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EFFECT OF PALM KERNEL SHELLS AND RICE HUSK ASH ON THE PHYSICAL AND MECHANICAL PROPERTIES OF NORMAL WEIGHT CONCRETE

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DECLARATION

I, EZEKIEL SAAH PHILIPS, the undersigned do solemnly declare to the best of my knowledge that this thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

I dedicate this dissertation to my loving families and the God's Glory Free Pentecostal Church for their love, prayers, support and care throughout this program.

I also dedicate this achievement to those great giants in my life who continue to give me a shoulder to see ahead. Few of those giants include my aunt, Mrs. Betty S. Boakai, mother, Catherine F. Sondoe, Uncle, C. Sylvester N. Bundoo, grandparents, Nessie Sia Mayah, Rev. Elizabeth Mayah Sahr, Elder Joseph Tamba Mayah, and a dear friend Ms. Joan R. Sumo.

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ABSTRACT

Concrete is the most used construction material in the world and also the second most consumed substance in the world after water. Concrete flexibility and increase in population has resulted in the high use of the material for the construction of shelters, infrastructures, and work places among other, thereby contributing to the high cost of the material. There is a worry in the construction industry about the depletion of natural resources from which concrete is produced in the near future. This high demand for concrete has also increased the price of the material making it almost impossible for low income earners to own houses and leaving many homeless. Also, increased in population has increased agricultural activities across the globe in order to tackle the problem of food insecurity amongst which include rice and palm farming. The negative effect of these increased agricultural activities is the high environmental pollution as wastes from these activities are openly burned in many instances as a mean of disposal, releasing a significant amount of carbon dioxide (CO_2) in the atmosphere. These concerns have prompted research towards waste materials that could be used as alternatives to those conventional materials for concrete production while at the same time minimizing the high environmental pollution. Through these efforts, it was discovered that Palm Kernel Shell (PKS), the by-product of palm farming, can partially replace coarse aggregate to produce structural concrete. Similarly, it was discovered that Rice Husk Ash (RHA), a waste from the rice farming, can be used as a pozzolana to replace portion of the cement in concrete production. However, limited information was found on the combine effect of PKS and RHA as partial replacements for coarse aggregate and Portland cement respectively on normal concrete. It was the aim of this research to investigate the effect of PKS and RHA on normal weight concrete (NWC) as partial replacements for coarse aggregate and ordinary Portland cement (OPC) respectively. Effects were determined in terms of concrete workability, density, water absorption, compressive strength, and splitting tensile strength. Twelve mixes were designed in which PKS was varied at 0, 25, and 50% and RHA at 0, 10, 15, and 20% in a mix ratio of 1:2:3 for cement, fine aggregate, and coarse aggregate respectively with a constant free water to cement ratio of 0.58. Batching was by volume and a total of 108 cubes and 72 cylinders were casted. Specimens were cured for 7 and 28 days. It was found out that PKS and RHA use in concrete reduce workability, density, compressive strength and splitting tensile strength and increase water absorption at 28 days of curing. However, the resulting concrete was satisfactory for structural used.

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LIST OF ABBREVIATIONS AND ACRONYMS

AIV	Aggregate Impact Value
ACV	Aggregate Crushing Value
ACI	American Concrete Institute
ASTM	American Society for Testing Materials
BS	British Standard
BS EN	British Standard European Norm
ETSAP	Energy Technology Systems Analysis Programme
FAO	Food and Agriculture Organization
LOI	Loss on Ignition
LWA	Light Weight Aggregate
MPa	Mega Pascal
NWC	Normal Weight Concrete
OPC	Ordinary Portland Cement
PKS	Palm Kernel Shell
PKSC	Palm Kernel Shell Concrete
PRB	Population Reference Bureau
PSD	Particle Size Distribution
RHA	Rice Husk Ash
SLWC	Structural Light Weight Concrete
UTM	Universal Testing Machine

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Concrete is the most common construction material used in almost every construction all around the world. It is environmentally friendly and very easy to produce. Its applications include buildings, roads, bridges, dams, retaining structures, stadiums, airports, among others, thereby increasing its demand on the daily basis and also an increase in the price of the material. It is the second most consumed substance on Earth after water (Smith & Maillard, 2007). According to Ismail (2009), its usage is around 10 billion tons per year, which is equivalent to 1 ton per every living person. This high production and consumption of concrete is due to the continuous increase in the global population. According to the Population Reference Bureau (PRB, 2016), Africa has a population of 1.2 billion and it is estimated to double by 2050. Increase in population hence leads to an increase in the demand for the basic needs of mankind which include shelter, workplace, and infrastructure.

The most expensive constituent of concrete is cement. It is one of the active ingredients of concrete used as a binding agent. The high need for concrete has increased the demand for cement thereby making it the most expensive constituent. According to the United States Geological Survey (USGS, 2015), the world cement production for the year 2011 was 3.6 billion tons and that by 2012, the production was increased to 3.7 billion tons. From this statistics, it can therefore be seen that demand of cement continues to increase on a yearly basis. What this means is that, more natural resources and energy are needed for the production of cement leading to the depletion of resources and emission of high amount of Carbon dioxide (CO_2) in the atmosphere. According to the Trend in Global CO_2 Emission (TGCE, 2015), cement production accounts for roughly 8% of the global CO_2 emissions. Also, the Cement Sustainability Initiative (CSI)/European Cement Research Academy (ECRA, 2009), stated that the grinding of clinker with additives to produce cement requires only electricity and accounts for about 38% of total electricity used.

Aggregates are also used in concrete production and account for about 60 – 80 percent of the total volume of concrete depending on the mix design. Extraction and crushing of these natural aggregates usually involve stripping, drilling and blasting, and impact crushing causing pollution and environmental instability. Again, the high demand of concrete has resulted in an increased in aggregate production leading to increase environmental pollution and a total depletion of the natural resource causing geographical instability to the environment.

On the other hand, increase in population has not only resulted in the need for more shelters and infrastructures, but also the problem of food insecurity. This problem of food insecurity has led to an increased in agricultural activities all across the world due to the strategic planning policies for food security of many countries. With rice being the primary food for many people particularly Africans, rice production has spread all across the continent. Food and Agriculture Organization of the United Nations (FAO, 1996), reported that Africa consumes a total of 11.6 million tonnes of milled rice per year. Mehta (1992), reported that approximately 20kg of rice husks are obtained for 100kg of rice produced. Hence, it can be seen that of the 11.6 million tonnes of milled rice consumed per year, 2.32 million tonnes of rice husks are produced as waste which is usually dispose of through open burning.

Similarly, there is a steady increase in palm production across the African continent. According to the Global Palm Oil Conference (2015), world production of palm oil and palm kernel oil has grown rapidly in recent decades: from about 2 million metric tonnes in 1961 to over 56 million tonnes in 2012. Main drivers behind this growth are the high productivity of oil palms, the development of applications beyond their traditional food use, and the production of biodiesel. The World Bank has therefore estimated that world consumption of palm oil will double by 2020 to about 112 million tonnes (Global Palm Oil Conference, 2015). Similarly, Budu and Sarpong (2013) stated that the consumption of palm oil and other palm products is expected to increase in West Africa and in other parts of the continent as the population grows. Hence, this high increase in Palm farming across the world and Africa in particular has resulted in high pollution across the continent as the by-product is openly burn as a mean of disposal.

Hence, increase in population requires more shelters and infrastructures as well as increase in agricultural activities. With cement and aggregates being the main constituents of concrete, there are worries that the natural resources will be depleted in the near future. Also, with rice and palm farming on the increase, there is high pollution of wastes from these activities. Addressing some of these problems have been a major challenge in the engineering field. However, as a mean of mitigating some of these problems, engineers are now focusing on producing low cost concrete by incorporating wastes produced from agricultural activities. With low cost concrete produced from wastes, more shelters can be built at affordable cost while at the same time reducing the high pollution cause by those wastes. According to the British Standards for concrete, concrete materials should satisfy the requirement for the safety, structural performance, durability and appearance of the finished structure, taking full account of the environment to which it will be subjected (BS 5328, 1997). With this as a guide, Palm Kernel Shell (PKS), waste from the palm oil manufacturing process, was found to have satisfied the provisions of BS 5328 making it suitable for concrete production as a replacement for coarse aggregate in terms of its crushing value, impact value, density, specific gravity and size. With the fact that PKS is a waste, its replacement for coarse aggregate brings about a significant reduction in the cost of concrete, preservation of the natural resource, and also a better way of managing waste leading to a safer environment. Also, Rice Husk Ash (RHA), waste from the rice manufacturing process was found to be a good pozzolana for concrete production replacing a portion of cement as it satisfied pozzolana requirements of ASTM C618 (2005) in terms of its physical and chemical properties. As with the PKS, RHA replacement for cement also brings about a reduction in cement demand, boost in resource preservation, and also minimizes the high pollution associated with the production of cement.

