Cleaner Engineering and Technology 3 (2021) 100120

Contents lists available at ScienceDirect

Cleaner Engineering and Technology

journal homepage: www.sciencedirect.com/journal/cleaner-engineering-and-technology

Influence of moisture and geofluids (GF) on the morphology of quarry fines treated lateritic soil

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A R T I C L E I N F O

Keywords:
GF
Absorbed & adsorbed fluid
Geomorphology
Double diffused layer (DDL)
Soil stabilization
Soil-ash interaction

A B S T R A C T

The influence of moisture migration in the form of GF on the morphology of lateritic soil has been studied with laboratory experiments. This was important due to the effect of adsorbed moisture during molding moisture addition in a stabilization protocol that gives rise to hydration. In addition, moisture adsorption and absorption play a very vital engineering role during the seasonal changes of wet and dry seasons when the water table rises and drops. This occurrence brings about alternate effects of wetting and drying of hydraulically bound structures like in pavement foundations. Therefore, it was pertinent to study how these changes affect soil microstructure to enable good design decisions. The soil used in this exercise was classified as highly plastic, poorly graded A-7-6 soil group according to AASHTO classification method. The soil was mixed with various proportions of quarry fines under different molding moisture conditions and the specimens were prepared for scanning electron microscopy (SEM) exposure. The results of the SEM exposure showed that GF applied here as molding moisture improve the agglomeration of treated soil particles to form flocs in a stabilization process. However, the microspores and crack propagation were observed more in the structure with less amount of quarry fine, i. e., at 2% QF than that at 4% QF. This showed the pozzolanic effect of QF on soil under the influence of GF. GF in all its forms should be studied for sustainable earthwork design and construction.

1. Introduction

The influence of moisture migration on the erratic properties of expansive clayey soils during earthwork construction cannot be overemphasized. More so is the effect of moisture existing as GF on the foundation of flexible pavements; the compacted subgrade built with either treated or untreated soils subjected to hydraulically bound conditions. GF are subsurface fluids such as groundwater, geothermal fluids, or magnetic fluids (Hurai et al., 2015), during high tides or during wet seasons, GF rise and this behavior affects clayey soil structures (Hurai et al., 2015), so, whether fluid exist as GF or moisture used during soil stabilization operations, they both affect the properties of soil during earthwork or during the lifetime of foundations. When the clayey soil comes in contact with the fluid (moisture), it swells through the dispersion of the interparticles by weakening the van der Waal's forces existing between particles. A layer of diffusion is produced between clay minerals and moisture films, which is called the diffused double layer (DDL) within which exists the adsorbed moisture. Meanwhile, the adsorbed moisture is the moisture located within the influence zone of the contact between water films and particles of clay whose properties are very viscous and different from those of free or normal water at the same temperature (Das and Sobhan, 2012) (Bui Van and Onyelowe, 2018). The behavior of a soil matrix depends upon the behavior of the discrete particles which embody the mass and the physical pattern or morphology of the particle's arrangement (Onyelowe et al. 2020) (Smith and Smith, 1998). Moisture and GF play an essential role as it is applied in soil stabilization at different moisture contents and dry densities and during the operational life of the structure built with clayey soil of high plasticity and expansivity (Onyelowe et al. 2020) (K. C. Onyelowe et al. 2020a). The reaction of the soil mass is clearly affected by the inter-particle-water relations, the ability of the soil elements to adsorb exchangeable cations, and the amount of dipolar moisture present and free to react. This also depends on the orientation of the total ions within the clay mass and the dipolar water (Das and Sobhan, 2012) (Bui Van and Onyelowe, 2018) (Onyelowe et al. 2019, 2020). It is known from the literature that clay particles carry negative charge ions on their outer

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https://doi.org/10.1016/j.clet.2021.100120
Received 28 January 2021; Received in revised form 11 May 2021; Accepted 12 May 2021

