# ASSESSMENT OF THE MICRO-STRUCTURE OF COMPACTED SOILS USING VARIED COMPACTIVE EFFORTS: A CASE STUDY OF SOME SELECTED AREAS IN PORT HARCOURT, NIGERIA

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**ABSTRACT**

***This research studies the effects of varying British standard heavy and British standard light compactions on the resulting micro-structures of soils using digital microscope. Three soils classified as A-6, A-7-6, and A-2-7 using AASHTO classification system were analysed. The initial properties tests and moisture- dry density relationship were carried out in accordance to British standard 1377 of 1990. The liquid limits ranged from 50.5% to 34.7% using the Casagrande liquid limit apparatus, plasticity index ranged from 22.3% to 12.4% and natural moisture content ranged from 24.3% to 21.2%. The lower the plasticity index the higher the maximum dry density for both degrees of compactions. From the micro-structural analysis, there was evidence of lines of shear at the wet-side of optimum moisture for all compactions and that the presence of these lines is high for soils of lower plasticity index at low compaction energies. At higher compaction effort, there was closer inter-particle aggregation of grains than at lower compaction efforts. The voids at the optimum moisture are smaller compared to those at the extremes of optimum, with voids on the wet-side of optimum larger than those at the dry side of optimum moisture for both compactive efforts. Thus, the micro-structure of the compacted soil revealed that the degree of compaction influences the degree of compactness of gains, the average dimension of voids, and the occurrence of thin lines of shear in their structure.***

**Keywords:** Compaction, moisture content, dry density, micro-structure

## INTRODUCTION

This research sterns from the need to understand at the microscopic level, the behavior of soil which is complicated by the presence of both air and water in the pore-space, and the settlements of un-compacted fills have shown serious level of concern to geotechnical engineers as the rapid development of the automobile and the need of soils to be efficiently used in unpaved conditions has created an increasing demand for hard surface roads. Compacting a material at water contents higher than (wet of) the OMC results in a relatively soil structure that is weaker, more ductile, less pervious, softer, more susceptible to shrinking; and compacting dry soil at moisture lower than the OMC) does not achieve the specified degree of densification (Borys and Mosiej, 2006)
Understanding soil mechanics at the microscopic level is particularly pertinent to unsaturated soils, specifically clay-based materials, whose behavior is complicated by the presence of both air and water in the pore-space. From a fundamental point of view, measurements and observations at the micro-structural level involving clay units and their aggregations are very important, since they help in further understanding of higher structural levels, their interactions, the stability of the arrangements and their consequences for material properties and behavior under various hydro-mechanical stress state conditions. Vinma et al. (2012) buttressed the fact that some aspects of mechanical response of compacted soils are still poorly understood especially for tropical soils as the micro-structural features related to geotechnical behavior are rarely quantified. Also, the investigations of researchers in the field have shown that no one method of compaction is equally suitable for all types of soils.

Maximum dry density (MDD) is generally one of the most important factors determining soil's capacity to bear a load, and the behavior of a soil mixture is influenced more by its moisture content than by the other reasons (Inhoff *et al.,* 2004). Being the quantitative measure of wetness of a soil mass the moisture content of the soil, it is an important property that controls its compaction behavior and potential flooding (Osula, 1996). The maximum density of a material for a specific compaction effort is the highest density obtainable when the compaction is carried out on the material at varied moisture contents (Alavi *et al.,* 2010). The optimum moisture content (OMC) for a specific compaction effort is the moisture content at which the maximum density is obtained. It is the water content that results in the greatest density for a specified compaction effort. Mitchell (1993) stated that a major factor in the formation of fabric in a compacted fine-grained soil is whether or not large shear strains are induced by the compaction rammer. If the rammer does not penetrate the soil, as is usual for compaction dry of optimum moisture content, then there may be a general alignment of particles or particle groups in horizontal planes. However, if the soil is sufficiently wet of optimum that the compaction rammer penetrates the soil as a result of bearing capacity failure under the rammer, there is an alignment of particles along the failure surfaces.

