel loads (Omowumi, 2017). In view of this nature of lateritic soils, some modifications to their properties are often required to satisfy design criteria.

Measurement of shrinkage is of great importance when studying compaction and the use of soil shrinkage curves has been proposed as a means of characterizing changes in porosity (Boivin et al., 2006). Compacted soil liners and covers in waste containment facilities are usually rich in clay particles, because these clay particles have good sorption ability for contaminants in addition to their self-restoration ability under wet condition and are normally compacted on the wet side of optimum moisture content (OMC) (Osinubi and Nwaiwu, 2002, 2005, 2006, 2008; Osinubi and Eberemu, 2005; Eberemu, 2008). However, according to Bae and Inyang (2006), lateritic soils under dry conditions, crack and release dust particles which is detrimental to landfill especially in arid regions. These cracks and fissures serve channels for leachate flow thereby increasing the hydraulic conductivity and hence, failure of the compacted clay liner (Cawley, 1999). Daniel (1987) reported that increase in hydraulic conductivity by as much as 1,000 times the value measured in the laboratory can result from the effects of desiccation and cracking. The cracking is as a result of shrinkage by desiccation of hydraulic barriers clay materials which is dependent on the characteristics of the clay materials present in the compacted soil under differing stress modes encountered in the field (Ghezzehei and Or, 2001; Osinubi and Eberemu, 2010). Various researchers have studied the desiccation effect of soils containing clayey materials. Dejong and Warkentin (1965) in their study noticed shrinkage potential increasing linearly with increasing clay content. The use of gravel materials to reduce shrink-swell potential as well as hydraulic conductivity has been suggested by Daniel and Wu (1993).

Soil improvement is one of the most practical, and cheapest ways of improving the resistance, strength, and permeability of soil (Marto et al., 2013). One of the most popular methods of soil improvement is known as soil stabilization. Adetuberu and Amu (2010) defined soil stabilization as the process of enhancing certain desired properties in a soil material so as to render it stable for use in construction purposes where these desired properties are required. George and Karibo (2014) also defined soil stabilization as the alteration of soils characteristics in order to enhance their physical properties.

Mechanical soil stabilization such as combination with sand have been found to improve the density of lateritic soils while at the same time reducing its plasticity (Mu'Azu, 2002). However, quarry dust can be used as a substitute for sand to improve the properties of lateritic soil according to Soosan et al. (2001), and Onyelowe and Okoafor (2012). This line of thought is in agreement with Sridharan et al. (2005), who conducted studies on the effect of quarry dust on the geotechnical properties of soil used in highway construction and concluded that the California Bearing Ratio (CBR) value steadily increased with increase in percentage of quarry dust and Sridharan et al. (2006) who also conducted studies on the shear strength of soil-quarry dust mixtures and the results showed that the quarry dust proved to be a promising substitute for sand and can be used to improve the engineering properties of soils.

Although, a lot of research have been carried out on the use of stabilizing materials on lateritic soils, there is little literature on the effect of these materials on the shrinkage behavior of the soils. The purpose of this study is to investigate the effect of sand and quarry dust on the shrinkage behavior of compacted lateritic soils.

## 2. MATERIALS AND METHODS

Three lateritic soils labelled LAT 1, LAT 2 and LAT 3 were used in this study. The soils were obtained from Ring Road, Agu Awka (TAHMAD burrow pit) and Nawfia bypass respectively all in Awka, Anambra State, Nigeria (6°12'45.68" N 7°04'19.16" E).

Compaction tests were performed on the specimens which were previously mechanically crushed to sizes small enough to pass through 4.76mm (BS No. 4) sieve sizes, similar to the procedures by Osinubi and Nwaiwu (2008). The test specimens were mixed with water to the desired moulding water contents. Five moulding water contents ranging from 4% to 20% by weight of dry soil were utilized in preparing the specimens. Two compactive efforts were used in preparing the test specimens; namely British Standard Heavy (BSH) and British Standard Light (BSL). The BSH and BSL compaction are the British Standard (BS) equivalents of the Modified and Standard Proctor compactions (ASTM D 1557 and ASTM D 698), respectively (Osinubi and Nwaiwu, 2008). Subsequently, the soil samples were also compacted with varying percentages (ranging from 10% to 50%) of sand and quarry dust independently. The maximum dry unit weights along with the corresponding optimum compaction water contents for the three lateritic samples when no granular materials were added and when the varying percentages (10% to 50%) of sand and quarry dust were independently introduced.