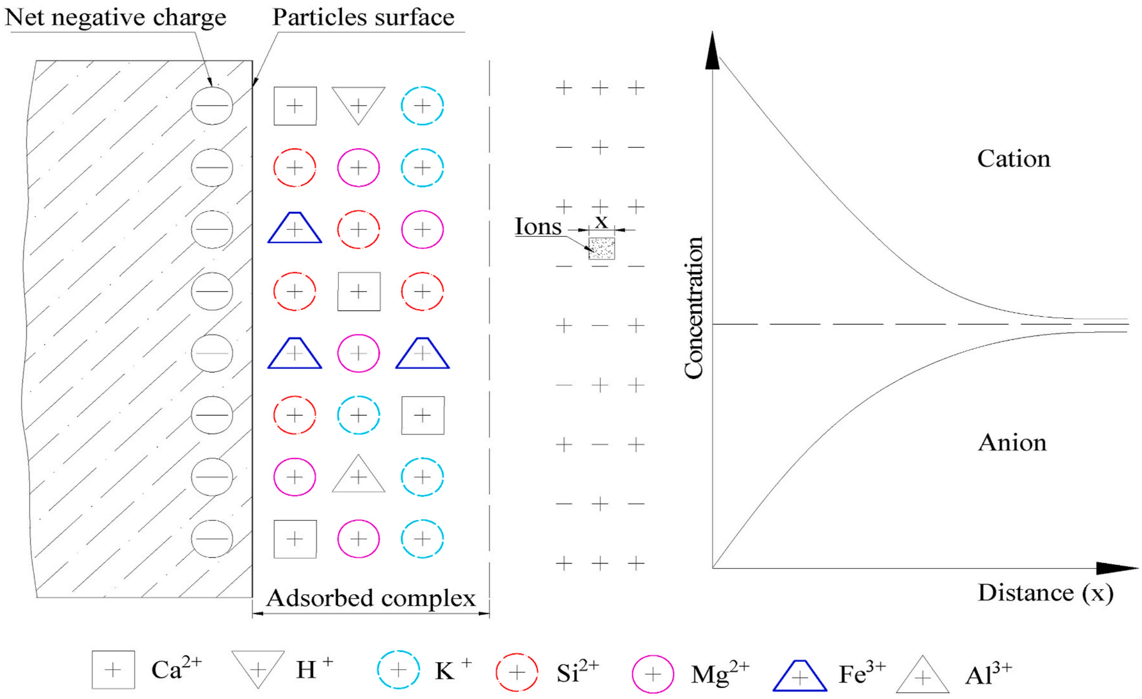

Fig. 1. Release of ions and cation migration and exchange reaction in the adsorbed layer and the repulsion potential of the treated lateritic soil (Das and Sobhan, 2012) (Bui Van and Onyelowe, 2018) (Onyelowe et al. 2020).

surface and this is the result of isomorphous substitution and of a discontinuous structure at its edges (Das and Sobhan, 2012). It has been mentioned that cation exchange (CE) is a process by which stronger ions in the electrochemical series displace weaker ions. Electrolytes dissociate when dissolved in fluid into charged cations and anions like water, which dissociates into hydrogen H^+ and hydroxyl OH^- (K. C. Onyelowe et al. 2019, & 2020a) (Ling et al. 2016). In a fluid-clayey soil interface, these positively charged ions migrate to the clay surface dominated by the negatively charged particles and form the adsorbed layer. From the electrochemical order of the ions, these H^+ ions can be replaced by other cations such as Ca^{++}, Al^{+++}, Na^+, K^+, or Mg^{++} as presented in Fig. 1 (Das and Sobhan, 2012) (Onyelowe et al. 2020).