**METHODOLOGY**

Disturbed soil samples were taken from borrow pits at Rivers State University, Choba and along airport road on coordinates 4° 48' 14.2"N and 6° 58' 35.0" E, 4° 53' 52.9" N and 4° 55' 00.1" E, 4° 46' 14.3" N and 7° 01' 21.4" N respectively, all in Rivers State, Nigeria. In order to avoid the significant changes in compaction due to excess oven drying, the soil samples were oven dried for about 24 hours at 105°C. They are then stored under cover in a room protected from extremes of heat and cold. Natural moisture content test was carried out to determine the amount of water within the pore space between the soil grains of the freshly obtained samples. Upon passing the oven dried samples through sieve 425μm, and using the Casagrande liquid limit apparatus, the water content at which the soil changes from the liquid state to the plastic state and the plastic limit which is the moisture content at which the soil becomes too dry to be plastic was obtained. About 40g of the samples too were placed on a glass plate and thoroughly mixed with water, molded with the fingers and rolled between the palms of the hands until it shears longitudinally. Particle size distribution test was carried out to classify the soil by wet sieving upon sieving dried samples through 2mm and 63μm sieves, while the washed samples where passed through a range a sieve to determine the percentages of various fine materials in the soil.

To vary the compaction effort applied on the soil, British standard heavy compaction which applies a 57 blows of a 4.5 Kg rammer, at a free drop of 457 mm and at five layers was compared to British standard light compaction which applies 25 numbers of blows of a 2.5 Kg rammer at three layers of compaction. The soil samples for compaction were prepared by mixing five percent of the weight of the soil sample with water, which is thoroughly mixed and used for compaction. Upon full compaction, the weight of the soil and the mould is weighed. Compaction process is stopped when the weight of the mould and the compacted samples drop, which signifies that the samples have failed and the optimum moisture content has been reached.

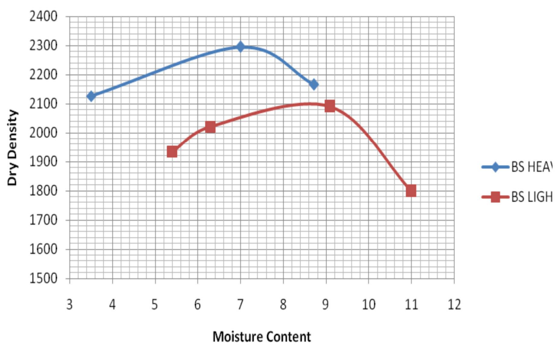
At each compaction point, samples of the compacted soil were taken to get an idea of the inter-particle aggregation of soil grains using a digital microscope. By preparing the samples to a flat thickness of about 5mm, beams of electrons are generated on the samples which have been placed on a platform having electric light. These beams were controlled using a computer to adjust the magnification and area to be scanned. The scattered pattern made by the interaction between incident electrons and the surface of the sample, yields information on size, shape, texture and composition of the sample.

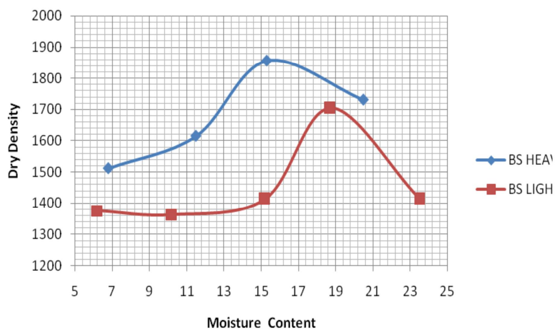
**RESULTS AND DISCUSSION**

Sample A was found to be Inorganic clay of low plasticity and low compressibility and classified by AASHTO as A-6, and USCS as CL. Sample B is an inorganic soil of high plasticity and compressibility and classified by AASHTO as A-7-6 and USCS as CH, while sample C is an inorganic soil with medium plasticity and intermediate compressibility, which is clayey gravel and classified by AASHTO as A-2-7 and USCS as CI, and the average moisture contents of the samples were 22.8%, 24.3% and 21.2%, respectively, as shown in Table 1.

