MODELLING COMPRESSIVE AND FLEXURAL STRENGTHS OF CONCRETE WITH PERIWINKLE SHELLS AS PARTIAL REPLACEMENT OF COARSE AGGREGATES BY RESPONSE SURFACE METHODOLOGY

BY

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ABSTRACT

Concrete has been identified over many decades as the most common and used material in the construction industry. The continuous use of normal concrete products has resulted into high cost of constituent materials, high self weight, and depletion of rock fragments, which distorts the ecosystem. This research work focuses on the compressive and flexural strength of concrete using periwinkle shell as partial replacement to coarse aggregate. The physical and mechanical properties of sharp sand, granite and periwinkle shell were determined. Absolute volume method of mix design was used with the inclusion of four independent variables of water/cement ratio, total aggregate/cement ratio, coarse aggregate/total aggregate ratio and periwinkle shell/coarse aggregate ratio, and the MINITAB software was used to generate the number of mixes for the work. A total of 204 each of concrete cubes of 150mm x 150mm x 150mm and concrete beams of 100mm x 100mm x 500mm were cast from the generated mixes, tested, and their physical and mechanical properties were determined. The analyses of the result were done and computations of compressive and flexural strengths were calculated. The results obtained for the 28th day compressive and flexural strengths ranged from 9.99-19.30, and 6.25-11.13 N/mm^2 respectively. As obtained from experiment, the results from the mechanical properties test complied with the requirement of structural and non structural lightweight concrete as stipulated in British Standard, BS 8110 :Part 2 :1985. Concrete mixes which gave compressive strengths greater than 17N/mm^2 can be used as structural lightweight concrete. The polynomial models have proven to be adequate in predicting the compressive and flexural strength of concrete incorporating periwinkle shell to 80.11% accuracy at the minimum.

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CHAPTER ONE

1.0 INTRODUCTION

1.6 Background to the Study

Concrete is one of the major building materials in civil engineering practice and construction works in Nigeria and most countries of the world. The use of concrete for structural elements can easily seen in buildings, highways/bridges, runways, jetties. The increased demand for constituent's materials for concrete gave rise to the need for researches into materials that are locally available. Concrete is defined by the kind of aggregate or cement used, the specific qualities it manifests or the methods adopted to produce it. The behaviour of concrete is greatly determined by a water/cement ratio. So different types of concrete are produced based on the material constituents, mix design, method of construction, area of application, and form of hydration reaction. Normal strength concrete, plain or ordinary concrete, reinforced concrete, prestressed concrete, precast concrete, light weight concrete, high density concrete are some types of concrete (Olutoge *et al.*, 2012). Light weight concrete (LWC) has been found to be lighter than conventional concrete with normal weight aggregate concrete (El Zareef, 2010; Babu, 2008). LWC has an oven dry density which ranges from about 300 to not more than 2000 kg/m^3, with a compressive strength for a cube from 1 - 60 N/mm^2. These values can be compared to those for normal weight concrete with approximately 2100-2500 kg/m^3, 15 to greater than 100 N/mm^2 (Newman *et al.*, 2003). Lightweight concrete can be classified according to:

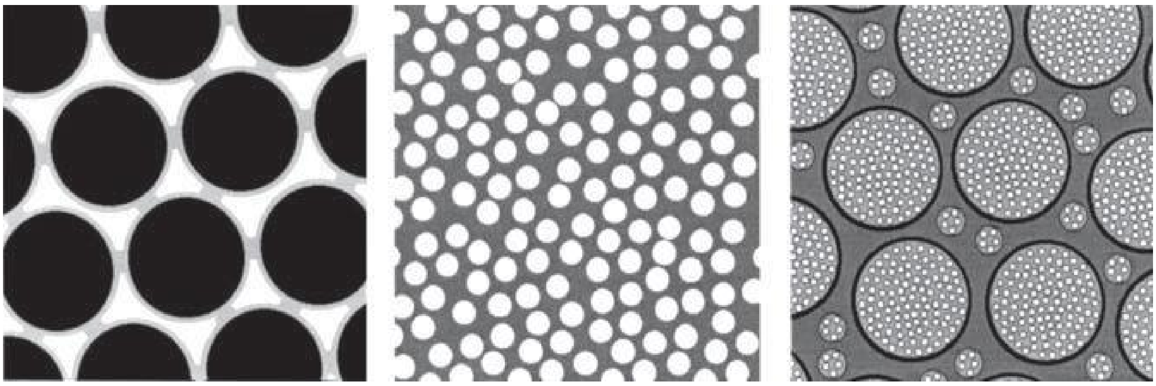
(i) The production methods

These classes of lightweight concrete are based on the method of production:

(a) Lightweight aggregate concrete: This kind of concrete is prepared using lightweight aggregate of low specific gravity in place of the normal weight aggregate, that is the specific gravity of lightweight aggregate is lower than 2.6.

(b) Aerated concrete: this is made by inducing bubble voids within the concrete or mortar mass. This type of concrete is known as cellular, or foamed, or gas concrete.

(c) No- fines concrete: Elimination of the fine aggregate from the mix so that the coarse aggregate of ordinary weight is generally used (Neville and Brooks, 2010; Slaby *et al.*, 2008; Sommerville *et al.*, 2011). Figure 1.1 shows these types of lightweight concrete (Newman *et al*, 2003).



No-fines concrete **Aerated concrete** **Lightweight aggregate concrete**

Figure 1.1: Basic shapes of lightweight concrete

(ii) The utilization purpose

Light weight concrete is classified considering its utilization purpose as:

(i) Structural lightweight concrete with compressive strength at 28 days equal or more than 17 N/mm^2 and the approximate density range 1400-1800 kg/m^3.

(ii) Masonry concrete (structural / insulating lightweight concrete) has been noted to have a compressive strength between 7-14 N/mm^2 and density range 500-800kg/m^3.

(iii) Insulating concrete has a compressive strength between 0.7-7 N/mm^2 and density lower than 800 kg/m^3 (Neville and Brooks, 2010).

The conventional normal weight coarse aggregates needed for construction purposes are expensive (Ede *et al.*, 2014). The alternative coarse aggregates such as periwinkle shells which is an external exoskeleton that protects the periwinkles from their predators and mechanical damage. These periwinkles are commonly found in the lagoons and mudflats of the South West and Niger Delta of Nigeria (Dahunsi, 2003; Olutoge *et al.*, 2012).

The Periwinkle shell has been investigated by several researchers as a coarse aggregate, which were regarded as pollutants due to their unsightly appearance in open dumpsites and used as partial replacement for the scarce and expensive conventional normal weight coarse aggregates for the production of lightweight concrete.

It has been argued that the flexural strength property of concrete is important particularly when the concrete structure has no steel reinforcement. For example, unreinforced concrete roads and runways rely on their flexural strengths to safely distribute concentrated loads over wide areas. It appears to be true for tensile strength property of concrete (Mtallib and Marke, 2010).

1.2 Problem Statement

After centuries of speedy advancement and the accompanying gap between the rich and the poor, the world is becoming more conscious of the ecosystem and the future of mankind. This has led to the growing quest for sustainable development. Researches focused on materials for affordable housing for the increasing low-income masses which are on the increase (Ede *et al.*, 2014).

Over the years, quarry activities in sourcing for granite and gravel have greatly impacted the environment negatively due to continual distortion of the ecosystem (Olutoge *et al.*, 2012).

Several works have been done to utilise Periwinkle Shell as partial replacement to coarse aggregate but most of the work dwells on compressive strength and flexural strength of concrete Adewuyi and Adegoke (2008), Amaziah *et al*. (2013), Ettu *et al*. (2013), Falade *et al*. (2010), and Osarenwinda and Awaro (2009). Limited works are on modelling compressive and flexural strength as a function of mix constituents. Also, limited emphasis was made on modelling the relationship between compressive strength and flexural strength of concrete.

1.3 Aim and Objectives of the Study

Aim;

The aim of this work is to model the compressive and flexural strengths of concrete using periwinkle shell as partial replacement to coarse aggregate.

Objectives;

The objectives of the work are;

(i) to determine the physical characteristics of the constituent materials.

(ii) to determine the compressive and flexural strengths of the concrete.

(iii) to develop models for predicting compressive and flexural strengths of concrete.

1.4 Justification of the Study

Efforts were constantly made in the direction of waste management strategies which include performance of concrete using Periwinkle Shells as partial replacement to coarse aggregates. The research work would provide numerical data for compressive and flexural strengths of concrete using several mix compositions. In areas where construction materials are not readily available and are relatively expensive, this would give more people affordable access to housing as a result of huge saving in the cost of construction. This would help in converting waste to wealth in areas where periwinkle shells are largely dumped as waste and hereby creating timely employment and livelihood for the teaming youth.

Models for compressive and flexural strengths of concrete incorporating periwinkle shells would serve as a guide to Engineers for mix design.

The relationship between the compressive and flexural strengths of concrete incorporating periwinkle shells would assist Engineers in estimating the strength parameters of interest during design and construction.

This research work would further intensify the awareness and importance on the use of concrete made with the incorporation of periwinkle shells at varying percentages in areas where it is readily available.

The findings of this research work would be additional knowledge to the available knowledge on the concrete made with cement, fine aggregates, coarse aggregates and periwinkle shells.

1.5 Scope of the Study

This research work is limited to modelling compressive and flexural strengths of concrete using periwinkle shells as partial replacement to coarse aggregates. The materials used for the laboratory work were cement (OPC), water, sharp sand, granite, and periwinkle shells. This research work requires the following

(i) The mix proportion for the light weight concrete will be designed using MINITAB soft ware.

(ii) Material and concrete testing would be limited to laboratory conditions.

(iii) The concrete properties considered are only compressive and flexural strengths.

(iv) Modelling of the properties of concrete considers the input variables as its independent variables.

(v) Modelling of the compressive and flexural strengths would be done using MINITAB soft ware.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Materials

2.1.1 Cement

Cement is used as a binder in the concrete where the strength and durability are significantly important. The ordinary Portland cement of (OPC) 53 grades conforming to the British standards BS 12 (1996) can be used.

2.1.2 Fine aggregates

It consists of small angular or grounded grains of silica (SiO_2) and is formed by decomposition of sand stone under the effect of weathering. The size, which is less than 4.75mm is referred to be fine aggregates. River sand can be used as fine aggregates in accordance to the requirements of BS 933 - 1 (1997).

2.1.3 Coarse aggregates

Coarse aggregates may be found in the form of irregular broken stones or naturally occurring rounded gravels, which are large to be retained on 4.75mm sieve size are known as coarse aggregate. Preliminary tests are to be carried out on aggregates in accordance to BS 812 (1990).

2.1.4 Periwinkle shells (coarse aggregates)

Periwinkle shell is a waste product obtained from the consumption of small marine animal (periwinkle) which is shelled in a v-shaped spiral shell and is found in many coastal communities in Nigeria and other countries. Periwinkles are commonly found in the lagoons and mudflats of the South West and Niger Delta; and the people in these areas take the edible part as sea food and disposed the shells as waste, thus constituting environmental nuisance (Olutoge *et al.*, 2012).

2.1.5 Water

Water plays an important role in mixing, laying, and compaction, setting and hardening of concrete. Water influences the strength development and durability of concrete. Ordinary drinking water (as specified in NIS 554: 2007 for Nigerian Standard for drinking water quality) and BS 3148 (1980) can be used for preparing concrete.

2.2 Lightweight Concretes, Types of Lightweight Concrete and Their Mechanical Properties

2.2.1 Lightweight aggregate concrete

Lightweight concrete is produced using lightweight aggregates whose weights are lower than 1120 kg/m^3 (Mehta and Monteiro, 2006). Lightweight aggregates are sourced from natural materials, such as, shales, clays, pumice, diatomite, volcanic cinders, and slates or artificial materials which are by products such as iron blast furnace slag, sintered fly ash, and shale. Figure 2.1 shows the sorts of the lightweight aggregates (Shetty, 2006).

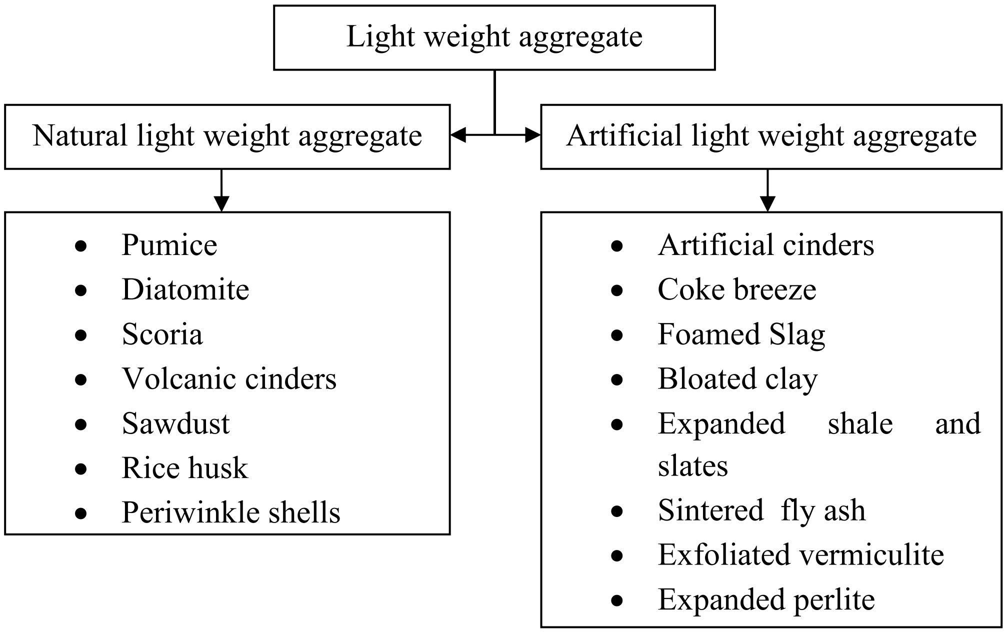


Figure 2.1: Natural and artificial light weight aggregate

2.2.2 Aerated lightweight concrete

The aerated concrete is a type of lightweight concrete, which is commonly referred to as cellular concrete. It can be divided into two types according to the method of production. These are foamed concrete or non-autoclaved aerated concrete (NAAC) and autoclaved aerated concrete (AAC) (Neville and Brooks, 2010).

(i) Foamed concrete is produced by injecting preformed stable foam or by adding a special air-entraining admixture known as a foaming agent into a base mix of cement paste or mortar (cement + water or cement + sand + water).

(ii) Autoclaved aerated concrete is produced by adding in a predetermined amount of aluminum powder and other additives into slurry of ground high silica sand, cement or lime and water.

2.2.3 No-fine concrete (pervious concrete)

No fine concrete can be produced by mixing of cement, water and coarse aggregates without fine aggregates (sand). Density of no fine concrete is dependent on the type and grading of the aggregates. No-fine concrete has attributes of lower cost (as a result of reduced cement content), good thermal conductivity, relatively low drying shrinkage, no segregation even in case of material discharge from high levels, no capillary movement of water due to low hydrostatic pressure when wet, better insulating characteristics compared to conventional concrete (Alam *et al.*, 2012).

2.2.4 Structural and nonstructural lightweight concrete

Lightweight aggregate concretes can be considered for use for structural applications. Structural lightweight concrete has minimum 28-day compressive strength and maximum density as 17 N/mm^2 and 1840 kg/m^3 respectively. The practical range for the density of structural lightweight concrete is between 1400 and 1840 kg/m^3. Nonstructural lightweight concrete are considered to have compressive strength less than 17 N/mm^2. These are benefits of using Lightweight aggregate concrete such as improved thermal specifications, better fire resistance, and dead load reduction (Hedjazi, 2019).

2.3 Mix Design

The basic procedure for the mix design method is applicable to concrete for most purposes including pavements. It is restricted to designing concrete mixes to meet workability, compressive strength and durability requirements using Portland cements complying with BS 12 (1996) and natural aggregates complying with BS 882 (1992). Generally, designing a concrete mix design is associated with the problems of selecting the correct proportions of cement, fine and coarse aggregate and water to produce concrete with specified properties. The mix design process must take into account of those factors that have a major effect on the characteristic strength of the concrete, and the variability of concrete strengths for the mix must be designed to have a considerably higher mean strength than the strength specified (Teychenne *et al*., 1997)

2.4 Absolute Volume Method of Concrete

In the further use of aggregate packing in proportioning the following basic relations for absolute volume yields (Stefan & Arntsen, 2007):

$$V_W + V_C + V_{FA} + V_{CA} + V_{AIR} = V_{tot} \quad (2.1)$$

Where,

V_W = Volume of water

V_C = Volume of cement

V_{FA} = Volume of fine aggregates

V_{CA} = Volume of coarse aggregates

V_{AIR} = Volume of air

V_{tot} = the total concrete volume in question often $1m^3$

In conventional normal concrete (compressive strength < 41 MPa), the properties of coarse aggregates seldom become strength-limiting, because this type of concrete mixtures typically correspond to a water - cement ratio (w/c) in the range of 0.5 - 0.7. Within this range, the weakest components in concrete are the hardened cement paste and the transition zone between the cement paste and the coarse aggregate, rather than the coarse aggregate itself (Zia, 1994).

The water/cement (w/c) ratio, coarse and fine aggregates (FA), CA/total aggregate (CA/TA) ratio, TA/C ratio, and curing methods (air curing, oven curing, and water curing) influenced the compressive strength of concrete. Mathematical formulas were developed for concrete strength as a function of CA and FA and also as a function of compressive strength (Bilal, 2006).

2.5 Production of Light Weight Concrete

The properties of lightweight concrete, such as aggregate impact value, aggregate crushing value and compressive strength were assessed utilizing periwinkle shells (PWS) as partial replacement for coarse aggregates. Concrete mix ratio of 1:2:4 with water/cement (w/c) ratio of 0.55 was used at varying percentage replacement of coarse aggregates with periwinkle shells at 0, 10, 20, 30, 40, 50 and 100%. A total of Seventy two (72) cubes of 150 x 150 x 150 mm were cast and tested at the curing ages of 7, 14, 21 and 28 days. The compressive strength of each cube was determined. Optimum compressive strength value of 16.79 and 16.71 N/mm^2 was obtained with 20 and 30% periwinkle shells inclusion at 28 days. The values were within 15-25 N/mm^2 and it was concluded to be suitable for use in the production of lightweight concrete **(**Oyedepo, 2016).

Eziefula *et al.* (2018) investigated the use of mollusc seashells such as periwinkle shell, mussel shell, oyster shell, cockle shell, crepidula shell, clam shell and scallop shell as aggregate replacement materials in concrete. The seashells were utilised as partial or total replacement of fine and coarse aggregates in concrete. This paper is a literature review of seashell aggregate concrete. The physical, mechanical and chemical properties of the seashells were determined. The physical, mechanical and durability properties of seashell aggregate concrete in fresh and hardened states were determined. It was concluded to be suitable for use at recommended percentage replacement of seashell in the construction industry.

An investigation was done to examine the effect of periwinkle shell ash as cement replacement by comparing its established relationship between the compressive strength and static modulus of elasticity of concrete with an existing model. The shell was calcined at a temperature of 800^oC. Specimens were prepared from a mix of designed strength 25 N/mm^2 and cement was partially replaced with 0 to 40% by volume of periwinkle shell ash. The compressive strength and static modulus of elasticity increased with increase in curing age but decreased with increasing periwinkle shell ash content. The design strength was attained with 10% periwinkle shell ash at 28 days. It was concluded that the relation between compressive strength and static modulus of elasticity correlated with the existing model for normal-weight concrete (Umoh and Olusola, 2012).

Bamidele (2002) carried out a research work on "the properties of periwinkle granite concrete and whereby periwinkle shells were used as coarse aggregates with varying mix designs with percentage inclusion of 0-100% of periwinkle shells", and the corresponding 28 days compressive strength found and recorded. The 28 days compressive strength of the concrete made with 100% periwinkle shells ranged from 11.77 to 15.65 N/mm^2.

Osarenmwinda and Awaro (2009) investigated the potential of periwinkle shells as coarse aggregates for concrete. The results showed that concretes produced with ratio (1:1:2, 1:2:3 and 1:2:4) mixes gave the compressive strengths of 25.67, 19.5 and 19.83 N/mm^2 at 28 days respectively which met the recommended standard minimum strength of 17 N/mm^2 for structural light weight concrete. Concrete produced from total replacement of coarse aggregate with periwinkle shells were reportedly light (1944 kg/m^3)

and the compressive strengths at 28 days lower (13.05 N/mm^2) when compared with concrete with partial coarse aggregate replacement.

Olutoge *et al*. (2012) investigated the suitability of periwinkle shell ash as partial replacement for Ordinary Portland Cement, and the compressive strength was determined and found to decrease with increases in the percentage of Periwinkle Shell Ash. The initial and final setting time of the concrete made with ordinary Portland cement and periwinkle shell ash at 5% and 10% increased as the percentage replacement increased.

Bharathi *et al.* (2016) performed experimental studies on convectional concrete and concrete made with sea shell (cockle shell) as partial replacement to coarse aggregates varied from 0, 3, 5, 7, 9 and 11% and the cement were replaced at 25% for fly ash. The mechanical properties of concrete, such as, compressive strength, tensile strength, flexural strength, and workability are evaluated. The optimum percentage of the combined mixtures were determined and which can be recommended as suitable alternative construction material in low cost housing in areas where seashells and flyash are readily found as wastes.

