International Journal of Multidisciplinary Research And Studies

Available online at www.ijmras.com
INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND STUDIES

E ISSN: 2640 -7272
Volume:09:Issue:04 (2026)

Page no. 59-74

A Review of Properties and Behavior of Sand-Clay Mixtures

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ABSTRACT

The properties and engineering behavior of sand-clay mixtures has been the greatest concern among civil and geotechnical engineers in field of practice. The reason has been that, it is an important factor that should be put first because of the important properties of the mixture in the construction site. However, Sand-clay mixtures were not commonly found in its required proportion in nature and therefore rarely available for civil engineering projects unless by improvise method through a geotechnical engineer. The mixtures are prepared through the blending of clay and sand materials together with the required proportions by a geotechnical engineer. In this review, the general properties of the mixtures were discussed. Also the different categories of sands and clay materials available in the construction industries were itemized including their man-made/processed sources. The techniques applied in the preparation of different percentages of sand and clay in the mixtures was considered including the Sand gradation, chemical composition of the mixtures, clay mineralogy, compaction behavior, the CBR, effect of volume change and sand range on the volume change behavior. Finally their transitional behaviors as well as its application were looked into in order to enhance the full understanding of the properties with much emphasis on the engineering behavior of the mixture under discussion.

Keywords: Sand- Clay Mixtures, Sand gradations, Properties, Behaviors, Blending, Processed

INTRODUCTION

Sand-clay mixtures are the mixtures of sand and clay materials together discovered for a specific engineering purpose. It was earlier found that most of the civil and geotechnical engineering design were mainly based on ideal soils such as pure sands or pure clays, but it is unfortunate that these ideal soils are not commonly found alone in real life. In other words, there are some specific engineering projects that may not go well in both pure sands and pure clays except on sand-clay mixtures. Therefore, the idea of blending sand/ gravel with clay came into existence to cover or bridge the gap created by using a particular ideal soil in the design of some sensitive engineering projects. Sand as a component of sand- clay mixtures are made up of many types and also vary according to sources. Sand can also be classified according to color such as red-orange color, black sand, and pink sand, white – grey color, white sand, light-brown color and others. It is quite clear that the classification of sand has not been an easy one simply because of its variability in nature and also from one location to the other. These are possible because the request for natural sand are on the daily increase and natural sand itself is not enough to satisfy the demand as a result of that, the artificial sand becomes a strong substitute in the construction industry.

Clay material does not have a stable behavior due to the mineral content and seasonal changes; hence it can expand in the presence of moisture contents and at same time contrast when the moisture disappears/dry season. However, it is also important to state that there are some clays that contains minerals that made them to swell more than others apart from the seasonal changes. The main target of blending clay with sand to obtain a sand-clay mixture is to improve the mechanical properties of the constituents for the intended engineering project/purpose. Therefore, most of the natural soils with inadequate strength can be improved through this way instead of chemical treatment or reinforcement as reported by Latifi, et al (2015); Anagnostopoulos, (2015) Rashid, et al(2017)., Geng,andYu,(2017) and Morales,et al (2019). Sand-clay mixtures has been found to exhibit higher strength when stabilized or reinforced with other materials such as biopolymer rather than when pure soils (sand or clays) are reinforced or stabilized with chemicals as reported by (Chang,et al 2015, Latifi, etal 2016, Chang et al,2019, Buchmann,et al 2020, Chang et al 2020). Therefore, the constituents of sand and clay would have their strength enhanced when reinforced with biopolymer but however their strength will improve more when sand and clays were mixed together to form a sandclay mixtures as stated by Chang, et al 2019. Generally in natural soils, sand-clay mixtures are commonly seen as composites well as road embankments materials, but whichever way, the behavior is often controlled by the minerals that are contained in clay materials according to (Deng, et al 2017, Wang, et al 2018). Besides, the strength ability of a sand-clay mixture is controlled or influenced by both sand and clay soils depending on their ratios or proportioning. As result of these, there exist a transition point/ mark that show whether sand or clay is dominating in the mixtures. And that is evidence that controlled the behavior of the mixture as found by (Skempton, 1985, Monkul, and Ozden, 2007, Vallejo, and Mawby, 2000, Kim, et al 2016).