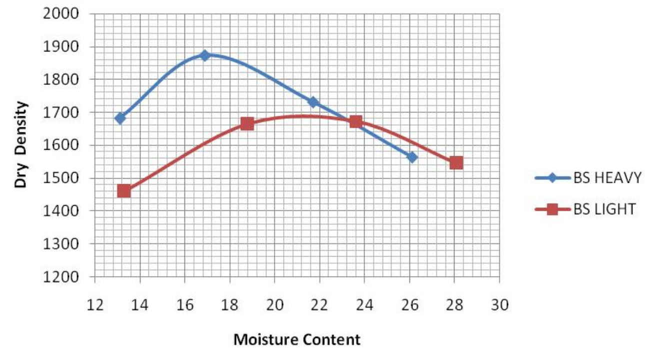
At 25 numbers of blows, the liquid limit which depends on the clay mineral present for sample A is 34.7%, that of sample B is 57.5% and sample C is at 46.5%. As liquid limit is a function of compressibility of soils, it follows that sample C is more compressible than sample A as well that sample B is more compressible than sample C, which means that for a known volume, sample could achieve higher density than sample C, followed by sample A in that order. Based on the nature and amount of fine materials present in the soil mass, Sample C has the highest plastic limit value of 34.1% which indicate that the soil can take up appreciably high percentages of moisture in its structure before reaching a plastic state, than sample B having plastic limit of 28.2%, with sample A having the least plastic limit of 17.5%.

For all the samples compacted, figure 1 shows that it took fewer numbers of compaction points before reaching maximum dry density and at lower moisture content for heavy compaction than light compaction. This can be viewed as a result of increased compaction effort which makes the soil grains to occupy closer spacing and air is removed from the voids. The dry density and moisture content graphs of sample A and sample B are similar at both BS light and BS heavy compaction effort, compared to sample C. But sample A show slightly higher maximum dry density than B at both compaction effort with sample A reaching maximum dry density at moisture content lower than those of sample B. sample C has exceedingly higher maximum dry density at lower moisture content than sample B at both compaction effort as a result of increased proportion of larger diameter particles in its soil mass.




(i)




(ii)

(iii)

Figure 1: Dry Density against Moisture content relationship at BS light and BS heavy compaction for (i) soil sample A (ii) soil sample B (iii) soil sample C

Table 1: Summary of results of Atterberg limits for soil samples

| | Soil A | Soil B | Soil C |
|---|---|---|---|
| Liquid limit | 34.7 | 57.5 | 46.5 |
| Plastic limit | 17.5 | 28.2 | 34.1 |
| Plastic index | 17.2 | 22.3 | 12.4 |
| AASHTO classification | A-6 | A-7-6 | A-2-7 |
| USCS classification | CL | CH | CI |

Table 2: Summary of results of compaction for soil samples

| | Sample A | Sample B | Sample C |
|---|---|---|---|
| **BS Heavy** | | | |
| Maximum dry density (Kg/m$^3$) | 1856 | 1874 | 2295 |
| Optimum moisture content (%) | 15.3 | 16.9 | 7.0 |
| **BS Light** | | | |
| Maximum dry density (Kg/m$^3$) | 1704 | 1672 | 2091 |
| Optimum moisture content (%) | 18.7 | 23.6 | 9.1 |

Also, it is observed that as the plasticity index of the soil reduces, the degree of compaction as viewed from the maximum dry density increases for all samples at both the British standard light and British standard heavy compaction, and as water content of the compacted soils are increased, it follows that their shear strength increases too with increase in dry density up to a point which it starts to reduce, as a result of excess water occupying the spaces which is supposed to be occupied by soil grains under compaction.

