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Consolidation Properties of Compacted Lateritic Soil Treated with Glass Cullet

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ABSTRACT

One Dimensional Laboratory Consolidation Test was conducted on Lateritic Soils treated with up to 16% Glass Cullet (GC), to assess its consolidation properties. Specimens were prepared at three different moulding water contents (2% dry of optimum, optimum moisture content and 2% wet of optimum) and compacted using the British Standard Light compactive effort. Preliminary tests on soils showed improved index properties with a decrease in liquid limits (LL), a decrease in plastic limits (PL) with a resulting decrease in plasticity index (PI). Gross yield stress (σ_y) generally increased for up to 12% GC treatment before decreasing at 16% GC treatment. Higher values of σ_y are recorded at 12% GC treatment. σ_y showed no observable trend with increased moulding water content. Reductions in compression index (C_c) and swelling index (C_s) with increased GC content were recorded. C_c generally increased with increased moulding water content while C_s decreased before increasing with increased moulding water content. The coefficient of volume compressibility (M_v) increased and decreased with higher GC content; they were also affected by the soil particle state with increasing pressure. The coefficient of consolidation (C_v) generally decreased before increasing with increased GC content. C_v generally decreased with higher consolidation pressure on the dry side of OMC, OMC and wet side of OMC. Optimal reduction of C_v was obtained at 8% GC for the dry side of OMC, OMC and wet side of OMC. For more effective results, 8% to 16% of GC should be used.

Keywords: Coefficient of Volume Change; Coefficient of Volume Compressibility; Compression Index; Consolidation; Gross Yield Stress, Glass Cullet; Swelling Index, Coefficient of Consolidation;

INTRODUCTION

Any structure that is placed above a buried stratum of compressible soil undergoes settlement because of the compression that takes place in the soil.

The consolidation of compressible soils is of concern to engineers in the design and construction of foundations, earth dams, embankments, bridge abutments etc.

The theory of consolidation was first introduced by Karl Terzaghi in 1923. The theory of consolidation since its introduction by Terzaghi has formed the foundation of modern geotechnical engineering where the interaction of soil and water dominates. Although consolidation is used for estimating settlements, it has also played key roles in the design of piled foundations, laboratory tests [1].

Consolidation settlements occur usually after construction and loading. It's a time dependent process that occurs due to the expulsion of excess pore pressure which results in the soil due to application of loading in a saturated soil.

Lateritic soil is one of the most abundant soils found mostly in the tropical and subtropical regions of the world. It is mostly used in construction projects, be it construction of roads, bridges, earth dams, backfilling and so many other construction works. Lateritic soil plays a very important role in the construction industry worldwide [2].

It is almost impossible to execute any construction work in Nigeria without the use of lateritic soils [3].

The consolidation characteristics of most residual lateritic soils appear to depend upon the nature of the soil, the position of the sample in the profile and the characteristics of the material deposit [2].
Glass is an amorphous (non-crystalline) solid material.
Glasses are typically brittle and often optically transparent. The United State Environmental Protection Agency (USEPA) reported that a total of 206.1 million tons of waste is generated annually [4]. Glass comprises 6.2% of this waste, meaning that approximately 12.8 million tons of glass disposed of per year, about 31% is reuse by glass container manufacturers for re-melt and remold applications, 7% is used for a host of secondary markets such as fiberglass production and construction aggregate, and the remaining 62% is disposed in landfills. Assuming that the container industry has all the cost-effective glass it can use, the 31% should remain static in the years to come. The portion that deserves attention is the 62% of recovered glass that takes up space in landfills throughout the country. Large quantities of recycled glass, or glass cullet, are taking up valuable space in landfills [5].

Recently, prices paid for glass cullet have decreased due to the apparent over-supply of mixed colour glass and green glass, which is not in demand by the container industry. As a result, alternative uses of this commodity are receiving greater scrutiny, and engineers are being challenged to find viable uses for the 9.7 million tons of glass that now take up precious space annually in landfills [5].

This research focuses mainly on the effect of glass cullet (GC) on the properties of lateritic soil when it is subjected to one dimensional oedometer consolidation test.

These soil tests help to provide the consolidation properties of the soil, which further helps to provide information on the physical properties of the soil itself and the improved or modified soil, thereby improving the design of earthworks and foundation for proposed engineering structures and for repair of distress to earth work and structures caused by subsurface conditions[6].

The results obtained from the analysis of the physical and consolidation properties of some of these soils do not really support the placement of some specific proposed engineering structures due to the soils being too weak to support the structures, thereby creating a need to improve the quality and properties of the soil and hence, prompting the need for this research works, "Consolidation Properties of Glass Cullet treated Lateritic Soil".

This research work deals with the treatment of Lateritic soil with Glass Cullet (GC) and the suitability of the blended products for engineering works. One of the factors that motivated this work is the need to improve the consolidation properties of laterite and to control or prevent indiscriminate disposal of broken bottles. Glass Cullet (GC) had received extremely limited use due to unfamiliarity, negative perception and lack of approved specifications [6].

An interesting and potentially cost effective solution to both recycling challenges is presented by blending crushed glass with lateritic soil to improve the consolidation and workability characteristics of both materials for engineering works. Here, the term workability is used to describe the ease of handling, transport, placement and compaction of the crushed glass-lateritic soil blends [7].

Accordingly, a comprehensive evaluation of Glass Cullet (GC), laterite and Glass Cullet treated lateritic soil [blends] was undertaken to provide a basis for the geotechnical design and construction communities to utilize Glass Cullet laterite blends in general engineering work.

MATERIALS AND METHODS OF TESTING

MATERIALS

SOIL

The soil used is a naturally reddish-brown lateritic soil obtained from a borrow pit in Shika area of Zaria (Lati-tude 11°15'N and Longitude 7°45'E), Nigeria. A study of the geological and soil maps of Nigeria [10,11] show that the samples taken belong to the group of ferruginous tropical soil derived from acid igneous and metamorphic rocks. Previous studies on soils from this area have been shown to contain kaolinite as the dominant clay mineral [3]. The soil is classified as A-7-6 (10) according to AASHTO soil classification system [11] and low plastic-ity clay (CL) according to the Unified Soil Classification System [12]. A summary of the engineering
properties of the natural soil is shown in Table 1.

Table 1: Index Properties of Natural Soil

Property	Natural Soil
Natural Moisture Content (%)	13.4
Specific Gravity	2.63
Liquid Limit (%)	44.1
Plastic Limit (%)	23.3
Plasticity Index (%)	20.8
AASHTO Classification	A-7-6 (11)
USCS Classification	CL
Maximum Dry Density(mg/m^3)	1.57
Optimum Moisture Content (%)	26.80
Colour	Reddish brown

GLASS CULLET

The glass cullet used for this research work was collected from a glass dumping field along Nigeria College of Aviation Technology, Zaria, Kaduna State. The broken glasses were crushed at the Department of Chemical Engineering, Ahmadu Bello University, Zaria. The broken glass was then pulverized and passed through British Standard Sieve No.4 (aperture size 4.76mm). The glass cullet that passed through the sieve was immediately stored in an airtight container to avoid moisture soaking it during storage. The laterite was treated with the glass cullet at different percentages of dry weight. The glass cullet treatment considered were 0%, 4%, 8%,12% and 16% by dry weight of soil used. This gives five different Laterite-Glass cullet mixtures with 0% as the natural soil.

METHODS

INDEX PROPERTIES

Laboratory tests were conducted to determine the index properties of the natural soil and soil-glass cullet mixtures in accordance with British Standards [13].

COMPACTION

The compaction test was conducted in accordance with British Standard [13]. A 2500g of soil sample was air-dried and pulverized sufficiently to run through BS sieve No.4 (aperture size 4.76mm).

Various percentages of Glass cullet were mixed with the portion of the soil sample. The soil sample taken was mixed thoroughly with water. The water was added in an increment of 6% of the weight of the soil. The British Standard Light (BSL) compaction effort was used compacting the samples in a BS mould of 105mm diameter and a 2.5kg rammer with 50mm diameter head falling over a controlled height of 300mm. The soil is compacted in three layers, each layer is given 27blows. At the end of the compaction, the top of the mould was trimmed with a straight edge to remove excess projected moulded soil. The mould and soil samples were weighed as m_2. The compacted soil was then removed from the mould and a representative sample was taken from the top and bottom of the mould for moisture determination.

