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Structural Degradation of Masonry Buildings in Bambili Due to Rising Damp (Humidity)

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Abstract

In order to investigate the effects of humidity on structures in Bambili, a total of 216 concrete specimens measuring 220mm x 110mm x 65mm each were produced for the compressive strength test using three cement dosages of 300Kg/m^3,350Kg/m^3, and 400Kg/m^3 for Cimaf cement concrete(CICC), Conch cement concrete(COCC), and Dangote cement concrete(DCC) for both buried and unburied samples. After each day's moulding, the test specimens were de-moulded after 24 hours and cured in a water tank by immersion for 28days. A total of 18 different sets of samples were then buried beneath the earth in Bambili at a humidity-conditioned environment of 48.25% moisture content. After removing test specimens from the curing tank on each day, they were allowed to dry off for 30 minutes in the laboratory environment. Crushing then followed for 28days, 56days, 84days, and 112days ,respectively for each cement type. The concretes dosed at 300Kg/m^3 suffered the greatest strength loss considering buried and unburied samples, followed by concretes dosed at 350Kg/m^3 and 400Kg/m^3, irrespective of the concrete age and concrete brand Thus, the greater the cement dosage, the lesser the strength loss , and the lower the cement dosage, the greater the strength loss .The results of this study reveal that for all three brands of concrete, the compressive strength loss increases with increase in concrete age. Dangote cement concrete outperforms the other concrete types. It was also deduced that compressive strength values for CICC, COCC and DCC stood in the ranges 19.98 MPa – 24.73MPa, 20MPa−24.33MPa and 21.29MPa−25.65MPa, respectively. Other tests such as the tensile strength, soil porosity, and bearing capacity tests were conducted in relation to humidity on structures.

Keywords*: Humidity, Compressive strength, Moisture content, Tensile strength, Soil porosity, Bearing capacity*

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I. Introduction

Buildings have an expected lifespan of 60 to over 100 years, during which they offer shelter from the weather to human beings, animals and properties. Weather and its variations cause degradation of building materials and structures [7,8,9].When designing a sustainable building, it is important to take into

consideration the location, natural shading, shelter (from storms, etc.) and structural materials[1]. This is because certain parameters such as ambient air temperature and humidity, solar radiation, wind, precipitation and ground water cause different processes of deterioration in buildings[18,19,20]. Serious

environmental problems can also arise where existing buildings have other design problems. A common problem that can result from such conditions is moisture problems[2]. Typical of these moisture problems is rising dampness, a type of dampness which occurs where ground water is conducted up through a masonry wall or a concrete floor slab. Dampness in buildings is one of the most widespread problems associated with both historic and modern types of buildings. Moisture in general causes damage to the exterior and interior walls of buildings, high heating energy consumption and uncomfortable indoor environment for occupants[15,16,17]. The building envelope restoration suffering from moisture problems is one of the critical issues in sustainable refurbishment of buildings[4]. The transfer of moisture in buildings is a very complex issue and has been a topical issue for decades. Moisture in buildings can cause deterioration of buildings by damaging brick/block work, cause decay and breaking up of mortar joints, fungal attack in timber and corrosion in iron and steel as well as stained wall surfaces internally and externally[10,13,14]. Damp surfaces encourage the formation of mould, and the spread of mould and mites in conditions of high relative humidity is associated with ill health. Damp conditions also typically affect the mental health of dwelling occupants, causing depression and anxiety, particularly where there is damage to decoration from mould or damp staining[3]. As the most frequently reported cause of building deterioration, dampness in all its forms has assumed an alarming proportion and countries like the United Kingdom, United States of America, Australia, Denmark, Canada, Japan, Estonia, Iceland, Norway, Sweden, Taiwan, etc. have recorded the enormity of the problem[11,12] .

II. Materials And Methods

2.1 Materials

The materials used for experimentation in this study for fabrication of samples were water, sand, cement, and gravel. The water that was used came from CAMWATER Cameroon and from BAMBUI WATER AUTHORITHY and were all of drinkable quality and therefore ideal for concrete production. Three types of imported cements were used in this study, notably, Dangote, Conch, and Cimaf cements and sold in bags of 50Kg (see fig.1). The hydraulic binders were purchased from a local vendor around Amour Mezam Bus Station at Mile 3, Nkwen Bamenda. Some of the sand and gravel that was used was obtained from aggregate piles in Bambili and then transported to the point of usage in G.T.H.S. Bamenda, and Bambuiy Geotechnical Laboratory in Bamenda (see fig.2). From these piles (aggregate population), samples were obtained for experimental investigations. The sand had some debris, and so it was sieved manually through a 5mm sieve before further usage. The gravel used was clean as it had been exposed to rain in the open air for long.