Test specimens for the volumetric shrinkage were compacted (at optimum moisture content (OMC), +2 OMC and -2 OMC), trimmed, carefully extruded from compaction moulds and allowed to dry undisturbed at normal room temperature of about 20°C. Natural drying is considered as a simulation of field conditions (George et al., 2016). An average of at least three measurements of the heights and diameters of the specimen were made after being left to dry for 10 days using a Vernier Caliper. The diameters and heights obtained were used to compute the volumetric shrinkage strain thus;

$$VSS = \frac{(\mathrm{V} - \mathrm{Vf})}{\mathrm{V}} \qquad (1)$$

Where:
VSS = Volumetric shrinkage strain.
V= Original volume of moist compacted cylindrical specimen.
Vf = Final volume of dry compacted cylindrical specimen.

Two – way analysis of variance (ANOVA) was used to determine if the effect of differences in compaction conditions on volumetric shrinkage strain is statistically significant while multiple regression analysis was used to express the volumetric shrinkage strain (VSS) in terms of logarithm of compaction energy (CE), water content relative to optimum (WRO), specific gravity (SG), percentage fines (F) and plasticity index (PI) and percentage granular material included.

## 3. RESULTS AND DISCUSSION

The specific gravity of these samples of lateritic soil ranged from 2.51 to 2.62 (see Table 1), the fines content of the samples falls within a very short band ranging from 38.18% to 40.70% while the percentage of sand ranged from 59.30 % to 61.82% as compared to 99.25% and 93.41% for sand and quarry dust respectively. The three lateritic soils can all be classified as inorganic clays of low plasticity (LAT 1) and inorganic silts of low compressibility (LAT 1 and LAT 3) based on the Unified Soil Classification System, USCS ASTMD 2487 (ASTM 2006).

Table 1: Index properties of the lateritic soils, sand and quarry dust

| Property | Lat 1 | Lat 2 | Lat 3 | Sand | Quarry |
|---|---|---|---|---|---|
| Specific gravity | 2.61 | 2.51 | 2.62 | 2.63 | 2.75 |
| Coefficient of uniformity | | | | 2.22 | 8.88 |
| Effective size $D_{10}$ (mm) | | | | 0.18 | 0.1 |
| Mean size $D_{50}$ (mm) | 0.18 | 0.13 | 0.28 | 0.33 | 0.6 |
| Sand (%) | 59.30 | 60.26 | 61.82 | 99.25 | 93.41 |
| Silt and clay (%) (fines) | 40.70 | 39.74 | 38.18 | 0.75 | 6.59 |
| Natural moisture content (%) | 14.60 | 9.87 | 8.43 | - | - |
| Liquid limit (%) | 36.1 | 34.35 | 32.80 | - | - |
| Plastic limit (%) | 20.33 | 24.36 | 24.07 | - | - |
| Plasticity index (%) | 15.67 | 9.99 | 8.73 | - | - |
| USCS Classification | CL | ML | ML | | |

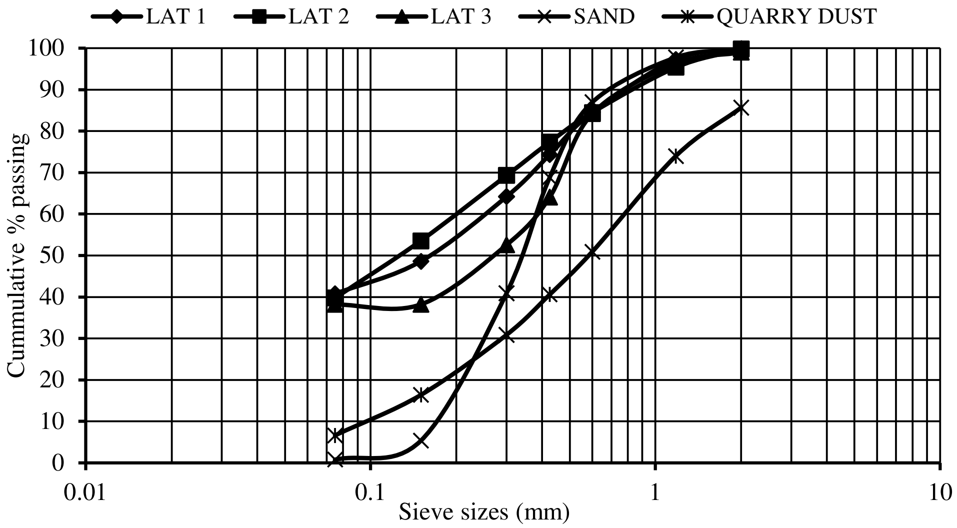


Figure 1: Particle grading for lateritic soils and granular materials

### 3.1. Effect of Compaction Energy

The variation of volumetric shrinkage with moulding water content relative to optimum of the three soil samples (LAT 1, LAT 2 and LAT3) for the two compactive efforts are shown in Figures 2 and 3(a – j), taking into consideration the natural soil with no treatment and when varying percentages each of sand or quarry dust that were added. The general trend for the natural and treated soil shows that samples compacted with the BSH compaction energy exhibited lower volumetric shrinkage as compared to those compacted with the BSL compaction energy. hence, for a particular moulding water content, the greater the compaction energy, the lower the volumetric shrinkage strain.