Amaziah *et al*. (2013) carried out an exploratory study of crushed periwinkle shells as partial replacement for fine aggregates in concrete. Crushed periwinkle shells were used as partial replacement for fine aggregate (river sand) in concrete. The Mechanical and Physical properties of the Crushed periwinkle shell, river sand and crushed granite stones were determined and compared. A total of thirty two (32) concrete cubes were produced with concrete mix ratios of 1:2:4 and 1:3:6 by weight whereby the proportion of crushed periwinkle shell to river sand used 0:100, 30:70, 50:50 and 70:30 for 1:2:4 and 0:100, 30:70, 50:50 and 100:0 for 1:3:6. Compressive strength tests for 14, 21 and 28 days were determined and compared with the strengths of convectional normal concrete. It was concluded that crushed periwinkle shells could be used as partial replacement for fine aggregates (sharp sand) in the production of concrete.

Ettu *et al.* (2013) reinvestigated the prospects of using periwinkle shell as partial replacement for granite in concrete. Concrete mix ratios, 1: 1.5: 3; 1: 2: 3; and1: 2.5: 3 were used. For each mix ratio, coarse aggregate (granite) were partially replaced with periwinkle shells at 25, 35, 45, 50, 55, 65, and 75%. A control mix with 100% granite was used for each of the three concrete mix ratios. All mixes were prepared using water/cement ratio of 0.65. Batching was done by weight and a total of 144 concrete cubes were cast. The bulk densities and compressive strengths were determined for 7 and 28 days, and strongly confirmed the findings of earlier researchers. It was concluded that periwinkle shells could be used as partial replacement of granite for reinforced concrete works under the stated conditions of exposure and good supervision. The minimum and maximum 28 days compressive strength is 9.96 and 21.04 N/mm^2 respectively.

Ayegba (2013) worked on the strength characteristics of concrete made with rice husk ash as partial replacement of cement using periwinkle shell as coarse aggregate. Concrete were made as cement was partially replaced with Rice Husk Ash at 0, 30, 40 and 50%, sand and periwinkle shell with concrete mix ratios of 1:2:4, 1:3:6 and 1:1:2 respectively. Absolute Volume Method and water/cement ratio of 0.7 were used. Specific gravities and bulk densities of Rice Hush Ash and periwinkle shells were determined. Compressive strength test was carried out on a total of 144 concrete cubes at 7, 14, 21and 28/days respectively. Values ranging between 3.64-17.96 N/mm^2, were obtained for compressive strength at the 28th day hydration period for all mixes. It was concluded that compressive strength values were low but still falls within the minimum standard for lightweight concrete. It was recommended for use in masonry concrete, lean concrete bases, and simple foundations as lightweight concrete for masonry work and insulating concrete.

Falade *et al.* (2010) investigated the behaviour of lightweight concrete containing periwinkle shells at elevated temperature. The particle size analysis was carried out on fine (sand) and coarse aggregates (periwinkle shells). Concrete mix ratios of 1:2:2 and 1:2½:2 with water/cement ratios of 0.6 and 0.8 were used. The concrete was made with sand and periwinkle shells as fine and coarse aggregates respectively. A total number of one hundred and forty-four 150 x 150 x 150mm concrete cubes were cast for each curing age of 7, 21 and 90 days respectively. Three cubes for each curing age were weighed and crushed, and then the average weight, density and compressive strength were determined and noted. Also, three cubes each at different levels of heating between 50 and 800^{o}C/hr, were heated, weighed and crushed and then the average weight, density and compressive strength were determined and noted. It was observed that the loss of appearance, reduction in weight and strength of cubes decreased with increased temperatures in the function of mix design and curing age. It was recommended that lightweight concrete containing periwinkle shells should be used for structures only in areas with expected temperature exposure of less than 300^{o}C.

Agbede and Manasseh (2009) investigated the suitability of periwinkle shell as partial replacement for river gravel in concrete. The concrete was produced with a mix design ratio of 1:1.5:3 and periwinkle - gravel mix ratios of 0:1, 1:0, 3:1, 1:3, 1:1 were used with water/cement ratio of 0.5. The physical and mechanical properties of concrete were determined and compared with that of convectional normal concrete. The densities and compressive strengths for 7, 14 and 28 days were determined and the 28 day density and compressive strength of concrete made with the inclusion of periwinkle shells were recorded to be 1944 kg/m^3 and 13.05 N/mm^2 respectively. The concrete were classified according to 28 days densities. The workability, density, and compressive strength of periwinkle-gravel concrete reduced with increased periwinkle shell content. And it was concluded that periwinkle shells is suitable for partial replacement for river gravel in normal construction works in areas where periwinkle shells are readily available in abundance.

Olivia *et al.* (2015) investigated mechanical properties of seashell concrete. Cockle was burnt, grinded and passed through sieve no. 200, and the ground cockle was used to partially replace cement at 2, 4, 6 and 8% by weight. The concrete used was prepared with an expected optimum strength of 35 N/mm^2 at 28 days. Concrete specimens of 150 x 300mm cylinders and 100 x 100 x 400mm beams were used and tested at 7, 28 and 91 days for mechanical properties. It was concluded that concrete with partial inclusion of ground seashell developed relatively better tension properties, but lower compressive strength and modulus of elasticity than the control concrete.

Adewuyi and Adegoke (2008) investigated and reported the explanatory study on the suitability of the periwinkle shells as partial or full replacement for granite in concrete works. The physical and mechanical properties for periwinkle shell and crushed granite were determined and comparisons were made. Concrete mix ratios of 1:2:4 and 1:3:6 were used respectively in the production and casting of a total of 300 concrete cubes with crushed granite to periwinkle shell in different percentages by weight in the order of

100:0, 75:25, 50:50, 25:75 and 0:100 with water cement ratios of 0.60 and 0.55, respectively. The concrete cubes were tested and their physical and mechanical properties of aggregates were determined. Compressive strengths for 3, 7, 14, 21 and 28 days were determined. Cost analysis were made and it was concluded that concrete with 35.4 and 42.5% periwinkle shells inclusion gave the minimum 28-day cube strength values that are satisfactory for concrete mixes 1:2:4 and 1:3:6.

Dahunsi (2003) carried out a study on the properties of concrete made by periwinkle shell and granite. It was concluded that periwinkle shells could be used as a partial replacement for granite in civil engineering and construction industries and the strengths developed were similar to those of convectional concrete made by granite.

Dahiru *et al.* (2018) investigated the characteristics of concrete produced with periwinkle and palm kernel shells as coarse and fine aggregates respectively. The physical and mechanical properties of the periwinkle shell, palm kernel shell, fine aggregates (sharp sand) and coarse aggregates (crushed granite stones) were determined. Crushed palm kernel shell was used for partial replacement of fine aggregates, and periwinkle shell was used for partial replacement of coarse aggregates. The concrete was produced with mix design of 1:2:4 and a water/cement ratio of 0.6, and the quantities were determined using the absolute volume method with varying percentage replacements of fine and coarse aggregates at 0, 25, 50 and 100% with crushed palm kernel shell and periwinkle shell respectively. Replacement at 0% was used for control samples. A total of 48 concrete cubes of 100 x 100 x 100mm were cured and crushed for 7, 14, and 28 days, hence its compressive strengths were determined. It was recommended that the maximum of 25% replacement level of palm kernel shell and periwinkle shell as fine and coarse aggregates respectively can be used in concrete production.

Soneye *et al.* (2016) studied the use of periwinkle shells as fine and coarse aggregates in concrete works. The physical and mechanical properties of periwinkle shell and crushed granite were evaluated and compared. A concrete mix ratio of 1:2:4 was used to produce a total of six concrete cubes of size 150 x 150 x 150 mm each with different percentage replacements by weight in the order of 0, 10, 30, 50 and 100% of periwinkle shells to fine aggregates and coarse aggregates respectively. A total of 60 concrete cubes were tested at 3, 7, 28 and 56 days and their physical and mechanical properties were determined. Two cubes each were crushed for 3 and 7 days, while one each was crushed for 28 and 56 days. It was concluded that concrete made with 100% of periwinkle shell as fine and coarse aggregates respectively attained about half of the designed strength. It failed at 50% replacements and was said to be satisfactory at 30% replacement without compromise.
Adewuyi *et al.* (2015) investigated a research topic titled utilization of mollusc shells for concrete production for sustainable environment, and the materials used are cement, sand, natural gravel, periwinkle shell, snail shell, oyster/cockle shell, periwinkle shell ash, snail shell ash and oyster shell ash. Physical and chemical properties of the materials were determined. Batching by weight was used with grade strength of 25 N/mm^2 to produce mixes with different material constituents at varying percentage replacements. The compressive strengths were determined at 7, 14, 21 and 28 days for every form of concrete produced. It was concluded that the 3Rs (reduce, reuse and recycle) of integrated waste management are effective in shell wastes and applicable to civil works.

Deepapriya *et al.* (2018) did a comparative study of concrete strength by partial replacing of coarse aggregate with crushed tiles and sea shell. A mix ratio of 1:1:2 (25 N/mm^2) was used with water/cement ratio of 0.5 to produce concrete with the coarse aggregate partially replaced at 20 and 30% with crushed tiles waste and sea shell respectively. Slump test was done and determined. Compressive strength and split tensile test was carried out and determined at 7, 14 and 28 days. It was concluded that concrete containing crushed tiles gave more strength compared to that containing sea shell and it was said to be economical and produces best concrete.

2.6 Curing

Afuye *et al.* (2018) investigated the effect of curing methods on the characteristic strength of concrete with lateritic sand and periwinkle shell. The materials used were ordinary Portland cement, fine aggregates (sand, lateritic sand), coarse aggregates (granites, periwinkle shells). Concrete used were produced by weight with mix ratios of 1:2:4 and 1:3:7, and water/cement ratio of 0.65. The sand and granite were replaced with lateritic sand and periwinkle shells respectively at 10, 20, 30, 40 and 100%. The control mixture was produced with target strength of 25 N/mm^2. Slump tests were carried out and determined. A total of 45 cubes specimens of 100 x 100 x 100mm for each percentage replacements were cast and cured in water and open air for 7, 14 and 28 days. Compressive strength test was carried out on the concrete cubes and determined. It was concluded that the workability decreases with increases in the percentage inclusion of lateritic sand and periwinkle shell. Also, the compressive strength values obtained for 7, 14, and 28 days were noted to be greater for concrete cubes cured by immersion in water compared to those cured in the moist or open air.

2.7 Characterisation of Periwinkle Shell

2.7.1 Characterisation of periwinkle shell as asbestos-free brake pad materials

Brake pads are important parts of braking system for all types of vehicles that are equipped with disc brake. Brake pads are steel backing plates with friction material bound to the surface facing the brake disc. The brake pads were originally made from asbestos fibers because of its properties and being withdrawn from all the applications due to the risks of carcinogenic nature of asbestos and availability of alternate materials such as periwinkle shell which are non-carcinogenic materials (Aigbodion and Agunsoye, 2010).

Aku *et al.* (2012) studied the characterization of periwinkle shell as asbestos-free brake pad material. Density, hardness values and wear rate of the periwinkle shell were determined. The various results obtained were comparable with asbestos commonly used in brake pad production. These results confirm that periwinkle shell can be used as a material for brake pad production.

Amaren *et al.* (2013) investigated the effect of periwinkles shell particle size on the wear behavior of asbestos free brake pad. The asbestos free brake pad produced by varying the periwinkle shell particles was from +125 to +710 µm with varying percentage of phenolic resin. The wear test was conducted using pin on disk machine by altering the sliding speed, applied load, temperatures and periwinkle shell particle size. The wear rate increases with increases in the sliding speed, load, temperature, and periwinkle particle size. It was concluded and recommended that periwinkle shell particles can be used as a replacement for asbestos in brake pad manufacture.

2.7.2 Characterization of periwinkle shell powder as part of polymer composites

Polymer composites are increasingly replacing metals in structures, such as, gears, wheels, clutches, housings, bushings and other areas where tribology is of great importance. The tribological behaviour of periwinkle shell powder-filled recycled polypropylene composite was studied. Injection moulding was used for the preparation of the composites and the impact strength, wear resistance and fatigue strength were examined. The results showed that the incorporation of periwinkle shell powder into polypropylene improved the wear resistance and fatigue strength but showed no improvement in impact strength (Onuoha, 2019)

Onyechi *et al.* (2015) studied the effect of particle size on the mechanical properties of periwinkle shell reinforced polyester composite. Particle sizes used are 400, 600, 766, 1180 and 1760μm. Five repeated samples of each particle sizes were used for volume fraction of 10, 20, 30, 40 and 50%. It was concluded that as the particle sizes decreased, the tensile strength and flexural strength increased. In impact test, the strength increased as the particle size increased. For the filler content, the tensile and the flexural strength at 30% content was highest and it then decreased sharply, but in hardness and impact test, as the filler content increased, the hardness number and impact strength increased.

2.7.3 Periwinkle shells ash as composite materials for particle board production

Composites based on natural fibre reinforcement have generated wide research and engineering interest in the last few decades due to their low density, high strength, low cost, renewability, and biodegradability. The results obtained meet the minimum standard requirement for particle board production, and the usage of periwinkle shell particles as reinforcement in polythene matrix brings about improvement in the physical and mechanical properties (Abdullahi and Sylvester, 2015)

2.7.4 Periwinkle shell ash as partial replacement for cement in concrete

Investigation on the assessment of physico-chemical properties of periwinkle shell ash as a replacement for cement in concrete was made. The physical properties and chemical composition of the periwinkle shell ash were determined and compared with specific standard specifications for such material. Cement replacement with periwinkle shell ash calcined at 800 and 1000°C at 0, 10, 20, 30 and 40% with mix ratio 1:1:2 and 1:2:4. The compressive strengths were determined in the function of the stated percentage replacement of cement with periwinkle shell ash and mix ratio at 28 days. It was concluded that periwinkle shell ash calcined at a temperature range of 800 to 1000 °C is suitable for use as partial replacement for cement in the production of concrete (Offiong and Akpan, 2017)

Ukpaka and Okochi (2018) studied the production of cement from mixture of palm kernel and periwinkle shell. Materials used were periwinkle shell ash, palm kernel shell ash, crushed granite, river sand, Gypsium (used as hardening retard agent), Calcium Oxide (used as drying agent). The periwinkle shell ash and palm kernel shell ash were mixed in various proportion, 4:1, 3:2, 2:3, 1:4 and 1:1 respectively and incubated at a temperature of 350°C and with the inclusion of different percentages of additives to produce five samples of cement. Initial and final setting time of each sample was determined. Three concrete mixes from each sample were produced with the addition of fine aggregates and coarse aggregates in the ratio 1:2:3, with cement/water ratio of 0.6, cured for 7, 14 and 21 days for each sample. Compressive strength test was conducted on the samples. It was concluded that periwinkle shell ash and palm kernel shell ash can be used to produce cement with appropriate additives added, and recommendation was made to develop appropriate technology for proper utilization.

2.7.5 Periwinkle shell-rice husk composite as a replacement for granite in concrete

The research work examined the investigation of periwinkle-rice husk ash composite as a replacement for granite in concrete was done. Characterisation of the rice husk ash, and periwinkle shells were determined and compared. The percentage replacement at 0:100, 20:80, 40:60, 60:40, 80:20 and 100%:0% and the mix adopted were 1:2:1$\frac{1}{2}$ for the first treatment (control) and 1:1:1$\frac{1}{2}$ for the second treatment. Concrete cubes with periwinkle-rice husk as coarse aggregate were lighter with low compressive strengths compared to the normal weight concrete, and was concluded that periwinkle-rice husk ash can be used as a light weight concrete for the replacement of granite in concrete (Orji *et al.*, 2017).

2.8 Modelling of Lightweight Concrete

The researchers know that a Box-Behnken is the right design, but they are worried about collecting the right amount of data, under the right conditions, with the right settings, in the right order. Setting up even the simplest of designed experiments by hand can be very difficult and leaves plenty of room for error. MINITAB'S Create Response Surface Design creates a data collection worksheet for one, indicating the factor combinations to run as well as the random order in which to collect ones data. One can also print the worksheet to simplify data collection. Create Response Surface Design ensures that one covers all possible factor level combinations in the experiment, but in some cases one may not want or be able to test extreme setting combinations. MINITAB offers two customizable response surface designs to ensure that ones experiment is as detailed as it must be and as simple as it can be. A surface plot provides a three-dimensional view of how the factors affect the response. For a more complete interpretation, use a surface plot with a contour plot. A response surface experiment can help one to determine the combination of factor level settings that are necessary to achieve the best response.

(a) First-order model

A linear function of the factors, the first-order model is:

$$Y = b_0 + b_1x_1 + \dots + b_kx_k \tag{2.2}$$

Where Y = response, x = factors, b_k= regression coefficients

(b) Second- order model

A polynomial model of higher degree is also known as a second-order model and which is:

(i) Pure Quadratic Model:

$$Y = b_0 + b_1x_1 + b_3x_3 + b_3x_3 + b_4x_4 + b_5x_1^2 + b_6x_2^2 + b_7x_3^2 + b_8x_4^2 \tag{2.3}$$

(ii) Interaction Model:

$$Y = b_0 + b_1x_1 + b_3x_3 + b_3x_3 + b_4x_4 + b_5x_1x_2 + b_6x_1x_3 + b_7x_1x_4 + b_8x_2x_3 + b_9x_2x_4 + b_{10}x_3x_4 \tag{2.4}$$

(iii) Full Quadratic Model:

$$Y = b_0 + b_1x_1 + b_3x_3 + b_3x_3 + b_4x_4 + b_5x_1^2 + b_6x_2^2 + b_7x_3^2 + b_8x_4^2 + b_9x_1x_2 + b_{10}x_1x_3 + b_{11}x_1x_4 + b_{12}x_2x_3 + b_{13}x_2x_4 + b_{14}x_3x_4 \tag{2.5}$$

Ibearugbulem and Ajoku (2016) worked on a research topic titled prediction of the flexural strengths of lightweight periwinkle shell-river gravel concrete. The research work made use of the regression equation derived by Ibearugbulem for a four component mixture of concrete. Water, Ordinary Portland Cement (OPC), river sand, river gravel, and periwinkle shells were used whereby river gravel and periwinkle shells were joined to be one at a volumetric mix ratio of 1:1 to have four material components instead of five. A total of 30 mix ratios were chosen arbitrarily from Scheffe's simplex latex structure for a four component mixture. While the first 15 mix ratios were used in the formulation of the model, the last 15 mix ratios were used in the validation of the formulated model using Fisher's statistical test. For each mix ratio, three concrete beams measuring 150 x 150 x 600mm were produced, cured and tested for 28 days. A regression model was developed, and the flexural strength results from the experiment and those from the model were compared and found favourable with each other. It was concluded that the regression model proved adequate for the prediction of the 28 day flexural strengths of lightweight concrete with equal volume of river gravel and periwinkle shell. The model is recommended for use within the research boundaries in concrete and construction industries.

Ajoku (2015) generated six regression models to validate the laboratory results of the compressive and flexural strengths tests performed on the concrete cubes and beams made from concrete mix ratios of 1:1.5:2; 1:1.65:2.75 and 1:2:3.5 with water/cement ratios of 0.5, 0.53, 0.58 respectively. The results from the developed models revealed that three equations for the prediction of 28 day compressive strength gave optimum strengths of 14.93, 19.28, and 21.47 N/mm^2. Concrete were produced with these concrete mix ratios of 1:1:1.5, 1:1.75:3 and 1:1.75:3 with water/cement of 0.45, 0.55, 0.55 for periwinkle shell-river gravel concrete, periwinkle shell-sand stone concrete and periwinkle shell-granite concrete respectively and the results were used to predict flexural strengths using the other three for the prediction of flexural strength and optimum values of 3.79, 3.89, and 3.16 N/mm^2 were attained at the corresponding mix ratios. The model results were validated using the Fisher's statistical test to check the adequacy of the six generated models with the control mix ratios. These models were recommended for use in concrete/construction industries for easy prediction of compressive and flexural strengths of lightweight concrete.

Yusuf *et al.* (2016) studied the determination of an appropriate compressive–flexural strength model of palm kernel shell concrete (PKSC). The direct and indirect Ultrasonic

Pulse Velocity (UPV) measurements, with respect to mechanical properties of compression (cube) and flexural (slab) elements, of concrete at various mixes and water/cement (w/c) ratios were made. The 28 day compressive strength–UPV and strength–age statistical relationships at w/c ratio of 0.5 determined from the velocity–strength data set in linear, power, logarithm, exponential and polynomial trend forms. The polynomial trend line was found appropriate, among others, was proposed for the formulation of the compressive strength–flexural strength model of PKSC at w/c ratio of 0.5.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Preamble

In this stage the collection of materials and data required for the mix design are obtained by sieve analysis and specific gravity. Sieve analysis was carried out from various fine aggregate (FA) and coarse aggregate (CA) samples and the samples, which suits the requirement is selected. Specific gravity tests are carried out for fine and coarse aggregate. There are several stages to finish this study; First stage for this study is material preparation. After that, the sample preparations for cubes and beams moulds were ready for concrete production. Concrete mix design was used to prepare the concrete and curing process were commenced 24 hours after all the concrete were cast into the moulds. For concrete cubes and beams, compressive and flexural test were carried out at the 7 and 28 days of curing. The data were collected and analysed.

3.2 Materials for Concrete

The following materials were used to produce the concrete for this research work:

3.2.1 Cement

Cement is used as binding material in the concrete. The ordinary Portland cement brand used for the study was produced by Dangote Cement Company, Nigeria and in compliance to the British standards BS 12 (1996). The cements were bought from a local dealer in Minna and used all through for the production of cube and beam specimens.

3.2.2 Fine aggregates

River sand used as fine aggregates for this work was obtained from Abuja and air dried, then sieved with a 5mm BS sieve, in order to remove the impurities and larger aggregates, which complied with BS 882 (1992) for specifications of aggregates from natural sources. Before use, sieve analysis, bulk density test, specific gravity test of the fine aggregate were carried out in compliance to BS 933 -1 (1997), BS 812 -2 (1995), BS 1377 (1990), respectively.

