THE EFFECT OF PERIWINKLE SHELL ASH AND DUST ON THE COMPRESSIVE STRENGTH OF CONCRETE

BY

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DECLARATION

I hereby declare that the work in this Dissertation entitled "**The Effect of Periwinkle shell ash and dust on the compressive strength of concrete"** was carried out by me in the Department of Civil Engineering, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this work has been presented for another degree at any institution.

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CERTIFICATION

This Dissertation entitled "**The Effect of Periwinkle shell ash and dust on the compressive strength of concrete"** by Mark Onimisi Zuberu meets the regulation governing the award of Master of Science (MSc.) degree in Civil Engineering of the Ahmadu Bello Univversity, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This Dissertation is dedicated to God Almighty, the omnipotent, omniscient and omnipresent, the giver of life for his preservation, provision and guidance, for leading me throughout to the completion of this work. Also to my loving Father, Dr. Emmanuel O. Zuberu for his undeniable love to me and my siblings, may God continuously guide and protect you in Jesus name. (Amen)

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ABSTRACT

The study examined the partial replacement of Ordinary Portland Cement (OPC) with Periwinkle shell Ash (PSA) and Periwinkle Shell Dust which was obtained from burning 200kg of Periwinkle shell at 600^0C and grinding 200kg with ball mill respectively. Concrete cubes were prepared from design mix with target strength of 20N/mm^2, 25N/mm^2, 30N/mm^2 and 40N/mm^2 and the replacement of the PSA and PSD were 0%, 5%, 10% and 20% respectively. The chemical analysis of both samples indicated that CaO content in PSA is higher than PSD leading to quick reaction with water. The presence of organic calcium in PSD was responsible for slowing setting of the concrete and subsequently leading to disintegration of the paste at 20% replacement when tested for soundness. The workability test indicated that as the percentage replacement of PSA and PSD increases the slump test value degreases, while compressive strength decrease with increasing replacement and increase with curing age. The design compressive strength was attained at 5% and 10% replacement for both PSA and PSD based on the 75% strength of OPC recommended by ASTM C618 for grades of concrete at 28days. The scanning electron microscopy (SEM) analysis of concrete showed an increase in pore space as the percentage replacement increases. However, at 20% PSA replacement the SEM result indicates as uneven distribution of Ca(OH) as a result of increase in lime (CaO). The One-way analysis of variance (ANOVA) on the laboratory test result shows a statistically significant effect of percentage replacement and workability on the compressive strength of concrete. The test concluded that 10% PSA and PSD content is enough for cement replacement at any strength grade.

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Concrete as a composite material consists of cement, coarse aggregate, fine aggregate, etc, the addition of other materials in order to alter or improve it properties has been a subject of intense research. These properties include strength, durability, resilience to certain chemical attacks, weathering and for special purposes. To achieve the stated properties both natural and artificial pozzolana has been used. However, for sustainability and reusability, agricultural wastes products like rice husk, groundnut shell, sawdust, palm kernel nut, periwinkle shell etc is being used than ever before (Yusuf, 2016)

In heterogeneous materials like concrete, the structure, quality of the constituent and proportions in which they are mixed determine the strength and properties of the resulting products. A good knowledge of the properties of cement, aggregates and water is required in understanding the behaviour of concrete.

Periwinkle a marine mollusks (gastropods) whose thick shell is the source of periwinkle shells. As they grow, gastropod shells follow a mathematically regular pattern and when it increases in size still retains its original form. The resulting shell becomes a strong compact home for the mollusk inside. They are common in North America and European shores and are widely distributed in their littoral drifts and sand banks. The major species available in the lagoon and mudflats of Nigeria's Niger Delta, between Calabar in the east and Badagry in the west, are Tympanostomus species and Pachmellania species (Dahunsi and Bamisaiye, 2002).

Periwinkle shell was used by Olarunge and Olabisi, (2003) as partial alternative to coarse aggregate in light weight concrete, Koffi, (2008) determined compressive strength of concrete incorporating periwinkle shell ash, to assess the suitability of periwinkle shell ash as partial replacement for ordinary Portland cement in concrete and Ibearugbulem, *et al.,* (2014) analyzed the stress of stick reinforced granite- periwinkle concrete slab under uniformly distributed load.

1.2 Statement of the Problem

Cement production require large emission of carbon dioxide (CO_2) estimated to be 7% of global CO_2 emission Kaura *et al.,* (2016) and other compounds which are not friendly to the environment. Hence, the need to make use of agricultural waste that is sustainable and reusable.

The cost of producing concrete has increased due to increasing cost of cement production Adaba *et al*., (2012), this can be reduced by the use of sustainable material like periwinkle shell and other pozzolanas such as rice husk ash, groundnut shell ash, coconut shell ash, sawdust ash, etc.

Large amounts of periwinkle shell are difficult to dispose and thus constitute a problem in coastal communities in Nigeria were large deposits of the periwinkle shell can be found.

1.3 Justification for the Study

As a result of rising cost of cement in concrete production, the need to find a suitable replacement had lead to investigation in use of waste to improve the properties of concrete. In recent years agricultural/industrial waste has gain wide acceptance due to their availability, environmental friendliness and easy workability.

Presently, there is great awareness that landfills are filling up, shortage of non-renewable resources and environment population during cement production has prompt urgent need to result to eco-friendly material that is economical. By using Periwinkle shell ash or dust which is renewable due to it availability and emit little or no greenhouse gases during production will ensure an improvement in the properties of concrete and reduce the need for landfills.

1.4 Aim and Objectives

1.4.1 Aim

The aim of the research is to investigate the influence of periwinkle shell ash (PSA) and Periwinkle shell dust (PSD) on the compressive strength of concrete.

1.4.2 Objectives:

The specific objectives include

i. To determine the oxide composition of both periwinkle shell (ash and dust) using X-ray Florescence Analysis (XRF).
ii. To determine the degree of strength improvement in concrete obtained with mixes incorporating 0%, 5%, 10% and 20% PSD as replacement for cement and 0%, 5%, 10% and 20% PSA as replacement for cement in grade 20, 25, 30 and 40 respectively.
iii. To determine the compressive strength of the concrete and compare their effect.
iv. To investigate the microstructure of the periwinkle shell (ash and dust) using Scanning Electron Microscopy (SEM).

v. To develop a statistical model that could be use in predicting the strength of concrete mixed with periwinkle shell ash or dust.

1.5 Scope of Work

The scope of this research is to analyze the effect of periwinkle shell (ash and dust) on the compressive strength of concrete, determine their effect on Microstructure of concrete and develop a statistical model for predicting strength using Analysis of Variance (ANOVA). The tests carried out on the fresh and dried concrete were in accordance with relevant BS codes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

When designing concrete for durable performance attention must be paid to the strength, durability and other performance standards. Due to the availability of concrete and its flexibility in formwork, concrete has become the most popular building material available and is known for its good compressive strength.

The construction industry which is the largest user of concrete relies heavily on cement for its operation in the development of shelter, pavement and other structures (Alabadan *et al.*, 2005). However, the cost of cement production and the effect on the environment has encouraged more researches in the use of agricultural waste to partially replace cement. However, it has been shown that the hydration process of concrete is slowed down by the addition of these substitutes and early stage strength is reduced in comparison with normal ordinary Portland cement concrete Abdulawal and Warid-Hussin (2011) and early stage strength is reduced in comparism with normal ordinary Portland cement concrete.

Several works has being carried out on agricultural wastes such as the use of palm kernel shell ash as substitute for sand in concrete Falade (1992), properties of sawdust concrete (Sumaila and Job 1999). A study was also carried out to determine the workability and compressive strength characteristics of corn cob ash blended cement concrete Adesanya and Raheem (2009); and strength of binary blended cement composites containing saw dust ash (Ettu *et al.*, 2013).

Periwinkle shell as an agricultural waste product has been researched upon in various way such as the use of periwinkle shell ash as partial replacement for cement in

concrete Dahunsi and Bamisaye (2002); strength characteristics of periwinkle shell ash blended with cement concrete Olusola and Umoh (2012), the suitability of periwinkle shell ash as partial replacement for ordinary Portland cement in concrete (Olutoge *et al.,* 2012). Periwinkle shell which has also being used as aggregate such as investigation on periwinkle shell as coarse aggregate in concrete Falade (1995), determination of the engineering properties of sandcrete blocks containing periwinkle shell Job *et al*., (2009) and Suitability of Periwinkle Shell as Partial Replacement for River Gravel in Concrete(Agbede and Manasseh, 2009).

2.2 Sustainable Concrete

In today's society, the word sustainability has become part of human existence and covers all aspect of human endeavors including the concreting industry. Sustainability means "meeting the

needs of the present without compromising the ability of the future generations to meet their own needs" (Naik and Asce, 2008). The environment, economy and society are the components of renewed sustainability. The word sustainability has been largely aligned with the environment, due to the huge CO_2 content being emitted by industries including cement companies and thus emitting greenhouse gases leading to environmental hazards.

The need to continuously produce low cost building material due to the rapidly growing population and construction of infrastructure for our expanding cities the world over has lead to huge demand for sustainable material. The question then is we have to identify how a sustainable development will be executed (Mehta, 1999). The following are the related concerns which lead to sustainable development (Meyer, 2002)

i. Previous mistake could be corrected by purifying the polluted water and soil

ii. Reducing the global warming by neglecting the contamination of air, water and soil and curtailing CO_2 emission
iii. Balance between consumption and generation of natural resources.
iv. Searching for equilibrium between economic development and preservation of the environment (that is balancing between upgrading social life and living standard by avoiding the disturbance of the environment as much as possible).

It takes the professional responsibility of engineers to develop a fully sustainable concrete through improvement of the current building codes and laws. They also need to take the following special responsibility to develop a world view in problem solving which considers the effects of infrastructure decisions on the earth and on all living things.

2.3 Benefit of Using Agricultural Waste Material in Concrete

The use of agricultural by-products such as rice-husk ash, wood ash, silica fume and other pozzolanic materials, in addition to coal fly ash, can help to reduce the need for portland cement in addition to creating more durable concrete and reducing greenhouse gas emissions (Malhotra 2004; Mehta 2002; ACI 2004). Ezeh and Ibearugbulem (2009) found good prospect in partially replacing cement with periwinkle shell ash in river stone aggregate concrete while Adewuyi and Ola (2005) successfully applied waterworks sludge as partial replacement for cement in concrete production. Elinwa and Awari (2001) investigated the potentials of groundnut husk ash concrete by partially replacing Ordinary Portland Cement with groundnut husk ash. Many other researchers have confirmed rice husk ash a pozzolanic material that can be used to partially replace OPC in making cement composites (Cordeiro *et al*., 2009). A number of researchers have also found good prospects in using blended cements made with sawdust ash (Elinwa and Ejeh 2004).

Periwinkle shell as being described as a light weight material with a bulk density of 515kg/m^3 compared to river gravel with a bulk density of 1611kg/m^3. The low bulk density of periwinkle shells suggests that lighter concrete can be produced from them. The aggregate crushing value (ACV) is 59.6% and 27.1% for periwinkle shells and river gravel respectively. The ACV values suggest that periwinkle shells are not suitable for normal dense concrete because a maximum ACV value of 30% was recommended for normal dense concrete. The values also suggest that river gravel is more adequate for concrete and can withstand more load than periwinkle shells. Materials with density between 300 and 800 kg/m^3 can be classified as low density concrete, while those with densities between 960 and 1300 kg/m^3 are the moderate strength concrete and the ones having density value in the range of 1350 to 1900 kg/m^3 are structural light weight concrete. Normal concrete are those with density of 2200 to 2600 kg/m^3 (Olarunge and Olabisi, 2003). Therefore Periwinkle-gravel concrete of 1:0 can be classified as structural lightweight concrete while the other mixes can be classified as normal weight concrete.

Moreover when agricultural wastes are recycled for use in concrete, some important properties of the hardened concrete such as ductility and durability can be improved upon. The following are the advantages of using agricultural waste in concrete:

i. Rice husk ash (RHA) improves compressive strength of concrete (Safiuddin, 2010).
ii. Sawdust ash (SDA) improves self compactibility in concrete (Elinwa and Mahmmod 2002)
iii. Utilization of Palm Oil Fuel Ash (POFA) in concrete could reduce the cost of concrete production due to less cement use and disposal problems minimized (Rukzon *et al*, 2009).

iv. Using Periwinkle shell in concrete as aggregate produce light weight concrete (Agbede and Manasseh, 2012)
v. Periwinkle shell ash (PSA) improves comprehensive strength and lowers water absorption and porosity (Umoh and Olusola, 2012)
vi. Periwinkle shell ash (PSA) increases the setting time of concrete (Olutoge *et al* 2012)

2.4 Production of Pozzolana from Waste

2.4.1 Producing ash from waste

According to Adeyemi *et al*., (2013) to produce a good pozzolana, the burning of the shell must be carefully controlled to keep the temperature below 700^0C and above 400^0C. Keeping it below 700^0C ensure that the creation of carbon is kept to a minimum by supplying an adequate quantity of air. At a burning temperature below 700^0C the ash is rich in amorphous silica which is formed and is highly reactive. Burning the shell above 700^0C will convert the amorphous silica to crystalline silica which is far less reactive.

Taku and Amartey, (2016) burned Soybeans husk ash at 600^0C for a time range of 1 to 6hours produce ash of specific gravity higher than 2.2 but generally lower than the specific gravity of cement while setting time increases with calcinations time.

Research indicates that calcining a material at the same temperature but different methods has produced different silica content levels (Salas *et al.,* 2009). There are several designs of small simple incinerators, normally made of fired clay bricks, which are capable of burning ash at temperature below 700^0C and without excessive quantities of carbon. The temperature is monitored using a pyrometer (an industrial instrumental used to measure high temperature) and rapid cooling is necessary if the temperature

rises above 650^0C. To achieve the rapid cooling the ash is removed and spread on the ground. Incinerators of this type are normally used in batches of three (3) and Four (4) to produce approximately a ton of ash per day. The advantages of using small incinerators are that: they are simple and inexpensive to construct, easy to operate and will produce ash of an acceptable quality. The difficulty with using small incinerator is that there output is small; require more supervision and they don't make use of the energy of the shell.

2.4.2 Production dust from waste

In order to obtain pozzolana from waste, the waste is grinded to powdery form using ball mill (Kim *et al.,* 2017). The Indian standard recommends a minimum fineness level of 320 and 250m^2/kg for grade 1 and grade 2 pozzolana respectively measured by the Blaine air permeability test. Although this standard is recommended for calcined clay, the fineness requirements were suitable for both periwinkle shell ash (PSA) and Periwinkle shell dust (PSD.

2.4.3 Sieving of the ash and dust

ASTM C187 (2011) and ASTM C786 (2016) stated that particles that passed through 75µm sieve are recommended for use as partial replacement for cement. Umoh and Olusola (2012) used periwinkle shell ash that passed 75µm sieve. According to Islam *et al.,* (2017) that glass powder that passes sieve number 200 (75µm) were suitable for cement replacement.

2.5 Cement

The ordinary Portland cement is a binding material commonly used for construction of structures, roads and general works. Portland cements are commonly characterized by

their physical properties for quality control purposes. Their physical properties can be used to classify and compare Portland cements. The physical tests that can be conducted on cement are:

i. **Consistency test:** this test is used to determine the water content required to produce a standard cement paste. The water content of a paste of standard consistency is greater for a finer cement, but conversely an increase in fineness of cement slightly improves the workability of a concrete mix (Neville 2000). The requirements in the fresh state are that the consistency of the mix, be such that it is easily compacted without excessive effort and also that the mix be cohesive enough for transporting and placing in the mould so as to prevent segregation and bleeding which is a consequent of lack of homogeneity in the finished product. Dahunsi and Bamisaye (2002) stated that the range specified by the BS 196-3 (1995) is 26% - 33% for a standard paste.

ii. **Setting time**: cement paste setting time is affected by a number of items including cement fineness, water-cement ratio, chemical content (especially gypsum content) and admixtures. Setting time tests are used to characterize how a particular cement paste set.

Setting time are classified into initial and final setting time, initial setting time occurs when the paste begins to stiffen considerably while final setting time occurs when the cement has hardened to the point at which it can sustain some load

False set can also occur when the cement set without evolving heat and can be remixed without adding water and it occurs due to the conversion of

unhydreous gypsum to hydrous gypsum ($CaSO_4.2H_2O$). Flash set is due to absence or insufficiency of gypsum specifically used for under water repair.

The minimum initial setting time as recommended by the code is 45mins while the maximum final setting time is 600mins (Umoh and Olufemi 2012, Olutoge *et al* 2012)

The effects of setting time delays become more significant with the increase in the levels of cement substitutions with ash (Elinwa and Ejeh, 2004; Elinwa and Mahmood, 2002)

iii. **Soundness:** this property exams the rate of expansion of a cement paste after casting, standard cement paste should not expand beyond 10mm Afolayan *et al.*,(2013) which is the standard recommended by the BS 196-3(2016). The presence of excess free unburnt lime, Magnesium oxide and Calcium Sulfate can lead to cement paste undergoing appreciable change in volume leading to cracking and subsequent disintegration. Other factors that could lead to unsoundnesss of cement include fineness of the cement, non-uniform mixing of raw material and insufficient burning of the cement during production (guide.wikinut.com)

iv. **Fineness:** this exams the particle size of the Portland cement and it affects the hydration rate and thus the rate of strength gain. The smaller the particle size, the greater the surface area-to-volume ratio, and thus, the more area available for water-cement interaction per unit volume. The effects of greater fineness on strength are generally seen during the first seven days

2.5.1 Oxide Composition of Cement

From literature the Table 2.1 shows the oxide composition of cement

Table 2.1 Chemical Properties of Ordinary Portland cement

Cement Component	Composition%
Al2O	5.28
CaO	64.40
MgO	1.65
SiO	21.35
Fe2O3	3.95
SO3	1.20
Loss of Ignition	1.44
Insoluble Residue	0.65

Source: (Afolayan *et al*., 2013)

2.5.2 Cement Blending

Blended cements as defined by ASTM (ASTM C 150, 2005) is cement mixtures containing Portland cement and one or more supplementary cementitious materials, with potential benefits of reducing the overall concrete costs, improving concrete durability, flowability/workability and strength. The term blended cement often refer to cement products that are factory blended by cement companies and mixing on site with Portland cement is referred to as Partial replacement (Horst, 2001).