The bulk density in $^{mg}/_{m^3}$ calculated for each compacted layer as

$$\rho_b = \frac{m_2 - m_1}{1000} \quad (1)$$

Where ρ_b is the bulk density

m_1 is the weight of mould and base (g)

m_2 is the weight of mould and soil (g)

The dry density is as well calculated as

$$\rho_d = \frac{100\rho_b}{100 + w} \quad (2)$$

Where ρ_d is the dry density

ρ_b is the bulk density and

W is the moisture content in (%)

CONSOLIDATION TEST

The test was carried out in accordance with the British Standard [13]. The consolidation apparatus were prepared for carrying out the consolidation test ensuring that the consolidation ring is clean and all components of the cell fit appropriately. The dial guage was also ensured to move freely. The internal diameter (D) and height (H_o) of the consolidation ring were measured. The weight of the empty ring(M_R) was also measured. The air dried soil sample was compacted using the British Standard Light compactive effort and extruded from the mould. The sample from the mould was cut into the oiled consolidation ring, trimmed properly at the top and bottom and then weighed. The consolidation cell was then assembled fitting the cell in the load frame, setting up the loading yoke and dial gauge. The pressure loads applied to the specimen are 10kN/m^2(1lb), 20kN/m^2(2lbs), 50kN/m^2(5lbs), 100kN/m^2(10lbs), 200kN/m^2(20lbs) and 400kN/m^2(40lbs) after which it was unloaded to 200kN/m^2 and then 100kN/m^2. The dial gauge readings were observed and recorded in a consolidation test form at various time intervals i.e. 10secs, 15secs, 30secs, 1min, 2mins, 4mins, 8mins, 15mins, 30mins, 1hour, 2hrs, 4hrs, 6hrs, 12hrs and then 24hours. After the 24hours settlement, the process was repeated with additional loads 20, 50, 100, 200 and 400kN/m^2 respectively. After which the 400 and 200kN/m^2 loads were unloaded after 24hours each measuring the swell. The cell is then dismantled and the sample oven dried for moisture content determination.

The consolidation test was repeated for other percentages of treatment with Glass Cullet content from 4%, 8%, 12% and 16% at -2% side of OMC, OMC and at +2% side of OMC.

The Taylor method (Square Root of Time method) was used to analyse experimental results. The coefficient of consolidation is computed using Taylor method because in Casagrande method, the curves were not parabolic in shape. Therefore, it causes a problem in determining the value of t_{50}.

Voids ratio versus pressure curves were plotted to determine the compression index (C_c), swell index (C_s) and pre-consolidation pressure (σ_c). The coefficient of volume compressibility (M_v) and the coefficient of consolidation (C_v) were calculated from the settlement readings for each of the representative samples.

DISCUSSION OF TEST RESULTS

INDEX PROPERTIES

The Atterberg limit results show improved index properties with a decrease in liquid limit (LL). The liquid limit decreased from 44.1% to 34.4% with increase in GC content from 0% to 16%. This decrease was as a result of GC

having a lower ability to retain wateras against higher water retaining ability of the laterite. Similar results were obtained by other researchers [8].

The decrease in liquid limit improves the consolidation properties of the material as it causes an increase in the density and strength of the material and decrease in the plasticity, swelling ability and shrinkage of the material, thereby preventing cracks on pavement surfaces, stripping of the surface, waviness of pavement surface etc when used for road construction. It also makes the material suitable for other engineering works such as construction of embankment and backfilling for retaining wall.

The Atterberg limit results show improved index properties with a decrease in plastic limits (PL). The plastic limit decreased from 23.3% to 15.9% with increase in GC content from 0% to 16%. This is because GC has little or no plasticity, thereby combining with the soil to produce a continuously reduced plastic limit (PL) with increase in GC. Similar results were obtained by other researchers [8].

Reduction in PL of the material enhances its usage for engineering work (construction of sub-grade, sub-base, base course, embankments and retaining wall backfill material).Because the material becomes more stable and workable, therefore being able to resist continual deformation on the application of shear stress.

The Atterberg limit results show improved index properties with a decrease in plasticity index (PI). The plasticity index decreased from 20.8% to 10.9% with increase in GC content from 0 to 16%. This is because GC is non-plastic filler, rather than a cementing agent. The decreased in plasticity index shows that the engineering properties of the soils were improved. This is in agreement with the works of other researchers [8].

COMPACTION CHARACTERISTICS

The effect of Glass Cullet content on the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the lateritic soil-glass cullet mixtures is shown in **figure 1** and **figure 2** respectively. With increased glass cullet treatment for up to 16%, the MDD increased from 1.57 to 1.63Mg/m^3. This was simple because the GC is denser than the laterite, which automatically changed the molecular arrangement of the soil samples to give a continues increase in MDD. It could also be as a result of the GC reducing the plasticity of the soil which on the other hand increases the density.

The OMC reduced with glass cullet treatment for up to 16% with values decreasing from 26.8 to 19.9%. Similar results were reported by Eberemu [8]. With increase in MDD and decrease in OMC, the consolidation properties of the material are improved and enhances their usage in the engineering world. This is because the increase MDD causes the strength of the material to increase, thereby making it useful as field material for construction of embankments and roads, and the decrease in OMC also makes the strength of the material to increase thereby making the material more stable[.

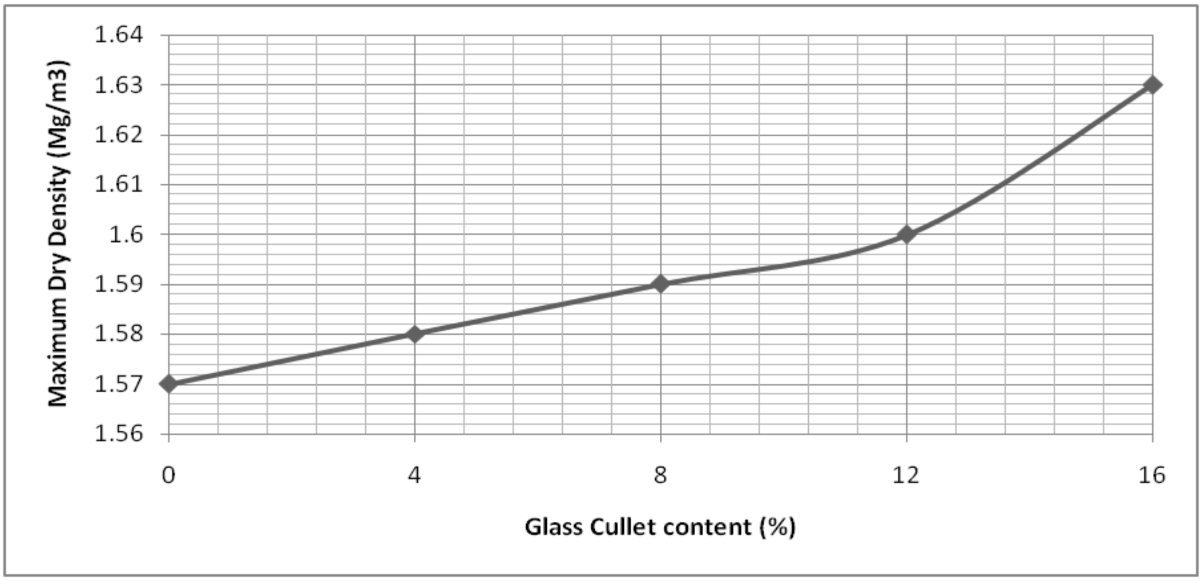

Figure 1 Variation of Maximum Dry Density with Glass Cullet content

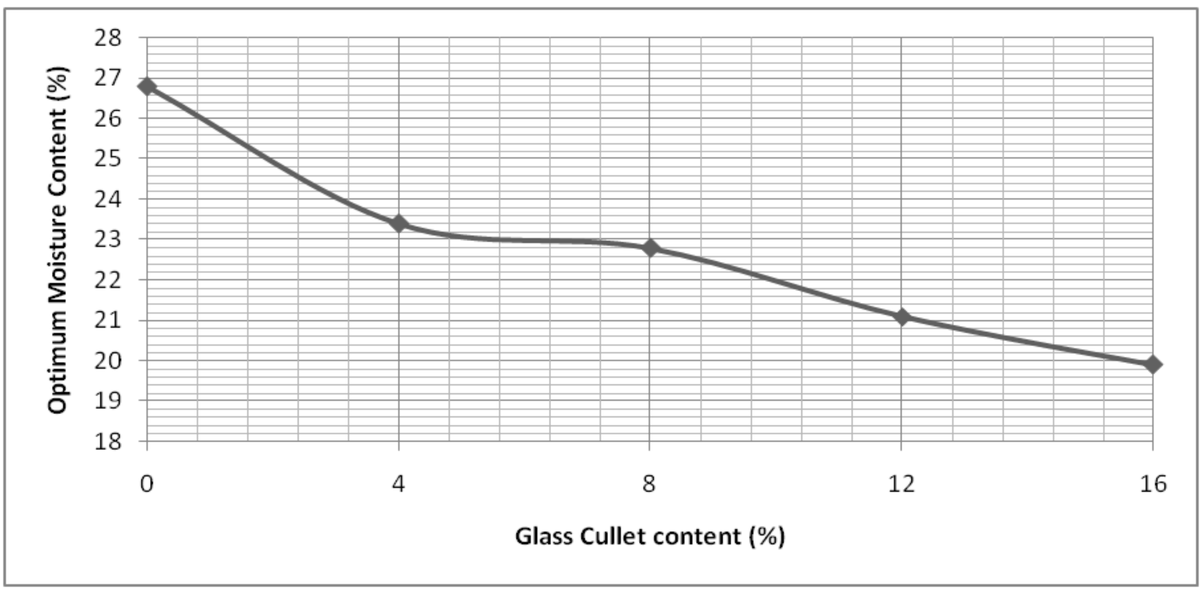

Figure 2 Variation of Optimum Moisture Content with Glass Cullet content

CONSOLIDATION CHARACTERISTICS

The consolidation characteristics of the various soil-Glass cullet mixtures compacted at different moulding water contents were observed through the gross yield stress, compression index, swelling index, coefficient of volume compressibility and coefficient of consolidation. These are discussed under the effect of glass cullet content and effect of moulding water content and effect of pressure where applicable.