When these ions migrate into the adsorbed layers, they constitute the “adsorption complex”. This process of replacement of cations of one kind by those of the stronger kind within the adsorption complex is known as “Base Exchange”. This means the capacity of colloidal particles to change the cations adsorbed on their surface. This occurs by a constant percolation of water containing dissolved sodium salts (Onyelowe and Bui Van, 2018). And the amount of exchangeable cations in a soil mass is called “exchange capacity”. The above illustrations are the mechanics of the interactions that take place in any soil treatment and modification operation. In earthworks, weak soils or problematic soils require treatment to chemically or mechanically change their properties to make them serviceable and applicable (Onyelowe et al. 2019). And the soils used in earthworks are made of clay. Clay minerals contained in expansive soils are complex aluminum silicates, compounds of one of two basic units, which are tetrahedral units of four oxygen atoms surrounding a silicon atom forming silica sheets and the octahedral units of six hydroxyl compounds surrounding an aluminum atom forming gibbsite sheets or surrounding a magnesium atom forming brucite sheets (Das and Sobhan, 2012). These are the major building blocks of clay minerals. These minerals in clay react when the soil is worked on during either in-situ or laboratory compactions with the injection of moisture. Therefore it’s also important to understand moisture and its phases since they play a essential role in earthwork operation, onsite or offsite. In Fig. 2, the phase diagram of water is presented to show the behavior of the fluid, either as moisture or GF. Note that water existing as moisture serves a great purpose during soil compaction to determine the maximum dry density of soil during earthworks. Then, water existing as a GF adversely affects the performance of expansive soil during the life of subgrade structures. Therefore the overall behavior of fluids is important to the geo-engineer. According to Tsuchiya and Hirano (2007), in their study, “chemical reaction diversity of GF revealed by hydrothermal experiments under sub- and supercritical states”, the phases and behavior of water with respect to the effect of pressure and temperature were presented in Fig. 2. This study shows the critical points of moisture phases and the effects on its interface with construction materials with great affinity with moisture like expansive clayey soils. This also presents a clue to how to manage soils in contact with moisture in the arctic regions where freezing and thawing are critical considerations. In the regions where the fluid phase enters the critical and triple points, the behavior and reaction of moisture within the adsorbed complex during the stabilization protocol is hampered while absorption by the GF during the service life of foundation structures under hydraulically bound conditions become critical as to cause unstable responses of the underlain structures (Mibe et al., 2007) (Ling et al., 2016).

High temperatures according to Fig. 2 support supercritical conditions and the fusion of soil particles and moisture dipoles is supported by pressure (Tsuchiya and Hirano, 2007) (Mibe et al., 2007). When soil is subjected to admixture treatment and properties’ modification procedures by a combined effect of chemical, mechanical, and admixture procedures and processes, ions are released within the interface between the clay particles and the additives due to hydration (Bui Van and Onyelowe, 2018). The dominant negative ions from clay are balanced by known exchangeable cations like Ca^{++}, Mg^{++}, Na^+ and K^+ from the admixtures of supplementary cements. This surrounds the particles being held by electrostatic attraction and the van der Waal’s force (Das and Sobhan, 2012) (Hausmann, 1990). The release of ions on the other hand depends also on the oxide composition of the admixture. When moisture is added to the mass being treated, these cations and a small number of anions float around the clay particles within the diffused double layer (DDL) (Das and Sobhan, 2012). Research has shown that cation concentration decreases with the distance from the surface of the

