

**DRY AND WET PROPERTIES OF RICE HUSK CONCRETE VARYING WATER TO
CEMENT RATIO AND COMPACTION PRESSURE**

BY

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CERTIFICATION

This is to certify that the project topic titled “Dry and Wet Properties of Rice Husk Concrete. Varying Water to Cement Ratio and Compaction Pressure/Effect” was done by Okonkwo Andrew Nwabueze with registration number (NAU/2017224037) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka. Anambra State.

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APPROVAL PAGE

This research work “Dry and Wet Properties of Rice Husk Concrete. Varying Water to Cement Ratio and Compaction Pressure/Effect” has been assessed and approved by department of Civil Engineering Nnamdi Azikiwe University, Awka.

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DEDICATION

This work is dedicated to God Almighty. Also dedicated to my Parents and Siblings

ACKNOWLEDGEMENT

Special thanks goes to God Almighty for giving me the strength to complete this work and also for His guidance and protection throughout my stay in Nnamdi Azikiwe University.

Also, I will like to express my profound gratitude to my parents; Mr and Mrs Okonkwo for their moral support, constant prayers throughout my stay in school, special thanks goes to my Siblings for their encouragement during trying times of my academic pursuit.

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ABSTRACT

The study was undertaken to evaluate the wet and dry properties of rice husk concrete with varying water to cement ratio and compaction pressure. The pressure required to crush the concrete was determined and varied at intervals ranging from 15kN, 75kN, 150kN, 225kN and 300kN with water to cement ratio ranging from 0.4, 0.45, 0.5, 0.55, 0.6 and 0.65. Sand was used to partially replace rice husk in an increasing order of 7.5%, 15% and 22.5% by weight of sand. The rice husks concrete were subjected to testing. Test conducted on the aggregates was sieve analysis test and specific gravity test while test conducted on the rice husk concrete was water absorption test and compressive strength test. Results obtained from sieve analysis test suggest that sand and granite was classified as A-2-4 and A-1-b according to AASHTO Soil Classification System, SM and SC according to USCS Soil Classification System. Water absorption test results conducted on the rice husk concrete cubes revealed that the water absorption of the concrete increased with addition of rice husk but decreased with increase in compaction pressure, results obtained from compressive strength test of the hardened rice husk concrete cubes revealed that the hardened density and compressive strength decreased with increase in rice husk but increased with increase in compaction pressure. Assessment of the effect of water to cement ratio on the hardened density and compressive strength of the concrete revealed that the hardened density and compressive strength increased from 0.4 water to cement ration to 0.55 water to cement ratio beyond water to cement ratio of 0.55, the hardened density and compressive strength of the concrete decreased. The study recommended the use of 7.5% rice husk as effective quantity for production of light weight concrete.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Concrete is a versatile engineering material comprising of fine aggregate (natural river sand), coarse aggregate (granite), water and cement in their correct proportion (Apebo et al., 2013). Admixtures are also added in other to improve certain properties of both the fresh and hardened concrete for desirable performance (Shetty, 2015). The costs of concrete production have risen significantly due to increasing cost of fine aggregate. The importance of fine aggregate in concrete production cannot be overemphasized. As a result of its relative importance in concrete production, demand for fine aggregate even among construction industry is relatively high. Also Nigeria is currently experiencing negative environmental impacts caused by excessive excavation and mining of natural river sand. Among these are erosion and failure of river banks, lowering of river beds and damage of structures situated closer to the rivers, saline water intrusion into the land and coastal erosion are the major adverse effects due to intensive river sand mining (Subramanian and Kannan, 2013). The rising cost of concrete and negative environmental resulting from excessive mining and excavation of natural river sand have necessitated research into the use of environmentally friendly alternative for partial replacement of fine aggregate in concrete production.

Rice husk, also called rice hull, is the coating on a seed or grain of rice. It is a major agricultural by-product produced during the de-husking process of paddy rice. It is formed from hard materials, including silica and lignin, to protect the seed during the growing season. During rice milling, about 78% of weight is received as rice, broken rice and bran, and the rest 22% of weight of paddy is received as husk (Rao et al., 2014). Agricultural by-product have advantages over conventional materials in low cost construction (Abdullah, 2014). The use of this waste materials in construction contribute to conservation of natural resources and the protection of the environment. (Ramezaniapour, et al., 2015).

The mechanical properties of concrete in both wet and dry state are greatly influenced by compaction pressure and water to cement ratio (Marar and Eren, 2017). The compressive strength of hardened concrete and workability of the fresh concrete depends mainly on water to cement ratio and degree of compaction (Tuncan, et al., 2007; Marar and Eren, 2017).

Compressive strength and workability are significant criteria for concrete mix design and important properties affecting the placement and later performance of the hardened state of concrete (Marar and Eren, 2017). The water to cement ratio in concrete is the ratio of mass of water to the mass of cement used in the concrete mix (Oyenuga, 2011). The ratio of water to cement significantly influences the properties of concrete in both wet and dry state (Oyenuga, 2011). Small water to cement ratio will produce concrete with considerable strength but minimum workability (Oyenuga, 2011). However extremely small ratio of water to cement could result to poor chemical action of the cement thereby leading to incomplete hydration (Oyenuga, 2011). Extremely high water to cement ratio could result to separation of the coarse aggregate from the finer materials during placement (Harrison, 2014). Good quality control on water to cement ratio is rarely observed in field construction and as a results study of the effect of varying water to cement ratio on wet and dry properties of concrete becomes a priority.

When concrete is fully compacted, the strength is inversely proportional to the water to cement ratio of the mixture. However in practice, concrete may contain some voids due to improper compaction pressure and presence of such imperfections in concrete significantly reduces its strength. There are different compaction pressure adopted in compaction of concrete such as manual compaction (rodding, ramming and tamping), mechanical compaction (use of vibrators), compaction by pressure and jolting and compaction by spinning method (Tuncan, et al., 2007). These different compaction pressures significantly influences the mechanical properties of concrete and the discrepancy in mechanical properties is a major problem in concrete technology and construction practices.

In other to reduce concrete production cost and negative environmental impacts resulting from excessive mining and excavation of natural river sand, proffer solution to deficiencies in mechanical properties of concrete in both wet and dry state, this study will therefore investigate the effect of variation of water to cement ratio and compaction pressure of wet and dry properties of rice husk concrete.

1.2 Statement of Problem

Increasing cost of concrete as a result of high cost of fine aggregate (natural river sand) coupled with the negative environmental impact of excessive mining and excavation of river sand have necessitated research into the use of environmentally friendly alternative for partial replacement of fine aggregate in concrete production. The properties of concrete in both wet and dry state

depend largely on compaction pressure and water to cement ratio (Marar and Eren, 2017). Poor quality control in mix design and compaction pressure have been largely responsible for deficiencies in the performance of concrete in both wet (fresh) and dry (hardened) state influenced by compaction pressure and water to cement ratio (Marar and Eren, 2017). The ratio of water to cement significantly influences the properties of concrete in both wet and dry state (Oyenuga, 2011). Small water to cement ratio will produce concrete with considerable strength but minimum workability (Oyenuga, 2011). However extremely small ratio of water to cement could result to poor chemical action of the cement thereby leading to incomplete hydration (Oyenuga, 2011). Extremely high water to cement ratio could result to separation of the coarse aggregate from the finer materials during placement (Harrison, 2014).

Therefore, it is extremely important to ascertain the water to cement ratio and compaction pressure required to produce the desired properties of the concrete in both wet and dry state.

In other to proffer solution to the aforementioned problem, this study will therefore investigate the effect of variation of water to cement ratio and compaction pressure of wet and dry properties of concrete produced with partial replacement of fine aggregate with rice husk.

1.3 Aim and Objectives of Study

The aim of the study is to evaluate the effect of varying water to cement ratio and compaction pressure on wet and dry properties of rice husk concrete while the objectives are:

- 1 Ascertain the efficacy of using rice husk as an alternative material for concrete production.
- 2 Characterize the aggregates used for the concrete production.
- 3 Produce concrete of different water to cement ratio and under different compaction pressure using factorial design.
- 4 Study the effect of varying water to cement ratio on properties of rice husk concrete in both wet and dry state.
- 5 Test the finished concrete for workability, dry and wet density and compressive strength.
- 6 Make comparative analysis on the effect of varying water to cement ratio and compaction pressure on wet and dry properties of concrete produced with conventional materials and non conventional material (rice husk concrete) and also for the significance of water to cement ratio and compaction pressure on the finished concrete.

1.4 Scope of Study

The study is centered at investigating the effect of varying water to cement ratio and compaction pressure on wet and dry properties of rice husk concrete. Concrete cubes with different quantity of rice husk ranging from 7.5%, 15% and 22.5% by weight of sand will be produced. The pressure at which the hardened rice husk concrete cubes is crushed will be ascertained and varied at intervals. Varying water to cement ratio ranging from 0.4, 0.45, 0.5, 0.55, 0.6 and 0.65 will be added to the rice concrete mix. The rice husk concrete will be subjected to various experimental test such as sieve analysis test specific gravity test, water absorption and compressive strength test. Chart depicting the wet and dry properties of the rice husk concrete will be plotted against percentages of rice husk so as to determine the appropriate quantity of rice husk to be used for concrete production.

1.5 Significance of Study

Key findings obtained from the study on effect of compaction pressure and varying water to cement ratio on fresh and dry properties of rice husk concrete will be valuable in reducing the cost of concrete production. The reduction in overall concrete cost will be achieved through the optimum replacement of fine aggregate with rice husk. Apart from reduction in concrete production cost, optimum replacement of sand with rice husk will result to the production of light weight concrete. Light weight concrete are beneficial in reduction of dead loads making considerable savings in foundation and usage of reinforcement, improved thermal properties and fire resistance of the concrete, reduction in formwork and propping and considerable savings in transportation and concrete handling (Uchech, et al., 2017).

From environmental standpoint, reduction in the volume of rice husk generated annually through its incorporation into concrete production will not only ensure rational use of earth resources in concrete production but will protect the environment particularly the rural communities where rice husk are generated in appreciable quantity. This study will therefore seek to actualize the above stated significance.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview

Concrete is the most versatile heterogeneous construction material and the most valuable construction material for infrastructural development of any nation. Civil engineering practice and construction works around the world depend to a very large extent on concrete. Concrete is a synthetic construction material made by mixing cement, fine aggregates, coarse aggregates and water in the proper proportions. Aggregates serve as inert filler materials while at the same time improving concrete workability, volume stability and durability. Concrete may be defined as a composite material consisting of a binding material, water, fine and coarse aggregates, and in some instances, the incorporation of admixtures all in definite proportions to achieve a desired property. The binding material in most instances is the Ordinary Portland Cement (OPC) although other binding materials are also in used. Concrete is an artificial material comparable in appearance and properties to some natural lime stone rock. It is a man-made composite, the major constituent being natural aggregate such as gravel, or crushed rock, sand and fine particles of cement powder all mixed with water. The concrete as time goes on through a process of hydration of the cement paste, producing a required strength to endure the load (Maninder and Manpreet, 2012).

2.2 Concrete Production Process

2.2.1 Batching

The correct measurement of the various materials used in the concrete mix is called batching. Errors in batching are partly responsible for the variation in the quality of concrete. Concrete can be batched in two ways:

- a) By volume batching and
- b) By mass (weight) batching

Weigh-batching of materials is always preferred than volume batching. When weigh-batching is not possible and the aggregates are batched by volume, such volume measures to be regularly checked for the weight-volume ratio.

2.2.2 Mixing

This is the practical means of producing fresh concrete and placing it in the form so that it can harden into the structural or building material referred to as concrete'. The sequence of operation is that the correct quantities of cement, aggregates and water, possibly also admixture are batched and mixed in a concrete mixer which produces fresh concrete. This is transported from the mixer to its final location. The fresh concrete is then placed in the forms, and compacted so as to achieve a dense mass which is allowed and helped, to harden. The objective of mixing of concrete is to coat the surface of all aggregate particles with cement paste and to blend all ingredients of concrete into a uniform mass. Mixing of concrete is done either by hand or by machine. Mixers performances shall be checked for conformity to the requirements of the relevant standards. Concrete shall be mixed for the required time; both under-mixing and over-mixing shall be avoided.

2.2.3 Transportation

After mixing, concrete shall be transported and placed at site as quickly as possible without segregation, drying, etc. as soon as concrete is discharged from the mixer, internal as well as external forces starts acting to separate the dissimilar constituents. If over-weight concrete is confined in restricting forms, the coarser and heavier particles tend to settle and finer and lighter materials tend to rise. If concrete is to be transported for some distance over rough ground the runs shall be kept as short as possible since vibrations of this nature can cause segregation of the materials in the mix. For the same reason concrete should not be dropped from a height of more than 1m. If this is unavoidable a chute shall be used. The green concrete shall be handled, transported and placed in such a manner that it does not get segregated. The time interval between mixing and placing the concrete shall be reduced to the minimum possible.

2.2.4 Placing

The formwork and position of reinforcement shall be checked before placing concrete to make sure that they are clean and free of any detritus, such as ends of tying wire. The fresh concrete shall be deposited as close as possible to its ultimate position. Care need to be taken when discharging concrete from skips to avoid dislodging the reinforcement or over filling the formwork. When filling columns and walls, care shall be taken that the concrete does not strike

the face of the formwork, which might affect the surface finish of the hardened concrete. For deep sections the concrete shall be placed in uniform layers, typically not more than about 500 mm thick, each layer being fully compacted.

2.2.5 Compaction

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In the process of placing and mixing of concrete, air is likely to get entrapped in the concrete. If this air is not detrained out fully, the concrete loses strength considerably. Anticipated targets of strength, impermeability and durability of concrete can be achieved only by thorough and adequate compaction. One per cent of the air voids left in concrete due to incomplete compaction can lower the compressive strength by nearly five percent (Gambhir, 2004).

2.2.6 Curing

Curing of concrete is the process of maintaining satisfactory moisture content and a favorable temperature in concrete during the period immediately after the placement of concrete so that hydration of cement may continue till the desired properties are developed sufficiently to meet the requirements of service. The reasons for curing concrete are to keep the concrete saturated or as nearly saturated as possible, until the originally water filled space in the fresh cement paste has been filled to the desired extent by the product of hydration of cement, to prevent the loss of water by evaporation and to maintain the process of hydration, to reduce the shrinkage of concrete and to preserve the properties of concrete. Concrete derives its strength by the hydration of cement particles. The hydration of cement is of momentary action but a process continuing for a long time. The rate of hydration is fast to start with but continues over a long time at a decreasing rate. Curing is usually required for at least 7 days after the day the concrete is placed, this may vary in certain special circumstances (Onwuka and Omerekpe, 2003). Adequate curing is essential for the handling and development of strength of concrete. The curing period depends upon the shape and size of member, ambient temperature and humidity conditions, type of cement, and the mix proportions. Nevertheless, the first week or ten days are the most critical, as any drying out during this young age can cause irreparable loss in the quality of concrete. Generally, the long-term compressive strength of concrete moist cured for only 3 days or 7 days

will be about 60 per cent and 80 per cent, respectively, of the one moist cured for 28 days or more (Gambhir, 2004).

2.2.7 Formwork

Formwork is a structure, usually temporary, used to contain poured concrete and to mould it to the required dimensions and support until it is able to support itself. It consists primarily of the face contact material and the bearers that directly support the face contact material. Proper removal of formwork is an important factor to achieve good quality of concrete during the service life.

2.2.8 Inspection and Testing

Inspection and testing play a vital role in the overall quality control process. Inspection could be of two types, quality control inspection and acceptance inspection. For repeated operations early inspection is vital, and once the plant has stabilized, occasional checks may be sufficient to ensure continued satisfactory results. The operations which are not of repetitive type would require, on the other hand, more constant scrutiny. Apart from the tests on concrete materials, concrete can be tested both in the fresh and hardened states. The tests on fresh concrete offer some opportunity for necessary corrective actions to be taken before it is finally placed. These include tests on workability, unit weight or air content (if air-entrained concrete is used).

2.3 Components of Concrete

Chudley and Greeno, (2006) assert that the proportions of each of concrete materials control the strength and quality of the resultant concrete. Fresh concrete is a plastic mass, which can be moulded into any desired shape. This is its main advantage as a construction material (Gupta and Gupta, 2004). They further assert that aggregate, coarse and fine combined occupy about 70% space in a given mass of concrete and the rest 30% space is filled by water, cement and air voids. Bert-Okonkwor, (2012) in his definition described concrete as a mixture of Portland cement, fine aggregate coarse aggregate, air and water. Sharma, (2008) concludes in stating that concrete is a heterogeneous mix consisting of the following materials: cement, aggregate (coarse and fine),

water and admixture (when necessary). Below are descriptions of some of these components of concrete.

2.3.1 Cement

Cement is a binder material, a substance made of burned lime and clay which after mixing with water, set and harden independently and can bind other materials together Ezeokonkwo, (2014). According to (Onwuka and Omerekpe, 2003), cement as a hydraulic binders react exothermically with water to form hard strong masses with extremely low solubility. They consist of chemical compounds such as calcium silicate and calcium aluminates. Cement is a cementitious material which has adhesive and cohesive properties necessary to bound inert aggregates into a solid mass of adequate strength and durability. Neville, (1993) also adds that cement is the binding material constituent of concrete which reacts chemically with water and aggregate to form a hardened mass on hydrating. Iheama, (2010) further defines it as a finely pulverized product resulting from calcination of natural argillaceous limestone at a temperature below the fusion. In addition to this Ivor, (1995), defines cement as a mixture of compounds, consisting mainly of silicates and aluminates of calcium, formed out of calcium oxide, silica, aluminium oxide and iron oxide. Hydraulic cements are of four types: Portland cement, Blended Portland Cement, and Portland cement with additives and High Alumina Cement. Cement varying chemical composition and physical characteristics exhibit different properties on hydration. The cement of desired properties can be produced by selecting suitable mixture of raw materials. The various types of Portland cement used in the construction industry are: Ordinary Portland Cement(OPC), Rapid Hardening Portland Cement(RHPC), Sulphate resisting Portland Cement(SRPC), Low Heat Portland Cement(LHPC), Blast Furnace Portland Cement(BFPC), Portland Pozzolana Cement(PPC), Modified Portland Slag Cement(MPC).

Many authors (Ezeokonkwo, 2014: Anosike, 2010: Gupta and Gupta, 2004: Iheama, 2010) agreed to the fact that on the addition of water to cement, hydration takes place, liberating a large quantity of heat. On hydration of cement, the gel is formed which binds the aggregate particles together and provides strength and water tightness to concrete on hardening. Thus cement has the property of setting and hardening underwater by a chemical reaction with it. Portland cement is a substance which binds together the particles of aggregates (usually sand and gravel) to form a mass of high compressive strength concrete. It is a combination of limestone or chalk with clay

mixed in a proportion depending on the type of cement desired. Portland cement is the most common type of cement generally used around the world because it is a basic ingredient of concrete, mortar and stucco. It is a fine powder produced by grinding Portland cement clinker more than 90%, and a limited amount of calcium sulphate which controls the set time. Portland cement clinker is a hydraulic material which consist at least two-thirds by mass of calcium silicates ($3\text{CaO}\cdot\text{SiO}_2$ and $2\text{CaO}\cdot\text{SiO}_2$).

Okereke, (2003), Portland cement is manufactured by firing a controlled mixture of chalk or limestone (CaCO_3) and substances containing silica and alumina such as shale in a kiln at 1500°C temperature. They are heated to clinker and grounded to a fine powder with a small proportion of gypsum (calcium sulphate) which regulates the rate of setting when the cement is mixed with water. Anosike, (2010) also states that the manufacture of PC consists of the following three distinct processes: Mixing, Burning and Grinding. Mixing can be done by dry-process or wet-process. The wet process is the most common. The main difference between the wet and dry production process is the larger amount of water expelled from the kiln during the production process.

2.3.1.1 Chemical Composition of Portland Cement

Anosike, (2010), the ordinary and rapid hardening PC can be tested by the methods given in I.S. 4032. The results of the tests should comply with the following chemical requirements:

- a) The ratio of the percentage of lime to the percentage of silica, alumina and iron oxide when calculated by the following formula:

$$\frac{\text{CaO} - 0.7\text{SO}_3}{\text{SiO}_2 + 1.2\text{AL}_2\text{O}_3 + 0.65 \text{Fe}_2\text{O}_3}$$

It should be between 0.66 and 1.02.