COMPRESSION INDEX (C_c)

EFFECT OF GLASS CULLET CONTENT

The variation of compression index with glass cullet content is shown in **figure 3**. The trend shows that the compression index (C_c) generally decreased with increasing GC for up to 16% treatment. C_c ranged from 0.182 – 0.111, 0.191 – 0.133 and 0.210 – 0.165 at dry side (-2%), optimum moisture content and wet side (+2%) of optimum moisture content respectively with increasing GC content. This decreasing behavior of compression index may not be unrelated to the reduction in the mutual attraction that existed between the fine particles (in the laterite) that tends to hold them together in a solid mass. Eberemu [9] observed that the addition of Rice Husk Ash reduces the compressibility of laterite. When the GC content exceeds the quantity required for the soil-GC reaction, they will be filled between the voids of the soil. The graph also shows that at dry side of the OMC, lower value of the compression index are observed, thus -2% side of OMC may be taken as the optimum state for reduction of compression index. The settlement of soils is directly related to the compression index which implies that GC can be used to reduce the settlement of soils[19].

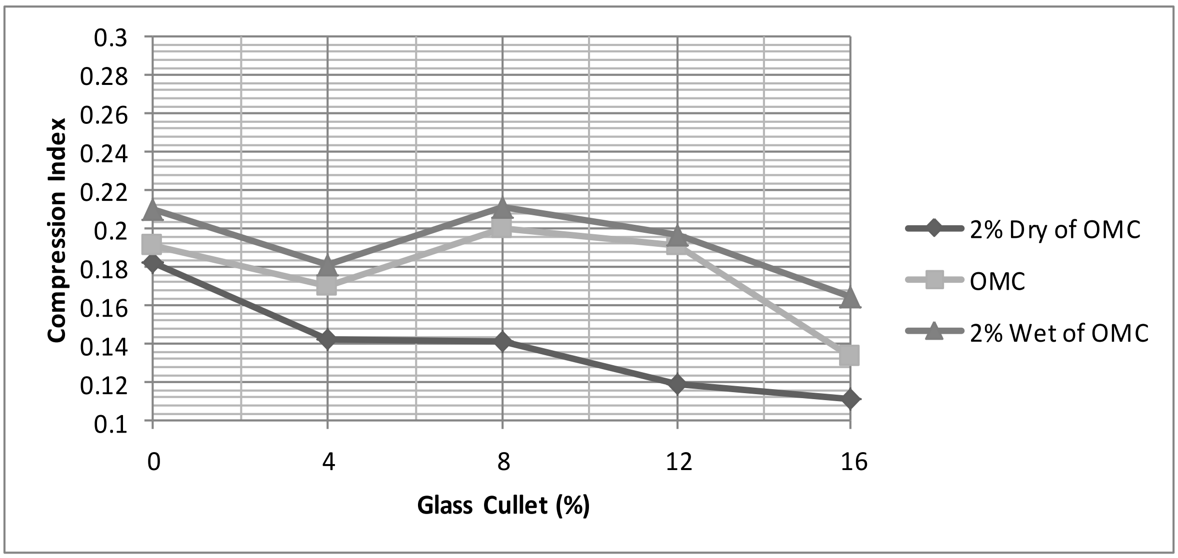

Figure 3 Variation of compression index with glass cullet

EFFECT OF WATER CONTENT RELATIVE TO OPTIMUM

The variation of compression index with moulding water content relative to optimum is shown in **Figure 4**. The trend generally shows that compression index increases with higher moisture contents from the dry side up to the wet side of optimum. For 0, 4, 8, 12 and 16% GC content, the compression index increase from 0.182-0.210, 0.142-0.181, 0.141-0.284, 0.119-0.214 and 0.111-0.165 respectively. The result shows that compression index is reduced by decrease in moulding water content. The significance of this is that at higher GC content, less compression is achieved when the soil is compacted at the dry side of optimum[10].

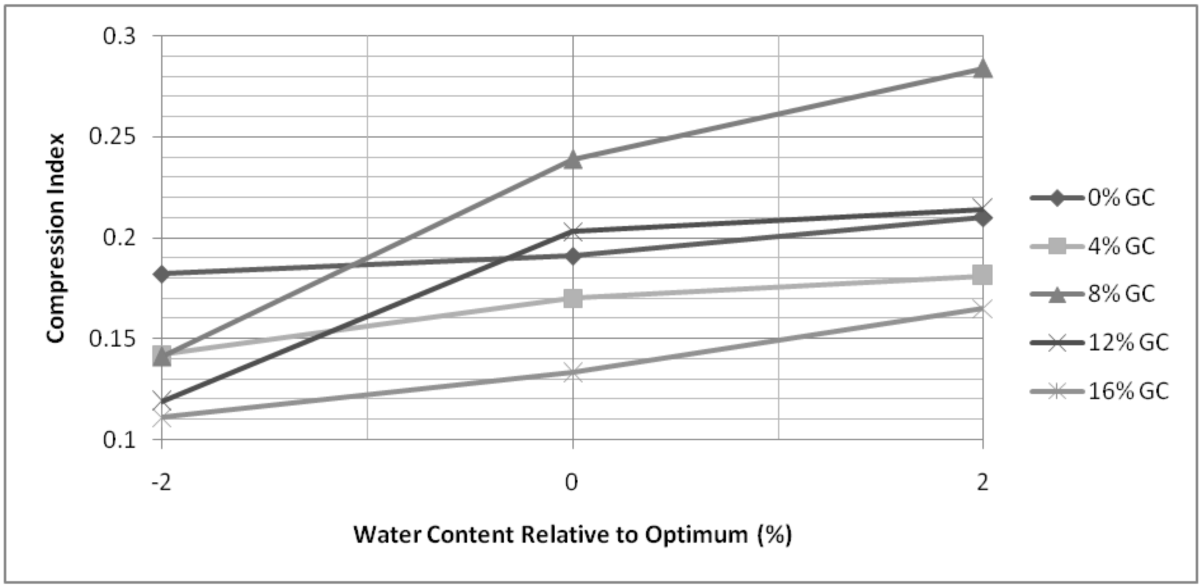

Figure 4 Variation of compression index with water content relative to optimum

SWELLING INDEX (C_s)

EFFECT OF GLASS CULLET CONTENT

The variation of swelling index with increasing glass cullet content is shown in **Figure 5.** The swelling index generally decreased with increased GC content. It ranged from 0.114-0.020, 0.95-0.007 and 0.142-0.017 at the dry side, optimum moisture and wet side of optimum moisture content respectively with higher GC content. Eberemu [9] observed a decrease in the swelling index of lateritic soil treated with rice husk ash treated up to 16%.

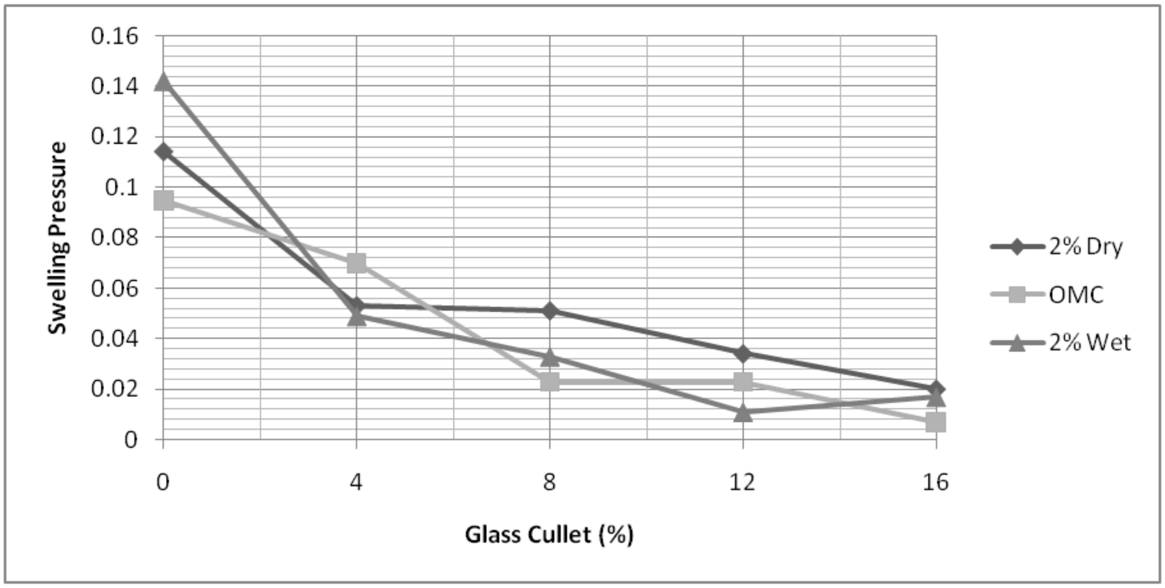

Figure 5 Variation of swelling index with glass cullet

EFFECT OF WATER CONTENT RELATIVE TO OPTIMUM

The variation of swelling index with water content relative to optimum is shown in **Figure 6.**The swelling index increases and decreases depending on the GC treatment as the moulding water content relative to optimum increases from 2% dry side of optimum and increased slightly on 2% wet side of optimum. The results show that the swelling index is influenced by the particle state of the soil fabric which is controlled by the moulding water content. A more compact state of soil is attained at optimum moisture content and the samples at optimum moisture content will swell less when unloaded[11].