3.2.3 Coarse aggregates

The coarse aggregates used were crushed granite stones obtained from single quarry site in Abuja. The preliminary tests carried out on these materials are;

(i) Sieve analysis (BS 933 -1, 1997)

(ii) Bulk density (BS 812 -2, 1995)

(iii) Specific gravity (BS1377, 1990)

(iv) Aggregate impact value test (BS 812 -112, 1990)

(v) Aggregate crushing value test (BS 812 -110, 1990)

3.2.4 Periwinkle shells (coarse aggregates)

Periwinkle shell was obtained from Port Harcourt. The preliminary tests carried out on this material are;

(i) Sieve analysis (BS 933 -1, 1997)

(ii) Bulk density (BS 812 -2, 1995)

(iii) Specific gravity (BS1377, 1990)

(iv) Aggregate impact value test (BS 812 -112, 1990)

(v) Aggregate crushing value test (BS 812 -110, 1990)

3.2.5 Water

Water influences the strength development and durability of concrete. Ordinary drinking water can be used for preparing concrete. Potable tap water used for this research work for mixing and curing was supplied by the Works Department of FUT, Minna, Gidan Kwano Campus. It was ensured to meet the standard of the BS 3148 (1980) code for water quality control.

3.3 Methods

3.3.1 Physical characterization of material constituents

3.3.1.1 Moisture content

The moisture content does have impacts on the physical properties of concrete, such as, its weight, density, refractive index, electrical conductivity. The test is carried out in the laboratory by means of the oven-drying method in accordance to British Standard BS812 -109, 1990.

The purpose of this test is to determine or measure the amount of water present in a sample of aggregate and hereby expressed as a percentage of dry mass.

The percentage total moisture content of the dry mass of aggregate is given as:

$$\frac{B-C}{C-A} \times 100 \tag{3.1}$$

Where;

A is the mass of an air-tight container,

B is the mass of the container and sample, and

C is the mass of the container and sample after drying.

Required Apparatus:

The required apparatus are

(i) a drying oven

(ii) a weighing balance

(iii) a metal container

(iv) a scoop

(v) a riffle box

Procedure:

The container was cleaned, dried and weighed as A. Sample was put in the container using the scoop, then weighed and recorded as B. The container with the test portioned sample was placed in the oven to dry at 105 °C for minimum of 12 hours, and it was removed from the oven and allowed to cool, then weighed and recorded as C after drying.

3.3.1.2 Sieve analysis

The sieve analysis test was performed to obtain a distribution of grain size of the aggregates. The test was performed for 20mm aggregates, river sand and periwinkle shells for the project in accordance to the British Standard, BS 882, 1992; BS 933 -1, 1997.

3.3.1.3 Bulk density

Bulk density is a measure of the weight of the soil per unit volume, usually given on an oven-dried (110 °C) basis. Bulk density can also be considered to be a measure of how dense or closely packed a sample is. It is determined by measuring the mass of dry sample per unit volume (g/ml or g/cm^3). The bulk density of a sample depends on the structure of the sample beds, how tightly they are packed, the number of spaces (pores), and its composition. Bulk density is used to connect between mass and volume of a sample. Bulk density test was done in accordance to BS 812 -2 (1995).

$$\text{Bulk density} = \frac{W2 - W1}{W3} \qquad (3.2)$$

Equation (3.2) is used in calculating the compacted and uncompacted bulk density of the samples.

Apparatus:

(i) Steel Cube Container

(ii) Weighing Balance

(iii) Scoop

(iv) Tamping rod

Procedure:

The bulk density test was carried out for both compacted and non-compacted samples. For non-compacted samples; the sample was loosely placed into the steel container till it was over filled. The sample in the steel container was leveled to the brim by using 16mm steel rod; while the content of the container was discharged into a tray and weighed and recorded. The same procedure was repeated for two more runs and their respective masses were recorded.

For the compacted samples; the steel container was filled with the sample to about one third of the container using the scoop, and was tamped 25 times using 16mm rod and the steps were repeated for the second and third layers. The container was then over filled, leveled and weighed. The procedure was repeated for two more samples and their masses were recorded.

3.3.1.4 Specific gravity

Specific gravity (S.G) is also known as relative density and it is defined as the ratio of mass (weight in air) of unit volume of water at the same temperature. Substances with specific gravity greater than one or lesser than one are heavier or lesser than water respectively.

The specific gravity of the sample is calculated using the expression:

$$\text{Specific gravity} = \frac{\text{density of sample}}{\text{density of water}} = \frac{\text{M2}-\text{M1}}{(\text{M4}-\text{M1})-(\text{M3}-\text{M2})} \tag{3.3}$$

The specific gravity test was done in accordance to BS 1377 (1990).

3.3.1.5 Aggregate impact value (AIV) test

The Aggregate impact value (AIV) gives a relative measure of the resistance of an aggregate to sudden shock or impact.

This test was done in accordance to BS 812 -112 (1990)

The aggregate impact value is calculated using Equation (3.4)

$$\text{Aggregate Impact Value} = \frac{\text{W2}}{\text{W1}} \times 100 \tag{3.4}$$

Apparatus

(i) Weighing balance

(ii) Tamping rod

(iii) Mould

(iv) BS sieve 14mm and 10mm, and a woven wire 2.36 mm sieve

(v) Aggregate impact testing machine

Procedure

The entire dried test portion of aggregates was sieved on the 14mm and 10mm sieves to remove the oversize and undersize fractions. The aggregates passing through 14mm and retained on 10mm BS Sieves were used to fill the mould to over flowing and compacted in three layers by tamping of 25 strokes of the tamping rod and the weight of the mould and sample was recorded as W_1, which is fixed firmly in position on the base of the machine and the whole of the test sample is placed in it and a hammer was raised until its lower face is 380mm above from the upper surface of the aggregate in the cup, and was allowed to fall freely on the aggregate, The test sample was subjected to a total of 15 of such blows each being delivered at an interval of not less than one second, then crushed aggregates was removed from the cup and the whole of it was sieved using BS sieve 2.36mm, until no further significant amount passes, the fraction passing the sieve was weighed to an accuracy of 0.1 gram and recorded as W_2. The procedure was repeated for the second and third terms, and the respective masses were recorded.

3.3.1.6 Aggregate crushing value (ACV) test

The Aggregate crushing value (ACV) gives a relative measure of the resistance of an aggregate to crushing under a gradually applied load.

The aim of this test is to determine the aggregate crushing value of a coarse aggregate. Aggregates should be strong enough to resist crushing under loads. If the strength of aggregate is weak, then failure is inevitable. The strength of aggregate was accessed by the means of aggregate crushing value test in accordance to BS 812 -110 (1990).

The aggregate crushing value is calculated using Equation (3.5)

$$\text{Aggregate Crushing Value} = \frac{W2}{W1} \times 100 \tag{3.5}$$

Apparatus

(i) Weighing balance

(ii) Tamping rod

(iii) Mould

(iv) BS sieve 14mm and 10mm

(v) Compressive strength testing machine

Procedure

The entire dried test portion of aggregates was sieved on the 14mm and 10mm sieves to remove the oversize and undersize fractions. The aggregates passing through 14mm and retained on 10mm BS Sieves were used to fill the mould to over flowing and compacted in three layers by tamping of 25 strokes of the tamping rod and the weight of the mould and sample was recorded as W_1. The apparatus is then placed in the compression testing machine and loaded at a uniform rate so as to achieve 400 kN load in 10 minutes. After this, the load is released, then the sample was sieved through a BS sieve 2.36mm and the fraction passing through the sieve is weighed and recorded as W_2

3.2.2 Mix design

The concrete mix design begins by determining the requirements of the concrete. These requirements take into consideration the required design strength. The mix design was done using MINITAB 16 soft ware and Microsoft Excel considering the Absolute

Volume Method of concrete. By using Table 3.1, data were generated and are shown in Tables A1 to A3.

Absolute volume method;

The concrete constituents are calculated for a cubic metre of concrete using Equation (3.6) as:

$$V_W + V_C + V_{FA} + V_{CA} + V_{AIR} = 1(m^3) \quad (3.6)$$

Where,

V_W = Volume of water

V_C = Volume of cement

V_{FA} = Volume of fine aggregate

V_{CA} = Volume of coarse aggregate

V_{AIR} = Volume of air

Also Equation (3.7) was generated from Equation (3.6) when the volume of air was taken as 0.02

$$\frac{W_W}{1000S.G_W} + \frac{W_C}{1000S.G_C} + \frac{W_{FA}}{1000S.G_{FA}} + \frac{W_{CA}}{1000S.G_{CA}} + \frac{W_{PS}}{1000S.G_{PS}} + 0.02 = 1 \quad (3.7)$$

Where,

W_W= Weight of water

W_C= Weight of cement

W_{FA}= Weight of fine aggregate

W_{CA}= Weight of coarse aggregate (gravel)

W_{PS}= Weight of periwinkle shell

Using Table 3.1, the following were considered;

Water/Cement ratio

$$x_1 = \frac{W_W}{W_C} = 0.5 \tag{3.8}$$

$$W_W = 0.5W_C \tag{3.9}$$

Total aggregate/Cement ratio

$$x_2 = \frac{W_{TA}}{W_C} = 6 \tag{3.10}$$

$$W_{TA} = 6W_C \tag{3.11}$$

Coarse aggregate/Total aggregate ratio

$$x_3 = \frac{W_{CA}}{W_{TA}} = 0.7 \tag{3.12}$$

$$W_{CA} = 0.7W_{TA} \tag{3.13}$$

Periwinkle/Coarse aggregate ratio

$$x_4 = \frac{W_{PS}}{W_{CA}} = 0.2 \tag{3.14}$$

$$W_{PS} = 0.2W_{CA} \tag{3.15}$$

Put Equation (3.11) in Equation (3.13) to give Equation (3.16)

$$W_{CA} = 0.7 \times 6W_C \tag{3.16}$$

Put Equation (3.16) in Equation (3.15) to give Equation (3.17)

$$W_{PS} = 0.2\times 0.7 \times 6W_C \tag{3.17}$$

Subtracting the weight of coarse aggregates from total aggregates to get the weight of fine aggregates gives

$$W_{FA} = W_{TA} - W_{CA}$$

$$W_{FA} = 6W_C\text{–}(0.7 \times 6W_C) \tag{3.18}$$

Putting 3.6, 3.15, 3.13, and 3.14 into 3.4 to give 3.16

$$\frac{0.5W_C}{1000S.G_W} + \frac{W_C}{1000S.G_C} + \frac{6W_C-(0.7\times 6W_C)}{1000S.G_{FA}} + \frac{0.7\times 6W_C}{1000S.G_{CA}} + \frac{0.2\times 0.7\times 6W_C}{1000S.G_{PS}} = 1 - 0.02 \tag{3.19}$$

Therefore Equations (3.9), (3.16), (3.17), (3.18), and (3.19) were rewritten as Equations (3.20), (3.21), (3.22), (3.23), (3.24) respectively and taken to Microsoft Excel and used to calculate the proportions of mix constituents as shown in Table 3.4.

$$W_W = x_1 . W_C \tag{3.20}$$

$$W_{CA} = x_3 . x_2 . W_C \tag{3.21}$$

$$W_{PS} = x_4 . x_3 . x_2 . W_C \tag{3.22}$$

$$W_{FA} = x_2 . W_C (1 - x_3) \tag{3.23}$$

$$W_C = \frac{1-0.02}{\frac{x_1}{1000S.G_W} + \frac{1}{1000S.G_C} + \frac{x_2 - (x_3 \times x_2)}{1000S.G_{FA}} + \frac{x_3 \times x_2}{1000S.G_{CA}} + \frac{x_4 \times x_3 \times x_2}{1000S.G_{PS}}} \tag{3.24}$$

Table 3.1: Assumed Material Constituents' Ratios

Coded	W/C ratio, X_1	TA/C ratio, X_2	CA/TA ratio, X_3	PS/CA ratio, X_4
-1	0.4	3	0.55	0.2
0	0.5	4.5	0.62	0.25
1	0.6	6	0.7	0.3
1.414	0.64	6.62	0.73	0.32
-1.414	0.36	2.38	0.52	0.18

3.4 Production of Concrete

The Project Stages include

(a) Materials preparation (including formwork)

(b) Concrete preparation

(c) Mixing Process

(d) Curing

(e) Testing

(f) Data Collection

Types of mould that was used:

(a) Beam mould for bending test

(b) Cube mould for compression test

Mixing of Concrete was done to meet the British Standard BS1881:126 (1986) for Compressive and Flexural Strength Tests.

(a) Hand Mixing

(i) Mix the cement and fine aggregates on a water tight none-absorbent platform until the mixture is thoroughly blended and uniform.

(ii) Add the coarse aggregates (granite and periwinkle shells) and mix with cement and fine aggregate until the coarse aggregates are uniformly distributed throughout the batch.

(iii) Add water and mix it until the concrete appears to be homogeneous and of the desired consistency.

(b) Sampling of Cubes and Beams for Test

(i) Clean the moulds and apply oil.

(ii) Fill the concrete in the moulds in layers approximately 5cm thick.

(iii) Compact each layer with not less than 25 strokes per layer using a tamping rod (steel bar 20mm diameter and 60cm long).

(iv) Level the top surface and smoothen it with a trowel.

(c) Curing of Cubes and Beams

The test specimens are stored in moist air for 24 hours and after this period the specimens are marked and removed from the moulds and kept submerged in clear fresh water until taken out prior to test according to BS1881 -108 (1983).

3.5 Testing of Concrete

To determine the workability of the concrete, the Slump Test and Compacting Factor Test can be used. All of these tests can be called Non-Destructive Test. It is because when doing this testing, the samples are not crushed to get the result. Most engineers use Slump Test to determine the workability of the concrete. Slump Test is carried out to measure the consistency of plastic concrete.

For the physical properties (Destructive Test), one of the tests is Concrete Flexural Test. The objective of this test is to prescribe and describe the flexural strength test of specimens of hardened concrete and demonstrate the method for determining the flexural strength of concrete beam by means of a constant moment in the centre zone (two-point loading).

3.5.1 Slump

The Concrete slump test (or simply the slump test) is an insitu test or a laboratory test used to determine and measure on how hard and consistent a given sample of concrete is before curing. The concrete slump test is in essence, a method of quality control. For a particular mix, the slump should be consistent. Slump test is the test carried out to measure the differences in height between fresh mix concrete and height of cone. The following apparatus can be used.

Apparatus

(i) Tray

(ii) Slump cone

(iii) Tampering rod

(iv) Rule

(v) Trowel

(vi) Scoop

Procedure

The cone which was properly cleaned is held firmly against its base during the entire process by handles of the moulds on a flat surface. It was then gently filled with concrete in three layers, each of the layers was tamped 25 times with the tampering rod, the surface and edges were trimmed using the trowel to have a level surface. After leveling the surface, the cone is gently removed and then placed beside the concrete (slump) and then measured, according to BS 1881 -102 (1983). This procedure was repeated and the result is shown in Chapter 4.

3.5.2 Compressive strength

The compressive strength of cubes is tested by using the compressive testing machine by applying the load at the rate of 30 N/mm^2 per minute. Compressive strength may be defined as the measured maximum resistance of a concrete specimen to axial loading. Compressive strength test was done in adherence to BS 1881 -116 (1983). Thus,

$$\text{Compressive strength} = \frac{\text{Crushing load(N)}}{\text{Cross section area of concrete cube } (\text{mm}^2)} \qquad (3.25)$$

Six cube samples measuring 150 x 150 x150mm were moulded and stored in water for 28 days before test for compressive strength. Six similar samples were prepared for each mix proportion. The casting was made by filling each mould of 150 x 150 x 150mm with freshly mixed concrete in three layers. Each layer was compacted manually using a 25mm diameter steel tamping rod to give 25 strokes on a layer. The moulds containing the cubes were left for 24 hours under a room temperature for the beams to set before removing the moulds. The cube samples were removed after 24 hours and taken to the curing tank, BS 1881 -116 (1983).

Apparatus

(i) Crushing machine

(ii) Weighing balance

Procedure

The cubes (3 pieces) of each mix according to the mix designed were removed from curing tank and air dried, and then the hardened cube was placed on the compression testing machine to test for compressive strength for 7 days. The crushing machine continues to compress the cubes until the cube failed and the reading were taken and recorded immediately and steps were repeated for other samples. The same procedures were repeated for 28 days. (BS EN 12390-3: 2009). The results obtained are given in

Chapter 4.

3.5.3 Flexural strength

It is also known as modulus of rupture, or bending strength, or fracture strength, which is a mechanical parameter for brittle materials.

Flexural strength is the amount of force an object can take without breaking or permanently deformed or as a material's ability to resist deformation under load. It is the maximum surface stress in a bent beam at the instance of failure.

There are two methods of testing flexural strength, which are three point bending test and four point bending test, but they are very similar. A long rectangular sample of the material is supported at its ends. A load or force is then applied to the middle section until the material breaks.

For a three point test, the flexural strength (σ) can be calculated by using:

$$\sigma = \frac{3FL}{2wd^2)} \tag{3.26}$$

Where:

F is the maximum force applied

L is the length of the sample

w is the width of the sample

d is the depth of the sample

For a four point test, the flexural strength (σ) can be calculated by using:

$$\sigma = \frac{FL}{wd^2} \tag{3.27}$$

Where:

F is the maximum force applied

L is the length of the sample

w is the width of the sample

d is the depth of the sample

For this work, a Three Point Bending Test is adopted in accordance to BS 1881 - 118 (1983); (BS EN 12390-5: 2009). Six beam samples measuring 500 x 100 x 100mm were moulded and stored in water for 7 and 28 days for flexural strength test. Six similar samples were prepared for each mix proportion. The casting was made by filling each mould of 500 x 100 x 100mm with freshly mixed concrete in three layers. Each layer was compacted manually using a 25mm diameter steel tamping rod to give 25 strokes on a layer. The moulds containing the beams were left for 24 hours under a room temperature for the beams to set before removing the moulds. The beam samples were removed after 24 hours and taken to the curing tank. The beams (3 pieces) for each mix were removed and air dried. The hardened beam was placed on the universal testing machine with capacity of 150 kN to test for flexural strength for 7 days. A force or load is applied at the centre of the beam specimen. The reading of the load that caused the beam to break or fail were taken and recorded and then repeated for other samples. The same procedures were repeated for the 28 days specimens. The results obtained are given in Chapter 4.

3.6 Modelling

The modelling of the compressive and flexural strengths was done using MINITAB 16 soft ware and response surface methodology was adopted at 95% confidence level. The Stat icon in the Menu bar was used to gain access to the DOE option, that is, Response Surface through which Create Response Surface Design, Define Custom Response Surface Design, Analyse Response Surface Design and Contour/Surface Plots tasks were done to develop model and obtain the surface plots.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

The results of the tests carried out in this research work are presented in this chapter.

4.1.1 Physical and mechanical characterisation of periwinkle shell, sharp sand, and granite

The physical and mechanical characterisation of aggregates (Periwinkle shell, Sharp sand and Granite) were determined by sieve analysis, bulk density, specific gravity, moisture content, water absorption, aggregate impact value, and aggregate crushing value test. The physical and mechanical characteristics test carried out on the aggregates are summarised in Table 4.17a-b

4.1.1.1 Sieve analysis

The results of sieve analysis carried out on fine aggregate (sharp sand), granite, and periwinkle shell used in the production of cube and beam specimens are shown in Tables B1, B2 and B3 respectively.

The values in Tables B1, B2, B3 were plotted in Figure 4.1 and the S- shaped curves of the particle size distribution shows that the aggregate are well graded.

