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Original Research Article

Experimental Analysis on the Effect of Calcination on the Index and Engineering Properties of Clay Soil

H. D. Mac-Eteli[1], S. Sopakirite[2*]

[1]Lecturer 2, Department of Civil Engineering, Niger Delta University, Bayelsa State, Nigeria
[2]Lecturer 2, Department of Civil Engineering, Federal University Otuoke, Bayelsa State, Nigeria

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***Corresponding author:** S. Sopakirite

Abstract

The paper aims to access and evaluate the index as well as engineering properties of clay soil when subjected to controlled thermal treatment. To achieve this, clay soil was collected from a specific location in Amassoma, Southern Nigeria, and heated up at 200°C, 400°C, 600°C and 800°C. To adequately inform the engineering society on the potentials of thermally treated clay soil in the construction industry, properties such as specific gravity, Atterberg limits, California bearing ratio test (CBR), and compactibility were determined. Specific gravity increased by 60% between the control at room temperature and the specimen produced at 800°C. The increment was direct showing flattening tendencies between 600°C and 800°C. A direct relationship was found to exist between calcination and compactibility for all specimens between 27°C and 800°C. A similar trend was observed for CBR values of which at 800°C, the soil specimen having a CBR of 13.51 had improved in CBR by 655% when compared to the control's CBR of 1.79. An inverse relationship was observed between calcination and Plasticity Index. At 800°C, the plasticity index having a value of 6.9 had reduced by 63% when compared to the control specimen having a PI of 18.4. By the process of calcination, the soil was successfully transformed from a clayey, high plastic, cohesive soil with very high affinity for water and unsuitable subgrade for pavement purposes, into a silty, low plastic, partly cohesive soil with reduced affinity for water having a fair CBR and applicable for subbase utilization in pavement construction.

Keywords: Calcination, Clay soil, Physio-Mechanical Properties, California Bearing Ratio, Plasticity Index, Maximum dry density.

1. INTRODUCTION

The engineering society is constantly embodied with the responsibility of conserving nature while harvesting nature's resources in its vision for a more comfortable society. In the developing world and the world over, clay is yet to attain its peak of efficient utilization particularly in the construction industry, due its limitation in friction and load bearing. Even as a fill material, its mechanical efficiency is questioned due to its non-aquific properties. Abel 2019, established that particularly in the developing countries, high cost of materials remains the bane of the construction industry.

The Engineering society therefore considers it needful to research on local materials and how they can be engineered towards the construction industry.

Soil stabilization is a critical component in construction as only a stabilized soil can adequately support load or resist shear. In highway engineering, the subgrade is usually a clay soil; a weak foundation requiring some sort of stabilization either by compaction or the use of lime and other materials with cement-like properties.

Clay soil has been one the major construction materials for a long time. The main reason lies on the fact that it is readily available and the cost of obtaining it is comparatively low (Agbede, 2003). This however would be greatly appreciated if its physio-mechanical properties could be made similar to that of sand whose angle of friction, porosity as well as CBR aligns with the ideal material for general foundation of civil engineering structures.

1.1 General Hypothesis

Clay is a finely textured natural rock or soil material that clay minerals with possible traces of quartz (SiO_2), metal oxides (Al_2O_3, MgO etc.) and organic matter, (Olive *et al.*, 1989). The mineral composition of clay gives it a high affinity for water hence are high in plasticity. Alhassan *et al.*, (2014) established that a clay mineral in the chlorite group called lepidolite is responsible for higher plasticity in clay while kaolinite with reduced affinity for water, responsible for a reduction in the plasticity of clay. On a general note, clay is high is plasticity, low in strength, high in compressibility, high in volumetric changes and hence practically an unstable material for construction, (Ural 2018).

Calcination of clay samples for improved engineering properties is opined on the context of expansion of the clay sample to drive off trapped carbon dioxide as well as impurities and reduce clays affinity for water by thermally refining its mineral composition at controlled temperatures in the absence of oxygen. Clay minerals with high affinity for water will be broken down under the treatment of heat and impurities driven off.