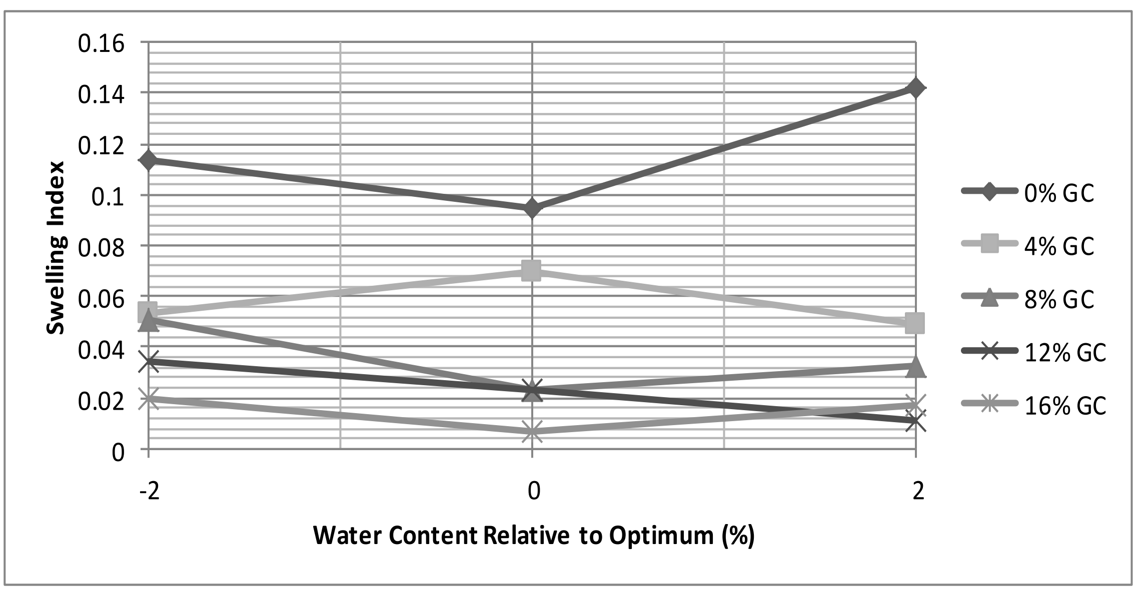

Figure 6 Variation of swelling index with water content relative to optimum

GROSS YIELD STRESS (σ_y)

EFFECT OF GLASS CULLET CONTENT

The variation of gross yield stress with GC content is shown in **Figure 7**. The gross yield stress generally increased for up to 12% GC treatment before decreasing at 16% GC treatment at the dry side of optimum, optimum moisture content and wet side of optimum. Similar results were obtained by other researchers [9]. The increase was due to the reinforcing and interlocking abilities of the glass cullet, which displayed itself as the GC content was being increased. This increase in gross yield stress values increase the strength of the materials for up to 12% GC treatment, therefore improving their consolidation properties and making them suitable for engineering works. The engineering implication of this result is that the soil is able to withstand increased pressure without settling at higher glass cullet contents (for up to 12% GC treatment).

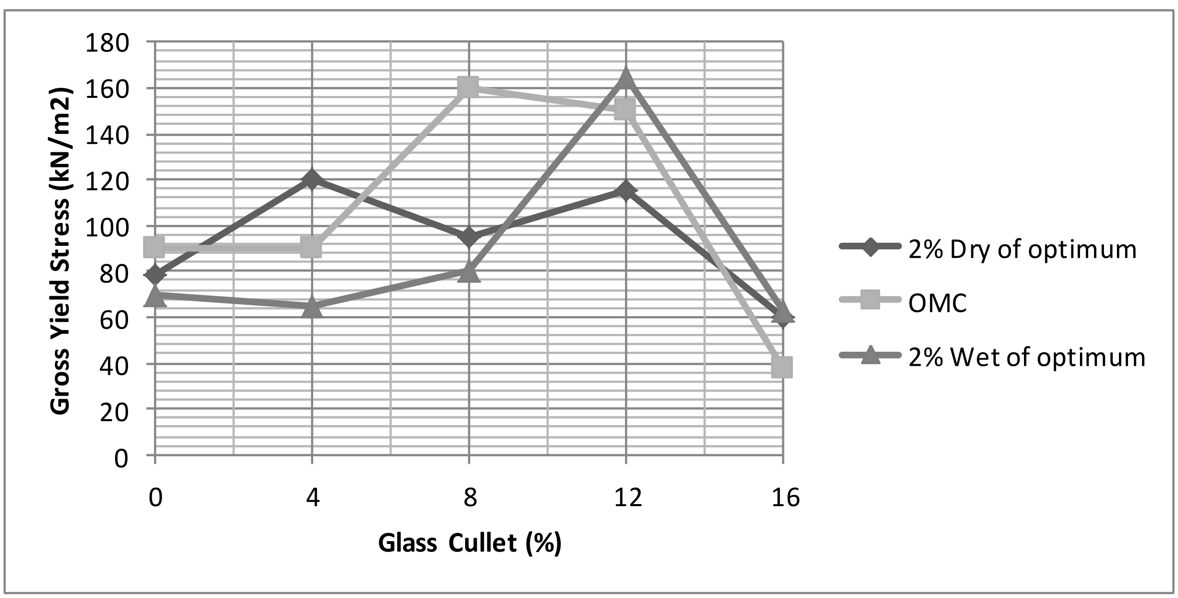

Figure 7 Variation of gross yield stress with glass cullet

EFFECT OF WATER CONTENT RELATIVE TO OPTIMUM

The variation of gross yield stress with moulding water content relative to optimum is shown in **Figure 8.**No trend was observed on σ_y with moulding water content relative to the optimum. This result is not in agreement with the results of other researchers [9].

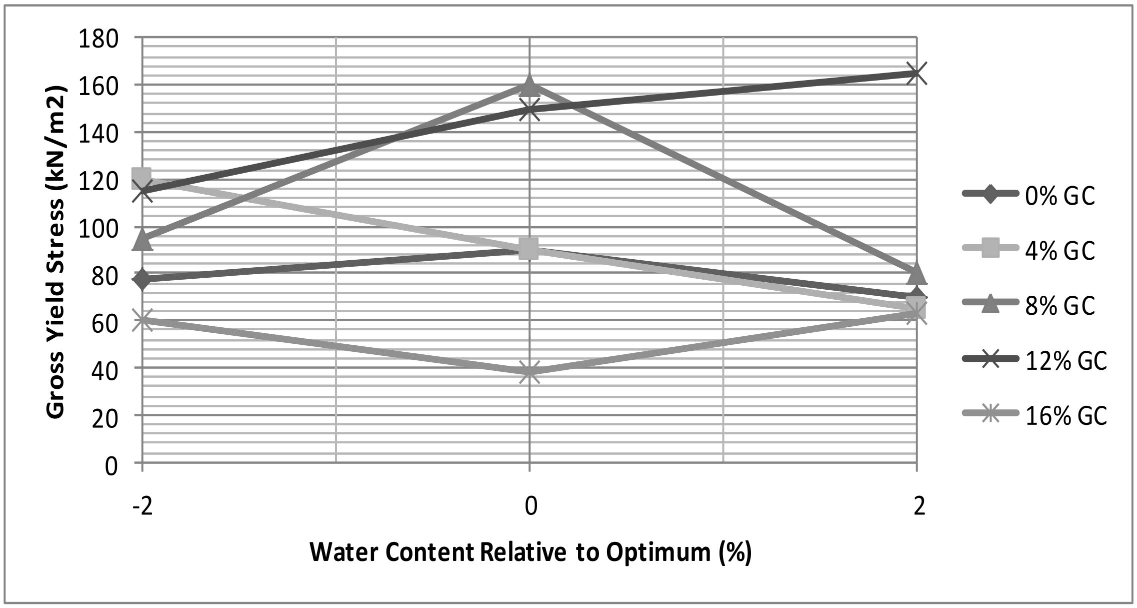

Figure 8 Variation of gross yield stress with water content relative to optimum

COEFFICIENT OF VOLUME COMPRESSIBILITY (M_v)

EFFECT OF GLASS CULLET CONTENT

Figures 9, 10 and **11**show the variation of the coefficient of volume compressibility with respect to glass cullet at -2% of OMC, OMC and +2% of OMC. At -2% side of OMC,$M_v$increases from 0.000-0.138, 0.000-0.069, 0.022-0.115, 0.423-1.047, 0.398-0.930 and 0.200-0.203m^2/MN at 10, 20, 50, 100, 200 and 400kN/m^2 pressure increments respectively. Similar trend is observed at OMC and 2% wet of optimum. This increase may be as a result of the effect of the glass cullet on the soil's strength, as the GC increased the strength of the soil due to floating of the GC particles in the matrix of the fine particles of the soil, therefore, developing particle to particle interactions in the GC-laterite mixes and hence increasing the coefficient of volume compressibility [8].