- b) The Ratio of the percentage of alumina to iron oxide should not be less than 0.66.
 c) Weight of insoluble residue should not be more than 2%.
 d) Weight of magnesia should not exceed 6%.
 e) Total sulphur content calculated as sulphuric anhydride (SO_3) should not exceed 2.75 or 3.0%.
 f) Total loss of ignition should not be more than 2%.

According to Shetty, (2005), the raw materials used in the manufacture of Portland cement consist mainly of lime (CaO), silica (SiO₂), alumina (Al₂O₃) and iron oxide (Fe₂O₃). The four compounds are usually regarded as the major constituents of cement. They are described in abbreviated form by cement chemists as follows: CaO = C; SiO₂ = S; Al₂O₃ = A; and Fe₂O₃ = F. Likewise, H₂O in hydrated cement is denoted by H, and SO₃ by S. In addition to the main compounds listed above, there exist minor compounds, such as MgO, TiO₂, Mn₂O₃, K₂O and Na₂O; they usually amount to not more than a few per cent of the mass of cement. Two of the minor compounds are of particular interest: the oxides of sodium and potassium, Na₂O and K₂O, known as the alkalis. They have been found to react with some aggregates, the products of the reaction causing disintegration of the concrete, and have also been observed to affect the rate of the gain of strength of cement (Neville, 2005). The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding.

The oxides present in the raw materials when subjected to high clinkering temperature combine with each other to form complex compounds. The identification of the major compounds is largely based on R.H. Bogue's work and hence it is called Bogue's Compounds. The four compounds usually regarded as major compounds are tricalcium silicate (C₃S), dicalcium silicate (C₂S), tricalcium aluminate (C₃A) and tetracalciumaluminoferrite (C₄AF). Shetty, (2005). The Bogue's formula used in calculating the percentage of the various compounds is given as follow:

$$\begin{aligned}
 C_3S &= 4.07 (CaO) - 7.60 (SiO_2) - 6.72 (Al_2O_3) - 1.43 (Fe_2O_3) - 2.85 (SO_3) \\
 C_2S &= 2.87 (SiO_2) - 0.754 (3CaO \cdot SiO_2) \\
 C_3A &= 2.65 (Al_2O_3) - 1.69 (Fe_2O_3) \\
 C_4AF &= 3.04 (Fe_2O_3)
 \end{aligned}$$

2.3.1.2 Properties of Cement

a) Fineness of Cement

Fineness is a vital property of cement which influences the rate of reaction of cement with water (hydration). The fineness of the cement affects the rate of hydration. It also affects its place ability, workability and water content of a concrete mix much like the amount of cement used in

concrete. For a given weight of a finely ground cement, the surface area of the particles is greater than for a coarsely ground cement. The advantages of finer cement include:

- a) Increases the rate of hydration
- b) More rapid and greater strength development,
- c) Reduced bleeding rate of concrete
- d) Improving the workability of concrete

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence fastens the development of strength. Fineness of cement is determined by permeability. For example in the blaine air permeability method, a known volume of air is passed through cement. The time is recorded and the specific surface is calculated by a formula. Fineness is expressed in terms of specific surface of the cement (Cm^2/gr). For OPC specific surface area is 2600-3000 Cm^2/gr . This test is conducted as per BS EN196-6:1995.

Neville and Brooks, (2004), three methods of determining the fineness of cement are by sieve analysis, by specific surface area method and by LEA and nurse method.

b) Soundness of Cement

Soundness is referred to as the volume stability of cement paste. The cement paste should not undergo large changes in volume after it has set. Free CaO and MgO may result in unsound cement (Chanadan. 2019). Upon hydration, C and M (calcium and magnesium) will form CH and MH with volume increase thus cracking. (Gartener, et al. 1989), since unsoundness is not apparent until several months or years, it is necessary to provide an accelerated method for its determination which includes:

- a) Lechatelier Method where only free CaO can be determined.
- b) Autoclave Method where both free CaO and MgO can be determined.

In the soundness test a specimen of hardened cement paste is boiled for a fixed time so that any tendency to expand is sped up and can be detected. Soundness means the ability to resist volume expansion. For ordinary Portland cement, BS-EN 197 part1 (2000) has specified a maximum expansion of 10mm. The work of Chowdhury et al., (2015) indicated that the soundness of cement was improved with the addition of saw dust ash as partial replacement. In

the research, cement was replaced by the ash within the range of 5% to 30% and the soundness was found to increase with an increase in the ash content.

c) Setting Time of Cement

Setting time refers to a change from liquid state to solid state. During setting time, cement paste acquire some strength (Gartener, et al. 1989). The water content has a marked effect on time of setting. In acceptance test for cement, the water content is regulated by bringing the paste to a standard condition of wetness and this is referred to as “normal consistency”. Normal consistency of OPC ranges from 20-30% by weight of concrete. Vicat apparatus is used to determine normal consistency. Normal consistency is that condition for which the penetration of a standard weighed plunger into the paste is 10mm in 30sec. In practice, the terms initial set and final set are used to describe arbitrary chosen time of setting. Initial set indicates the beginning of a noticeable stiffening and final set may be regarded as the start of hardening (or complete loss of plasticity). It is the also the period between the time water is added to cement and time at which 1 mm square section needle fails to penetrate the cement paste, placed in the Vicat’s mould 5 mm to 7 mm from the bottom of the mould. Final setting time is that time period between the time water is added to cement and the time at which 1 mm needle makes an impression on the paste in the mould but 5 mm attachment does not make any impression. The setting time test is carried out using the Vicat apparatus as per BS-EN 196 part3 (1995). The results of the test should comply with the requirements of BS-EN 197 part1 (2000), which recommend a minimum of 60 minutes and a maximum of 10 hours as the initial and final setting times of ordinary Portland cement respectively. (Gartener, et al. 1989) summarized the factors affecting setting time as:

- a) Temperature and Humidity.
- b) Amount of water
- c) Chemical composition of cement
- d) Fineness of cement (the finer the cement, the faster the setting)

Marthong, (2012), investigated that the addition of saw dust ash in OPC grade 42.5 had increased the initial and final setting times. This was attributed to the low rate of hydration in the paste containing the saw dust ash.

2.3.2 Aggregate

Ezeokonkwo, (2014), the term aggregate includes the natural sand, gravels and crushed stone used in making concrete. Bert-Okonkwo, (2012) describes the term aggregate, as inert materials like gravel, crushed stones, broken bottles which are mixed with cement and water to make concrete. (Merritt, 1983: Rangwala, 2005), in their contribution describe aggregates as inert or chemically inactive materials which form the bulk of concrete and are bound together using cement as a binder. In any concrete, aggregates (fine and coarse) usually occupies about 70-75% (Gupta and Gupta, 2004: Neville and Brooks, 2004). The aggregates have to be graded so the whole mass of concrete acts as a relatively solid, homogeneous, dense combination with the smallest particles acting as inert filler for the voids that exist between the larger particles (Nawy, 2002). This statement gives us the suggestion that the selection and proportioning of aggregates should be given due attention as it not only affects the strength but the durability and structural performance of the concrete also.

Aggregates are considered clean if they are free of excess clay, silt, mica, organic matter, chemical salts and coated grains Ezeokonkwo, (2014). In addition to that, (Merritt, 1983: Rangawala, 2005: Neville, 1993), support the idea that an aggregate should be physically sound if it retains dimensional stability under temperature or moisture change and resists weathering without decomposition. Ezeokonkwo, (2014) concludes that for an aggregate to be considered adequate in strength, aggregate should be able to develop the full strength of the cementing matrix. Anosike, (2010), aggregates provide better strength, stability and durability to the structure made out of cement concrete than cement paste alone.

Aggregate is not truly inert because its physical, thermal and chemical properties influence the performance of concrete. While selecting aggregate for a particular concrete, the economy of the mixture, the strength of the hardened mass and durability of the structure must first be considered (Gupta and Gupta, 2004).

2.3.3 Water

Water used in the concrete reacts with cement and causes it to set and harden. It also facilitates mixing, placing and compacting of fresh concrete. Abruckle, (2007), states that mixing water for concrete is required to be fit for drinking or to be taken from an approved source. Findings in previous works (Ezeokokwo, 2014: Bert-Okonkwo, 2012: Neil and Ravrinda, 1996) suggest that,

to achieve the required workability and strength of concrete in both its fresh and hardened state, the water used for mixing and curing needs to be of appropriate quality, that is, it should be free from impurities such as suspended solids, organic matter and salts which may adversely affect the setting, hardening, strength and durability of the concrete.

Water is used in the production of concrete, washing of aggregates, mortar and bricks formation. Water is also used for construction operations like casting, painting, terrazzo finishing, plastering and other operations. After casting of concrete, water is poured on the concrete to give it strength in a process known as curing. After completion of the building, water is used for cleaning the building in readiness for inspection, handing-over and occupancy. As a result of these facts, it is obvious that water is very important in building construction and related activities. Neil and Ravindra, (1996) further define water to cement ratio (w/c) as the weight of water divided by the weight of cement.

According to (BS8110: Part 1, 1997), the amount of water required in a concrete mix is the minimum for complete hydration of cement. If such concrete is fully compacted without segregation, it would develop the maximum attainable strength at a given age. The BS8110, (1997) further states that the water-cement ratio of approximately 0.25 weights is required for full hydration of cement. Omuvwie and Mosaku, (2010) suggest that if the water is not properly managed, it can turn around to inflict serious structural damage to the building over time and that such damage can lead to structural failure of the building and eventual collapse aside of the economic drain on client, safety risks as well as aesthetic devaluation.

2.3.4 Admixture

Admixtures are not a primary constituent of concrete. They are added to concrete if necessary and not all the time. Brantley and Brantley, (2004) admixtures are those chemicals that can be added to the concrete mix to achieve special purposes or meet certain construction conditions. Admixtures are mixed into the concrete to change or alter its properties.

The use of admixtures should offer improvement in the properties of concrete by adjusting the proportions of cement and aggregates. However, it should not affect adversely any property of concrete. An admixture should be used only after assessing its effect on the concrete to be used under an intended situation. It should also be known that admixtures are no substitute for good workmanship i.e. the effect of bad workmanship cannot be improved by the use of admixtures.

Gupta and Gupta, (2004) and Anosike, (2010) suggest that admixtures perform the following functions:

- a) Accelerate the initial setting and hardening of concrete.
- b) Retard the initial setting of concrete
- c) Increase the strength of concrete
- d) Improve the workability of fresh concrete
- e) Improve the durability of concrete
- f) Reduce the heat of evaluation
- g) Control the alkali-aggregate expansion
- h) Aid in the curing of concrete
- i) Improve wear resistance to concrete
- j) Reduce shrinkage during the setting of concrete

Bamibgoye et al., (2016) undertook particle size distribution analysis, slump test and compressive strength on hardened concrete in exploiting economics of gravel as a substitute to granite in concrete production. Sulymon et al. (2017) reported that sources of gravel greatly influence compressive, flexural and split-tensile strength of concrete David, et al., (2018).

2.4 Properties of Fresh Concrete

2.4.1 Workability

It is vital that the workability of concrete is matched to the requirements of the construction process (Reynolds and Steadman, 2008). The ease or difficulty of placing concrete in sections of various sizes and shapes, the type of compaction equipment needed the complexity of the reinforcement, the size and skills of the workforce are amongst the items to be considered (Reynolds and Steadman, 2008). In general, the more difficult it is to work the concrete; the higher should be the level of workability. But the concrete must also have sufficient cohesiveness in order to resist segregation and bleeding (Shetty, 2005). Concrete needs to be particularly cohesive if it is to be pumped, or allowed to fall from a considerable height.

2.4.2 Plastic Cracking

There are two basic types of plastic cracks, plastic settlement cracks, which can develop in deep sections and, often follow the pattern of the reinforcement and plastic shrinkage cracks which are most likely to develop in concrete slabs (Reynolds and Steadman, 2008). Both types form while the concrete is still in its plastic state, before it has set or hardened and, depending on the weather conditions, within about one to six hours after the concrete has been placed and compacted (Reynolds and Steadman, 2008). They are often not noticed until the following day. Both types of crack are related to the extent to which the fresh concrete bleeds.

Fresh concrete is a suspension of solids in water and, after it has been compacted, there is a tendency for the solids (both aggregates and cement) to settle. The sedimentation process displaces water, which is pushed upwards and, if excessive, appears as a layer on the surface. This bleed water may not always be seen, since it can evaporate on hot or windy days faster than it rises to the surface. Bleeding can generally be reduced, by increasing the cohesiveness of the concrete (Reynolds and Steadman, 2008). This is usually achieved by one or more of the following means: increasing the cement content, increasing the sand content, using finer sand, using less water, air-entrainment, using rounded natural sand rather than an angular crushed one. The rate of bleeding will be influenced by the drying conditions, especially wind, and bleeding will take place for longer on cold days. Similarly, concrete containing a retarder tends to bleed for a longer period of time, due to the slower stiffening rate of the concrete, and the use of retarders will, in general, increase the risk of plastic cracking.

Plastic settlement cracks, caused by differential settlement, are directly related to the amount of bleeding (Reynolds and Steadman, 2008). They tend to occur in deep sections, particularly deep beams, but they may also develop in columns and walls. This is because the deeper the section, the greater the sedimentation or settlement that can occur. However, cracks will form only where something prevents the concrete 'solids' from settling freely. The main danger from plastic cracking is the possibility of moisture ingress leading to corrosion of any reinforcement (Reynolds and Steadman, 2008). If the affected surface is to be covered subsequently, by either more concrete or a screed, no treatment is usually necessary. In other cases, often the best repair

is to brush dry cement (dampened down later) or wet grout into the cracks the day after they form, and while they are still clean; this encourages natural or autogenous healing.

2.4.3 Early Thermal Cracking

The reaction of cement with water, or hydration, is a chemical reaction that produces heat (Reynolds and Steadman, 2008). If this heat development exceeds the rate of heat loss, the concrete temperature will rise. Subsequently the concrete will cool and contract. If the contraction of the concrete were unrestrained, there would be no cracking at this stage. However, in practice there is nearly always some form of restraint inducing tension, and hence a risk of cracks forming. The restraint can occur due to both external and internal influences. Concrete is externally restrained when, for example, it is cast onto a previously cast base, such as a wall kicker, or between two already hardened sections, such as in infill bay in a wall or slab, without the provision of a contraction joint. Internal restraint occurs, for example, because the surfaces of an element will cool faster than the core, producing a temperature differential. When this differential is large, such as in thick sections, surface cracks may form at an early stage. Subsequently, as the core of the section cools, these surface cracks will tend to close in the absence of any external restraints. Otherwise, the cracks will penetrate into the core, and link up to form continuous cracks through the whole section.

The main factors affecting the temperature rise in concrete are the dimensions of the section, the cement content and type, the initial temperature of the concrete and the ambient temperature, the type of formwork and the use of admixtures (Reynolds and Steadman, 2008). Thicker sections retain more heat, giving rise to higher peak temperatures, and cool down more slowly.

2.5 Properties of Hardened Concrete

2.5.1 Tensile Strength

The direct tensile strength of concrete, as a proportion of the cube strength, varies from about one-tenth for low-strength concretes to one-twentieth for high-strength concretes (Reynolds and Steadman, 2008). The proportion is affected by the aggregate used, and the compressive strength is therefore only a very general guide to the tensile strength (Reynolds and Steadman, 2008). For specific design purposes, in regard to cracking and shear strength, analytical relationships

between the tensile strength and the specified cylinder/cube strength are provided in codes of practice. The indirect tensile strength (or cylinder splitting strength) is seldom specified nowadays. Flexural testing of specimens may be used on some airfield runway contracts, where the method of design is based on the modulus of rupture, and for some precast concrete products such as flags and kerbs.

2.5.2 Shrinkage

Withdrawal of water from hardened concrete kept in unsaturated air causes drying shrinkage (Reynolds and Steadman, 2008). If concrete that has been left to dry in air of a given relative humidity is subsequently placed in water (or a higher relative humidity), it will swell due to absorption of water by the cement paste. However, not all of the initial drying shrinkage is recovered even after prolonged storage in water. For the usual range of concretes, the reversible moisture movement represents about 40%–70% of the drying shrinkage. A pattern of alternate wetting and drying will occur in normal outdoor conditions. The magnitude of the cyclic movement clearly depends upon the duration of the wetting and drying periods, but drying is much slower than wetting. The consequence of prolonged dry weather can be reversed by a short period of rain. More stable conditions exist indoors (dry) and in the ground or in contact with water (e.g. reservoirs and tanks).

Shrinkage of hardened concrete under drying conditions is influenced by several factors in a similar manner to creep (Reynolds and Steadman, 2008). The intrinsic shrinkage of the cement paste increases with the water/cement ratio so that, for a given aggregate proportion, concrete shrinkage is also a function of water/cement ratio. The relative humidity of the air surrounding the member greatly affects the magnitude of concrete shrinkage according to the volume/surface area ratio of the member (Reynolds and Steadman, 2008). The lower shrinkage value of large members is due to the fact that drying is restricted to the outer parts of the concrete.

2.5.3 Creep

The increase in strain beyond the initial elastic value that occurs in concrete under a sustained constant stress, after taking into account other time-dependent deformations not associated with stress, is defined as creep (Reynolds and Steadman, 2008). If the stress is removed after some

time, the strain decreases immediately by an amount that is less than the original elastic value because of the increase in the modulus of elasticity with age (Reynolds and Steadman, 2008). This is followed by a further gradual decrease in strain. The creep recovery is always less than the preceding creep, so that there is always a residual deformation.

The creep source in normal-weight concrete is the hardened cement paste. The aggregate restrains the creep in the paste, so that the stiffer the aggregate and the higher its volumetric proportion, the lower is the creep of the concrete. Creep is also affected by the water/cement ratio, as is the porosity and strength of the concrete (Shetty, 2005). For constant cement paste content, creep is reduced by a decrease in the water/cement ratio. The most important external factor influencing creep is the relative humidity of the air surrounding the concrete. For a specimen that is cured at a relative humidity of 100%, then loaded and exposed to different environments, the lower the relative humidity, the higher is the creep. The values are much reduced in the case of specimens that have been allowed to dry prior to the application of load. The influence of relative humidity on creep is dependent on the size of the member. When drying occurs at constant relative humidity, the larger the specimen, the smaller is the creep. This size effect is expressed in terms of the volume/surface area ratio of the member. If no drying occurs, as in mass concrete, the creep is independent of size.

Creep is inversely proportional to concrete strength at the age of loading over a wide range of concrete mixes (Reynolds and Steadman, 2008). Thus, for a given type of cement, the creep decreases as the age and consequently the strength of the concrete at application of the load increases. The type of cement, temperature and curing conditions all influence the development of strength with age.

2.5.4 Compressive Strength

The strength of concrete is specified as a strength class or grade, namely the 28-day characteristic compressive strength of specimens made from fresh concrete under standardized conditions (Reynolds and Steadman, 2008). The results of strength tests are used routinely for control of production and contractual conformity purposes. The characteristic strength is defined as that level of strength below which 5% of all valid test results is expected to fall.

In principle, compressive strengths can be determined from cores cut from the hardened concrete. Core tests are normally made only when there is some doubt about the quality of concrete placed (e.g. if the cube results are unsatisfactory), or to assist in determining the strength and quality of an existing structure for which records are not available. Great care is necessary in the interpretation of the results of core tests, and samples drilled from in situ concrete are expected to be lower in strength than cubes made, cured and tested under standard laboratory conditions.

2.6 Quality of Concrete

Like all other engineering operations, concrete mixed at site requires special quality control which should be carried out during preparation, batching, mixing and placing of the concrete mix (Oyenuga, 2011). The quality control of concrete should aim at producing a uniform material which provides properties particularly desirable for the work. The basic reason for quality control includes: ensuring that workmanship does not fall below a certain specified standard and limiting the overall variation in the quality of concrete (Oyenuga, 2011). Variations in concrete quality are due to a large number of factors which includes: variation batching, mixing variation, variation in quality of cement, variation in degree of compaction and variation in curing.