1.2 STATEMENT OF THE PROBLEM

The high demand for concrete is the result of the increase needs for shelters, workplaces, and infrastructures as the population increases. This has resulted in an increase in the prices of constituent materials thereby making total construction cost very high. Global Construction Perspective (2015) reported that global construction had reached 8.7 trillion United States Dollars (USD) in 2012 and is expected to rise to 15 trillion USD by 2025. The cost of concrete together with the high quantity needed is one of the reasons for this high construction cost globally. This explains why many low-income earners especially in Africa are without shelters and are homeless because they cannot afford these high costs thereby impeding on Africa's agenda for 2063 which include poverty reduction.

Also, the high demand for concrete is leading to the gradual depletion of natural resources. According to Ismail (2009), the usage of concrete is around 10 billion tons per year, which is equivalent to 1 ton per every living person. Following this trend, Africa with a population of 1.2 billion and is said to double by 2050 according to the Population Reference Bureau (PRB, 2016), it can therefore be stated that by 2050 Africa alone will be using around 2.4 billion tons of concrete per year. This will then lead to a very high demand of these materials leading to a total depletion of natural resources thereby causing geographical instability and damage to the environment.

Again, increased demand for concrete has increased production activities for cement. Cement production is expensive, requires high energy, reduces natural resources, and emits large amount of CO_2. United States Geological Survey (USGS, 2015) stated that the world cement production for the year 2012 was 3.7 billion tons. According to Lun (2015), approximately 4.9 million Kilo Joules (KJ) of energy is required to produce a ton of cement. Therefore producing

3.7 billion tons of cement will required around 1.8 trillion KJ of energy. Also, cement production emits a large quantity of CO_2. Shivaram (2014) stated that producing a ton of cement will generate approximately a ton of CO_2. Therefore, to produce 3.7 billion tons of cement will also generate approximately 3.7 billion tons of CO_2. According to Trend in Global CO_2 Emission (TGCE, 2015), cement production accounts for roughly 8% of global CO_2 emissions.

Increase in population has also led to increase agricultural activities across the globe. For instance, in Africa, rice is a stable food of many countries. Production of rice continues to increase on a yearly basis. It was reported by Food and Agriculture Organization of the United Nations (FAO, 1996), that Africa consumes a total of 11.6 million tonnes of milled rice per year. Mehta (2015) reported that approximately 20kg of rice husks are obtained for 100kg of rice. Therefore, production of 11.6 million tonnes of milled rice produces approximately 2.32 million tonnes of husks as waste. This waste is disposed by open burning thereby polluting the environment.

Therefore, with these problems as a result of increase in population, there is an urgent need for research towards low cost construction and also to find means by which waste materials can be utilize.

1.3 OBJECTIVES

1.3.1 General Objective

- To investigate the effect of Palm Kernel Shells (PKS) and Rice Husk Ash (RHA) on the physical and mechanical properties of Normal Weight Concrete (NWC).

1.3.2 Specific Objectives

- To determine the characteristics of Palm Kernel Shells, Normal Weight Aggregate, Fine Aggregate, Rice Husk Ash, and Portland Cement.
- To determine the effect of Palm Kernel Shells as partial replacement of coarse aggregate in normal weight concrete.
- To determine the effect of Rice Husk Ash as partial replacement of Ordinary Portland Cement in normal weight concrete.
- To determine the effect Palm Kernel Shells and Rice Husk Ash as partial replacements of coarse aggregate and Ordinary Portland Cement respectively on the physical and mechanical properties of normal weight concrete.

1.4 JUSTIFICATION

Increase in population has increased the need for shelters, workplaces, and infrastructures. With the cost of concrete being very high, low income earners are unable to own their own shelters or afford rents for them. Therefore, finding low cost materials to replace these conventional materials use for concrete production significantly reduces the cost of concrete and hence total construction cost. Hence, finding low cost materials will enables even low income earners shelters at affordable costs.

Also, with an increase in the consumption of concrete on a yearly basis, fear that the natural resources might get depleted in the long run is another major concern. Therefore using waste to substitute these natural resources reduces the high demand on them thereby leading to a boost in resource preservation. Also, this minimizes the high pollution level associated with the processing of these natural resources. For instance, it was reported that cement production accounts for roughly 8% of the global CO_2 emissions and requires huge amount of energy. Hence, the use of waste in concrete production minimizes some of these pollutions.

Again, with an increased in agricultural activities across the globe and Africa in particular, increased amount of wastes are anticipated from these activities. With poor waste management being a major issue in Africa, it can be seen that environmental pollutions will be on the increase all across the continent. Therefore, incorporating some of these wastes in the production of concrete will help to minimize some of these pollutions leading to a safer environment.

Therefore, this research is significant as it addressed some of Africa's main challenges. That is, by combining PKS and RHA to substitute coarse aggregate and OPC in the production of concrete, the cost is significantly reduced and hence total construction cost. Also, the incorporation of PKS and RHA in concrete production reduces the high demand on the natural resources boosting resources preservation, reduction in environmental pollution, and a better mean of waste management.

1.5 SCOPE OF THE STUDY

The Study was involved with the determination of the effect of PKS and RHA on the physical and mechanical properties of NWC. Physical properties considered for the concrete produced were in terms of workability, concrete density and water absorption. Mechanical properties were in terms of compressive and splitting tensile strengths. Characterization of PKS and coarse aggregate were in terms of Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), water absorption, specific gravity, bulk density, loose density, and Particle Size Distribution (PSD). RHA and OPC were characterized in terms of chemical properties, PSD, and specific gravity. Concretes with PKS and RHA were compared with NWC. Determination of the mechanical properties was at 7 and 28 days of curing. The design mix used in this study was 1:2:3 for cement, fine aggregate and coarse aggregate and a water to cement ratio of 0.58 for all concretes.

Geographically, the study was conducted in Kenya at the Jomo Kenyatta University of Agriculture and Technology (JKUAT). The study was completed within a six months’ time duration.

2. LITERATURE REVIEW

2.1 INTRODUCTION

Concrete is a composite material consisting of cement, aggregates and water with water and cement being the only active constituents. Production of cement has steadily increased to 3.7 billion tons in 2012 (USGS, 2015) thereby releasing a significant amount carbon dioxide (CO_2) in the atmosphere. Aggregates serve as inert filler materials while at the same time improving concrete workability, volume stability and durability. Recent studies (Alengaram et al., 2013; Yap et al., 2013; Williams et al., 2014; Itam et al., 2016) have shown the suitability of PKS in concrete production as coarse aggregate replacement. Also, it was recently shown by Ponmalar and Abraham (2015) that RHA can partially substitute OPC in concrete production. Rice Husk Ash in concrete improves the performance of concrete in strength and reduces chloride ions penetration. However, little information is available on the effect of PKS and RHA on the physical and mechanical properties of NWC as coarse aggregate and OPC replacements respectively. Hence it is necessary to investigate the effect PKS and RHA on the physical and mechanical properties of NWC.

2.2 CONCRETE

Concrete may be defined as a composite material consisting of a binding material, water, fine and coarse aggregates, and in some instances, the incorporation of admixtures all in definite proportions to achieve a desired property. The binding material in most instances is the Ordinary Portland Cement (OPC) although other binding materials are also in used.

Normal Weight Concrete (NWC) can be defined as a concrete with a density of 2400 kg/m^3 (145 lb/ft^3). According to BS 5328 (1997), it is a hardened concrete having an oven dried density greater than 2000 kg/m^3 but not exceeding 2600 kg/m^3. It has a setting time of 30 - 90 minutes depending upon the moisture in the atmosphere and fineness of cement among others.

According to Stanley and Bond (1999), the oldest concrete discovered dates from around 7000 BC, and was found in 1985 when a bulldozer uncovered a concrete floor during the construction of a road at Yiftah El in southern Galilee, Israel. It was also reported that the Romans also developed the concept of light weight concrete by casting jars into wall arches as well as the use of pumice aggregates. However, though concrete might have existed as early as 7000 BC, the massive use of it might have started around the 19th century.

2.2.1 Benefits of Using Concrete

Concrete provides so many benefits among which include its low cost when compared to steel. By incorporating waste materials for its production, the cost can significantly reduce hence leading to a significant reduction in the total construction cost. Also, repairing work for concrete is easier and more economical than other construction materials. It is durable and can also be recycled for use in other areas such as a filler material for road construction. Unlike wood, for example, which can rot and decay and is susceptible to natural disaster, concrete requires little or no maintenance and can stand up to the toughest winds, the harshest of weather conditions and resist fire with ease. Concrete can also have a decorative function. Concrete does not burn and therefore provides comprehensive fire protection including life safety, protection of properties and of the environment. Concrete is one of the more sustainable building materials when both the energy consumed during its manufacture and its inherent properties in-use are considered. Concrete’s thermal mass can be used to avoid or reduce temperature swings in the building and to eradicate the need for energy guzzling air conditioning systems. Dense, heavyweight concrete provides the highest amount of thermal mass (European Concrete Platform ASBL, 2009).