2.6 Pozzolanic Activity of Pozzolans

A pozzolana is a siliceous or aluminosiliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by

the hydration of Portland cement to form calcium silicate hydrate and other cementitious compounds. Pozzolans are generally categorized as supplementary cementitious materials or mineral admixtures (Detwiler *et al* 1996). The process of hydration in cement is the result of reaction that occurs between water and the chemicals compounds of Tricalcium Silicate (C_3S) and Dicalcium Silicate (C_2S) producing calcium silicate hydrate (C-S-H) and Ca(OH) plus water

$CaO.Si_2.H_20 + Ca(OH)_2$ (2.1)

Hence when pozzolana is added to the hydrating cement (Pozzolana + $Ca(OH)_2$ + H_2O) produces the gel of the cementitious substances of C-S-H;

$3CaO.SiO_2 – 2CaO.SiO_2 + H_2O\ CaO.SiO_2.H_2O + Ca(OH)_2$ (2.2)

In contrast to siliceous reactions, Edwin (2011) states that pozzolanic reactions could be between lime and aluminous compounds in cement is assumed to be $3(CaO)Al_2O_36(H_2O)$. Consider the pozzolanic reaction as expressed in eq 2.3.

$3[Ca(OH)_2] + Al_2O_3 + 3[H_2O] = 3(CaO)Al_2O_36(H_2O)$ (2.3)

The process of gel formation as stated by Neuwald, (2004) is the pozzolanic reaction of the pozzolan. The formation of the C-S-H prevents water soluble compounds from migrating out of the concrete and thus makes the cements paste denser and a reduction in the permeability of the concrete is enhanced. When the pozzolanic reaction of the pozzolan continues with the production of additional gels of C-S-H and continuous reaction of $Ca(OH)_2$ is termed the Pozzolanic Activity of Pozzolana Zhang and Malhota, (1996), thus the most important constituents for any mineral admixture are silica and alumina oxide (Sadaqat *et al* 2014).

Table 2.2 shows the specification for Fly Ash and Raw or Calcined Natural Pozzolanas for Use as a Mineral Admixture in Portland cements Concrete. American Society for Testing and Materials, Philadelphia.

Table 2.2 Classes of Pozzolanas

Property	Class N	Class F	Class C
Chemical Properties			
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	70	70	50
SO_3 (Max %)	4	5	5
MgO (Max %)	5	5	5
Loss on ignition	10	2	6
Physical Properties			
Moisture content (%)	3	3	3
Fineness (%) on sieve No. 200 (mm)	85	85	85
Pozzolanic Activity			
Index No with OPC at 28 days (%)	75	75	75
Pozzolanic Activity Index with lime at 7 days	5.5	5.5	5.5

Source: ASTM (2013)

2.6.1 Periwinkle Shell as a Pozzolona

Periwinkle shell ash can be said to be a pozzolana due to the presence of large quantity of CaO and SiO in it chemical composition in accordance to BS 1881: Part 103. Periwinkle shell ash and dust can be classified as natural pozzolanas used due to the fact they are obtained from periwinkle shell which is an agricultural waste product. Like all pozzolanas, periwinkle shell ash or periwinkle dust does not possess any cementing properties of their own, but they contain silica and alumina in reactive form. Ancient Romans produced exceptional cement by mixing pozzolanic materials with lime to build structures some of which are standing today (Osei and Jackson, 2012).

The mechanism by which the pozzolanic reaction exercises a beneficial effect on the properties of concrete is the same irrespective of whether it is added to concrete in the form of a mineral admixture or as component of a blended Portland cement (Malhota and Mehta 2006; Bhatty and Taylor 2006).

2.6.2 Oxide Composition of Periwinkle Shell Ash

Table 2.3 is a typical oxide composition of periwinkle shell ash

Table 2.3 Chemical composition of PSA

Chemical Component	Composition(wt%)
MgO	1.2
SiO_2	33.2
ZnO	3.2
Fe_2O_3	5.04
MnO_2	1.2
Al_2O_3	9.2
CaO	41.3
CuO	1.03
K_2O	1.4
Na_2O	1.38
TiO_2	0.05
LOI	1.8

Source: (Felix et.al, 2014).

According to Nagarjan et al., (2014) for hydration to occur a material must contain an important constituent CaO, and this enables the material to gain strength.

2.6.3 Physical Properties of Periwinkle Shell Ash

The physical properties of periwinkle shell ash have been well researched and these properties include specific gravity, fineness modulus, consistency, setting time and soundness. According to Olutoge *et al.*,(2012) the specific gravity of PSA is 2.5 which is lower than the specific gravity of cement at 3.15 and deduced that greater volume of cementitious material can be obtained for mass replacement.

Table 2.4 Summary of Physical Properties of PSA Concrete

Properties	Specific Gravity	Consistency	Soundness	Moisture Content
Values	2.5	28%	1.0mm	1.5

Source: (Olutoge et.al, 2012, Umoh and Olusola, 2012)

2.7 Aggregate

This is an important constituent in concrete that gives stability to the concrete, reduce shrinkage and affect the economy (Afolayan, *et al.,* 2013). Aggregate constitute the basic components to manmade environment on which civil engineering infrastructure such as roads, buildings, airport are built and maintained by the use of large quantities of aggregate-sand, gravels and stones (Amartey *et al.*, 2013). Aggregates are considered to be chemically inert materials but now it has been recognized that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bound at the interface of aggregate and paste (Bhattacharjee *et al*., 2015). According to Neville (2005) the physical, thermal and chemical properties of aggregate influences the performance of the concrete to a great extent and provide better strength, stability and durability to the structure made from cement concrete than cement paste alone. In concrete ingredients such as aggregates and water are natural materials and can vary to any extent in many of their properties, hence the need for in depth range of studies that are required to be made in respect of aggregates to understand their effect and the influence on the properties of concrete cannot be underrated.

2.7.1 Classification of Aggregate

Aggregate can be classified according to the following:

i. Geological origin: this considers aggregates as natural resources and has been reduced to size (eg gravel or shingle) or may have to be reduced by crushing. Aggregates can be classified as natural and artificial aggregates. Examples of natural aggregates are aggregates obtained from natural deposits of sand and gravel or from quarries by cutting rocks. Artificial aggregate can be clear broken bricks and air cooled fresh blast furnace-slag
ii. Size: the size of aggregate is also used to classified aggregate either as fine or coarse aggregate. The maximum size of the aggregate may vary, but in each case it is to be so graded that the particle of different size fractions are incorporated in the mix in appropriate proportions.
iii. Shape: the shape of aggregate has great influence on fresh concrete more than those of hardened concrete. The shapes of aggregates can be classified as rounded, irregular or partly round, angular or flaky.
iv. Unit Weight: aggregate can also be classified as normal weight, heavy weight and light weight aggregates

2.7.2 Physical Effect of Aggregates

The physical properties of aggregates were found to have an immense effect on the quality of concrete. Khoury (1992) studied the physical properties of aggregate and concluded that it affects the water absorption; particle shape and surface texture. Aggregate must be clean, strong, durable, hard and free from clay and other fine material (Dahiru *et al.,* 2014)

Elongated and flaky aggregate increases the permeability of the concrete by trapping air bubbles and bleed water under their flat surface and hence produce under-aggregate zones and fissures. The outcome of this formation is a weak transition zone in which the micro-cracks can easily be formed. Micro-cracks are essential contributing influence in enhancing the permeability of hardened concrete. The proportional representation of coarse and fine aggregate is also important in determining properties of concrete. The ultimate requirement of an aggregate for concrete is that it remains stable within the concrete throughout the design life of the concrete.

The following test are conducted to determine the suitability of aggregate

2.7.2.1 Bulk Density of aggregate

The weight of the aggregate required to fill a container of a specified unit volume. Volume is occupied by both the aggregates and voids between the aggregate particles. Depends on size distribution and shape of particles and how densely the aggregate is packed. Voids contents affect mortar requirements in mix design; water and mortar requirement tend to increase as aggregate void content increases. Voids contents between aggregate particle increases with increasing aggregate angularity. Void contents range from 30% to 45% for coarse aggregate to about 40% to 50% for fine aggregates (Arumugam, 2014)

2.7.2.2 Specific Gravity of aggregate

Specify gravity is the ratio of the density of the substance to the density of water. The density and specify gravity of an aggregate particle is dependent upon the density and specify gravity of the minerals making up the particle and upon the porosity of the particle.

2.7.2.3 Fineness Modulus of aggregate

Fineness Modulus is defined as an index to the particle size not to the gradation. Fineness Modulus is calculated from the sieve analysis. An empirical factor obtained by adding the total percentage of sample of the aggregate retained on each of a specified series of sieves, and dividing the sum by 100.If the fineness Modulus is constant, the volume of coarse aggregate increase with size of the aggregate, or with the decrease in surface area of the coarse aggregate (Arumugam, 2014) . The coarse aggregate specific gravity test is used to calculate the specific gravity of coarse aggregate sample by determining the ratio of use

2.7.2.4 Sieve analysis of aggregate

Sieve analyses are performed on aggregates used in roadways bases and in Portland cement and asphalt cement (asphalt) concrete. Sieve analyses reveal the size makeup of aggregate particles from the largest to the smallest. In Portland cement concrete gradation influences shrinkage cracking, workability, pumpability, permeability and other characteristics. Umoh and Olusola (2012) used fine aggregate from river bed sand passing 4.75mm sieve and falls within zone 2 while coarse aggregate were crushed granite of maximum size 20mm.

2.8 Workability of Fresh Concrete

The term workability is broadly defined and no single method is capable of measuring all aspects of workability. The American concrete institute (ACI) (2000) defined workability as the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. Neville (2000) defines workability as the amount of useful internal work necessary to produce full compaction. A description of workability is based not just on the properties of the concrete, but also on the nature of the application. The strength and durability of

hardened concrete, in addition to labour costs, depend on the concrete having appropriate workability Khan *et al.*, (2014). Determining workability is based on two methods,

i. Slump method: is where the degree of consistency of the concrete is measured in order to determine workability. Slump can be classified to be true slump, shear slump and collapse slump (BS 1881: 102, ASTM C 143). Ghassan *et al*., (2011) stated that decreasing the water cement ratio decreases slump value.

ii. Compacting factor test: is defined as the weight ratio of the concrete in the cylinder to the same concrete fully compacted in the cylinder (filled in four layers and tempered or vibrated).

2.8.1 Workability of Concrete Containing Pozzolana

Workability of concrete mixed with mineral pozzolana has being tested using several materials like Silica Fume (SF) which attain maximum slump at the water/binder ratio of 0.3 (Wong and Razak series). The workability of concrete with microfiller mineral admixtures (low to moderate reactive pozzolan) greatly depends on the particle size, specific surface area, particle shape, and replacement level. In general, the smaller the particle size and higher the specific surface of mineral admixture increases the water demands of concrete Ahmed (2002). The low to moderate reactivity and filler effect help to maintain the workability and sometimes increase the workability.

According to Muangtong *et al*., (2012) partially replacing cement with Sugar Cane Bagasse Ash at 20% and water cement ratio of 0.735 an appropriate workability is obtained in concrete. Umoh and Olusola (2012) stated that periwinkle shell ash which has a slump range of between 25mm – 29mm has good workability which is recommended as 10 – 30mm. The value of Compacting Factor for cement partially replaced with periwinkle shell ash range between 0.83 and 0.87, which is within the

stipulated range of compacting factor (0.85 to 0.90) workability of concrete containing pozzolana according to Umoh and Olusola (2012)

2.9 Compressive Strength of Concrete

This is a measure of the maximum resistance of a concrete specimen to an axial load usually expressed in N/mm^2 at an age of 28-days. Concrete is known to be very good in compression. The compressive strength of concrete is the most common performance measure used by the engineer in designing buildings and other structures. The compressive strength is measured by crushing cylindrical concrete specimens in a compression-testing machine. Compressive strength test results are primarily used to determine that the concrete mixture as delivered meets the requirements of the specified strength in the job specification. The compressive strength of concrete depends on several factors, namely: water cement ratio, curing age, presence of addictive and design target.

Strength test results from cast cylinders may be used for quality control, acceptance of concrete or for estimating the concrete strength in structure for the purpose of scheduling construction operations such as form removal or for evaluating the adequacy of curing and protection afforded to the structure. Cylinders tested for acceptance and quality control are made and cured in accordance with procedures prescribed by BS 5500.

Addition of other constituents over time can either reduce or increase the compressive strength of the concrete. Mehta (1981) partially replaced cement with Santorin earth at different ranges and concluded that at 7days compressive strength was approximately proportional to the amount of Portland cement present in the blended cement.

2.9.1 Compressive Strength of Concrete Containing Periwinkle Shell Ash

Folagbade (2014) posited that cement combinations usually have delay strength development at early ages. Previous research works on the use of PSA in concrete production (Koffi 2008; Dahunsi and Bamisaye 2002) have been centered on the effect of the ash on the concrete compressive strength up to 28-days hydration period. The use of PSA as partial replacement of cement in concrete by these authors only investigated the effect of varying percentages of the ash on the compressive strength of the concrete produced. Since pozzolanic reaction depends on the liberation of calcium hydroxide from cement hydration, the effect became much more beneficial to compressive strength development of concrete at later ages (Olusola and Umoh 2012). Although compressive strength decreases as the percentage of Periwinkle Shell Ash (PSA) increases and for each of percentage replacement the compressive strength increases as the curing age increases this is an indication that the crushing strength increases with curing age increase (Olutoge *et al*., 2012).

2.10 Scanning Electron Microscopy

A scanning electron microscopy (SEM) scans a focused beam of high energy electrons over a surface to create an image (Swapp, 2013). The electrons in the beam interact with the sample, producing various signals that can be used to obtain information about the surface topography and composition. The microstructure expresses a high number of properties of a material. A modern light microscope has a maximum magnification of about 1000x. The resolving power of the microscope is not only limited by the number and quality of the lenses but also by the wavelength of the light used for illumination. The quality and resolution of SEM images are function of three major parameters

i. Instrument performance

ii. Selection of imaging parameters (eg operator control)

iii. Nature of the specimen

2.10.1 Application of SEM

SEM is routinely used to generate high-resolution images of shapes of objects (SEI) and to show spatial variations in chemical compositions. Typical application include: acquiring elemental maps or spot chemical analyses using EDS, discrimination of phases based on mean atomic number using backscattered electron (BSE) and compositional maps based on differences in trace element "activators" (typically transition metals to rare earth elements)

According to Govindarajan and Jayalksmi (2011) the microstructure of cement paste with or without replacement of ash at 7days and 28 days produces a needle-like formation of ettringite, C-S-H and crystals of $Ca(OH)_2$. At 28 days the structure becomes denser when compared to the early stage of curing. Faria and Holanda (2000) observed that when heat is applied at 700 to 900^0c the fracture surface is rough and the porosity of the material becomes visible and at higher than 900^0c the phase transformation will occur such as dehydration of hydroxides. (Barker and Cory 1991) observed that use of 25% limestone influences both the size and distribution of calcium hydroxide deposits in cement paste. They found that in ordinary portland cement paste small regions of calcium hydroxide are evenly distributed throughout the paste, while in the limestone-filled pastes larger regions of calcium hydroxide were unevenly distributed throughout the paste.

2.11 Regression and Analysis of Variance (ANOVA)

Regression analysis is a statistical tool for the investigation of relationship between variables. Regression equation shows that the independent variable does not have a significant effect on the relation between dependent variable when it showed a negative coefficient (Tanko, 2016)

Analysis of variance (ANOVA) can be used for examining the significance of the factors considered for developing the strength model and subsequently fitting an empirical model for compressive strength in terms of the significant mixture factors using polynomial regression (Ahmad and Alghamdi, 2014).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The main materials used for the experiment were sourced from different locations and each of them were tested to conform to the required code of practice. Below are the lists of materials namely:

Ordinary Portland cement (OPC), Periwinkle Shell (ash and dust), Fine Aggregate, Coarse Aggregate and Water

3.1.1 Aggregate

The fine aggregate (sand) and the coarse aggregate were obtained from a block industry in Zaria. The tests carried out includes, particle size distribution analysis, specific gravity and bulk density.

3.1.2 Cement

The Dangote brand of Ordinary Portland cement with strength class of 42.5R was used as the binder and obtained from a local dealer in Samaru Zaria. Both physical and chemical properties test were carried out on the Cement in accordance with BS 4550: Part1, NIS 367:1997 and Part 2, NIS 368:1990.

3.1.3 Periwinkle Shell

The periwinkle shell was obtained from mammy market Ikeja Military cantonment in Lagos state, where they are sold in 100kg bags. The shells were dried first and transported to Zaria, Two bags of 100kg periwinkle shell were calcined at 600^0C to obtain the Periwinkle shell ash (PSA) and two bags of the shell were also crushed in a local rice mill to obtain the Periwinkle shell dust. Plate I represent a picture of Periwinkle shell

Plate I Periwinkle Shell

3.1.4 Water:

Water used was obtained from ABU Zaria tape which is clean and in accordance with (BS 3184).

3.2 Methods

All the experiments conducted on the materials, the test specimens (Concrete cubes) and also the analysis on the concrete cubes are presented in this chapter. The test involves the preliminary and major tests on the constituent materials (cement, Periwinkle shell ash, Periwinkle shell dust and aggregates) and the test specimens. All the tests were carried out in the department of Civil Engineering, Ahmadu Bello University, Zaria with the exception of X-ray fluorescence analysis carried out in Chemistry Department

and Scan Electron Microscopy (SEM) test conducted in Chemical Engineering Department all in ABU Zaria.

3.2.1 Physical Properties of Aggregate

3.2.1.1 Sieve analysis of fine and coarse aggregate

Sieve analysis was conducted on fine and coarse aggregate using various sieve sizes in accordance with BS 812: Part 103 (1985), the result of sieve analysis is shown in appendix I-a and I-b. The initial weights of coarse and fine aggregate were 3000g and 1200g respectively.

3.2.1.2 Fineness modulus aggregates

Fineness moduli of coarse and fine aggregate were determined from the parameter of the sieve analysis. This parameter is used for checking the uniformity of grading. The result is presented in appendix I

3.2.1.3 Specific gravity of coarse and fine aggregate

The specific gravity tests for coarse and fine aggregate were conducted in accordance with BS 812: Part 2. Three samples were conducted for each material and the average specific gravity result was presented. Appendix I-c and appendix I-d represent specific gravity for coarse and fine aggregate respectively.