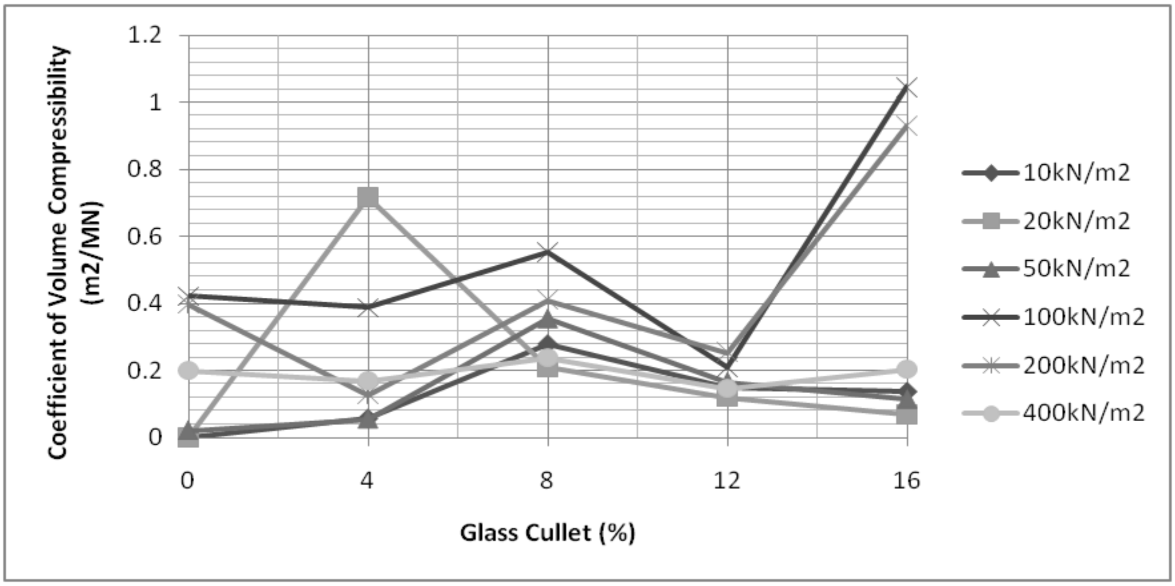

Figure 9: Variation of coefficient of volume compressibility with glass cullet at 2% dry of optimum

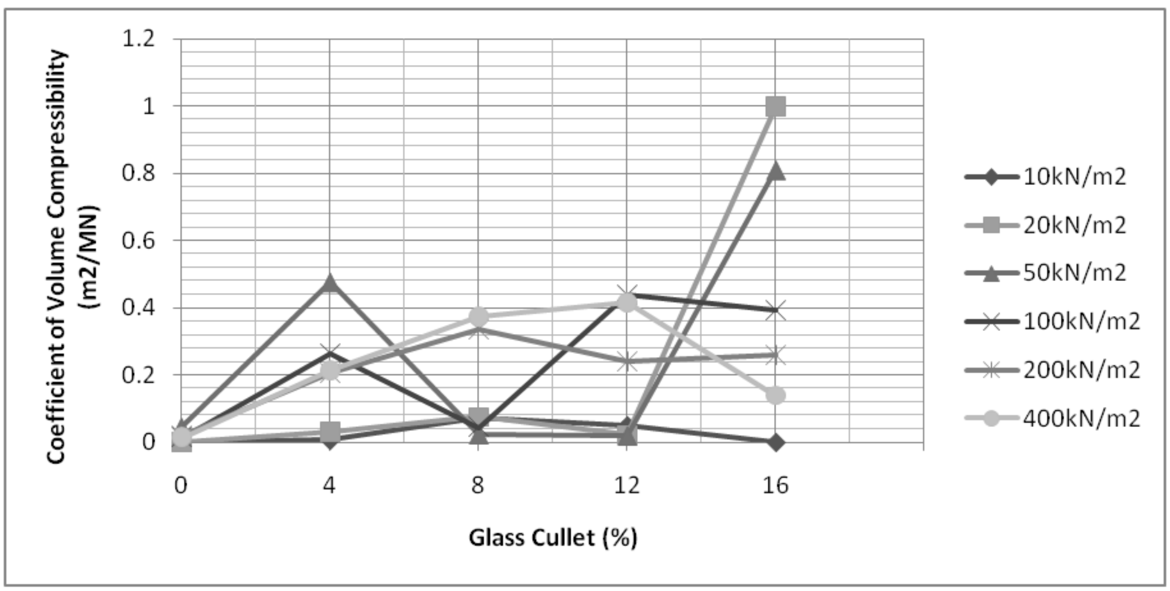

Figure 10: Variation of coefficient of volume compressibility with glass cullet at OMC

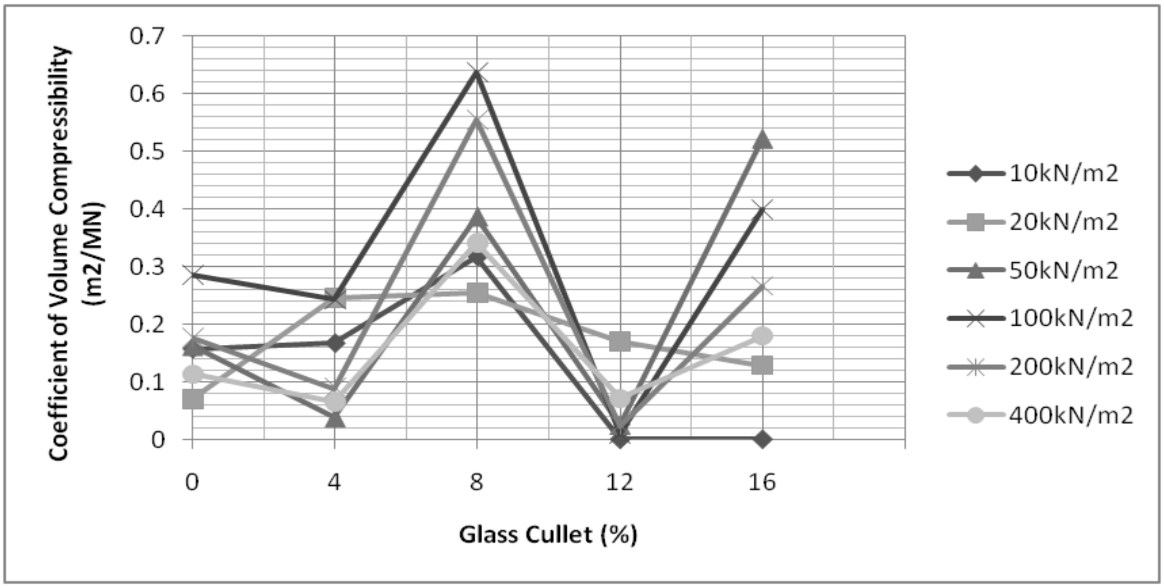

Figure 11: Variation of coefficient of volume compressibility with glass cullet at 2% wet of optimum

EFFECT OF PRESSURE

Figure 12, 13 and **14** show the variation of coefficient of volume compressibility with pressure at -2% of OMC, OMC and +2% of OMC. At -2% side of optimum, M_v increase with increasing pressure from 0.000-0.200, 0.058-0.169, 0.238-0.280, 0.147-0.149 and 0.138-0.203m^2/MN) at 0, 4, 8, 12 and 16% GC for increment from 10 to 400kN/m^2respectively. The same trend can be seen at OMC and wet side of OMC. Similar results were also obtained by Eberemu [9].