Another important feature of concrete is that it is environmentally friendly. Concrete is one of the best, most natural building materials to use when considering the environmental impact of construction. The use of waste in the production of concrete helps to reduce environmental pollution and also addresses the problem of waste management. Concrete walls and floors are effective storage heaters, absorbing free heat from the sun during the daytime and releasing heat at night. Concrete stores heat in the winter and cools buildings in the summer, creating optimum comfort conditions for the occupants (European Concrete Platform ASBL, 2009). Concrete in buildings provides exceptional levels of security and safety.

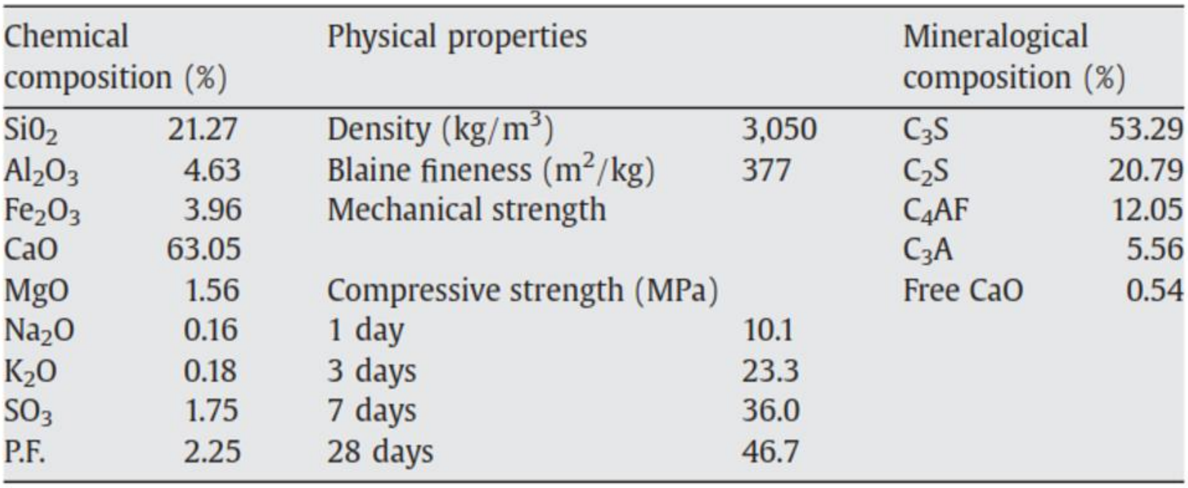
2.3 CONSTITUENTS OF CONCRETE

2.3.1 Cement

Cement is a substance that is used in construction as a binder for bonding mineral fragments into a compact whole. According to the Energy Technology Systems Analysis Programme (ETSAP, 2010), global cement production has grown steadily from less than 200 million tonnes in 1950 to more than 2500 million tonnes in 2006. There are different types of cements with different properties and performance. BS EN 197-1 (2000) stated that the choice of cement, especially the type and/or strength class, based on the requirements for durability largely depends on the exposure and type of construction in which it is incorporated. The most common type of cement used in construction is the Ordinary Portland Cement (OPC).

The manufacture of OPC involves two stages, notably, clinker production and cement grinding. In the clinker production stage, raw materials are fed to the kiln system to produce clinker. These materials are crushed, grounded and mixed to obtain a homogenous blend. During this process, significant amount of carbon dioxide (CO_2) is released to the atmosphere. Shivaram (2014) stated that producing a tonne of cement will generate approximately a ton of CO_2. This stage ends with the cooling of the clinker in a cooler system. In the second stage, the clinker is grounded with the addition of other minerals to obtain cement with desired properties such as setting time and strength grade. According to Cement Sustainability Initiative/European Cement Research Academy (CSI/ECRA, 2009), the grinding of clinker with additives to produce cement requires only electricity (no heat) and accounts for about 38% of total electricity used. Table 2-1 shows the physical, chemical, and mechanical properties of Portland cement. As can be seen from the table, Portland cement contains over 60% of lime (calcium oxide) which makes cement sound and also provides strength to the cement. It is the excess of this lime that reacts with pozzolana in the presence of moisture to produce cementitious properties.

Table 2-1: Physical, Chemical, and Mechanical properties of Portland cement (Salas et al., 2009)



Chemical composition (%)		Physical properties		Mineralogical composition (%)	
SiO_2	21.27	Density (kg/m^3)	3,050	C_3S	53.29
Al_2O_3	4.63	Blaine fineness (m^2/kg)	377	C_2S	20.79
Fe_2O_3	3.96	Mechanical strength		C_4AF	12.05
CaO	63.05			C_3A	5.56
MgO	1.56	Compressive strength (MPa)		Free CaO	0.54
Na_2O	0.16	1 day	10.1		
K_2O	0.18	3 days	23.3		
SO_3	1.75	7 days	36.0		
P.F.	2.25	28 days	46.7		

2.3.2 Aggregate

Aggregate is a collective term for the mineral materials such as sand, gravel and crushed stone that are used with a binding medium to form concrete. Aggregate may be defined as an inert filler material in concrete. It is a granular material, such as sand, gravel, crushed stone, and iron blast-furnace slag, used with a cementing medium to form a hydraulic cement concrete or mortar (ACI 318, 1995). According to Gambhir (2013), the reasons of using aggregate in the construction of concrete are due to the economic reasons, volume stability and durability of concrete. As shown in Table 2-2, aggregates can be classified according to the production method, petrological characteristics, unit weight, and according to the particle sizes. Depending on the mix design, aggregate may occupy about 70 – 80 percent of the total volume of concrete.

Table 2-2: General classification of aggregates

No.	**Classification Type**		**Examples**
1.	**According to production method:**		
	a.	Natural Aggregates (no change in their natural state except for crushing, grading, or washing	Sand, gravel, crushed stone, lime rock.
	b.	By-product aggregates	Blast-furnace slags and cinders, fly ash
	c.	Processed aggregates (heat treated0	Perlite, burnt clays, shales, processed fly ash
	d.	Colored Aggregates	Glass, ceramics, manufactured marble
2.	**According to Petrological Characteristics**		
	a.	Igneous Rocks	Quartz, granite, basalt, obsidian, pumice, tuff
	b.	Sedimentary Rocks	Sandstone, limestone, shale
	c.	Metamorphic Rocks	Marble, slate, schist
3.	**According to Unit Weight**		
	a.	Normal Weight Aggregates	Sand, gravel and crushed rock
	b.	Light Weight Aggregates	Slag, slate
	c.	Heavy Weight Aggregates	Hemotite, barite magnetite, steel and iron punchings
4.	**According to Particle Size**		
	a.	Fine Aggregate	Sand
	b.	Coarse Aggregate	gravel

Generally, fine aggregates include particles that pass through 4.75mm sieve and retain on a 0.075mm sieve such as river sand. Their functions include filling the voids between the coarse aggregate while holding them in suspension, producing workable and uniform concrete mixtures. On the other hand, coarse aggregate are those particles retain on a 4.75mm sieve and use as an inert filler material.

2.4 PALM KERNEL SHELLS

Palm kernel shells (PKS) also known as Oil Palm Shells (OPS), shown in Figure 2-2, are the by-product of palm oil and palm kernel oil production, and are fractions of shells that result from the cracking of the nuts. PKS is obtained as crushed pieces, the sizes of which vary from fine aggregates to coarse aggregates, after the crushing of palm kernel to remove the seed, which is used in the production of palm kernel oil (Olutoge, 2010). Palm kernel shells are hard, flaky and of irregular shape (Oti and Kinuthia, 2015). There is no single type of shape that can be used to describe the palm kernel shell. The shape depends on the pattern of breaking during the nut cracking. It is usually composed of many shapes among which are roughly parabolic or semi-circular shapes, flaky shapes and other irregular shapes (Okafor, 1988). PKS are hard in nature and do not deteriorate easily when used for concrete and therefore, do not contaminate or leach to produce toxic substances (Basri *et al*., 1999). PKS may consists of about 65 to 70% of medium size particles in the range of 5 to 10 mm based on the method of cracking the nut (Alengaram et al., 2010).

Figure 2-1: Crushed palm kernel shells of different sizes

PKS physical and mechanical properties make it suitable for so many applications. It can be used as an aggregate for concrete production (Okafor, 1988; Okpala, 1990; Osei and Jackson, 2012). Okoroigwe et al. (2014) used PKS as a sorbent material for industrial water treatment and stated that the physical and chemical properties of the material make it suitable for the purpose. PKS can also be used in road construction. However, for heavily trafficked roads, PKS replacement for aggregate of stone dust and bitumen in 10% blend with asphalt is recommended (Ndoke, 2006). PKS is also used in the preparation of pozzolana, a cement substitute material that has been developed by the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana (FAO Rome, 2002). Also, Oti and Kinuthia (2015) used PKS ash to produce concrete and stated that the potential to replace up to 50% Portland cement with PKS ash burnt at oven temperature of 750°C is more feasible. Also, a recent study has shown that PKS can be used as a partial replacement for sand in sandcrete block production. Blocks produced from PKS aggregates are heavier, denser and stronger than the traditional sandcrete blocks when the PKS aggregate content do not exceed 10% (Dadzie and Yankah, 2015).