Kleppe and Olson (1985) defined major cracking as the development of cracks greater than 10 mm wide and this category of cracks occurred when volumetric shrinkage strains in cylindrical specimens compacted to the same water content and dry density as the slab specimen were greater than 4%.

From Figure 2(a -j,) it is observed that all samples compacted with the BSH compactive effort at -2%OMC and OMC had a volumetric shrinkage strain below 4%, while those samples compacted on the wet side of optimum moisture content had shrinkage values of over 4%. However, samples compacted with the BSL effort had volumetric values of over 6.2% at -2%OMC and OMC, and over 12.12% on the wet(+2OMC) of optimum moisture content. This is in agreement with the findings of Albrecht and Benson (2001) and Oluremi et al. (2014), who concluded that specimens compacted with the lowest energy had higher volumetric shrinkage values as to those compacted with higher compaction energies.

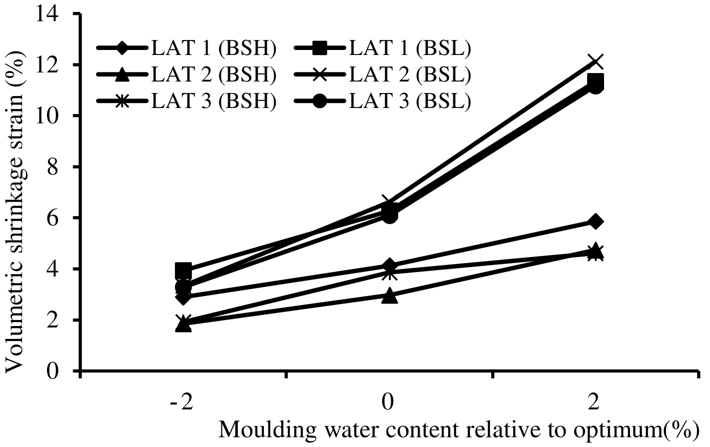
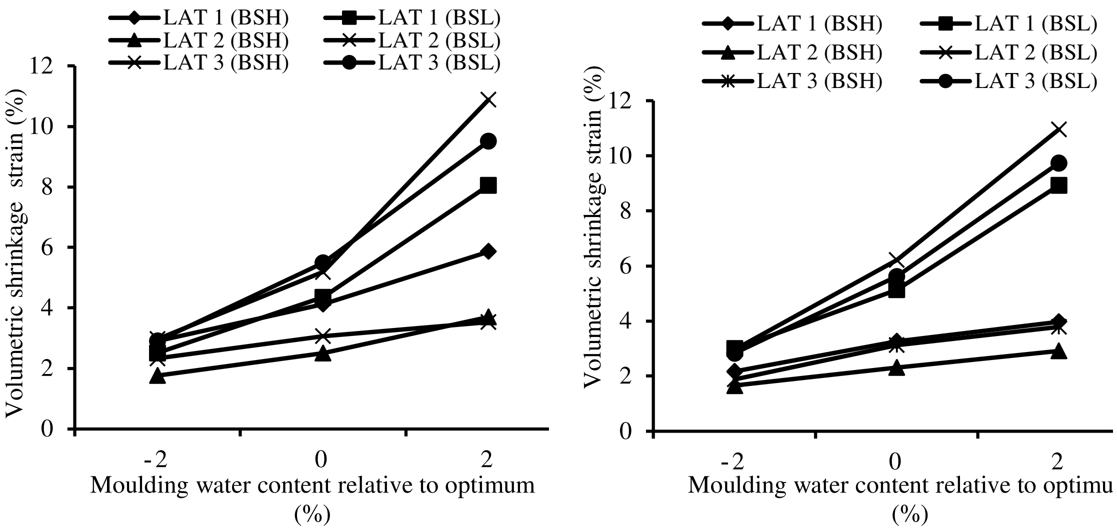
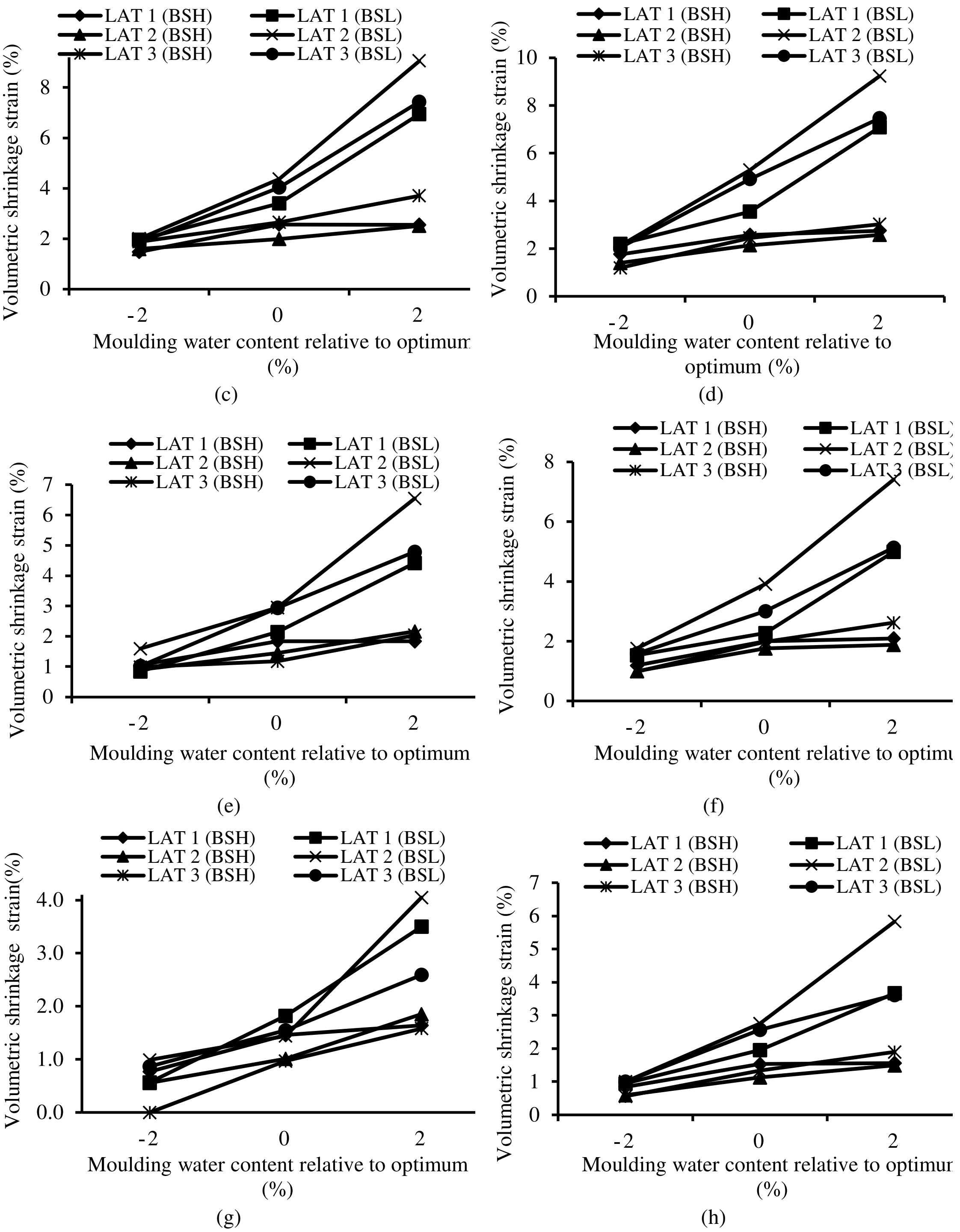