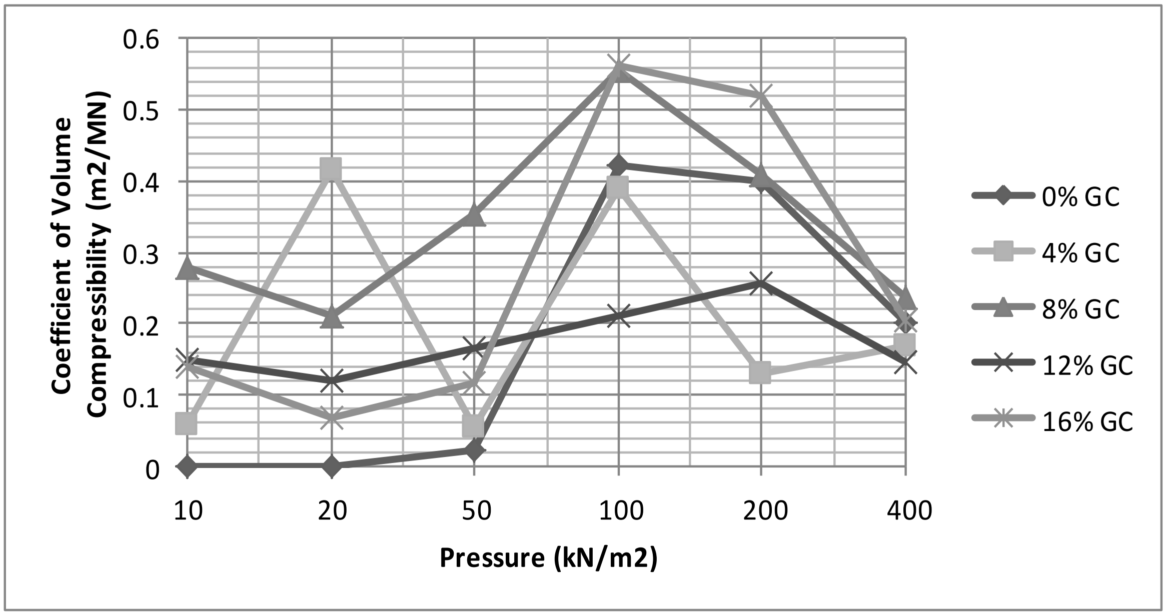

Figure 12: Variation of coefficient of volume compressibility with consolidation Pressure at dry side of OMC

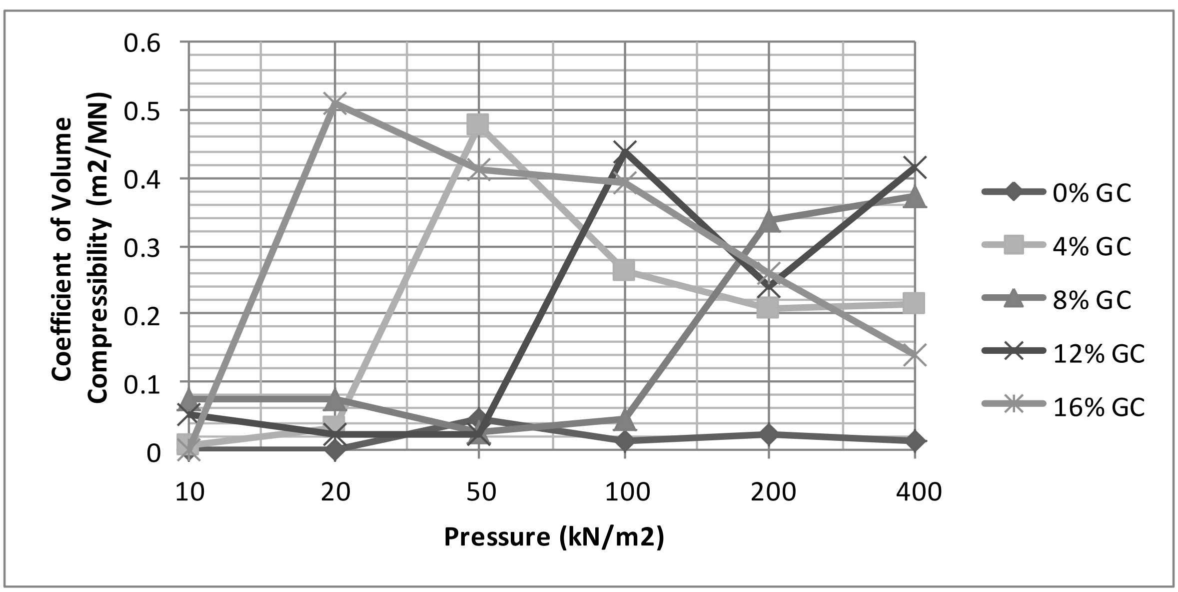

Figure 13 Variation of coefficient of volume compressibility with consolidation pressure at OMC

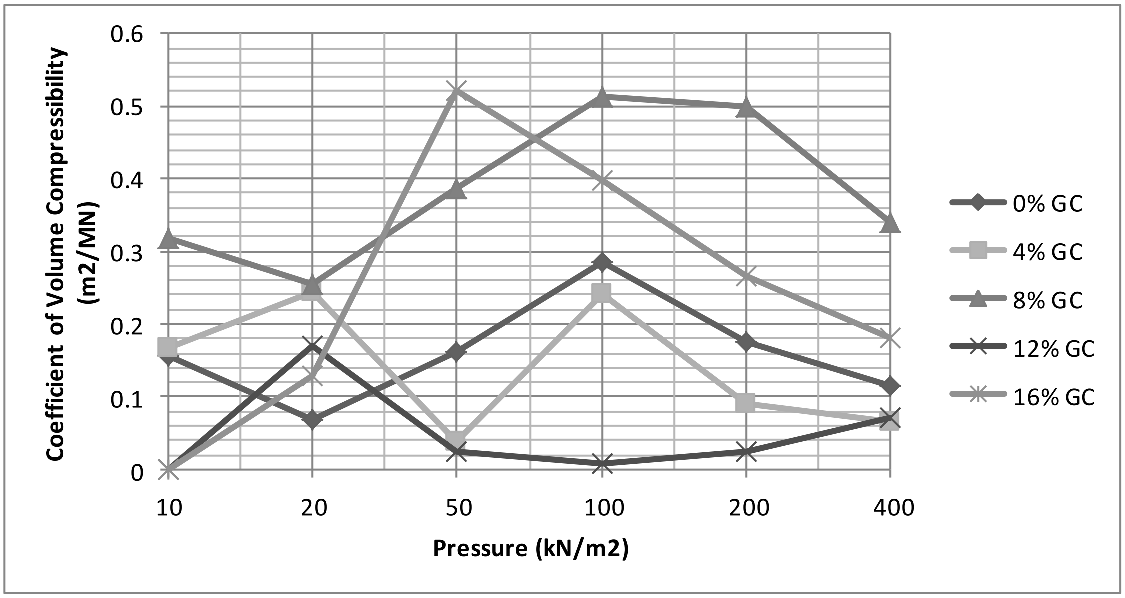

Figure 14 Variation of coefficient of volume compressibility with consolidation pressure at Wet side of OMC

COEFFICIENT OF CONSOLIDATION (C_v)

EFFECT OF GLASS CULLET CONTENT

The variation of coefficient of consolidation with GC content is shown in **Figure 15, 16** and **17** at dry side of OMC, OMC and at the Wet side of OMC. At the dry side of OMC, C_v decreased from 7.000-5.210$m^2/year$, 6.099-4.843$m^2/year$, 5.721-2.087$m^2/year$, 4.002-3.662$m^2/year$ and 2.194-1.765$m^2/year$ respectively from 0, 4, 8, 12 and 16% glass cullet at 10, 20, 50, 100, 200 and 400kN/m^2. From the trend, it is observed that lower values of C_v are recorded at 8% GC treatment at dry side of OMC, OMC and at the wet side of OMC.

Okoro et.al [10] observed that stabilization with lime and coal decrease the coefficient of consolidation of a soil [11].