3.2.1.4 Aggregate Impact Value

To determine the toughness and strength characteristics of coarse aggregate, aggregate impact test was conducted. The test was in accordance with BS 812: Part 112 (1990) and is presented in appendix I-e.

3.2.1.5 Aggregate crushing value

Aggregate crushing value gives the relative measure of the crushing resistance of an aggregate under an increasing compressive load. The test was conducted in accordance to BS 812: Part 110 (1990) the result is shown in appendix I-f.

which specify that aggregate crushing value (ACV) should not be more than 45% for aggregate used for concrete not subject to wearing and 30% for concrete used for wearing surfaces such as runways and roads.

3.2.1.6 Bulk density of aggregate

The bulk density test was performed to determine the weight that would fill a unit volume in accordance to BS 812: 2(1995) as shown in appendix I-h.

3.2.2 Properties of Cement

3.2.2.1 Cement specific gravity:

This is one of the fundamental characteristics of the material and is defined by the mass of a unit volume of material substance, expressed as grams per cubic centimeter (g/cm^3). Specific gravity test was in accordance with BS 4550: Part 3 (1978) using the density bottle (Pycnometer method). Appendix I-i shows the result of specific gravity test for cement.

3.2.2.2 Consistency test for cement

The basic aim of this test is to find out the water content required to produce a cement paste mix with different percentages of PSD and PSA. The tests were carried out in accordance with BS 4550: Part 3(1978) using a vicat apparatus with plunger. Standard consistence of cement is specified by resistance to penetration by standard plunger defined as that consistency which will permit the vicat plunger to penetrate to a point 5 to 7mm from the bottom of vicat mould. This test was conducted in the concrete

laboratory of Ahmadu Bello University Zaria and also on cement paste containing periwinkle shell ash and dust. Equation 3.1 is used for the calculation consistency of cement paste.

$$\text{Standard Consistency} = \frac{\text{Mass of water}}{\text{Mass of sample}} \times 100\% \quad (3.1)$$

The result of consistency test of cement is shown in Appendix I-j

3.2.2.3 Setting time of OPC

This test is used to characterize the cementing material. The test comprises of the initial setting time and final setting time in determining the hardening of the cement paste, in accordance with BS 4450: Part 3(1978) using Vicat apparatus with steel needle. Initial and final setting time results are shown in Appendix I-k and I-l respectively.

3.2.2.4 Soundness test

Soundness test was conducted to determine the expansion of cement paste using La' Chatelier apparatus in accordance with BS 4550: Part 3 (1978). The result of soundness test on cement is presented in Appendix I-m.

Table 3.1 shows the summary of the physical properties of cement.

Table 3.1 Summary of Physical Properties of Cement

Physical Property	Results Obtained
Normal Consistency (%)	31.5
Initial Setting time (min)	108
Final Setting time (min)	168
Specific gravity	3.34
Soundness (mm)	0

3.2.3 Properties of Periwinkle Shell Ash and Dust

3.2.3.1 Periwinkle Shell Dust (PSD)

To obtain periwinkle shell dust the dry shells of the periwinkle was grinded using the automatic poultry feed grinding machine. Physical and chemical properties test were conducted on the PSD sample in accordance with the relevant British standard code for cement and pozzolana.

3.2.3.1.1 Chemical Properties of PSD:

The X-Ray Fluorescence test was conducted at the Department of Chemistry using 1g of periwinkle shell dust to determine the oxide composition of the sample and it was labelled sample x. The test result is presented in table 3.2.

Table 3.2 Chemical Analysis of PSD

Element	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3	LOI
Conc (Wt%)	11.31	3.68	15.08	45.50	0.30	1.02	13.20	0.02	9.89	-

3.2.3.1.2 Physical properties of PSD

The test conducted to determine the physical properties of PSD include sieve analysis, consistency test, setting time test, soundness test and specific gravity test. The tests were conducted in accordance to BS 6699: 1992. Table 3.3 shows the summary of the physical properties of PSD while, the complete test results are presented in Appendix I-n to Appendix I-r.

Table 3.3 Physical Properties of PSD

S/No	Physical Properties	PSD
1	Colour	Light gray
2	Specific gravity	2.21
3	Fine Modulus	2.82

Plate II Periwinkle shell dust (PSD)

3.2.3.2 Periwinkle Shell Ash (PSA)

Periwinkle shell ash was obtained from the calcination of the dry periwinkle shell at a temperature of 600^0C and then grounded to obtain smooth surface texture.

3.2.3.2.1 Chemical Properties of PSA:

The X-Ray Fluorescence test was conducted at the Department of Chemistry using 1g of periwinkle shell dust to determine the oxide composition of the sample and it was labelled sample Y. Table 3.4 represents the chemical analysis of PSA.

Table 3.4 Chemical Properties of PSA

Element	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3	Others
PSA (Wt%)	0.45	0.48	18.93	39.98	0.58	0.33	30.39	0.68	6.34	1.84

3.2.3.2.2 Physical properties of PSA

The physical properties of PSA were determined based on the following tests conducted on the PSA sample namely: Sieve analysis, Consistency test, Setting time test and Soundness test. These tests were conducted according to BS 6610: 1991. Table 3.5

shows the summary of the physical properties of PSD while the overall result is presented in appendix I-s to I-w.

Table 3.5 Physical Properties of PSA

S/No	Physical Properties	PSA
1.	Colour	White
2.	Specific gravity	2.46
3.	Fine Modulus	2.62

Plate III Periwinkle shell ash (PSA)

3.2.4 Design Mix:

The aim of mix design is to determine the proportion of each of the constituents of the cement mortar in the mix. The absolute volume method of mix design was used and in accordance with ACI 211 for non-air entrained concrete.

$$\frac{W}{1000} + \frac{C}{1000\rho c} + \frac{A}{1000\rho A} = 1m^3 \quad (3.2)$$

W= water (kg/m^3), C= cement (kg/m^3), A= aggregate (kg/m3), rc = specific gravity of cement and rA = specific gravity of aggregates

Table 3.6 shows the summary of the different mix ratio for the different grade of concrete considered.

Table 3.6 Mix Ratio of Concrete Cubes

Grade N/mm^2	Water/cement	Cement	Fine Aggregate	Coarse Aggregate
20	0.56	1	2	4
25	0.49	1	1.5	2.7
30	0.44	1	1.3	2.5
40	0.36	1	1	2

The calculation and full result of the mix design is presented in appendix II.

3.3 Tests on Concrete

The various test conducted on the concrete mortal and the hardened concrete include workability and compressive strength test, test are in accordance BS 1881 for concrete.

3.3.1 Workability of fresh concrete

Basically, concrete is characterized by it passing ability, filling ability and resistance to segregation. The test was conducted on the freshly cast concrete cube using the slump method in accordance with BS 1881-102: 1983. Slump test was used to ensure uniformity for different batches of similar concrete under laboratory condition. The slump could be collapse slump, shear slump and true slump. The result is presented in the Table 3.7.

Table 3.7 Workability of Fresh concrete

Sample	Grade of concrete N/mm^2	Percentage Replacement (%)	Slump test(mm)
PSD	20	0	30
		5	30
		10	30
		20	25
	25	0	30
		5	30
		10	30
		20	25
	30	0	30
		5	30
		10	25
		20	25
	40	0	30
		5	30
		10	30
		20	25
PSA	20	0	30
		5	30
		10	25
		20	25
	25	0	30
		5	30
		10	30
		20	25
	30	0	30
		5	30
		10	30
		20	30
	40	0	30
		5	30
		10	30
		20	30

3.3.2 Unit weight of concrete (kg/m^3)

The unit weight of hardened concrete was determined from the weight after each curing days of 7, 14, 21 and 28. The density of concrete is dependent on the weight of the material this was in accordance with BS 1881: Part 114 (1983) BS EN 12390-3 (2009) and BS EN 12390-6 (2009), the result is as shown in Appendix III

3.3.3 Compressive strength test (N/mm^2)

The compressive strength test of the hardened concrete was determined after the required curing days of 7, 14, 21 and 28days using the Compressive testing machine (Denison) at the concrete laboratory of Ahmadu Bello University Zaria in accordance with BS 1881: Part 116 (1983). The compressive test result is shown in Appendix III

3.4 Scan Electron Microscopy (SEM)

This test was conducted in the chemical engineering department of the Ahmadu Bello University to determine the microstructure of the sample and the effect of cement replacement with PSA and PSD on the concrete composition. Plates IV – XI in chapter four.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Ordinary Portland cement (OPC)

4.1.1 Cement Consistency

The result of the consistency test for cement paste are presented in Table 4.1.

Table 4.1 Consistency of Cement Paste

Sample	Consistency%	Water/Cement ratio
Sample A	32	0.32
Sample B	30	0.30
Sample C	33	0.33
Average	31.7	0.32
Standard requirement	26<X<33	

From the Table 4.1 the average consistency of the OPC cement paste used was 31.7% which falls within the range recommended by BS 12: 1991 that is (26 – 33%) and agrees with Dahunsi and Bamisaye, (2002). This value obtained shows the consistency of the water/cement ratio required to produce a standard paste for the determination of setting time and soundness of the cement.

4.1.2 Setting Time of cement paste

Table 4.2 shows the result of setting time of cement paste and compared with the standard requirement.

Table 4.2 Setting Time of Cement Paste

Sample	Initial setting time(mins)	Final setting time(mins)
Sample A	109mins	169mins
Sample B	108mins	168mins
Sample C	108mins	168mins
Standard Requirements	≥45mins	≤600mins

According to BS4450: part 3 (1978) and EN 196 -1: 1983 the minimum initial setting time for cement paste is 45mins and the maximum final setting time is 600mins. From Table 4.2 the least initial setting time obtain was 108mins and the highest final setting time was 169mins. Thus the Dangote brand of cement used, satisfied the specification as recommended by the code for Ordinary Portland cement. However, for a cement paste with initial setting time exceeding 90mins indicates long storage time.

4.1.3 Cement Soundness

The test conducted were compared with standard specification as shown in Table 4.3

Table 4.3 Soundness of Cement Paste

OPC Sample	Average Expansion (mm)	Code Specification BS 4550, NIS 447 Recommendation
A	0	≤ 10mm
B	0	
C	0	

The cement satisfied the code of practice in terms of expansion and is in agreement with (Afolayan 2013). This indicates that the cement does not contain unburnt lime (CaO),

dead burnt MgO and $CaSO_4$ which are known compounds responsible for expansion of cement after setting.

4.2 Properties of Ash and Dust

4.2.1 Sieve Analysis of PSD and PSA

The sieve analysis of the periwinkle shell dust (PSD) and periwinkle shell ash (PSA) which is presented in Appendix I-n and Appendix I-s respectively are plotted in Fig 4.1. From the plot it can be deduced that PSD has better particle size distribution than PSA as a result of it representation in each sieve size used.

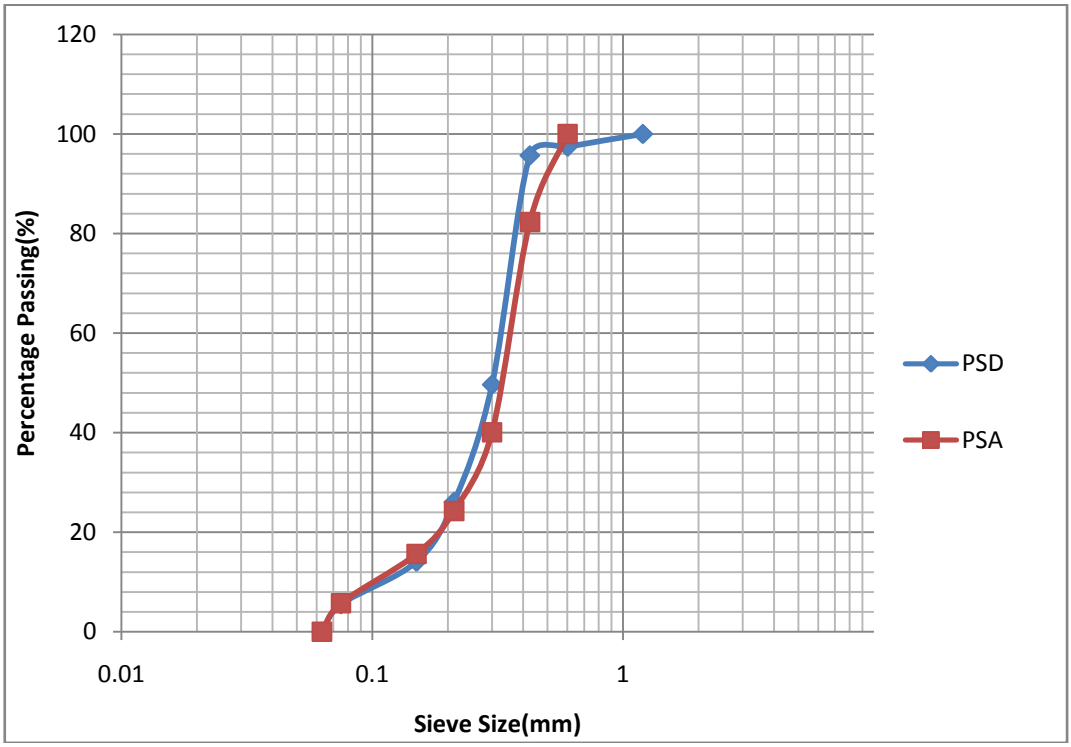


Fig 4.1Particle size distribution of PSD and PSA

4.2.2 Physical properties of ash and dust

Table 4.4 compares the physical properties of the Periwinkle shell ash (PSA) and Periwinkle shell dust (PSD).

Table 4.4 Physical Properties

S/No	Physical Properties	PSD	PSA
1	Colour	Light Grey	White
2	Specific Gravity	2.21	2.46
3	Fineness Modulus	2.82	2.62

From the Table 4.4 the specific gravity of 2.46 and 2.21 for PSA and PSD respectively is less than 3.15 for cement, agreeing with Olutoge *et al*., (2012) who had a value of 2.50 for PSA and stated that a lower specific gravity will yield greater volume of cementitious material for mass replacement with cement. During the determination of specific gravity for PSD, kerosene was used due to the presence of unburnt CaO, water will naturally react with lime.

$$CaO + H_2O \longrightarrow Ca(OH)_2 \quad (4.1)$$

The specific gravity of PSD was 2.21 which is lighter than PSA while the fineness modulus of PSD is higher than PSA and this can be attributed to the loss of certain volatile material due to increase temperature.

4.2.3 Chemical properties of PSA and PSD

Table 4.5 shows the chemical properties of Periwinkle shell ash PSA and Periwinkle shell dust PSD

Table 4.5 Chemical Properties of Ashe and Dust

Element	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3	LOI
PSA (Wt%)	0.45	0.48	18.93	39.98	0.58	0.33	30.39	0.68	6.34	1.84
PSD (Wt%)	11.31	3.68	15.08	45.50	0.30	1.02	13.20	0.02	9.89	-

From the Table 4.5 CaO has a value of (13.20 and 30.93) for PSD and PSA respectively indicate that the materials contain the require constituent needed for a proper hydration reaction to take place and thus conforms to Nagarajan *et al*., (2014). The most important constituents for any mineral admixture are silica and alumina oxides (Sadaqat *et al*., 2014). Since PSD was not subjected to heat the presences of SiO_2 from soil and food consumed by the molusk would be visible in the chemical composition. The high presence of SiO_2 in PSD aligns with 68.1% for Glass Powder and 68% for Waste Glass by Islam *et al*., (2017). Both materials however contains substantive amount of SiO_2 and Al_2O_3 which are the main constituent responsible for pozzolanic reaction in concrete. The presence of silica oxide in PSA and PSD combines with the primary hydrate of cement to produce calcium silicate hydrate (CSH) which is the strengthening gel in concrete (Salas *et al*., 2009).

To further classify the pozzolana according to ASTM;

Table 4.6 Class of Pozzolana

Component	PSA(%)	PSD(%)
SiO_2	39.98	45.50
Al_2O_3	18.93	15.08
Fe_2O_3	6.34	9.89
Total	65.25 (Class F)	70.47 (Class N)

From Table 4.6 when compared with Table 2.2, Periwinkle shell ash as combined total of 65.25 approximately 70 and also have a loss of ignition (LOI) 1.84 and thus can be classified as class F fly ash while Periwinkle shell dust has a combine total of 70.47 >70 can be referred to as a class N pozzolana.

4.2.4 Pozzolanic reaction of the dust and ash

A pozzolanic reaction occurs when a siliceous or aluminous material combines with calcium hydroxide in the presence of water to form compounds exhibiting cementitious properties (Detwiler *et al*., 1996). In process of hydration the calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$or CH) are released within the hydration of two main components of cement namely Dicalcium silicate (C_2S) and tricalcium silicate (C_3S) where C, S represent CaO and SiO_2 (Omotoso *et al*., 1998). Hydration of C_3S, C_2S also C_3A and C_4AF (A and F symbolize Al_2O_3 and Fe_2O_3) as stated in eqns 4.2, 4.3 and 4.4.

$$2(3CaO.SiO_2) + 6H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \quad (4.2)$$

$$2(2CaO.SiO_2) + 4H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2 \quad (4.3)$$

$$3Ca.Al_2O_3 + 31H_2O + 3CaSO_4 \longrightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O \quad (4.4)$$

$$6CaO.Al_2O_3.Fe_2O_3 + 10H_2O + Ca(OH)_2 \longrightarrow 6\ CaO.Al_2O_3.Fe_2O_3.12H_2O \quad (4.5)$$

The C-S-H gel generated by the hydration of C_3S and C_2S in eqns (4.2) and (4.3) are the main strengthening constituent. Calcium hydroxide and Ettringite ($3CaO.3CaSO_4.31H2O$, eqn 4.4) that are crystalline hydration products are randomly distributed and form the frame of the gel-like products. Hydration of C_4AF (eqn 4.5), consumes calcium hydroxide and generates gel-like products. Excess calcium hydroxide can be detrimental to concrete strength, due to tending the crystalline growth in one direction. It is known that by adding pozzolanic material to mortal or concrete mix, the pozzolanic reaction will only start when CH is released and pozzolan/CH interaction exist (Villar *et al.,* 2003). In the pozzolana-lime reaction, OH^- and Ca2+ react with the SiO_2 or Al_2O_3–SiO_2 framework to form calcium silicate hydrate (C-S-H). Pozzolana-lime reactions are slow, generally starting after one or more weeks (Englehand *et al*., 2005), the delay in pozzolanic reaction will result in more permeable concrete at early ages and gradually becomes denser than plain concrete with time. This behavior is due to two reasons namely

i. Pozzolana particles become the precipitation sites for early hydration C-S-H and CH that hinders pozzolanic reaction
ii. The strong dependency of breaking down of glass phase on the alkalinity of the pore water which could only attain the high pH after some days of hydration.