1.2 Scope of Research

This work is limited to investigating the use of calcinated clay soil as an engineering material. Hence, clay soil will be subjected to 5 calcination temperatures (atmosphere temperature, 200^0, 400^0, 600^0 and 800^0) respectively, and thereafter tested for Specific gravity, Porosity, Plasticity, CBR value, moisture content and compaction to ascertain their behavior under the above temperatures.

2. MATERIALS

2.1 Clay

Natural clay sample collected at a depth of 1m below natural ground level was used in this study. The soil investigated was collected form Amassoma community, Southern Ijaw LGA, Bayelsa state, Southern Nigeria. Unlike the clay soil found in china which is predominantly kaolinite having a very low affinity for water, the clay found in the southern region of Nigeria is predominantly expansive in nature readily changing its volume with changing concentration of water. Laboratory tests were conducted on the clay in accordance to the British standard to ascertain the index and engineering properties of the clay sample. Table-1 summarizes the index and engineering properties of the clay used in this study.

Table-1: Engineering Properties of Expansive Clay Soil

S/N	INDEX PROPERTIES OF CLAY SAMPLE	LABORATORY VALUES
1	Specific Gravity	1.4
2	Moisture Content (%)	29.3
3	Liquid Limit (%)	47.03
4	Plastic Limit (%)	28.6
5	Plasticity Index (%)	18.40 (**Highly Plastic**)
6	Classification	CIO (**BS Classification**)
7	Optimum Moisture Content (%)	26.7
8	Maximum Dry Density (kg/m3)	1931
9	CBR at OMC (%)	1.79

3. EXPERIMENTAL OBSERVATION

3.1 Specific Gravity Test

Specific gravity, is the ratio of weight of soil and weight of water of equal volume. Clay soil exhibits shrinkage and swelling due to the presence of trapped voids. These voids tend to reduce the density and specific gravity of clay. It is expected that at calcination, trapped air will be given off and hence specific gravity improved. At improved specific gravity, the stability of the material will be improved and greater compatibility can be achieved. Specific gravity test was conducted in accordance to ASTM C128.

Fig-1: Clay Sample Passing 40 Micron BS Sieve

3.2 Compaction Test

The Proctor compaction test is a laboratory method of experimentally determining the optimal moisture content (OMC) at which a given soil type will become most dense and achieve its maximum dry density (MDD). This is quite essential if a soil is to be engineered mechanically towards improved load resistivity. At reduced porosity and improved specific gravity, it is expected that the maximum dry density of a soil which is an index property of its compatibility will be enhanced. While it is logical to expect a reduction in porosity, increase in Specific gravity and increase in MDD at increasing calcination temperatures, no boundary conditions have been developed in this regard as to what temperature offers better results for calcination of clay. Proctor compaction test was conducted on the clay samples in accordance to BS 1377.

3.3 Atterberg Limit Test

Atterberg limits generally illustrate the forms in which a clay can exhibit under different moisture content conditions. Whilst at Solid and shrinkage limits, the soil is at the risk of crack failure when exposed to mechanical or environmental loadings, somewhere between the plastic limit and liquid limit, the soil becomes fluid losing its load carrying potentials. So, whilst we do not need our soil to be too dry, we equally do not need our soil to be too wet. However, the water retaining property of a soil is closely tied to its void ratio and affinity for water. The effect of calcination temperature will hence be studied on clay soil's affinity for water and invariably its plasticity index.

Table-2: Soil classification based on Plasticity Index (Roy, 2017)

Plasticity index (%)	Soil type	Degree of plasticity	Degree of cohesiveness
0	Sand	Non-plastic	Non-cohesive
<7	Silt	Low plastic	Partly cohesive
7-17	Silt clay	Medium plastic	Cohesive
>17	Clay	High plastic	cohesive

3.4 California Bearing Ratio Test

The Californian Bearing Ratio (CBR) test is a penetration test used to examine the foundation of roads and pavements. Results gotten are raw data for the pavement engineer to determine appropriate thickness of successive layers of the road or pavement. Comparatively, CBR is a measure of the strength index of the soil or material tested.