Fig.1: View of cement samples


Fig.2: Pile of gravel used for research

2.2 Methods

The Quartering Method was used for extraction of the aggregate samples. The quartering method consists of first taking a reasonable amount of a sample from the population. The sample is then divided into four nearly equal parts. Opposite quarters are then mingled to form two parts. The two parts are mixed and quartered again. This operation may continue several times until the aggregate particles are properly mixed. It should be recalled that the quartering operation is performed in order for the aggregates to be properly mixed so as to obtain representative samples.

A total of 216 concrete specimens measuring 220mm x 110mm x 65mm each were produced for the compressive strength test. The preparation of these specimens commenced with the fabrication of wooden moulds which can be used to mould 18 concrete cubes per day per cement type. Moulding was carried out within a period of 4days. A local carpenter operating around the entrance to the Market at Bambui Four Corners was paid to produce the moulds. However, some moulds were fabricated by the researcher using wood in the G.T.H.S. workshop in Bamenda.

Concrete specimens for all Basalt ravel concrete were fabricated with a constant water/cement ratio of 0.5. Three cement dosages of 300Kg/m^3, 350Kg/m^3 and 400Kg/m^3 were used in the study. For the production of concrete with all three cement types, and considering 300Kg/m^3, 350Kg/m^3 and 400Kg/m^3 cement dosage, the slump values were 6.1cm, 5.6cm and 5.3cm, respectively. As stated before, a total of 18 samples for each type of cement per day were moulded within a time frame of 4 days. After each day's moulding, the test specimens were de-moulded after 24 hours and cured in a water tank by immersion for 28days. Thus 18 different sets of samples were buried beneath the earth in Bambui at a humidity-conditioned environment of 48.25% moisture content .

Samples for water absorption test were immersed in a water tank for various durations before being tested.

The type of data collected in this study is primary in nature. The data was collected from the civil engineering laboratory of GTHS Bamenda through experimentation and observation. Data concerning the sand equivalent test, slump test, sieve analysis test, and compressive strength results were all obtained from the laboratory with the aid of various geotechnical and structural engineering equipment such as the compressive strength machine, the grain size sieves, graduated cylinders, and the slump cone. As the tests were being performed, recording was done in a special recording booklet.

Data collected during the sand equivalent test is analysed in accordance with BS 933-Part 8. According to appendix 1, the formulae to be used for the calculations are:

S.E.= S.E.=$\frac{h_2}{h_1} \times 100$ and V.S.E.=$\frac{h'_2}{h_1} \times 100$; Where, h_1 is the height of suspension, $h_2 = height\ of\ sand\ from\ piston$ and h'_2 is the visual height of sand. If S.E. $\geq 80\%$ then the quality of sand is good for concrete works. If S.E.<70% then the sand must be washed again to eliminate the fine particles. If 70$\leq S.E. < 80$ then the sand should be used with Portland cement only.

The compressive and tensile strength results shall be analysed using BS 8110 (1997)[5,6]. This process shall be carried out considering dosages of 300Kg/m^3, 350Kg/$m^3 and$ 400Kg/m^3, and for all cement types (CIMAF, Dangote, and Conch). After removing test specimens from the curing tank on each day, they were allowed to dry off for 30 minutes in the laboratory environment. Crushing then followed for 28days,

56days, 84days, and 112days, respectively for each cement type. Force values at failure were observed and recorded and the compressive stress values calculated using the following formula.

Compressive strength $= \frac{Force\ at\ failure}{Cross-sectional\ \ area\ of\ specimen}$

III. Results and Discussions

3.2 Sand equivalent test

The aim of the test is to determine the degree of cleanliness of sand. It was performed in accordance with BS 933-Part 8[5,6]. The sand equivalence was 78.26%. Thus, it can be deduced that the sand was clean and could be used with Ordinary Portland Cement. That explains why Ordinary Portland Cement was utilised in this research work.

3.3 Grain size analyses of aggregates

The granulometric analysis has as aim to determine the relative sizes of aggregates to be used for a particular job. Thus, it characterises the material by determining the sizes of the grains and proportion in percentage of grains for each particle size.