Figure 2: Volumetric shrinkage strain versus water content relative to optimum for the natural lateritic soils



(a)

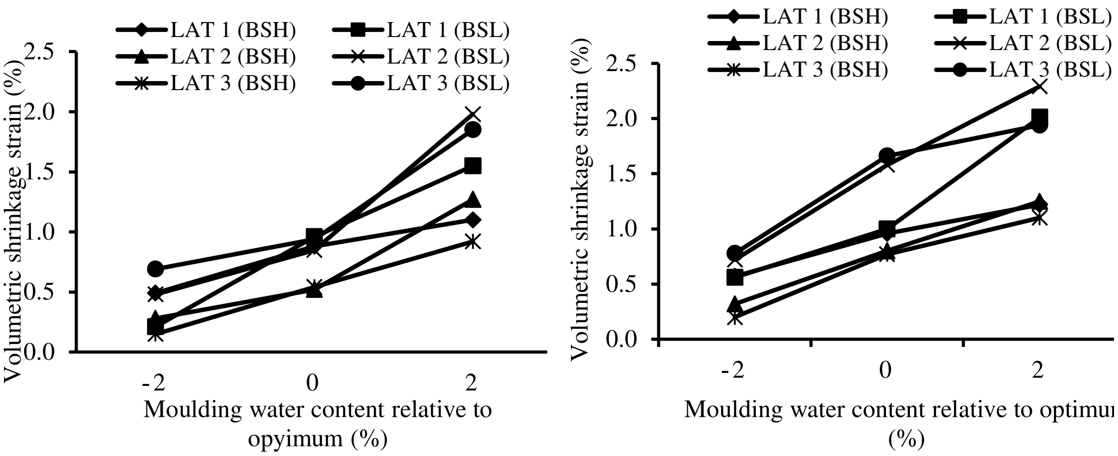
(b)