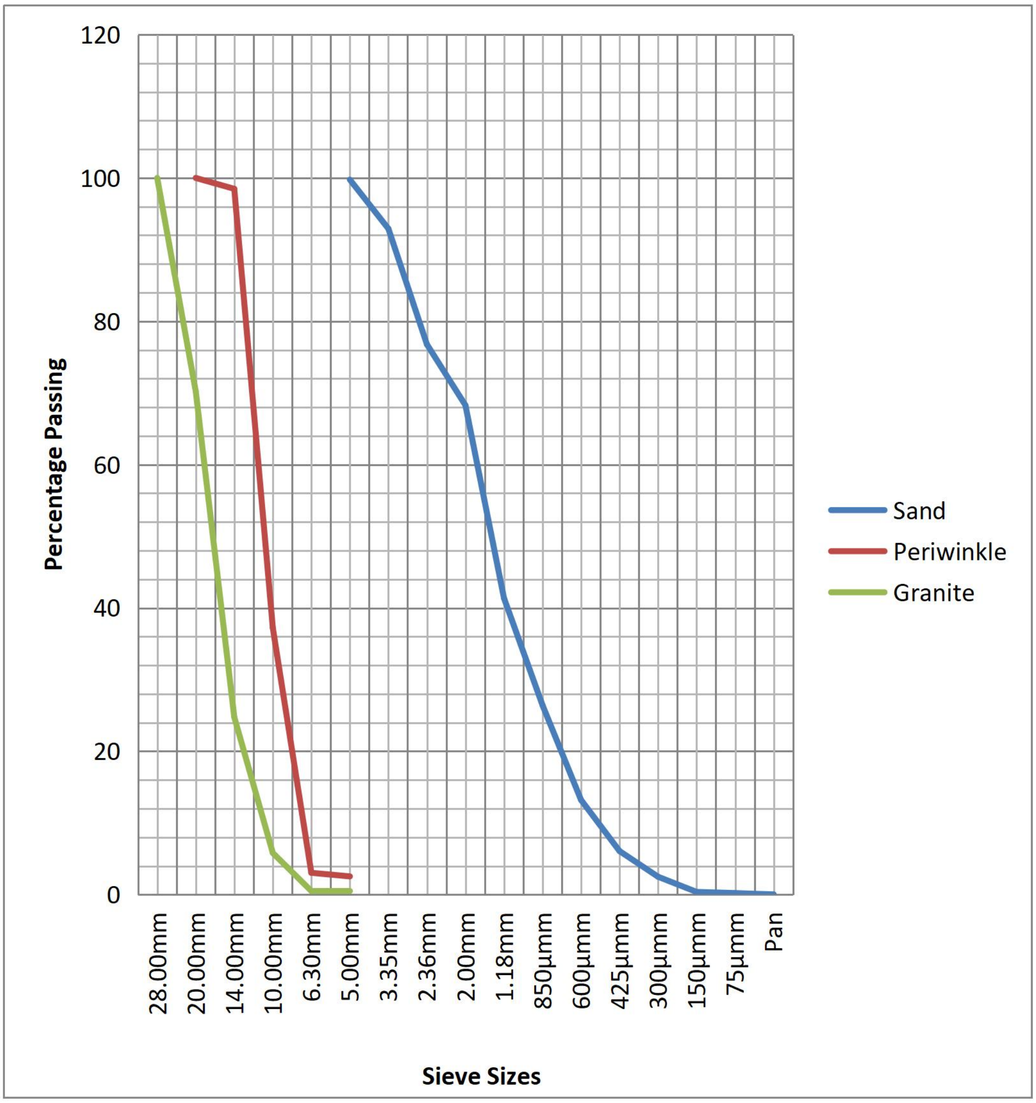


Figure 4.1: Sieve Analysis of Materials Used

4.1.1.2 Bulk density

The results of compacted and uncompacted bulk densities tests carried out on fine aggregates (sharp sand), granite, and periwinkle shells used in the production of cube and beam specimens are1695.65, 1820.74 and 706.86 kg/m^3 respectively, and are shown in Tables 4.1, 4.2, 4.3, and Figure D3. The findings of some researchers for average bulk density of aggregates are shown in Table 4.17a. According to BS 3681(1973), and Neville and Brooks (2010) the important requirement for a dry normal aggregate must have minimum compacted bulk density of 1200 kg/m^3 for fine aggregates and 960 kg/m^3

for coarse aggregate. Thus, the bulk density of periwinkle shells in Tables 4.3 was used for the production of concrete for this work falls below these values while the bulk density of the sharp sand and the granite in Tables 4.1 and 4.2 respectively satisfies the required bulk density of normal aggregates and were used for the production of concrete. The values obtained for this work falls within the range of the values from other researchers.

Table 4.1: Result of Bulk Density Test for Fine Aggregate (Sharp Sand)

Measurement	Uncompacted			Compacted		
No. of trials	1	2	3	1	2	3
Weight of sample & mould, W_2 (kg)	0.638	0.6395	0.6365	0.6601	0.6489	0.657
Weight of empty mould, W_1 (kg)	0.2672	0.2672	0.2672	0.2672	0.2672	0.2672
Weight of sample, W_2-W_1 (kg)	0.3708	0.3723	0.3693	0.3929	0.3817	0.3898
Volume of mould, W_3 (m^3)	0.0002	0.00023	0.00023	0.00023	0.00023	0.00023
Bulk density (kg/m³)	1619.9	1626.47	1613.37	1716.47	1667.54	1702.93
Average (kg/m³)	1619.92			1695.65		

Table 4.2: Result of Bulk Density Test for Coarse Aggregate (Granite)

Measurement	Uncompacted			Compacted		
No. of trials	1	2	3	1	2	3
Weight of sample & mould, W_2 (kg)	0.6338	0.6455	0.6421	0.6812	0.6746	0.6961
Weight of empty mould, W_1 (kg)	0.2672	0.2672	0.2672	0.2672	0.2672	0.2672
Weight of sample, W_2-W_1 (kg)	0.3666	0.3783	0.3749	0.414	0.4074	0.4289
Volume of mould, W_3 (m^3)	0.0002	0.00023	0.00023	0.00023	0.00023	0.00023
Bulk density (kg/m^3)	1601.6	1652.69	1637.83	1808.65	1779.82	1873.74
Average (kg/m^3)		1630.7			1820.74	

Table 4.3: Result of Bulk Density Test for Coarse Aggregate (Periwinkle Shell)

Measurement	Uncompacted			Compacted		
No. of trials	1	2	3	1	2	3
Weight of sample & mould, W_2 (kg)	0.4048	0.4035	0.4132	0.4267	0.4284	0.4319
Weight of empty mould, W_1 (kg)	0.2672	0.2672	0.2672	0.2672	0.2672	0.2672
Weight of sample, W_2-W_1 (kg)	0.1376	0.1363	0.146	0.1595	0.1612	0.1647
Volume of mould, W_3 (m^3)	0.0002	0.00023	0.00023	0.00023	0.00023	0.00023
Bulk density (kg/m^3)	601.14	595.457	637.833	696.811	704.238	719.528
Average (kg/m^3)		611.48			706.86	

4.1.1.3 Specific gravity

The results of specific gravity test carried out on fine aggregates (sharp sand), granite, and periwinkle shells used in the production of cube and beam specimens are 2.58, 2.79 and 1.28 respectively as shown in Tables 4.4, 4.5, 4.6, and Figure D1. Dahiru *et al.* (2018) stated the specific gravity of gravel to be 3.20, sand to be 2.66 and that of periwinkle shells as 1.73.

Table 4.17b shows the results of specific gravity of aggregates found by other researchers. Olali (2019) classified aggregates having specific gravities ranging from 2.5 - 2.7 as normal weight aggregates. From the data and analysis of periwinkle shells by previous researchers and this work, the periwinkle shell can be classified as a lightweight aggregate, because it falls below the stated classification.

Table 4.4: Result of Specific Gravity Test for Fine Aggregate (Sharp Sand)

No. of trials	1	2	3
Mass of empty cylinder, M_1 (g)	69	69	69
Mass of cylinder & sample, M_2 (g)	131.9	122.7	121
Mass of cylinder, sample & water, M_3 (g)	206.9	200.8	200.2
Mass of cylinder & water, M_4 (g)	168.2	168.2	168.2
Specific gravity (G_s)	2.599	2.545	2.6
Average specific gravity		2.58	

Table 4.5: Result of Specific Gravity Test for Coarse Aggregate (Granite)

No. of trials	1	2	3
Mass of empty cylinder, M_1 (g)	394.1	394.1	394.1
Mass of cylinder & sample, M_2 (g)	666.5	540.4	556.9
Mass of cylinder, sample & water, M_3 (g)	1058	980.7	992.7
Mass of cylinder & water, M_4 (g)	886.7	886.7	886.7
Specific gravity (G_s)	2.694	2.797	2.866
Average specific gravity		2.79	

Table 4.6: Result of Specific Gravity Test for Coarse Aggregate (Periwinkle Shell)

No. of trials	1	2	3
Mass of empty cylinder, M_1 (g)	116.6	116.6	116.6
Mass of cylinder & sample, M_2 (g)	175.9	176.9	180.2
Mass of cylinder, sample & water, M_3 (g)	358.7	365.9	372.5
Mass of cylinder & water, M_4 (g)	352.9	352.9	352.9
Specific gravity (G_s)	1.108	1.275	1.446
Average specific gravity		1.28	

4.1.1.4 Moisture content

The results of natural moisture content test carried out on fine aggregate (sharp sand), granite, and periwinkle shell used in the production of cube and beam specimens are 2.49, 0.2, and 4.13% respectively as shown in Tables 4.6, 4.8, 4.9, and Figure D3. The results of moisture content of aggregates by previous researchers are shown in Table 4.17a. The values obtained fall within the range of values of the earlier researchers.

Table 4.7: Result of Moisture Content Test for Fine Aggregate (Sharp Sand)

No. of trials	1	2	3
Mass of empty cylinder, A (g)	22	24.3	18.5
Mass of cylinder & wet sample, B (g)	50.4	56.8	55.2
Mass of cylinder & dried sample, C (g)	49.6	55.8	54.7
Moisture Content (%)	2.899	3.175	1.381
Average (%)		2.49	

Table 4.8: Result of Moisture Content Test for Coarse Aggregate (Granite)

No. of trials	1	2	3
Mass of empty cylinder, A (g)	23.1	25.3	22.8
Mass of cylinder & wet sample, B (g)	147.1	136.5	141.1
Mass of cylinder & dried sample, C (g)	146.9	136.1	141
Moisture Content (%)	0.162	0.361	0.0846
Average (%)		0.2	

Table 4.9: Result of Moisture Content Test for Coarse Aggregate (Periwinkle Shell)

No. of trials	1	2	3

Mass of empty cylinder, A (g)	21.9	22.4	19.8
Mass of cylinder & wet sample, B (g)	42.6	42	46.7
Mass of cylinder & dried sample, C (g)	41.8	41.3	45.5
Moisture Content (%)	4.02	3.704	4.669
Average (%)		4.13	

4.1.1.5 Water absorption test

The results of the average percentage water absorption test carried out on fine aggregate (sharp sand), granite, and periwinkle shell used in the production of cube and beam specimens are 20.02, 1.83, and 5.13% respectively as shown in Tables 4.10, 4.11, 4.12 and Figure D4. The values of the water absorption test of aggregates found by other researchers are stated in Table 4.17a.

Table 4.10: Result of Water Absorption Test for Fine Aggregate (Sharp Sand)

No. of trials	1	2	3
Mass of empty cylinder, A (g)	24.1	29.8	23.4
Mass of cylinder & dry sample, C (g)	88.9	115.9	99.7
Mass of cylinder & wet sample, B (g)	100.8	133.3	116.1
Water Absorption (%)	18.364	20.209	21.494
Average (%)		20.02	

Table 4.11: Result of Water Absorption Test for Coarse Aggregate (Granite)

No. of trials	1	2	3

Mass of empty cylinder, A (g)	26	26.2	23.3
Mass of cylinder & dry sample, C (g)	131	114.7	105
Mass of cylinder & wet sample, B (g)	132.5	115.7	107.4
Water Absorption (%)	1.429	1.13	2.938
Average (%)		1.83	

Table 4.12: Result of Water Absorption Test for Coarse Aggregate (Periwinkle Shell)

No. of trials	1	2	3
Mass of empty cylinder, A (g)	27.9	22.6	25.7
Mass of cylinder & dry sample, C (g)	55.9	49.5	59.4
Mass of cylinder & wet sample, B (g)	57.3	50.3	61.9
Water Absorption (%)	5	2.974	7.418
Average (%)		5.13	

4.1.1.6 Aggregate impact value test

The aggregate impact and crushing values for granite and periwinkle shells are shown in Tables 4.13, 4.14, 4.15, 4.16, and Figures D5, and D6. The results of the aggregate impact values (AIV) of coarse aggregate are given in Table 4.17b.

BS 812 (1975) stated that the wearing surface aggregates were expected to have a maximum impact value of 30% and concrete aggregates are to have a maximum value of 45%. The results of the periwinkle shell shows low resistance to impact when compared to granite. According to the results of impact values of periwinkle shell obtained for this work, it is clearly shown that the periwinkle shell used is not for wearing course but can be used for some structural elements.

Table 4.13: Result of Aggregate Impact Value Test for Coarse Aggregate (Granite)

No. of trials	1	2	3
Mass of sample (W_1)	620	620	620
Mass passing 2.36mm sieve (W_2)	65.5	87.5	74.5
Impact value (%)	10.565	14.113	12.016
Average (%)		12.23	

Table 4.14: Result of Aggregate Impact Value Test for Coarse Aggregate (Periwinkle Shell)

No. of trials	1	2	3
Mass of sample (W_1)	220	220	220
Mass passing 2.36mm sieve (W_2)	75.2	84.2	80.7
Impact value (%)	34.182	38.273	36.682
Average (%)		36.38	

4.1.1.7 Aggregate crushing value test

The impact values used in the production of cube and beam specimens are as shown in Tables 4.15, and 4.16

Table 4.15: Result of Aggregate Crushing Value Test for Coarse Aggregate (Granite)

No. of trials	1	2	3
Mass of sample (W_1)	3000	3000	3000
Mass passing 2.36mm sieve (W_2)	465.6	326.4	437.5
Impact value (%)	15.52	10.88	14.583
Average (%)		13.66	

Table 4.16: Result of Aggregate Crushing Value Test for Coarse Aggregate (Periwinkle Shell)

No. of trials	1	2	3
Mass of sample (W_1)	1000	1000	1000

Mass passing 2.36mm sieve (W_2)	318.4	338.9	341.15
Impact value (%)	31.84	33.89	34.115
Average (%)		33.28	

Table 4.17a: Summary of Physical and Mechanical Properties of Aggregates

Physical Properties	Sharp Sand	Granite	Periwinkle Shell	Researchers
Moisture Content			1.44%	Adewuyi and Adegoke, (2008)
	7.80%		11.65%	Amaziah et al, (2013)
	2.49%	0.20%	4.13%	Irior, (2021)-(Present study)
Water Absorption Test	-	-	2.40%	Ibearugbulem and Ajoku, (2016)
	10%	-	25%	Dahiru et al, (2018)
	-	-	3.05%	Olali , (2019)
	20.02%	1.83%	5.13%	Irior, (2021)-(Present study)
Bulk Density (kg/m^3)	-	2860kg/m^3	1243kg/m^3	Adewuyi and Adegoke, (2008)
	-	-	590kg/m^3	Ayegba, (2013)
	1636kg/m^3	-	1504kg/m^3	Amaziah et al, (2013)
	1670kg/m3	-	520kg/m^3	Ibearugbulem and Ajoku, (2016)
	1681.4kg/m^3	-	619.90kg/m^3	Dahiru et al, (2018)
	-	-	552.10kg/m^3	Olali , (2019)
	1695.65kg/m^3	1820.74kg/m^3	706.86kg/m^3	Irior, (2021)-(Present study)
	>1200kg/m3	>960kg/m^3		According to BS3681(1973)

Table 4.17b: Summary of Physical and Mechanical Properties of Aggregates

Physical Properties	Sharp Sand	Granite	Periwinkle Shell	Researchers

Specific Gravity	-	-	2.07	Ayegba, (2013)
	2.64	-	2.1	Amaziah et al, (2013)
	2.59	-	2.6	Bharathi et al, (2016)
	2.602	-	1.16	Ibearugbulem and Ajoku, (2016)
	2.66	-	1.73	Dahiru et al,(2018)
	-	-	1.154	Olali , (2019)
	2.58	2.79	1.28	Irior, (2021)- (Present study)
Aggregate Impact Value for Concrete Aggregates		45% Max	45% Max	Shetty, (2009),BS 812(1975)
		-	21.49%	Ibearugbulem and Ajoku, (2016)
		-	14.23%	Olali , (2019)
		12.23%	36.38%	Irior, (2021)- (Present study)
Aggregate Crushing Value for Concrete Aggregates		13.66%	33.28%	

4.1.2 Compressive strength test results

The compressive strength test for this research work was carried out with a total immersion of cube specimens in the curing tank for 7 and 28 days respectively. The compressive strength is calculated and the results are shown in Tables C1 to C6.

The summary of the result of compressive strength and the corresponding densities of concrete for 7 and 28 days is shown in Table C15. The mixes which had 28 days compressive strengths that falls on or in the range of 17 - 42 N/mm^2 in accordance to BS 8110 (1997) can be used for structural purposes.

4.1.3 Flexural strength test results

A three point flexural strength test was adopted for this research work and the test was carried out with the total immersion of beam specimens in the curing tank for 7 and 28 days respectively. The flexural strength is calculated using Equation 4.6 and the results are shown in Tables C7 to C12. The 7 and 28 days summary result of the flexural strength and respective densities are also given in Table C15.

4.1.4 Modelling the compressive and flexural strengths

Tables C13 and C14 were imported into MINITAB while analysis was done at 95% confidence interval. Several models were tried and the best with adequate fit was considered.

4.1.4.1 Compressive strength model

Models were developed for the 7 and 28 days compressive strength which are shown in Equations (4.1) and (4.2) respectively, and Table 4.18.

Table 4.18: Statistical Summary of Regression Models for Compressive Strength

The Coefficient and significant p-values of each term in the pure quadratic model

7 Days Compressive strength, Y_1 (N/mm^2)			28 Days Compressive strength, Y_1 (N/mm^2)		
Term	Coef	P-value	Term	Coef	P-value
Constant	45.911	0	Constant	64.398	0
x_1	4.012	0.018	x_1	6.008	0.002
x_2	-1.148	0	x_2	-2.687	0.01
x_3	-22.458	0	x_3	-25.607	0
x_4	-90.272	0.046	x_4	-204.98	0
$x_4 * x_4$	94.575	0.281	$x_2 * x_2$	0.3	0.009
			$x_4 * x_4$	303.834	0.004
R-Sq(pred) = 90.68%	R-Sq(adj) = 93.30%		R-Sq(pred) = 91.14%	R-Sq(adj) = 92.98%	

$$Y_1 = 45.911 + 4.012x_1 - 1.148x_2 - 22.458x_3 - 90.272x_4 + 94.575x_4^2 \quad (4.1)$$

R-sq (adj) = 93.30%

$$Y_1 = 64.398 + 6.008x_1 - 2.687x_2 - 25.607x_3 - 204.98x_4 + 0.3x_2^2 + 303.834x_4^2 \quad (4.2)$$

R-sq (adj) = 92.92%

4.1.4.2 Residual and response surface plots for compressive strength

The residual and response surface plots for 7 and 28 days compressive strength models are shown in Figures 4.2, 4.3, 4.4, and 4.5 respectively.