1.1 General Properties of sand-clay mixtures

The properties of sand-clay mixtures are not obtainable in any of the ideal soil be it sand or clay soil materials. These properties are follows; load bearing capacity, the shear strength, permeability, reduction in volume or compressibility, stickiness, and water retention. Permeability has to do with the ease with which water enters into the soil. Sand is a porous material when compared with clay, but when both are blended together to form a mixture, the presence of fines from the clay material would reduce the porosity forming a lower hydraulic conductivity. In other words, the combination with well known mineral charged clay material and sand would drastically reduce the permeability which is used as a good material or barrier for waste containment or landfill materials. However, the blending of clay materials with sand together would results into high load bearing capacity because the fine material from clay has filled in the void spaces in the mixtures leading to strength mobilization compared to using the ideal soils only. Therefore it has became, an established fact that when clay and sand materials are blended together with their ratios being controlled, the resulting void ratio would surely reduce. **Shear strength**; the mixture of clay and sand together has a ratio where the strength is at best (highest) beyond which one would notice a reduction in strength. It is therefore necessary to have a close monitoring of clay material up to 10% depending on the mineral content with sand inclusion in order to prevent reduction in strength. **Stickiness** has to do with plasticity that are contain in clay materials in the sand-clay mixtures. The presence of plastic minerals has a serious effect on the sand-clay mixtures and this has effect largely on the type of mineral that contains on each clay and also its ratio or proportion with sand. **Water retention** is the ability of the sand -clay mixtures to retain waters moderately in the mixtures since the presence of fines from clay material has reduced the void ratio, in the same way, the permeability of the resulting mixtures will also reduced when compared to pure sand or pure clay materials. **Compressibility** has to do with volume change of a material; therefore since the blending of sand and clay together leads to a reduction in permeability, it then means that, the reduction in volume of sand-clay mixtures is minimal when compared to ideal soils. More so, it is also important to consider the effect of sand gradation when blending the soils because research has shown that effect of sand gradations is not negligible. Hence the interaction of the two materials in the matrix speaks volume of the overall results. However, sand-clay mixtures are commonly applied as liners in waste disposal and landfills. It is also used in steep slope road embankment construction (Cabalar, and Mustafa 2017). Hence sand-clay mixtures are the best alternative to both ideal sands and ideal clay soils.

1.2 CATEGORIES OF CLAYS AND SANDS IN SAND-CLAY MIXTURES

1.2.1 Clay Minerals

A Clay soil material occurs naturally as a mineral that is primarily made-up of fined-grained materials. It is commonly found all over the globe and behaves as plastic at appropriate water contents and also hardens when the temperature increases. Because we have different types of clay, it therefore accounts for different types of minerals contained in each clay materials and its associated characteristics.

Clay material does not have a stable behavior due to the mineral content and seasonal changes; hence it can expand in the presence of moisture contents and at same time contrast when the moisture disappears/dry season. However, it is also important to state that there are some clays that contains minerals that made them to swell more than others apart from the seasonal changes. There are different types of clay such as; kaolinite, bentonite (swelling) clays examples are sodium smectites which swells more than the calcium smectites, Attapuigite or palygorskite clay, Chlorite clay, Illite clay, Vermiculite clay, montmorillonite clay etc. Apart from the natural clays, processed clay were also made available by man to augment or close the gap resulting from natural clays where the need be. Examples are earthenware clay, stoneware clay, Ball clay, and Porcelain, kaolin clay, fire clay etc.

Skempton (1953) classified clay ratios activities as follows;

Inactive clays << 0.75, normal clays 0.75-1.25, active clays >> 1.25.

1.2.2 Sand Materials

Sands are made up of the different types such as; gypsum sand, ooid sand, glass sand, coral sand, pit sand, river sand, silica sand, sea sand, desert sand, green sand, mixed carbonate silicate sand, lithic sand, volcanic sand, biogenic sand, olivine sand, garnets sand, heavy mineral Sand, Sand with hematite pigment, continental sand, quartz sand, Leighton buzzard sand etc. of course there properties varies based on their sources as stated earlier. Also sand can as well be categorized according to its ability to pass through the sieve numbers such as Very coarse, Coarse, Medium, and Fine-grained material. There are some of the sand made available or processed by man such as crushed stone sand made for the purpose of asphalt and concrete crushing rocks like granite or basalt, quarry dust, a fine byproduct of crushing stone, and even artificial sand for beaches,etc. These are possible because the request for natural sand are on the daily increase and natural sand itself is not enough to satisfy the demand as a result of that, the processed sand becomes a strong substitute in the construction industry.

Table(1) International soil congress at Washington in 1927

Clay	Silt	Sand			Gravel		Cobles
		F	M	C	F	C	

0.002 0.075 0.475 2 4.75 20 80

Classification soil from clay soil to coble

A soil is referred to as a coarse-grained material (sandy or gravelly) when more than 50% is retained on a No 200 sieve and also as a fine-grained material (clay and silt) when more than 50% is Passing through a sieve No-200.

Unified Soil Classifications (USCS) soils and their symbols are as follows;

Sand (S), well-graded (W), poorly gap graded (P), Gravel (G), wet graded with some fines (C), well graded with excess fines (F), silt (M), clay (C), organic (O), peat (highly organic) (Pt), low plasticity (L), intermediate plasticity (I).