2.6.1 Factors Affecting Quality of Concrete

In view of the different processes involved in the manufacture of concrete, the problems of quality control are diversified and their solution elaborated. The factors involved are the personnel, the materials and equipment, the workmanship in all stages of concreting, i.e. batching of materials, mixing, transportation, placing, compaction, curing, and finally testing and inspection. It is therefore necessary to analyze the different factors causing variations in the quality and the manner in which they can be controlled.

2.6.1.1 Materials

For a uniform quality of concrete, the ingredients (particularly the cement) shall preferably be used from a single source. When ingredients from different sources are used, the strength and other characteristics of the materials are likely to change and, therefore, they should only be used after proper evaluation and testing.

2.6.1.2 Portland Cement

Cement is any material that hardens and becomes strong adhesive after application in plastic form. Cement is the binding constituent of concrete. Similar types of cement from different sources and at different times from the same source exhibit variations in properties of concrete, especially in compressive strength. This variation in the strength of cement is related to the composition of raw materials as well as variations in the manufacturing process. The cement shall be tested initially once from each source of supply and, subsequently, at every two months interval. Adequate storage under cover is necessary for protection from moisture. Set cement with hard lumps is to be rejected.

2.6.1.3 Aggregates

In any concrete, aggregates (fine sand and Coarse) usually occupies about 70-75% and between 60 – 80% of the total volume of the concrete mass. The aggregates have to be graded so the whole mass of concrete acts as a relatively solid, homogeneous, dense combination with the smallest particles acting as inert filler for the voids that exist between the larger particles. This therefore suggests that the selection and proportioning of aggregates shall be given due attention as it not only affects the strength, but the durability and structural performance of the concrete also. Further, the aggregate is cheaper than cement and thus it is cheaper to use as much quantity of aggregate and as little of cement as possible. Aggregates provide better strength, stability and durability to the structure made out of cement concrete than cement paste alone. Aggregate is not truly inert because its physical, thermal and chemical properties influence the performance of concrete. While selecting aggregate for a particular concrete, the economy of the mixture, the strength of the hardened mass and durability of the structure must first be considered. Grading, maximum size, shape, and moisture content of the aggregate are the major source of variability. Aggregate shall be separately stock piled in single sizes. The graded aggregate should not be allowed to segregate.

2.6.1.4 Water

The water used for mixing concrete shall be free from silt, organic matter, alkali, and suspended impurities. Sulphates and chlorides in water should not exceed the permissible limits. Generally, water fit for drinking may be used for mixing concrete.

2.6.1.5 Personnel

The basic requirement for the success of any quality control plan is the availability of experienced, knowledgeable and trained personnel at all levels. The designer and the specification-writer should have the knowledge of construction operations as well. The site engineer shall be able to comprehend the specification stipulation. Everything in quality control cannot be codified or specified and much depends upon the attitude and orientation of people involved. In fact, quality must be a discipline imbibed in the mind and there shall be strong motivation to do everything right the first time.

2.6.1.6 Equipments

The equipment used for batching, mixing and vibration shall be of the right capacity. Weigh-batchers shall be frequently checked for their accuracy.

2.6.1.7 Workmanship

The activities involved in the workmanship in all stages of concreting, i.e. batching of materials, mixing, transportation, placing, compaction, curing and finally testing and inspection.

2.6.1.8 Ready Mixed Concrete

If instead of being batched and mixed on site, concrete is delivered for placing from a central plant, it is referred to as ready-mixed or pre-mixed concrete. This is used for large batches with lorry transporters up to 6m³ capacity. It has the advantage of eliminating site storage of materials and mixing plant, with the guarantee of concrete manufactured to quality-controlled standards. Placement is usually direct from the lorry therefore site-handling facilities must be co-ordinate with deliveries. Advantages of Ready-Mix Concrete:

- (a) Close quality control of batching which reduces the variability of the desired properties of the hardened concrete.
- (b) Use on congested sites or in highway construction where there is little space for a mixing plant and aggregate stockpiles.
- (c) Use of agitator trucks to ensure care in transportation, thus preventing segregation and maintaining workability
- (d) Convenience when small quantity of concrete or intermittent placing is required.

The disadvantage of ready-mix concrete is that it is costlier by about 10 – 15% than concrete mixed at project site. But this is often off-set by savings in site organization, in supervisory staff, and in cement content.

2.6.1.8 Concrete Mix Ratio

When making concrete it's important to use the correct concrete mixing ratios to produce a strong, durable concrete mix. Mixing water with the cement, sand, and stone will form a paste that will bind the materials together until the mix hardens. The strength properties of the concrete are inversely proportional to the water/cement ratio. Basically this means the more water you use to mix the concrete (very fluid) the weaker the concrete mix. The less water you use to mix the concrete (somewhat dry but workable) the stronger the concrete mix. Accurate concrete mixing ratios can be achieved by measuring the dry materials using buckets or some other kind of measuring device. By measuring the mixing ratios you will have a consistent concrete mix throughout your entire project.

2.7 Rice Husk (RC)

Rice husk, also called rice hull, is the coating on a seed or grain of rice. It is a major agricultural by-product produced during the de-husking process of paddy rice. It is formed from hard materials, including silica and lignin, to protect the seed during the growing season. During rice milling, about 78% of weight is received as rice, broken rice and bran, and the rest 22% of weight of paddy is received as husk (Rao et al., 2014). It is separated from the brown rice grain as part of the milling process, after which the rice is polished. Rice husk in its loose form as shown in Figure 2-6, is mostly used for energy production, such as combustion and gasification. Rice husk was long considered a waste from the rice milling process and was often dumped and/or burned. But because it can be easily collected and is cheap, some amount of rice husk has always been used as an energy source for small applications, such as for brick production, for steam engines and gasifiers used to power rice mills, and for generating heat for rice dryers.

Rice husk have been utilized by researchers as an admixture in the production of concrete. Lawal, et al., (2019) investigated the effect of un-burnt rice husk on properties of concrete. The experimental study evaluated the different content of rice husk added to concrete which may influence the workability, water absorption and compressive strength of concrete with 0, 1.5, 2.5,

5, 7.5 and 10% addition of grinded rice husk by weight of cement at a fixed water to cement ratio. Results obtained were compared to a controlled sample and the viability of adding grinded rice husk to the concrete was verified. Result obtained suggested that the water absorption capacity increased and workability of rice husk concrete increased with increasing percentages of rice husk with the workability ultimately lying within the allowable limit for construction. The compressive strength increased up to 15% addition of rice husk but beyond this point, the compressive strength decreased.

Bheel, et al., (2018) investigated the effect of rice husk ash and water to cement ratio on strength of concrete. The rice husk ash was used to partially replace cement in increasing percentages of 2% to 10% by weight of cement. Concrete cubes were casted and tested at water to cement ratio of 0.45, 0.50 and 0.60 and at each specified water to cement ratio, the compressive strength, split tensile strength and workability of the fresh concrete was determined. Result obtained suggest that the compressive strength and split tensile strength increased up to 14.51% and 10.71% respectively at water to cement ratio of 0.45 suggesting a relatively higher compressive and split tensile strength test at the lowest water to cement ratio. The workability of the plain concrete increased with an increasing water to cement ratio while that of the rice husk ash concrete decreased with increasing water to cement ratio.

2.8 Compaction and its Relevance to Civil Engineering

Compaction is the process which expels entrapped air from freshly placed concrete and packs the aggregate particles together so as to increase the density of concrete (Mata, et al., 2014). The aggregate particles, although coated with mortar, tend to arch against one another and are prevented from slumping or consolidating by internal friction. Compaction of concrete is, therefore, a two-stage process. In first stage with the vibration, initial consolidation of the concrete can often be achieved relatively quickly (Mata, et al., 2014). The concrete liquefies and the surface levels, giving the impression that the concrete is compacted, then after the second stage, entrapped air is expelled. Entrapped air takes a little longer to rise to the surface. Compaction must therefore be prolonged until this is accomplished, i.e. until air bubbles no longer appear on the surface.

Proper compaction also ensures that the formwork is completely filled that is there are no pockets of honeycombed material and that the required finish is obtained on vertical surfaces. Even air-entrained concrete needs to be compacted to get rid of entrapped air voids. The difference between air voids and entrained air bubbles should be noted at this stage. The air bubbles that are entrained are relatively small and spherical in shape, increase the workability of the mix, reduce bleeding, and increase frost resistance. Entrapped air on the other hand tends to be irregular in shape and is detrimental to the strength of the mix. It is to remove this air that the concrete must be properly compacted (Mata, et al., 2014). There is little danger that compaction will remove the minute air bubbles that have been deliberately entrained, since they are so stable.

It is important to compact the concrete fully because, Air voids reduce the strength of the concrete. For every 1% of entrapped air, the strength falls by somewhere between 5 and 7%. This means that concrete containing about 5% air voids due to incomplete compaction can lose as much as one third of its strength. Air voids increase concrete's permeability. That in turn reduces its durability. If the concrete is not dense and impermeable, it will not be watertight. It will be less able to withstand aggressive liquids and its exposed surfaces will weather badly. Moisture and air are more likely to penetrate to the reinforcement causing it to rust. Air voids impair contact between the mix and reinforcement (and, indeed, any other embedded metals). The required bond will not be achieved and the reinforced member will not be as strong as it should be. Air voids produce blemishes on struck surfaces. For instance, blowholes and honeycombing might occur. Summing up, fully compacted concrete is dense, strong and durable; badly compacted concrete will be porous, weak and prone to rapid deterioration. Sooner or later it will have to be repaired or replaced. It pays, therefore, to do the job properly in the first place.

2.8.1 Compaction Pressure Applicable in Concrete Technology

Compaction pressure in concrete technology ranges from manual (hand), mechanical, compaction by spinning and compaction by jolting (Singh and Srivastava, 2017). Hand Compaction is done by rodding, tamping and ramming whereas mechanical compaction is done by mean of internal Vibrations external Vibration table vibration platform vibrations and surface vibrations. Vibrations in concrete are incorporated through different Vibrators.

2.8.1.1 Methods of Mechanical Compaction

In immersion vibration a mechanical device termed as needle vibrator is broadly used by many firms frequently referred to as poker or needle vibrators, immersion vibrators consist essentially of a tubular housing which contains a rotating eccentric weight. The out-of-balance rotating weight causes the casing to vibrate. When immersed in concrete, the concrete itself. Depending on the diameter of the casing or head, and on the frequency and the amplitude of the vibration, an immersion vibrator may have a radius of action between 100 and 600 mm. The effectiveness of an immersion vibrator is dependent on its frequency and amplitude, the latter being dependent on the size of the head, the eccentric moment and the head weight. The larger the head, the larger the amplitude. As the water cement ratio of concrete decreasing the higher compactive effort required so we should use the larger diameter head for such kind of work. Immersion vibrators may be driven by: a flexible shaft connected to a petrol, diesel, or electric motor; or an electric motor situated within the tubular casing; or compressed air. But most commonly vibrators on the site are driven by a flexible shaft connected to a petrol, diesel, or electric motor.

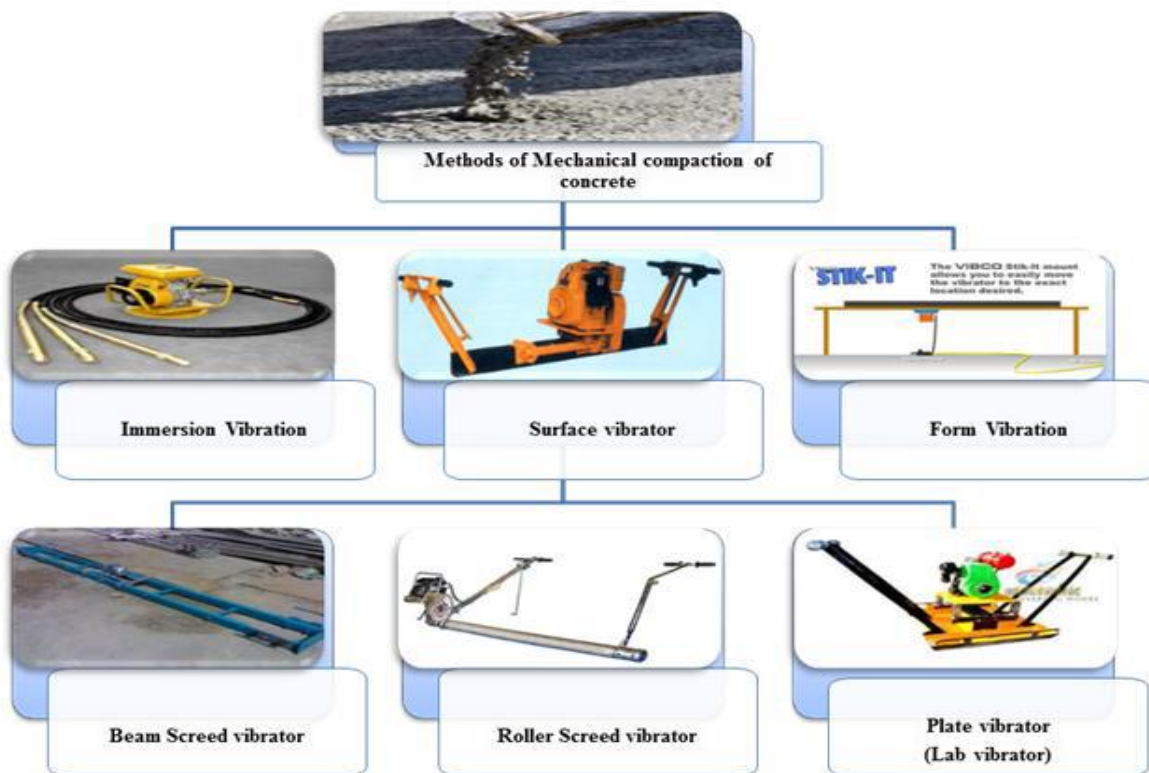


Plate 2.0: Method of Mechanical Compaction (Mata, et al., 2014).

2.8.2 Previous Studies on Effect of Compaction Pressure on Concrete

Mata, et al, (2014) investigates the effect of compaction pressures on mechanical properties of concrete. Findings obtained revealed that immersion vibration (use of poker) produced concrete with relatively high compressive and flexural strength than other compaction pressures.

Singh and Srivastava,(2017) conducted a study on comparison between hand and mechanically compacted concrete and deduced that compressive strength and density of mechanically compacted concrete is more than that of manually compacted.

(Arioz, et al., 2007) conducted an experimental investigation on the effect of compaction on concrete strength assessed by rebound hammer, ultrasonic pulse velocity, and pull-out techniques. Concrete mixture was prepared by ordinary Portland cement, crushed limestone aggregate, water, and a plasticizing admixture. The cubes and beams were cast by the prepared mixture. Beams were compacted in three different levels. The results have shown that the rebound number, ultrasonic pulse velocity, pull-out force, and core strength were significantly affected by the level of compaction.

2.9 Water to Cement Ratio

Water to cement ratio is the ratio of water to cement (Oyenuga, 2011). Water to cement ratio have appreciable impact on wet and dry properties of concrete. The smaller the water to the cement (above a certain minimum limit) the greater the strength (oyenuga, 2011). If the quantity of water, it may be insufficient to ensure that the chemical action of the setting cement (hydration) is complete, also the materials may be too dry to be properly mixed or the resulting mixture may be too stiff to be satisfactorily compacted (Oyenuga, 2011). If too much water is used, there is a tendency for the coarse aggregate to separate from the finer materials during placing (segregation).

Bheel, et al., (2018) investigated the effect of rice husk ash and water to cement ratio on strength of concrete. The rice husk ash was used to partially replace cement in increasing percentages of 2% to 10% by weight of cement. Concrete cubes were casted and tested at water to cement ratio of 0.45, 0.50 and 0.60 and at each specified water to cement ratio, the compressive strength, split tensile strength and workability of the fresh concrete was determined. Result obtained suggest

that the compressive strength and split tensile strength increased up to 14.51% and 10.71% respectively at water to cement ratio of 0.45 suggesting a relatively higher compressive and split tensile strength test at the lowest water to cement ratio. The workability of the plain concrete increased with an increasing water to cement ratio while that of the rice husk ash concrete decreased with increasing water to cement ratio.

Apebo, et al., (2013) conducted a research on the effect of water to cement ratio on compressive strength of gravel – crushed over burnt bricks concrete. Water to cement ratio of 0.4, 0.5, 0.55 and 0.6 was used to prepare the concrete. Results obtained indicate that compressive strength increased with decreasing water to cement ratio with the highest compressive strength (35N/mm²) recorded at water to cement of 0.4. The workability of the concrete increased with increasing water to cement ratio.

Marar and Eren, (2011) investigated the effect of cement content and water to cement ratio on properties of fresh concrete without admixtures. Slump test, density and compressive strength test was conducted from eight different concrete mixtures prepared from ordinary Portland cement (cement content of 300, 350, 400, 450, 500, 550, 600 and 650kg/m³) and water to cement ratio of 0.43, 0.45, 0.5, 0.55, 0.6, 0.67 and 0.79 were used for the experimental study. From the findings, it was observed that the workability, unit weight and compressive strength of the concrete increased with decreasing water to cement ratio and increasing cement content.

2.10 Summary of Past Research Findings

Key findings obtained from study on effect of variation of water to cement ratio and compaction pressure on wet and dry properties of concrete is summarized in Table 2.0 below.

Table 2.0: Summary of Research Findings

Researchers	% of Rice Husk in Concrete	Compaction Pressure Employed	Water to Cement Ratio Employed	Findings on Wet Properties of Concrete	Findings on Dry Properties of Concrete
Marar and Eren, (2011)	-	-	0.43, 0.45, 0.48, 0.50,	Workability increased	Compressive strength and

			0.55, 0.6, 0.67 and 0.7	with increasing decreasing water to cement ratio	unit weight increased with decreasing water to cement ratio
Lawal, et al., (2019)	1.5, 2.5, 5, 7.5 and 10% by weight of cement	-	-	Workability increased with increasing rice husk content	Water absorption capacity increased with increasing rice husk content, compressive strength increased up to 15% rice husk content.
Bheel, et al., (2018)	2, 4, 6, 8 and 10% by weight of cement	-	0.45, 0.5 and 0.6	Workability of the plain concrete at all water to cement ratio was relatively higher than that of rice husk concrete	Compressive strength and split tensile strength increased with decreasing water to cement ratio
Apebo, et al., (2013)	-	-	0.4, 0.5, 0.55 and 0.6	Workability increased with	Compressive strength increased

				increasing water to cement ratio	with decreasing water to cement ratio.
Singh and Srivastava,(2017)	-	Compaction by tamping and compaction by use of immersion vibration	-	Workability of immersion vibration was higher than that of concrete produced by tamping	Compressive strength of immersion vibration was relatively higher than that of concrete produced by tamping
Mata,et al,(2014)	-	Compaction by ramming and compaction by use of immersion vibration	-	Workability of immersion vibration was higher than that of concrete produced by ramming	Compressive and flexural strength of immersion vibration was relatively higher than that of concrete produced by ramming

In other to build on research gaps and thoroughly study the effect of variation of water to cement ratio and compaction pressure on wet and dry properties of concrete, this study will adopt the tamping and immersion compaction methods and the water to cement ratio will be varied in an increasing order of 0.4, 0.45, 0.55, 0.6, 0.65 rice husk will be partially added to fine aggregate in a stepped increase of 7.5% to 22.5% by weight of fine aggregate.

CHAPTER THREE

3.0 MATERIALS AND METHODS

This section presents the materials and methods used to actualize the research goal. Relevant standards were employed to ascertain how the materials collected be analyzed and also the various laboratory tests to be conducted. All Tests such as sieve analysis test specific gravity and compressive strength of hardened concrete were carried out at Nnamdi Azikiwe University Civil Engineering Laboratory located inside the school campus.

3.1 Collection and Preparation of Materials

3.1.1 Cement

Dangote cement designated as DT was used for the experimental study. The cement was purchased at Onitsha Market in Anambra State. Upon purchase, the cement was conveyed to school laboratory where it was kept in a cool dry place preparatory for various laboratory testing. The cement sample satisfy the requirement for use as one of the major component of concrete in that, it was not caked or baked through visual inspection and quick setting time.

3.1.2 Water

Water sample used for the experimental study was collected within the school environment. The water sample passed all the necessary requirement for use as ingredient of concrete based on the fact that it is colourless, devoid of suspended solid particles, contains infinitesimal trace of dissolved solid particles with no trace of turbidity after being subjected to laboratory testing. The water was collected in two gallons. Water to cement ratio will be added to the rice husk concrete in an increasing order of 0.4, 0.45, 0.5, 0.55, 0.6 and 0.65.