At the same magnification level, visual observation of sample A shows that soil grains are closely packed and compressed to the maximum at the optimum moisture content, while the compacted soil at the extremes of the optimum exhibits slightly lower packing of grains at BS light compaction, while higher packing is obtain at both sides of the optimum for BS heavy compaction. Also, there occur lines of shear at the wet-side of optimum moisture in the micro-structure of the compacted samples, at both BS heavy and BS light. This could be as a result of excess water in the structure which reduces the shear capacity of the compacted sample. The average void dimensions shows that the least void dimensions occurs at the maximum moisture content with the voids bigger at the dry side of optimum moisture at BS light compaction while the voids were bigger at the wet-side of optimum moisture for the BS heavy compaction.

Micro-structure of Sample B shows slightly packed soil grains at both optimum moisture and dry side at BS light compaction, due to lower moisture content and light compaction efforts and very low degree of compactness of grains with large voids compacted to those at optimum moisture and dry side of optimum moisture which has similar void dimensions. At this degree of compaction energy, there occurs presence of lines of shear at optimum moisture and wet-side of optimum. At BS heavy compaction, the degree of compaction of the samples increases as the moisture content increases, with the wet-side of optimum moisture, where there exists presence of lines of shears having lower degree of compactness than the dry side, whose average diameter of voids lower than those of the dry side of compaction.

The microstructure of compacted sample C shows maximum degree of compactness can only be achieve at optimum moisture for BS light, unlike BS heavy whose grains are closely packed at moisture content immediately before and after the optimum. At BS light compaction, the lowest dimension of voids occurs at the optimum moisture and there occurs lines of shear at the optimum moisture and its dry and wet extremes, partly due to the occurrence of larger percentages of sandy particles in its grains. Whereas, as for heavy compaction, there occurs abnormal increase of average dimension of voids as moisture content increases. At constant BS light compaction energy for all samples, the compacted samples of C shows more grain to grain connection at all moisture contents, with lower diameter of voids, than sample A then sample B in that order. Although all the compacted samples shows the presence of lines of shear at the wet-side of optimum moisture regardless of their degree of compaction, but sample Band C shows the same line of weakness at the optimum moisture and the lather showing also lines at weakness at the dry side of compaction (Plates 1and 2).