1.3 Techniques for Preparation /Proportioning of Sand and Clays in Sand-Clay Mixtures

Mekkiyah, et al (2015) initiated the engineering behavior of clay soil when mixed with fine sand by using the percentages of sand from 0 to 80%. From the result, it was found that as the percentage of fines increases, the liquid limit,(LL), the plastic limit(P.L), the plastic index (P.I), the Optimum moisture contents (O.M.C.), and the Specific gravities (G.S) of the entire mixtures continues to reduce up to 80% fine sand contents. However, the dry density (DD) of mixtures increases from the addition of 10% fines up to 60% fines and start decreasing at 80% fines addition. Therefore, the table above gave the summary of the behavior of clay with fine sand from 0% up to 80% of fine sand as reported by Mekkiyah and Al-Khazragie (2015). They also found that both the liquid (LL%) and plastic limit (PL%) of the mixture decreases as the sand increases from 0% up to the highest percentage of fine sand addition (Alnmr and Ray, (2024). They therefore shows how the sand controls the mixtures, hence the densities increases upon more sand inclusion and in the order way round, the optimum moisture contents of the mixtures also reduces due to sand addition Srikanth and Mishra (2019).

Table 2. Behavior of clay soil with fine sand

Mixing ratio	Plain soil	10% fine sand	20% fine sand	30% fine sand	40% fine sand	50% fine sand	60 % fine sand	80 fine sand
L L (%)	56	50	44	38	33	28	24	18
P .L (%)	24	21	17	15	14	13	10	N.P
P.I (%)	32	29	27	23	20	15	14	-
$\gamma \gamma_d$ KN/m	19.4	19.6	19.9	20.1	20.6	20.9	22	20.8
G s	2.76	2.74	2.72	2.71	2.7	2.69	2.67	2.66
O. m. c (%)	16	14.2	13.9	13	12.2	11	9	8.4
Classification	CH	CH	CL	CL	CL	SC	SC	SP-SM or SM

Applied research journal volume (one)

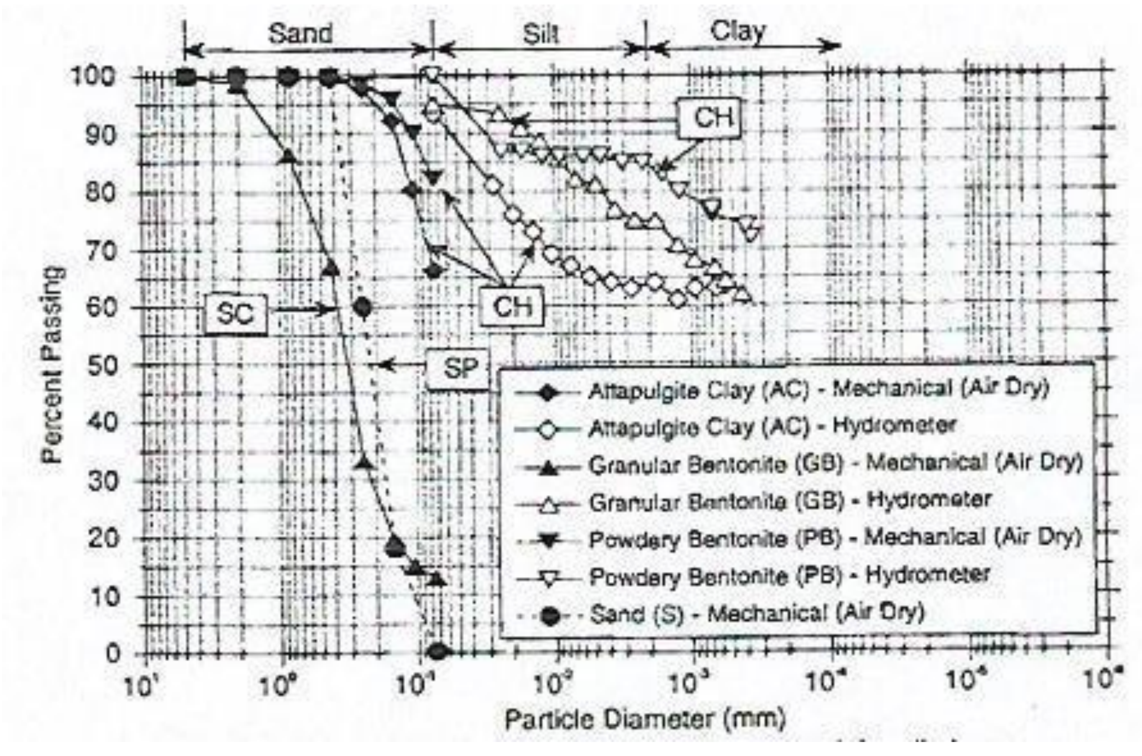

Fig.1 -Particle size distribution for soil constituents used in sand-clay mixtures.