2.4.1 Characteristics of Palm Kernel Shells

Table 2-3: Properties of palm kernel shell

Author	**Specific Gravity**	**Bulk Density (kg/m^3)**	**Shell Thickness (mm)**	**Water Absorption for 24 hr. (%)**	**Fineness Modulus**	**Aggregate Impact Value (%)**
Okafor, 1988	1.37	589	-	27.3	-	6.0
Okpala, 1990	1.14	595	-	21.3	-	-
Alengaram et al., 2010	1.27	620	≈3.0	25.0	6.24	3.91
Shafigh et al., 2010	1.22	-	-	18.73	5.72	-
Itam et al., 2016	1.21	572	-	25.64	-	6.65

PKS has both physical and machemical properties suitable for use as coarse aggregate in concrete. According to Okoroigwe et al. (2014), the material physical and chemical properties determined using standard methods showed that it can fill useful applications in light weight construction as material filler and as sorbent material for industrial water treatment. The shell has a 24 hours water absorption capacity range of 21 – 33% (Shafigh et al., 2010). Okpala (1990) stated that the indirect compressive strength of PKS aggregate was 12.1 MPa with a standard deviation of about 2 MPa. The material bulk density ranges from 572 to 620 kg/m^3 (Itam et al., 2016; Okafor, 1988; Alengaram et al., 2010). The material has been found to have a specific gravity of 1.34 (Williams et al., 2014). Properties of PKS given by researchers summerized in Table 2-3, show that the material possesses desired characteristics that rendered it necessary to be used as coase aggregate for concrete production.

2.5 PALM KERNEL SHELL CONCRETE

Palm Kernel Shell concrete (PKSC) is a concrete produce by substituting coarse aggregate either partially or fully with PKS. Depending on the mix design, it can be classified as either Structural Light Weight Concrete (SLWC) or an Insulating Light Weight Concrete when the 28-day compressive strength is below 17 MPa. According to the American Concrete Institute (ACI), Structural Light Weight Concrete is defined as a concrete made with low density aggregate that has an air-dry density of not more than 115 lb/ft^3 (1840 kg/m^3) and a 28 day compressive strength of more than 2,500 psi/17 MPa (ACI 116R, 2000). BS 5328 (1997), defined SLWC as hardened concrete having an oven dried density not greater than 2000 kg/m^3. Okafor (1988) suggested that the use PKS as a full replacement of coarse aggregate cannot produce concrete with compressive strength above 30 MPa and that PKS is suitable for concrete grade 25 and below compared to conventional coarse aggregates. However, in latter researches, Alengaram et al. (2010) increased the 28-days compressive strength to 36-38 MPa by incorporating silica fume while Shafigh et al. (2011) developed a new method to produce high strength PKS concrete of 28-days compressive strength of 53MPa by using crushed PKS. Osei and Jackson (2012), studied PKS as Coarse Aggregates in Concrete and ascertained the possibility to replace coarse aggregate up to 100 percent but recommended that batching by volume should be used for better results. The mechanical and structural properties of PKSC have been compared with normal weight concrete (NWC) by many researchers to show the effectiveness of PKSC (Alengaram et al., 2013).

2.6 PHYSICAL PROPERTIES OF PALM KERNEL SHELL CONCRETE

Physical properties of NWC are the same for PKSC. Main physical properties of concern for PKSC include those of workability, density, and water absorption of the concrete.

2.6.1 Workability of Palm Kernel Shell Concrete

The most important property of fresh concrete is its workability defined as the ease with which concrete is mixed, transported, placed, compacted, and finished without segregation. Slump test is a standard test for determining the workability of concrete. It is used to calculate the variation in the uniformity of mix of a given proportion and also to measure the consistency of the concrete. Workability of PKSC is dependent on the water to cement ratio and also the content of PKS. As can be seen in Figure 2-2, Danashmand and Saadatian (2011) performed a slump test on PKSC for different percentages of PKS (Oil Palm Shell-OPS-as on the figure) content as a partial replacement for coarse aggregate with a constant water cement ratio of 0.5 and showed that with increase in PKS content, the workability of the concrete reduces.

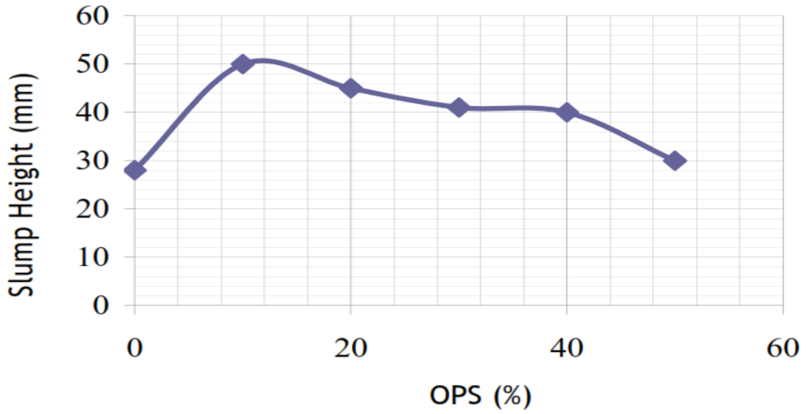


Figure 2-2: Slump Test for different percentage of PKS content (Danashmand and Saadatian, 2011).

Also, according to Alengaram et al. (2008), higher PKS content in the mix combined with the irregular and angular shapes of the PKS result in poor workability. This poor workability might be due to the friction between the angular surfaces of the PKS particles and lower fine content.

A reduction in PKS content and a subsequent increase in fine aggregate content increases workability as can be seen from reports by different researchers summarized in Table 2-4.

Table 2-4: Slump of PKSC by researchers for different mixes

Author	**w/c**	**Mix Proportion**	**Slump (mm)**
Abdullah 1984	0.6	1:1.5:0.5	200
	0.4	1:2:0.6	260
Okafor 1988	0.48	1:1.7:2.08	8
	0.65	1:2.1:1.12	50
Okpala 1990	0.5	1:1:2	30
	0.6	1:1:2	63
	0.7	1:1:2	Collapse
	0.5	1:2:4	3
	0.6	1:2:4	28
	0.7	1:2:4	55
Mahmud et al. 2009	0.35	1:1:0.8	160

2.6.2 Density of Palm Kernel Shell Concrete

For structural applications of Light Weight Concrete (LWC), the density is often more important than the strength (Rossignolo et al., 2003). The density of concrete is study in terms of bulk density, fresh density, and dry density. According to Okafor (1988), the fresh density of PKSC is in the range of 1753 – 1763 kg/m^3 depending on the mix proportion, water to cement ratio, and also the use of sand. Mannan and Ganapathy (2001), based on the mix proportion also reported the fresh density of PKSC in the range of 1910 – 1958 kg/m^3. Alengaram et al., 2008, reported the fresh density of PKSC to be approximately 1880 kg/m^3 by incorporating 10% silica fume and 5% fly ash by weight with a cement : sand : aggregate : water ratio of 1:1.2:0.8:0.35. Usually the fresh density of PKSC is about 100 – 120 kg/m3 lower than the saturated density of LWC (Alengaram et al., 2013). As shown on Figure 2-3, Osei and Jackson (2015) showed that the dried density of PKSC reduces with an increase in PKS content but increases with curing time.

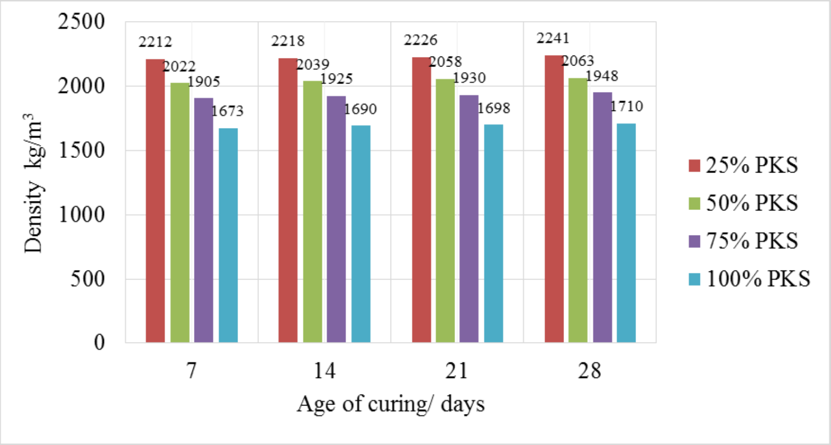


Figure 2-3: Densities of hardened PKSC at different curing age (Osei and Jackson, 2015)