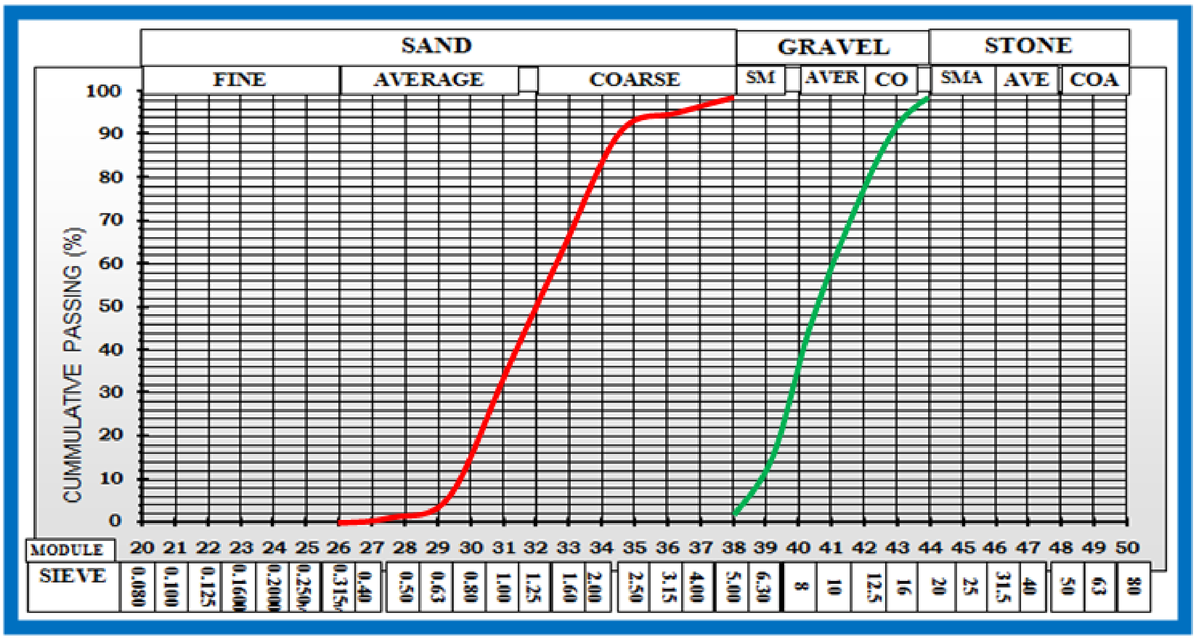

Fig.3: Grain size analyses curves of aggregate

The grain size analysis was performed in accordance with BS 933-Part 1[5,6]. The aggregate samples were placed successively in different columns of sieves and agitated for 5minutes. Thereafter, the samples were weighed. Percentage passing and retained were then computed and the results recorded. The results of the dry sieve analysis displayed in fig.3 revealed that sand and gravel have coefficients of uniformity of 7.03 and 4.16, respectively. Thus sand and gravel were well- graded according to (Vandevelde, 2008) and the Unified Soil Classification System (Holtz and Kovacs, 1981). These showed that the aggregates were suitable for making concrete, unlike a gap-graded or poorly graded aggregate having coefficient of uniformity less than 1.00.

3.4 Slump test

The aim of the slump test is to determine the workability of concrete. It was performed in accordance with BS 933-Part 8[5,6].