In the graph above, a plain clay composed of (kaolinite, montmorilonite and quartz) mineralsmaterial combined with two different sand-clay mixtures in order to obtain a homogeneous mixture, having considered the specific gravity, plasticity index and liquid limit to be 2.70, 18% and 42% respectively, while the specific gravity of the sand material used was 2.65 with a very high void ratio of (0.803) due to the size of sand distribution in the overall sample. Therefore, when this sand was applied to form sand-clay mixtures, it would be found to be floating in the overall mixtures especially when the quantity of sand is not enough which would have a serious effect on the mechanical strength of the sand-clay mixtures. However, the case would have been different if well graded sand were used to form the mixtures. Although, there are some other factors that affects the mechanical behavior of the mixtures apart from the size or range of sand in the mixtures. It is therefore, important to note that the mechanical strength of the above mixtures was affected simply because the riverbed sand applied was gap graded since it passes through a 4.75mm sieve and retained on a 3.35mm sieve. **Table 4. Sand-clay mix ratio**

Designation	Sand composition[%]	Clay composition [%]
A	100	0
C	75	25
D	50	50
F	0	100

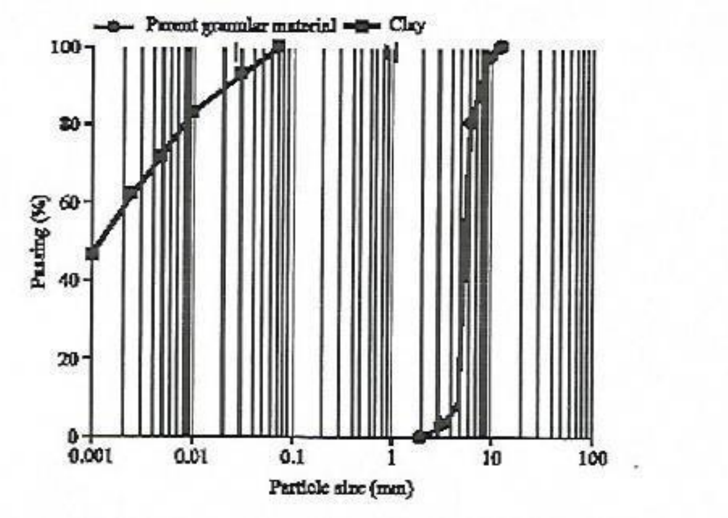

Fig.2. Particle size distribution of materials used in the research (Sharkelford et al (1997)

In the table above, different percentages of sand were mixed or combined with different amounts of clay up to 40% as the minimum required for cores in the embankment dams. The idea of combining different percentages or ratios of clays and sands is to optimize the strength where their ratios are at best for the mechanical behavior of the overall mixtures. But however, in the three mixtures formed, it was observed that different mixtures exhibits different characteristics which are mostly likely affects the mechanical strength/ behavior of the entire mixtures. Meanwhile, the behavior of different mixtures maybe affected by many factors such as the percentage of sand or clay in the mixtures, the size of sand or range, the grade of sand, the mineralogy content of clay or even the nature of sand either processed /man-made or natural sand. In the report from the above researchers, on the mixture of sand with clays such as kaolin and bentonite, the strength of the overall mixture is governed by the mineral content of each clay, the quantity of sand as well as the percentage content of the clay. It is expected that different percentages of sand and clay will behave differently simply because of the quantities of sand and clay that made up the mixtures including the type of minerals that are contained in clay materials as demonstrated in the table below. The result of a particular sand with different types of clay material is a clear indication that clays are possessed with different mineral contents and this minerals has a great influence on the so called sand-clay mixtures as found by Karakan, and Demir, (2018). Apart from the above factors which were identified to have a great influence on sand –clay mixtures, from the literature sand-clay mixtures are its best when 10% of clay material is blended with 40% of sand material for core embankments dam and up to 50% for other geotechnical engineering purposes. Therefore, it is important to note that this ratio would only obey a normal condition for both sand and clay materials and anything above the given ratio should have effect on the overall mechanical strength meaning that a particular material which is greater in quantity should have a domineering over the other.

1.3.1 SAND GRADATION CONSIDERATIONS IN SAND-CLAY MIXTURES

Sand gradations has a serious effect in the behavior of sand-clay mixtures, coarse sand has always shown a sharp interaction and strength mobilization with clay materials when compared to its interactions with fine sand. The behavior of natural sand with clay material have always been given a very good strength response than the processed/man-made sand with clay combinations according to Khan et al. (2014) in the literature. It can be said that neither clay nor sand can provide the required engineering properties for specified unique projects in geotechnical engineering; rather the two soils must be blended/combined together in other to achieve the expected result. Therefore, this finding is aligned with the result of other researchers in the literature in favor of the engineering properties of sand-clay mixtures over the use of ideal soils.

Sand gradations were found to play a vital role in the behavior of sand clay mixtures. Therefore, it was found that ideal (natural) soils hardly contains the mixture of clays and sand in their required proportions or different gradations (sizes and ranges) and therefore, has a serious influence in the overall mixtures. However, on the volume change behavior, the result shows that the compressibility and swell of sand-montmorillonite or sand-bentonite mixtures affects the stability of the structural foundation unlike the sand-kaolinite whose volume does not change even in the presence of water. Also it was found that sand has an optimum quantity beyond which its percentage contents in the mixture would lead to decrease in strength of the sand-clay mixtures despite its size contents. Therefore, the full understanding of the sand gradation and its effect of mineral present in each clay could be properly enhanced when pure clay minerals are mixed with sand Skempton (1953).