2.6.3 Water Absorption of Palm Kernel Shell Concrete

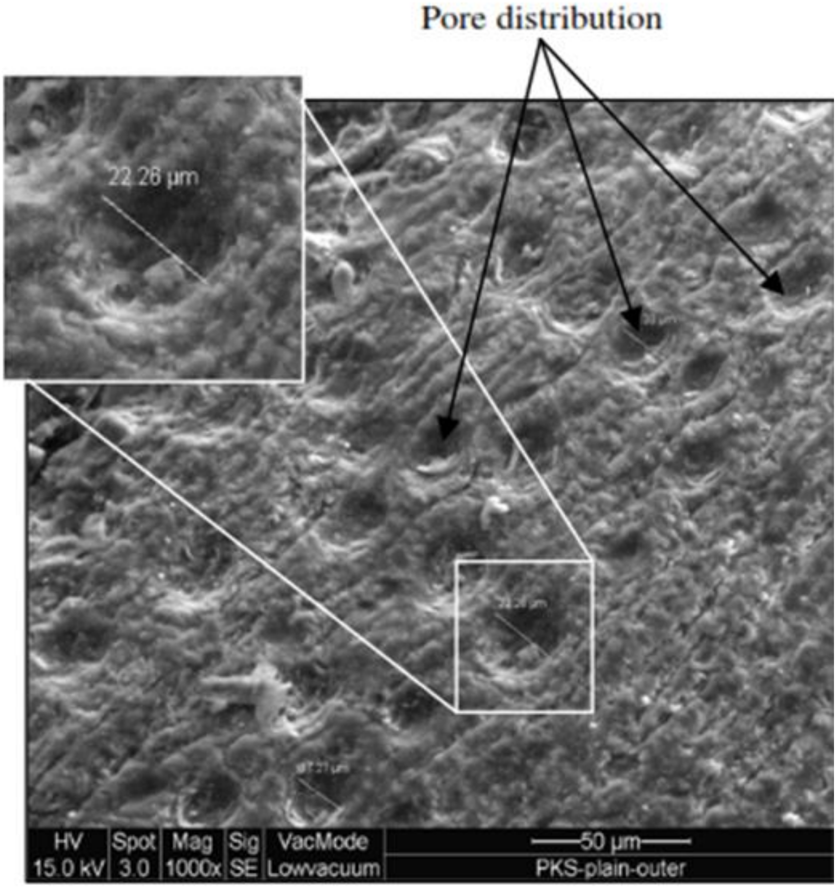


Figure 2-4: Pores of the outer surface of PKS (Alengaram et al., 2011).

According to Basheer et al. (2001), water absorption is the transport of liquids in porous solids caused by surface tension acting in the capillaries. Water absorption for LWC such as expanded polystyrene concrete and pumice aggregate concrete is in the range of 3 – 6% according to

Babu and Babu (2003), and 14 – 22% according to Guduz and Ugur (2005) respectively. For PKSC, Teo et al. (2007) showed that the water absorption is 11.23% and 10.64% for air dry curing and full water curing respectively. This high water absorption for PKSC can be explained by the analysis of the PKS structure. Alengaram et al. (2011) examined the structure of the PKS using a scanning electron microscope and it was observed that tiny pores in the range of 16 - 24μm exist on the convex surface of the PKS as shown in Figure 2-4, which are responsible for the high water absorption of PKSC.

2.7 MECHANICAL PROPERTIES OF PALM KERNEL SHELL CONCRETE

The mechanical properties of PKSC are dependent on the mixed design chosen. According to Shetty (2005), mix design methods that apply to normal weight concrete are generally difficult to use with lightweight aggregate concrete. Abdullah (1996) suggested that trial mixes are necessary to achieve a good mix design for PKSC. Also, Osei and Jackson (2012), after batching by weight and by volume for PKSC, concluded that batching by volume gives better mechanical properties than batching by weight.

2.7.1 Compressive Strength of Palm Kernel Shell Concrete

The compressive strength is the most commonly used parameter to describe the quality of concrete in practice (Weigrink et al., 1996). All other mechanical parameters such as flexural strength, splitting tensile strength and modulus of elasticity directly depend on the compressive strength of the concrete (Alengaram et al., 2013). As shown in Figure 2-5, Ikponmwosa et al., (2014), Daneshmand and Saadatian (2011), and Olutoge et al. (2012), all reported that the compressive strength of PKSC is dependent on the amount of PKS aggregate in the concrete and that the strength increases with curing age.

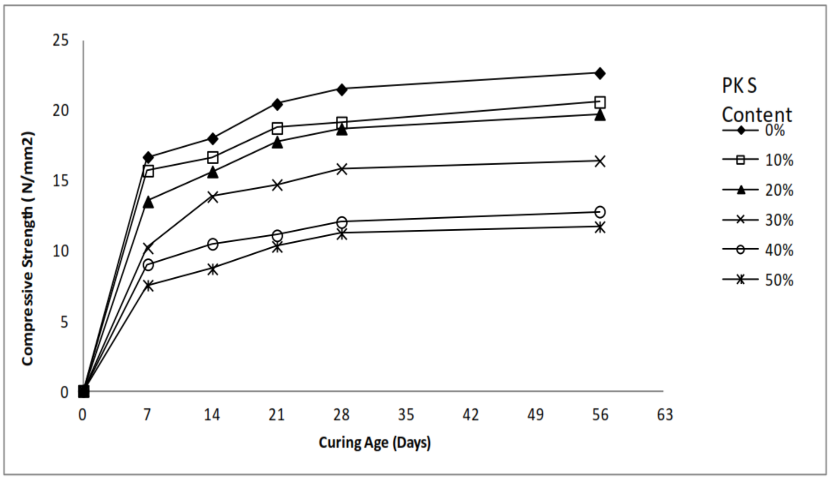


Figure 2-5: Compressive strength of PKSC with curing age (Ikponmwosa et al., 2014)

Depending on the mix design, percentage of PKS aggregate, and method of curing, different grades of PKSC have been reported by researchers. Table 2-5 shows the compression strength of PKSC by various researchers. Okpala (1990) reported a 28 – day compressive strength of 22.2 MPa using a water to cement ratio of 0.5 and a mix design of 1 : 1 : 2 (cement : sand : aggregate). Shafigh et al. (2011), incorporated steel fibers using a water to cement ratio of 0.38 and a design mix of 1 : 1.736 : 0.72 (cement : sand : aggregate) and reported a 28 – day compressive strength in a range of 39.34 – 44.95 MPa.

Table 2-5: The compressive strength of PKSC at 28 – day

Author	**Water/Cement ratio**	**Mix Proportion**	**Compressive Strength at 28 days (MPa)**
Okafor, 1988	0.48	1 : 1.7 : 2.08	23
Okpala, 1990	0.5	1 : 1 : 2	22.2
Alengaram et al., 2010	0.35	1 : 1.2 : 0.8	37.41
Shafigh et al., 2011	0.38	1 : 1.736 : 0.72 (steel fibers)	39. 34 – 44.95

2.7.2 Splitting Tensile Strength of Palm Kernel Shell Concrete

The tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. Since concrete is very weak in tension due to its brittle nature, it is not expected to resist the direct tension. According to Mannan and Ganapathy (2001), splitting tensile strength of PKSC depends on the curing condition and the physical strength of the PKS. Okafor (1988) showed that the splitting tensile strength of PKSC varied in the range of 2.0 – 2.4 by varying water to cement ratio from 0.48 – 0.65. Shafigh et al. (2011) obtained the splitting tensile strength of 5.55 by incorporating steel fibers. Table 2-6 shows a summary of splitting tensile strength reported by different researchers.

Table 2-6: Splitting Tensile Strength of PKSC by different Researchers

Author	**w/c**	**Mix Proportion**	**Splitting Tensile Strength (MPa)**
Okafor 1988	0.48 0.65	1:1.7:2.08 1:2.1:1.12	2.4 2.0
Teo and Liew 2006	0.41	1:1.12:0.8	2.24
Mahmud et al. 2009	0.35	1:1:0.8	1.98
Shafigh et al. 2011	0.38	1:1.736:0.72 (+steel fiber)	5.55

2.8 SUITABILITY OF PALM KERNEL SHELLS IN CONCRETE

PKS has been experimented in research as light weight aggregate (LWA) to produce light weight and low cost concrete since 1984 (Alengaram et al., 2013). According to Shafigh et al. (2010), research over the last two decades has shown that PKS can be used as a lightweight aggregate for producing low cost and structural lightweight concrete. Also, it has been reported by Yap et al. (2013), that PKS is a suitable replacement for coarse aggregate to produce high strength LWC with 28 days compressive strength up to 53 MPa.