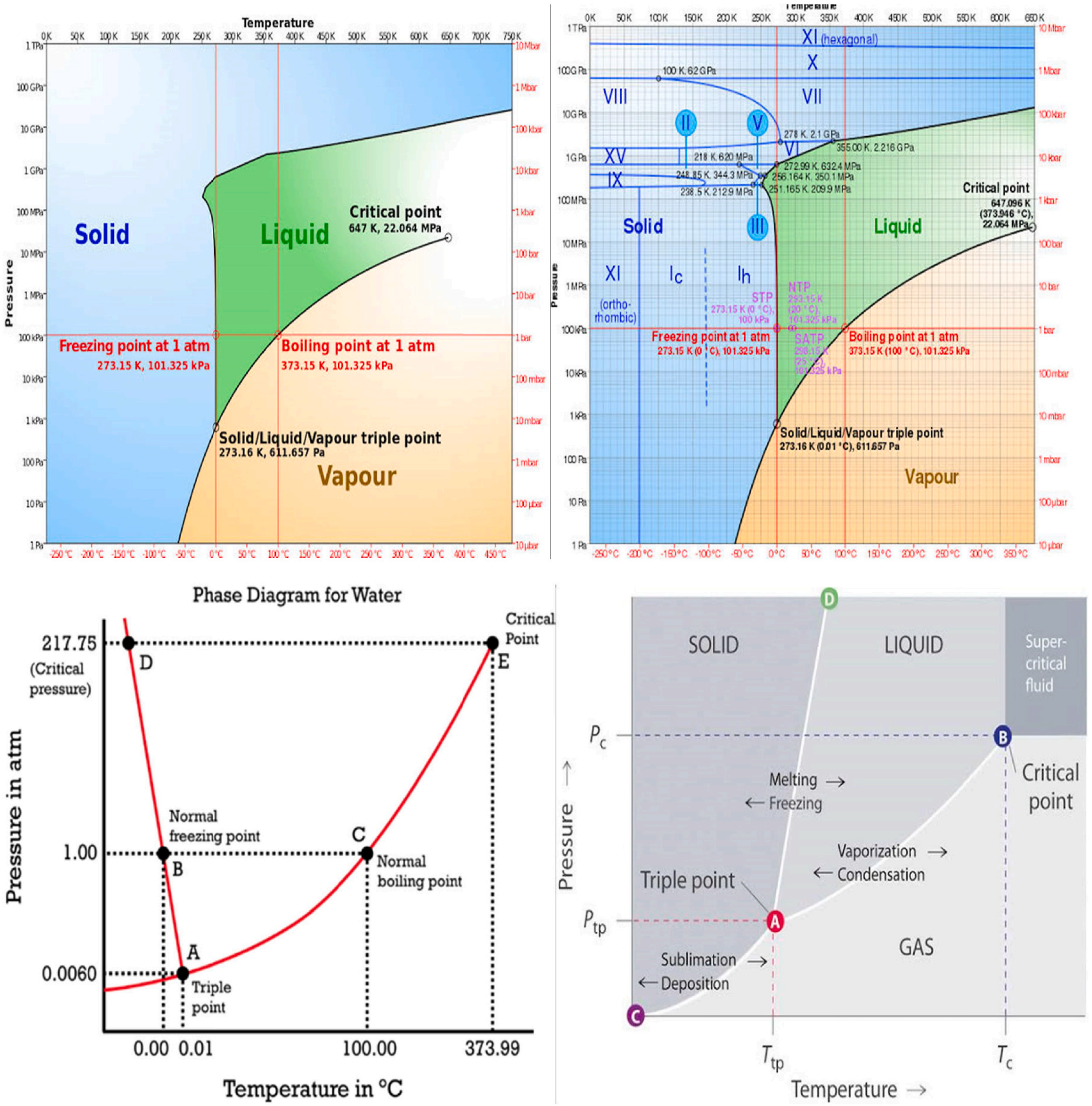

Fig. 2. Phase diagram of fluid (water) (Tsuchiya and Hirano, 2007) (Mibe et al., 2007).

particles while the anion concentration increases but slowly (Das and Sobhan, 2012) (Bui Van and Onyelowe, 2013). To enable the hydration reaction, cation exchange reaction flocculation, densification and gain in strength to be total, there must be a comprehensive cation exchange, which is to say that the interparticle gap in the soil has to be reduced to improve the cation concentration and bonding forces. If we assume that the ions in the double layer can be treated as point charges and that the surface of the stabilized clay elements is large compared to the thickness of the double layer, Poisson equation states that the Poisson's ratio is proportional to the repulsion potential existing between particles of clay (Bui Van and Onyelowe, 2018) (Das and Sobhan, 2012). This is with respect to the distance between the charged particles and the clay surface under adsorbed moisture (for a stabilization protocol) and absorbed moisture (for a hydraulically bound condition state). The repulsion potential is the tendency for the interparticle gap, which we consider as charged points to increase, thereby reducing the potential for the treated mass to form floccs and eventually gain strength and density. Hence, the primary aim of this research work was to take an overview on the effect of GF in the form of adsorbed and absorbed moisture and quarry fines on treated soil mass. And the specific objectives of this research are; (i) to review the relevant literature, and (ii) to take an overview, through laboratory results, the effect of molding moisture and quarry fine (QF) blend on the microstructure of the treated lateritic soil. Many researchers have in the recent past applied ash materials like bagasse ash, derived lateritic gravels, palm bunch ash, nanostructured clay, waste, paper ash, etc. to achieve strength gain and modification of problematic