3.1.3 Fine Aggregate (Sand)

Sand sample used in producing the concrete was provided at a construction site at Nnamdi Azikiwe University Campus. The sand was Sieved through 5.0mm test sieve to remove larger particles and then air-dried to a saturated state of an aggregate. The sample passed the necessary requirement for use as ingredient of concrete based on the fact that it is gritty with particle sizes visible to the naked eyes, physical properties of the sand samples were determined prior to its

incorporation into the concrete. Index properties of the sand sample were determined prior to its incorporation into the concrete. Sand used for this experimental study will be partially admixed with rice husk in a stepped increase of 7.5% to 22.5% by weight of sand.

3.1.4 Coarse Aggregate (Granite)

Granite samples designated as GT was procured from Infrastructure Development Company (popularly known as IDC) located along Enugu-Onitsha express way. After procurement, the granite samples were conveyed to the laboratory unit of Department of Civil Engineering Nnamdi Azikiwe University Awka Anambra State where the index properties of the aggregate were determined. The granite sample passed all the necessary physical test in that, it has high crushing strength, it is relatively large in size (within range of 4.75mm to 20mm) and is a representative of granite (chippings) in color

3.1.5 Rice Husk

Rice husk used for the experimental study designated as RH was procured from a rice plantation at Aguleri in Anambra State. The rice husk was collected in two cement bags and conveyed to Civil Engineering Laboratory, Nnamdi Azikiwe University Awka, Anambra State, Nigeria. Rice husk will be used to completely replace sand to produce light weight concrete at varying water to cement ratio and compaction pressure.

3.1.2 Test Result Template

Table 3.1: Wet and Dry Properties Result Template for the Concrete at Varying Water to Cement Ratio and Compaction Pressure

W/Ratio/Compaction Pressure (kN)	0.4	0.45	0.5	0.55	0.6	0.65
300						
225						
150						
75						
15						
0						

3.3 Experimental Investigation

This section presents the experimental procedure and laboratory tests that were used to investigate the effect of variation of water to cement ratio and compaction pressure on wet and dry properties of concrete. The tests were conducted for all the constituents of concrete and these tests include: sieve analysis test specific gravity test and compressive strength of hardened concrete. The above listed tests were carried out at Nnamdi Azikiwe University Civil Engineering Laboratory located inside the school campus. Below is a description of test procedures and apparatus:

3.3.1 Specific Gravity of Fine Aggregate

Specific gravity is the ratio of mass of unit volume of soil at a stated temperature to mass of equal volume of gas-free distilled water at the same temperature (Krishna, 2002). Also as defined by Braja, (2006), Specific gravity can be defined as the ratio of unit weight of a material to unit weight of water. The specific gravity of soil solids is often needed for various calculations in soil mechanics. It can be determined accurately in the soil laboratory.

Apparatus employed for this experiment includes:

- 1 Density bottle of 50ml capacity and a stopper.
- 2 Desiccator containing anhydrous silica gel.
- 3 Thermostatically controlled oven with temperature of about 80-110°C.
- 4 Weighing balance of 0.01g sensitivity.
- 5 Mantle heater.
- 6 Plastic wash bottle.
- 7 Distilled water.
- 8 Funnel
- 9 Thin glass rod for stirring.
- 10 425um Sieve.
- 11 Dry piece of cloth for cleaning.
- 12 Masking tape for identification of sample.
- 13 Exercise book and pen for recording of result.

Test Procedure

- 1 The density bottle properly cleaned and rinsed with distilled water, thereafter oven- dried and then cooled it in a desiccator so as to remove any moisture present.
- 2 The empty clean and dry density bottle was weighed and recorded as (M_1).
- 3 About 10-15g of soil passing through 425um sieve was placed inside the density bottle, weigh and the weight of density bottle +dry soil + stopper was recorded as (M_2).
- 4 Distilled water was added to fill about half to three-fourth of the density bottle, and then the sample was soaked for 24hrs (The time stated is to enable complete settlement of the soil particle which is evident when clear water appears above the submerged soil).
- 5 The density bottle was gently stirred using thin glass rod and thereafter connected to a mantle heater to de-air the sample, the sample was not allowed to boil over.
- 6 After agitation, the sample was allowed to cool at room temperature and then filled with distilled water up to the specified mark (at lower meniscus level), the exterior surface of the density bottle was cleaned with a clean dry cloth and the weight of the density bottle + stopper +soil filled with water was determined and recorded as (M_3).
- 7 The density bottle was emptied, cleaned and rinsed with distilled water, then filled with distilled water up to the same mark. The exterior surface of the density bottle was cleaned with a clean dry cloth and the weight of the density bottle filled with distilled water + stopper was determined and recorded as (M_4).
- 8 The test procedure was repeated for two more trials and the average specific gravity value was obtained from the total no of trial, the variation in the specific gravity result obtained for each trial must not exceed 2%, otherwise repeat the experiment.

The Procedure for Computation of result obtained are as follows:

$$\text{Specific gravity (G}_s\text{)} = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

Where M_1 = weight of density bottle + stopper

M_2 = Weight of density bottle + air-dried soil + stopper.

3.3.2 Specific Gravity of Coarse Aggregate

The specific gravity of aggregate is defined as the ratio of aggregate to the weight of equal volume of water (Braja, 2006). The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Aggregate having low specific gravity are generally weaker than those with high specific gravity (Braja, 2006). This property helps in general identification of aggregate.

Apparatus Employed

- 1 Wires mesh Bucket or perforated container of convenient sizes with thin wire hangers for suspending it from a balance.
- 2 Pycnometer of 1000ml.
- 3 Set up consisting of container for filling water and suspending the wire basket in it and airtight container of capacity similar to that of a bucket, a shallow tray, two dry absorbent clothes.

Test Procedure

1. About 2 kg of aggregate sample is taken, washed to remove fines and then placed in the wire basket. The wire basket is then immersed in water, which is at a temperature of 22⁰C to 32⁰C.
2. Immediately after immersion the entrapped air is removed from the sample by lifting the basket 2mm above the base of the tank and allowing it to drop, 25 times at a rate of about one drop per second.
3. The basket, with aggregate are kept completely immersed in water for a period of 24 ± 0.5 hour.
4. The basket and aggregate are weighed while suspended in water, which is at a temperature of 22⁰C to 32⁰C.
5. The basket and aggregates are removed from water and dried with dry absorbent cloth.
6. The surface dried aggregates are also weighed.
7. The aggregate is placed in a shallow tray and heated to about 110⁰C in the oven for 24 hours. Later, it is cooled in an airtight container and weighed.

3.3.3 Particle Size Distribution Test

Sieve analysis is a procedure used to assess the particle size distribution of a granular material Atkinson (2000). The size distribution is often of critical importance to the behaviour of the material during use. Sieve analysis can be performed on any type of non-organic or organic granular material including sand, crushed rock, clay, granite, feldspar and a wide range of manufactured powders, grains and seeds down to minimum size depending on the exact method. The standard grain size analysis test determines the relative proportion of different grain sizes as they are distributed among certain size ranges.

Soil possesses a number of physical characteristics which can be used as aid to identify its sizes in the field. A handful of soil rubbed through the finger can yield the following:

1. Sand and other coarser particles are visible to the naked eye.
2. Silt particles become dusty and are easily brushed off.
3. Clay particles are greasy and sticky when wet and hard when dry and have to be scraped or washed off hand and boot.

For a soil to be well graded the value of coefficient of uniformity (C_u) has to be greater than 4 and 6 for gravel and sand respectively, while the Coefficient of Curvature (C_v) should be in the range of 1 to 3.

The apparatus needed for this experiment is listed below:

1. Stack of sieves including pan and cover.
2. Mechanical sieve shaker.
3. Weighing balance of 0.01g sensitivity.
4. Hand brush
5. Mortar and pestle (Used for crushing if the sample is conglomerated or lumped)
6. Thermostatically controlled Oven (With temperature of about 80°C-110°C).
7. Masking tape for identification of sample.
8. Exercise book and pen for recording of result.
9. The calculation for attaining Coefficient of uniformity and Coefficient of curvature are outlined below.

$$\text{Percentage retained (\%)} = \frac{\text{mass of soil retained in the sieve (g)}}{\text{total mass of soil sample (g)}} \times 100$$

$$\text{Cumulative percentage retained} = \sum \text{Percentage retained (\%)}$$

$$\text{Cumulative Percentage Finer (\%)} = 100 - \text{Cumulative percentage retained.}$$

$$\text{Coefficient of Curvature} = \frac{D_{60}}{D_{10}}$$

$$\text{Coefficient of Uniformity} = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

Where

D₁₀= particle size such that 10% of the soil is finer than the size

D₃₀= particle size such that 30% of the soil is finer than the size.

D₆₀= particle size such that 60% of the soil is finer than the size.

Test Procedure

- 1 The stack of sieves to be used for the experiment was properly cleaned using hand brush.
- 2 About 500g of air-dried soil sample was weighed with the aid of a weighing balance.
- 3 The weighed soil sample was poured into 75µm sieve and wash under a steady supply of water until clear water start coming out from the sieve after passing through the soil sample.
- 4 After washing pour the washed soil sample into a pre-weighed plate and dry it inside the thermostatically controlled oven at a controlled temperature of 80-110°C for 16-24hrs.
- 5 The sample was removed from the oven and the weight was determine (net weight) by deducting the weight of plate from the weight of plate and soil.
- 6 The stacks of sieve was arranged in the ascending order, placed in a mechanical sieve shaker, and thereafter the sample was poured and connected to the shaker for about 10-15 minute.
- 7 The sieve shaker was disconnected and the mass retained on each of the sieve sizes was determined.

- 8 The percentage retained, Cumulative percentage retained and Cumulative percentage finer was determined.
- 9 The graph of sieve Cumulative percentage finer against sieve sizes was plotted.
- 10 D10, D30 and D60 were determined from the plotted graph.
- 11 The Coefficient of Curvature and Coefficient of Uniformity was determined and used to classify the soil adopting the American Association of State Highway and Transportation Official (AASHTO) and Unified Soil Classification System (USCS) respectively.

3.3.3 Compressive Strength of Hardened Concrete Cubes

This is aimed at determining the compressive strength of concrete made with variation of water to cement ratio and compaction pressure. Compressive strength test is conducted by the application of compressive axial load to molded cubes at a rate which is within a prescribed range until failure occurs.

The Apparatus Used includes:

- 1. Testing Machine** - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.
- 2. Cube Moulds** - The mould shall be of 150 mm size conforming to IS: 10086-1982.
- 3.** Weights and weighing device
- 4.** Tools and containers for mixing,
- 5.** Tamper (square in cross section)

Preparation of Samples

For this research concrete mix design of 1:2:4 with water/cement ratio of 0.55 was used. The materials used were batched by weight and mixing was carried out manually and separately for each of the Ordinary Portland Cement (OPC) under laboratory conditions. 150mm×150mm×150mm metallic moulds with oil smeared on the inside of the mould to avoiding sticking was used for casting the concrete specimen after obtaining a uniform and consistent mixture. Vibration to remove entrapped voids was done manually and the concrete

specimens were left in the mould for 24hours after casting before they were removed from the mould.

Test Procedure

1. Sampling of Materials - Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.

2. Proportioning - The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.

3. Weighing - The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

4. Mixing Concrete - The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

5. Mould - Test specimens cubical in shape shall be $15 \times 15 \times 15$ cm. If the largest nominal size of the aggregate does not exceed 2 cm, 10 cm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter.

6. Compacting - The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

7. Curing - The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of $27^{\circ} \pm 2^{\circ}\text{C}$ for 24 hours $\pm \frac{1}{2}$ hour from the time of addition of water to the dry ingredients.

8. Placing the Specimen in the Testing Machine - The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression plates.

9. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom

10. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.

11. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.

12. The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted.

The compressive strength of concrete cube is computed as follows:

$$\text{Compressive Strength (N/mm}^2\text{)} = \frac{\text{Applied load (N)}}{\text{Area of Cube (mm}\times\text{mm)}}$$

Where applied load (N) = Force

Now conversion of applied load from Ton force to KN or N.

1 Ton force = 10kN or 10,000N.

For 220kN = 220× 1000 = 220,000N

Area of cube = 150mm×150mm = 22,500mm²

$$\text{Compressive Strength} = \frac{220,000\text{N}}{22,500\text{mm}^2} = 9.78\text{N/mm}^2$$

CHAPTER FOUR

RESULTS AND DISCUSSION

During the experimentation phase of the study, certain results were obtained which was useful in evaluating the effect of varying water to cement ratio and compaction pressure on wet and dry properties of rice husk concrete. These results are presented below:

4.1 Results

The experimental results which will be valuable in assessing the effect of varying water to cement ratio and compaction pressure on wet and dry properties of rice husk concrete includes the following:

- 1 Sieve Analysis Test Results
- 2 Specific Gravity Test Results
- 3 Water Absorption Test Results
- 4 Compressive Strength Test Results

Below is a detailed description of the test results:

4.1.1 Sieve Analysis Test

Table 4.1: Sieve Analysis Result for Sand

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
2	16.42	5.47	5.47	94.53
1.18	13.07	4.36	9.83	90.17
0.85	20.89	6.96	16.79	83.21
0.6	22.74	7.58	24.37	75.63
0.425	38.75	12.92	37.29	62.71
0.3	47.76	15.92	53.21	46.79
0.15	70.04	23.35	76.55	23.45
0.075	3.27	1.09	77.64	22.36
Tray	0.68	0.23	77.87	22.13

Table 4.2: Sieve Analysis Result for Granite

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
31.25	0.14	0.01	0.01	99.99
25	88.5	8.63	8.644146341	91.36
20	362.11	35.33	35.33780488	64.66
12.5	504	49.17	49.18073171	50.82
9.5	14.61	1.43	1.435365854	98.56
6.3	29.02	2.83	2.841219512	97.16
4.75	14.83	1.45	1.456829268	98.54
Tray	12.44	1.21	1.223658537	98.78

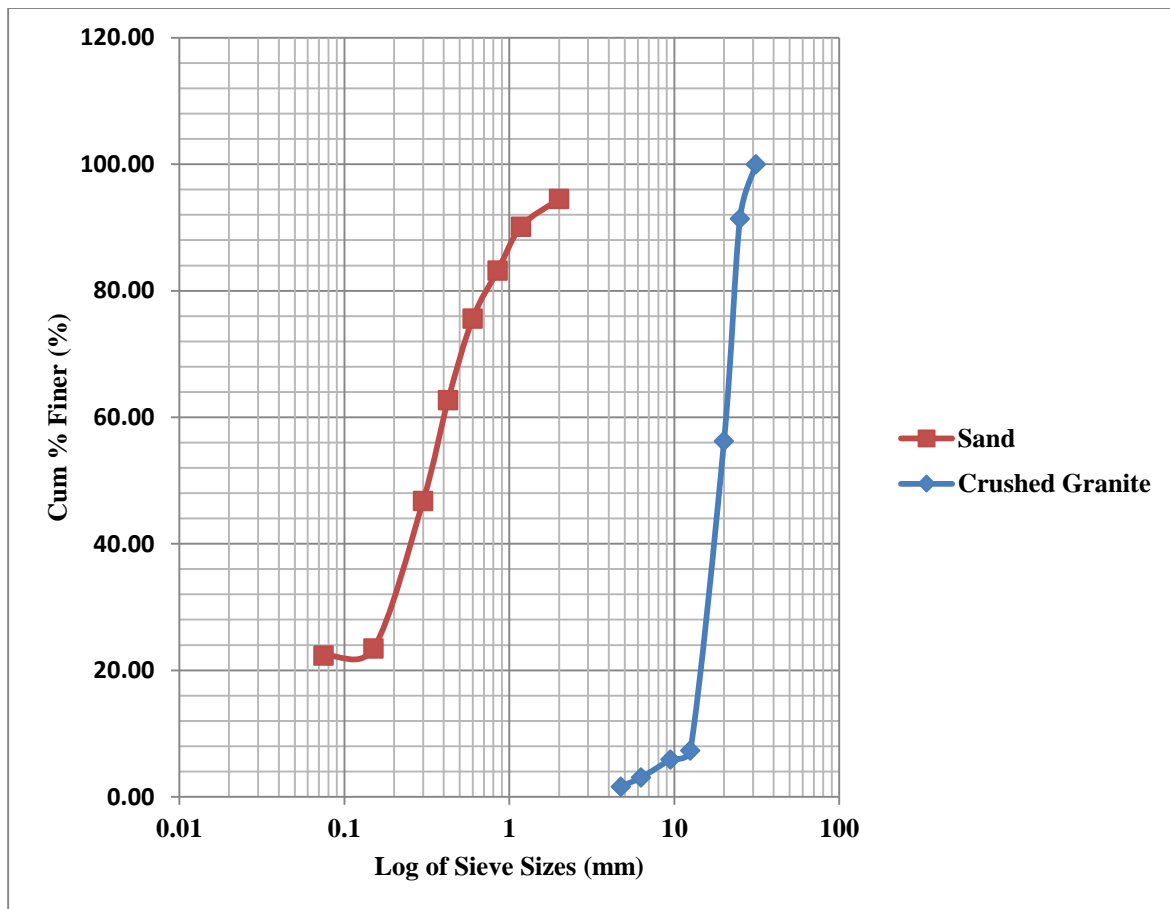


Figure 4.0: Particle Size Distribution Curve for Sand and Granite.

Figure 4.1 is a semi logarithmic plot of the particle size distribution of granite and sand sample respectively. Results obtained revealed that the percentage passing through sieve size 4.75mm for granite was 0.16, coefficient of uniformity and curvature were 1.42 and 0.82 and according to AASHTO classification system, the granite sample was classified as A-1-b and SC (sand mixed with clay) according to unified soil classification system. The percentage passing through sieve size 0.075mm for sand was 43.56 and as a result, the sand sample was classified as A-2-4 according to AASHTO Classification System and SM (sand mixed with silt) according to unified soil classification system.

4.1.2 Specific Gravity Test

Table 4.3: Specific Gravity Result for Sand

Determinants	Trial 1	Trial 2	Trial 3
Wt of density bottle, W₁ (g).	24.64	25.32	25.12
Wt of bottle + dry soil, W₂ (g).	34.48	35.31	35.10
Wt of bottle + soil + water, W₃ (g).	84.43	86.39	85.03
Wt of bottle + water, W₄ (g).	78.35	80.32	78.93

Table 4.4: Specific Gravity Result for Crushed Granite.

Determinants	Trial 1	Trial 2	Trial 3
Wt of empty bucket (W₁)	185.84	198.65	205.82
Wt of bucket + saturated aggregate (W₂)	452.72	465.88	480.75
Wt of Saturated aggregate in air	438.62	442.24	440.82

W₃ (g).			
Wt of Oven-dried aggregate in air	432.80	434.28	434.86
W₄ (g).			