Okafor (1988) tested the physical properties of the shell, the compressive, flexural, and tensile splitting strength of the PKS concrete. Three mixes of widely different water to cement ratio were used with 100% coarse aggregate replacement with PKS. The properties tested were compared with those of similar concrete specimens made with crushed granite as coarse aggregate. The results showed that the material is suitable to produce concrete grade 25 and below. Similarly, Williams et al. (2014), produced a concrete with 100% replacement of coarse aggregate using PKS at a mix design of 1:2:4 (cement : sand : coarse aggregate) and a water to cement ratio of 0.65. The results showed that the compressive and flexural strength improved with age of curing, though the compressive and flexural strength of PKSC were low as compared to that of the NWC. They concluded that PKS can be used for concrete production as lightweight aggregate and therefore can be used to produce LWC. The properties of PKS fresh concrete are however excellent, very workable, consistent and easily placed.

Therefore, with the above information, it can be seen that the PKS is suitable for the production of low structural concrete by replacing coarse aggregate.

2.9 RICE HUSK

Figure 2-6: Rice husk in its loose form

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

2.10 RICE HUSK ASH

Rice husk ash (RHA) is the remaining by-product after combustion of the rice husk is done. It is a general term describing all types of ash produced from burning rice husks. The amount of carbon remaining in the ash depends on the combustion performance (i.e., complete or incomplete combustion). RHA can be used as a soil amendment and as additive in cement and steel, among others. However, only small amounts compared to the total rice husk production are used for such purposes. RHA typically contains approximately 80 per cent silica and is therefore an excellent natural pozzolana. According to ASTM C618 (2005), a pozzolana is a siliceous or siliceous and aluminous material which in itself, possesses little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. In practice, the type of ash obtained varies considerably according to the burning technique. At 550°C – 800°C amorphous ash is formed and at temperatures greater than this, crystalline ash is formed and loses a degree of reactivity (Azhagarsamy & Jaiganesan, 2016). The ash so produced is pulverized or ground to required fineness using a Los Angeles machine or any other grinder. Antiohos et al. (2014) concluded that RHA is a material extremely “sensitive” to fineness changes; the higher being the fineness the more positive is the effect of RHA inclusion in the mix. The high silica content of rice husk ash makes it a good additive for the steel and concrete industries.

2.11 PROPERTIES OF RICE HUSK ASH

Studies by Chandrasekar et al. (2003) have shown that the physical and chemical properties of RHA are dependent on the soil chemistry, paddy variety, and climatic conditions. Similarly, studies made by Maeda et al. (2001) also showed that the differences in the physical and chemical properties of RHA may be due to fertilizers applied during rice cultivation. Therefore, properties of RHA largely depend on chemistry, paddy variety, climatic conditions, and fertilizers applied during the rice cultivation.

2.11.1 Chemical Properties of Rice Husk Ash

The chemical compositions of RHA from various locations are presented in Table 2-7. It can be seen that the chemical composition of RHA from the various location consisted of silica content above 70% and loss on ignition (LOI) not exceeding 12%, thereby satisfying ASTM C618 requirement for pozzolans. Hence, RHA can be used in the production of concrete by substituting cement thereby leading to a significant reduction in concrete cost.

Table 2-7: Comparison of chemical properties of RHA from various locations in % by weight (Omondi, 2013)

Constituents	Malaysia	Brazil	Netherlands	Kenya
Silica(SiO_2)	93.1	92.9	86.9	75.8
Alumina(Al_2O_3)	0.21	0.18	0.84	1.15
Iron Oxide(Fe_2O_3)	0.21	0.43	0.73	0.86
Calcium Oxide(CaO)	0.41	1.03	1.4	3.25
Potassium Oxide(K_2O)	2.31	0.72	2.46	1.5
Magnesium Oxide(MgO)	1.59	0.35	0.57	0.23
Sodium Oxide(Na_2O)	-	0.02	0.11	0.35
Sulphur Oxide(SO_3)	-	0.1	-	-
Loss of Ignition(LOI)	2.36	-	5.14	10.2
Total $SiO_2+Fe_2O_3+Al_2O_3$	**93.52**	**93.51**	**88.47**	**77.81**

2.11.2 Physical Properties of Rice Husk Ash

The physical properties of RHA are dependent on the soil chemistry, paddy variety, and climatic conditions. The average particle size of rice-husk ash ranges from 5 to 10µm. Physical properties values as reported by few researchers are given in Table 2-8.

Table 2-8: Physical Properties of RHA (Abubakar, 2010)

Property	**Value**			
	Mehta et al	Zhang et al	Feng et al	Bui et al
Specific gravity	2.06	2.06	2.10	2.10
Mean particle size(μm)	-	-	7.4	5.0
Fineness (Passing 45 μm)	99	99	-	-

2.11 RICE HUSK ASH CONCRETE

Concrete produced from RHA has unique characteristics similar to NWC. Researchers have reported that the properties of concrete made from RHA greatly depend on the quantity of RHA in the concrete, the water cement ratio, and also the age of curing. According to Ponmalar and Abraham (2015), replacement of 15% OPC with RHA brought about 11.4% improvement in the strength of concrete and also a significant reduction in chloride ion penetration. Similarly, Kartini (2011) reported that replacement of OPC with RHA reduces the water permeability of the concrete, thus reduces coefficient of permeability, and hence improves the durability of the concrete. Also, Marthong (2012) studied the effect of RHA as partial replacement of cement on concrete properties by replacing cement at 10, 20, 30, and 40% with RHA. He stated that up to 20% replacement of OPC with RHA has the potential to be used as partial cement replacement, having good compressive strength and durability.

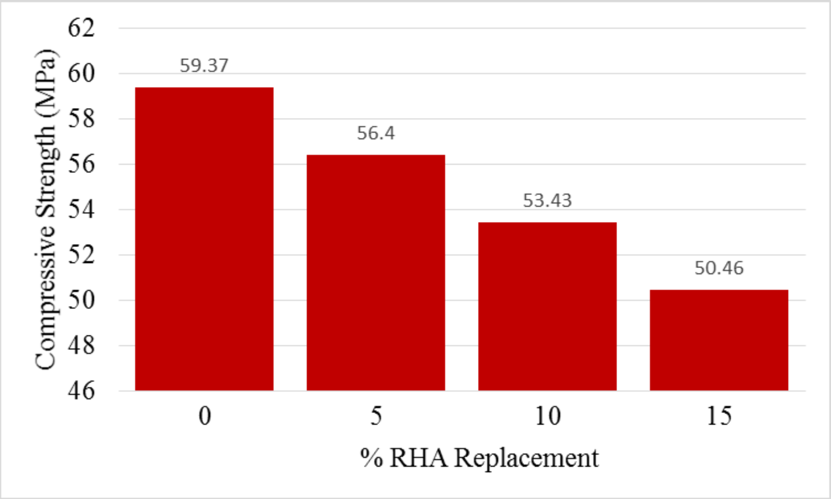


Figure 2-7: Compressive strength of RHA concrete at 28 days curing (Yap et al., 2013).

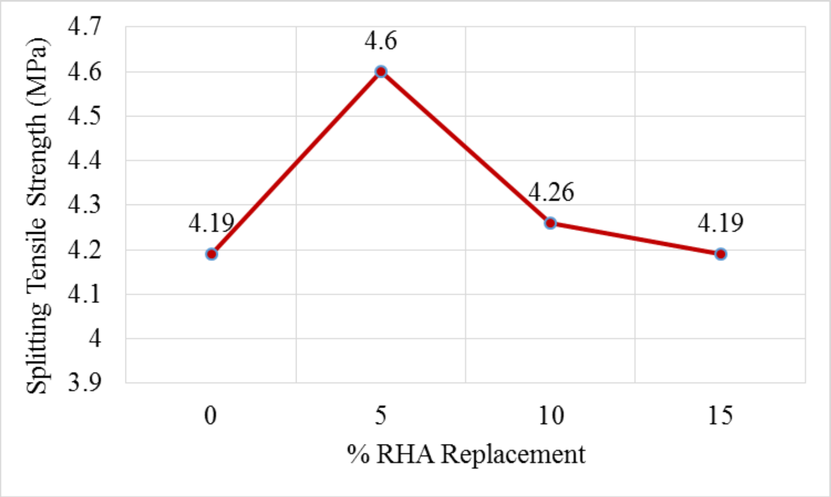


Figure 2-8: Splitting tensile strength of RHA concrete at 28 days curing (Yap et al., 2013).

However, as shown in Figures 2-7 and 2-8, Yap et al. (2013) reported that at 28 days of curing, there was a reduction in the compressive strength of the concrete with increase in RHA content but a significant increase in the splitting tensile strength of the concrete at 5% replacement level.

2.13 SUITABILITY OF RICE HUSK ASH IN CONCRETE

Researchers have ascertained that RHA can be used to replace portion of the cement used in concrete production. Substitution for Ordinary Portland Cement (OPC) in concrete production brings about a significant reduction in the cost of concrete as OPC is the most costly constituent in concrete. According to Kartini (2011), up to 30% replacement of OPC with RHA has the potential to be used as partial cement replacement, having good compressive strength and durability, and can therefore contribute to sustainable construction. However, he suggested that RHA can be used as partial replacement of cement up to a maximum of 10% by volume in all grades of cement.