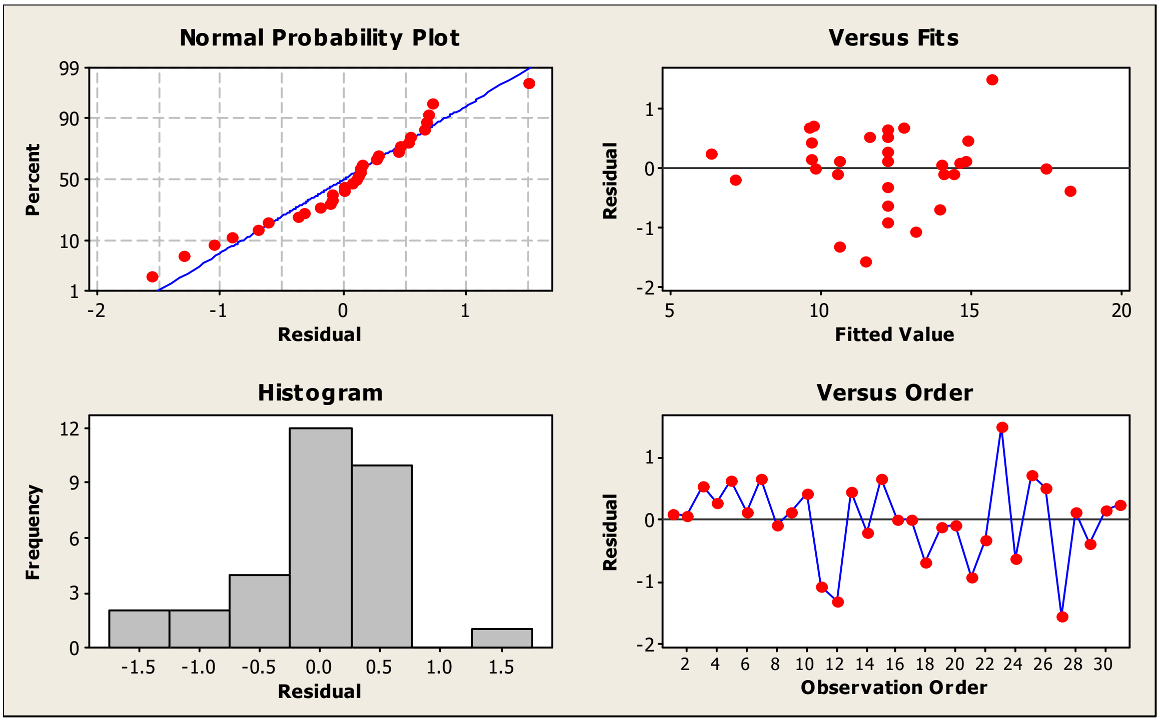


Figure 4.2: Residual plots for 7 days compressive strength, Y_1

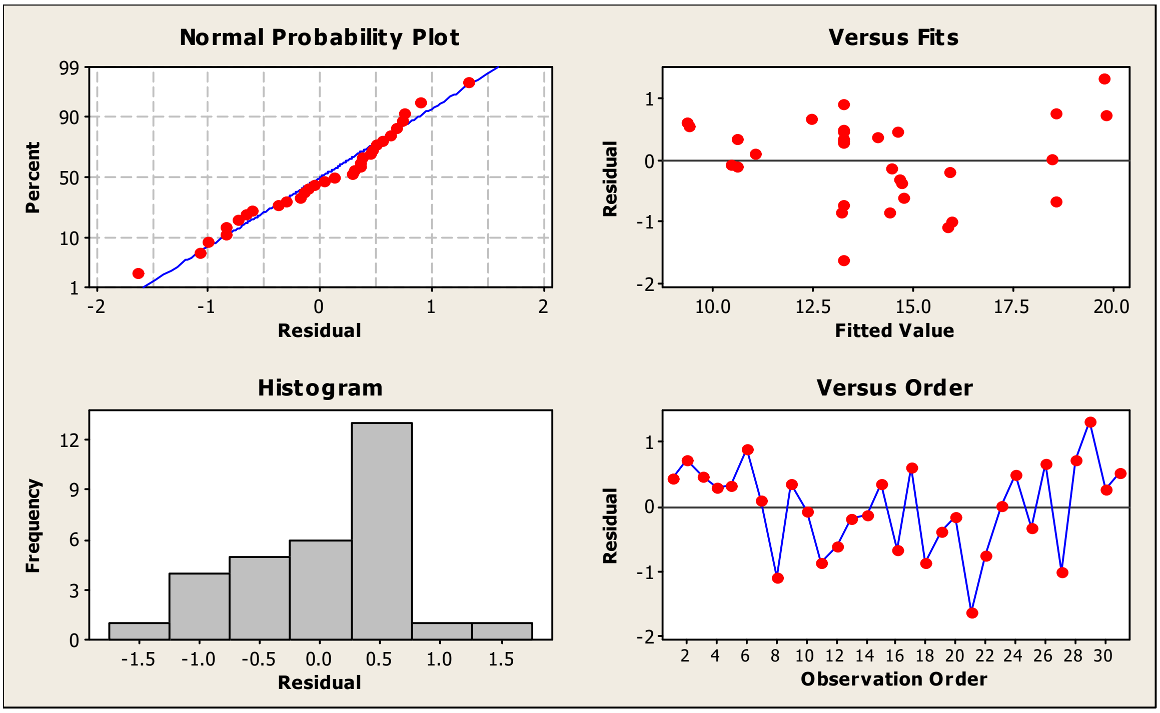


Figure 4.3: Residual plots for 28 days compressive strength, Y_1

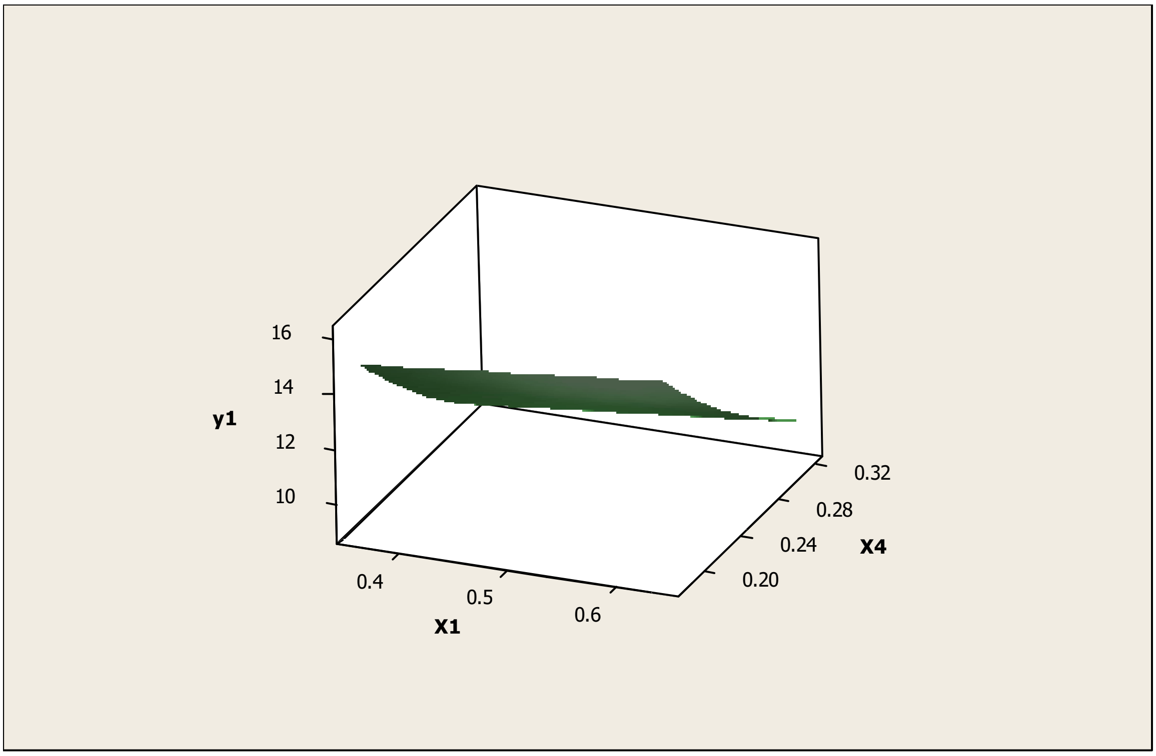


Figure 4.4: Surface plots for 7 days compressive strength, Y_1

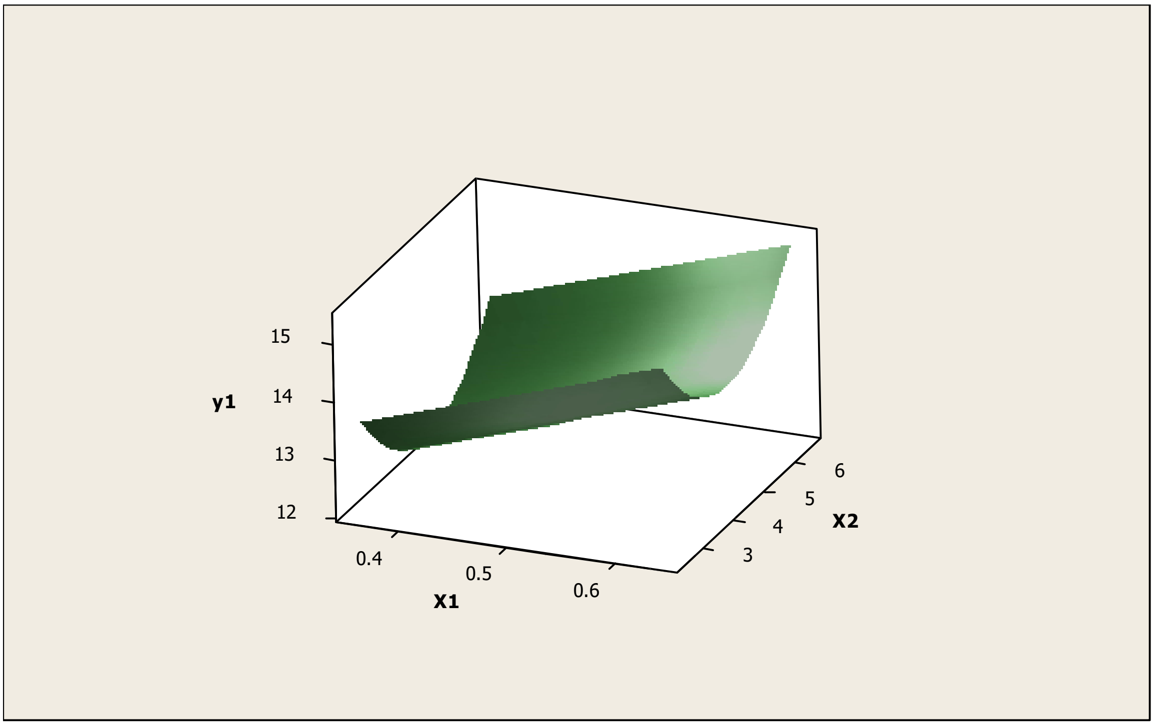


Figure 4.5: Surface plots for 28 days compressive strength, Y_1

4.1.4.3 Flexural strength model

Models were developed for the 7 and 28 days flexural strength are as shown in Equations (4.3) and (4.4) respectively, and Table 4.19.

Table 4.19: Statistical Summary of Regression Models for Flexural Strength
The Coefficient and significant p-values of each term in the pure quadratic model

7 Days Flexural strength, Y_2 (N/mm^2)			28 Days Flexural strength, Y_2 (N/mm^2)		
Term	Coef	P-value	Term	Coef	P-value
Constant	0.675	0.954	Constant	22.592	0
x_1	6.654	0	x_1	9.232	0
x_2	-0.136	0.108	x_2	1.545	0.029
x_3	59.625	0.136	x_3	-4.577	0.008
x_4	-101.4	0.007	x_4	-119.45	0.002
$x_3 * x_3$	-49.385	0.122	$x_2 * x_2$	-0.192	0.015
$x_4 * x_4$	157.37	0.032	$x_4 * x_4$	173.712	0.016
R-Sq(pred) = 72.53%	R-Sq(adj) = 80.11%		R-Sq(pred) = 86.50%	R-Sq(adj) = 90.00%	

$$Y_2 = 0.675 + 6.654x_1 - 0.136x_2 + 59.625x_3 - 101.396x_4 - 49.385x_3^2 + 157.37x_4^2 \quad (4.3)$$

R-sq (adj) = 80.11%

$$Y_2 = 22.592 + 9.232x_1 + 1.545x_2 - 4.577x_3 - 119.451x_4 - 0.192x_2^2 + 173.712x_4^2 \quad (4.4)$$

R-sq (adj) = 90.00%

4.1.4.4 Residual and response surface plots for flexural strength

The residual and surface plots are shown in Figures 4.6, 4.7, 4.8, and 4.9 for 7 and 28 days flexural strength respectively.

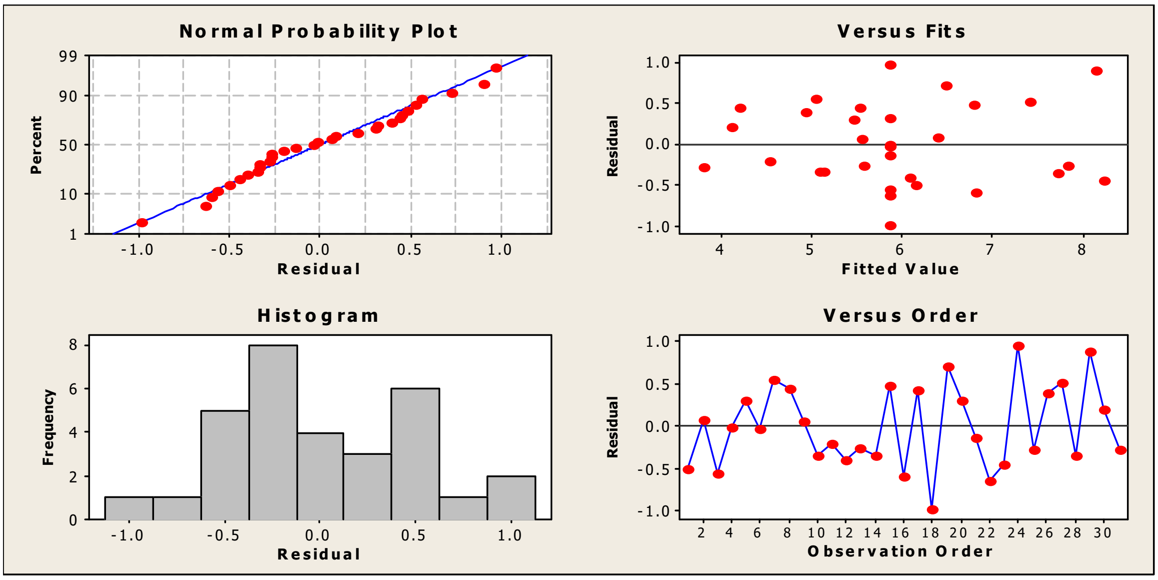


Figure 4.6: Residual plots for 7 days Flexural strength, Y_2

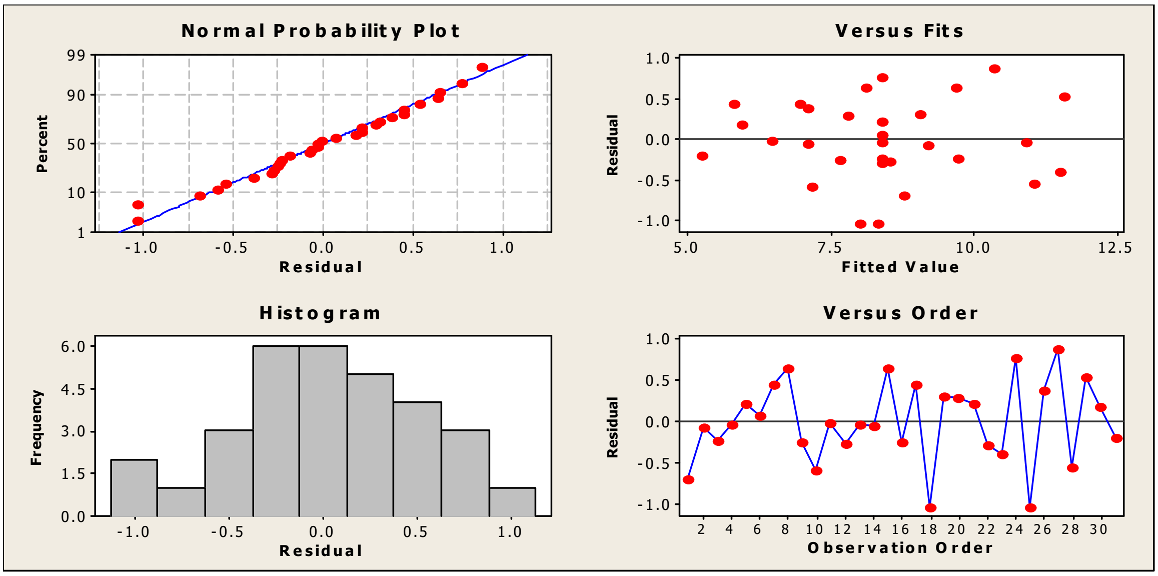


Figure 4.7: Residual plots for 28 days Flexural strength, Y_2

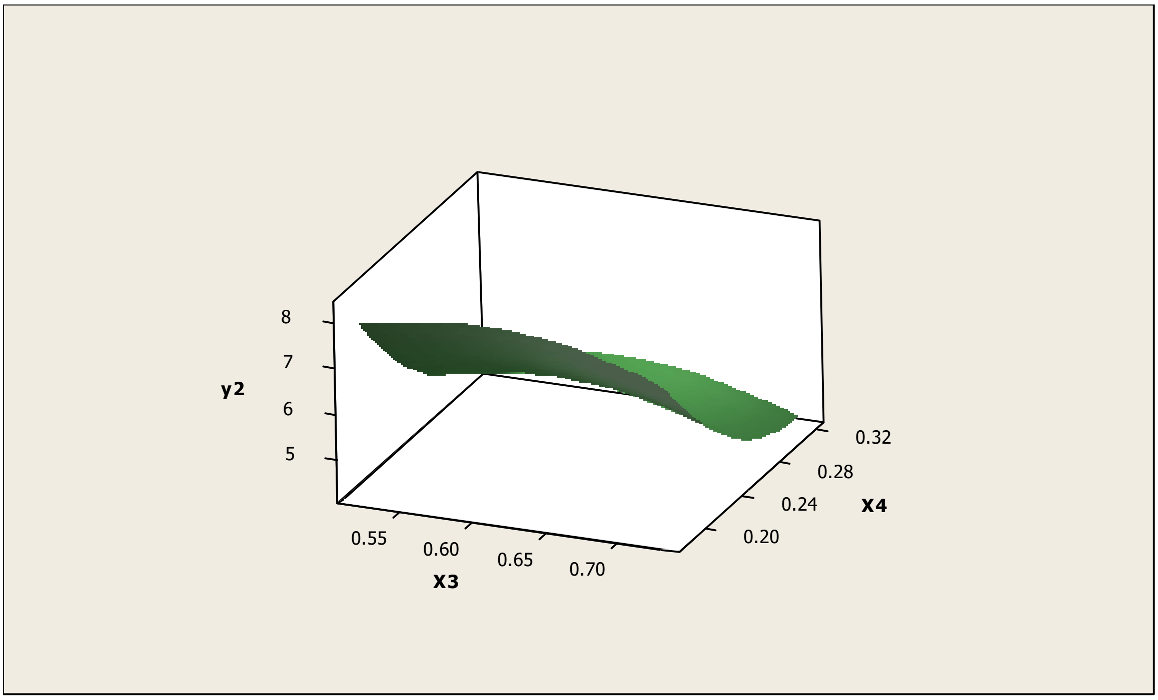


Figure 4.8: Surface plots for 7 days Flexural strength, Y_2

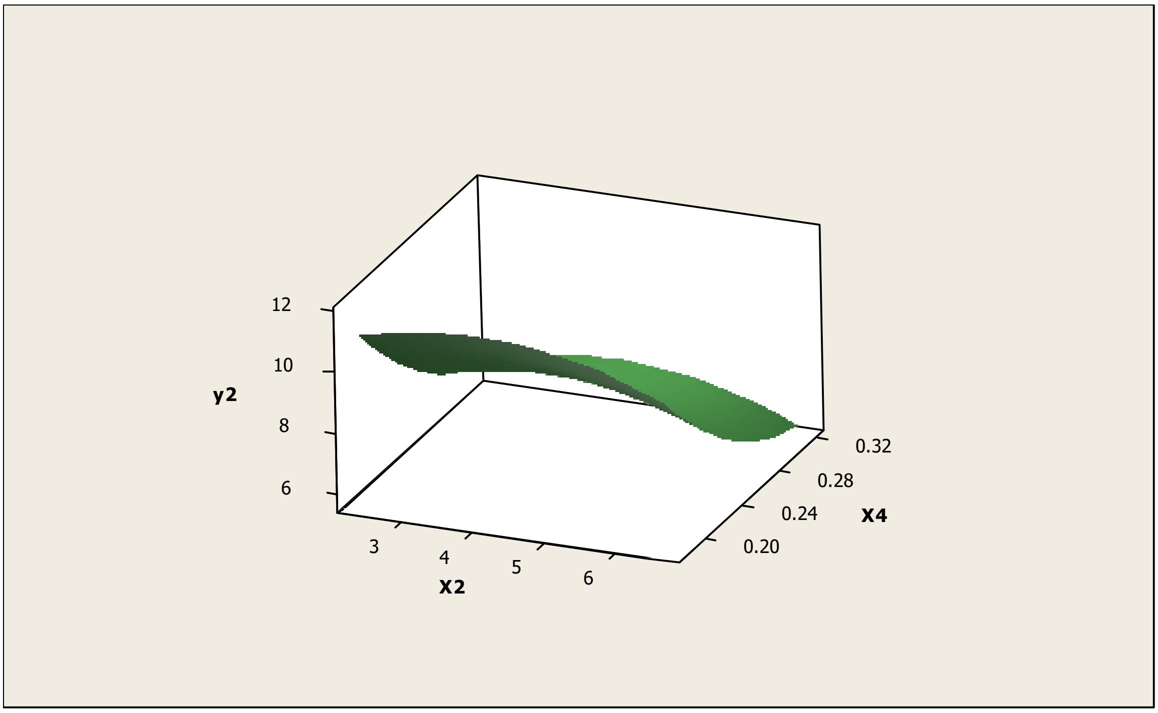


Figure 4.9: Surface plots for 28 days Flexural strength, Y_2

4.1.5 Model validation

Equations (4.1), (4.2), (4.3), and (4.4) are used to validate the models, and Tables 4.20 and 4.21 show some few results of the validation carried out and were found adequate for predicting the compressive and flexural strengths of concrete incorporating periwinkle shell as partial replacement of coarse aggregates.