The effect of pozzolanic reaction produces more cement gel (ie. C-S-H and C-A-H) reducing the pore size, blocks the capillary and produces denser concrete thus making it stronger and more durable. Amorphous silica that is found in some pozzolanic materials reacts with lime more eagerly than those of crystalline form (Lin *et al*., 2003).

4.2.5 Consistency of OPC partially replaced with PSD and PSA

Table 4.7: Consistency of OPC partially replaced with PSD and PSA

Percentage Replacement (%)	PSD(%)	PSA(%)
0%	33	33
5%	33.5	37
10%	35.5	42.5
20%	38.5	48.5

From Table 4.7 the consistency of the paste partially replaced with PSD and PSA at various percentage replacement are higher than that of OPC without replacement indicating that PSD and PSA requires more quantity of water to keep the mix uniform. According to (Olutoge et.al 2012) OPC/PSA has a standard consistency of 28% which was greater than that of OPC cement paste only (26-26.5%) and stated that PSA does not have adverse effect on the consistency of the OPC cement. This also implies that PSD has no adverse effect on OPC.

4.2.6 Setting Time of OPC partially replaced with PSD and PSA

Table 4.8 reflects the changes in the setting time of OPC as it is partially replaced with either PSD or PSA.

Table 4.8 Setting time of OPC partially replaced with PSD and PSA

Percentage Replacement	PSD		PSA	
	Initial(mins)	**Final (mins)**	**Initial (mins)**	**Final (mins)**
0%	108	168	108	168
5%	238	414	162	304
10%	244	422	190	346
20%	255	439	203	362

From the table, the initial and final setting time of PSD is far higher than PSA. The high setting time of PSD could be as a result of the formation of complexes with calcium ions in solutions, increasing their solubility and discouraging the formation of nuclei of calcium hydroxide which is a known characteristic of retarders. From this discovery it shows that PSD can be used as retarder in concreting.

4.2.7 Soundness of OPC Partially Replaced with PSA and PSD

Table 4.9 shows the soundness of the OPC paste partially replaced with PSA and PSD respectively.

Table 4.9 Soundness of OPC partially replaced with PSA and PSD

Percentage Replacement (%)	**PSD (mm)**	**PSA (mm)**	Specification **BS4550 Recommended**
0	0	0	≤ 10mm
5	0	0	
10	2	1	
20	>10	1	

At 5% and 10% replacement of PSD and PSA the material satisfied the specification recommended by BS 4550 and is in agreement with (Olutoge *et al*., 2012, Umoh and Olusola, 2012, Afolayan *et al*., 2013) for pozzolanic material. At 20% replacement PSD expanded beyond 10mm which was attributed to the presences of unburnt lime CaO reacting with water slowly thus increasing the volume considerably which result in cracking, distortion and disintegration. The expansion of PSD at this replacement implies the material is not durable at percentage replacement beyond 10%.

4.3 Properties of Aggregate (Coarse and Fine Aggregate)

4.3.1 Sieve Analysis of Coarse and fine Aggregate

The sieve analysis fine and coarse aggregate which is presented in Appendix I-a and I-b respectively in chapter 3 are plotted below in Fig4.2 and Fig 4.3 respectively which are in accordance with BS 812: Part 103 (1985) for particle size distribution. The sieve analysis of the sand shows that it is in zone 2 with a fineness modulus of 3.37 passing 4.75mm sieve conforms with Umoh and Olusola, (2012); while the coarse aggregate were predominantly of maximum aggregate size of 19mm with a fineness modulus of 2.42.

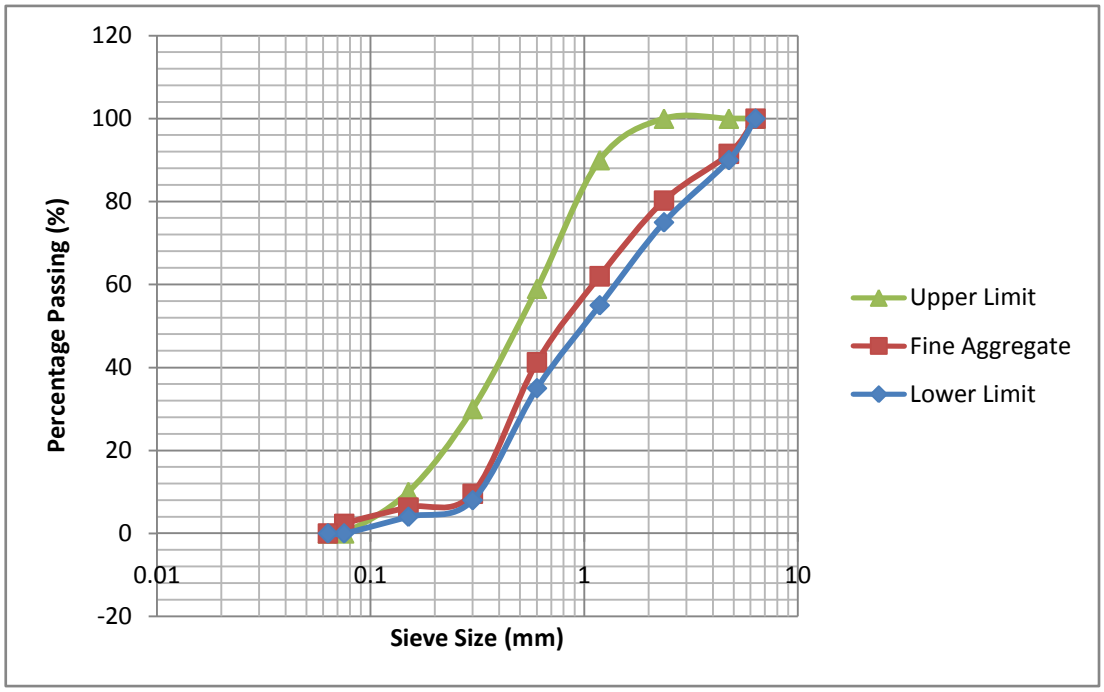


Fig 4.2 Plot of Sieve Analysis of Fine Aggregate

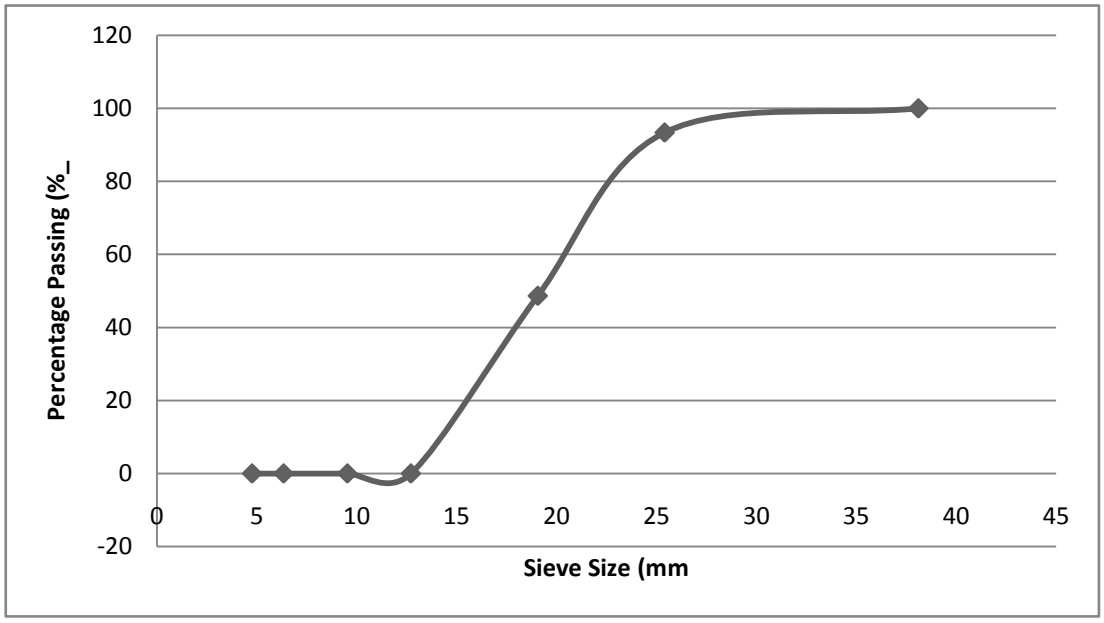


Fig 4.3 Plot of Sieve Analysis of Coarse Aggregate

Table 4.10 Summary of Coarse and Fine Aggregate

Physical Property	Coarse Aggregate	Fine Aggregate
Specific gravity	2.56	2.5
Aggregate Impact Value	21.33	-
Aggregate crushing value	19.23	-
Bulk Density	1706.7 kg/m^3	1525 kg/m^3
Fineness Modulus	2.42	3.37

4.4 Properties of Fresh Concrete Mixes

4.4.1 Workability of Concrete

The results of the workability test are presented in Table 3.7. To attain the same workability level of 10-30mm in the mixes containing PSA and PSD with that of conventional concrete (OPC), higher water content was required. This is reflected in the gradual increase in the ratio of water and cementitious material with a corresponding increase in the amount of water over control as the PSA and PSD percentage content increases.

The high water requirement in mixes containing PSA and PSD could be attributed to the high fineness of PSA and PSD which meant a greater specific surface to be wetted and lubricated. This is in agreement with the earlier finding of the effect of rice husk ash in concrete by (Zhang and Malhotra 1996) and effect of periwinkle ash in concrete (Olusola and Umoh 2012). Decreasing the water cement ratio decrease the slump which conforms with (Ghassan et.al 2011), the high water content is also attributed to the density of the materials which are less than Portland cement

It was also observed that the PSA has a higher slump value than PSD and it could be attributed to the fact that PSA is much finer than PSD conforms with (Ahmed 2002). As the grade of concrete increases the workability of the concrete also increases.

Generally workability decreases with increasing percentage replacement of cement with either PSD or PSA and increases with increase in grade of concrete.

4.5 Properties of Hardened Concrete

4.5.1 Compressive strength

The compressive strengths tabulated in Appendix III-a to III-i are plotted in Fig 4.4 – 4.7 of the concrete specimens used in the study. The results obtained showed that the compressive strength decreases as the percentage of Periwinkle Shell Ash (PSA) and Periwinkle shell dust (PSD) increases and for each of percentage replacement the compressive strength increase as the curing age increases which are an indication that the crushing strength increases with curing age which conforms with finds by Otunyo *et al*., (2013).

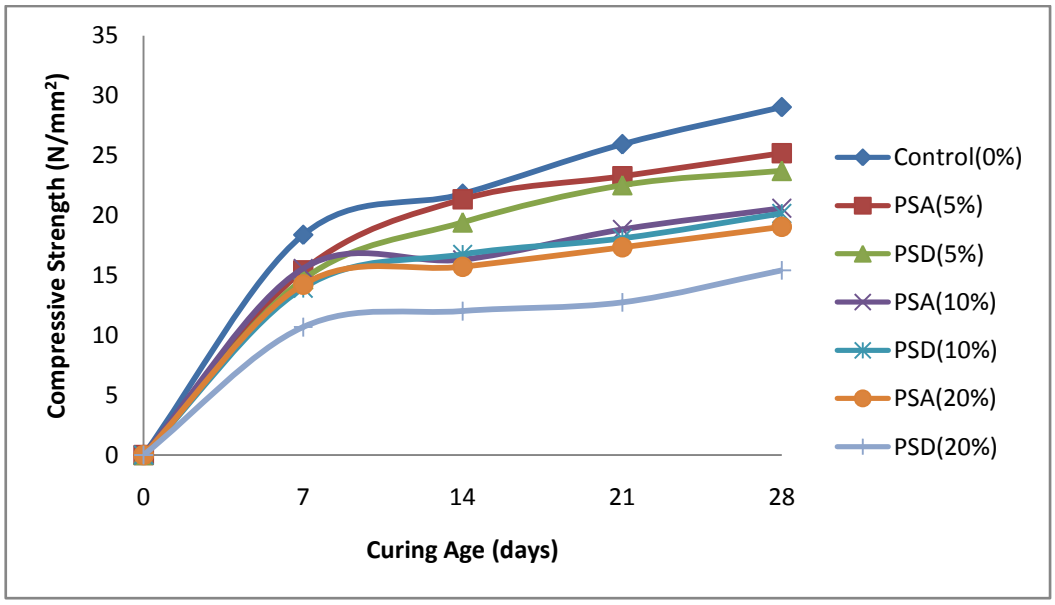


Fig 4.4 Compressive Strength of PSA and PSD Concrete Grade 20

From Fig 4.5 compares the compressive strengths of concrete containing OPC only, PSA and PSD at grade 20. The plot shows that as percentage replacement of cement increase with PSA or PSD, the strength of the concrete degreases but strength increases with curing days. At 5% replacement of cement with PSA it was observed that strength gained is 86.81% strength of the control concrete at 28days curing and is higher than 81.6% strength gain by PSD concrete.

At 10% cement replacement with PSA it was observed that there was rapid gain in strength compared to the PSD replacement at the same percentage replacement, this was attributed to the high presence of CaO which produces react with elements of hydration (C_3S) in the cement to produce CSH as presented in eqn 4.2. It is of note that C_3S is responsible for rapid strength gain in concrete (Neville 2000).

Compressive strength gain at 20% replacement for 20% PSA followed similar pattern as 5% replacement with gradual strength gain as the curing days increases. However, concrete cube at 20% cement replacement with PSD showed drop in strength which was attributed to the presences of organic Calcium which retard the setting of concrete and slow hydration (Clare and Sherwood 2007).

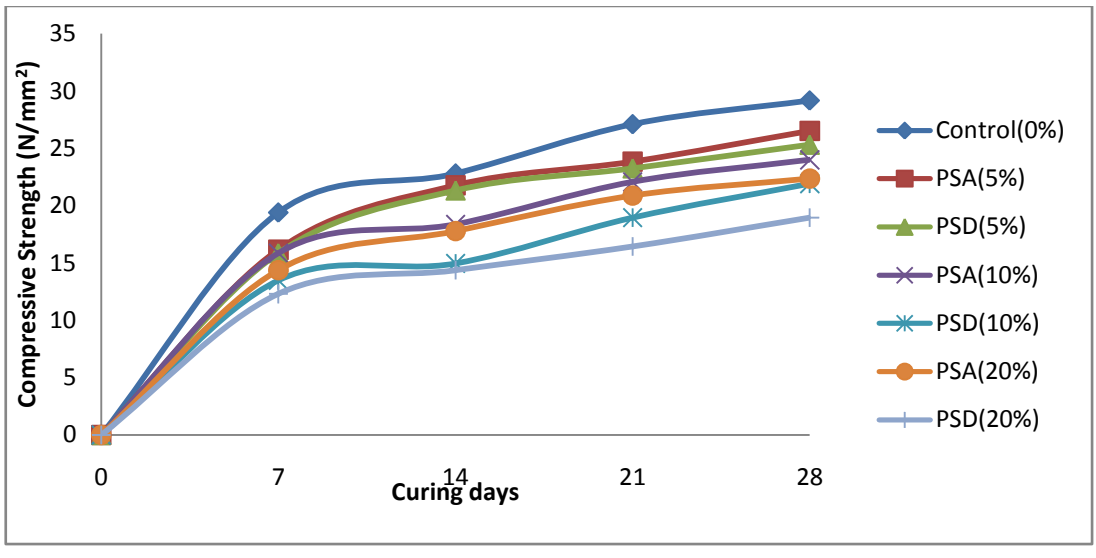


Fig 4.5 Compressive Strength of PSA and PSD Concrete grade 25

From Fig 4.5 that the control sample gained strength indicating the presences of more cement which lead to early hydration, at day 14 however, the rate of strength gain slowed as a result of the action C_2S which also contribute to strength gain but at a slower rate than C_3S. At 5% cement replacement with PSA the strength gained by the concrete is 90.75% strength of the control sample, while PSD replacement gave 86.34% of control sample. This implies that the chemical component of PSA is much more reactive than that of PSD.

Other percentage replacement has shown a repetitive trend of early strength gain for first 7days of curing and closely followed by gradual drop in strength as the curing day progress. However, each concrete cube increases in strength as the curing days increase but decrease in strength as the percentage replacement increase.

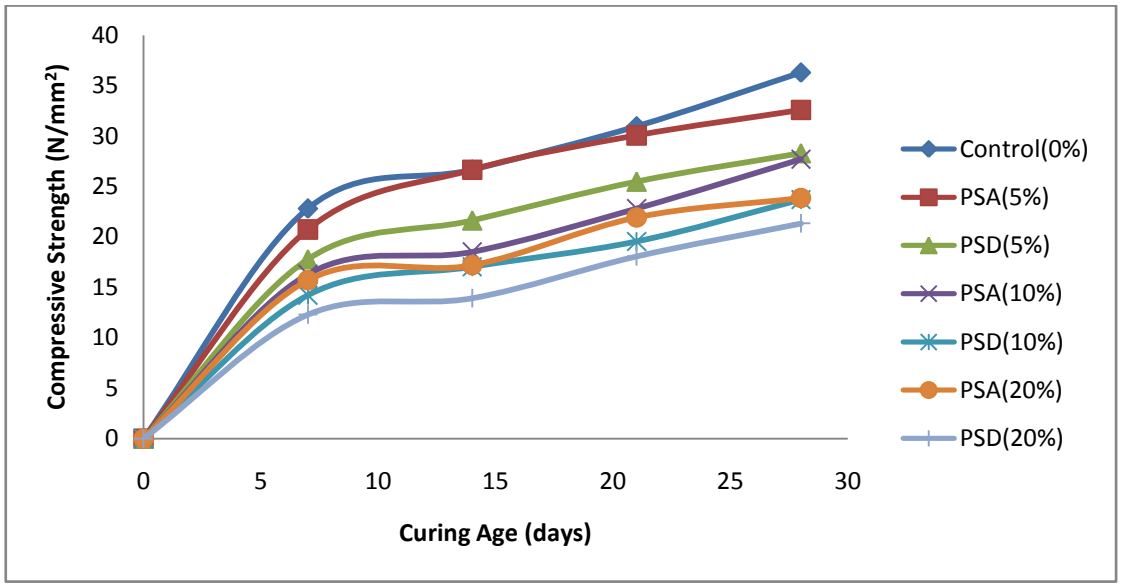


Fig 4.6 Compressive Strength of Concrete PSA and PSD Concrete grade 30

For grade 30, it was observed that Fig 4.6 followed similar trend as with Fig 4.4 and 4.5 with PSA gaining more strength than PSD when used as cement replacement in the

concrete cube. It was also observed that 20% cement replacement with PSA gave slightly higher strength value than PSD at 10%. The strength value of PSD at 10% when compared to the control sample is 65.29% of the control and therefore does not meet up with the 75% recommended by ASTM C618. Thus, making it unsuitable to replace cement with PSD greater than 5% in concrete of grade 30.