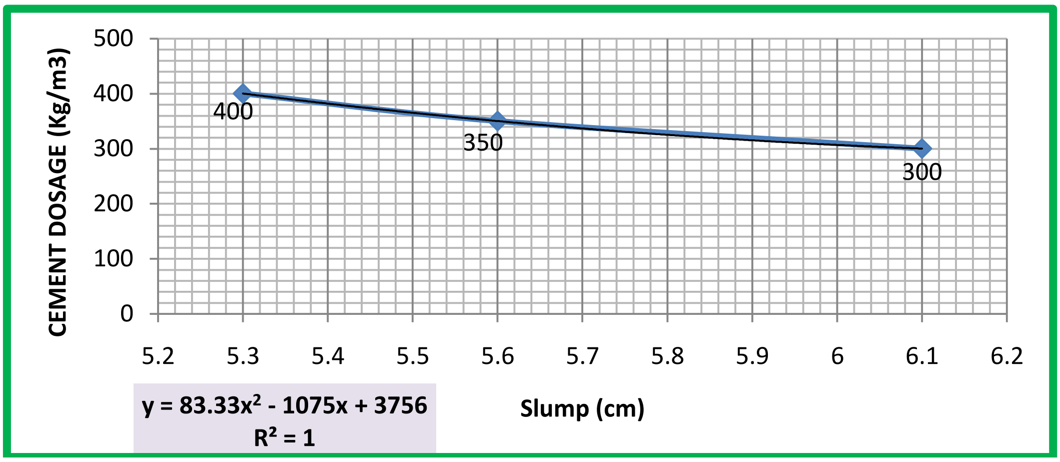

Fig.4:Interpolation graph of slump versus Cement dosage

The results of the slump test indicating the workability of concrete are indicated in fig. 4. For concrete dosed at 300Kg/m^3, 350Kg/m^3 and 400Kg/m^3 the slump values were 6.1cm, 5.6cm, and 5.3cm respectively. When a slump ranges from 3cm to 5cm, it means that the concrete is stiff and should be given a good vibration. When the slump is from 6cm to 9cm, it means that the concrete is plastic and should be given normal vibration. A slump ranging from 10cm to 13cm implies that the concrete is watery or soft and the vibration mode is pricking.

3.5 Experimental investigation of humidity response of sandcrete block wall

The reseacher construted an experimental wall with sandcrete blocks in order to determine the humidity response of the wall in relation to the compressive strength of the blocks, mix proportion, and soil porosity.

3.5.1 Water absorption test on blocks

The water absorption test has as aim to determine the water absorption of the blocks that were used for the experimental wall construction and the corresponding moisture rise due to capillarity. The mix proportioning was done using prescribed wheelbarrow mix proportions. A 50Kg bag of Dangote cement was mix with 65 litres struck capacity wheelbarrows in various proportions as shown on the table below.

Table 1: Table showing water absorption capacity

Mix proportion	Initial Mass of block(Kg)	Wet mass of block(Kg) after 24 hours	Water absorption capacity (%)	Humidity height (cm)	Compressive strength(MPa)
1:2	16.60	16.90	**1.81**	**32.6**	**3.2**
1:3	16.72	17.32	**3.58**	**40.8**	**2.4**
1:4	16.81	17.64	**4.94**	**50.3**	**1.4**

It can be observed from table 1 that the greater the sand proportion used in block fabrication, the greater the height of humidity rise on the wall. This phenomenon can be attributed to the fact that blockwall porosity and permeability increase with sand content since a lesser amount of cement is available to fill in the voids(pores) created by sand. So moisture easily trickle through the gaps of sand via capillarity effect.

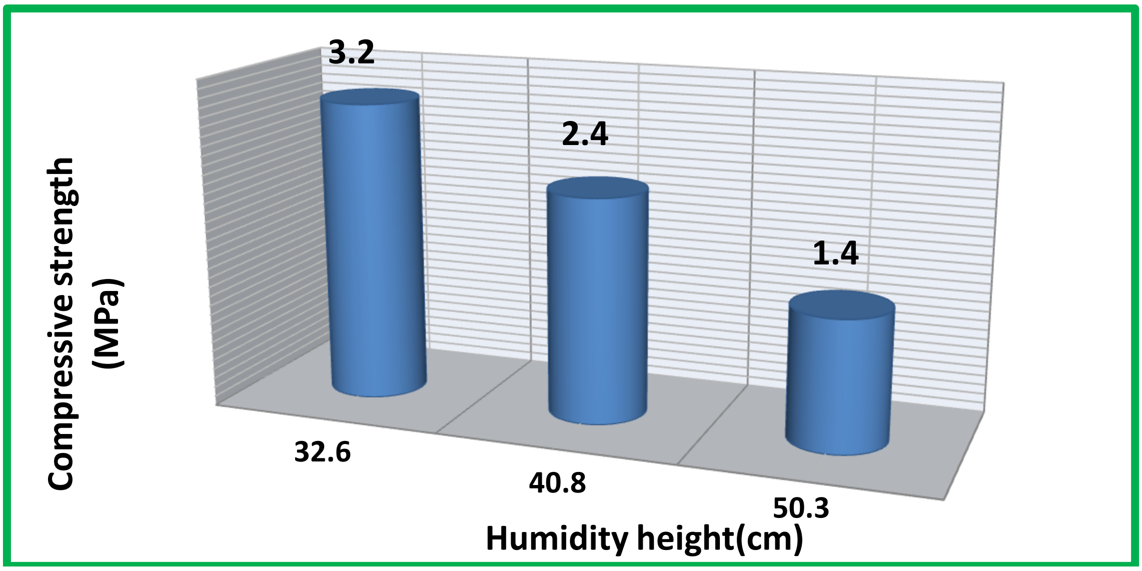

Fig.5: Graph showing the relationship between the compressive strength of blocks(MPa) and humidity height(cm)

Fig.5 shows the relationship between the compressive strength of blocks(MPa) and the humidity height (cm). It can be observed that the strength of blocks reduces with increase in humidity height. In order words, the height of damp increases when the compressive strength of blocks reduces. This can be ascribed to the fact that the lesser the compressive strength, the greater the cement content which is the chief binding ingredient responsible for mortar strength.