Table 4.20: Results of Validation for Compressive Strength

	Validation mix trials				7 Days		28 Days	
Responses	x_1	x_2	x_3	x_4	Predicted value	Experimental value	Predicted value	Experimental Value
Compressive	0.5	2.38	0.62	0.25	14.60	14.7	14.57	15.02
strength	0.4	6	0.55	0.2	14.00	14.07	18.55	19.3
(N/mm^2)	0.5	4.5	0.62	0.25	12.17	12.71	13.25	13.72
	0.4	3	0.55	0.2	17.45	17.01	18.51	17.48
	0.5	6.62	0.7	0.3	6.03	11.56	10.69	13.6
	0.64	6	0.73	0.25	8.54	14.49	11.97	17.04

Table 4.21: Results of Validation for Flexural Strength

Responses	Validation mix trials x_1	x_2	x_3	x_4	7 Days Predicted value	7 Days Experimental value	28 Days Predicted value	28 Days Experimental Value
Flexural strength (N/mm^2)	0.5	2.4	0.62	0.25	6.15	5.7	7.9	8.1
	0.4	6	0.55	0.2	6.39	6.5	9.2	9.1
	0.5	4.5	0.62	0.25	5.86	5.3	8.4	8.2
	0.4	3	0.55	0.2	6.80	7.3	9.7	10.4
	0.5	6.6	0.7	0.3	4.39	4.8	5.6	6.8
	0.64	6	0.73	0.25	5.81	6.5	8.5	9.3

4.1.6 The relationship between the compressive and flexural strengths of concrete incorporating periwinkle shell

Equations (4.5), (4.6), Figures 4.10, and 4.11 show the relationship between the compressive and flexural strengths for 7 and 28 days respectively.

$$y = 0.008x^2 + 0.079x + 3.559 \quad (4.5)$$

$$y =- 0.015x^2 + 0.928x - 1.353 \quad (4.6)$$

Where y is for the Flexural strength and x is for the compressive strength

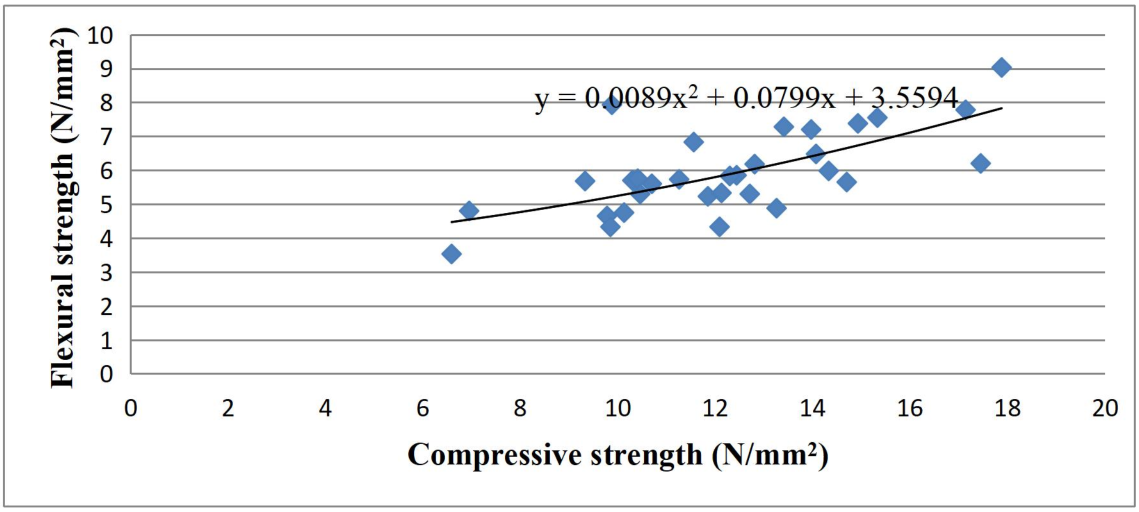


Figure 4.10: Relationship between compressive and flexural strengths at 7 days

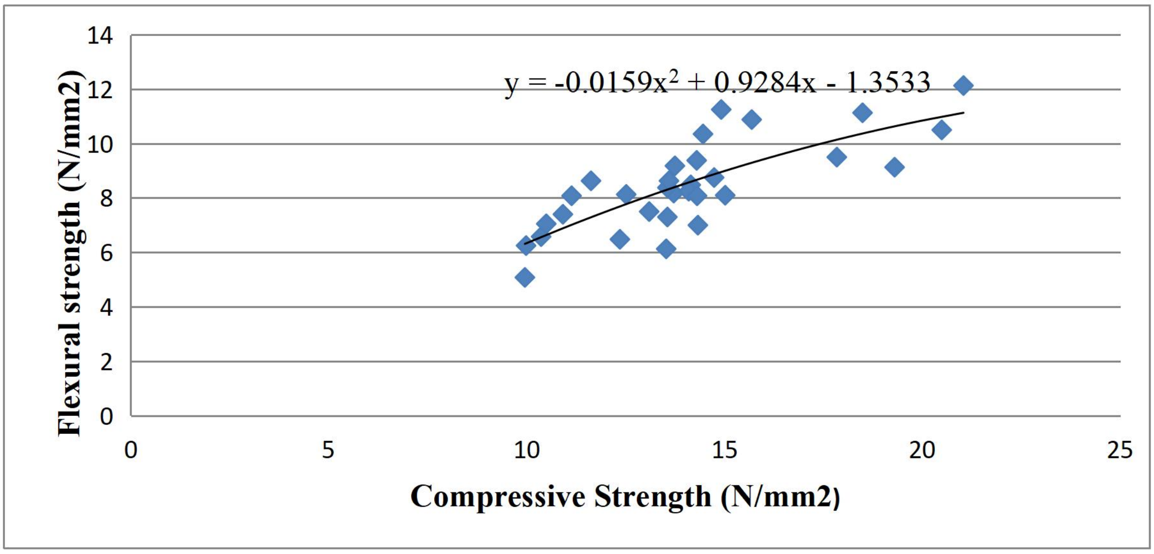


Figure 4.11: Relationship between compressive and flexural strengths at 28 days

4.1.7 Validation of the relationship between the compressive and flexural strengths at 7 and 28 days

By using Equations (4.5) and (4.6) to validate the relationship between the compressive and flexural strengths of concrete incorporating periwinkle shell as partial replacement of coarse aggregates, Tables 4.22 and 4.23 show some few validation trials and are found adequate when the predicted values were compared with the experimental values obtained from the laboratory.

Table 4.22: Results of Validation for relationship between the compressive and flexural strengths for 7 days

7 Days Compressive Strength (N/mm^2)	7 Days Flexural Strength (N/mm^2)	
Experimental Value	Predicted value	Experimental Value
14.7	6.45	5.65
14.07	6.25	6.48
12.71	5.86	5.3
17.01	7.22	7.23
11.56	5.54	4.78
14.49	6.38	6.48

Table 4.23: Results of Validation for relationship between the compressive and flexural strengths for 28 days

28 Days Compressive Strength (N/mm^2)	28 Days Flexural Strength (N/mm^2)	
Experimental Value	Predicted value	Experimental Value
15.02	9.20	8.1
19.3	10.97	9.13
13.72	8.56	8.18
17.48	10.29	10.38
13.6	8.49	6.75
17.04	10.10	9.25

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the outcome of this work, the following conclusion are made:

The physical characteristics of the constituent's materials: The compacted bulk densities for fine aggregates (sharp sand), granite, and periwinkle shells were found to be 1695.65, 1820.74 and 706.86 kg/m³ respectively, and the specific gravities of sharp sand, granite and periwinkle shells were obtained to be 2.58, 2.79 and 1.28 respectively. The natural moisture content for fine aggregates (sharp sand), granite, and periwinkle shells were determined to be 2.49, 0.20 and 4.13% respectively.

The maximum compressive and flexural strengths of concrete at 28 days are 19.30 and 11.13 N/mm^2 respectively with densities below 2400 kg/m³ for normal concrete.

The polynomial models adopted in this study have proved to be adequate to predict the compressive strength and flexural strength of concrete incorporating periwinkle shell to a minimum of 80.11% accuracy.

5.2 Recommendations

From the outcome of this work, the following recommendations are made:

(i) Periwinkle shell is recommended to be used for the production of structural light weight concrete having produced concrete with maximum compressive strength of 21.04 N/mm^2.

(ii) The developed polynomial models are also recommended to be used for predicting the compressive and flexural strengths of concrete incorporating periwinkle shells to serve as a guide in mix design process.

(iii) The periwinkle shells used in this study were obtained from Portharcourt, Rivers state and periwinkle shells from other parts of the country may be used for the production of light weight concrete and model development.

5.3 Contribution to Knowledge

The study revealed that the maximum compressive and flexural strengths of concrete incorporating periwinkle shells as coarse aggregates are 19.30 and 11.13N/mm^2 respectively at 28 days. Also, the polynomial models developed to predict the compressive and flexural strengths are of 80.11% accuracy.

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APPENDICES

Appendix A: Values from Minitab 16 Soft ware

Table A1: Coded Values from Minitab 16 Soft ware

RunOrder	PtType	Blocks	X_1	X_2	X_3	X_4
1	-1	1	0	-1.414	0	0
2	1	1	-1	1	-1	-1
3	0	1	0	0	0	0
4	0	1	0	0	0	0
5	0	1	0	0	0	0
6	0	1	0	0	0	0
7	-1	1	0	0	0	1.414
8	-1	1	0	0	-1.414	0
9	1	1	1	-1	1	1
10	-1	1	0	0	1.414	0
11	1	1	-1	-1	-1	1
12	1	1	-1	1	1	-1
13	1	1	1	-1	1	-1
14	1	1	1	1	1	1
15	-1	1	1.414	0	0	0
16	1	1	-1	-1	-1	-1
17	1	1	-1	-1	1	1
18	1	1	1	-1	-1	1
19	1	1	-1	-1	1	-1
20	1	1	1	1	-1	1
21	0	1	0	0	0	0
22	0	1	0	0	0	0
23	-1	1	0	0	0	-1.414
24	0	1	0	0	0	0
25	-1	1	0	1.414	0	0
26	-1	1	-1.414	0	0	0
27	1	1	1	1	1	-1
28	1	1	1	1	-1	-1
29	1	1	1	-1	-1	-1
30	1	1	-1	1	-1	1
31	1	1	-1	1	1	1

Table A2: Uncoded Values

RunOrder	PtType	Blocks	X1	X2	X3	X4
1	-1	1	0.5	2.38	0.62	0.25
2	1	1	0.4	6	0.55	0.2
3	0	1	0.5	4.5	0.62	0.25
4	0	1	0.5	4.5	0.62	0.25
5	0	1	0.5	4.5	0.62	0.25
6	0	1	0.5	4.5	0.62	0.25
7	-1	1	0.5	4.5	0.62	0.32
8	-1	1	0.5	4.5	0.52	0.25
9	1	1	0.6	3	0.7	0.3
10	-1	1	0.5	4.5	0.73	0.25
11	1	1	0.4	3	0.55	0.3
12	1	1	0.4	6	0.7	0.2
13	1	1	0.6	3	0.7	0.2
14	1	1	0.6	6	0.7	0.3
15	-1	1	0.64	4.5	0.62	0.25
16	1	1	0.4	3	0.55	0.2
17	1	1	0.4	3	0.7	0.3
18	1	1	0.6	3	0.55	0.3
19	1	1	0.4	3	0.7	0.2
20	1	1	0.6	6	0.55	0.3
21	0	1	0.5	4.5	0.62	0.25
22	0	1	0.5	4.5	0.62	0.25
23	-1	1	0.5	4.5	0.62	0.18
24	0	1	0.5	4.5	0.62	0.25
25	-1	1	0.5	6.62	0.62	0.25
26	-1	1	0.36	4.5	0.62	0.25
27	1	1	0.6	6	0.7	0.2
28	1	1	0.6	6	0.55	0.2
29	1	1	0.6	3	0.55	0.2
30	1	1	0.4	6	0.55	0.3
31	1	1	0.4	6	0.7	0.3

Table A3: Proportion of Mix Constituents in kg/m³ for Concrete Production

X_1	X_2	X_3	X_4	W_W	W_C	W_{FA}	W_{CA}	W_{PS}	Wgr
0.5	2.38	0.62	0.25	246.84	493.679	446.483	728.473	182.118	546.355
0.4	6	0.55	0.2	113.217	283.041	764.211	934.036	186.807	747.229
0.5	4.5	0.62	0.25	161.974	323.948	553.952	903.816	225.954	677.862
0.5	4.5	0.62	0.25	161.974	323.948	553.952	903.816	225.954	677.862
0.5	4.5	0.62	0.25	161.974	323.948	553.952	903.816	225.954	677.862
0.5	4.5	0.62	0.25	161.974	323.948	553.952	903.816	225.954	677.862
0.5	4.5	0.62	0.32	154.197	308.394	527.354	860.42	275.334	585.085
0.5	4.5	0.52	0.25	166.079	332.157	717.459	777.248	194.312	582.936
0.6	3	0.7	0.3	234.154	390.256	351.23	819.537	245.861	573.676
0.5	4.5	0.73	0.25	157.688	315.375	383.181	1036.01	259.002	777.005
0.4	3	0.55	0.3	176.669	441.674	596.259	728.762	218.628	510.133
0.4	6	0.7	0.2	109.596	273.991	493.184	1150.76	230.152	920.609
0.6	3	0.7	0.2	250.521	417.535	375.781	876.823	175.365	701.458
0.6	6	0.7	0.3	143.244	238.74	429.732	1002.71	300.812	701.895
0.64	4.5	0.62	0.25	198.157	309.62	529.45	863.839	215.96	647.879
0.4	3	0.55	0.2	187.566	468.916	633.037	773.711	154.742	618.969
0.4	3	0.7	0.3	169.611	424.027	381.624	890.457	267.137	623.32
0.6	3	0.55	0.3	243.092	405.154	546.958	668.504	200.551	467.953
0.4	3	0.7	0.2	182.571	456.427	410.785	958.497	191.699	766.798
0.6	6	0.55	0.3	149.992	249.987	674.965	824.957	247.487	577.47
0.5	4.5	0.62	0.25	161.974	323.948	553.952	903.816	225.954	677.862
0.5	4.5	0.62	0.25	161.974	323.948	553.952	903.816	225.954	677.862
0.5	4.5	0.62	0.18	170.577	341.155	583.375	951.822	171.328	780.494
0.5	4.5	0.62	0.25	161.974	323.948	553.952	903.816	225.954	677.862
0.5	6.62	0.62	0.25	120.534	241.068	606.429	989.438	247.359	742.078
0.36	4.5	0.62	0.25	122.28	339.668	580.832	947.673	236.918	710.755
0.6	6	0.7	0.2	155.689	259.482	467.067	1089.82	217.965	871.858
0.6	6	0.55	0.2	160.551	267.585	722.479	883.029	176.606	706.423
0.6	3	0.55	0.2	256.777	427.961	577.748	706.136	141.227	564.909
0.4	6	0.55	0.3	105.371	263.426	711.251	869.307	260.792	608.515
0.4	6	0.7	0.3	100.387	250.968	451.742	1054.06	316.219	737.845

Appendix B: Result of Sieve Analysis for Aggregates

Table B1: Result of Sieve Analysis for Fine Aggregate (Sharp Sand)

Sieve size	Mass retained(g)	% mass retained	Cum.% mass retained	% passing
5.00mm	1.2	0.24	0.24	99.76
3.35mm	34.2	6.84	7.08	92.92
2.36mm	80.7	16.14	23.22	76.78
2.00mm	42.5	8.5	31.72	68.28
1.18mm	134.5	26.9	58.62	41.38
850µmm	74.7	14.94	73.56	26.44
600µmm	66.1	13.22	86.78	13.22
425µmm	35.7	7.14	93.92	6.08
300µmm	17.9	3.58	97.5	2.5
150µmm	10.6	2.12	99.62	0.38
75µmm	0.8	0.16	99.78	0.22
Pan	0.9	0.18	99.96	0.04

Table B2: Result of Sieve Analysis Test for Coarse Aggregate (Granite)

Sieve size	Mass retained(g)	% mass retained	Cum.% mass retained	% passing
28.00mm	0	0	0	100
20.00mm	297.7	29.77	29.77	70.23
14.00mm	454.6	45.46	75.23	24.77
10.00mm	189.5	18.95	94.18	5.82
6.30mm	53.1	5.31	99.49	0.51
5.00mm	0.8	0.08	99.57	0.43
Pan	1.9	0.19	99.76	0.24

Table B3: Result of Sieve Analysis Test for Coarse Aggregate (Periwinkle Shell)

Sieve size	Mass retained(g)	% mass retained	Cum.% mass retained	% passing
20.00mm	0	0	0	100
14.00mm	15.2	1.52	1.52	98.48
10.00mm	612.5	61.25	62.77	37.23
6.30mm	341.8	34.18	96.95	3.05
5.00mm	5	0.5	97.45	2.55
Pan	23.1	2.31	99.76	0.24

Appendix C: Compressive and flexural strengths of concrete for 7 and 28 days curing

Table C1: Compressive strength of concrete for 7 days curing

Sample no	Volume of cube (m^3)	Area of cube (mm^2)	Weight of cube (kg)	Crushing load (KN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
A1	0.0034	22500	6.1	340	15.111		1804.73	
A2	0.0034	22500	5.9	324	14.4	14.7	1745.56	1765.29
A3	0.0034	22500	5.9	328	14.578		1745.56	
B1	0.0034	22500	6.5	280	12.444		1923.08	
B2	0.0034	22500	5.6	350	15.556	14.07	1656.81	1814.6
B3	0.0034	22500	6.3	320	14.222		1863.91	
C1	0.0034	22500	5.3	178	7.911		1568.05	
C2	0.0034	22500	5.4	390	17.333	12.71	1597.63	1587.77
C3	0.0034	22500	5.4	290	12.889		1597.63	
D1	0.0034	22500	5.1	410	18.222		1508.88	
D2	0.0034	22500	5.5	180	8	12.44	1627.22	1558.19
D3	0.0034	22500	5.2	250	11.111		1538.46	
E1	0.0034	22500	5.2	185	8.222		1538.46	
E2	0.0034	22500	5.5	370	16.444	12.81	1627.22	1587.77
E3	0.0034	22500	5.4	310	13.778		1597.63	
F1	0.0034	22500	5.3	380	16.889		1568.05	
F2	0.0034	22500	5.3	180	8	12.3	1568.05	1558.19
F3	0.0034	22500	5.2	270	12		1538.46	
G1	0.0034	22500	5.3	144	6.4		1568.05	
G2	0.0034	22500	5.7	316	14.044	10.3	1686.39	1627.22
G3	0.0034	22500	5.5	235	10.444		1627.22	
H1	0.0034	22500	5.8	337	14.978		1715.98	
H2	0.0034	22500	5.6	310	13.778	14.33	1656.81	1686.39
H3	0.0034	22500	5.7	320	14.222		1686.39	
I1	0.0034	22500	5.2	247	10.978		1538.46	
I2	0.0034	22500	4.9	236	10.489	10.7	1449.7	1508.88
I3	0.0034	22500	5.2	239	10.622		1538.46	
J1	0.0034	22500	5.2	235	10.444		1538.46	
J2	0.0034	22500	5.3	223	9.911	10.13	1568.05	1538.46
J3	0.0034	22500	5.1	226	10.044		1508.88	
K1	0.0034	22500	5.3	280	12.444		1568.05	
K2	0.0034	22500	5.1	266	11.822	12.09	1508.88	1508.88
K3	0.0034	22500	4.9	270	12		1449.7	

Table C2: Compressive strength of concrete for 7 days curing

Sample no	Volume of cube (m^3)	Area of cube (mm^2)	Weight of cube (kg)	Crushing load (KN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
L1	0.0034	22500	5.2	215	9.556		1538.46	
L2	0.0034	22500	5.3	196	8.711	9.33	1568.05	1558.19
L3	0.0034	22500	5.3	219	9.733		1568.05	
M1	0.0034	22500	5.9	355	15.778		1745.56	
M2	0.0034	22500	6.1	338	15.022	15.33	1804.73	1804.73
M3	0.0034	22500	6.3	342	15.2		1863.91	
N1	0.0034	22500	5.2	160	7.111		1538.46	
N2	0.0034	22500	5.1	146	6.489	6.95	1508.88	1548.32
N3	0.0034	22500	5.4	163	7.244		1597.63	
O1	0.0034	22500	5.3	188	8.356		1568.05	
O2	0.0034	22500	5.8	411	18.267	13.41	1715.98	1646.94
O3	0.0034	22500	5.6	306	13.6		1656.81	
P1	0.0034	22500	5.9	404	17.956		1745.56	
P2	0.0034	22500	5.9	385	17.111	17.45	1745.56	1765.29
P3	0.0034	22500	6.1	389	17.289		1804.73	
Q1	0.0034	22500	5.3	226	10.044		1568.05	
Q2	0.0034	22500	5.1	216	9.6	9.78	1508.88	1548.32
Q3	0.0034	22500	5.3	218	9.689		1568.05	
R1	0.0034	22500	5.5	307	13.644		1627.22	
R2	0.0034	22500	5.6	292	12.978	13.26	1656.81	1646.94
R3	0.0034	22500	5.6	296	13.156		1656.81	
S1	0.0034	22500	6.2	323	14.356		1834.32	
S2	0.0034	22500	5.8	308	13.689	13.97	1715.98	1775.15
S3	0.0034	22500	6	312	13.867		1775.15	
T1	0.0034	22500	5.3	207	9.2		1568.05	
T2	0.0034	22500	5.4	259	11.511	10.41	1597.63	1577.91
T3	0.0034	22500	5.3	237	10.533		1568.05	
U1	0.0034	22500	5.1	210	9.333		1508.88	
U2	0.0034	22500	5.6	330	14.667	11.26	1656.81	1568.05
U3	0.0034	22500	5.2	220	9.778		1538.46	

Table C3: Compressive strength of concrete for 7 days curing

Sample no	Volume of cube (m^3)	Area of cube (mm^2)	Weight of cube (kg)	Crushing load (KN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
V1	0.0034	22500	5.3	350	15.556		1568.05	
V2	0.0034	22500	5.3	190	8.444	11.85	1568.05	1587.77
V3	0.0034	22500	5.5	260	11.556		1627.22	
W1	0.0034	22500	5.3	240	10.667		1568.05	
W2	0.0034	22500	5.7	526	23.378	17.14	1686.39	1656.8
W3	0.0034	22500	5.8	391	17.378		1715.98	
X1	0.0034	22500	4.9	240	10.667		1449.7	
X2	0.0034	22500	5.5	250	11.111	11.56	1627.22	1587.77
X3	0.0034	22500	5.7	290	12.889		1686.39	
Y1	0.0034	22500	5.2	208	9.244		1538.46	
Y2	0.0034	22500	5.4	260	11.556	10.46	1597.63	1597.63
Y3	0.0034	22500	5.6	238	10.578		1656.81	
Z1	0.0034	22500	5	170	7.556		1479.29	
Z2	0.0034	22500	5.6	372	16.533	12.13	1656.81	1587.77
Z3	0.0034	22500	5.5	277	12.311		1627.22	
A*1	0.0034	22500	5.1	228	10.133		1508.88	
A*2	0.0034	22500	5.4	207	9.2	9.88	1597.63	1568.05
A*3	0.0034	22500	5.4	232	10.311		1597.63	
B*1	0.0034	22500	5.8	297	13.2		1715.98	
B*2	0.0034	22500	5.9	371	16.489	14.93	1745.56	1715.98
B*3	0.0034	22500	5.7	340	15.111		1686.39	
C*1	0.0034	22500	5.9	444	19.733		1745.56	
C*2	0.0034	22500	6.2	370	16.444	17.88	1834.32	1794.87
C*3	0.0034	22500	6.1	393	17.467		1804.73	
D*1	0.0034	22500	5.2	196	8.711		1538.46	
D*2	0.0034	22500	5.5	245	10.889	9.85	1627.22	1617.36
D*3	0.0034	22500	5.7	224	9.956		1686.39	
E*1	0.0034	22500	4.9	152	6.756		1449.7	
E*2	0.0034	22500	4.8	138	6.133	6.59	1420.12	1459.57
E*3	0.0034	22500	5.1	155	6.889		1508.88	