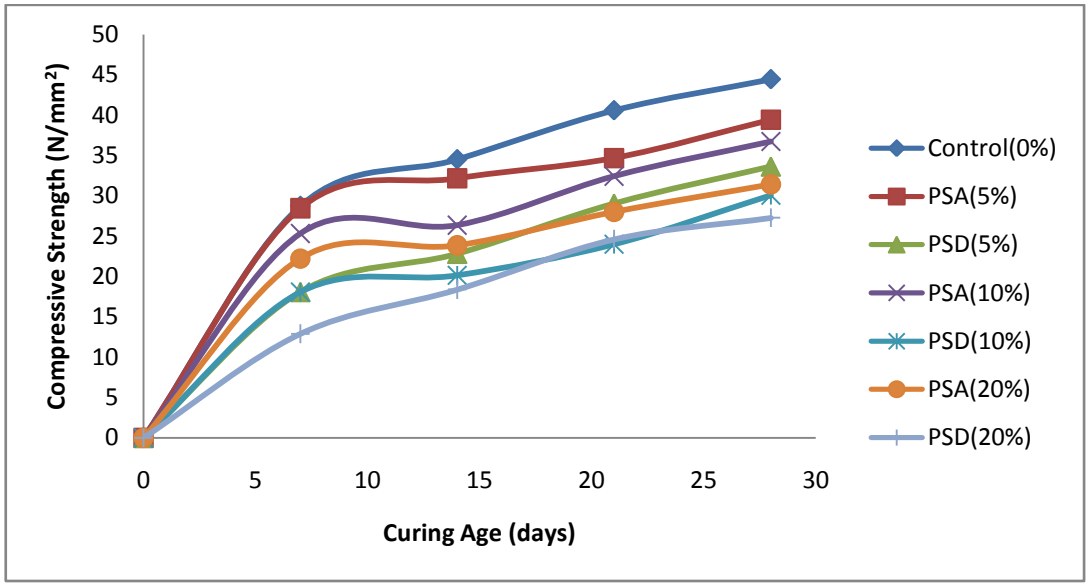


Fig 4.7 Compressive Strength of PSA and PSD Concrete grade 40

In Fig 4.7 which contains the plot of PSA, PSD and OPC concrete with curing day shows there was a reduction in strength also in grade 40 as the percentage replacement increases. In comparism with the OPC concrete, the 5% PSD replacement had strength of 33.6N/mm^2 for 28days curing which represents 75.68% of OPC strength grade 40. While 10% and 20% PSD replacement represents 67.79% and 61.49% respectively when compared with OPC concrete, thus only 5% replacement of PSD conforms with ASTM C618. Percentage replacement of cement with PSA also shows similar trend as PSD concrete with drop in strength as the percentage replacement increase.

4.6 Scanning Electron Microscopy (SEM)

The concrete cubes considered for SEM analysis were grade 25 at 0%, 5%, 10% and 20% of PSD and PSA for 28days curing period.

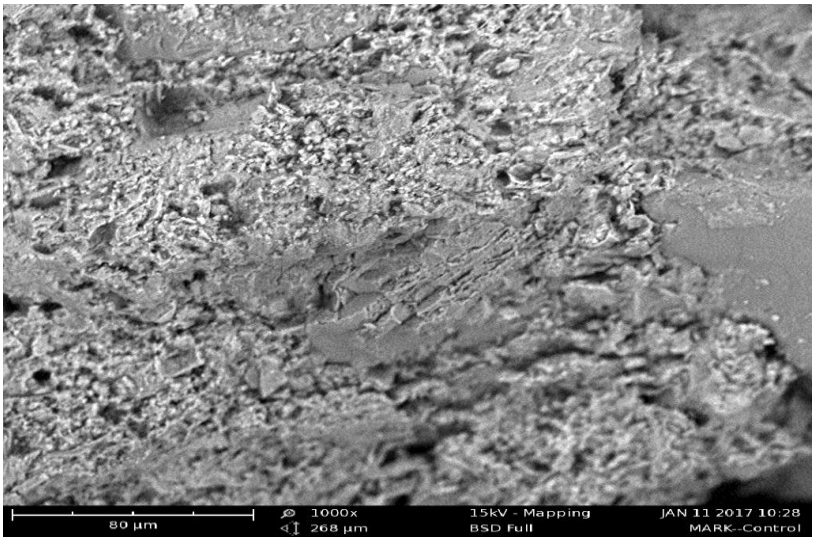


Plate IV SEM of 0%(Control)

Plate IV represents the microstructure of control sample that is 0% replacement, the concrete had undergone 28days curing in normal water. The presence of Calcium hydroxide formed by presence of lime (CaO) can be seen the white evenly distributed on the surface, thus conforming Baker and Cory (1991), that in ordinary Portland cement paste has small regions of Calcium hydroxide and are evenly distributed.

Plate V: SEM 5% PSA

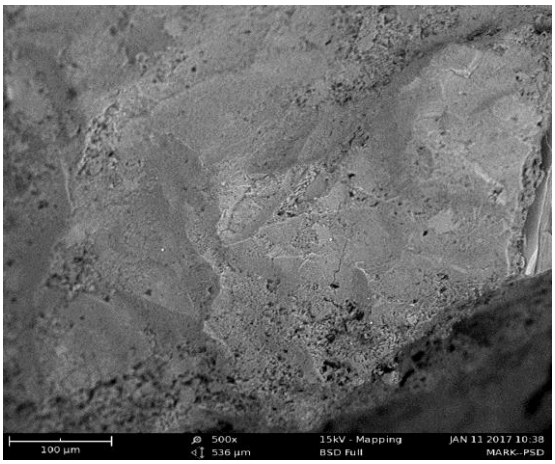
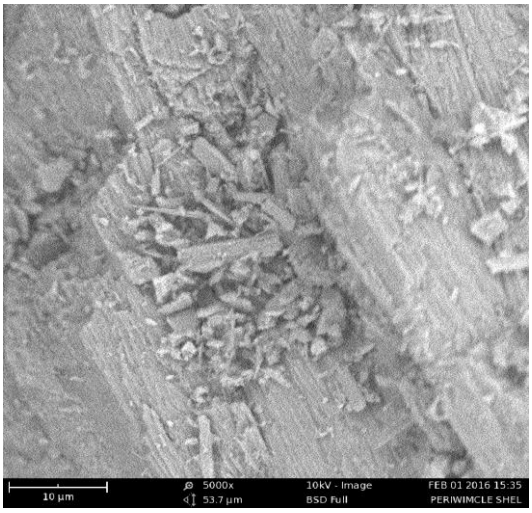


Plate VI: SEM of 5%PSD

Observing Plate V and Plate VI it can be observed that the surface of concrete containing PSD is much finer as a result of more CaO content in the PSA concrete. It was also observed both concrete containing 5% replacement PSA and PSD replacement have little effect on their pore spaces therefore allowing for cohesive reaction between the element of the concrete.



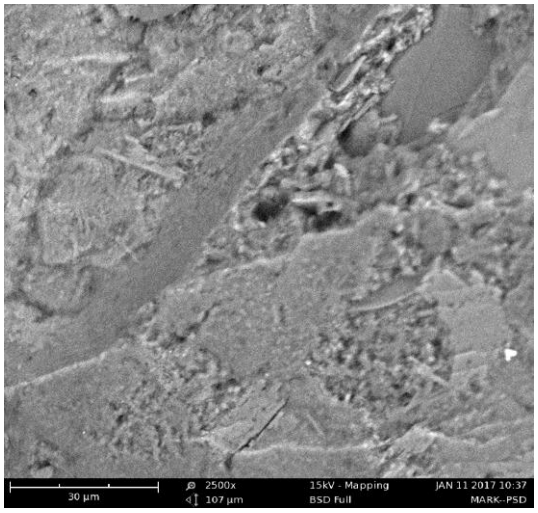


Plate VII: SEM of 10% PSA Replacement **Plate VIII: SEM of 10% PSD Replacement**

Plate VII and VIII represent PSA and PSD replacement at 10% respectively. At 10% replacement of PSD, the pore spaces of becomes greater thus causing the fractured surface to become rough which is in agreement with Faria and Holland (2000). However, the Calcium Hydroxide formed by the reaction of lime in the concrete increases in the PSA concrete and also makes the surface of the concrete to become rough.

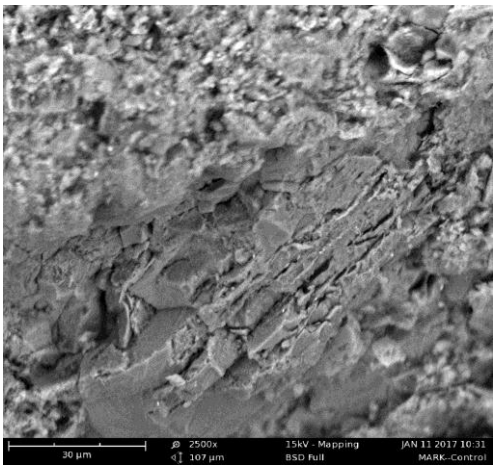


Plate IX: SEM of 20% PSA Replacement **Plate X: SEM of 20% PSD Replacement**

From the observation of the transition zone in the Plates IX and X concretes, there are large crystals of Ettringite and CH with preferred orientation and porous structure. Plate 4.6 which contains had lower porosity than Plate 4.7, but contains larger crystals of Ettringite and Calcium Hydroxide which conforms with the observation of Govindarajan and Jayalaksmi (2011). The large porosity in 20% PSD concrete is as a result of organic calcium which did not react properly with the inorganic CaO in the cement, this lead to the slow setting of the mix and subsequent disintegration of the paste when it was test for soundness.

4.7 Statistical Model for prediction of strength

Certain variables of the test were used to predict the strength of the concrete containing periwinkle shell dust (PSD) and periwinkle shell ash (PSA) after 28days only. Using ANOVA analysis and regression analysis the strength (Y) is the dependent variable, while workability (C) and percentage replacement (P) are the independent variable.

4.7.1 Regression analysis and Analysis of variance (ANOVA)

Considering grade 20 concrete with the following parameter of strength, workability and percentage replacement the following regression equations where obtained for both PSD and PSA

Y – Compressive Strength

C – Workability

P – Percentage Replacement

R – Adjusted Squared Value

$$Y(PSD20) = -3.166 + 1.104C - 0.443P; R^2 = 0.962 \quad (4.6)$$

Where PSD20 is the partial replacement of PSD at grade 20

$$Y(PSA20) = -18.271 + 1.640C - 0.197; R^2 = 0.900 \quad (4.7)$$

Where PSA20 is the partial replacement of PSA at grade 20

The PSD having a coefficient of determination (adjusted R squared) value of 0.962 which is 96.2% shows that its independent variable of workability and percentage replacement have a strong statistical relationship compare to PSA with adjusted R squared value of 0.900 which is 90.0% at 95% confidence level. For both equations the positive coefficient of the workability has greater effect on the strength than percentage replacement which has negative coefficient.

Grade 25 has the following regression equations and adjusted R squared value

$$Y(PSD25) = 5.422 + 0.815C - 0.361P; R^2 = 0.918 \quad (4.8)$$

Where PSD25 is the partial replacement of PSD at grade 25

$$Y(PSA25) = -5.485 + 1.199C - 0.139P; R^2 = 0.976 \quad (4.9)$$

Where PSA25 is the partial replacement of PSA at grade 25

From the PSA adjusted R squared values of 0.976 which is 97.6% has independent variable with stronger statistical association to the strength compared to PSD with 0.918 R^2 value at 91.8%. The coefficient of workability is positive in both Eqn 4.3 and 4.5, indicating that it has the most effect on strength compared to the negative coefficient of partial replacement.

Grade 30 also has the following regression equations and adjusted R squared value of

$$Y(PSD30) = -100.979 + 4.857C - 0.031P;\ R^2 = 0.861 \quad (4.10)$$

Where PSD30 is the partial replacement of PSD at grade 30

$$Y(PSA30) = -48.313 + 3.029C - 0.254P;\ R^2 = 0.992 \quad (4.11)$$

Where PSA30 is that partial replacement of cement at grade 30

The strongest statistical relationships exist between the independent variable and the strength when PSA is used. The adjusted R squared value is found to be 0.992 in comparism with adjusted R squared of PSD which is 0.861. Just as it was noticed in previous concrete grades the workability of the concrete has stronger effect or influence on the strength of concrete due to it positive coefficient. These, indicate that as workability increases strength increase while an increment in percentage replacement reduces strength.

Grade 40 has the following Eqns 4.2 and 4.3 and adjusted R squared values

$$Y(PSD40) = -135.062 + 6.123C - 0.672P;\ R^2 = 0.607 \quad (4.12)$$

Where PSD40 represent the partial replacement of cement with PSD at grade 40

$$Y = (PSA40) = -36.148 + 2.765C - 0.217P;\ R^2 = 0.968 \quad (4.13)$$

Where PSA40 is the partial replacement of cement with PSA at grade 40

The statistical relationship between the independent variables (workability and percentage replacement) and dependent variable strength in the Eqn 4.7 for PSD is very weak due to the low value of the adjusted R squared. The equation can be said to be less reliable to give accurate prediction of the strength when the criterias are applied.

From the equations above it can be deduced that strength is jointly proportional to workability and percentage replacement. As the grade of concrete increase it was observed that the adjusted R squared value for periwinkle shell dust (PSD) reduces and thus indicate that there is a weak relationship between the independent variable of workability(C) and percentage replacement (P) to the dependent variable strength. The best prediction is PSA at grade 30 because it has an adjusted R^2 of 0.992 which agrees with (Aggarwal *et al.*, 2015)

Also a one way analysis of variance (ANOVA) was conducted to determine the significance of percentage replacement and workability on strength. Using an α-value of 0.05 with a confidence level of 95% P-values where generated while the Fcal and Fcrit were also determined.

Table 4.11 ANOVA of PSD Concrete

Sample	Grade	Degree of freedom	F_{cal}	P-Value	F_{crit}	$F_{cal}>F_{crit}$ Remark
PSD	20	11	9.25	0.0067	4.26	Significant
	25	11	11.54	0.0033	4.26	Significant
	30	11	11.16	0.0037	4.26	Significant
	40	11	14.97	0.0014	4.26	Significant

The One-way statistical analysis of variance (ANOVA) in Table 4.11 test showed that for each grade of concrete workability and percentage replacement had significant effect on the compressive strength. The P-values of each grade was less than the α-value of 0.05 and the Fcal was greater than the Fcrit.

Table 4.12 ANOVA of PSA Concrete

Sample	Grade	Degree of freedom	F_{cal}	P-Value	F_{crit}	$F_{cal}>F_{crit}$ Remarks
PSA	20	11	11.18	0.0036	4.26	Significant
	25	11	14.53	0.0015	4.26	Significant
	30	11	15.16	0.0013	4.26	Significant
	40	11	25.31	0.0002	4.26	Significant

The one-way statistical analysis of variance (ANOVA) in Table 4.12 of the PSD concrete also indicates that workability and percentage replacement had significant effect on the compressive, the Fcal values of each grade of concrete was greater than Fcrit. The P-value at each grade was also less than the significant level α-value of 0.05.

4.7.2 Predicted Compressive Strength

These compressive strength values were generated from the regression equations and were then used to compare with the observed compressive strength to determine the degree of error. The Table 4.13 shows the 28days strengths for OPC (control), PSD and PSA.

Table 4.13 Comparing Observed Strength to Predicted Strength for PSD

Sample	Grade	Percentage Replacement	Predicted strength N/mm^2	Observed Strength N/mm^2
PSD	20	0	28.85	29.03
		5	23.32	23.70
		10	21.11	20.14
		20	15.02	15.41
	25	0	29.06	29.18
		5	24.81	25.33
		10	23.00	21.93
		20	18.58	18.96
	30	0	35.02	36.30
		5	30.01	28.30
		10	22.56	23.70
		20	19.83	21.33
	40	0	42.51	44.44
		5	33.62	33.63
		10	33.92	30.07
		20	25.33	27.26

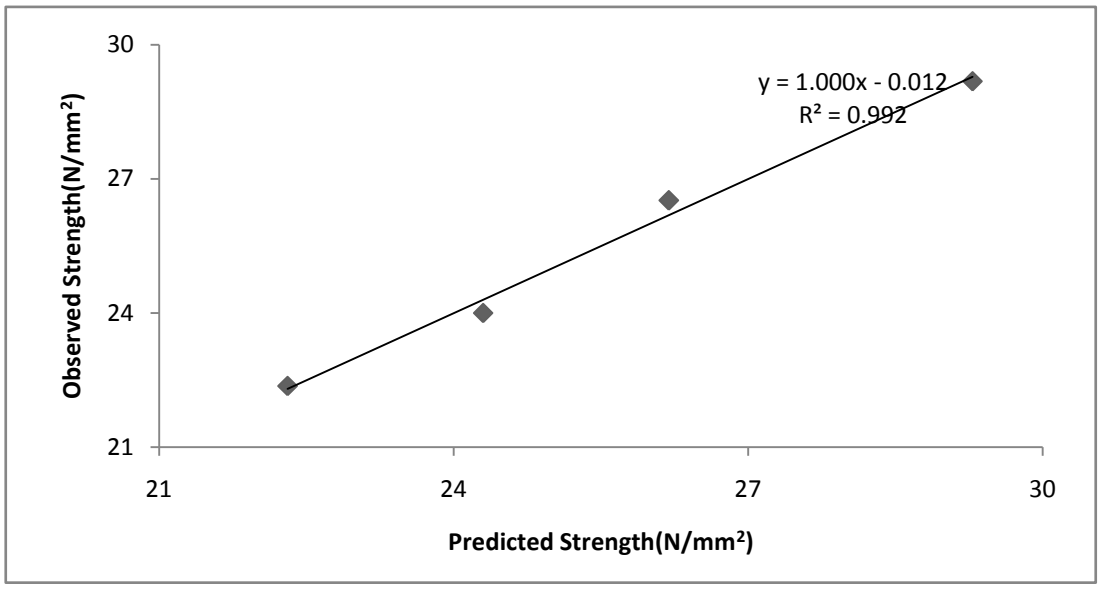


Fig 4.8 Plot of Observed Strength against Predicted Strength for Grade 20 PSD

The plot between the observed laboratory strength and predicted strength gave a regression equation with positive intercept for grade 20 PSD replacement. The correlation coefficient R^2 of 0.987 indicates strong relationship between the observed and predicted strength.