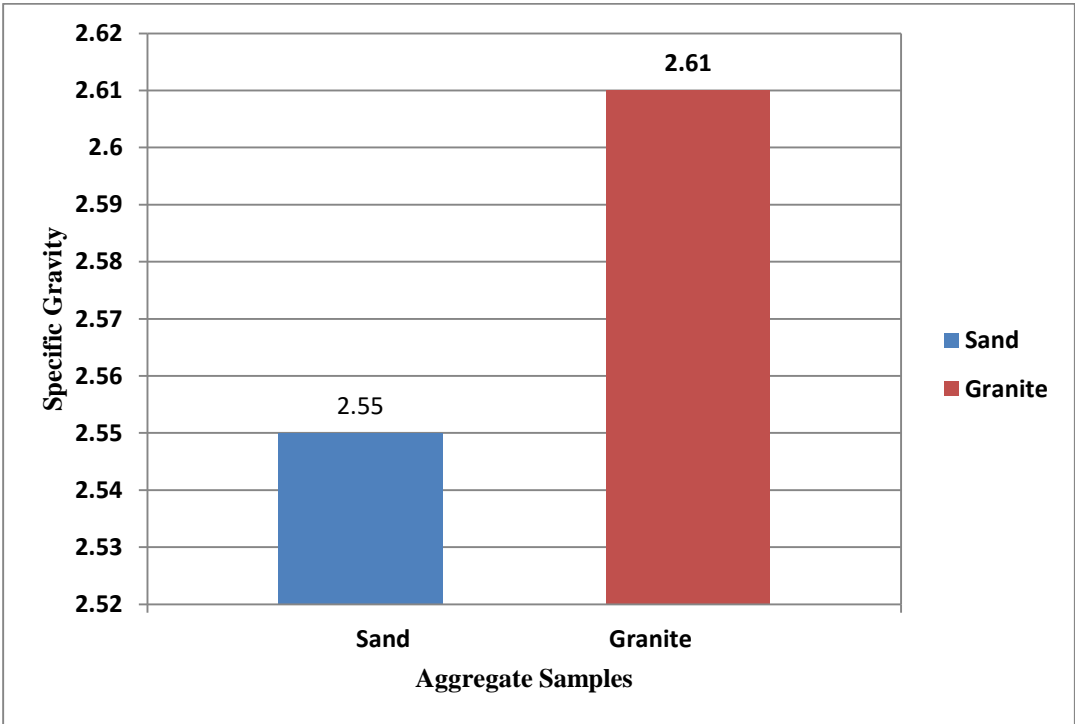


Figure 4.1: Specific Gravity Values for Sand and Granite

Figure 4.1 shows the specific gravity values obtained for granite and sand sample respectively. Comparative deduction revealed that granite sample with a specific gravity of 2.61 recorded the highest specific gravity value. The specific gravity of the aggregate sample tested was greater than 2.4 and as a result, they are classified as normal weight aggregate. The range of specific gravity values (2.55 -2.61) obtained by the study for sand and granite satisfied ASTM D854-14 requirements which state that the specific gravity of aggregate used for concrete production should lie between 2.55 to 2.9 and therefore, the result obtained justifies the use of this aggregates for the study.

4.1.3 Water Absorption Test

Table 4.5: Water Absorption Test Results at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.4	2.8	3.7	7.9	1.4	0.7
225	4.9	5.9	1.9	1.8	1.7	0.8
150	3.0	3.3	2.8	1.7	1.9	1.5
75	4.9	4.1	2.4	3.1	2.5	1.8
15	5.5	6.9	2.4	1.9	1.6	1.7
0	17.7	6.5	5.8	3.3	3.4	3.2

Table 4.6: Water Absorption Test Results at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4	4.1	4.1	1.8	2	3.3
225	5.9	3.8	1.3	1.7	3.1	1.3
150	4.7	3.1	2.3	1.8	1.6	1.4
75	6.1	4.9	1.5	1.5	1.8	1.9
15	9.4	4.4	2.4	1.9	2.3	2.7
0	11.5	9.3	3.7	2.6	3.2	2.4

Table 4.7: Water Absorption Tests Results at 22.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.4	3.3	2.0	1.4	1.3	1.1

225	6.3	2.6	6.9	1.7	1.7	1.0
150	7.3	4.7	2.5	3.5	3.2	2.3
75	6.6	5.8	3.3	4.1	3.1	2.3
15	13.8	6.9	4.1	2.4	3	1.3
0	19.3	12.8	8.2	3.8	3.5	2.7

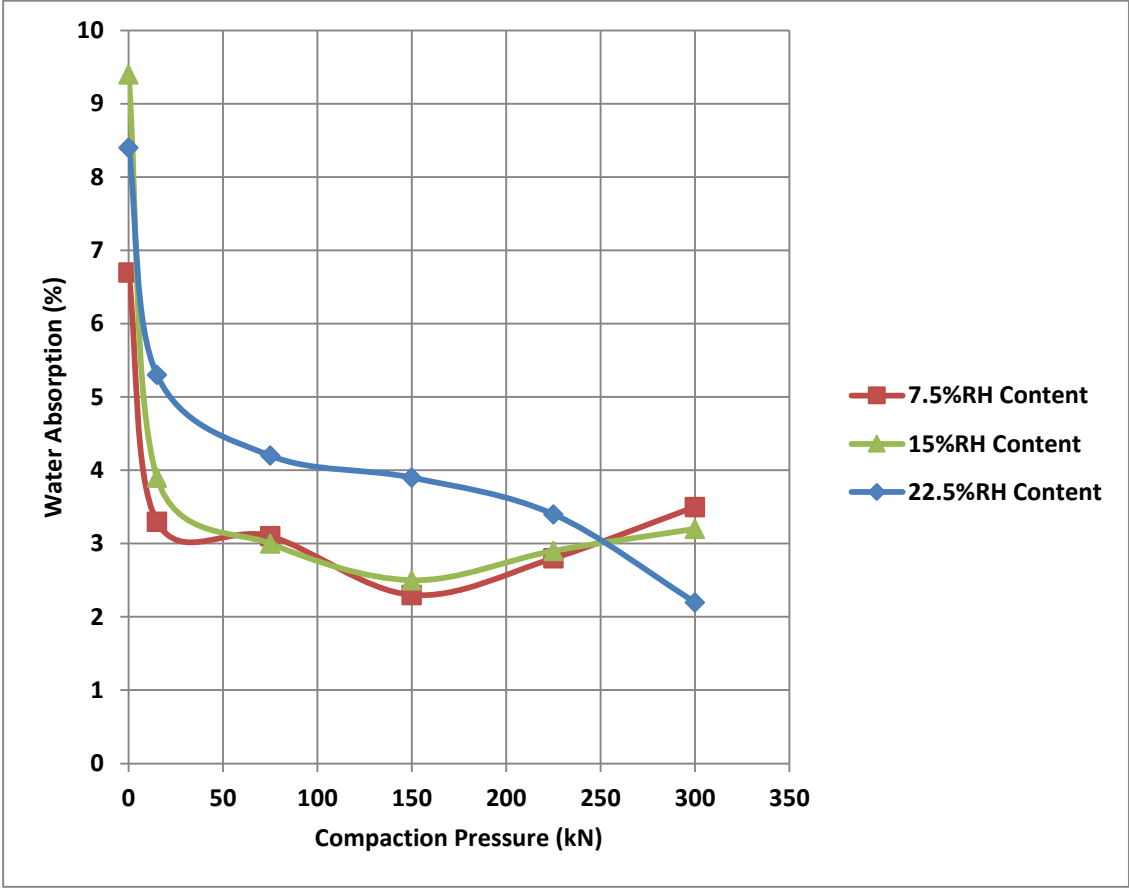


Figure 4.3: Graph of Water Absorption against Compaction Pressure

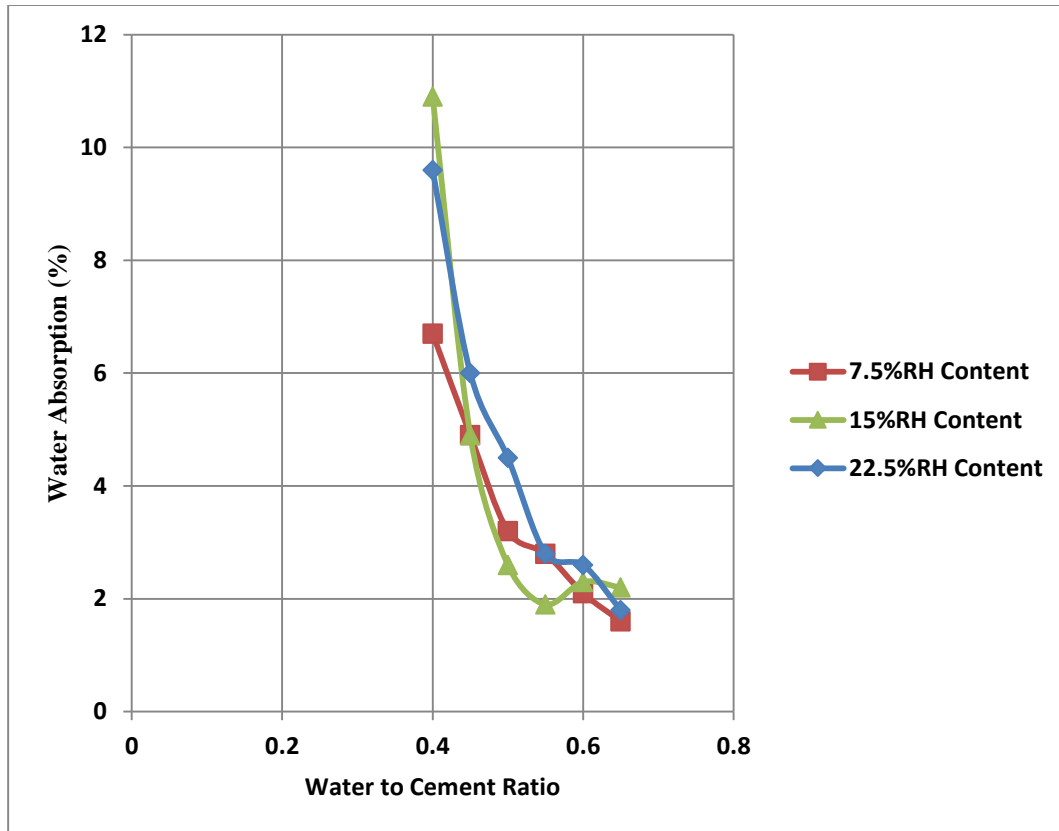


Figure 4.4: Graph of Water Absorption against Water to Cement Ratio

Table 4.5-4.7 shows the water absorption test results obtained for different quantity of rice husk at varying compaction pressure and water to cement ratio. It was observed that the water absorption of the rice husk concrete increased as the percentages of rice husk increases. Assessment of effect of water to cement ratio and compaction pressure on water absorption of rice husk concrete showed that increase in compaction pressure decreased the water absorption of the concrete while increase in water to cement ratio decreased the water absorption of the rice husk concrete. It can therefore be inferred that rice husk concrete with high water to cement ratio absorbs lesser quantity of water than that with lesser water to cement ratio.

4.1.4 Weight of Dry Concrete Cubes

Table 4.8: Weight of Dry Cubes at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	5.25	5.38	5.63	5.9	5.56	5.34
225	4.88	4.92	5.15	5.42	5.35	5.27
150	4.35	4.48	4.65	4.8	4.72	4.54
75	4.12	4.34	4.51	4.58	4.42	4.34
15	3.82	3.94	4.15	4.3	4.25	4.13
0	2.15	2.45	2.58	2.72	2.64	2.52

Table 4.9: Weight of Dry Cubes at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.75	4.88	4.92	5.11	5.05	4.88
225	4.22	4.45	4.58	4.75	4.65	4.54
150	4.04	4.15	4.28	4.35	4.25	4.14
75	3.42	3.64	3.88	4.08	3.85	3.64
15	2.45	2.72	2.88	3.15	3.04	2.92
0	1.87	1.94	2.15	2.28	2.18	2.05

Table 4.10: Weight of Dry Cubes at 22.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.05	4.22	4.48	4.75	4.68	4.55

225	3.78	3.85	3.93	4.15	4.05	3.88
150	3.15	3.38	3.54	3.75	3.7	3.52
75	2.42	2.58	2.75	2.92	2.88	2.65
15	1.88	2.04	2.22	2.48	2.35	2.25
0	1.45	1.72	1.95	2.35	2.3	2.22

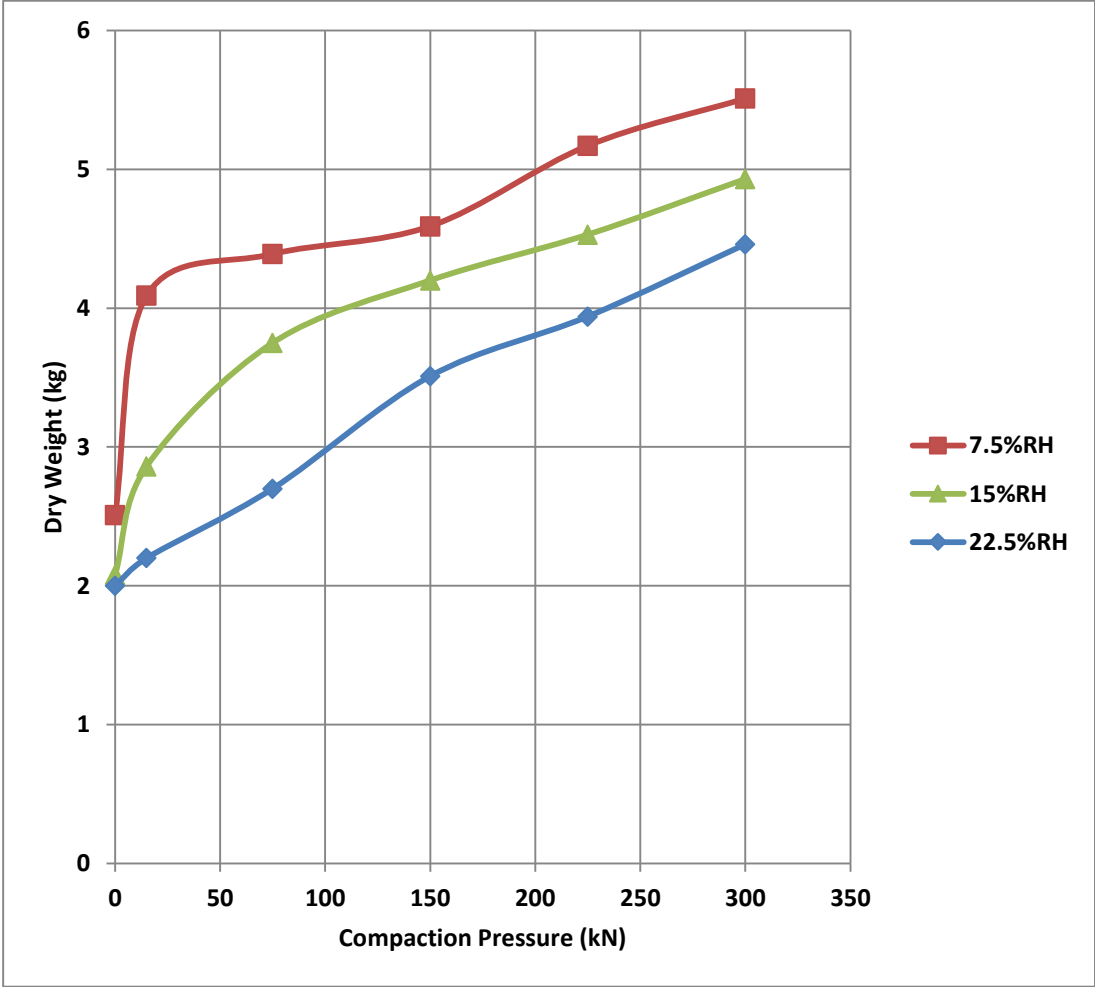


Figure 4.6: Graph Showing the Weight of Dry Concrete Cubes against Compaction Pressure

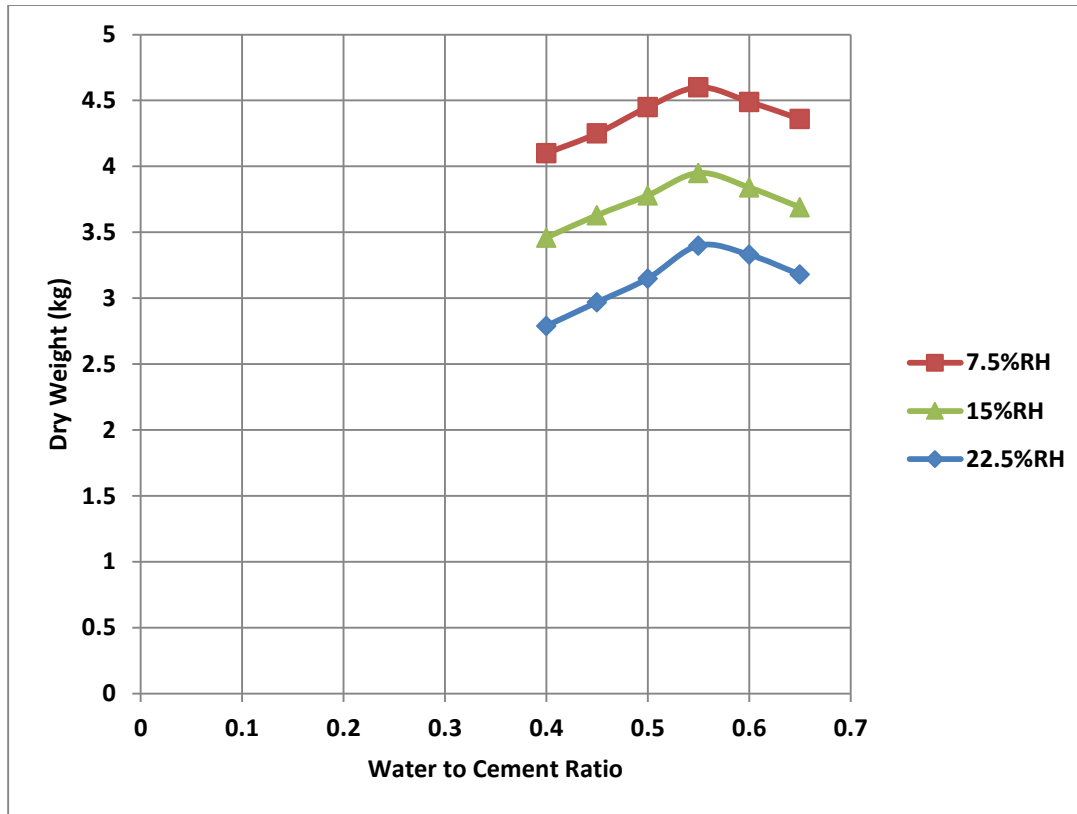


Figure 4.7: Graph Showing the Weight of Dry Concrete Cubes against Water to Cement Ratio

Figure 4.5-4.6 shows the dry weight of the concrete produced with different percentages of rice husk and at varying water to cement ratio and compaction pressure. It was observed that the weight of the dry rice husk concrete cubes decreased as the percentages of rice husk increased. This could be attributed to low density of rice husk as rice husk is a relatively light material. Evaluation of the effect of compaction pressure and water to cement ratio on the dry weight of rice husk concrete revealed that increase in compaction pressure increased the dry weight of the concrete while on addition of water to cement from 0.4 to 0.65, the dry weight of concrete increased from 0.4 to 0.55, beyond water to cement ratio of 0.55, the dry weight of the concrete decreased. The latter decline in dry weight could be attributed to high water to cement content which depressed the dry weight of the concrete. Similar results on effect of compaction pressure and water to cement ratio on weight of the dry rice husk concrete were obtained for all percentages addition of rice husk to the concrete.