Sand classifications

(a) Fine sand fractions (<425µm)

(b) Medium sand fractions (425µm–2mm)

(c) Coarse sand fractions (>2mm)

The use of medium and optimum size of sand in the design of sand-clay mixtures has always lead to a good result not minding the type of mineral present in the clay applied in the design.

Therefore, it is expected that when the three grades of sand above are combined/blended with clay materials their elasticity behavior would be entirely different which would also affect the design generally. Therefore, it was believed that proper selection of grades of sand will help to achieve sand-clay mixtures of high standards/grades. Prakasha and Chandrasekaran (2005)

2.0 COMPOSITION OF SAND-CLAY MIXTURES

2.1 Chemical oxide composition of sand-clay mixture

There are some chemicals that are contained in the sand-clay mixtures as a chemical compositions such as resins materials, lime, salt, bitumen, cement, calcium chloride etc.((Akinje, 2015) and (Kadyali and Lai, 2008, Firoozi et al 2017). Therefore, all these contributes to the challenges a geotechnical engineer would encounter in the field while making choice of materials for stabilization based on the available materials for use in the specified project. Meanwhile, the most important information, in the design is to achieve the maximum strength irrespective of the method or materials applied for instance road pavement design and its construction. Therefore, it is expected that the geotechnical engineer would apply a common knowledge on strength enhancing stabilizers such as cement, lime, and off-course bitumen in order to reduce compressibility on the side of soil with a minimal cost in the area of construction work to enable a tremendous achievement to be recorded (Osinubi and Amadi, 2010 Zhang and Yi, 2011) and (Latifi et al., 2013).

Sand-clay mixtures exhibits higher strength when stabilized or reinforced with other materials such as biopolymer rather than when pure soils (sand or clays) are reinforced or stabilized with chemicals as reported by (Chang,et al 2015, Latifi, etal 2016, Chang et al,2019, Buchmann,et al 2020, Chang et al 2020). Therefore, both sand and clay would have their strength enhanced when reinforced with biopolymer but however, their strength will improve more when sand and clays were mixed together to form a sand-clay mixtures as stated by Chang, et al 2019. Apart from, the traditional stabilizers,one may also decide to incorporate some non - traditional stabilizers such as silicates, liquid polymers, acid enzymes etc. in order to achieve same result (Akinwumi et al.,(2012);Garber and Hoel,(2010)). Some years back, geomembrane/geotextile or cement/lime/fly ash have been found to give a good result when combined with sand in order to achieve the expected mechanical strength or stress- strain behavior of the mixtures. Examples of chemical oxides compositions in the mixtures are: SiO_2, Al_2O_3, Fe_2O_3, CO_2 (Zada et al (2023).

Table 6. Chemical composition of sand-clay mixtures

Chemical composition oxide	Value[%]
SiO_2	25.46
Al_2O_3	31.10
Fe_2O_3	35.53
CO_2	7.91

3.0 MINERALOGY OF SAND-CLAY MIXTURES

3.1 Mineralogy of Sand-Clay Mixtures

The mineral content of clay minerals has a serious effect on the overall sand-clay mixtures hence the swelling and contraction could be measured/controlled by **exchangeable sodium percentage** (ESP). Hence the quantity of polycations required to prevent the swelling of clay materials also depends on ESP. The engineering behaviors of sand-clay mixtures were absolutely different from the characteristics of ideal soils because of the interactions of the quantities of sand and clay when they were mixed together. In that same way, the behavior of the mixtures differs from one another depending mostly on the type of mineral that each clay contains and also the percentage of sand in the mixtures were considered in the behavior of sand-clay mixtures. The results indicate that montmorillonte and bentonite are the most swelling clays when in contact with water and at the same time shrinks very easily in the absence of water/dry weather. Because of this property, the behavior of the mixtures was found to be different with kaolinite clay which does not expand in the presence of water unlike montmorillonte or bentonite clay mineral. Although, they all enhances or increases the strength behavior of the mixtures even though their strength would not be the same, but in terms of permeability, the expansive nature of the sand- montmorillonite mixtures affects its behavior when compared with sand-koalinte clays mixtures. Hence high charged density smectites swells less when compared with low density smectites. (Phanikumar et al (2021), Schanz and Elsawy (2017). Therefore, it has been noticed that ideal (natural) soils hardly contains the mixture of clays and sand in their required proportions or different gradations (sizes and ranges) and therefore, has a serious influence in the overall mixtures. However, on the volume change behavior, the evidence shows that the compressibility and swell of sand-montmorillonite or sand-bentonite mixtures affects the stability of the structural foundation unlike the sandkaolinite whose volume does not change even in the presence of water. Also it was found that sand has an optimum quantity beyond which its percentage contents in the mixture would lead to decrease in strength of the sand-clay mixtures despite its size contents. At the same time, the hydraulic conductivity can be ascertained through the discovery of the least amount of clay to be used to control sand porosity in such a way that when compacted, the minimum hydraulic conductivity would be achieved for the purpose of waste containment solution. Furthermore, the volume change behaviors of sand-clay mixtures can be said to be controlled by the type of mineral contend in each clay material. From the literature, sand- montmorillonite mixtures and sand-bentonite mixtures was observed to expand and also shrink in the presence and absence of water respectively, unlike kaolinite clay which does not experience much change in volume in the presence of water. It was the high plasticity that is contained in the momtmorillonite and bentonite clay that made it to experience drastic volume change unlike kaolinite clay.