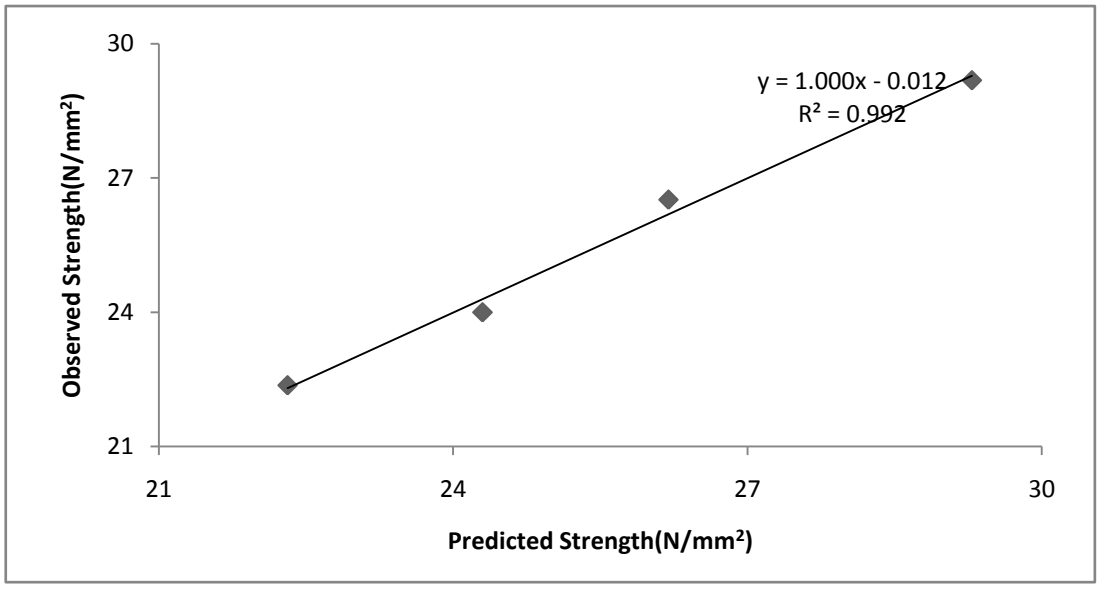


Fig 4.9 Plot of Observed Strength against Predicted Strength for Grade 25 PSD

From the Fig 4.9 above the regression equation indicate strong relationship between the two variables. It has also being observed that as the grade increases the coefficient of correlation R^2 decrease show an inverse relationship.

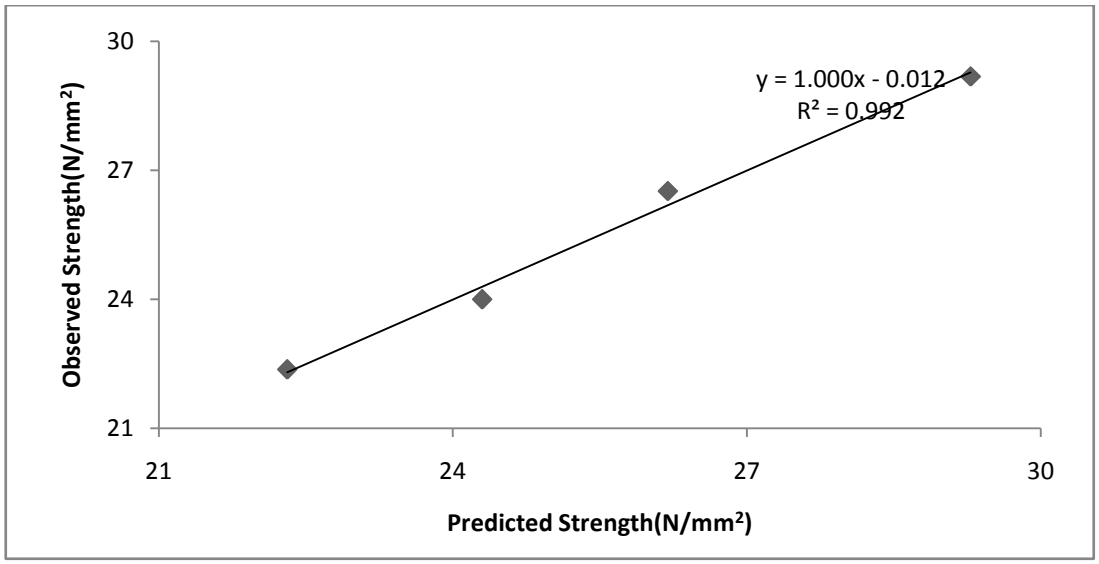


Fig 4.10 Plot of Observed Strength against Predicted Strength for Grade 30 PSD

The plot from Fig 4.10 above gave a linear regression equation with a correlation coefficient R^2 of 0.952 indicating a strong relationship between the predicted and the observed strength.

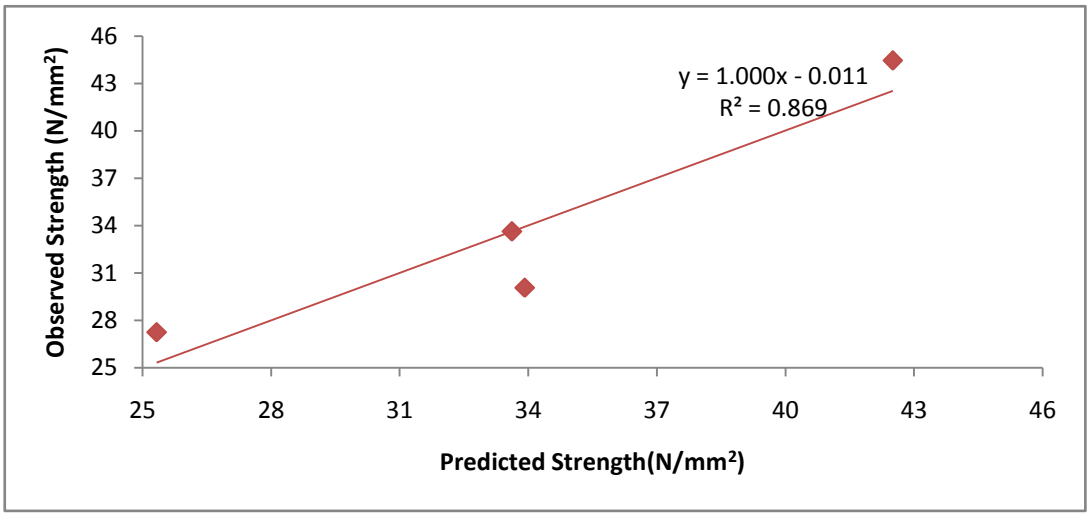


Fig 4.11 Plot of Observed Strength against Predicted Strength for Grade 40 PSD

Table 4.14 Comparing Observed Strength to Predicted Strength for PSA

Sample	Grade	Percentage Replacement	Predicted strength N/mm^2	Observed Strength N/mm^2
PSA	20	0	29.29	29.04
		5	24.20	25.19
		10	21.58	20.59
		20	18.79	19.04
	25	0	29.29	29.19
		5	26.19	26.51
		10	24.30	24.00
		20	22.31	22.37
	30	0	36.50	36.30
		5	32.20	32.59
		10	27.90	27.90
		20	23.85	23.85
	40	0	42.04	44.44
		5	40.19	39.41
		10	36.34	36.74
		20	31.40	31.41

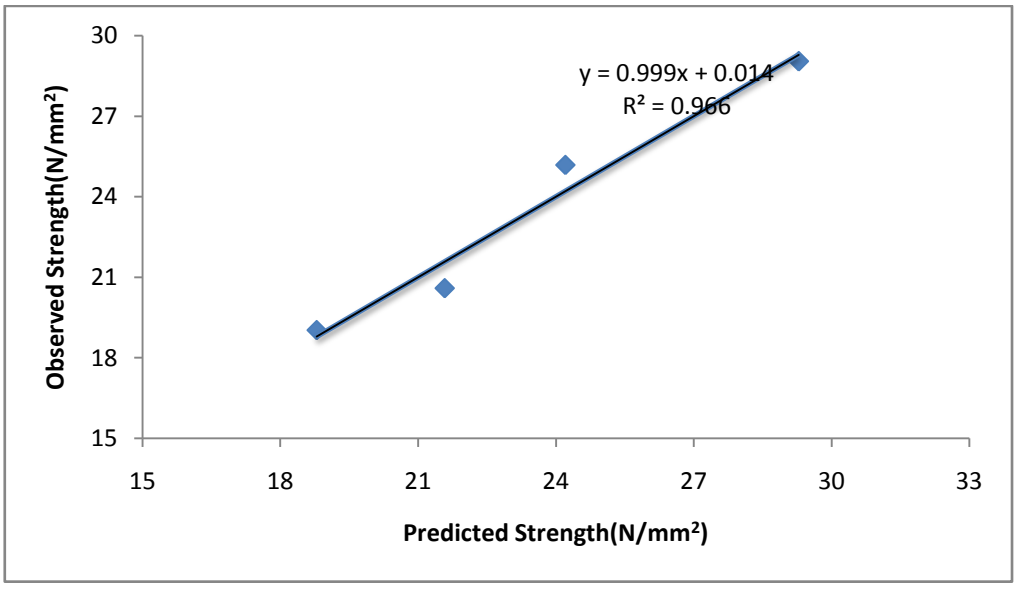


Fig 4.12 Plot of Observed Strength against Predicted Strength for Grade 20 PSA

From the Fig 4.12 grade 20 PSA observed strength versus predicted strength gave a very positive correlation coefficient of 0.966. The regression formula has a positive

coefficient of 0.999 and it indicates that strength is proportional to percentage increment.

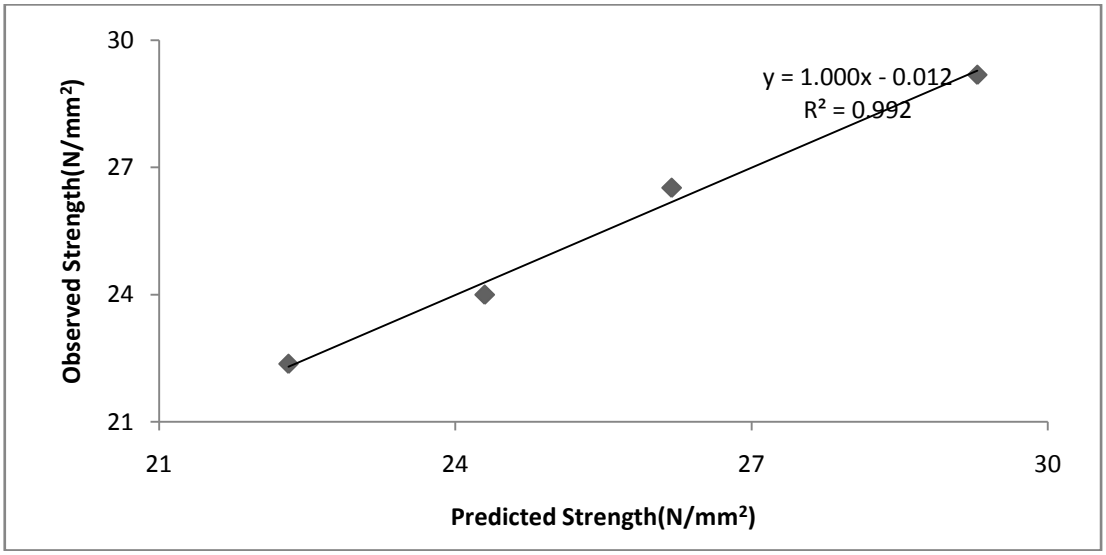


Fig 4.13 Plot of Observed Strength against Predicted Strength for Grade 25 PSA

From Fig 4.13 grade 25 PSA replacement the observed strength against the predicted strength shows the same trend as that of PSD but having a higher coefficient of regression of $R^2 = 0.992$ to PSD's 0.972.

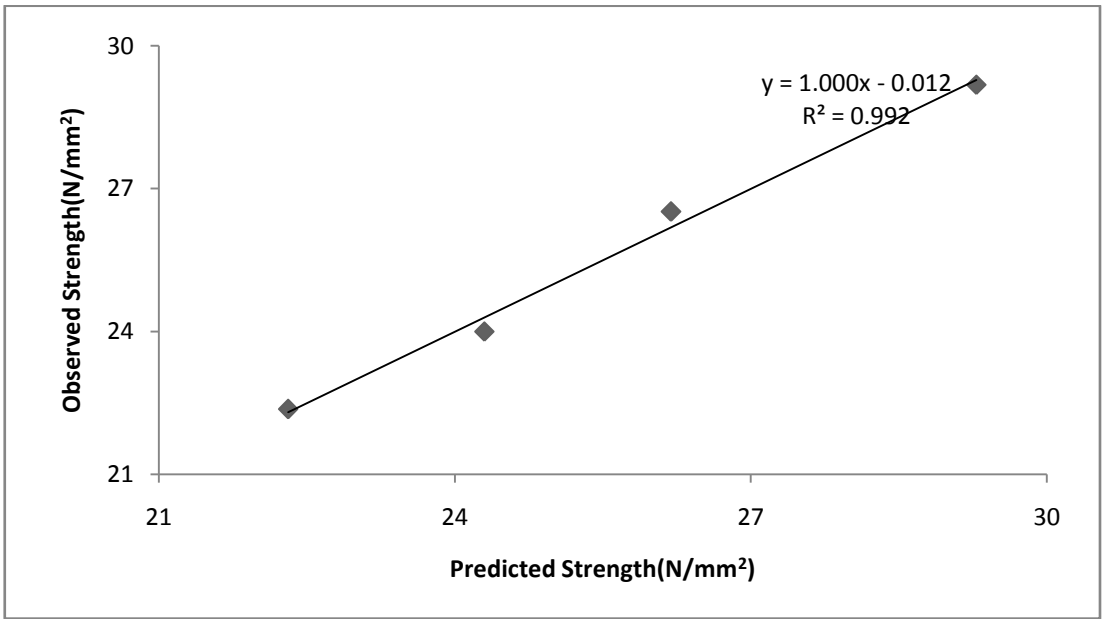


Fig 4.14 Plot of Observed Strength against Predicted Strength for Grade 30 PSA

From Fig 4.14 grade 30 PSA has a greater value of coefficient of correlation than that grade 30 PSD.

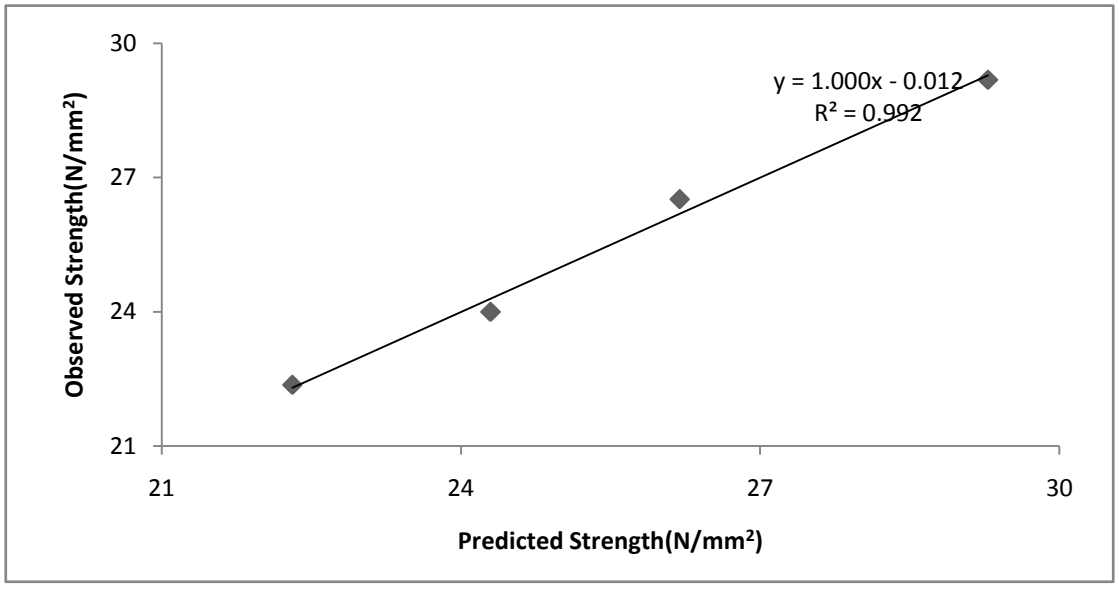


Fig 4.15 Plot of Observed Strength against Predicted Strength for Grade 40 PSA

Now comparing the graphs of the both materials periwinkle shell ash and periwinkle shell dust it is observed that as the grade increases in periwinkle shell dust (PSD) the coefficient of correlation that is R^2 value reduces while the coefficient of correlation increases with increase in the grade of concrete for PSA. The reduction in the R^2 value for PSD could be attributed to it the low presences of Silica and Alumina oxide which is the main compound responsible for pozzolanic activity. From the characterization test conducted it also found that PSA is finer than PSD thus making it more reactive than PSD and hence having a better binding effect as indicated by the matrices of their microstructure.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

Replacing cement either partially of fully with waste such as (PSD and PSD) in concrete production has gained considerable importance because of the requirement of environment and for sustainable construction in the near future.