LAT 1 (BSH)
LAT 1 (BSL)
LAT 2 (BSH)
LAT 2 (BSL)
LAT 3 (BSH)
LAT 3 (BSL)
Volumetric shrinkage strain (%)
0
2
4
6
8
10
-2
0
2
Moulding water content relative to optimum (%)
Volumetric shrinkage strain(%)
0.0
1.0
2.0
3.0
4.0
1
3
5
7

(c) (d)

(e) (f)

(g) (h)



(i)

(j)

Figure 3: Variation of volumetric shrinkage strain of the soils with moulding water content relative to optimum moisture content for (a) 10 % quarry dust (b) 10 % sand, (c) 20 % quarry dust (d) 20 % sand, (e) 30 % quarry dust (f) 30 % sand, (g) 40% quarry dust, (h) 40% sand, (i) 50% quarry dust, (j) 50% sand

### 3.2. Effect of Moulding Water Content

Generally, volumetric shrinkage strain is directly proportional to the water content in all compacted samples (Oluremi et al., 2014) Sample compacted at optimum moisture content had lower volumetric shrinkage than those compacted at the wet side of the OMC. The highest volumetric strain was observed in Figure 2 at wet (+2%OMC) of optimum moisture content at a value of 12.12% for LAT 1 (natural soil) using the BSL compactive effort. This had a corresponding volumetric shrinkage value of 6.62% and 3.33% for OMC and dry (-2%OMC) of optimum moisture content respectively. However, the lowest volumetric strain was observed in Figure 2i at dry (-2%OMC) of optimum moisture content at a value of 0.15% for soil sample LAT 3, treated with 50% quarry dust using BSH compactive effort with a corresponding volumetric shrinkage value of 0.54% and 0.92% for OMC and wet (+2%OMC) of OMC respectively. This shows that increase in moulding water content leads to increase in volumetric shrinkage strain. At low moisture content towards the optimum, the particles of soil become dispersed and dilated so that there is difficulty in aggregating together such that the interparticle pores becomes larger with reduced capillary stress (Oluremi et al., 2014).

These results are consistent with those reported by Albrecht and Benson (2001) who from the study of the effect of desiccation on compacted natural clays, noted that the lowest volumetric shrinkage strain generally occurred in specimens compacted near optimum water content, and that shrinkage strain increased with an increase in compaction water content relative to optimum.

### 3.3. Effect of Sand and Quarry Dust

The variation of volumetric shrinkage strain with sand content as well as with quarry dust content are shown in Figure 4(a–c) and Figure 5(a-c) respectively. From the results obtained, it can be observed that increase in sand content reduces the volumetric shrinkage strain. This is in agreement with the findings of Madu (1975) who, from the investigation of sand laterite mixtures observed that adding sand to laterite reduces the linear shrinkage. Also, increase in content of quarry dust in the soil reduces the volumetric shrinkage strain. This concurs with the findings of Onyelowe and Okafor (2012) who considered quarry dust as one of the well accepted as well as cost effective ground improvement technique for weak soil deposits, noting that they provide the primary function of reinforcement and drainage, and thus improve the strength and deformation characteristics of weak soil deposits.

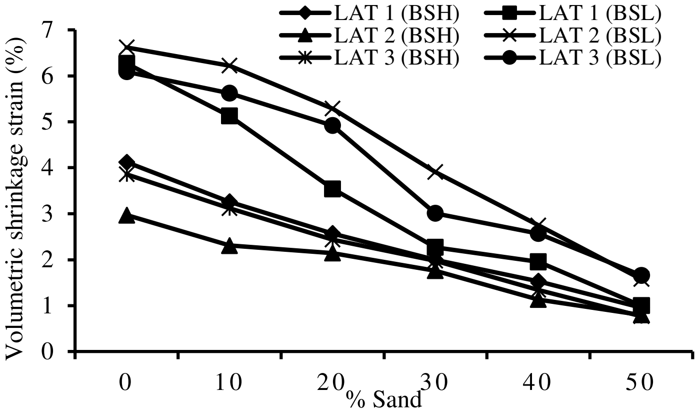


Figure 4(a): Variation of volumetric shrinkage strain with percentage sand content at OMC