Therefore, the compressibility and the swell behavior of every sand-clay mixtures are not expected to behave alike simply because of the clay mineral contents apart from the sand gradations. It is the duty of the geotechnical engineer to determine the type of clay mineral and the required ratio that should be blended with sand to achieve the engineering target based on the specification of the project.

4.0 COMPACTION OF SAND-CLAY MIXTURES

4.1 Compaction of sand- clay soil mixtures

The compacted sand-clay mixtures has become an ideal material for core dams embankments simply because of the high content of plasticity from a clay mineral such as montmorrilonite or bentonite clay material which makes the mixtures impervious enough for the intended purpose as stated by many research in the literature. The issue of compacted sand-clay mixtures takes lead and also controls the expected hydraulic conductivity applied in the low-permeability liners used for waste disposal or landfills. Hence sand-clay mixtures compaction exhibits a total influence on the entire mixtures to achieve the overall task (Jafari and shaffiee (2004), Shafiee , (2008); Mitchel et al. 1965). In most cases, the natural clays are not readily available for use in the preparation of compacted clayey liners used as landfills therefore it is advisable to apply bentonite due to the availability/ abundance of the processed one. Although, the sand-bentonite maybe associated with high swelling especially the sodium-bentonite when in contact with water and also shrinks in the absence of water respectively. Therefore, sandbentonite compacted mixtures have been chosen as a material for embankment dams because it successfully yields the required hydraulic conductivity for the landfills /waste disposals. It is expected that the hydraulic conductivity used as landfills in cores embankment dams shall not exceed $1x10^{-7}$cm/s.

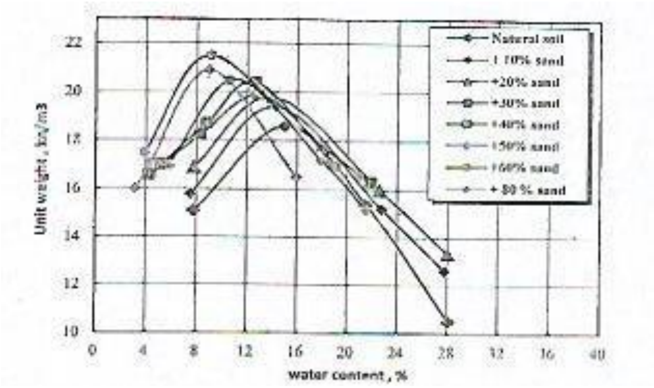

Fig.4 Compaction test for clayey soil mixed with different percentages of fine sand

5.0 CALIFORNIA BEARING RATIOS OF SAND-CLAY MIXTURES

5.1 California Bearing Ratios (CBR) of Sand-Clay Mixtures

It appears that most of the highway pavements in Nigeria including the states and federal roads got damaged always before their actual design period or some years after being constructed. Most often these problems comes from improper material applied on the sub-grade, whereas in some cases the fill materials maybe a good one, but due to poor compaction, the entire earthen materials becomes saturated during the raining season which surrounded the entire environment and causes liquefaction on the whole earthen material. In this case now, both the stiffness and the soil bearing capacity would be sacrificed as a result of heavy flood. In view of this challenge, the CBR test can be applied to checkmate the quality of these materials to be applied or used on the design of the road pavements to ascertain its performance for the durability of the road after construction. The materials involved maybe subjected in water for four days both soaking and unsoaking to get information about the material when in contact with water for a long time. The knowledge of sand-clay mixtures has proven that it can be applied to tackle a problem of saturation especially on the steep slope where a cohesionless soil may not be very much useful due to erosion. More so, the cohesive material can easily turn to a liquid on down slope if in contact water, hence sand-clay mixtures would be an intermediate material between both cohesive and cohesionless materials as well as filling materials for cores embankment dams Jafari and Shafiee (2003), Hossain,et al 2015). Therefore, the CBR test enables the engineer to scrutinize the sub-base and the subgrade materials in order to select a good material for the given project.