Table 2: Table porosity and humidity variation with soil type

Type of soil	Porosity (n)	Humidity height(cm)
Dense gravel	0.52	32.6
Sand gravel	0.45	40.8
Sandy loam	0.35	50.3

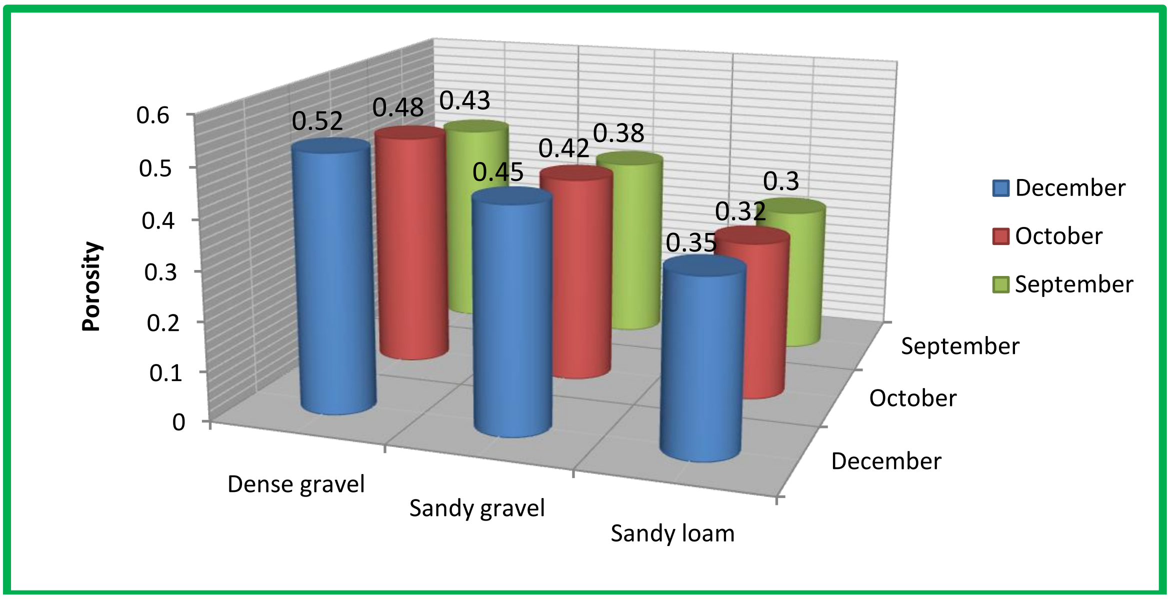

Fig.6: 3D Column graph showing soil porosity variation with respect to soil type and three months of the year

Table 2 and fig.6 portray the variation of humidity height(cm) with respect to porosity, soil type and different months of the year. It can be observed that the density and compacity has a dramatic influence on the porosity and humidity height on walls. Dense gravel witnesses the greatest porosity followed by sandy gravel and sandy loam. It should be noted that the greater the porosity, the greater the humidity height. Since the humidity height increases with an increment in porosity, it is advisable to compact the soil around buildings in order to curb the effect of damp penetration within buildings.

Furthermore, as we progress from the rainy season into the dry season, there is a rise in soil porosity. This phenomenon can be attributed to the fact that towards the dry season, water begin to dry off from soil masses, causing the soil to shrink in volume. Meanwhile, in a rainy month like September, the soil voids still comparatively have some amount of water, causing the soil to swell or expand. From the formula of porosity ($\frac{V_V}{V}$),it can be shown that as the volume increases, the porosity drops. This explains why during the rainy season there is a decrease in soil porosity.