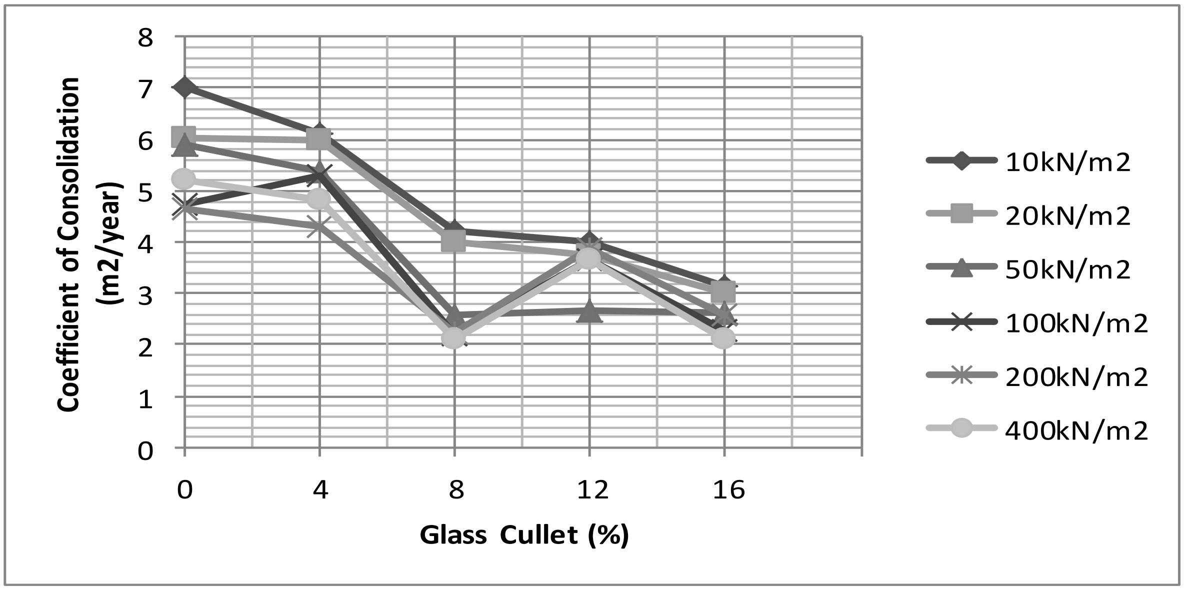

Figure 15: Variation of coefficient of consolidation with glass cullet at dry side of OMC

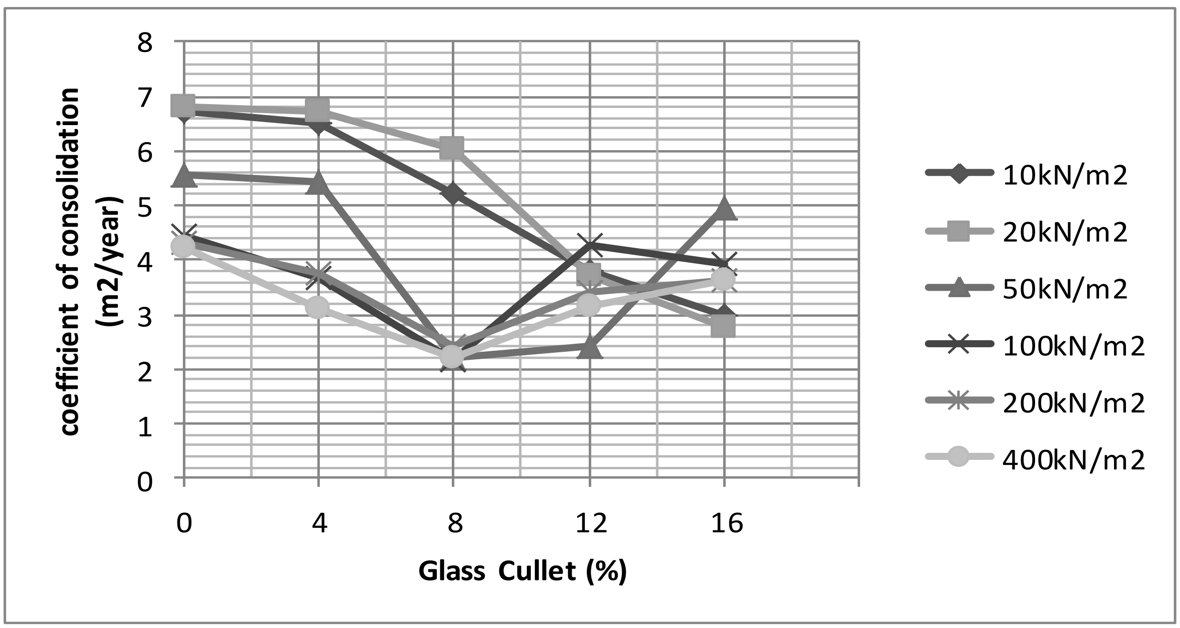

Figure 16: Variation of coefficient of consolidation with glass cullet at OMC

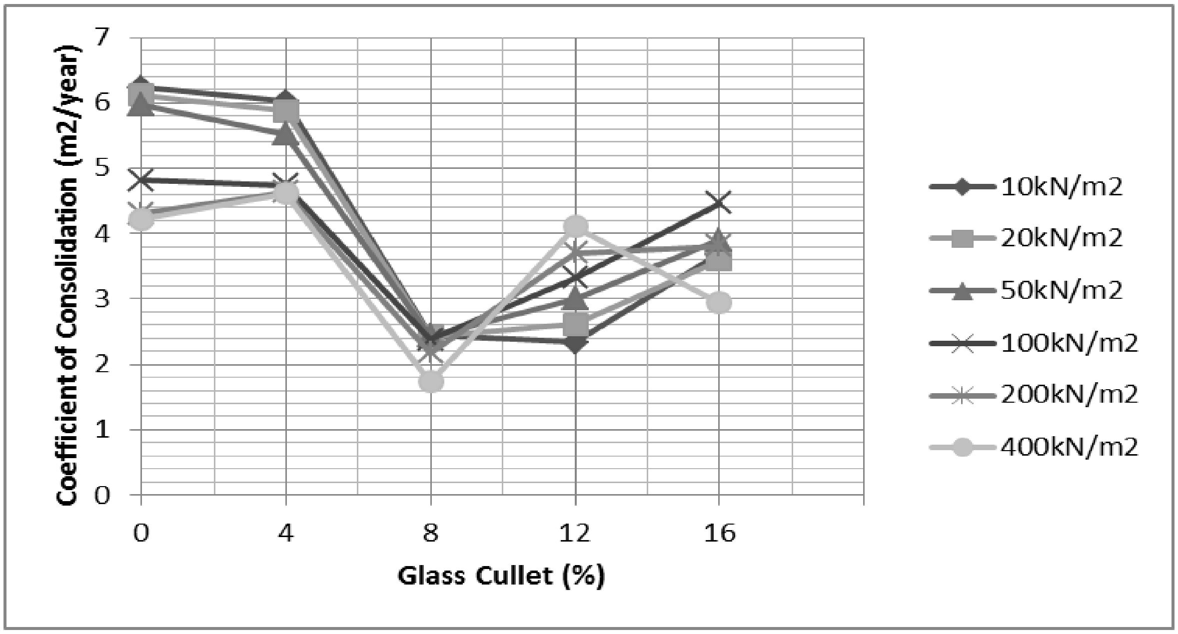

Figure 17 Variation of coefficient of consolidation with glass cullet at wet side of OMC

EFFECT OF PRESSURE

The variation of Coefficient of Consolidation with pressure is shown in **Figure 18, 19** and **20** at dry side of OMC, OMC and wet side of OMC. The trend shows that the coefficient of consolidation generally decreases with higher consolidation pressure on the dry side of OMC, OMC and the wet side of OMC. The behavior may be connected to the decrease in void ratio as pressure is added which make the soil particles more intact[12].

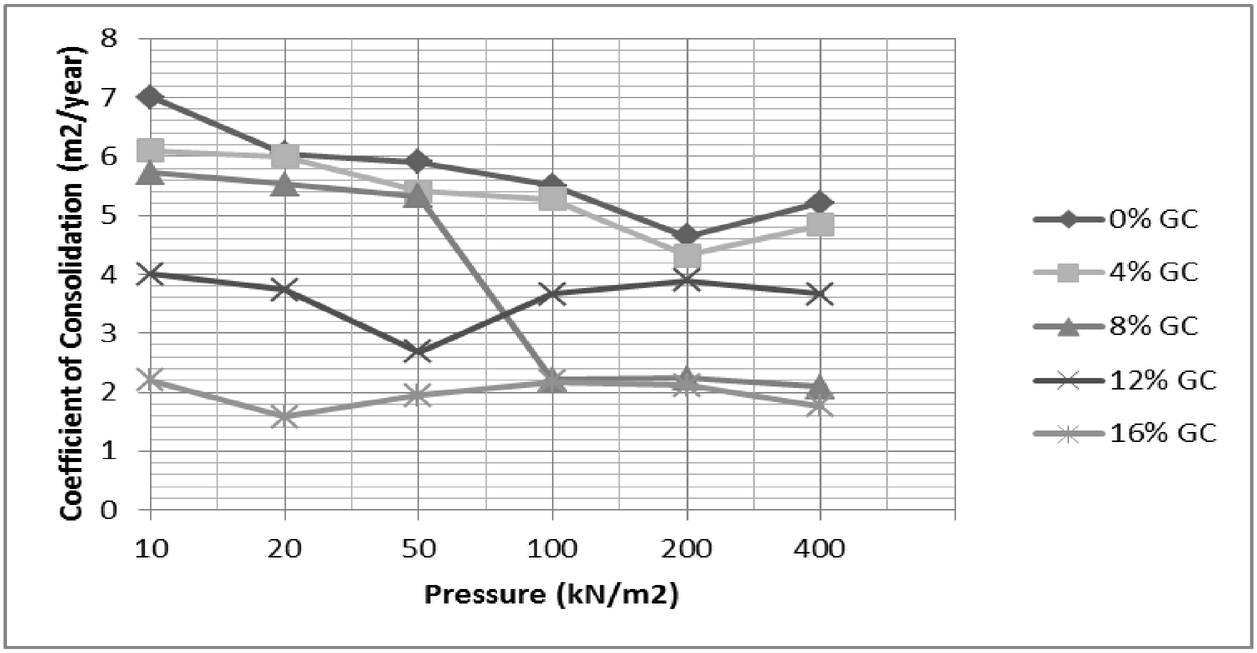

Figure 18: Variation of coefficient of consolidation with pressure at dry side of OMC