6.0 VOLUME CHANGE BEHAVIOUR OF SAND-CLAY MIXTURES

6.1 Swelling and compressibility characteristics of sand-clay mixtures

The expansion/swell or compression observed in the sand-clay mixtures has been seen as unavoidable phenomenon since some of the minerals were naturally contained in the clay material. Therefore, the issue of swell or compressibility must be carefully evaluated in order to give a good analysis of sand-clay mixtures at different mix ratios. However, if the properties of sand-clay mixtures were not properly evaluated, then it will cause foundational problems to structures built on them especially when the expansive clay minerals such as montmorillonite, bentonite or smectites were not figured out hence distortion would appear on the surfaces. Therefore, the idea of sand-clay mixtures is to examine the nature of clay minerals to be incorporated to get a required result. For instance, when the expansive clay is involve, it is more advisable to use a small quantity of clay material with inclusion of high porosity of sand to minimize the expansive ability relating to the expansive clay minerals. But generally, clay materials are characterized with fine a material which plays a role of reducing the permeability when combined with coarse sand material. Hence both expansive and compressible ability must be put into consideration while selecting sand-clay mixture that guarantees minimum hydraulic conductivity used for landfills or waste disposals. But in a situation where the natural clay is not available, unprocessed clay can be adopted such as Al-Qatif clay. Although it was found to have high swelling/ expansive ability due to the presence of plasticity content in it. It is obvious that the mechanical property/behaviour of any prepared sand-clay mixtures strongly depends on the percentage component of both sand and clay in the mixtures (Tsotsos et al.2010). Therefore, no particular model generated can handle the problems of sand-clay mixtures wholly except problems in the same category.(Dafalla (2012) Dafalla and Al-Mahbashi (2014)).

It was found that the engineering behavior of sand-clay mixtures were absolutely different from the characteristics of ideal soils because of the interactions of the quantities of sand and clay when they were mixed together. In that same way, the behavior of the mixtures differs from one another depending mostly on the type of mineral that each clay contains and also the percentage of sand in the mixtures were considered in the behavior of sand-clay mixtures. The information from the literature indicates that montmorillonte and bentonite are the most swelling clays when in contact with water and at the same time shrinks very easily in the absence of water/dry weather. Because of this property, the behavior of the mixtures was found to be different with kaolinite clay which does not expand in the presence of water unlike montmorillonte or bentonite clay mineral. Although, they all enhances or increases the strength behavior of the mixtures even though their strength would not be the same, but in terms of permeability, the expansive nature of the sand- montmorillonite mixtures affects its behavior when compared with sand-koalinte clays mixtures.

6.2 Effect of sand content and size / range on volume change of sand-clay mixtures

Soils are distributed in such a way that it would be difficult to see or identify an ideal soil as a separate or single entity. Although in most civil or geotechnical engineering design, the projects were designed to base on ideal soils, but it is unfortunate that the so- called ideal soils never existed as pure-clay or pure sand rather they mixed with other types of soil in a combined state. Therefore, soils appearing in the defined state have wide range of behavior because the percentage contents of those soils were not regulated including their gradations since it was naturally distributed. The properties of such soil cannot be easily predicted rather, the particular soil with the highest percentage will have the domineering influence over the other. However, the compressible/swell behaviors of sand-clay mixtures are reduced by incorporating a coarse sand of different gradations to remedy the drastic volume change behavior that may result to cracks when the soil material shrinks and respectively leads to distortions of structures when the underneath materials swells or expands excessively as the case maybe. Hence, the mechanical property has been proven to increase more with the addition of coarseness of sand to the mixtures.(Vallejo,and Mawby, 2000)

7.0 TRANSIONAL BEHAVIOR IN SAND-CLAY MIXTURES

7.1 **Transitional Behavior in Sand-Clay Mixtures**

The term transitional behavior has been adopted to explain the behavior of different mix ratios at their apex based on the capacity or percentage of each component in the sand-clay mixtures. In other words, whenever a transition point is emerged, the mixture changed from one behavior to another depending on the quantity of material that is in excess or smaller in the mixture. The transition point maybe caused due to addition of excess fine sand or reduction, increasing the percentage of coarse sand in the mixture or less. It can as well result to the addition of a certain percentage with a defined mineral content or less. These are the things that should be put together in order to evaluate properly the transitional behavior of sand-claying depending if the fines or clay is also dominating in the mixtures. Transition point is concerned about whether the sand is dominating or the clay or fines are dominating the mixtures. However, the transition point would actually explain the behavior the mixtures, when the fine content (Fc_t), is high or low. It will also introduce some of the terms to be used when the coarse contents are low, high or intermediates as the case maybe. For instance when clay and gravel were combined together, with gravel having a percentage less than 45%, the mixture formed would be identified as intergranular ratios given as;

$$e_s = \frac{Vv + Vf}{Vs} \qquad \text{--(1)}$$

Where v_v, v_f, v_s are the volume of voids, fines and sand, respectively. Hence v_v+v_f is the volume of intergranular void spaces. Kumar and Wood (1999). The same intergranuular parameters can as well be deduced by the model equation established as follows;

Monkul, (2005) or using a specific purpose (Monkul and Onal, 2006) or a spread sheet software described as;

$$e_s = \frac{e + \frac{G-FC}{Gf-100}}{\frac{G}{Gs} \cdot \left(1 - \frac{FC}{100}\right)} \qquad \text{------------------------------------- (2)}$$

(Monkul and Onal, 2006)

Where G_s and G_f are the specific gravity of sand and finer grain matrices forming the soil, respectively. G is the specific gravity of the soil itself. Therefore intergranular ratios is maximum at the point defined asfollows;

(i.e. $e_s=e_{max-c}$). $e_s = e_{max}$ $e_s = e_{max}$ --------------------------- (3)

(Monkul and Ozden, 2005)

Based on the mystery behind the transitional behavior of sand-clay mixtures, the interfines and the global void ratios contributed to the definition of the mixtures at critical point when the percentage of fines is dominating or when the percentage of coarse sand is taken lead in the overall mixtures.