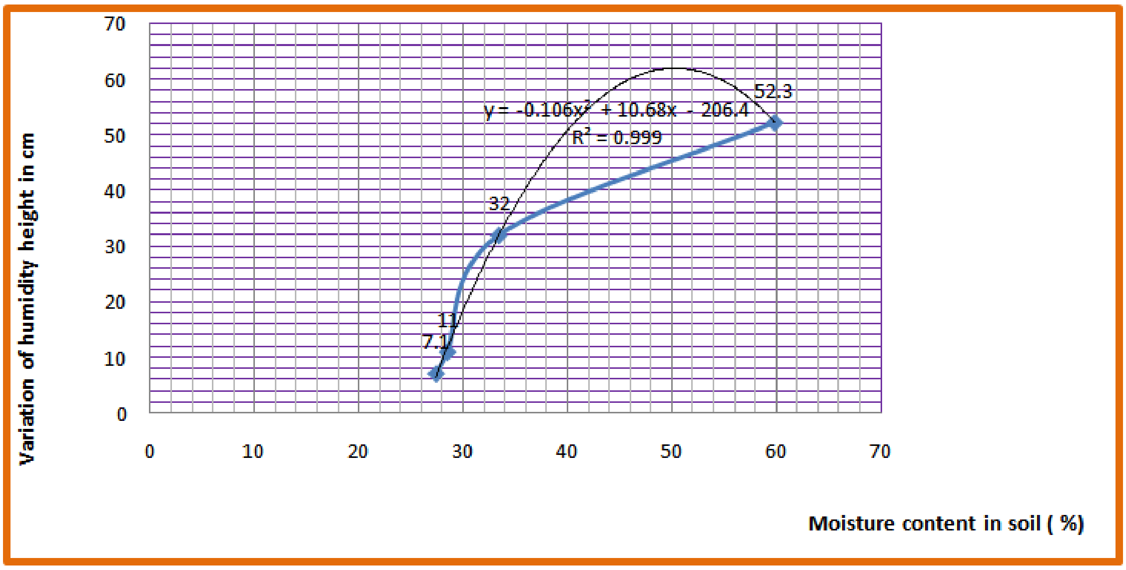

Fig. 7: Graph showing variation of humidity height with moisture content at test point 1

Fig.7 potrays the graph of moisture content versus variation in height of humidity at test point 1 located at the right edge of the back orientation of the building under study(see fig.8). The values were obtained in January, February, March, and April 2016 respectively. Results reveal that at height of rising damp of 7.1cm, 11cm, 32cm and 52.3cm, the moisture content values were 27.4%, 28.5%, 33.4%, and 59.8% ,respectively.

It can therefore be clearly seen that the greater the moisture content in the soil, the greater the height of rising damp. Moreover, the month of April witnessed the highest percentage of moisture content; this can be attributed to the fact that April also has greater rainfall.