Table-3: Rating of soils based on CBR values (Mina *et al*., 2019, as cited in Bowles, 1992)

CBR (%)	Level	Objective
0-3	Very poor	Subgrade
3-7	Poor to fair	Subgrade
7-20	Fair	Subbase
20-50	Good	Base or Subbase
>50	Excellent	Base

The CBR is a measure of resistance of a material to penetration of a standard plunger under controlled density and moisture conditions. Clay is known to have a CBR value of about 2% while that of sand ranges between 5% and 15%, (Jones 2017). A good subgrade material is therefore expected to have a minimum CBR value of 7%, and could be used as a subbase material is greater than 7% mostly for light traffic pavements.

In accordance to BS 1377, a standard piston, with a diameter of 1.954 in or 50 mm, is used to penetrate the soil at a standard rate of 1.25 mm/minute. The pressure up to a penetration of 12.5 mm and its ratio to the bearing value of a standard crushed rock is termed as the CBR. In most cases, CBR decreases as the penetration increases. The ratio at 2.5 mm penetration is used as the CBR. In any case whereby the ratio at 5 mm is greater than that at 2.5 mm, CBR value at 5mm is recorded as true CBR value.

The effect of thermal treatment on the CBR of clay was therefore studied experimentally to inform the engineering society on the possibility of improved potentials of clay in highway engineering.

4.0 RESULT AND DISCUSSION

4.1 Specific Gravity Results

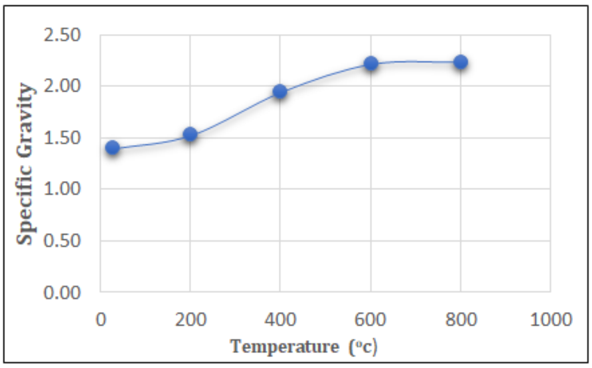

Chart-1: Effect of calcination on the specific gravity of clay

The specific gravity was found to be lowest when the sample was observed at atmospheric temperature having a value of 1.4. At 800^{0}C, the specific gravity had increased by 60% having a value of 2.24. Within the calcination temperatures, it was observed that at 400^{o}C, the specific gravity had already been improved by about 39.3% from its Atmospheric condition. Between 600 and 800oC, only 0.9% increase in specific gravity was observed.

4.2 Compaction Test Result

Quite revealing are the compaction results obtained for the clay specimens. It is conventional that proctor compaction results for soils tend to form a parabolic shape that opens downward and the crest point provides results for the optimum moisture content as well as the maximum dry density. The results obtained in this research did not exactly express the conventional shape as should be expected for normal soils. Whilst it is theoretically sound to expect oven dried soils to require higher concentration of water in pursuit for maximum dry density, this research was limited to the standard procedure of BS 1377.

Nonetheless, the control specimen having an atmospheric temperature of 27°C as well as the calcinated specimen at 200°C where observed to have developed the crests of their partial parabolic curves at 26.8% and 20.0% moisture contents having respective dry densities of 1931kg/m^3 and 2039kg/m^3, hence an increase in MDD by 5.6% between the control and 200°C specimen.