Table C4: Compressive strength of concrete for 28 days curing

Sample no	Volume of cube (m^3)	Area of cube (mm^2)	Weight of cube (kg)	Crushing load (KN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
A4	0.00338	22500	7.5	316	14.04		2218.9	
A5	0.00338	22500	7.3	358	15.91	15.02	2159.8	2189.4
A6	0.00338	22500	7.4	340	15.11		2189.3	
B4	0.00338	22500	7.2	434	19.29		2130.2	
B5	0.00338	22500	7.2	424	18.84	19.3	2130.2	2159.8
B6	0.00338	22500	7.5	445	19.78		2218.9	
C4	0.00338	22500	7.4	313	13.91		2189.3	
C5	0.00338	22500	7.2	293	13.02	13.72	2130.2	2179.5
C6	0.00338	22500	7.5	320	14.22		2218.9	
D4	0.00338	22500	7.1	305	13.56		2100.6	
D5	0.00338	22500	7.1	300	13.33	13.56	2100.6	2130.2
D6	0.00338	22500	7.4	310	13.78		2189.3	
E4	0.00338	22500	7.3	340	15.11		2159.8	
E5	0.00338	22500	7.2	270	12.00	13.6	2130.2	2179.5
E6	0.00338	22500	7.6	308	13.69		2248.5	
F4	0.00338	22500	7.3	315	14.00		2159.8	
F5	0.00338	22500	7.4	280	12.44	14.15	2189.3	2159.8
F6	0.00338	22500	7.2	360	16.00		2130.2	
G4	0.00338	22500	7.6	254	11.29		2248.5	
G5	0.00338	22500	7	238	10.58	11.14	2071.0	2179.5
G6	0.00338	22500	7.5	260	11.56		2218.9	
H4	0.00338	22500	7.4	325	14.44		2189.3	
H5	0.00338	22500	7.6	350	15.56	14.74	2248.5	2199.2
H6	0.00338	22500	7.3	320	14.22		2159.8	
I4	0.00338	22500	7.5	230	10.22		2218.9	
I5	0.00338	22500	7.5	260	11.56	10.92	2218.9	2179.5
I6	0.00338	22500	7.1	247	10.98		2100.6	
J4	0.00338	22500	7.3	218	9.69		2159.8	
J5	0.00338	22500	7.5	247	10.98	10.37	2218.9	2189.4
J6	0.00338	22500	7.4	235	10.44		2189.3	
K4	0.00338	22500	7.5	260	11.56		2218.9	
K5	0.00338	22500	7.3	294	13.07	12.36	2159.8	2199.2
K6	0.00338	22500	7.5	280	12.44		2218.9	

Table C5: Compressive strength of concrete for 28 days curing

Sample no	Volume of cube (m^3)	Area of cube (mm^2)	Weight of cube (kg)	Crushing load (KN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
L4	0.00338	22500	7.2	315	14.00		2130.2	
L5	0.00338	22500	7.1	325	14.44	14.1	2100.6	2179.5
L6	0.00338	22500	7.8	312	13.87		2307.7	
M4	0.00338	22500	7.3	330	14.67		2159.8	
M5	0.00338	22500	7.5	374	16.62	15.69	2218.9	2189.4
M6	0.00338	22500	7.4	355	15.78		2189.3	
N4	0.00338	22500	7	235	10.44		2071.0	
N5	0.00338	22500	7.2	242	10.76	10.5	2130.2	2100.6
N6	0.00338	22500	7.1	232	10.31		2100.6	
O4	0.00338	22500	7.2	330	14.67		2130.2	
O5	0.00338	22500	7.1	309	13.73	14.46	2100.6	2120.3
O6	0.00338	22500	7.2	337	14.98		2130.2	
P4	0.00338	22500	7.3	375	16.67		2159.8	
P5	0.00338	22500	7.6	425	18.89	17.84	2248.5	2199.2
P6	0.00338	22500	7.4	404	17.96		2189.3	
Q4	0.00338	22500	7.2	210	9.33		2130.2	
Q5	0.00338	22500	7	238	10.58	9.99	2071.0	2080.9
Q6	0.00338	22500	6.9	226	10.04		2041.4	
R4	0.00338	22500	6.9	285	12.67		2041.4	
R5	0.00338	22500	7.1	323	14.36	13.56	2100.6	2061.1
R6	0.00338	22500	6.9	307	13.64		2041.4	
S4	0.00338	22500	7.5	301	13.38		2218.9	
S5	0.00338	22500	7.1	341	15.16	14.3	2100.6	2169.6
S6	0.00338	22500	7.4	323	14.36		2189.3	
T4	0.00338	22500	7	322	14.31		2071.0	
T5	0.00338	22500	6.9	314	13.96	14.31	2041.4	2051.3
T6	0.00338	22500	6.9	330	14.67		2041.4	
U4	0.00338	22500	7.1	295	13.11		2100.6	
U5	0.00338	22500	7.4	240	10.67	11.63	2189.3	2149.9
U6	0.00338	22500	7.3	250	11.11		2159.8	

Table C6: Compressive strength of concrete for 28 days curing

Sample no	Volume of cube (m^3)	Area of cube (mm^2)	Weight of cube (kg)	Crushing load (KN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
V4	0.00338	22500	7.4	230	10.22		2189.3	
V5	0.00338	22500	7.4	305	13.56	12.52	2189.3	2199.2
V6	0.00338	22500	7.5	310	13.78		2218.9	
W4	0.00338	22500	7.5	422	18.76		2218.9	
W5	0.00338	22500	7.5	395	17.56	18.49	2218.9	2189.4
W6	0.00338	22500	7.2	431	19.16		2130.2	
X4	0.00338	22500	7	318	14.13		2071.0	
X5	0.00338	22500	7.5	380	16.89	13.75	2218.9	2159.8
X6	0.00338	22500	7.4	230	10.22		2189.3	
Y4	0.00338	22500	7.3	322	14.31		2159.8	
Y5	0.00338	22500	7.5	315	14.00	14.33	2218.9	2189.4
Y6	0.00338	22500	7.4	330	14.67		2189.3	
Z4	0.00338	22500	7.2	299	13.29		2130.2	
Z5	0.00338	22500	7.2	280	12.44	13.1	2130.2	2140.0
Z6	0.00338	22500	7.3	305	13.56		2159.8	
A*4	0.00338	22500	7.6	333	14.80		2248.5	
A*5	0.00338	22500	7.4	344	15.29	14.92	2189.3	2169.6
A*6	0.00338	22500	7	330	14.67		2071.0	
B*4	0.00338	22500	6.7	461	20.49		1982.2	
B*5	0.00338	22500	7.8	450	20.00	20.49	2307.7	2199.2
B*6	0.00338	22500	7.8	472	20.98		2307.7	
C*4	0.00338	22500	7.2	540	24.00		2130.2	
C*5	0.00338	22500	7.3	410	18.22	21.04	2159.8	2140.0
C*6	0.00338	22500	7.2	470	20.89		2130.2	
D*4	0.00338	22500	7.5	304	13.51		2218.9	
D*5	0.00338	22500	7.4	297	13.20	13.53	2189.3	2199.2
D*6	0.00338	22500	7.4	312	13.87		2189.3	
E*4	0.00338	22500	7	222	9.87		2071.0	
E*5	0.00338	22500	6.8	230	10.22	9.96	2011.8	2041.4
E*6	0.00338	22500	6.9	220	9.78		2041.4	

Table C7: Flexural strength of concrete for 7 days curing

Sample no	Volume of beam (m^3)	Area of beam (mm^2)	Weight of beam (kg)	Crushing load (KN)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
A1	0.005	50000	9.5	7.6	5.7		1900	
A2	0.005	50000	9.9	7.3	5.5	5.65	1980	1946.67
A3	0.005	50000	9.8	7.7	5.8		1960	
B1	0.005	50000	10.2	8.5	6.4		2040	
B2	0.005	50000	10.8	10.7	8.0	6.48	2160	2100
B3	0.005	50000	10.5	6.7	5.0		2100	
C1	0.005	50000	9.6	7.6	5.7		1920	
C2	0.005	50000	9.2	6	4.5	5.3	1840	1880
C3	0.005	50000	9.4	7.6	5.7		1880	
D1	0.005	50000	9.5	7.8	5.9		1900	
D2	0.005	50000	9.2	6.7	5.0	5.85	1840	1880
D3	0.005	50000	9.5	8.9	6.7		1900	
E1	0.005	50000	9.3	8.1	6.1		1860	
E2	0.005	50000	9.5	8.1	6.4	6.18	1900	1880
E3	0.005	50000	9.4	8.5			1880	
F1	0.005	50000	9.6	8	6.0		1920	
F2	0.005	50000	9.5	7.3	5.5	5.83	1900	1900
F3	0.005	50000	9.4	8	6.0		1880	
G1	0.005	50000	9.4	7.5	5.6		1880	
G2	0.005	50000	9.7	7.3	5.5	5.7	1940	1953.33
G3	0.005	50000	10.2	8	6.0		2040	
H1	0.005	50000	10	7.9	5.9		2000	
H2	0.005	50000	9.9	10	7.5	5.98	1980	1986.67
H3	0.005	50000	9.9	6	4.5		1980	
I1	0.005	50000	9.8	6.8	5.1		1960	
I2	0.005	50000	9.8	8.7	6.5	5.6	1960	1966.67
I3	0.005	50000	9.9	6.9	5.2		1980	
J1	0.005	50000	10	6.2	4.7		2000	
J2	0.005	50000	9.9	6.1	4.6	4.75	1980	1993.33
J3	0.005	50000	10	6.7	5.0		2000	
K1	0.005	50000	9.6	5.9	4.4		1920	
K2	0.005	50000	9.9	6.7	5.0	4.33	1980	1946.67
K3	0.005	50000	9.7	4.7	3.5		1940	

Table C8: Flexural strength of concrete for 7 days curing

Sample no	Volume of beam (m^3)	Area of beam (mm^2)	Weight of beam (kg)	Crushing load (KN)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
L1	0.005	50000	9.9	7.7	5.8		1980	
L2	0.005	50000	9.8	7.3	5.5	5.68	1960	1986.67
L3	0.005	50000	10.1	7.7	5.8		2020	
M1	0.005	50000	9.6	10.2	7.7		1920	
M2	0.005	50000	9.7	9.3	7.0	7.55	1940	1940
M3	0.005	50000	9.8	10.7	8.0		1960	
N1	0.005	50000	10.2	6.5	4.9		2040	
N2	0.005	50000	9.9	6	4.5	4.8	1980	1993.33
N3	0.005	50000	9.8	6.7	5.0		1960	
O1	0.005	50000	9.8	9.7	7.3		1960	
O2	0.005	50000	9.9	8.7	6.5	7.28	1980	1960
O3	0.005	50000	9.7	10.7	8.0		1940	
P1	0.005	50000	9.9	9	6.8		1980	
P2	0.005	50000	9.9	6.7	5.0	6.2	1980	1973.33
P3	0.005	50000	9.8	9.1	6.8		1960	
Q1	0.005	50000	9.6	5.9	4.4		1920	
Q2	0.005	50000	10.1	6.7	5.0	4.65	2020	1966.67
Q3	0.005	50000	9.8	6	4.5		1960	
R1	0.005	50000	9.8	6.8	5.1		1960	
R2	0.005	50000	9.8	6	4.5	4.88	1960	1960
R3	0.005	50000	9.8	6.7	5.0		1960	
S1	0.005	50000	9.9	8.8	6.6		1980	
S2	0.005	50000	10.4	10.7	8.0	7.2	2080	2040
S3	0.005	50000	10.3	9.3	7.0		2060	
T1	0.005	50000	10.6	7.5	5.6		2120	
T2	0.005	50000	10	8	6.0	5.75	2000	2066.67
T3	0.005	50000	10.4	7.5	5.6		2080	
U1	0.005	50000	9.3	7.6	5.7		1860	
U2	0.005	50000	9.4	8	6.0	5.73	1880	1873.33
U3	0.005	50000	9.4	7.3	5.5		1880	

Table C9: Flexural strength of concrete for 7 days curing

Sample no	Volume of beam (m^3)	Area of beam (mm^2)	Weight of beam (kg)	Crushing load (KN)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
V1	0.005	50000	9.3	7.8	5.9		1860	
V2	0.005	50000	9	6.4	4.8	5.23	1800	1826.67
V3	0.005	50000	9.1	6.7	5.0		1820	
W1	0.005	50000	10.1	10.6	8.0		2020	
W2	0.005	50000	9.8	10	7.5	7.78	1960	1966.67
W3	0.005	50000	9.6	10.5	7.9		1920	
X1	0.005	50000	9.6	8.7	6.5		1920	
X2	0.005	50000	9.2	9.3	7.0	6.83	1840	1880
X3	0.005	50000	9.4	9.3	7.0		1880	
Y1	0.005	50000	9.8	6.5	4.9		1960	
Y2	0.005	50000	9.8	6.7	5.0	5.3	1960	1960
Y3	0.005	50000	9.8	8	6.0		1960	
Z1	0.005	50000	9.5	7	5.3		1900	
Z2	0.005	50000	10.4	7.2	5.4	5.33	2080	2026.67
Z3	0.005	50000	10.5	7.1	5.3		2100	
A*1	0.005	50000	10.1	10.6	8.0		2020	
A*2	0.005	50000	9.9	10.7	8.0	7.93	1980	2013.33
A*3	0.005	50000	10.2	10.4	7.8		2040	
B*1	0.005	50000	10.3	9.9	7.4		2060	
B*2	0.005	50000	10.2	9.9	7.4	7.38	2040	2046.67
B*3	0.005	50000	10.2	9.7	7.3		2040	
C*1	0.005	50000	10	12	9.0		2000	
C*2	0.005	50000	10.1	11.8	8.9	9.03	2020	2026.67
C*3	0.005	50000	10.3	12.3	9.2		2060	
D*1	0.005	50000	10.1	5.7	4.3		2020	
D*2	0.005	50000	9.9	5.6	4.2	4.33	1980	2013.33
D*3	0.005	50000	10.2	6	4.5		2040	
E*1	0.005	50000	10.4	4.7	3.5		2080	
E*2	0.005	50000	10.7	4.6	3.5	3.53	2140	2080
E*3	0.005	50000	10.1	4.8	3.6		2020	

Table C10: Flexural strength of concrete for 28 days curing

Sample no	Volume of beam (m^3)	Area of beam (mm^2)	Weight of beam (kg)	Crushing load (KN)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
A4	0.005	50000	10.5	10.9	8.18		2100	
A5	0.005	50000	10.6	11	8.25	8.1	2120	2106.67
A6	0.005	50000	10.5	10.5	7.88		2100	
B4	0.005	50000	10.4	12	9.00		2080	
B5	0.005	50000	10.9	13	9.75	9.13	2180	2133.33
B6	0.005	50000	10.7	11.5	8.63		2140	
C4	0.005	50000	10.8	10.9	8.18		2160	2146.67
C5	0.005	50000	10.8	11	8.25	8.18	2160	
C6	0.005	50000	10.6	10.8	8.10		2120	
D4	0.005	50000	10.4	12	9.00		2080	
D5	0.005	50000	10.6	11	8.25	8.38	2120	2086.67
D6	0.005	50000	10.3	10.5	7.88		2060	
E4	0.005	50000	10.9	11	8.25		2180	
E5	0.005	50000	10.6	12.5	9.38	8.63	2120	2133.33
E6	0.005	50000	10.5	11	8.25		2100	
F4	0.005	50000	10.2	11.4	8.55		2040	
F5	0.005	50000	10	9.5	7.13	8.48	2000	2020
F6	0.005	50000	10.1	13	9.75		2020	
G4	0.005	50000	10.3	10.8	8.10		2060	
G5	0.005	50000	10.7	10.5	7.88	8.08	2140	2106.67
G6	0.005	50000	10.6	11	8.25		2120	
H4	0.005	50000	10.5	10.5	7.88		2100	
H5	0.005	50000	10.9	12.5	9.38	8.75	2180	2120
H6	0.005	50000	10.4	12	9.00		2080	
I4	0.005	50000	10.8	10	7.50		2160	
I5	0.005	50000	10.8	9.7	7.28	7.4	2160	2126.67
I6	0.005	50000	10.3	9.9	7.43		2060	
J4	0.005	50000	10.7	8.8	6.60		2140	
J5	0.005	50000	10.9	9	6.75	6.58	2180	2140
J6	0.005	50000	10.5	8.5	6.38		2100	
K4	0.005	50000	10.6	8.4	6.30		2120	
K5	0.005	50000	10.9	9	6.75	6.48	2180	2113.33
K6	0.005	50000	10.2	8.5	6.38		2040	

Table C11: Flexural strength of concrete for 28 days curing

Sample no	Volume of beam (m^3)	Area of beam (mm^2)	Weight of beam (kg)	Crushing load (KN)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
L4	0.005	50000	10.9	11	8.25		2180	
L5	0.005	50000	10.8	12	9.00	8.25	2160	2120
L6	0.005	50000	10.1	10	7.50		2020	
M4	0.005	50000	10.6	14.5	10.88		2120	
M5	0.005	50000	10.7	14	10.50	10.88	2140	2106.67
M6	0.005	50000	10.3	15	11.25		2060	
N4	0.005	50000	10.5	9.3	6.98		2100	
N5	0.005	50000	10.9	9.5	7.13	7.05	2180	2113.33
N6	0.005	50000	10.3	9.4	7.05		2060	
O4	0.005	50000	10.8	13.9	10.43		2160	
O5	0.005	50000	10.9	14	10.50	10.35	2180	2146.67
O6	0.005	50000	10.5	13.5	10.13		2100	
P4	0.005	50000	10.8	13	9.75		2160	
P5	0.005	50000	10.9	12.5	9.38	9.5	2180	2140
P6	0.005	50000	10.4	12.5	9.38		2080	
Q4	0.005	50000	10.6	8	6.00		2120	
Q5	0.005	50000	10.1	8	6.00	6.25	2020	2073.33
Q6	0.005	50000	10.4	9	6.75		2080	
R4	0.005	50000	10.8	9.5	7.13		2160	
R5	0.005	50000	10.4	9.7	7.28	7.3	2080	2120
R6	0.005	50000	10.6	10	7.50		2120	
S4	0.005	50000	10.9	12.5	9.38		2180	
S5	0.005	50000	10.4	13	9.75	9.38	2080	2106.67
S6	0.005	50000	10.3	12	9.00		2060	
T4	0.005	50000	10.5	11	8.25		2100	
T5	0.005	50000	10.8	10.5	7.88	8.08	2160	2100
T6	0.005	50000	10.2	10.8	8.10		2040	
U4	0.005	50000	10.4	11	8.25		2080	
U5	0.005	50000	10.7	12	9.00	8.63	2140	2080
U6	0.005	50000	10.1	11.5	8.63		2020	

Table C12: Flexural strength of concrete for 28 days curing

Sample no	Volume of beam (m^3)	Area of beam (mm^2)	Weight of beam (kg)	Crushing load (KN)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)	Density (kg/m^3)	Average Density (kg/m^3)
V4	0.005	50000	10.2	11	8.25		2040	
V5	0.005	50000	10.2	10.5	7.88	8.13	2040	2060
V6	0.005	50000	10.5	11	8.25		2100	
W4	0.005	50000	11.1	15	11.25		2220	
W5	0.005	50000	10.7	15	11.25	11.13	2140	2140
W6	0.005	50000	10.3	14.5	10.88		2060	
X4	0.005	50000	10.9	12.4	9.30		2180	
X5	0.005	50000	10.4	11.8	8.85	9.18	2080	2093.33
X6	0.005	50000	10.1	12.5	9.38		2020	
Y4	0.005	50000	10.8	9.5	7.13		2160	
Y5	0.005	50000	10.6	10	7.50	7	2120	2140
Y6	0.005	50000	10.7	8.5	6.38		2140	
Z4	0.005	50000	10.6	10	7.50		2120	
Z5	0.005	50000	10.3	11	8.25	7.5	2060	2100
Z6	0.005	50000	10.6	9	6.75		2120	
A*4	0.005	50000	10.2	15.2	11.40		2040	
A*5	0.005	50000	11	14.8	11.10	11.25	2200	2126.67
A*6	0.005	50000	10.7	15	11.25		2140	
B*4	0.005	50000	10.4	14	10.50		2080	
B*5	0.005	50000	10.9	13	9.75	10.5	2180	2106.67
B*6	0.005	50000	10.3	15	11.25		2060	
C*4	0.005	50000	10.4	17	12.75		2080	
C*5	0.005	50000	10.6	16	12.00	12.13	2120	2113.33
C*6	0.005	50000	10.7	15.5	11.63		2140	
D*4	0.005	50000	10.5	7	5.25		2100	
D*5	0.005	50000	10.8	8.5	6.38	6.13	2160	2126.67
D*6	0.005	50000	10.6	9	6.75		2120	
E*4	0.005	50000	10.5	5.3	3.98		2100	
E*5	0.005	50000	10.9	7	5.25	5.08	2180	2126.67
E*6	0.005	50000	10.5	8	6.00		2100	

Table C13: 7 days Compressive and Flexural strength

S/NO	W/C ratio, X_1	TA/C ratio, X_2	CA/TA ratio, X_3	PS/CA ratio, X_4	Compressive strength, Y_1	Flexural strength, Y_2
1	0.5	2.38	0.62	0.25	14.7	5.65
2	0.4	6	0.55	0.2	14.07	6.48
3	0.5	4.5	0.62	0.25	12.71	5.3
4	0.5	4.5	0.62	0.25	12.44	5.85
5	0.5	4.5	0.62	0.25	12.81	6.18
6	0.5	4.5	0.62	0.25	12.3	5.83
7	0.5	4.5	0.62	0.32	10.3	5.6
8	0.5	4.5	0.52	0.25	14.33	5.98
9	0.6	3	0.7	0.3	10.7	5.6
10	0.5	4.5	0.73	0.25	10.13	4.75
11	0.4	3	0.55	0.3	12.09	4.33
12	0.4	6	0.7	0.2	9.33	5.68
13	0.6	3	0.7	0.2	15.33	7.55
14	0.6	6	0.7	0.3	6.95	4.8
15	0.64	4.5	0.62	0.25	13.41	7.28
16	0.4	3	0.55	0.2	17.45	6.2
17	0.4	3	0.7	0.3	9.78	4.65
18	0.6	3	0.55	0.3	13.26	4.88
19	0.4	3	0.7	0.2	13.97	7.2
20	0.6	6	0.55	0.3	10.41	5.75
21	0.5	4.5	0.62	0.25	11.26	5.73
22	0.5	4.5	0.62	0.25	11.85	5.23
23	0.5	4.5	0.62	0.18	17.14	7.78
24	0.5	4.5	0.62	0.25	11.56	6.83
25	0.5	6.62	0.62	0.25	10.46	5.3
26	0.36	4.5	0.62	0.25	12.13	5.33
27	0.6	6	0.7	0.2	9.88	7.93
28	0.6	6	0.55	0.2	14.93	7.38
29	0.6	3	0.55	0.2	17.88	9.03
30	0.4	6	0.55	0.3	9.85	4.33
31	0.4	6	0.7	0.3	6.59	3.53