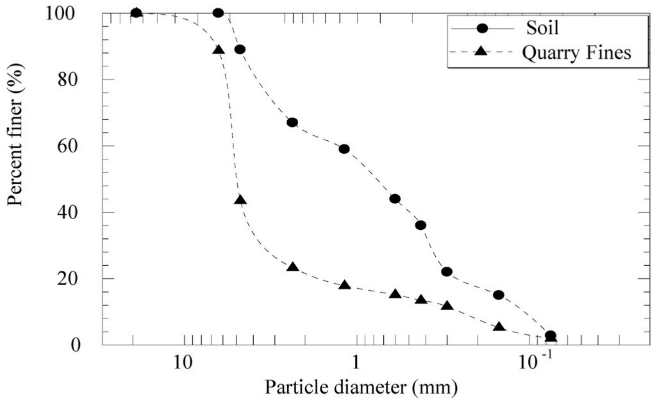

Fig. 3. Grading curves of the lateritic soil and quarry fines (Bui Van and Onyelowe, 2018).

soils (Osinubi et al. 2009) (Abdorelza et al. 2017) (Ling et al. 2016) (K. C. Onyelowe et al. 2020a; 2020b, & 2020c). There have also been mechanical procedures employed to alter the consistency and compaction properties of the stabilized soils for earthwork purposes (Onyelowe et al. 2020) The results achieved from these operations are applied in transportation infrastructures and geotechnics, mechanically stabilized earth (MSE) structures, dams, embankments, etc. (Gidigasu and Dogbey, 1980) (Bui Van and Onyelowe, 2018).

2. Materials

Quarry Fine was collected from the Quarry Factory in Amasiri, Afikpo, Nigeria. Quarry fine is commonly disposed at quarry sites during blasting and aggregate production, was collected, sundried, passed through sieve number 200 to obtain a homogenous fines, and was applied in the proportions 2% and 4% by weight of soil to modify the lateritic soil. Lateritic soil was collected from a construction borrow sites in Umuahia, Nigeria, prepared for use and stored in sacks. The soil was air-dried in trays for six days, after which the soil was tapped with a rubber pestle to remove lumps.

3. Methods

Preliminary and general tests were conducted in accordance with BS 1377-2 (1990) for classification and characterization, and chemical composition test was carried out on both the natural soil and the QF. Lastly, the scanning electron microscopy (SEM) test was conducted on the soil, the QF, and the QF treated soil at different molding moisture conditions to determine the microstructural changes that occur under different moisture conditions.

4. Results and discussions

From the general laboratory tests conducted on the expansive soil, the following were observed; (1) the natural moisture content was 18%, the liquid limit, 48%, the plastic limit, 23, the plasticity index, 25%, the maximum dry density, 1.76 g/cm^3 at an optimum moisture content of 15.2, the soil specific gravity, 1.87, QF specific gravity, 2.1 and the soil was classified as an A-7-6 group according to AASHTO classification system (AASHTO, 1993). The consistency test results showed that the soil was highly plastic, high swelling potential, and poorly graded. The grading of the soil and the QF are presented in Fig. 3.