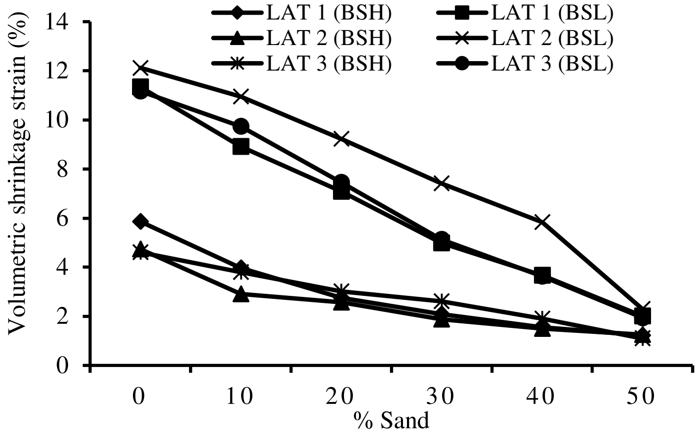


Figure 4(b): Variation of volumetric shrinkage strain with percentage sand content at +2%OMC

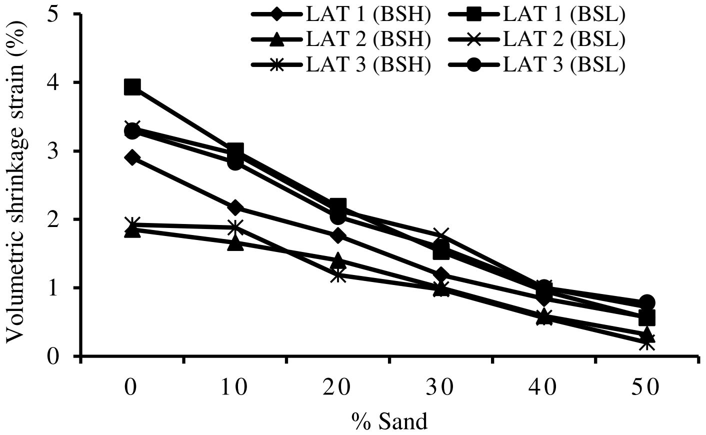


Figure 4(c): Variation of volumetric shrinkage strain with percentage sand content at -2%OMC

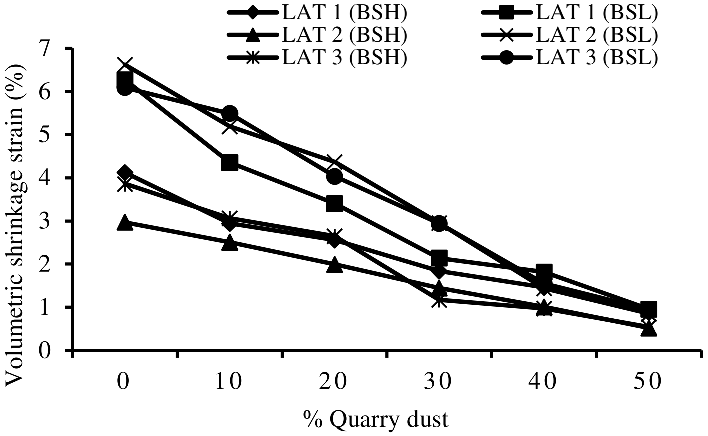


Figure 5(a): Variation of volumetric shrinkage strain with percentage quarry dust content at OMC

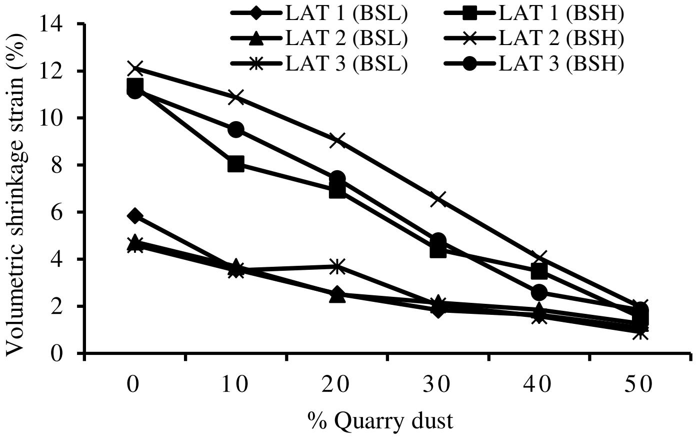


Figure 5(b): Variation of volumetric shrinkage strain with percentage quarry dust content at +2%OMC