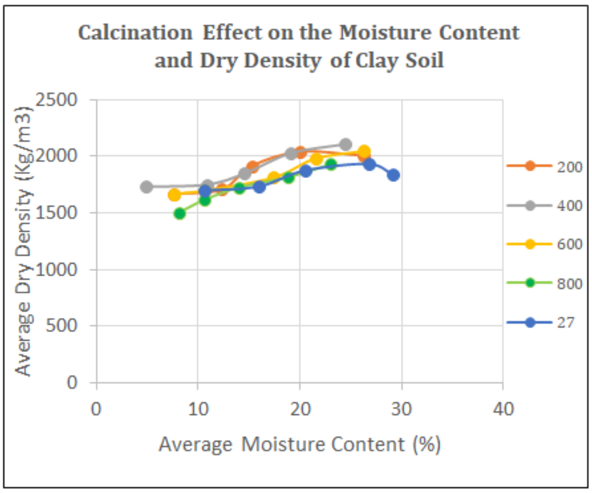

Chart-2: Calcination Effect on the Moisture Content and Dry Density of Clay Soil

Besides the control specimen and 200°C specimen, other specimens produced at 400°C, 600°C and 800°C, had their dry densities constantly increasing with an increase in moisture content for all the trials observed. Whilst 400°C and 600°C specimens seemed to be approaching the crest of their curves, 800°C specimen appear to be steps behind implying that a greater concentration of water is yet required if the maximum dry density is to be achieved.

Due to the partial nature of the curves for 400°C, 600°C, and 800°C samples, conclusive statements on their respective maximum dry densities as well as optimum moisture contents cannot be made yet. However, taking a close look at the cluster of the curves, it is evident that lower temperature specimens tend to form their crest first before higher temperature specimens. This implies that up to 800°C, the relationship between calcination temperature and dry density of clay soils is direct.

4.3 Atterberg Limit Test Results

Soils affinity for water is best explained by its Atterberg limits. Also, the cohesive nature of a soil can partly be understood from its Atterberg limits.

The effect of calcination on the liquid limit of the clay specimens is inconclusive. However, the trend of the curve seems to suggest that the higher the calcination temperature, the higher the amount of water required to make the clay sample begin flow.

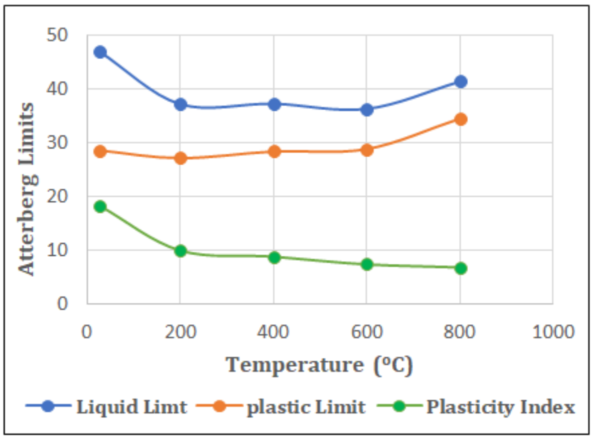

Chart-3: Effect of Calcination on the Atterberg limits of clay soil

Plastic limit results show a more direct path when compared to the liquid limit results. Between 200°C and 800°C was observed a steady increase in the amount of water required to make the clay behave like a plastic material.

It is noteworthy that the permeability, porosity and non-cohesive properties of sand give it its desirable increased compressibility as well as compatibility. Sand is known to have zero plasticity index and hence completely non-cohesive with zero affinity for water. Plasticity results observed illustrate a steady reduction in plasticity index at increasing calcination temperatures. A total reduction of 62.5% was observed between the plasticity indexes of the control specimen and the specimen produced at 800°C. Result obtained at 800°C was the best observed in terms of plasticity index and reduced affinity for water, but cannot be said to be optimum as the graph is still pointing downwards imply the possibility of obtaining better results at higher temperatures.

4.4 California Bearing Ratio Test Results

In the application of clay properties in pavement engineering, California Bearing Ratio (CBR) is one amongst the most informative properties to the engineer; informing the engineer on the strength of the soil and the necessary actions required to improve on the soil if need be. The CBR of the clay sample was observed to increase beyond the control by 69%, 600%, 637%, and 655% for respective temperatures of 200°C, 400°C, 600°C and 800°C.