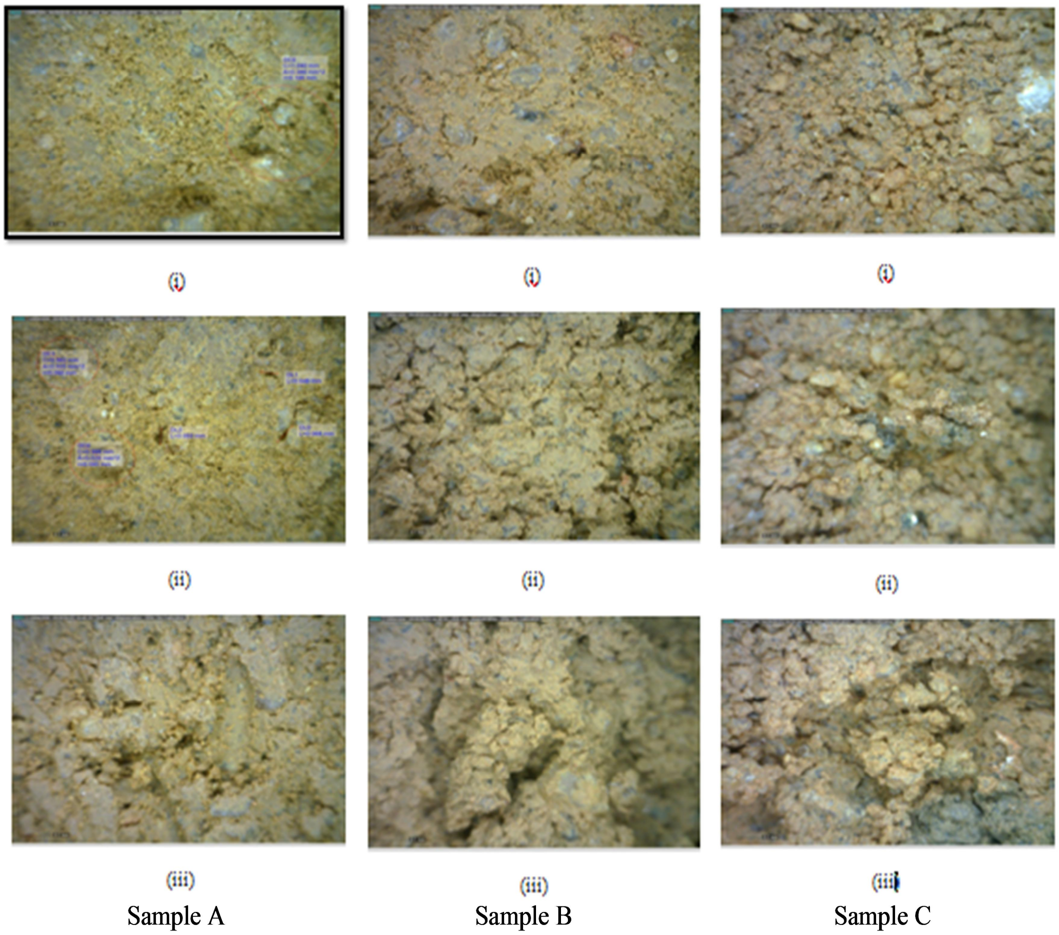



Plate 1: Micrograph of compacted samples using BS light compactive effort - (i) dry-side of optimum moisture (ii) optimum moisture content (iii) wet-side of optimum moisture for samples A,B, and C.

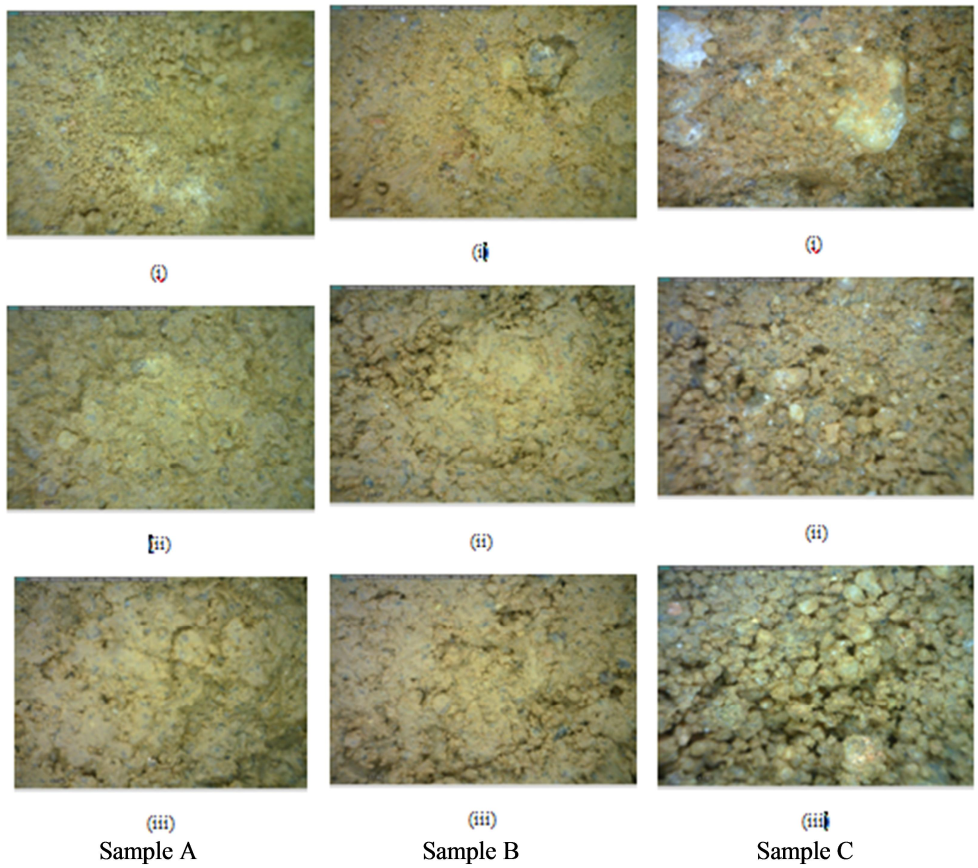



Plate 2: Micrograph of compacted samples using BS heavy compactive effort - (i) dry-side of optimum moisture (ii) optimum moisture content (iii) wet-side of optimum moisture for samples A,B, and C.