Fig. 8: Researcher and assistant measuring humidity height at back orientation

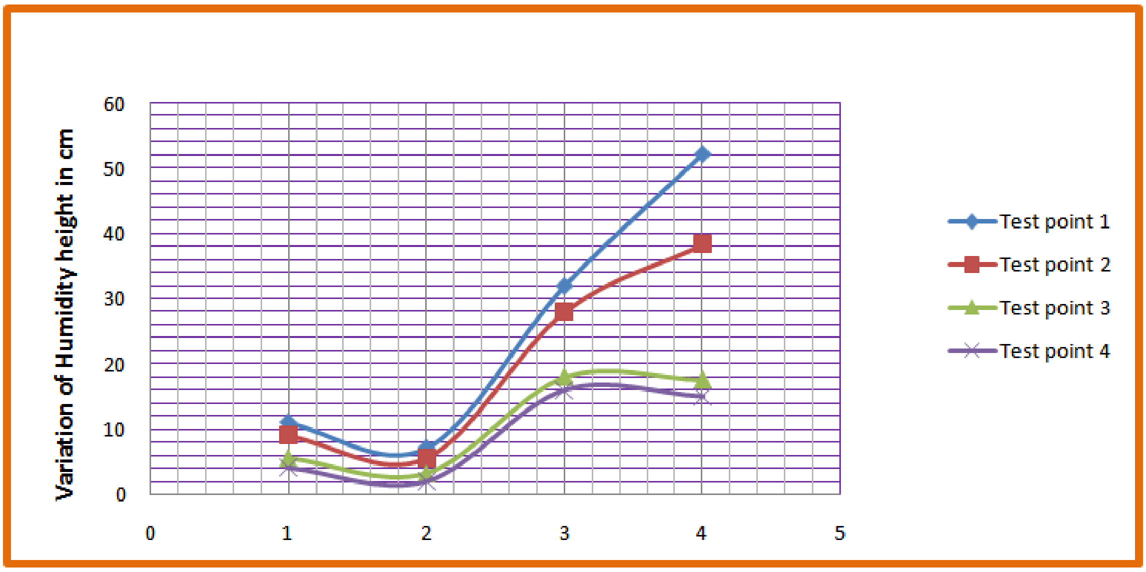

Fig. 9: Variation of humidity height with respect to some months of year

Fig.9 above indicates the variation of height of rising damp with respect to the months of January, February, March, and April at various test locations at the back orientation of the building under study. Results reveal that the month of April witnessed the highest humidity rise, while the month of February saw the lowest height of rising damp. This can be due to the fact that in February which is at the peak of the dry season, the soil mass experiences severe dessication, while in April which is already in the raining season, the water table witnesses a rise.

3.5 Compressive strength test

The aim of the test is to determine the various compressive strengths of concrete. The test was performed in accordance with BS 1881-Part 166(1983)[5,6].

Fig. 10: Researcher with assistant crushing test specimens at Digital compression test machine at Bambuiy Geotechnical Laboratory

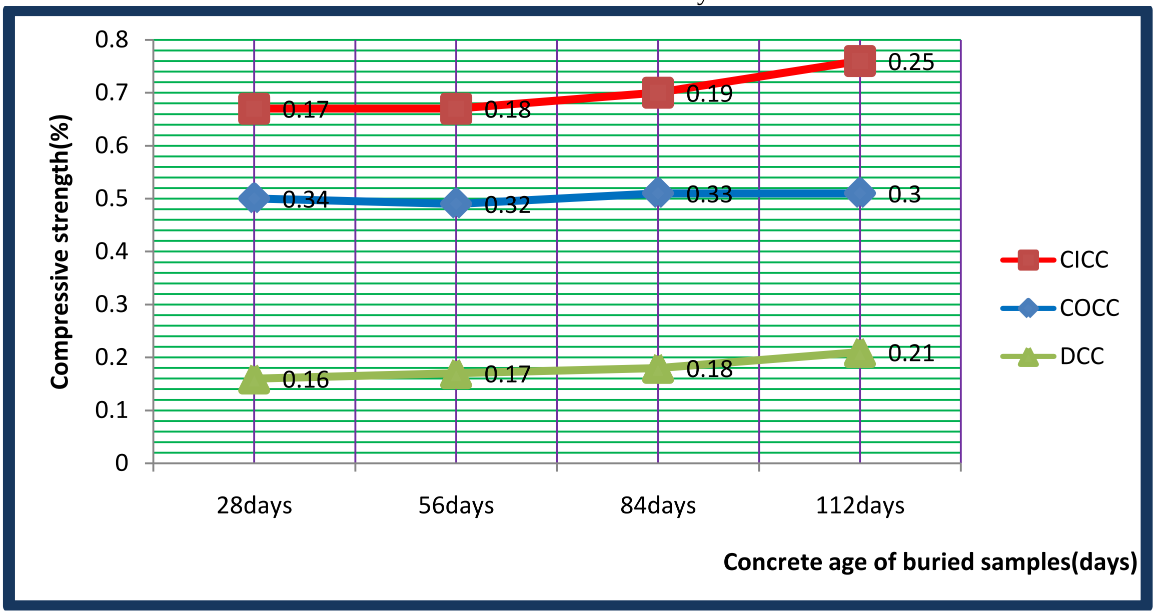

Fig.11: Comparative variation of compressive strength losses(%) of CICC, COCC and DCC at highest dosage (400Kg/m^3) and considering buried and unburied samples.

Figure 11 depicts the comparative compressive strength losses of CIMAF cement concrete, CONCH cement concrete, and Dangote cement concrete with variation in cement dosage, and concrete age of buried samples, considering a fixed water/cement ratio of 0.5 and a prescribed mix proportion of 1:2:4.

At 28days, the compressive strengths of CICC, DCC, and COCC are 0.17%, 0.16%, and 0.34%, respectively. At 56days crushing, the compressive strength losses of CICC, DCC, and COCC are 0.18%, 0.17%, and 0.32%, respectively. At 84days crushing, the compressive strengths of CICC, DCC, and COCC are 0.19%, 0.18%, and 0.33%, respectively. And at 112days, the compressive strength losses are 0.25%, 0.21%, and 0.3, respectively.

The general trend reveals that the compressive strength losses for the concrete increase with increase in concrete age and decrease with increase in dosage. The result further reveals a significant drop in the compressive strength of COCC compared to its CICC and DCC counterparts.