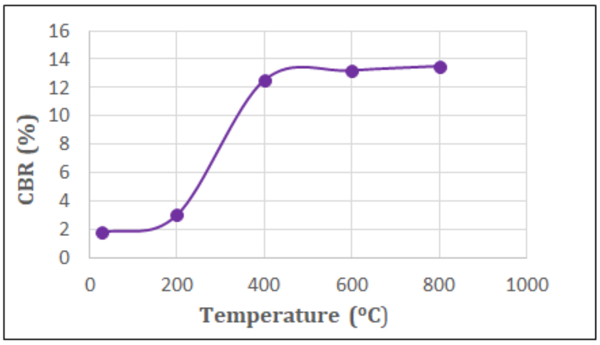

Chart-4: Effect of Calcination on the California Bearing Ratio of clay soil

A great deal of effect was observed between 200°C and 400°C (313% increase) which steadily reduced between 400°C and 600°C as well as 600°C and 800°C having respective incremental values of 5.43% and 2.35%. This trend as could be seen is the curve promises to flatten and form its crest point somewhere above 800°C before reducing in Bearing capacity, but this itself is a hypothetical statement. More directly, it can be stated from the observations in chart 4, that up to 800°C, increase in temperature directly affects the CBR of clay soils.

4.5 Plasticity Index and CBR Relationship

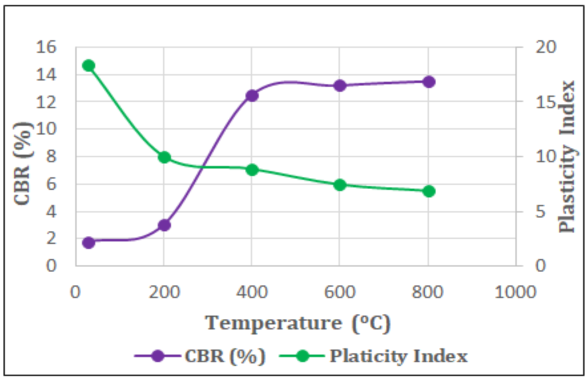

Chart-5: Relationship between Plasticity Index and CBR of clay soils subjected to Calcination

It follows theoretical background that plasticity index is inversely proportional to CBR of soils. Chart 5 above honours same theory and further illustrates the combined effect of temperature on both independent properties. Whilst temperature is directly proportional to CBR, it is inversely proportional to Plasticity index for the clay specimens covered under the scope of this research.

At the point intersection, which is just below 300°C, Plasticity index was observed to have a value of 8.89, while the CBR was observed to be about 7.3%. At this condition, the soil is deemed to have graduated from a very poor subgrade material to a fair subbase material (Mina *et al*, 2019, as cited in Bowles, 1992), and from a high plastic cohesive material to low plastic partly cohesive material, (Roy, 2017). It is therefore noteworthy that the engineering properties of the soil have been greatly and positively influenced by the effect of calcination.

5. CONCLUSIONS

This research has scratched the surface on the potentials of clay soil when engineered with the effect of calcination. Between 27°C, and 800°C, the effect of calcination of specific gravity, Atterberg limits, compactibility, and strength has been studied, from which the following conclusions and recommendations are drawn;

- The soil sample was found to be an organic clay, highly plastic and cohesive in nature.
- The soil was observed to have a very low specific gravity of 1.4
- Specific gravity increased by 60% between the control at room temperature and the specimen produced at 800°C. The increment was direct showing flattening tendencies between 600°C and 800°C.
- The compactibility of the specimen increases with increasing temperature up to 800°C.
- Plasticity reduces with increasing temperature. At 800°C, a 62.5% reduction of plasticity index was observed when compared to the control.
- The strength of the soil using CBR as a measure, increases with increasing temperature. At 800°C, an increase of 655% was observed when compared to the control.
- The compaction curve did not fully form for specimens treated at 400°C, 600°C, and 800°C. we hence recommend that proctor compaction test be carried out for these specific specimens in order fully ascertain their respective maximum dry densities and optimum moisture contents.
- Between 400°C and 800°C, the curve for plasticity index and CBR begins to flatten. We recommend that the further research be done to observe what becomes of these properties beyond 800°C.
- To fully understand the effect on calcination on the mineral and chemical composition of clay and how it affects its affinity to water, it is recommended that further research be done inclusive of X-ray diffractometric as well as X-ray fluorescence analysis.
- To hit the ground running on the comprehensive findings of this research, it is recommended that mechanical engineer's pry into low cost clay calcination techniques so as to increase the chances of the application of these innovative findings.

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