Table3: Summary of results obtained from the micro-structure analysis of compacted samples

| Soil class | Compaction point | Average dimension of voids (mm) | Presence of lines of shear | Relative degree of grain packing |
|---|---|---|---|---|
| **A-6** | | | | |
| | **BS Heavy** | | | |
| | Dry-side of OMC | 0.073 | No | High |
| | OMC | 0.056 | No | High |
| | Wet-side of OMC | 0.156 | Yes | High |
| | **BS Light** | | | |
| | Dry-side of OMC | 0.125 | No | Medium |
| | OMC | 0.053 | No | High |
| | Wet-side of OMC | 0.063 | Yes | Medium |
| **A-7-6** | | | | |
| | **BS Heavy** | | | |
| | Dry-side of OMC | 0.073 | No | Medium |
| | OMC | 0.036 | No | High |
| | Wet-side of OMC | 0.109 | Yes | High |
| | **BS Light** | | | |
| | Dry-side of OMC | 0.096 | No | Medium |
| | OMC | 0.084 | Yes | Medium |
| | Wet-side of OMC | 0.263 | Yes | Low |

| | | | | |
|---|---|---|---|---|
| **A-2-7** | | | | |
| | **BS Heavy** | | | |
| | Dry-side of OMC | 0.038 | No | High |
| | OMC | 0.078 | No | High |
| | Wet-side of OMC | 0.104 | Yes | High |
| | **BS Light** | | | |
| | Dry-side of OMC | 0.081 | Yes | Medium |
| | OMC | 0.056 | Yes | High |
| | Wet-side of OMC | 0.131 | Yes | Low |

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At constant BS heavy compaction energy, at optimum moisture, sample C has the highest packing of soil grains with sample B not as closely packed as sample A, with sample B having the least diameter of voids and sample C the highest diameter of voids. At moisture contents away from the optimum, the dry side of sample C exhibits the lowest diameter of grains and the highest packing of soil grains, while the wet-side of sample A shows the highest diameter of voids and the lowest degree of compactness. It is evident from the analysis of the micrograph that there exist lines of shear at the wt-side of optimum moisture content for all compaction and that the presence of this lines of weakness is high for soils of lower plasticity index at British Standard light compaction.

## CONCLUSION

From the analysis of the test results, it can be inferred that the degree of compaction based on the amount of effort used influences the mechanical behavior of soils, their micro-structure, degree of compactness of gains, the average dimension of voids, and the occurrence of thin lines of shear in their structure.
For inorganic clays of low plasticity and low compressibility, there is presence of lines of shear only at the wet-side of optimum moisture indicating susceptibility to shear failure, and, the higher the compaction effort, the higher the dimensions of voids at the wet-side of optimum and the lower it is at the dry side of optimum.
For inorganic clays of high plasticity and high compressibility, there was presence of lines of shear only at the wet-side of optimum for BS heavy compaction and presence of lines of shear at both optimum moisture and wet-side of optimum moisture indicating susceptibility to shear failure at those points, and the higher the compaction effort, the lower the dimensions of voids at both the wet and dry side of optimum moisture and at the optimum moisture content.
For inorganic soils of medium plasticity and intermediate compressibility, there was a presence of lines of shear at the optimum moisture, the wet-side, and dry side of optimum moisture for BS light due to the high dry density they possess and lines of shear only occur at the wet-side of OMC for BS heavy compaction, and the higher the compaction effort, the lower the dimensions of the voids at the dry and wet-side of optimum moisture and increases at the optimum moisture content.

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