Based on the research conducted, the following conclusion and recommendation can be drawn.

5.1 Conclusion

i. PSA which has a combined (SiO_2, Al_2O_3 and FeO_3) of 70% with loss of ignition (LOI) value of 2 is classified as class F pozzolana while PSD with a combined (SiO_2, Al_2O_3 and FeO_3) of 70.47% is considered a class N pozzolana. Based on their physical properites PSD with a specific gravity of 2.21 is lighter than PSA which has specific gravity of 2.46 and they are both lighter than OPC with a specific gravity of 3.15. At a 20%PSD replacement was unsound due to high presence of unburnt lime (CaO)

ii. Increasing replacement leads to increase in slump value and decrease in strength in both PSD and PSA concrete. The optimum strength of PSA and PSD concrete for all grades was 10% replacement based on the 75% strength of control sample recommended by ASTM C618.

iii. The SEM analysis indicates that pore space in concrete increases with increasing replacement in both PSD and PSA concrete, thus increasing the permeability of the concrete and reduces strength. The high presences of lime in PSA lead to uneven distribution of calcium hydroxide at 20% replacement.

iv. Strong relationship exit between percentage replacement, workability and strength in predicting the compressive strength of concrete. The relationship becomes stronger at higher grades for PSA concrete with grade 30 giving the best relationship with R^2 value of 0.999.

5.2 Recommendation

i. Based on the result it is recommended that in concrete production, PSD and PSA can be used to replace OPC up to5% and 10% respectively.

ii. Based on the research the presence of organic element in the Periwinkle shell dust result in increase in the setting time of the concrete which could serve as a retarding agent.

iii. Alkality test should be carried out in the future to determine the pH of both materials

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APPENDICES

APPENDIX I: Preliminary Test carried on Constituent Material

I-a: Sieve analysis for coarse aggregate

SIEVE SIZE	WEIGHT RETAINED	%RETAINED	Cumulative percentage retained	% PASSING
38.1	**0**	**0**	**0**	**100**
25.4	**0.2**	**6.67**	**6.67**	**93.38**
19.05	**1.34**	**44.67**	**51.34**	**48.66**
12.70	**1.46**	**48.67**	**100**	**0**
9.52	-	-		-
6.33	-	-		-
PAN	-	-		-

Fineness Modulus = 100+ 93.38 + 48.66 = 242.04/100 = 2.42

I-b: Sieve Analysis Of Fine Aggregate

SIEVE SIZE	WEIGHT RETAINED(g)	% RETAINED	Cumulative Percentage Retained	% PASSING
4.75	54	4.5	4.5	95.5
2.36	52.5	4.38	8.88	91.12
1.18	165.5	13.75	22.63	77.37
0.6	354	29.5	52.13	47.87
0.3	352	29.33	81.46	18.54
0.15	147.5	12.29	93.75	6.25
0.075	47.5	3.96	97.71	2.29
PAN	27.5	2.29	100	0

Fineness Modulus = 95.5 +91.12 +77.37 +47.87 +18.54 +6.25 = 336.65/100 = 3.37

I-c: Specific gravity of Coarse Aggregate

	Sample 1	**Sample 2**	**Sample 3**
Weight of Jar + Water (P)	2.15	2.15	2.15
Weight of sample only (B)	1.0	1.0	1.0
Weight of Jar + Water + Sample (P_s)	2.8	2.78	2.78
Specific gravity	2.86	2.70	2.70

Specific Gravity

$$G = \frac{B}{P + B - Ps} = 2.43$$

I-d: Specific gravity of Fine Aggregate

	Sample 1	**Sample 2**	**Sample 2**
Weight of Jar + Water (P)	1.28	1.26	1.28
Weight of sample only (B)	0.5	0.5	0.5
Weight of Jar + Water + Sample (P_s)	1.58	1.54	1.58
Specific Gravity	2.5	2.3	2.5

Specific Gravity

$$G = \frac{B}{P + B - Ps} = 2.43$$

I-e: AIV for Coarse Aggregate

Sample	**A(g)**	**B(g)**	**C(g)**
Weight of initial sample P	500	500	500
Weight of remaining sample after 25blows V	145	160	168
Weight of sample through sieve size 2.36mm after crushing S	75	72	72
Aggregate impact value= S/(A – B) x 100%	21.13	21.18	21.69
Average AIV	21.33		

I-f: ACV for Coarse Aggregate

Sample	**A(kg)**	**B(kg)**	**C(kg)**
Weight of initial sample P	5	5	5
Weight of remaining sample after 25blows V	1.2	1.15	1.18
Weight of sample through sieve size 2.36mm after crushing S	0.75	0.72	0.74
Aggregate crushing value= $\frac{S}{(A-B)}$ x 100%	19.74	18.57	19.37
Average ACV	19.23		

I-g: Bulk density of Coarse Aggregate

Sample	**A**	**B**	**C**
Weight of cylinder W_1	1.4	1.4	1.4
Weight of cylinder + sample W_2	16.9	19.5	18
Weight of Sample M = $W_2 - W_1$(kg)	15.5	18.1	16.6
Volume of Cylinder V (m^3)	0.01	0.01	0.01
Bulk Density = M/V (kg/m^3)	1550	1810	1660
Average Bulk density	1706.7		

I-h: Bulk density of Fine Aggregate

Sample	A	B	C
Weight of empty cylinder W_1(kg)	1.4	1.4	1.4
Weight cylinder filled with water W_2(kg)	4.1	4.1	4.1
Weight of cylinder + sample W_3(kg)	5.46	5.57	5.52
Weight of water S= (W_2 – W_1)kg	2.7	2.7	2.7
Density of water r= kgm^{-3}	1000	1000	1000
Volume of water V = S/r(m^3)	0.0027	0.0027	0.0027
Weight of sample M = W_3 – W_1(kg)	4.06	4.17	4.12
Bulk Density = M/V(kg/m^3)	1504	1544	1526
Average Bulk Density	1525		

I-i: Specific gravity of Cement

Sample	A	B
Weight of specific gravity bottle, W_1(g)	28.5	28.5
Weight of specific gravity bottle + dry sample W_2(g)	53.8	55.4
Weight of specific gravity bottle + cement sample + Kerosene W_3(g)	86.06	87.6
Weight of specific gravity bottle + Kerosene W_4(g)	69.2	68.93
Weight of cement sample only A(g) = W_2 – W_1	25.3	26.9
Weight of kerosene used B(g) = W_3 – W_2	32.26	32.3
Weight of kerosene only C(g) = W_4 – W_1	40.7	40.43
Specific gravity of cement sample = A/ (C – B)	2.99	3.31
Average specific gravity	3.15	

I-j: Consistency of Cement Paste

Sample	Water content%	Needle penetration (mm)	Water-Cement Ratio
Cement (A)	32	5	0.32
Cemment (B)	30	7	0.30
Cement(C)	33	5	0.33
Average	31.6	5.4	0.32

I-k: Initial Setting Time of Cement

Sample	Time started	Time finished	Initial setting time (mins)
Cement (A)	10:07am	11:56am	109
Cement (B)	10:08am	11:56am	108
Cement (C)	10:09am	11:57am	108
Average	10:08am	11:56am	108

I-l:Final Setting time of cement paste

Sample	Time started	Time finished	Final setting time (mins)
Cement (A)	11:56am	12:56pm	169
Cement (B)	11:56am	12:56pm	168
Cement (C)	11:57am	12:57pm	168
Average	11:56am	12:56pm	168

I-m: Soundness of cement

Sample	Initial Measurement (mm)	Final Measurement (mm)	Expansion (mm)
Cement (A)	5	5	0
Cement (B)	5	6	1
Cement (C)	5	5	0

I-n: Sieve Analysis of PSD

Sieve size	Weight Retained		Cumulative percentage of material retained	Percentage passing
	(kg)	(%)		
0.6	0.77	2.59	2.59	97.41
0.425	0.52	1.73	4.32	95.68
0.300	13.81	46.03	50.35	49.65
0.212	7.09	23.63	73.98	26.02
0.150	3.59	11.97	85.95	14.05
0.075	2.57	8.55	94.5	5.50
Pan	1.65	5.5	100	0
Total	3000			

Fineness modulus = 97.41 +95.68 +49.65 +26.02 +14.05 = 282.81/100 = 2.82

I-o: Consistency of OPC partially replaced with PSD

Percentage Replacement of OPC with PSD	5% PSD	10% PSD	20% PSD
OPC(g)	380	360	320
PSD	20	40	80
Water	134	142	154
Consistency (%)	33.5	35.5	38.5

I-p: Setting time of OPC replaced with PSD

Sample	Time started	Time finished	Initial setting time (mins)
PSD (5%)	10:10am	14:08pm	238
PSD(10%)	9:00am	13:04pm	244
PSD(20%)	8:43am	12:58pm	255

I-q: Final setting time of OPC replaced with PSD

Sample	Time started	Time finished	Final setting time
PSD (5%)	14:08pm	17:04pm	414mins
PSD(10%)	13:04am	16:02pm	422mins
PSD(20%)	12:58am	16:02pm	439mins

I-r: Soundness of OPC Partially Replaced with PSD

Sample	Initial Measurement (mm)	Final Measurement (mm)	Expansion (mm)
PSD 5%	5	5	0
PSD 10%	5	7	2
PSD 20%	5	8	3

I-s: Sieve Analysis of PSA

Sieve size	Weight Retained		Cumulative percentage of material retained	Percentage passing
	(kg)	(%)		
0.6	0.0	0.0	0.0	100
0.425	6.01	17.71	17.71	82.29
0.300	14.78	42.24	59.95	40.05
0.212	5.53	15.79	75.74	24.26
0.150	3.02	8.62	84.36	15.64
0.075	3.47	9.90	94.26	5.74
Pan	2.18	5.74	100	0
Total	35			

Fineness modulus = 100 +82.29 + 40.05 + 24.26 + 15.64 = 262.24/100 = 2.62

I-t: Consistency of OPC replaced with PSA

Sample	5% PSA	10% PSA	20% PSA
OPC(g)	380	360	320
PSA	20	40	80
Water	148	170	194
Consistency (%)	37	42.5	48.5

I-u: Initial Setting time of OPC replaced with PSA

Sample	Time started	Time finished	Initial setting time (mins)
PSA (5%)	9:26am	12:08pm	162
PSA (10%)	9:24am	12:34pm	190
PSA (20%)	9:00am	12:23pm	203

I-v: Final Setting time of OPC replaced with PSA

Sample	Time started	Time finished	Final setting time (mins)
PSA (5%)	12:08pm	14:30pm	304
PSA (10%)	12:34am	15:10pm	346
PSA (20%)	12:23am	15:02pm	362

I-w: Soundness of OPC Partially Replaced with PSA

Sample	Initial Measurement (mm)	Final Measurement (mm)	Expansion
PSA 5%	5	5	0
PSA 10%	5	6	1
PSA 20%	5	8	3

APPENDIX II: MIX DESIGN

II-a: Mix Design for grade 20 concrete

$f_{Cu} = 20N/mm^2$

W/C = 0.69 – non air entrained

Slump = 25 – 50mm

Coarse aggregate size = 19mm

$f'_{cu} = 20 + 8.5 = 28.5N/mm^2$

from table to obtain actual w/c ratio by interpolating

$$\frac{28.5 - 25}{28.5 - 30} = \frac{x - 0.61}{x - 0.54}$$

x = 0.56 therefore w/c =0.56

water content from table 9.5

water content = 190kg for air content of 5 – 8%

Therefore cement content = $\frac{190}{0.56}$ = 339.3kg

Using fineness modulus of 2.8 and bulk density of $1707kg/m^3$ from table

Bulk volume of coarse agg = 0.62

Therefore coarse agg = 0.62 x 1707 = $1058.34kg/m^3$

To determine volume of each ingredient

$$\text{Water} = \frac{190}{1 \times 1000} = 0.190m^3$$

$$\text{Cement content} = \frac{339.3}{3.15 \times 1000} = 0.108$$

$$\text{Coarse aggregate} = \frac{1058.34}{2.79 \times 1000} = 0.379$$

For $1m^3$ of concrete the fine aggregate required is

Therefore fine aggregate = 1 – (0.108 + 0.379 +0.190 +0.08) = 0.243

Cement = 0.108, Fine Aggregate = 0.243 and Coarse Aggregate = 0.379 water = 0.190

Weight of fine aggregate = 0.243 x 1000 x 2.55 = 619.65 kg

Summary of mix:

Water kg/m^3	**Cement kg/m^3**	**Coarse aggregate kg/m^3**	**Fine Aggregate kg/m^3**
190	339.29	1058.34	619.65
0.56	1	3.12	1.82

II-b:Mix Design for grade 25 concrete

f_{Cu} = 25N/mm^2

Slump = 25 – 50mm

Coarse aggregate size = 19mm

f'_{cu}= 25 +8.5 = 33.5N/mm^2

from table to obtain actual w/c ratio by interpolating

$\frac{33.5 - 30}{33.5 - 30} = \frac{x - 0.54}{x - 0.47}$

x = 0.49

therefore w/c =0.49

water content from table 9.5

Therefore cement content = $\frac{190}{0.49}$ = 387.76kg

Using fineness modulus of 2.8 and bulk density of 1707kg/m^3 from table

Bulk volume of coarse agg = 0.62

Therefore coarse agg = 0.62 x 1707 = 1058.34kg/m^3

To determine volume of each ingredient

Water = $\frac{190}{1 \times 1000}$ = 0.19m^3

Cement content = $\frac{387.76}{3.15 \times 1000}$ = 0.123

Coarse aggregate = $\frac{1058.34}{2.79 \times 1000}$ = 0.379

For 1m^3 of concrete the fine aggregate required is

Therefore fine aggregate = 1 – (0.123 + 0.379 +0.19 +0.08) = 0.228

Cement = 0.123, Fine Aggregate = 0.228, Coarse Aggregate = 0.379 and water = 0.19

Weight of fine aggregate = 0.228 x 1000 x 2.55 = 581.4 kg/m^3

Summary of mix:

Water kg/m^3	**Cement kg/m^3**	**Coarse aggregate kg/m^3**	**Fine Aggregate kg/m^3**
190	387.76	1058.34	581.4
0.49	1	2.73	1.5

II-c Mix Design for grade 30 concrete

f_{Cu} = 30N/mm^2

Slump = 25 – 50mm

Coarse aggregate size = 19mm

f'_{cu}= 30 +8.5 = 38.5N/mm^2

from table to obtain actual w/c ratio by interpolating

$\frac{38.5 - 25}{38.5 - 30} = \frac{x - 0.47}{x - 0.42}$

x = 0.44 therefore w/c =0.44

water content from table 9.5

Therefore cement content = $\frac{190}{0.44}$ = 431.8kg

Using fineness modulus of 2.8 and bulk density of 1707kg/m^3 from table

Bulk volume of coarse agg = 0.62

Therefore coarse agg = 0.62 x 1707 = 1058.34kg/m^3

To determine volume of each ingredient

Water = $\frac{190}{1 \times 1000}$ = 0.19m^3

Cement content = $\frac{431.82}{3.15 \times 1000}$ = 0.137

Coarse aggregate = $\frac{1058.34}{}$ = 0.379

2.79 x 1000

For $1m^3$ of concrete the fine aggregate required is

Therefore fine aggregate = 1 – (0.137 + 0.379 +0.19 +0.08) = 0.214

Cement = 0.137, Fine Aggregate = 0.214, Coarse Aggregate = 0.379 and water = 0.190

Weight of fine aggregate = 0.214 x 1000 x 2.55 = 545.7 kg/m^3

Summary of mix:

Water kg/m^3	**Cement kg/m^3**	**Coarse aggregate kg/m^3**	**Fine Aggregate kg/m^3**
190	431.82	1058.34	545.7
0.44	1	2.45	1.3

Mix Design for grade 40 concrete

$f_{Cu} = 40N/mm^2$

Slump = 25 – 50mm

Coarse aggregate size = 19mm

$f'_{cu} = 40 + 8.5 = 48.5N/mm^2$

from table to obtain actual w/c ratio by interpolating

$$\frac{48.5 - 40}{48.5 - 50} = \frac{x - 0.42}{x - 0.35}$$

x = 0.36 therefore w/c =0.36

water content from table 9.5

water content = 190kg for air content of 5 – 8%

Therefore cement content = $\frac{190}{0.36} = 527.78kg/m^3$

Using fineness modulus of 2.8 and bulk density of $1707kg/m^3$ from table

Bulk volume of coarse agg = 0.62

Therefore coarse agg = 0.62 x 1707 = $1058.34kg/m^3$

To determine volume of each ingredient

Water = $\frac{190}{1 \times 1000} = 0.190 m^3$

Cement content = $\frac{527.78}{3.15 \times 1000} = 0.168$

Coarse aggregate = $\frac{1058.34}{2.79 \times 1000} = 0.379$

For $1m^3$ of concrete the fine aggregate required is

Therefore fine aggregate = 1 – (0.168 + 0.379 +0.190 +0.08) = 0.183

Cement = 0.168, Fine Aggregate = 0.183, Coarse Aggregate = 0.379 and water = 0.190

Weight of fine aggregate = 0.183 x 1000 x 2.55 = 466.65 kg

Summary of mix:

Water kg/m^3	**Cement kg/m^3**	**Coarse aggregate kg/m^3**	**Fine Aggregate kg/m^3**
190	527.78	1058.34	466.65
0.36	1	2.01	0.88

APPENDIX III: Compressive Strength of Cubes (150x150x150)