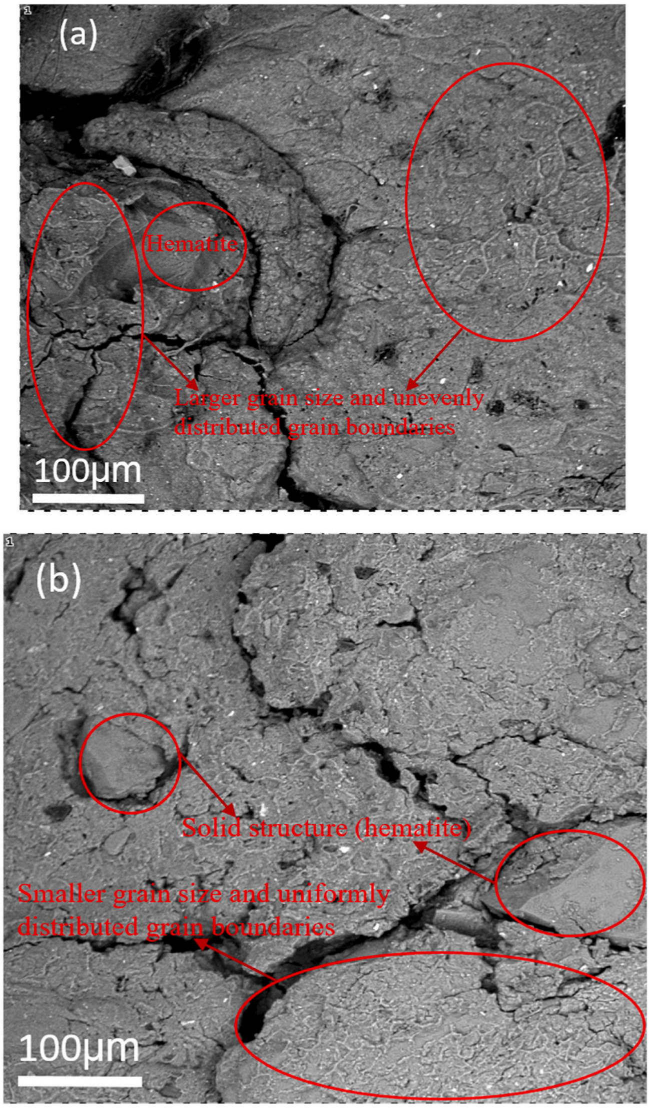

Fig. 4. Morphological arrangement of the natural soil at (a) 2% wet of OMC, (b) 4% wet of OMC.

The aluminum and silicate concentration and cementing potential of the soil, cement and the QF, which fulfilled material cohesion, is a factor as essential in soil additive blending and modification is presented in Table 1. Material requirement for supplementary cementing materials (SCM) is that the sum of the percentage composition of silicon oxide (SiO_2), aluminum oxide (Al_2O_3), and Iron oxide (Fe_2O_3) should be more than 70%. The composition of chemical oxides shows that the total of the percentage is 82.97% for QF, which is greater than 70%, and according to design standard requirements, this makes the QF a highly

Table 1
Chemical Oxide Composition of the materials used in this paper (Bui Van and Onyelowe, 2018).

Materials	Oxides Composition (content by weight%)											
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	Na_2O	TiO_2	LOI	P_2O_5	SO_3	IR	Free CaO
Lateritic Soil	76.56	15.09	2.30	2.66	0.89	2.10	0.33	0.07	–	–	–	–	–
QF	63.48	17.72	5.56	1.77	4.65	2.76	0.01	3.17	0.88	–	–	–	–

[a] IR is Insoluble Residue; LOI is Loss on Ignition, QF: Quarry Fines.