2.14 RESEARCH GAP

Increase in population has led to the rapid development in construction for meeting human needs for shelters, workplaces, and infrastructures. According to the Global Construction Perspective (2015), global construction had reached 8.7 trillion USD in 2012 and is expected to rise to 15 trillion USD in the year 2025. This is the result of the increase in the cost of construction materials such as cement and aggregates. These costs for materials along with their scarcity have pushed researchers to find alternatives for those conventional ones. For instance, Alengaram et al., 2013; Yap et al., 2013; Williams et al., 2014; Itam et al., 2016, used PKS as a replacement for coarse aggregate to produce concrete leading to a significant reduction in the cost of concrete. Similarly, Ponmalar and Abraham (2015) did a partial replacement of cement with RHA and stated that a possibility to replace up to 50% exists with a significant reduction in the cost of concrete. They also stated that RHA inclusion in concrete production didn’t only reduce the cost of concrete, but it also improved the compressive strength of the concrete and reduced water permeability leading to the durability of the concrete. Hence to further contribute towards low cost construction, production of concrete from PKS and RHA as coarse aggregate and OPC replacements respectively, will significantly reduce construction cost. However, limited information is available on the effect of PKS and RHA as partial replacements for coarse aggregate and OPC respectively on the properties of normal concrete. Therefore, investigating the effect of PKS and RHA on the physical and mechanical properties of NWC as partial replacements for coarse aggregate and OPC respectively was significant. Hence, this research investigated the effect of PKS and RHA on the physical and mechanical properties of NWC in terms of concrete workability, density, water absorption, compressive strength, and splitting tensile strength.

3. METHODOLOGY

3.1. INTRODUCTION

This chapter discusses the materials used and the methods applied in this research for the determination of the effect of PKS and RHA on the physical and mechanical properties of NWC. Constituent materials were also characterized. The effect of PKS and RHA on normal concrete was determined by conducting tests on fresh and hardened concretes and determining the workability, water absorption, compressive strength, and the splitting tensile strength of the concrete.

3.2 METHODOLOGY FLOW CHART

Figure 3-1 shows the flow chart for the activities adopted for the research from start up to the completion.

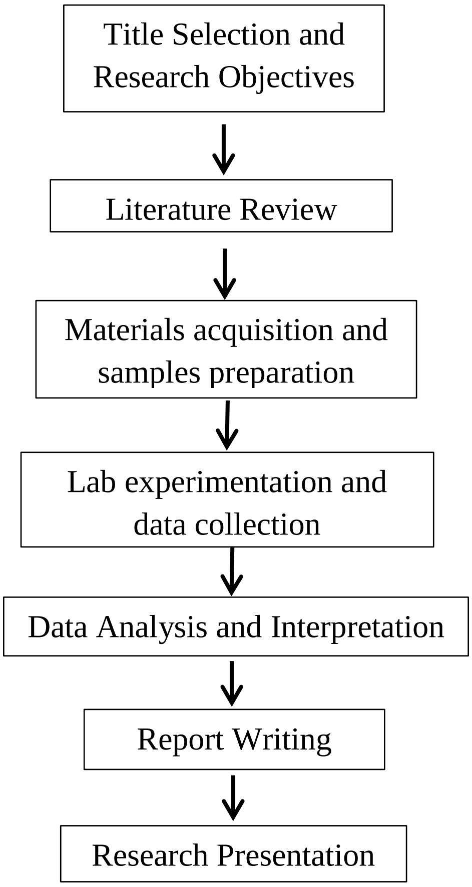


Figure 3-1: Research Flow Chart

3.3 MATERIAL COLLECTION AND PREPARATION

Materials used for this research included PKS, Coarse Aggregate, RHA, OPC, Fine Aggregate (river sand), and Water. PKS and RHA were used as partial replacements for coarse aggregate and Portland cement respectively.

3.3.1 Palm Kernel Shells

PKS were obtained from Uganda, Buggala Island in Kalangala (a district composed of a number of islands in Lake Victoria). The material was prepared by washing and then allowed to air-dry under ambient temperature for about 30 minutes to obtain saturated surface dried state such that the water to cement ratio was not much affected.

3.3.2 Coarse Aggregate

The coarse aggregate was locally obtained and prepared in accordance with BS 882 (1992). The crushing value, impact value, particle size distribution, as well as the 24 hrs water absorption of the aggregate were determined.

3.3.3 Rice Husk Ash

Rice husk ash was locally obtained from Mwea, a town situated on the Embu-Nairobi Highway in Kirinyaga County which is about 98 kilometers from Nairobi. The material was burned in a burnt brick kiln at a temperature of 600^{o}C (+/-50) for two days. The burnt ash was then heaped and was left to cool for 24hrs. The material was prepared by sieving on 0.3mm sieve to remove larger particles. Furthermore, hydrometer analysis as well as chemical composition of the material were also determined.

3.3.4 Ordinary Portland Cement

The cement used for this research was Ordinary Portland Cement (OPC) class 42.5N locally obtained and conforming to BS EN 197-1 (2000). It was readily available on the market for concrete production in the construction industry and for laboratory experimentation.

3.3.5 Fine Aggregate

Fine aggregate (river sand) used was collected locally from Meru, a town in eastern Kenya and the headquarters of the Meru County. The sand was Sieved on a 5.0mm test sieve to remove larger particles and then air-dried to a saturated state of an aggregate. Water absorption, particle size distribution and fineness modulus were determined before used.

3.3.6 Water

Potable water from Jomo Kenyatta University of Agriculture and Technology (JKUAT) was used throughout the research for both mixing and curing of concrete. The water was pure and free from impurities.

3.4 PREPARATION OF SAMPLES

3.4.1 Mix Proportion

After several trial mixes for a targeted strength, the mix ratio of 1:2:3 was adopted for cement, sand, and coarse aggregate respectively by volume with a constant free water to cement ratio of 0.58 in accordance with BS 1881-125 (1983). This mix ratio was used to produce twelve types of concretes as shown in Table 3-1. The control concrete consisted of cement, sand, and coarse aggregate all at 100%, while the rest had varied amount of PKS and RHA to determine their effect on the concrete properties.

Table 3-1: Experimental matrix used in the research

PKS %	**RHA %**			
	0	**10**	**15**	**20**
0	0%PKS + 0% RHA	0%PKS + 10%RHA	0%PKS + 15%RHA	0%PKS + 20%RHA
25	25%PKS + 0%RHA	25%PKS + 10%RHA	25%PKS + 15%RHA	25%PKS + 20%RHA
50	50%PKS + 0%RHA	50%PKS + 10%RHA	50%PKS + 15%RHA	50%PKS + 20%RHA

3.4.2 Mixing, Casting, Curing of Concrete

3.4.2.1 Mixing

Mixing was done manually in accordance with the provisions of BS 1881 – 125 (1983). All mixing was done on a tray using shovels and trowels as shown in Figure 3-2.

Figure 3-2: Tray used for the mixing of concrete

3.4.2.2 Casting

Concrete was casted in forms of cubes and cylinders with full compaction to expel entrapped air. Concrete was placed in three layers and compaction was made at each layer placement using a poker vibrator. Each mix casted a total of 9 cubes and 6 cylinders bringing the total to 108 cubes and 72 cylinders for the twelve mixes. The cubes had a dimension of 150 X 150 X 150mm and cylinders of 100mm in diameter and 200mm long.

3.4.2.3 Curing

Cubes and cylinders were open air cured for 24hrs after casting and then demolded for water curing for 7 and 28 days prior to testing in accordance with BS 1881 – 111 (1983). Method of water curing used was by immersing specimens in curing tanks as shown in Figure 3-3.

Figure 3-3: Curing of concrete by immersion

3.5 MATERIALS CHARACTERISTICS

The objective of these tests was to determine the characteristics of PKS, Coarse Aggregate, RHA, OPC, and fine aggregate for their use as constituents for concrete production. Samples of PKS and coarse aggregate were classified in terms of particle size distribution, aggregate impact value, aggregate crushing value, 24hrs water absorption, bulked density, and the specific gravity of the materials. Fine aggregate was classified in terms of particle size distribution, 24hrs water absorption, and the fineness modulus of the material. RHA and OPC were classified in terms of their physical and chemical properties.

3.5.1 Particle Size Distribution

The particle size distribution (PSD) or sieve analysis were perform for PKS, coarse aggregate, and fine aggregate in order to the determine the grading of each material in accordance with BS 812-103 (1990). Sieving was done by hand. The dried residue was placed on the top of the coarsest sieve and shaken for sufficient time to separate the test sample into the size fractions determined by the sieve apertures used. After sieving, each sieve, starting with the coarsest sieve was shaken separately over a clean tray until not more than a trace passed. Light brushes were used on the underside of the sieve to clear sieve opening. The material retained on each sieve was weighed and calculated as a percentage of the original mass and the mass passing each sieve was calculated as a cumulative percentage of the total sample mass.