3.6 Tensile strength test on steel rods

This test was conducted on steel rebars in order to help establish the effect of damp on the tensile strength of steel rods.Three test specimens of diameter 10mm high adhesive rods with an initial tensile strength of 400MPa were used. The test samples were immersed in 3 moisture controlled environment having a moisture content of 22.28%, 45.35%,and 54.8%, respectively for a period of 28days,58days, and 112days.

Table 3: Table showing Tensile strength variation with moisture exposure

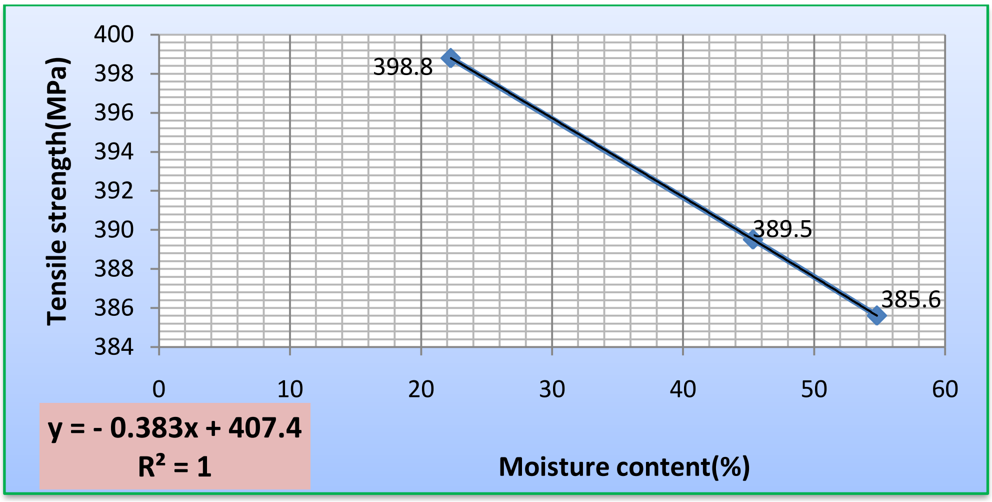

Fig.12: Tensile strength variation of steel rods with respect to moisture content

It can be shown from fig.12 and table 3 that with increase in humidity, the tensile resistance of steel rods drops. The decrease in the tensile strength can be attributed to the weakening of the molecular structure of steel due to the corrosive effect of moisture. When the tensile strength reduces, other mechanical properties of the material will also be affected such as the visco-plasticity, the elasticity, compressive resistance, and the Poisson ratio.

3.7 The Geotechnical effect of bearing Capacity distribution on the rise of humidity

A total of four test points were sampled for the assessment of the relationship between bearing capacity of soil and humidity rise. It was observed that test pit 1 had the greatest bearing capacity value distribution, followed by test pit 4, test pit 2, and test pit 3. It was observed that the greater the bearing capacity, the lesser the height of humidity at different test points around the building under investigation.

IV. Conclusion

It was also deduced that the concretes dosed at 300Kg/m^3 suffered the greatest strength loss with respect to concrete age of buried samples, followed by concretes dosed at 350Kg/m^3 and 400Kg/m^3, irrespective of the concrete age and concrete brand. Thus, the greater the cement dosage, the lesser the strength loss , and the lower the cement dosage, the greater the strength loss .

Duration	**Initial tensile strength (MPa)**	**Duration of exposure (days)**	**Moisture content of exposure environment(%)**	**Tensile strength after exposure to humidity(MPa)**
Sample 1	400	28	22.28	**398.8**
Sample 2	400	58	45.35	**389.5**
Sample 3	400	112	54.8	**385.6**

With increase in concrete age, the compressive strengths of CIMAF cement concrete, CONCH cement concrete, and Dangote cement concrete are different. Thus, at any given concrete age, there is a significant difference in the compressive strength of CICC, COCC, and DCC. The results of this study reveal that for all three brands of concrete, the compressive strength loss increases with increase in concrete age. This is in accordance with similar results from other researchers though working on different cement concrete combinations.

It was noticed that with increase in humidity, the tensile resistance of steel rods drops. The decrease in the tensile strength can be attributed to the weakening of the molecular structure of steel due to the corrosive effect of moisture. When the tensile strength reduces, other mechanical properties of the material will also be affected such as the visco-plasticity, the elasticity, compressive resistance, and the Poisson ratio.

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