8.0 APPLICATIONS OF SAND-CLAY MIXTURES

Sand-clay mixtures are globally applied all over the globe in the field of civil/geotechnical engineering works such as roads, embankments dams and also as a filling material. Sand-clay mixture can as well be used as soil filter which is achievable by introducing soil of plastic material into the coarse sand material to reduce the high level of permeability of the mixtures. Hence the mixtures formed on the process can serve the purpose of impervious materials for waste disposal. However, the secret behind the combination can only be controlled by the mixtures compactions and the Atterberg limits that made up the constituents which are equally applied in core of embankments dams. Sand-clay materials have remained an intermediate material which resists erosion in steep-slope environment unlike when the two ideal soils are present. The idea of sand-clay mixtures has brought many developments into the system such as the use of Oman shale in liners and Auchi shale discovered by Obrike et al (2009) applied in waste disposal/ landfills. The above local clay materials were found due to high cost of processed clays. Sand-clay mixtures have also been found worthy in the filling of sub- grade in the road pavement construction operations. Therefore, the knowledge of sand-clay mixtures research has been fully applied to resolve the problem of liquefaction caused by materials of high fine contents through the substitute of interfine content materials. The idea of sand-clay mixtures have been a serious guidelines in the choice of materials to be used at the right time, hence the modulus of elasticity of the mixtures plays a vital role in order to make good decisions. Presently, the idea of sand-clay mixtures has lead to the development of compacted clays and synthetic membrane such as HDPE (High Density Polyethylene) to avoid ground water contamination caused by waste liners.

8. 1 AREAS OF FUTURE RESEARCH

1. It is important to obtain optimum design ratio for sand-clay mixtures or models for sandclay mixtures to enable the solution of multiple problems in geotechnical and geoengineering.

2. Research effort should be made to obtain the predictive models of each type of clays in sandclay mixtures for field applications.

3. The effect of compactive effort on sand-clay mixtures for different clays and for sand having different gradations.

4. Research should be conducted to show differences in the behavior of sand-clay mixtures for either natural clay or processed clays.

5. Methods for improving the properties and behavior of sand-clay mixtures such as use of lime and cement for stabilization should be involved.

6. The factors that negatively affect the quality of sand-clay mixtures should be investigated.

Recommendation:

A continuous research should be going on to cover the gap/misconceptions among the researchers all over the universe hence a unified idea about the concept of sand-clay mixtures would be a great source of strength to young researchers on the theme of sand-clay mixtures.

Acknowledgements:

The author greatly appreciate the previous researchers on sand- clay mixtures for their concerned, input and the extent they have gone to address the problem and at the same time the significant of sand-clay mixtures in Civil and Geotechnical engineering.

9.0 CONCLUSION

The role of sand-clay mixtures in geotechnical and geo-environmental engineering cannot be underrated hence it is the best substitute for both ideal sands and ideal clays. Besides, the engineering principles behind the sand-clay mixtures are controlled by clay mineralogy and sand gradations. However, some ideal soils like clays are disqualified as a road embankment material in most geotechnical and geoenvironmental engineering projects simply because they are soft and compressible in nature. Therefore, these properties made them unfit for specific engineering projects. The idea of sand-clay mixtures made it possible for it to blend with granular materials in order to minimize its compressibility and settlement of structures imposed on it. The granular materials act as a reinforcement while the clay material seal-up the voids in the composite mixture thereby increasing the strength of the soil to enable it sustain a proposed structure for a designed period of time without failure. For instance, sand-clay mixture is currently used as filling materials when constructing roads or embankment dams. They are commonly used as liners in waste disposal and in the protection of strategic projects using bentonite-sand mixtures. Sand-clay mixture is also applied in steep slope road embankment construction hence sand-clay mixtures are the best alternative to both ideal sands and ideal clay soils.

Therefore, this finding is aligned with the result of other researchers in the literature in favor of the engineering properties of sand-clay mixtures over the use of ideal soils.

In the literature, the major contribution of the researchers have based on the ratio of clay to sand in the sand-clay mixtures, but the knowledge of sand-clay mixtures can be obtained fully by not only considering the proportion of clay to sand only, but rather should be extended to the type of clay mineral contend in each clay, the percentages of both soils in the mixtures, the grade of sand used in the mixtures. Also in the grade of sand, further consideration should be made apart from the size or range (coarse or fine), of sand such as whether it is natural or processed sand. The reason being that research has shown that natural sand has been given a greater strength mobilization when compared to man-made/processed sand. Therefore, when all these variations are put together, the concept of sand-clay mixtures would make a significant meaning among the researchers generally.

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