4.1.5 Weight of Wet Concrete Cubes

Table 4.11: Weight of Wet Cubes Results at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	5.48	5.53	5.84	6.08	5.64	5.38
225	5.12	5.21	5.25	5.52	5.44	5.31
150	4.48	4.63	4.78	4.88	4.81	4.61
75	4.32	4.52	4.62	4.70	4.53	4.42
15	4.03	4.21	4.25	4.38	4.32	4.2
0	2.53	2.61	2.73	2.81	2.73	2.6

Table 4.12: Weight of Wet Cubes Results at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.94	5.08	5.12	5.2	5.15	5.04
225	4.47	4.62	4.64	4.83	4.79	4.6
150	4.23	4.38	4.38	4.43	4.32	4.2
75	3.63	3.82	3.94	4.14	3.92	3.71
15	2.68	2.84	2.95	3.21	3.11	3.6
0	2.08	2.12	2.23	2.34	2.25	2.1

Table 4.13 Weight of Wet Cubes Results at 22.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.23	4.36	4.57	4.82	4.74	4.6

225	4.02	3.95	4.2	4.22	4.12	3.92
150	3.38	3.55	3.63	3.88	3.82	3.6
75	2.58	2.73	2.84	3.04	2.97	2.71
15	2.14	2.18	2.31	2.54	2.42	2.3
0	1.73	1.94	2.11	2.44	2.38	2.28

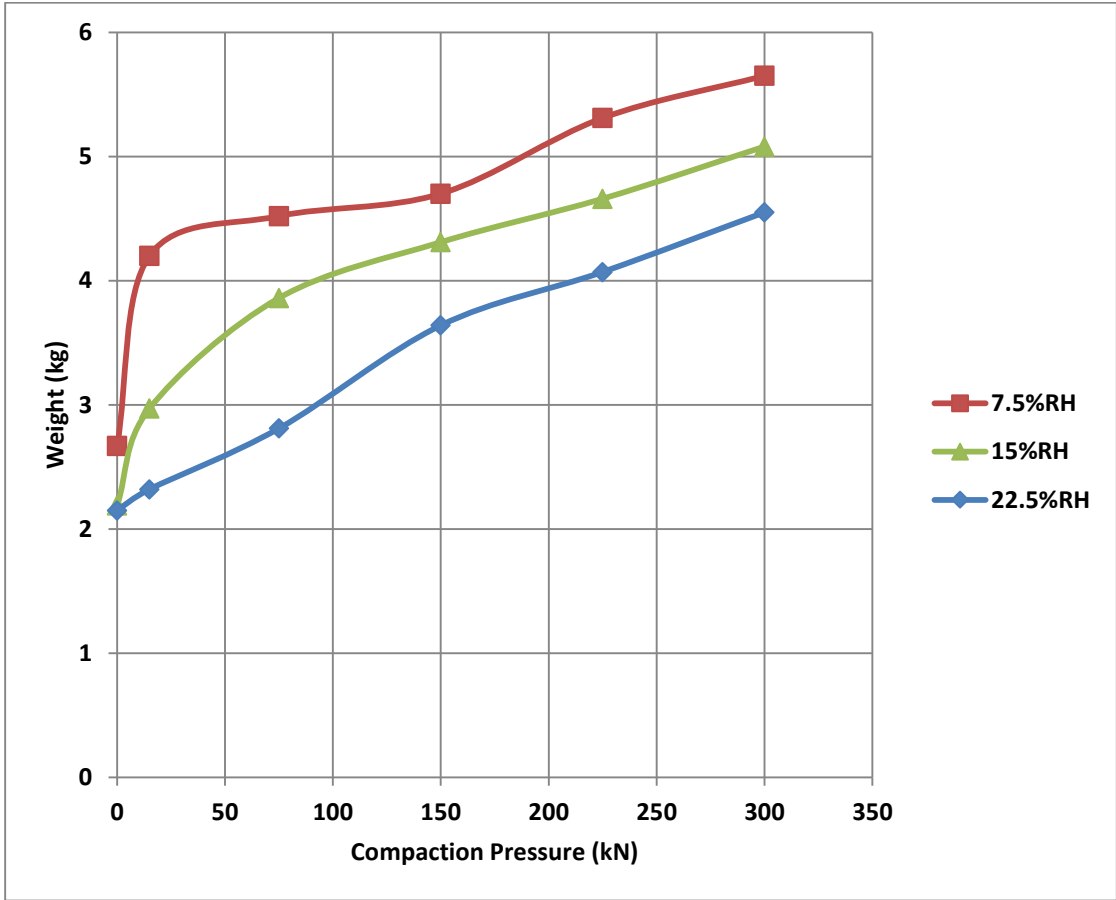


Figure 4.8: Graph Showing the Weight of Wet Concrete Cubes against Compaction Pressure

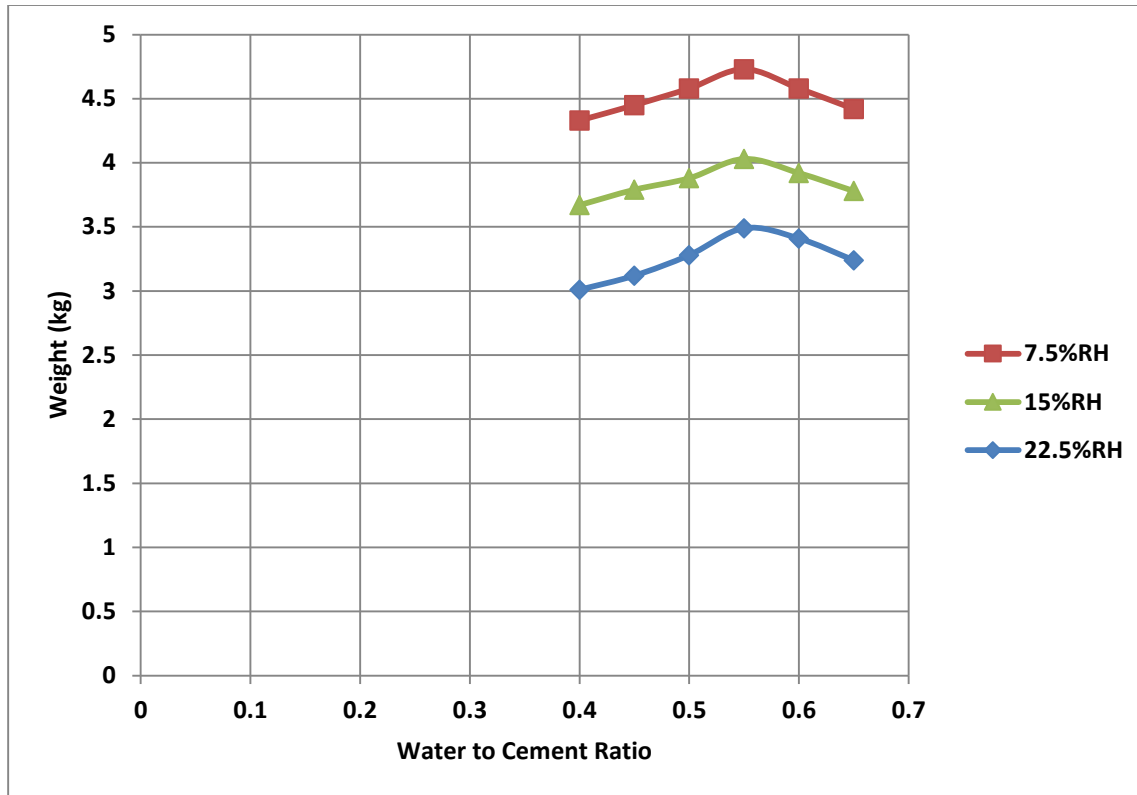


Figure 4.9: Graph Showing the Weight of Wet Concrete Cubes against Water to Cement Ratio

The weight of wet concrete cubes is one of the indices used for evaluating the effect of varying water to cement ratio and compaction pressure on wet properties of rice husk concrete. The results obtained for weight of wet rice husk concrete were similar to that of dry rice husk concrete. It was observed that the weight of the wet rice husk concrete decreased with increase in rice husk content. Variation of compaction pressure and water to cement ratio produced result similar to that of weight of dry concrete.

4.1.6 Failure Load

Table 4.13: Failure Load of the Concrete Cubes at 7.5% RH Content

W/C Ratio/ Compaction	0.4	0.45	0.5	0.55	0.6	0.65

Pressure						
300	420.5	435.7	450.4	462.3	455.2	440.3
225	408.7	414.8	428.2	440.7	432.5	422.4
150	304.7	315.8	338.9	350.4	344.8	330.7
75	282.5	292.8	305.9	323.5	314.5	302.8
15	228.8	245.5	323.5	280.4	272.3	261.4
0	114.3	128.8	280.4	150.3	144.5	132.8

Table 4.14: Failure Load of the Concrete Cubes at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	358.4	372.5	388.3	392.4	382	374.2
225	328.5	333.8	340.7	348.5	342	324.8
150	290.4	304.5	322.3	340.7	328.8	314.5
75	235.5	252.3	267.5	294.3	290.2	278.5
15	185.8	202.5	223.8	238.5	230.3	220.2
0	92.8	104.5	113.2	120.5	114.2	102.2

Table 4.15: Failure Load of the Concrete Cubes at 22.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	305.5	312.5	323.4	330.5	322.4	314.5
225	278.5	288.3	297.5	308.7	302.4	288.9
150	240.2	251.5	258.9	264.3	260.2	252.7
75	190.4	204.5	218.5	223.7	220.4	211.7
15	124.5	138.8	142.3	157.8	150.2	138.8
0	88.7	93.5	98.2	108.3	102.4	92.8

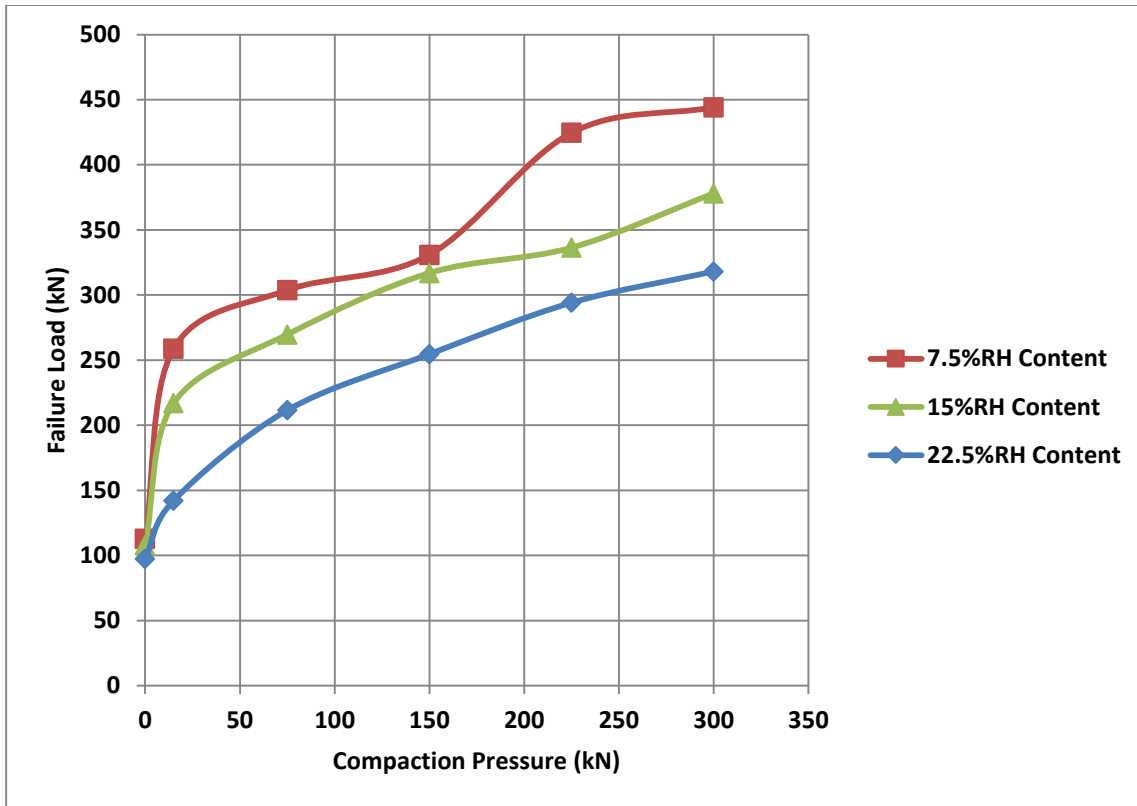


Figure 4.10: Graph of Failure Load against Compaction Pressure

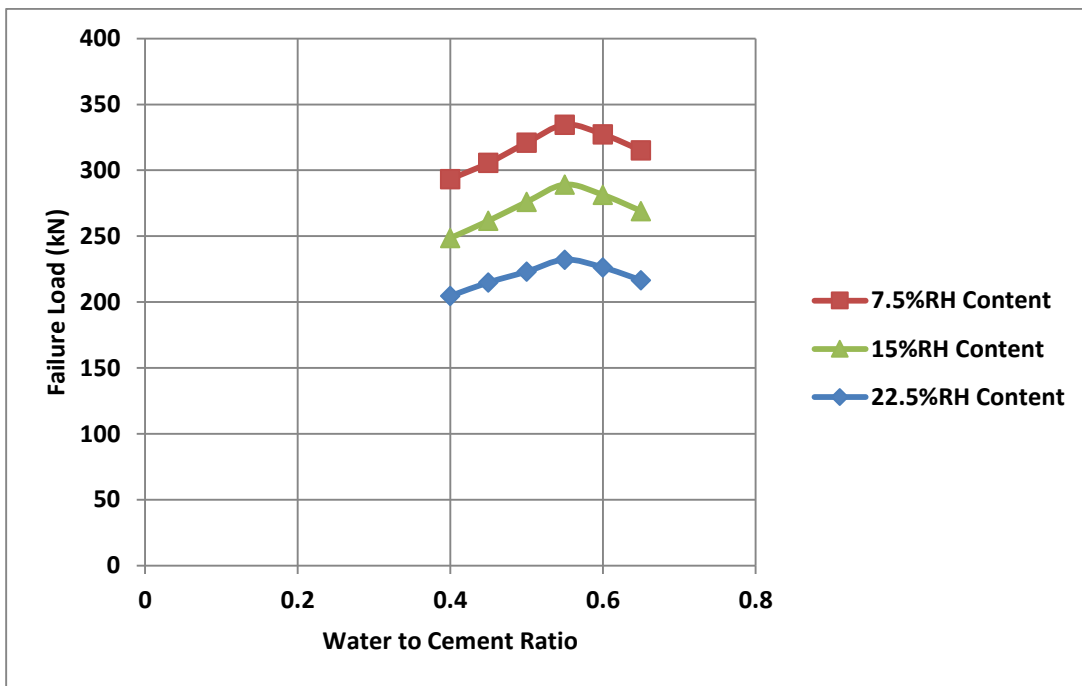


Figure 4.11: Graph of Failure Load against Water to Cement Ratio

Table 4.13-4.15 depicts the results of failure load obtained at different percentages of rice husk and at varying water to cement ratio. It was observed that the load required to crush the concrete cubes decreased as the percentages of rice husk increased. This implies that concrete produced with a relatively low quantity of rice husk can resist substantial amount of load before failure than concrete cubes produced with high amount of rice husk. Evaluation of the effect of compaction pressure and water to cement ratio on failure load of the rice husk concrete suggests that failure load of the concrete increased with increase in compaction pressure and water to cement ratio from 0.4 to 0.55, beyond 0.55, the failure load decreased. Similar results were obtained at all percentage addition of rice husk to the concrete.

4.1.7 Compressive Strength

Table 4.15: Compressive Strength of the Concrete Cubes at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	18.7	19.4	20.0	20.5	20.2	19.6
225	18.2	18.4	19.0	19.6	19.2	18.0
150	13.5	14.0	15.1	15.6	15.3	14.7
75	12.6	13.0	13.6	14.4	14.0	13.5
15	10.2	10.9	11.7	12.5	12.1	11.6
0	5.1	5.7	6.2	6.7	6.4	5.9

Table 4.16: Compressive Strength of the Concrete Cubes at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	15.9	16.6	17.3	17.4	17.0	16.6
225	14.6	14.8	15.1	15.5	15.2	14.4
150	12.9	13.5	14.3	15.1	14.6	14.0
75	10.5	11.2	11.9	13.1	12.9	12.4
15	8.3	9	10.3	10.6	10.2	9.8
0	4.1	4.6	5.0	5.4	5.1	4.5

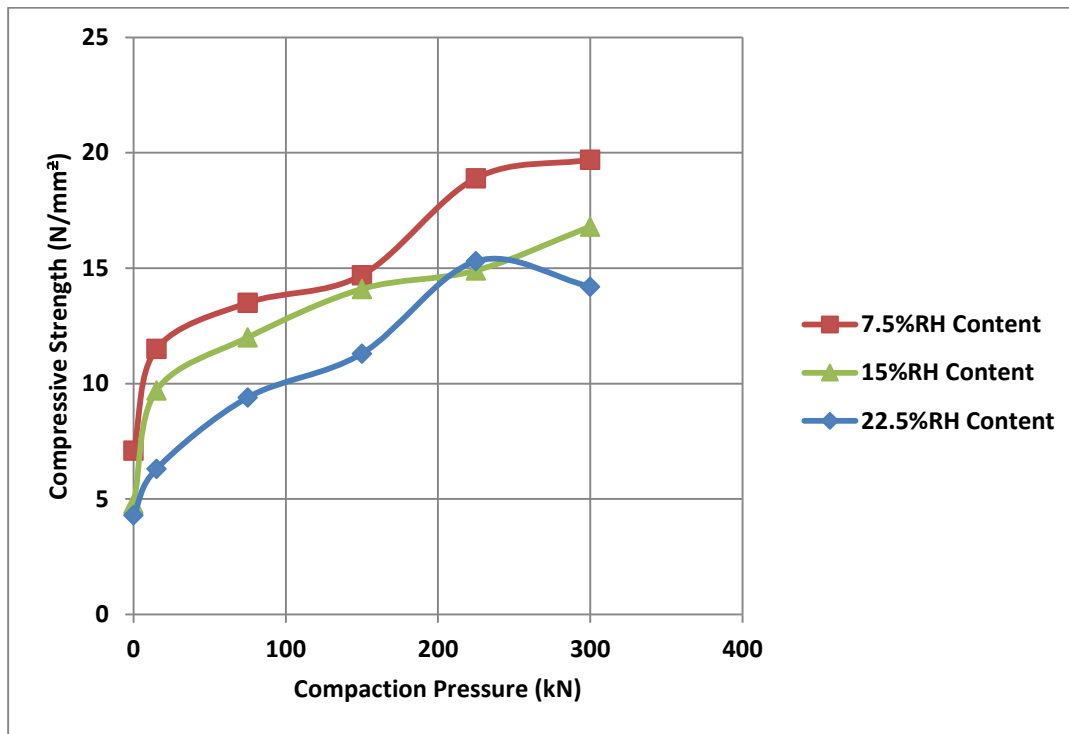


Figure 4.11: Graph of Compressive Strength against Compaction Pressure

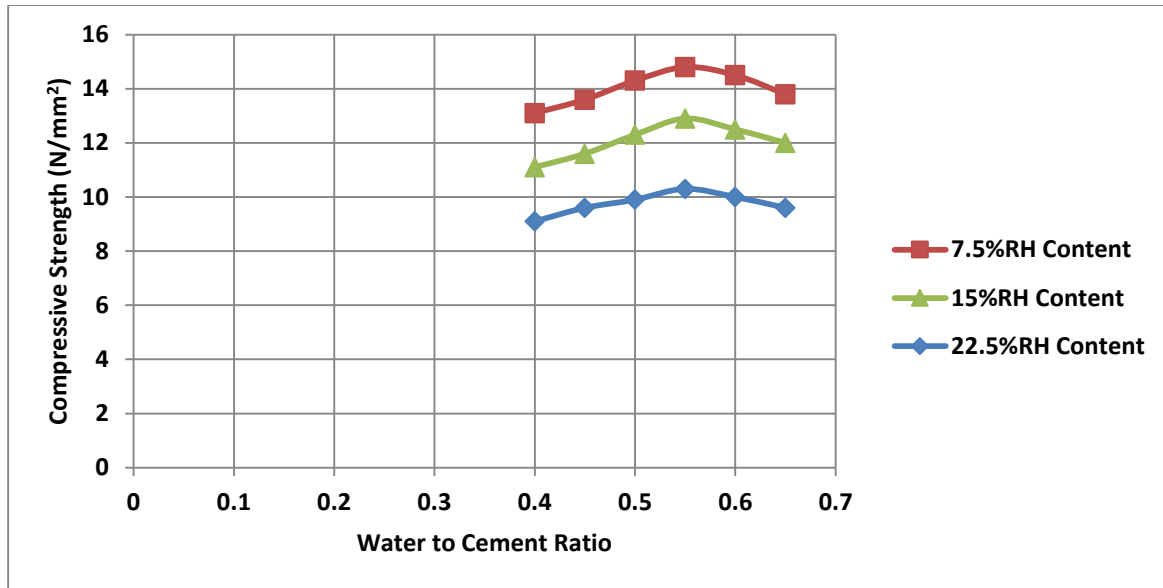


Figure 4.12: Graph of Compressive Strength against Water to Cement Ratio

Table 4.15-4.17 shows the results of compressive strength of the concrete produced using different percentages of rice husk and at varying compaction pressure and water to cement ratio. From the findings, it was observed that the compressive strength of the hardened rice husk concrete decreased with increase in rice husk from 7.5% to 22.5%. The decline in compressive strength on addition of rice husk could be attributed to the low weight of rice husk. Effect varying the water to cement ratio and compaction pressure during casting of rice husk concrete revealed that the compressive strength increased with increase in compaction pressure and increased with increase in water to cement ratio from 0.4 to 0.55 beyond 0.55, the compressive strength of the hardened rice husk concrete decreased. Similar result on effect of compaction pressure and water to cement ratio was obtained for all percentage addition of rice husk to the concrete. It was therefore adjudged that 7.5% rice husk content was deemed an effective quantity for cost effective production of light weight concrete using rice husk.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the findings obtained on the effect of varying compaction pressure and water to cement ratio on wet and dry properties of rice husk concrete, the following conclusion can be drawn:

- 1 Preliminary investigation of the index properties of the concrete components revealed that the materials met standard requirements for use as constituents for concrete production.
- 2 Evaluation of the wet properties of rice husk concrete suggest that the water absorption of the concrete increased with increase in percentages of rice husk and decreased with increase in compaction pressure and water to cement ratio.
- 3 Assessment of the dry properties of the concrete suggest that the weight (both wet and dry) and compressive strength of the concrete cubes increased with increase in compaction pressure and water to cement ratio up to 0.55 but decreased with increase in rice husk content.
- 4 The study adjudged that 7.5% rice husk content was deemed effective for production of light weight concrete using rice husk.