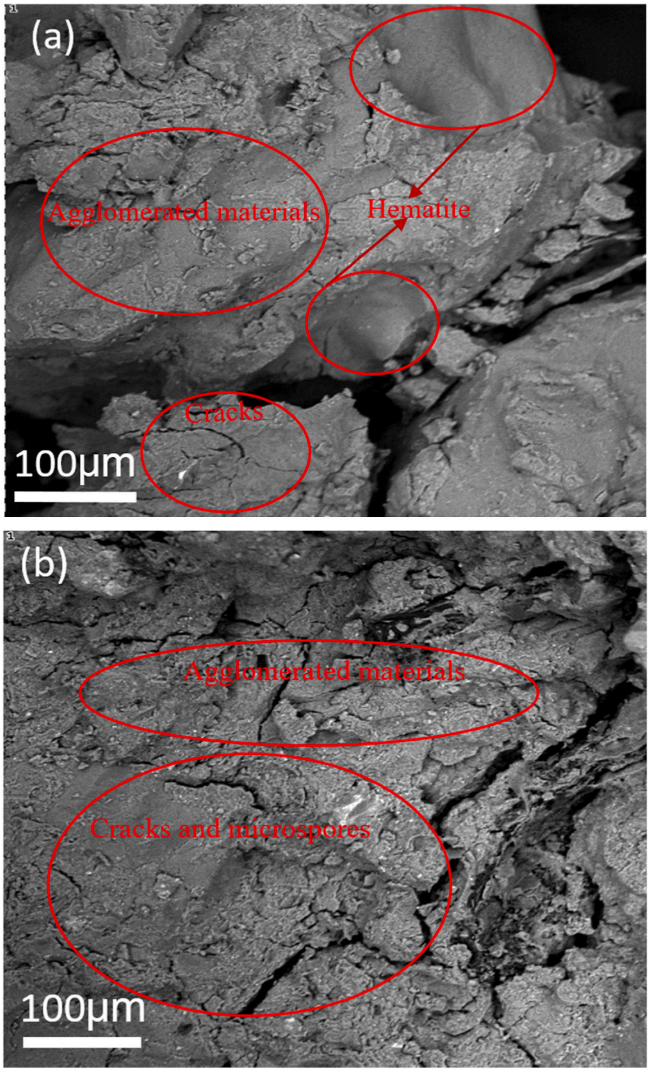

Fig. 5. Morphological arrangement of the 2% QF treated natural soil at (a) 2% wet of OMC, (b) 4% wet of OMC.

cementing material in accordance with the appropriate design standards (ASTM C618, 1978). This property produced high levels of cementing interaction and binding between the expansive soil and the admixture (QF). Secondly, the chemical oxide compounds presented in Table 1 show that the soil has metallic oxides; lime, that ensured hydration, and many more that ensured exchange of metallic ions and cementitious or binding reaction and the formation of flocs like SiO_2, Al_2O_3 and Fe_2O_3 combined formation of Al–S–H, which are responsible for the strength gain in a soil stabilization protocol. The low content of MgO shows that the soil has a very slim tendency to form the brucite sheets; the octahedral sheets formed with the replacement of aluminum atom by magnesium atom.

4.1. Morphological response of QF treated soil due to absorbed/adsorbed moisture

The SEM micrographs of both natural soil and QF treated soil at different moisture content are presented in Fig. 4 – 6. Microstructural changes were observed for soil matrices under different molding moisture conditions. Comparing Fig. 4a (natural soil with 2% wet of OMC) and Fig. 4b (natural soil with 4% wet of OMC), it was found that the micrographs indicated that the particles of the soil with 2% wet of OMC have different grain sizes with that of 4% wet of OMC. The soil with 2% wet of OMC revealed larger grain size particles with unevenly distributed grain boundaries compared to the soil with 4% wet of OMC, which indicated smaller grain size particles with uniformly distributed grain boundaries. The presence of cracks and microspores were observed in the micrographs of samples with 2% QF treated natural soil as shown in Fig. 5, and these defects were found to be absence in the micrographs of soil samples treated with 4% QF as presented in Fig. 6. This could be attributed to the binding that occurs between the soil particles and the QF in the presence of moisture during stabilization process/cementing reaction (Obianyo et al., 2020a). In Fig. 5, more cracks were observed in the sample treated with 2% QF at 4% wet of OMC when compared to the soil sample treated with 2% QF at 2% wet of OMC. This implies that the addition of excess moisture of about 4% wet of OMC could have a negative effect on the treated soil samples. In general, the presence of cracks was observed in the soil samples treated at 4% wet of OMC. This could be as a result of weak bonds formed by excess and unreacted moisture present in the soil matrix after inter-particle-water interactions (Bui Van and Onyelowe, 2018). Agglomerated materials were present in the treated soil samples as shown in Figs. 5 and 6. The agglomerated materials could be as a result of the cementation process that occurred between the soil particles and the QF stabilizer leading to improved strength (Obianyo et al., 2020b). Hematite, a common iron oxide of soil were observed for both treated and untreated soil samples as shown in