Table C14: 28 days Compressive and Flexural strength

S/NO	W/C ratio, X_1	TA/C ratio, X_2	CA/TA ratio, X_3	PS/CA ratio, X_4	Compressive strength, Y_1	Flexural strength,Y_2
1	0.5	2.38	0.62	0.25	15.02	8.1
2	0.4	6	0.55	0.2	19.3	9.13
3	0.5	4.5	0.62	0.25	13.72	8.18
4	0.5	4.5	0.62	0.25	13.56	8.38
5	0.5	4.5	0.62	0.25	13.6	8.63
6	0.5	4.5	0.62	0.25	14.15	8.48
7	0.5	4.5	0.62	0.32	11.14	7.4
8	0.5	4.5	0.52	0.25	14.74	8.75
9	0.6	3	0.7	0.3	10.92	7.4
10	0.5	4.5	0.73	0.25	10.37	6.58
11	0.4	3	0.55	0.3	12.36	6.48
12	0.4	6	0.7	0.2	14.1	8.25
13	0.6	3	0.7	0.2	15.69	10.88
14	0.6	6	0.7	0.3	10.5	7.05
15	0.64	4.5	0.62	0.25	14.46	10.35
16	0.4	3	0.55	0.2	17.84	9.5
17	0.4	3	0.7	0.3	9.99	6.25
18	0.6	3	0.55	0.3	13.56	7.3
19	0.4	3	0.7	0.2	14.3	9.38
20	0.6	6	0.55	0.3	14.31	8.08
21	0.5	4.5	0.62	0.25	11.63	8.63
22	0.5	4.5	0.62	0.25	12.52	8.13
23	0.5	4.5	0.62	0.18	18.49	11.13
24	0.5	4.5	0.62	0.25	13.75	9.18
25	0.5	6.62	0.62	0.25	14.33	7
26	0.36	4.5	0.62	0.25	13.1	7.5
27	0.6	6	0.7	0.2	14.92	11.25
28	0.6	6	0.55	0.2	20.49	10.5
29	0.6	3	0.55	0.2	21.04	12.13
30	0.4	6	0.55	0.3	13.53	6.13
31	0.4	6	0.7	0.3	9.96	5.08

Table C15: Summary of the mechanical properties and densities of concrete

COMPRESSIVE STRENGTH		FLEXURAL STRENGTH		DENSITY OF CUBES		DENSITY OF BEAMS	
7days	28days	7days	28days	7days	28days	7days	28days
14.7	15.02	5.65	8.1	1765.29	2189.35	1946.67	2106.67
14.07	19.3	6.48	9.13	1814.6	2159.76	2100	2133.33
12.71	13.72	5.3	8.18	1587.77	2179.49	1880	2146.67
12.44	13.56	5.85	8.38	1558.19	2130.18	1880	2086.67
12.81	13.6	6.18	8.63	1587.77	2179.49	1880	2133.33
12.3	14.15	5.83	8.48	1558.19	2159.76	1900	2020
10.3	11.14	5.7	8.08	1627.22	2179.49	1953.33	2106.67
14.33	14.74	5.98	8.75	1686.39	2199.21	1986.67	2120
10.7	10.92	5.6	7.4	1508.88	2179.49	1966.67	2126.67
10.13	10.37	4.75	6.58	1538.46	2189.35	1993.33	2140
12.09	12.36	4.33	6.48	1508.88	2199.21	1946.67	2113.33
9.33	14.1	5.68	8.25	1558.19	2179.49	1986.67	2120
15.33	15.69	7.55	10.88	1804.73	2189.35	1940	2106.67
6.95	10.5	4.8	7.05	1548.32	2100.59	1993.33	2113.33
13.41	14.46	7.28	10.35	1646.94	2120.32	1960	2146.67
17.45	17.84	6.2	9.5	1765.29	2199.21	1973.33	2140
9.78	9.99	4.65	6.25	1548.32	2080.87	1966.67	2073.33
13.26	13.56	4.88	7.3	1646.94	2061.14	1960	2120
13.97	14.3	7.2	9.38	1775.15	2169.63	2040	2106.67
10.41	14.31	5.75	8.08	1577.91	2051.28	2066.67	2100
11.26	11.63	5.73	8.63	1568.05	2149.9	1873.33	2080
11.85	12.52	5.23	8.13	1587.77	2199.21	1826.67	2060
17.14	18.49	7.78	11.13	1656.8	2189.35	1966.67	2140
11.56	13.75	6.83	9.18	1587.77	2159.76	1880	2093.33

10.46	14.33	5.3	7	1597.63	2189.35	1960	2140
12.13	13.1	5.33	7.5	1587.77	2140.04	2026.67	2100
9.88	14.92	7.93	11.25	1568.05	2169.63	2013.33	2126.67
14.93	20.49	7.38	10.5	1715.98	2199.21	2046.67	2106.67
17.88	21.04	9.03	12.13	1794.87	2140.04	2026.67	2113.33
9.85	13.53	4.33	6.13	1617.36	2199.21	2013.33	2126.67
6.59	9.96	3.53	5.08	1459.57	2041.42	2080	2126.67

Appendix D: Physical and Mechanical Properties of Aggregates

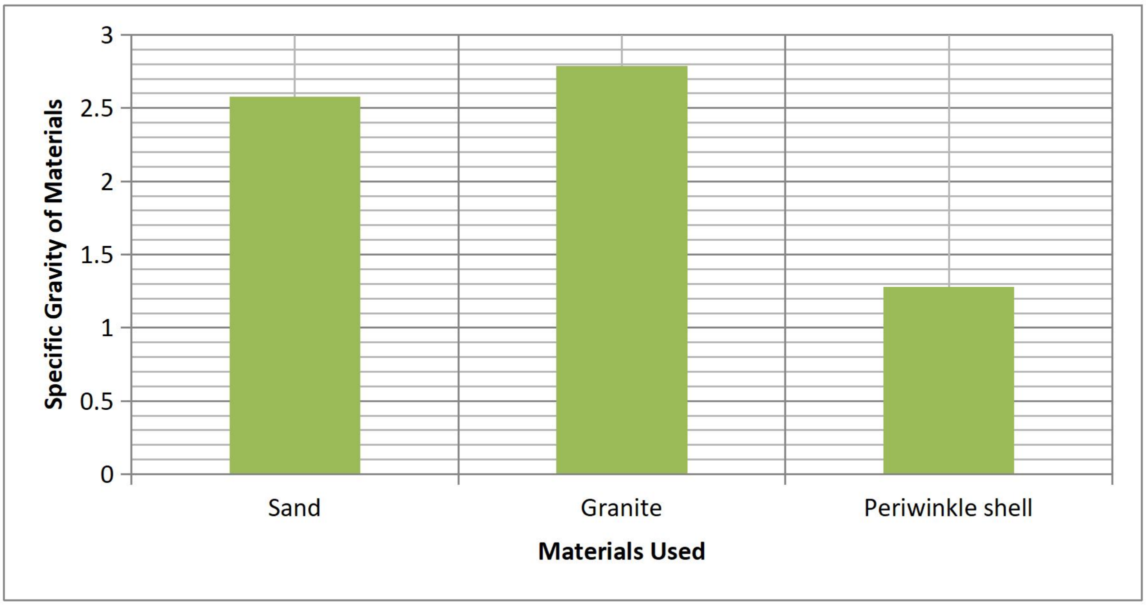

Figure D1: Specific Gravity of Materials Used

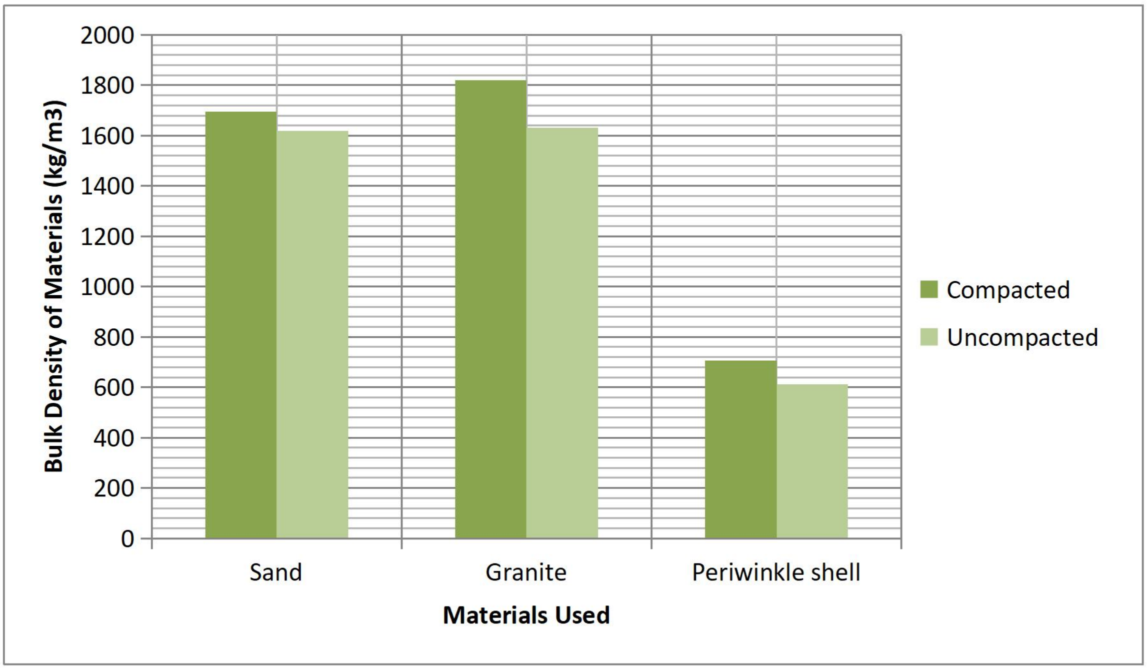

Figure D2: Bulk Density of Materials Used

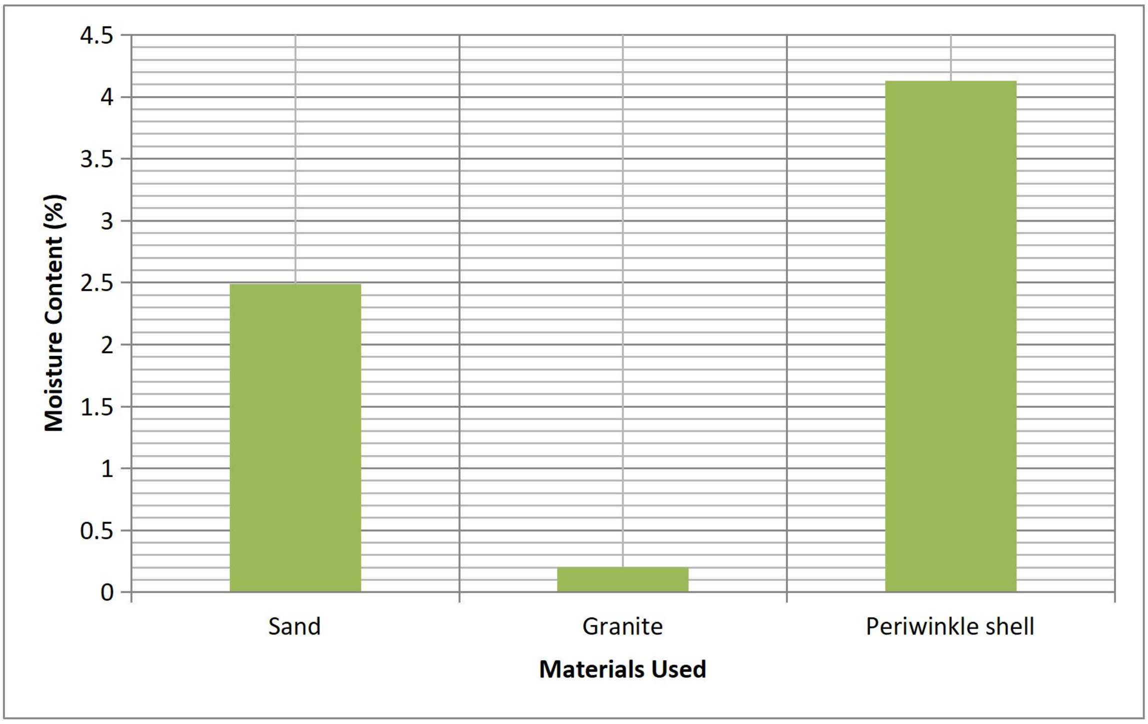

Figure D3: Moisture Content of Materials Used

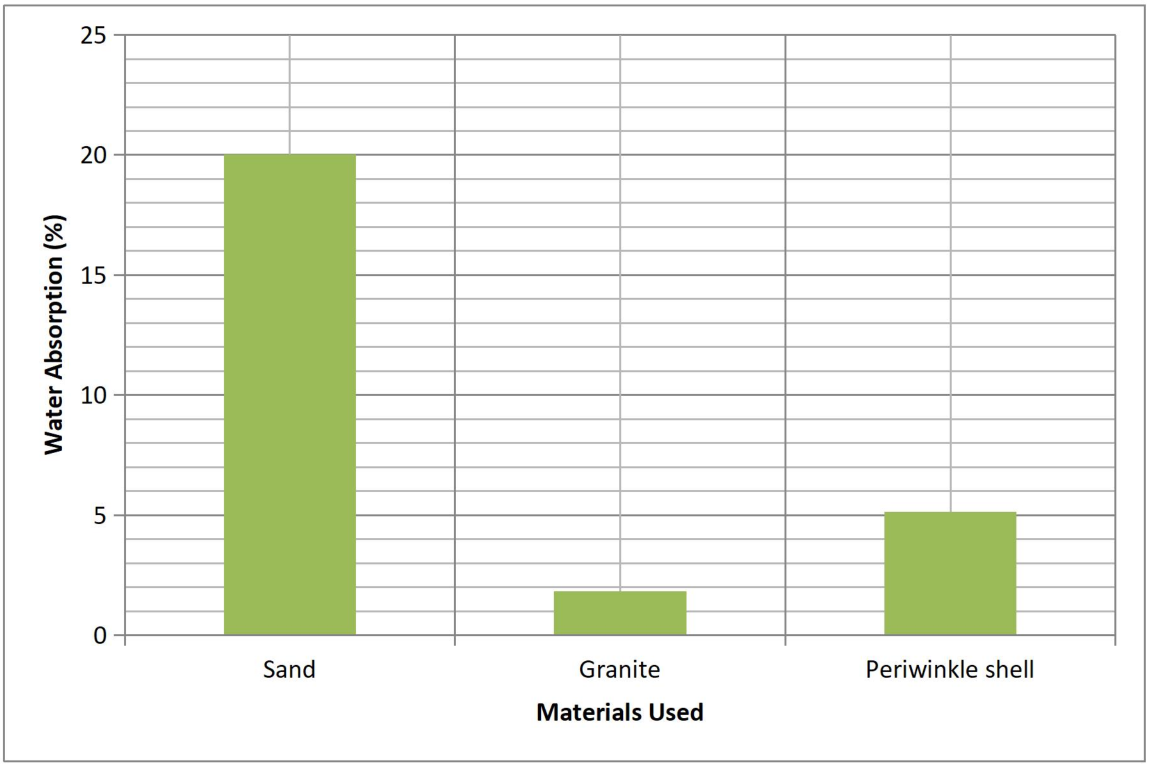

Figure D4: Water Absorption of Materials Used

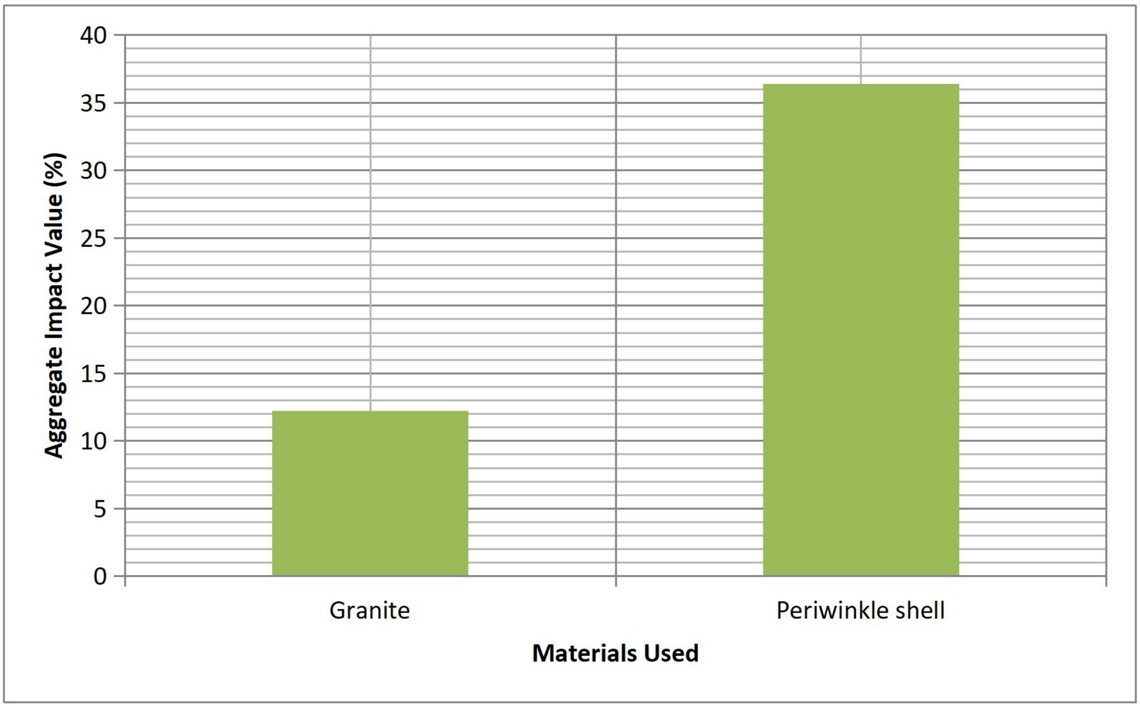

Figure D5: Aggregate Impact Values of Coarse Aggregates Used

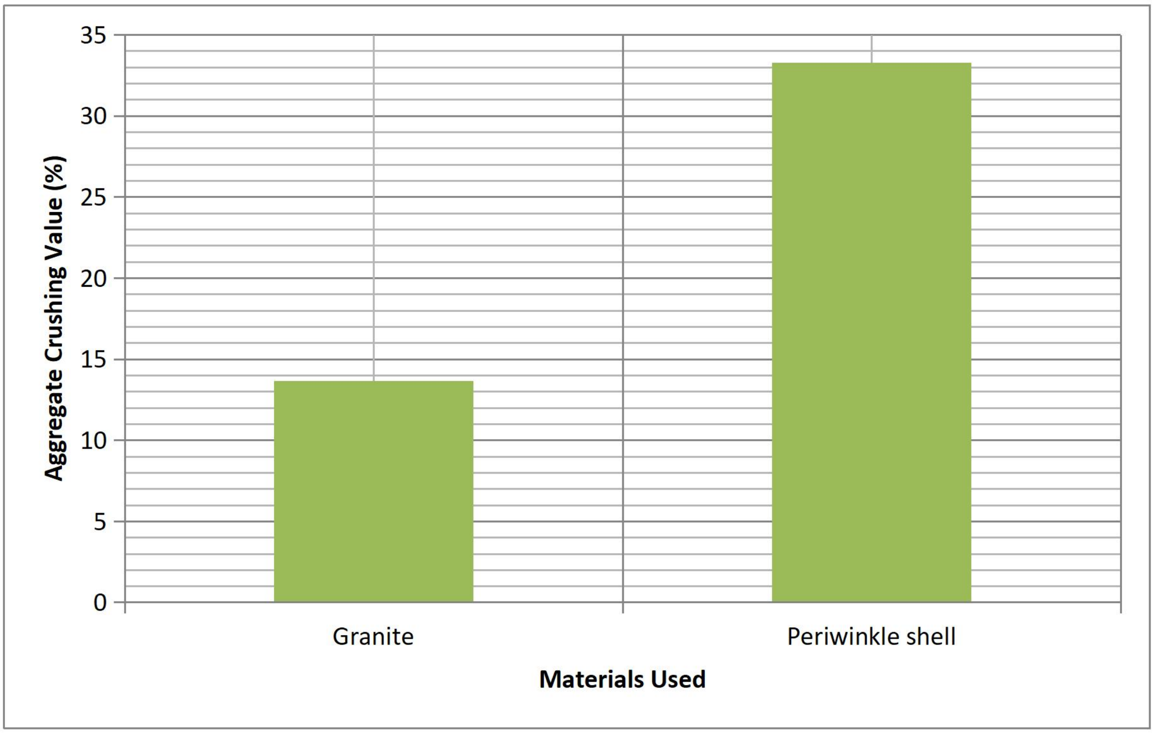

Figure D6: Aggregate Crushing Values of Coarse Aggregates Used