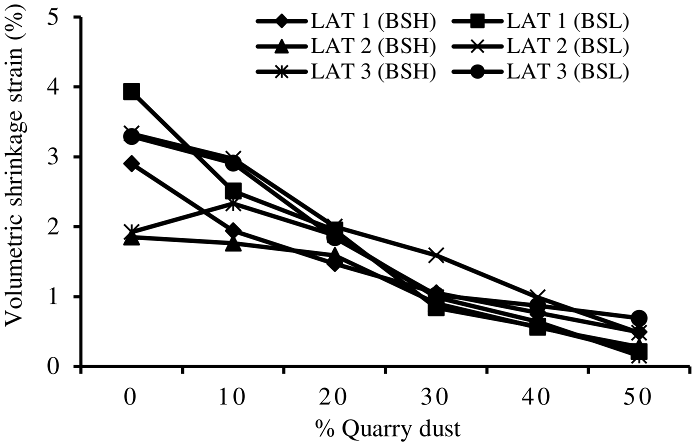


Figure 5(c): Variation of volumetric shrinkage strain with percentage quarry dust content at -2%OMC

Although, decrease in volumetric shrinkage strain was observed with increase in the percentage of granular materials included, these results were more favourable at dry (-2%OMC) of OMC for the granular material contents considered as lower volumetric shrinkage strain values were obtained while higher corresponding values were observed for wet side of OMC(+2%OMC). Thus, as the moulding water content relative to optimum moisture content increased the volumetric shrinkage strain increased and vice versa (Osinubi and Eberemu, 2010). Cracking due to desiccation is one of the major effects associated with drying. Cracking normally occurs in soil specimens with very high volumetric shrinkage strain (Albrecht and Benson, 2001). However, no cracking was observed in all the specimens during the study.

### 3.4: Statistical Analysis

Tables 2 and 3 show that the effects of differences in compaction condition on volumetric shrinkage strain for either quarry dust or sand is statistically significant. This validates the observation that for a particular moulding water content, the greater the compaction energy, the lower the volumetric shrinkage strain.

The volumetric shrinkage strain (VSS) in terms of logarithm of compaction energy (CE), water content relative to optimum (WRO), specific gravity (SG), percentage fines (F) and plasticity index (PI) was expressed as a function of percentage of sand added (S) and percentage of quarry dust added (QD) as shown in Equations 1 and 2 respectively

$$VSS = 0.803125WRO - 0.0859S - 3.38371CE + 3.120618SG + 0.506011F - 0.18036PI \quad (1)$$

$$VSS = 0.774167WRO - 0.09141QD - 2.90899CE + 2.859959SG + 0.443333F - 0.1641PI \quad (2)$$

The coefficient of multiple determination, $R^2$ value was 0.901, while the adjusted $R^2$ value was 0.886. The overall F- statistic (154.23) obtained is statistically significant at 95% confidence limit i.e. ($\alpha = 0.05$) for Equation 1 considering quarry dust as the granular material while the coefficient of multiple determination, $R^2$ value was 0.910, while the adjusted $R^2$ value was 0.896. The overall F- statistic (172.37) obtained was statistically significant at 95% confidence limit i.e. ($\alpha = 0.05$) for Equation 2, where quarry dust is considered. However, specific gravity was not statistically significant in Equation 2 when quarry dust was added to lateritic soils ($p > 0.05$) as shown in Table 4.

Table 2: Two – way analysis of variance (ANOVA) for volumetric shrinkage strain at different compaction conditions (sand)

| Soil | Relative moisture content (%) | Compactive effort | Source of variation | Degree of freedom | F – value (calculated) | P - value | F – value (critical) |
|---|---|---|---|---|---|---|---|
| LAT 1 | -2 | BSL | % Sand | 1 | 7.935412 | 0.018255 | 4.964603 |
| | | BSH | % Sand | 1 | 8.717261 | 0.014473 | 4.964603 |
| | 0 | BSL | % Sand | 1 | 9.004439 | 0.013327 | 4.964603 |
| | | BSH | % Sand | 1 | 9.390102 | 0.011956 | 4.964603 |
| | +2 | BSL | % Sand | 1 | 5.774597 | 0.037122 | 4.964603 |
| | | BSH | % Sand | 1 | 8.330619 | 0.01621 | 4.964603 |
| LAT 2 | -2 | BSL | % Sand | 1 | 7.19501 | 0.023 | 4.964603 |
| | | BSH | % Sand | 1 | 9.169363 | 0.012719 | 4.964603 |
| | 0 | BSL | % Sand | 1 | 9.013141 | 0.013141 | 4.964603 |
| | | BSH | % Sand | 1 | 9.751915 | 0.010822 | 4.964603 |
| | +2 | BSL | % Sand | 1 | 6.493576 | 0.028951 | 4.964603 |
| | | BSH | % Sand | 1 | 9.131023 | 0.012857 | 4.964603 |
| LAT 3 | -2 | BSL | % Sand | 1 | 7.505542 | 0.020846 | 4.964603 |
| | | BSH | % Sand | 1 | 8.83849 | 0.013975 | 4.964603 |
| | 0 | BSL | % Sand | 1 | 9.157448 | 0.012761 | 4.964603 |
| | | BSH | % Sand | 1 | 9.703008 | 0.010968 | 4.964603 |
| | +2 | BSL | % Sand | 1 | 5.654647 | 0.038748 | 4.964603 |
| | | BSH | % Sand | 1 | 8.379828 | 0.015975 | 4.964603 |