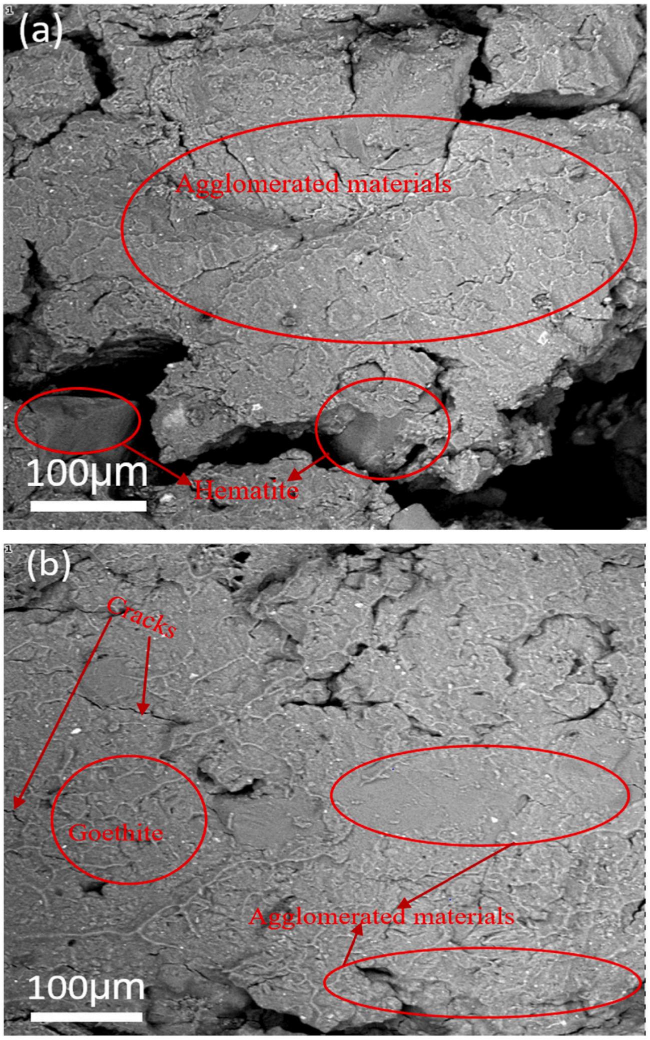

Fig. 6. Morphological arrangement of the 4% QF treated natural soil at (a) 2% wet of OMC, (b) 4% wet of OMC.

Figs. 4–6. Figs. 4–6 indicate that the two different molding moistures (2% wet of OMC and 4% wet of OMC) explored in this study have a significant influence on the morphology of both the untreated and treated soil samples. The resulting composite in Fig. 6a is a good material that could be used for earthwork construction applications.

5. Conclusions

From the foregoing study on the GF effect on the microstructure of QF treated soil admixed under 2% and 4% wet of optimum molding moisture, the following can be concluded;

- That the importance of adsorbed or adsorbed moisture in earthwork design cannot be neglected due to the engineering role GF play in the performance of hydraulically bound structures.
- Addition of molding moisture improves the agglomeration of lateritic soil particles during the stabilization process, but the addition of binding additives helps to protect crack formation.
- The blend of GF and quarry fine binder brought about agglomerated lateritic soil mass under laboratory conditions and should be considered in foundation design for a more sustainable earthwork.

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