III-a Compressive Strength of Control Sample

Grade	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
20	7	C7,1	7.52	430	19.11	18.37
		C7,2	7.5	400	17.78	
		410	7.52	410	18.22	
	14	C14,1	7.64	500	22.22	21.77
		C14,2	7.58	480	21.33	
		C14,3	7.60	490	21.78	
	21	C21,1	8.05	600	26.67	25.93
		C21,2	7.88	570	25.33	
		C21,3	7.92	580	25.78	
	28	C28,1	8.25	650	28.89	29.04
		C28,2	8.28	670	29.78	
		C28,3	8.16	640	28.44	
25	7	B7,1	7.72	460	20.44	19.41
		B7,2	7.72	450	20	
		B7,3	7.48	400	17.78	
	14	B14,1	7.88	520	23.11	22.81
		B14,2	7.82	520	23.11	
		B14,3	7.80	500	22.22	
	21	B21,1	7.92	580	25.77	27.11
		B21,2	8.20	640	28.44	
		B12,3	8.00	610	27.11	
	28	B28,1	8.50	680	30.22	29.19
		B28,2	8.26	640	28.44	
		B28,3	8.28	650	28.89	
30	7	D7,1	7.68	480	21.33	22.81
		D7,2	7.75	520	23.11	
		D7,3	7.84	540	24	
	14	D14,1	7.9	580	25.78	26.67
		D14,2	8.05	620	27.56	
		D14,3	8.00	600	26.67	
	21	D21,1	8.50	690	30.67	30.96
		D21,2	8.42	680	32.22	
		D21,3	8.58	720	32.00	
	28	D28,1	8.64	780	34.67	36.30
		D28,2	8.9	850	37.78	
		D28,3	8.74	820	36.44	
40	7	E7,1	8.4	640	28.44	28.74
		E7,2	8.46	680	30.22	
		E7,3	8.15	620	27.56	
	14	E14,1	9.20	800	35.56	34.52
		E14,2	8.62	750	33.33	

		E14,3	8.90	780	34.67	
	21	E21,1	9.68	940	41.78	40.59
		E21,2	9.75	880	39.11	
		E21,3	9.90	920	40.89	
	28	E28,1	10.00	1000	44.44	44.44
		E28,2	10.2	1020	45.33	
		E28,3	10.05	980	43.56	

III-b: Compressive Test on PSD Samples (Grade 20)

Percentage replacement (%)	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
5	7	P7,1	7.52	320	14.22	14.67
		P7,2	7.42	350	15.55	
		P7,3	7.32	320	14.22	
	14	P14,1	7.5	450	20.00	19.40
		P14,2	7.32	420	18.67	
		P14,3	7.42	440	19.55	
	21	P21,1	7.80	490	21.78	22.52
		P21,2	7.86	500	22.22	
		P21,3	7.88	530	23.56	
	28	P28,1	7.88	520	24.44	23.70
		P28,2	7.80	520	23.11	
		P28,3	7.90	530	23.56	
10	7	A7,1	7.3	300	13.33	13.93
		A7,2	7.35	340	15.11	
		A7,3	7.28	300	13.33	
	14	A14,1	7.46	360	16.0	16.74
		A14,2	7.42	380	16.89	
		A14,3	7.46	390	17.33	
	21	A21,1	7.48	400	17.78	18.07
		A21,2	7.55	420	18.67	
		A21,3	7.50	400	17.78	
	28	A28,1	7.82	480	21.33	20.15
		A28,2	7.76	460	20.44	
		A28,3	7.56	420	18.67	
20	7	K7,1	7.20	240	10.67	10.67
		K7,2	7.26	250	11.11	
		K7,3	7.24	230	10.22	
	14	K14,1	7.28	260	11.56	12.0
		K14,2	7.30	280	12.44	
		K14,3	7.30	270	12.0	
	21	K21,1	7.32	290	12.89	12.74
		K21,2	7.28	290	12.88	
		K21,3	7.30	280	12.44	
	28	K28,1	7.34	320	14.22	15.74
		K28,2	7.35	340	15.11	
		K28,3	7.46	380	16.88	

III-c: Compressive Test of PSD(Grade 25)

Percentage replacement (%)	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
5	7	X7,1	7.42	370	16.44	
		X7,2	7.4	350	15.56	15.85
		X7,3	7.38	350	15.56	
	14	X14,1	7.48	450	20.89	
		X14,2	7.42	420	21.33	21.33
		X14,3	7.5	440	21.78	
	21	X21,1	7.62	490	22.22	
		X21,2	7.65	500	24	23.26
		X21,3	7.7	530	23.56	
	28	X28,1	7.84	520	24.89	
		X28,2	7.88	520	24.89	
		X28,3	7.92	530	26.22	25.33
10	7	T7,1	7.28	300	13.33	
		T7,2	7.32	300	13.33	13.48
		T7,3	7.32	310	13.78	
	14	T14,1	7.38	350	15.56	
		T14,2	7.34	320	14.22	14.96
		T14,3	7.38	340	15.11	
	21	T21,1	7.45	400	17.78	
		T21,2	7.46	430	19.11	18.96
		T21,3	7.5	450	20	
	28	T28,1	7.6	500	22.22	
		T28,2	7.64	500	22.22	
		T28,3	7.6	480	21.33	21.93
20	7	M7,1	7.28	280	12.44	
		M7,2	7.26	260	11.56	12.30
		M7,3	7.3	290	12.89	
	14	M14,1	7.3	310	13.78	
		M14,2	7.34	320	14.22	14.37
		M14,3	7.35	340	15.11	
	21	M21,1	7.48	390	17.33	
		M21,2	7.42	340	15.11111111	16.44
		M21,3	7.46	380	16.88888889	
	28	M28,1	7.48	400	17.77777778	
		M28,2	7.56	460	20.44444444	
		M28,3	7.48	420	18.66666667	18.96

III-d: Compressive Test of PSD(Grade 30)

Percentage replacement (%)	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
5	7	L7,1	7.36	400	17.78	
		L7,2	7.32	380	16.89	17.78
		L7,3	7.54	420	18.67	
	14	L14,1	7.58	450	20	
		L14,2	7.62	500	22.22	21.63
		L14,3	7.6	510	22.67	
	21	L21,1	7.92	580	25.78	
		L21,2	7.85	560	24.89	25.49
		L21,3	7.9	580	25.78	
	28	L28,1	8.3	650	28.89	
		L28,2	8.25	640	28.44	
		L28,3	8.12	620	27.56	28.30
10	7	Q7,1	7.28	300	13.33	
		Q7,2	7.32	340	15.11	14.22
		Q7,3	7.3	320	14.22	
	14	Q14,1	7.42	420	18.67	
		Q14,2	7.35	360	16	17.04
		Q14,3	7.34	370	16.44	
	21	Q21,1	7.35	380	16.89	
		Q21,2	7.58	460	20.44	19.56
		Q21,3	7.58	480	21.33	
	28	Q28,1	7.7	520	23.11	
		Q28,2	7.72	540	24	
		Q28,3	7.68	540	24	23.70
20	7	W7,1	7.28	270	12	
		W7,2	7.25	280	12.44	12.30
		W7,3	7.28	280	12.44	
	14	W14,1	7.34	320	14.22	
		W14,2	7.28	300	13.33	13.93
		W14,3	7.34	320	14.22	
	21	W21,1	7.4	400	17.78	
		W21,2	7.32	380	16.89	18.07
		W21,3	7.48	440	19.56	
	28	W28,1	7.6	500	22.22	
		W28,2	7.54	480	21.33	
		W28,3	7.56	460	20.44	21.33

III-e Compressive Test of PSD(Grade 40)

Percentage replacement (%)	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
5	7	U7,1	7.48	400	17.78	18.07
		U7,2	7.55	420	18.67	
		U7,3	7.5	400	17.78	
	14	U14,1	7.84	520	23.11	22.81
		U14,2	7.8	500	22.22	
		U14,3	7.86	520	23.11	
	21	U21,1	8.15	630	28	29.04
		U21,2	8.42	680	30.22	
		U21,3	8.2	650	28.89	
	28	U28,1	8.62	750	33.33	
		U28,2	8.9	800	35.56	
		U28,3	8.5	720	32	33.63
10	7	V7,1	7.48	400	17.78	18.07
		V7,2	7.52	420	18.67	
		V7,3	7.5	400	17.78	
	14	V14,1	7.54	420	18.67	20.15
		V14,2	7.6	480	21.33	
		V14,3	7.58	460	20.44	
	21	V21,1	7.75	520	23.11	24
		V21,2	7.8	550	24.44	
		V21,3	7.82	550	24.44	
	28	V28,1	8.5	700	31.11	
		V28,2	8.46	680	30.22	
		V28,3	8.35	650	28.89	30.07
20	7	H7,1	7.3	280	12.44	12.89
		H7,2	7.3	290	12.89	
		H7,3	7.32	300	13.33	
	14	H14,1	7.48	420	18.67	18.37
		H14,2	7.45	380	16.89	
		H14,3	7.56	440	19.56	
	21	H21,1	7.75	520	23.11	24.59
		H21,2	7.84	560	24.89	
		H21,3	7.96	580	25.78	
	28	H28,1	8	600	26.67	27.26
		H28,2	8.06	620	27.56	
		H28,3	8.1	620	27.56	

III-f: Compressive Test of PSA(Grade 20)

Percentage replacement (%)	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
5	7	PP7,1	7.44	350	15.56	
		PP7,2	7.48	390	17.33	15.41
		PP7,3	7.32	300	13.33	
	14	PP14,1	7.56	470	20.89	
		PP14,2	7.58	480	21.33	21.33
		PP14,3	7.58	490	21.78	
	21	PP21,1	7.64	500	22.22	
		PP21,2	7.72	540	24	23.26
		PP21,3	7.7	530	23.56	
	28	PP28,1	7.82	560	24.89	
		PP28,2	7.75	550	24.44	
		PP28,3	7.98	590	26.22	25.19
10	7	AA7,1	7.35	340	15.11	15.56
		AA7,2	7.36	360	16	
		AA7,3	7.35	350	15.56	
	14	AA14,1	7.48	380	16.89	
		AA14,2	7.42	350	15.56	16.30
		AA14,3	7.42	370	16.44	
	21	AA21,1	7.5	400	17.78	
		AA21,2	7.55	430	19.11	18.81
		AA21,3	7.55	440	19.56	
	28	AA28,1	7.88	490	21.78	
		AA28,2	7.38	440	19.56	
		AA28,3	7.7	460	20.44	20.59
20	7	KK7,1	7.38	340	15.11	
		KK7,2	7.3	320	14.22	14.22
		KK7,3	7.3	300	13.33	
	14	KK14,1	7.42	370	16.44	
		KK14,2	7.38	350	15.56	15.70
		KK14,3	7.36	340	15.11	
	21	KK21,1	7.54	380	16.89	
		KK21,2	7.55	400	17.78	17.33
		KK21,3	7.52	390	17.33	
	28	KK28,1	7.54	410	18.22	
		KK28,2	7.6	440	19.56	
		KK28,3	7.58	435	19.33	19.03

III-g: Compressive Test of PSA(Grade 25)

Percentage replacement (%)	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
5	7	XX7,1	7.38	360	16	
		XX7,2	7.42	380	16.89	16.15
		XX7,3	7.36	350	15.56	
	14	XX14,1	7.78	490	21.78	
		XX14,2	7.75	480	21.33	21.78
		XX14,3	7.84	500	22.22	
	21	XX21,1	7.9	550	24.44	
		XX21,2	7.86	500	22.22	23.86
		XX21,3	7.95	560	24.89	
	28	XX28,1	8	600	26.67	
		XX28,2	8.05	620	27.56	
		XX28,3	7.9	570	25.33	26.52
10	7	TT7,1	7.38	360	16	
		TT7,2	7.36	370	16.44	15.86
		TT7,3	7.3	340	15.11	
	14	TT14,1	7.4	380	16.89	
		TT14,2	7.48	420	18.67	18.37
		TT14,3	7.42	440	19.56	
	21	TT21,1	7.48	490	21.78	
		TT21,2	7.5	480	21.33	22.07
		TT21,3	7.64	520	23.11	
	28	TT28,1	7.76	530	23.56	
		TT28,2	7.86	540	24	
		TT28,3	7.85	550	24.44	24
20	7	MM7,1	7.26	310	13.78	
		MM7,2	7.36	340	15.11	14.37
		MM7,3	7.3	320	14.22	
	14	MM14,1	7.42	380	16.89	
		MM14,2	7.52	420	18.67	17.78
		MM14,3	7.46	400	17.78	
	21	MM21,1	7.64	490	21.78	
		MM21,2	7.6	440	19.56	20.89
		MM21,3	7.68	480	21.33	
	28	MM28,1	7.68	500	22.22	
		MM28,2	7.64	490	21.78	
		MM28,3	7.7	520	23.11	22.37

III-h: Compressive Test of PSA(Grade 30)

Percentage replacement (%)	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
5	7	LL7,1	7.52	450	20	
		LL7,2	7.56	500	22.22	20.74
		LL7,3	7.54	450	20	
	14	LL14,1	8.1	620	27.56	
		LL14,2	7.95	580	25.78	26.67
		LL14,3	8.1	600	26.67	
	21	LL21,1	8.5	690	30.67	
		LL21,2	8.42	680	30.22	30.07
		LL21,3	8.4	660	29.33	
	28	LL28,1	8.62	750	33.33	
		LL28,2	8.6	750	33.33	
		LL28,3	8.56	700	31.11	32.59
10	7	QQ7,1	7.36	340	15.11	
		QQ7,2	7.46	380	16.89	16.30
		QQ7,3	7.42	380	16.89	
	14	QQ14,1	7.54	440	19.56	
		QQ14,2	7.5	400	17.78	18.52
		QQ14,3	7.48	410	18.22	
	21	QQ21,1	7.65	520	23.11	
		QQ21,2	7.54	500	22.22	22.81
		QQ21,3	7.58	520	23.11	
	28	QQ28,1	8.3	650	28.89	
		QQ28,2	8.1	600	26.67	
		QQ28,3	8.15	620	27.56	27.70
20	7	WW7,1	7.32	340	15.11	
		WW7,2	7.38	360	16	15.70
		WW7,3	7.34	360	16	
	14	WW14,1	7.36	380	16.89	
		WW14,2	7.38	400	17.78	17.19
		WW14,3	7.34	380	16.89	
	21	WW21,1	7.48	480	21.33	
		WW21,2	7.52	500	22.22	21.93
		WW21,3	7.54	500	22.22	
	28	WW28,1	7.9	550	24.44	
		WW28,2	7.72	540	24	
		WW28,3	7.6	520	23.11	23.85

III-i: Compressive Test of PSA(Grade 40)

Percentage replacement (%)	Testing age (days)	Spec Name	Weight of cube (kg))	Crushing load(kN	Crushing Strength (N/mm^2)	Mean Strength (N/mm^2)
5	7	UU7,1	8.25	620	27.56	28.44
		UU7,2	8.5	650	28.89	
		UU7,3	8.5	650	28.89	
	14	UU14,1	8.62	750	33.33	32.14814815
		UU14,2	8.54	700	31.11	
		UU14,3	8.58	720	32	
	21	UU21,1	8.92	800	35.56	34.66666667
		UU21,2	8.8	780	34.67	
		UU21,3	8.78	760	33.78	
	28	UU28,1	9.4	850	37.78	
		UU28,2	9.75	890	39.56	
		UU28,3	9.86	920	32	39.41
10	7	VV7,1	7.9	580	25.78	25.33
		VV7,2	7.92	580	25.78	
		VV7,3	7.58	550	24.44	
	14	VV14,1	7.92	580	25.78	26.37
		VV14,2	7.98	600	26.67	
		VV14,3	8	600	26.67	
	21	VV21,1	8.5	700	31.11	32.44
		VV21,2	8.58	750	33.33	
		VV21,3	8.55	740	32.89	
	28	VV28,1	9.1	820	36.44	
		VV28,2	8.92	800	35.56	
		VV28,3	9.5	860	38.22	36.74
20	7	HH7,1	7.8	520	23.11	22.22
		HH7,2	7.68	480	21.33	
		HH7,3	7.68	500	22.22	
	14	HH14,1	7.86	550	24.44	23.85
		HH14,2	7.84	540	24	
		HH14,3	7.78	520	23.11	
	21	HH21,1	8.05	600	26.67	28
		HH21,2	8.3	650	28.89	
		HH21,3	8.15	640	28.44	
	28	HH28,1	8.56	720	32	
		HH28,2	8.47	680	30.22	
		HH28,3	8.55	720	32	31.41

III-j: Comparing between Predicted strength and Observed strength for PSD

Sample	Grade	Percentage Replacement (%)	Workability mm	Predicted strength N/mm^2	Observed Strength N/mm^2	Absolute Error (N/mm^2)	Percentage error
PSD	20	0	29	28.85	29.03	0.19	0.64
		5	26	23.32	23.70	0.38	1.61
		10	26	21.11	20.14	0.96	4.76
		20	24.5	15.02	15.41	0.39	2.50
	25	0	29	29.06	29.18	0.13	0.44
		5	26	24.81	25.33	0.53	2.07
		10	26	23.00	21.93	1.08	4.91
		20	25	18.58	18.96	0.39	2.04
	30	0	28	35.02	36.30	1.28	3.52
		5	27	30.01	28.30	1.71	6.04
		10	25.5	22.56	23.70	1.14	4.81
		20	25	19.83	21.33	1.51	7.07
	40	0	29	42.51	44.44	1.94	4.36
		5	27	33.62	33.63	0.01	0.03
		10	26.5	33.92	30.07	3.84	12.78
		20	24	25.33	27.26	1.93	7.08

III-k: Comparing between Predicted strength and Observed strength for PSA

Sample	Grade N/mm^2	Percentage Replacement %	Workability mm	Predicted strength N/mm^2	Observed Strength N/mm^2	Absolute Error (N/mm^2)	Percentage error %
PSA	20	0	29	29.29	29.04	0.25	0.87
		5	26	24.20	25.19	0.98	3.89
		10	26	21.58	20.59	0.99	4.79
		20	24.5	18.79	19.04	0.25	1.30
	25	0	29	29.29	29.19	0.10	0.35
		5	26	26.19	26.51	0.33	1.23
		10	26	24.30	24.00	0.29	1.25
		20	25	22.31	22.37	0.06	0.27
	30	0	28	36.50	36.30	0.20	0.56
		5	27	32.20	32.59	0.39	1.20
		10	25.5	27.90	27.90	0.19	0.71
		20	25	23.85	23.85	0.01	0.02
	40	0	29	42.04	44.44	0.41	0.92
		5	27	40.19	39.41	0.78	1.98
		10	26.5	36.34	36.74	0.40	1.09
		20	24	31.40	31.41	0.01	0.02