Table 3: Two – way analysis of variance (ANOVA) for volumetric shrinkage strain at different compaction conditions (quarry dust)

| SOIL | Relative moisture content (%) | Compactive effort | Source of variation | Degree of freedom | F – value (calculated) | P - value | F – value (critical) |
|---|---|---|---|---|---|---|---|
| LAT 1 | -2 | BSL | % Quarry dust | 1 | 8.092357 | 0.017407 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 8.799736 | 0.014132 | 4.964603 |
| | 0 | BSL | % Quarry dust | 1 | 9.22021 | 0.012538 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 9.558873 | 0.01141 | 4.964603 |
| | +2 | BSL | % Quarry dust | 1 | 5.997335 | 0.03432 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 8.406305 | 0.015851 | 4.964603 |
| LAT 2 | -2 | BSL | % Quarry dust | 1 | 9.120879 | 0.012894 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 9.733428 | 0.010877 | 4.964603 |
| | 0 | BSL | % Quarry dust | 1 | 9.120879 | 0.012894 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 9.733428 | 0.010877 | 4.964603 |
| | +2 | BSL | % Quarry dust | 1 | 5.373395 | 0.042914 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 8.481135 | 0.015505 | 4.964603 |
| LAT 3 | -2 | BSL | % Quarry dust | 1 | 7.822734 | 0.018894 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 8.990143 | 0.013381 | 4.964603 |
| | 0 | BSL | % Quarry dust | 1 | 9.218433 | 0.012544 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 9.594158 | 0.0113 | 4.964603 |
| | +2 | BSL | % Quarry dust | 1 | 5.807941 | 0.036685 | 4.964603 |
| | | BSH | % Quarry dust | 1 | 8.454029 | 0.015629 | 4.964603 |

Table 4a: Multiple regression analysis for volumetric shrinkage strain (sand)

| | Coefficients | t Statistic | p-value | Regression statistics | |
|---|---|---|---|---|---|
| Intercept | 0 | 0 | 0 | Multiple R | 0.954061 |
| S | -0.0859 | -12.1281 | 1.71E-21 | R Square | 0.910232 |
| CE | -3.38371 | -9.13354 | 6.72E-15 | Adjusted R Square | 0.896028 |
| WRO | 0.803125 | 10.8422 | 1.12E-18 | Standard Error | 1.257078 |
| SG | 3.120618 | 2.024133 | 0.045571 | Observations | 108 |
| F | 0.506011 | 4.528787 | 1.61E-05 | | |
| PI | -0.18036 | -3.50577 | 0.000678 | | |

Table 4b: Multiple regression analysis for volumetric shrinkage strain (quarry dust)

| Variables | Coefficients | t Statistic | p-value | Regression Statistics | |
|---|---|---|---|---|---|
| Intercept | 0 | 0 | 0 | Multiple R | 0.949062 |
| QD | -0.09141 | -12.8117 | 5.72E-23 | R Square | 0.900718 |
| CE | -2.90899 | -7.79461 | 5.68E-12 | Adjusted R Square | 0.886047 |
| WRO | 0.774167 | 10.37467 | 1.21E-17 | Standard Error | 1.266358 |
| SG | 2.859959 | 1.841466 | 0.068459 | Observations | 108 |
| F | 0.443333 | 3.938741 | 0.00015 | | |
| PI | -0.1641 | -3.16635 | 0.002036 | | |

## 4. CONCLUSION

The effect of granular material inclusion on shrinkage behaviour of compacted lateritic soils has been investigated in this study and the following conclusions were drawn.

1. The variation of volumetric shrinkage strain with compactive effort for the three soil samples investigated showed that as compactive effort increases, volumetric shrinkage strain decreases.
2. Lowest volumetric shrinkage strain generally occurred in specimens compacted at dry (+2%OMC) of optimum water content, and strain increased with an increase in compaction water content relative to optimum.
3. As sand content increased in the soil samples investigated, volumetric shrinkage strain decreased.

4. As quarry dust content increased in the soil samples investigated, volumetric shrinkage strain decreased

## 5. ACKNOWLEDGMENT

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## 5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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