5.2 Recommendation

The following recommendation in the light of the findings obtained from te study can be made:

- 1 The use of rice husk as a constituent for production of light weight concrete should not exceed 7.5% by weight of the material as progression beyond this limit undermines the compressive strength of the concrete.
- 2 Rice husk concrete to be used for non structural purposes should be subjected to an optimum compaction pressure during crushing and water to cement ratio not exceeding 0.55.

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APPENDICES

APPENDIX A

Table 4.1: Sieve Analysis Result for Sand

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
2	16.42	5.47	5.47	94.53
1.18	13.07	4.36	9.83	90.17
0.85	20.89	6.96	16.79	83.21
0.6	22.74	7.58	24.37	75.63
0.425	38.75	12.92	37.29	62.71
0.3	47.76	15.92	53.21	46.79
0.15	70.04	23.35	76.55	23.45
0.075	3.27	1.09	77.64	22.36
Tray	0.68	0.23	77.87	22.13

Table 4.2: Sieve Analysis Result for Granite

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
31.25	0.14	0.01	0.01	99.99
25	88.5	8.63	8.644146341	91.36
20	362.11	35.33	35.33780488	64.66
12.5	504	49.17	49.18073171	50.82
9.5	14.61	1.43	1.435365854	98.56
6.3	29.02	2.83	2.841219512	97.16
4.75	14.83	1.45	1.456829268	98.54
Tray	12.44	1.21	1.223658537	98.78

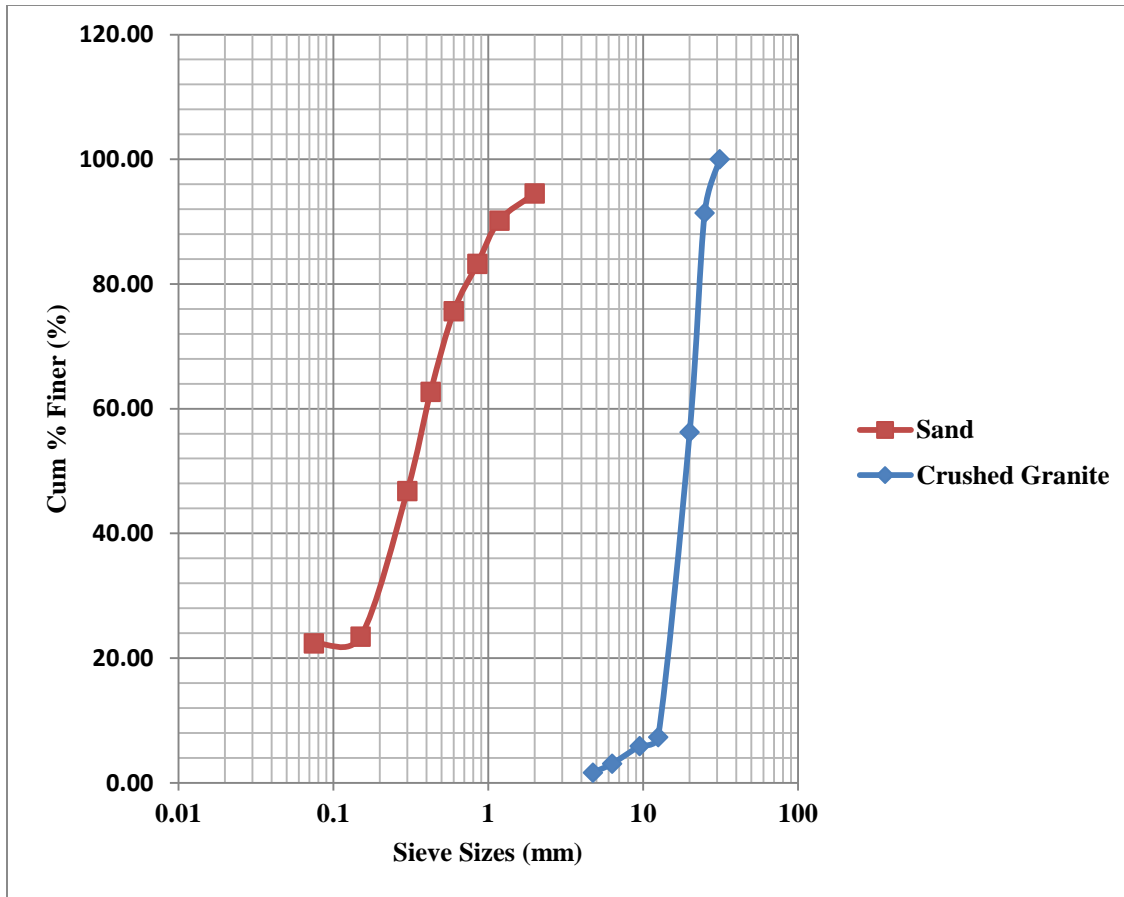


Figure 4.0: Particle Size Distribution Curve for Sand and Granite.

APPENDIX B

4.1.2 Specific Gravity Test

Table 4.3: Specific Gravity Result for Sand

Determinants	Trial 1	Trial 2	Trial 3
Wt of density bottle, W_1 (g).	24.64	25.32	25.12
Wt of bottle + dry soil, W_2 (g).	34.48	35.31	35.10
Wt of bottle + soil + water, W_3 (g).	84.43	86.39	85.03
Wt of bottle + water, W_4 (g).	78.35	80.32	78.93

Table 4.4: Specific Gravity Result for Crushed Granite.

Determinants	Trial 1	Trial 2	Trial 3
Wt of empty bucket (W_1)	185.84	198.65	205.82
Wtof bucket + saturated aggregate (W_2)	452.72	465.88	480.75
Wt of Saturated aggregate in air W_3 (g).	438.62	442.24	440.82
Wt of Oven-dried aggregate in air W_4 (g).	432.80	434.28	434.86

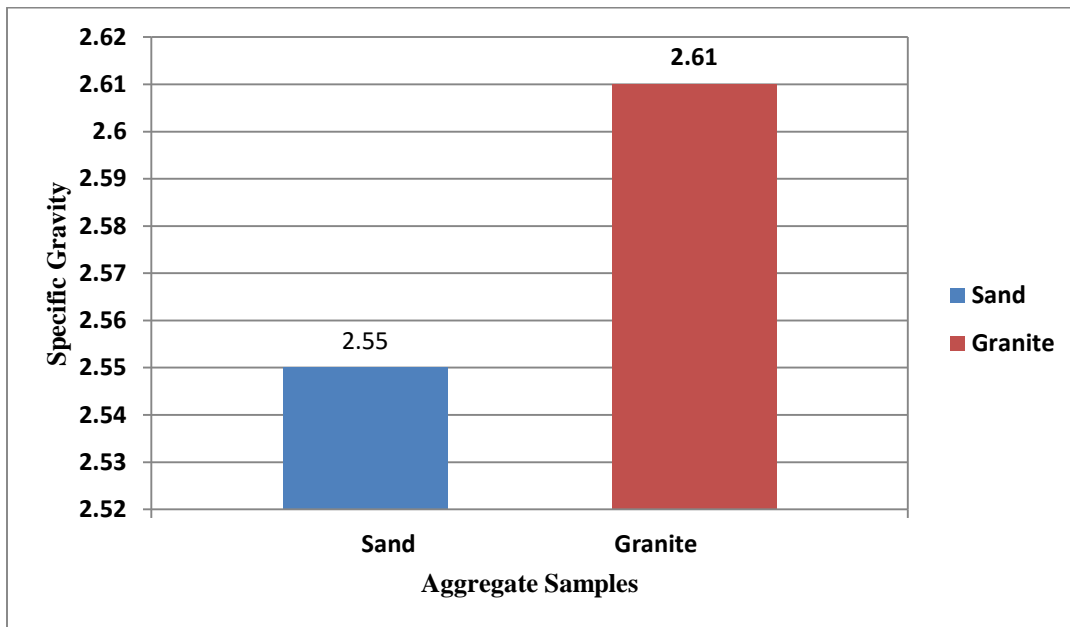


Figure 4.1: Specific Gravity Values for Sand and Granite

APPENDIX C

4.1.3 Water Absorption Test

Table 4.5: Water Absorption Test Results at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.4	2.8	3.7	7.9	1.4	0.7
225	4.9	5.9	1.9	1.8	1.7	0.8
150	3.0	3.3	2.8	1.7	1.9	1.5
75	4.9	4.1	2.4	3.1	2.5	1.8
15	5.5	6.9	2.4	1.9	1.6	1.7
0	17.7	6.5	5.8	3.3	3.4	3.2

Table 4.6: Water Absorption Test Results at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4	4.1	4.1	1.8	2	3.3
225	5.9	3.8	1.3	1.7	3.1	1.3
150	4.7	3.1	2.3	1.8	1.6	1.4
75	6.1	4.9	1.5	1.5	1.8	1.9
15	9.4	4.4	2.4	1.9	2.3	2.7
0	11.5	9.3	3.7	2.6	3.2	2.4

Table 4.7: Water Absorption Tests Results at 22.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.4	3.3	2.0	1.4	1.3	1.1
225	6.3	2.6	6.9	1.7	1.7	1.0
150	7.3	4.7	2.5	3.5	3.2	2.3
75	6.6	5.8	3.3	4.1	3.1	2.3
15	13.8	6.9	4.1	2.4	3	1.3
0	19.3	12.8	8.2	3.8	3.5	2.7

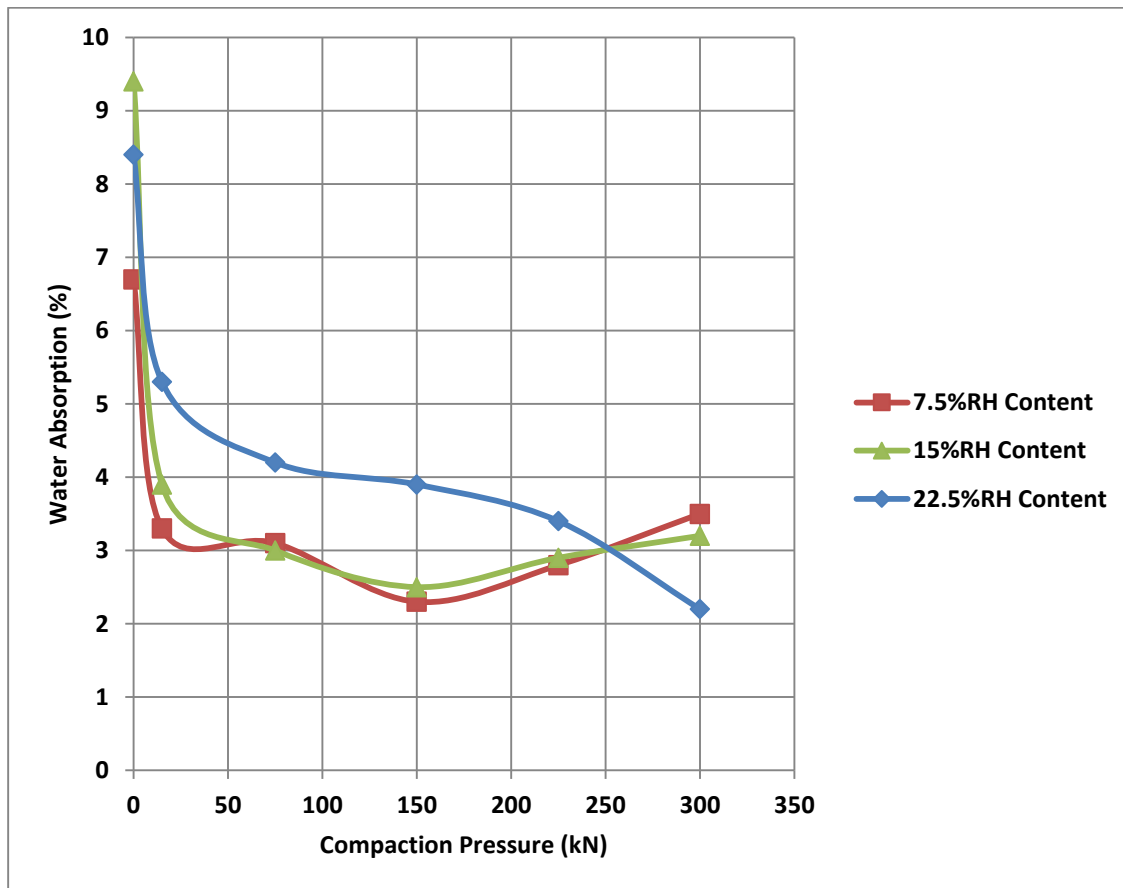


Figure 4.3: Graph of Water Absorption against Compaction Pressure

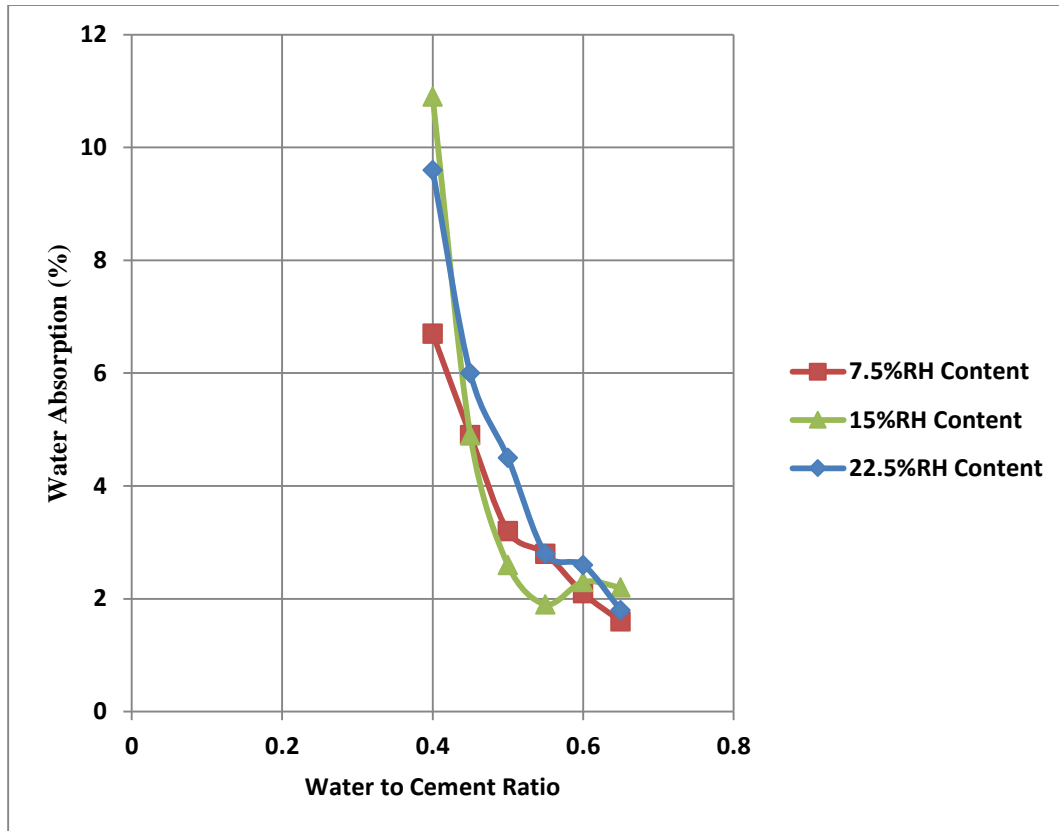


Figure 4.4: Graph of Water Absorption against Water to Cement Ratio

APPENDIX D

COMPRESSIVE STRENGTH TEST

4.1.4 Weight of Dry Concrete Cubes

Table 4.8: Weight of Dry Cubes at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	5.25	5.38	5.63	5.9	5.56	5.34
225	4.88	4.92	5.15	5.42	5.35	5.27
150	4.35	4.48	4.65	4.8	4.72	4.54
75	4.12	4.34	4.51	4.58	4.42	4.34
15	3.82	3.94	4.15	4.3	4.25	4.13
0	2.15	2.45	2.58	2.72	2.64	2.52

Table 4.9: Weight of Dry Cubes at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.75	4.88	4.92	5.11	5.05	4.88
225	4.22	4.45	4.58	4.75	4.65	4.54
150	4.04	4.15	4.28	4.35	4.25	4.14
75	3.42	3.64	3.88	4.08	3.85	3.64
15	2.45	2.72	2.88	3.15	3.04	2.92
0	1.87	1.94	2.15	2.28	2.18	2.05

Table 4.10: Weight of Dry Cubes at 22.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.05	4.22	4.48	4.75	4.68	4.55
225	3.78	3.85	3.93	4.15	4.05	3.88
150	3.15	3.38	3.54	3.75	3.7	3.52
75	2.42	2.58	2.75	2.92	2.88	2.65
15	1.88	2.04	2.22	2.48	2.35	2.25
0	1.45	1.72	1.95	2.35	2.3	2.22

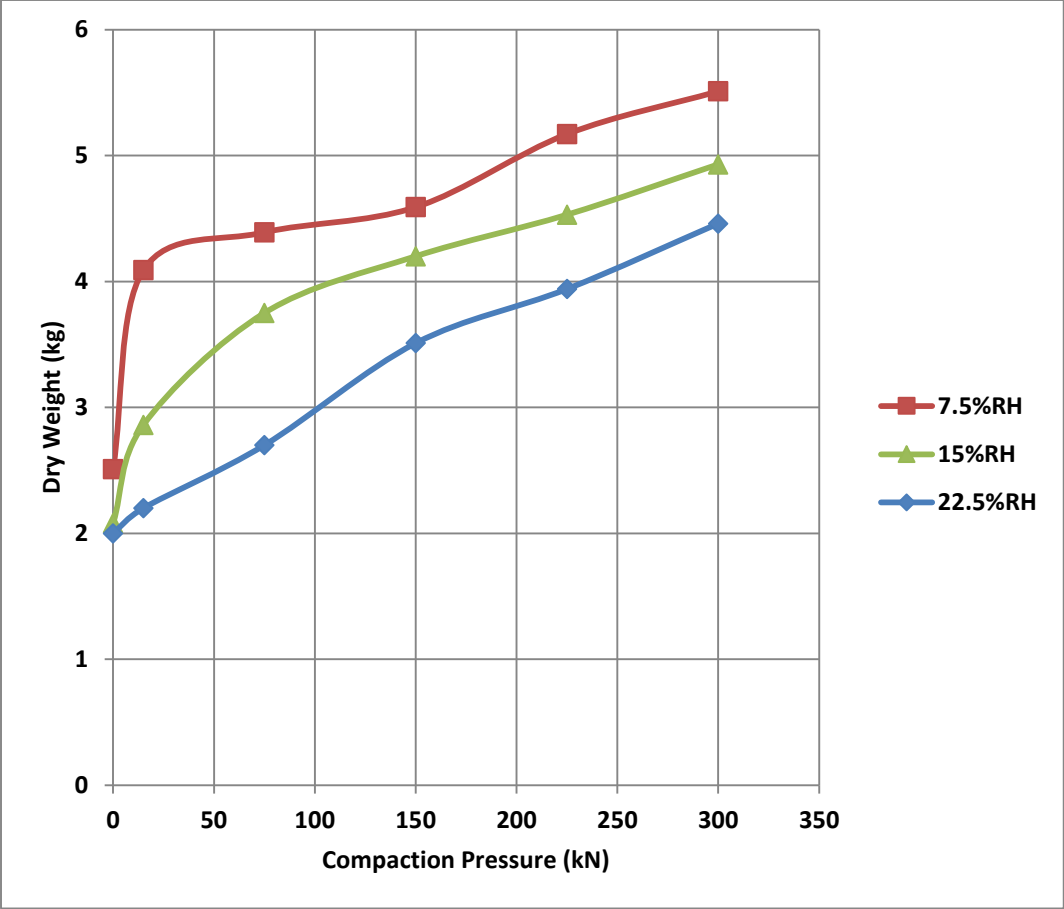


Figure 4.6: Graph Showing the Weight of Dry Concrete Cubes against Compaction Pressure