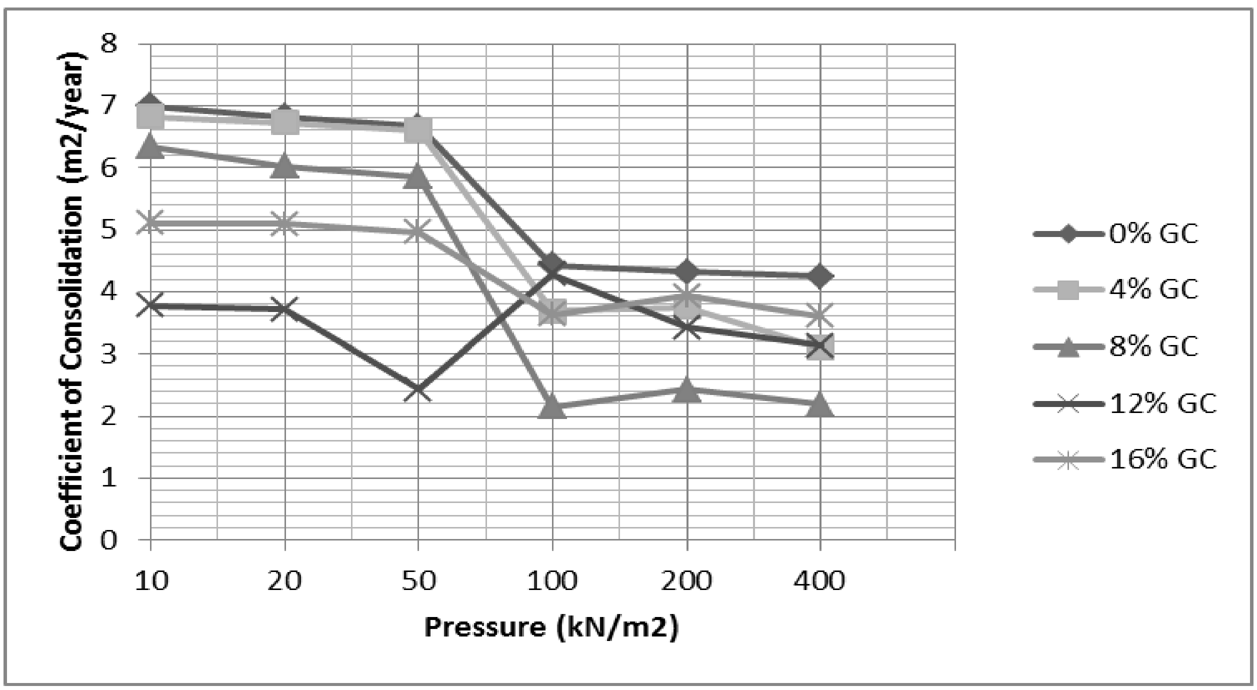

Figure 19: Variation of coefficient of consolidation with pressure at OMC

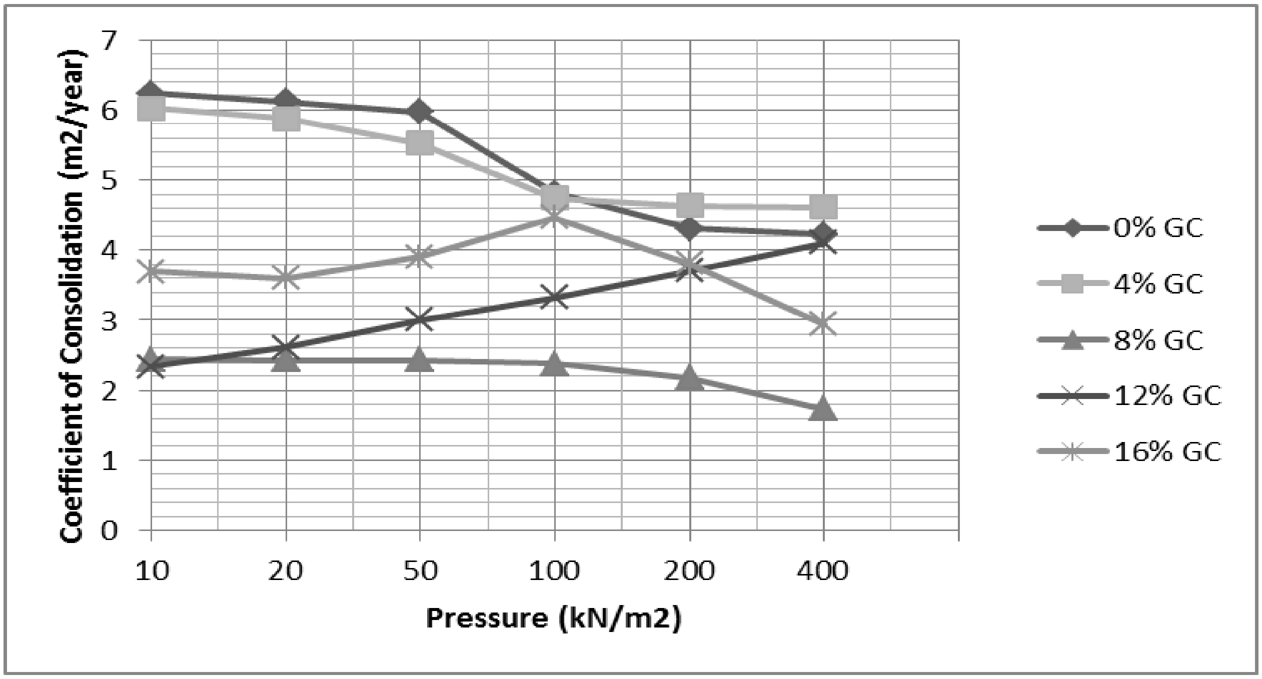

Figure 20: Variation of coefficient of consolidation with pressure at wet side of OMC

CONCLUSIONS

A reddish brown lateritic soil was treated with up to 16% glass cullet. Treated specimens were compacted using British Standard Light compactive effort at different moulding water content (2% dry of optimum, optimum moisture content and 2% wet of optimum) and subjected to one dimensional consolidation test; to assess their consolidation characteristics. The test conducted include Atterberg limits, Compaction characteristics and One dimensional consolidation properties [13].

The following conclusions can be drawn from the results obtained.

ATTERBERG LIMITS

a. The liquid limit values were found to decrease from 44.1% to 34.4% for up to 16% glass cullet treatment. It shows that the liquid limit of the soil decreased as GC content increased.
b. The plastic limit values decreased from 23.3% to 15.9% for up to 16% glass cullet treatment. It shows that plastic limit of the soil decreased as GC content increased.
c. The plasticity index values decreased from 20.8% to 10.9% for up to 16% glass cullet treatment. The significance of these is that addition of glass cullet can reduce plasticity of laterite soil.

COMPACTION CHARACTERISTICS

a. The Optimum Moisture Content values decreased from 26.8% to 19.9% for up to 16% glass cullet treatment. It shows that the OMC of the soil decreased with increase in GC content.

b. The Maximum Dry Density values increased from 1.57Mg/m^3 to 1.63Mg/m^3 for up to 16% glass cullet treatment. It implies that the MDD of the soil increased with increase in GC content.

CONSOLIDATION PARAMETERS

COMPRESSION INDEX

a. The compression index generally decrease steadily with higher GC content for up to16% treatment irrespective of the moulding water content. The compression index also increased with higher moulding water content.
b. Swelling indexThe swelling index generally decreases with higher GC contents for up to 16% treatment irrespective of the moulding water content. Decrease in swelling index is best achieved at the dry side of optimum.
c. Gross yield stressThe gross yield stress generally increased for up to 12% GC treatment irrespective of the moulding water content. Higher values of σ_y are recorded at 12% GC treatment[12].

COEFFICIENT OF VOLUME COMPRESSIBILITY

a. The coefficient of volume compressibility increases with increasing GC content for up to 16% treatment on specimens prepared at 2% dry, optimum moisture content and 2% wet of optimum. The variation of coefficient of volume compressibility (M_v) with pressure shows that M_v increases with increase in pressure from 10 to 400kN/m^2.

COEFFICIENT OF CONSOLIDATION

The coefficient of consolidation is observed to decrease from 0% GC to 16% GC. Lower values of C_v are recorded at 8% GC treatment. This implies that, the magnitude of settlement is reduced at 8% glass cullet.

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