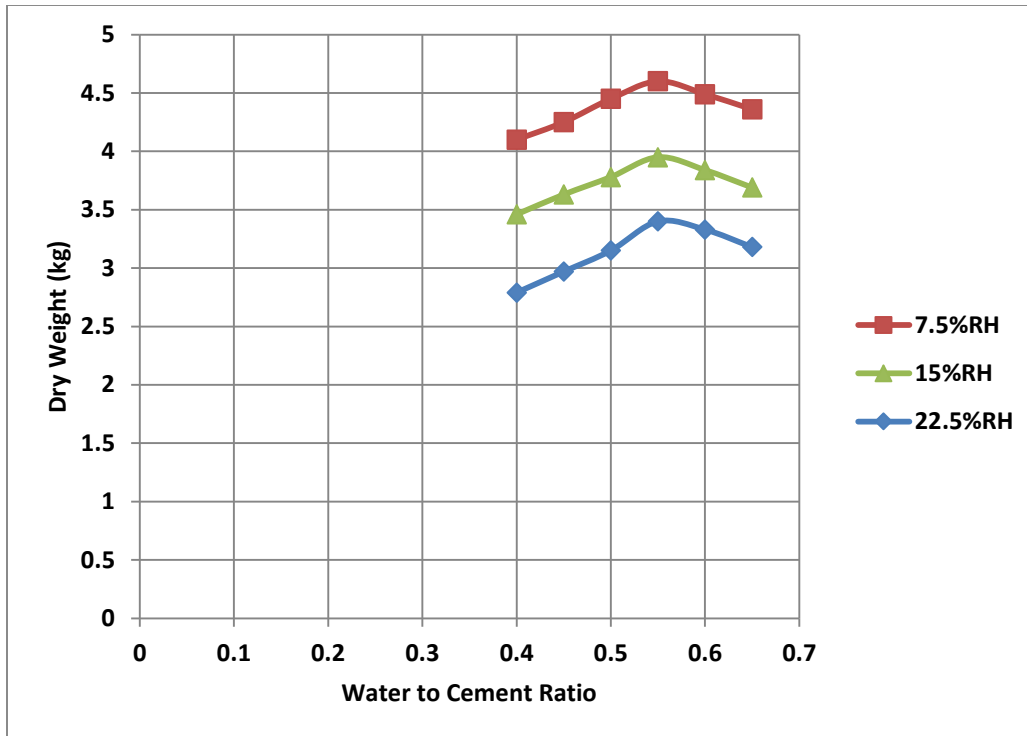


Figure 4.7: Graph Showing the Weight of Dry Concrete Cubes against Water to Cement Ratio

4.1.5 Weight of Wet Concrete Cubes

Table 4.11: Weight of Wet Cubes Results at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	5.48	5.53	5.84	6.08	5.64	5.38
225	5.12	5.21	5.25	5.52	5.44	5.31
150	4.48	4.63	4.78	4.88	4.81	4.61
75	4.32	4.52	4.62	4.70	4.53	4.42
15	4.03	4.21	4.25	4.38	4.32	4.2
0	2.53	2.61	2.73	2.81	2.73	2.6

Table 4.12: Weight of Wet Cubes Results at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.94	5.08	5.12	5.2	5.15	5.04
225	4.47	4.62	4.64	4.83	4.79	4.6
150	4.23	4.38	4.38	4.43	4.32	4.2
75	3.63	3.82	3.94	4.14	3.92	3.71
15	2.68	2.84	2.95	3.21	3.11	3.6
0	2.08	2.12	2.23	2.34	2.25	2.1

Table 4.13 Weight of Wet Cubes Results at 22.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	4.23	4.36	4.57	4.82	4.74	4.6
225	4.02	3.95	4.2	4.22	4.12	3.92
150	3.38	3.55	3.63	3.88	3.82	3.6
75	2.58	2.73	2.84	3.04	2.97	2.71
15	2.14	2.18	2.31	2.54	2.42	2.3
0	1.73	1.94	2.11	2.44	2.38	2.28

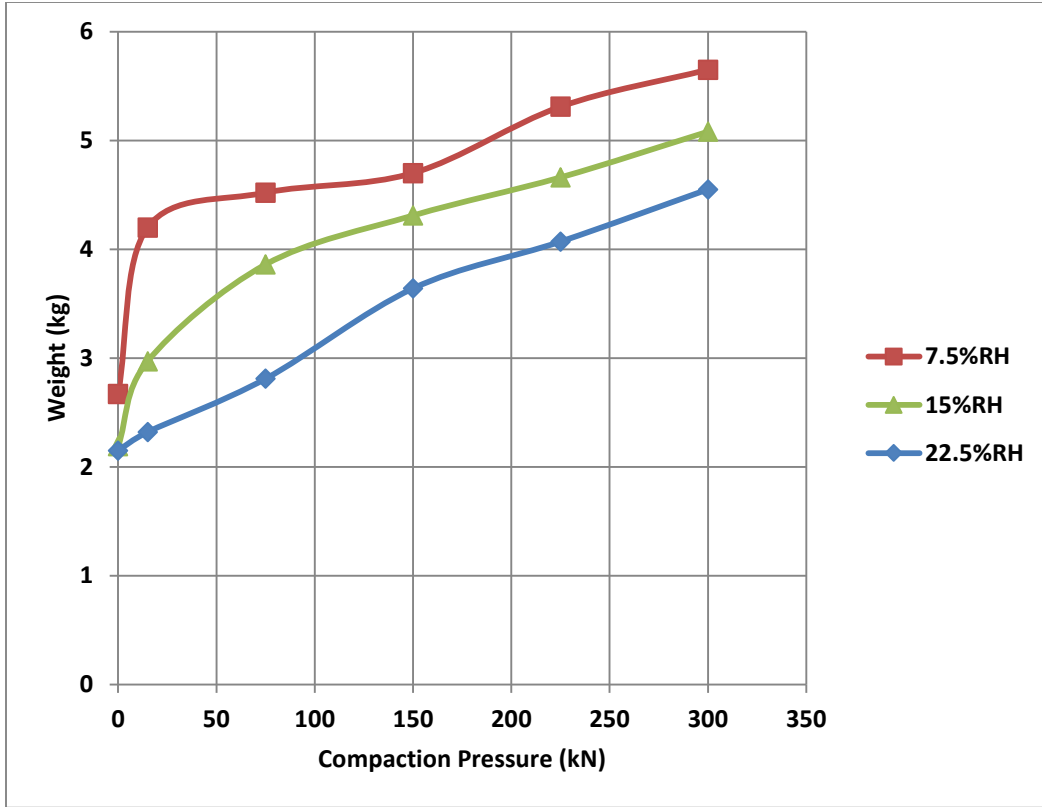


Figure 4.8: Graph Showing the Weight of Wet Concrete Cubes against Compaction Pressure

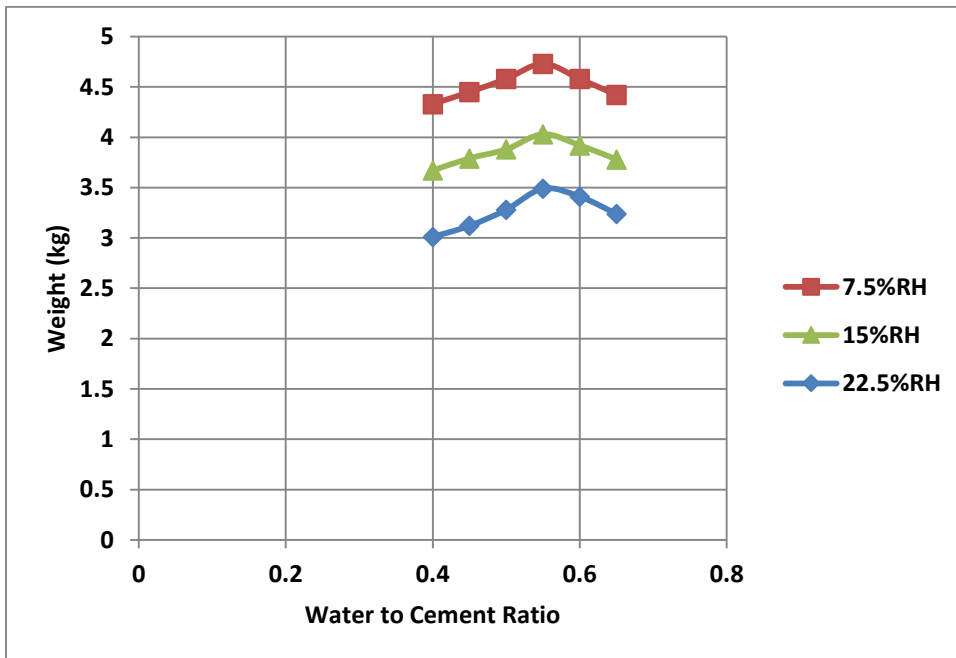


Figure 4.9: Graph Showing the Weight of Wet Concrete Cubes against Water to Cement Ratio

4.1.6 Failure Load

Table 4.13: Failure Load of the Concrete Cubes at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	420.5	435.7	450.4	462.3	455.2	440.3
225	408.7	414.8	428.2	440.7	432.5	422.4
150	304.7	315.8	338.9	350.4	344.8	330.7
75	282.5	292.8	305.9	323.5	314.5	302.8
15	228.8	245.5	323.5	280.4	272.3	261.4
0	114.3	128.8	280.4	150.3	144.5	132.8

Table 4.14: Failure Load of the Concrete Cubes at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	358.4	372.5	388.3	392.4	382	374.2
225	328.5	333.8	340.7	348.5	342	324.8
150	290.4	304.5	322.3	340.7	328.8	314.5
75	235.5	252.3	267.5	294.3	290.2	278.5
15	185.8	202.5	223.8	238.5	230.3	220.2
0	92.8	104.5	113.2	120.5	114.2	102.2

Table 4.15: Failure Load of the Concrete Cubes at 22.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	305.5	312.5	323.4	330.5	322.4	314.5
225	278.5	288.3	297.5	308.7	302.4	288.9
150	240.2	251.5	258.9	264.3	260.2	252.7
75	190.4	204.5	218.5	223.7	220.4	211.7
15	124.5	138.8	142.3	157.8	150.2	138.8
0	88.7	93.5	98.2	108.3	102.4	92.8

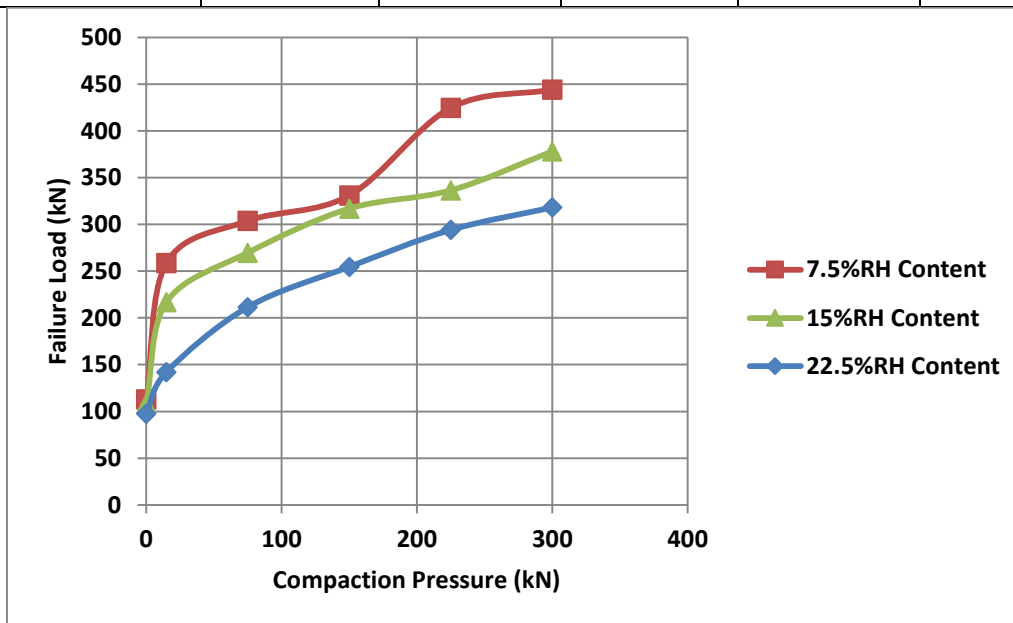


Figure 4.10: Graph of Failure Load against Compaction Pressure

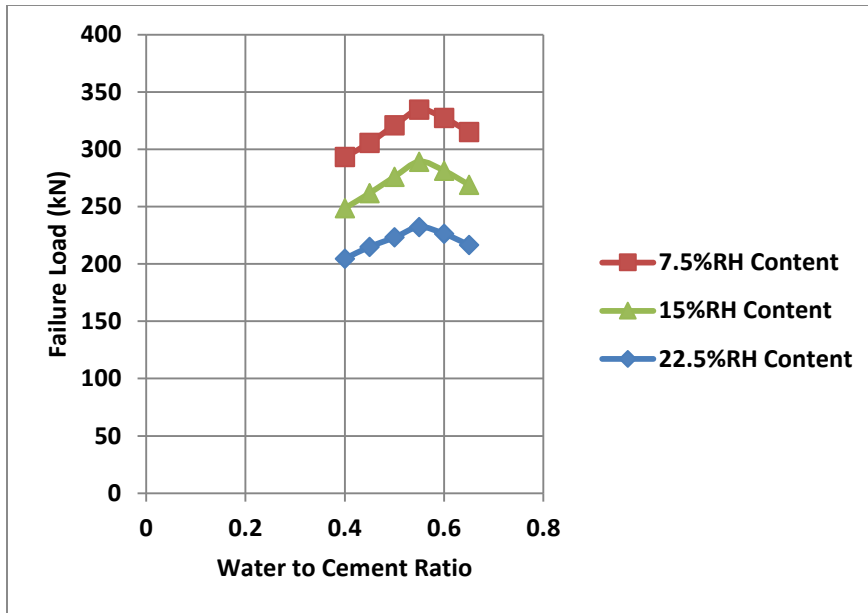


Figure 4.11: Graph of Failure Load against Water to Cement Ratio

4.1.7 Compressive Strength

Table 4.15: Compressive Strength of the Concrete Cubes at 7.5% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	18.7	19.4	20.0	20.5	20.2	19.6
225	18.2	18.4	19.0	19.6	19.2	18.0
150	13.5	14.0	15.1	15.6	15.3	14.7
75	12.6	13.0	13.6	14.4	14.0	13.5
15	10.2	10.9	11.7	12.5	12.1	11.6
0	5.1	5.7	6.2	6.7	6.4	5.9

Table 4.16: Compressive Strength of the Concrete Cubes at 15% RH Content

W/C Ratio/ Compaction Pressure	0.4	0.45	0.5	0.55	0.6	0.65
300	15.9	16.6	17.3	17.4	17.0	16.6
225	14.6	14.8	15.1	15.5	15.2	14.4
150	12.9	13.5	14.3	15.1	14.6	14.0
75	10.5	11.2	11.9	13.1	12.9	12.4
15	8.3	9	10.3	10.6	10.2	9.8
0	4.1	4.6	5.0	5.4	5.1	4.5

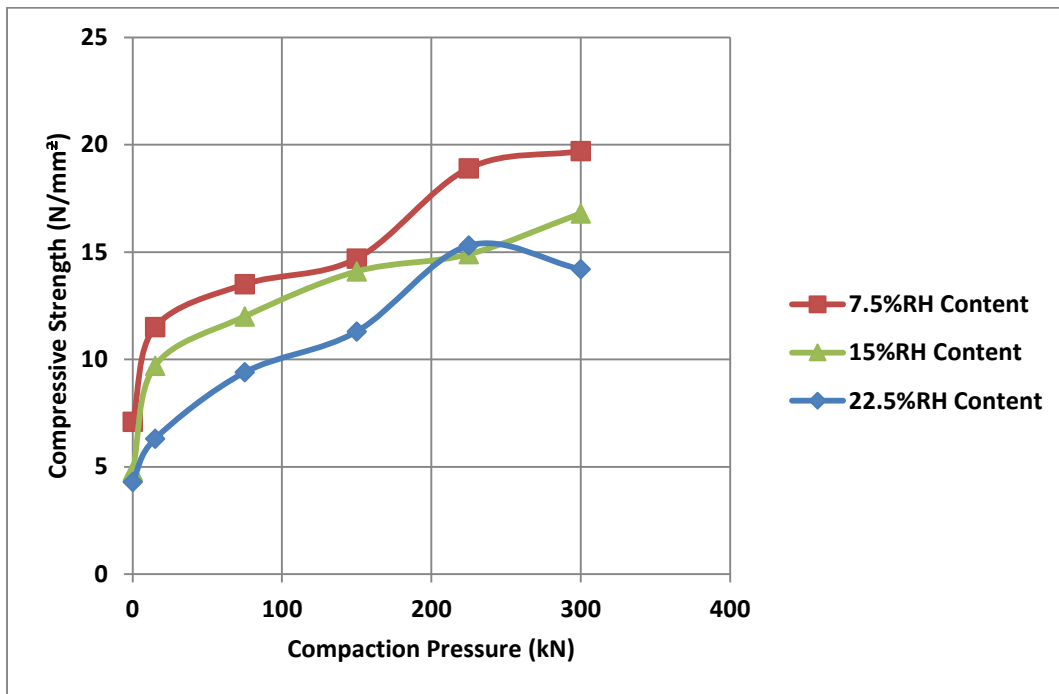


Figure 4.11: Graph of Compressive Strength against Compaction Pressure

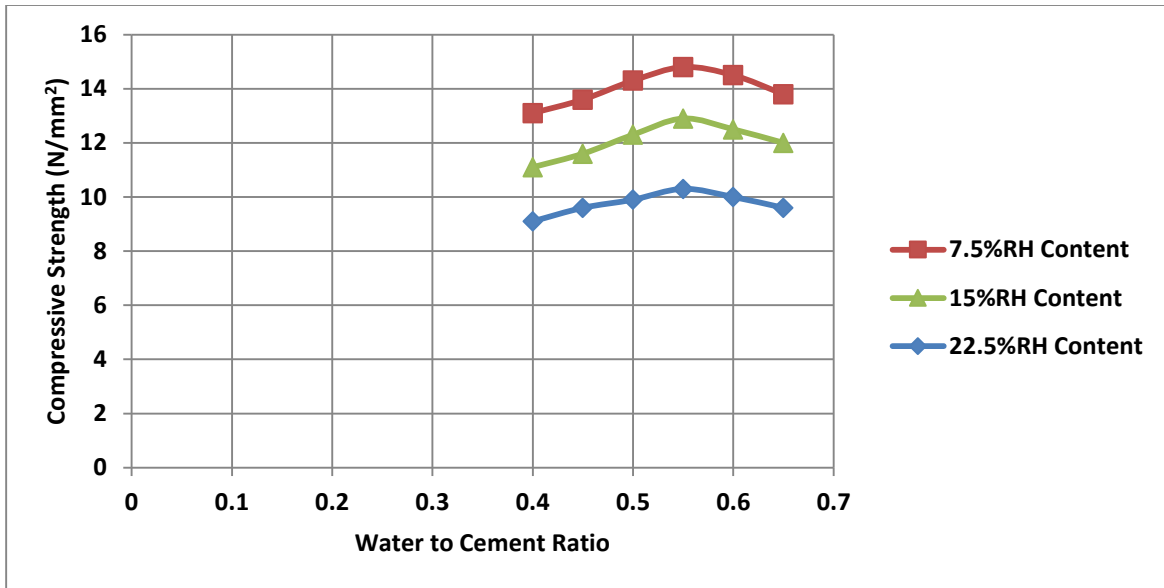


Figure 4.12: Graph of Compressive Strength against Water to Cement Ratio