3.5.2 Specific Gravity and Water absorption.

The specific gravity and water absorption tests in accordance with BS 812-2 (1995) were also done for both PKS, coarse aggregate, and fine aggregate. Samples were immersed in water for 24 hours and then dried with a cloth to removed films of water while the aggregate still had a damp appearance. The aggregate was weighed and mass recorded (mass A). A glass vessel/jar (Pyknometer) containing the sample and filled with water was also weighed and recorded (mass B). The vessel was then filled with water only and was weighed and the mass recorded (mass C). The sample was then placed on a clean tray and oven dried at a temperature of 105^{o}C for 24 hours. The sample was cooled after oven drying and the mass weighed and recorded (mass D). The specific gravity and water absorption were then calculated using Equations 3-1 and 3-2 respectively.

$$\textbf{\textit{Specific Gravity}} = \frac{D}{A-(B-C)} \text{ -- } \quad \text{Equation } 3-1$$

$$\textbf{\textit{Water Absorption}} = \frac{100(A-D)}{D} \text{-- } \quad \text{Equation } 3-2$$

Where A – is the mass of the saturated surface-dry aggregate

B – is the mass of vessel containing sample and filled with water

C – is the mass of vessel filled with water only

D – is the mass of the oven-dried aggregate in air.

3.5.3 Aggregate Crushing Value

The aggregate crushing value (ACV) test was conducted for both the PKS and coarse aggregate in accordance with BS 812 (1990). Aggregates passing a 14mm test sieve and retained on a 10mm test sieve were used. The resulting 14mm to 10mm fraction was divided to produce three test specimens. Each test specimen was dried by heat at a temperature of 105°C for a period of 3 hours and then cooled at room temperature before testing.

The cylinder of the test apparatus was placed in position on a baseplate and the test specimen added in three layers of approximately equal depth, each layer being subjected to 25 strokes from the tamping rod distributed evenly on the surface of the layer and dropping from a height approximately 50mm above the surface of the aggregate. The apparatus with the specimen was placed in position between the platens of the testing machine and loaded at a uniform rate until the required loading of 400KN was reached in 10 minutes. The load was released and the crushed material removed in a clean tray of known mass. The mass of the crushed aggregate (M_1) was then determined and specimen was then sieved using a 2.36mm test sieve. Passed and retained masses were recorded as M_2 and M_3 respectively. ACV was then calculated and expressed as a percentage using equation 3-3. The average ACV was computed from the three results obtained.

$$\boldsymbol{ACV} = \frac{M2}{M1}(100) \text{ --- } \qquad \text{Equation } 3 - 3$$

3.5.4 Aggregate Impact Value

The aggregate impact value (AIV) was also done for both PKS and coarse aggregate as specified in BS 882 (1992). Aggregates passing a 14mm test sieve and retained on a 10mm test sieve were used. The resulting 14mm to 10mm fraction was divided to produce three test specimens. Each test specimen was oven dried at a temperature of 105°C for a period of 3 hours and then cooled at room temperature before testing.

The impact machine was then rested on the floor such that it was rigid and the hammer guide column vertical. The specimen was placed in the cup and compacted by 25 strokes of the tamping rod. The cup was fixed firmly in position on the base of the machine and the hammer adjusted to about 380mm above the upper surface of the aggregate in the cup. The hammer was then made to fall freely on the aggregate for about 15 times. The aggregate was removed to a clean tray of known mass and the weight of the aggregate measured as M_1. The specimen was then sieved using a 2.36mm test sieve until no significant amount was passed. Fractions of passed and retained were weighed and recorded as M_2 and M_3 respectively. The AIV for each test specimen was then calculated as a percentage using Equation 3-4, and the average AIV computed.

$$\boldsymbol{AIV} = \frac{M2}{M1}(100) \text{ --- } \quad \text{Equation } 3-4$$

3.5.5 Hydrometer Analysis of Rice Husk Ash

Hydrometer analysis is a widely used method for obtaining an estimate of the distribution of particle sizes from No. 200 (0.075mm) sieve to around 0.01mm. Analysis was done in accordance with BS 1377-2 (1990). Sample mass of 50g was used for the analysis. This sample was then placed in a wide-mouth conical flask and then 100ml of sodium hexametaphosphate added. The mixture was shaken until all the particles were in suspension. It was then further mixed in a mixing machine for about 5 minutes until the materials were further broken down into individual particles. The suspension was then transferred from the flask to a 75µm sieve and washed with 500ml of distilled water. The suspension that passed through the sieve was transferred to a 1L measuring cylinder up to the 1 L graduation mark. This suspension was used for the sedimentation analysis. The material retained on the 75µm sieve was oven-dried and re-sieved on relevant sieves upon cooling while recording the mass retained on each sieve down to the 75µm sieve. Material that passed the 75µm sieve was added to the measuring cylinder.

For the sedimentation analysis, a separate solution was prepared in a 1 L measuring cylinder consisting of 100ml of the sodium hexametaphosphate and diluted with distilled water up to the 1 L graduation mark. The suspension was mixed in the measuring cylinder by placing the palm of one hand over the open end of the cylinder and turned vigorously end-over-end about 60 times within 2 minutes. The cylinder was quickly placed on the table after mixing and timing for sedimentation was started. The hydrometer was then immersed in the suspension and was allowed to float freely. Hydrometer readings were taken at the upper ring of the meniscus after a period of 0.5min., 1min., 2min. and 4 minutes without removing the hydrometer. The hydrometer was then removed after 4 minutes and was rinsed with distilled water and was placed in the dispersant solution cylinder and reading taken at the top of the meniscus as R_o. The hydrometer was reinserted into the suspension cylinder and readings recorded for the periods of 8min, 15min, 30min, 1hr, 2hrs, 4hrs, and 24hrs from the start of the sedimentation while withdrawing and reinserting the hydrometer after each reading. The temperature of the suspension was also recorded after every subsequent reading.

The true hydrometer reading R_h was calculated from Equation 3-5.

Hydrometer reading Rh) = $R'_h + C_m$ ---------------------------- Equation 3 – 5

Where R_h' is the observed hydrometer reading, and C_m is the meniscus correction faction (C_m = 0.5).

The modified hydrometer reading, Rd, was calculated using Equation 3-6.

Modified hydrometer reading $(R_d) = R'_h - R'_o$ ----------------- Equation 3 – 6

Where R_o' is the hydrometer reading at the upper rim of the meniscus in the dispersant solution.

3.5.6 Chemical Analysis of Rice Husk Ash and Cement

The chemical characteristics of RHA and OPC were determined at the Ministry of Mining in Nairobi. The objective of this test was to determine the chemical composition of these materials, especially the silica content of RHA as it defines the criterion for a good pozzolana and also the calcium oxide (CaO) content of the OPC, before their use in concrete production. Several methods were used to determine these chemicals composition. The Atomic absorption spectroscopy method was used to determine Al_2O_3, CaO, $Fe2O_3$, MgO, MnO_2 and CuO contents in the sample; Flame photometry method, used to determine Na and K content in the sample; loss on ignition (LOI), was used to determine the organic content in the samples. The LOI was done by igniting a known mass of the sample in a furnace and heated gradually up to a temperature of 1000^oC. This temperature was maintained for 30 minutes after which it was allowed to cooled and weighed. The LOI was expressed as a percentage of the original sample weight.

3.6 TESTING OF PALM KERNEL SHELLS AS COARSE AGGREGATE PARTIAL REPLACEMENT IN NORMAL WEIGHT CONCRETE

The objective of this test was to determine the impact of PKS on concrete when used as a partial replacement for coarse aggregate. To determine this impact, PKS was varied at 0%, 25% and 50% as coarse aggregate replacement in the production of concrete producing a total of 9 cubes and 6 cylinders at each percentage. The effect of PKS was determined in terms of workability of concrete, density, water absorption, compressive strength, and splitting tensile strength.

3.7 TESTING OF RICE HUSK ASH AS ORDINARY PORTLAND CEMENT PARTIAL REPLACEMENT IN NORMAL WEIGHT CONCRETE

The objective of this test was to determine the impact of RHA on concrete when used as a partial replacement for OPC. To determine this impact, RHA was varied at 0%, 10%, 15% and 20% for OPC, producing a total of 9 cubes and 6 cylinders for each mix. The effect was determined in terms of workability of concrete, density, water absorption, compressive strength, and splitting tensile strength.

3.8 TESTING OF PALM KERNEL SHELLS AND RICE HUSK ASH AS PARTIAL REPLACEMENTS OF COARSE AGGREGATE AND ORIDINARY PORTLAND CEMENT RESPECTIVELY ON THE PHYSICAL AND MECHANICAL PROPERTIES OF NORMAL WEIGHT CONCRETE

The objective of this test was to determine the combined effect of PKS and RHA on concrete. Six mixes of concrete were produced by varying PKS at 0, 25 and 50%, and RHA at 0, 10%, 15%, and 20% for coarse aggregate and OPC respectively. Physical properties studied were in terms of workability, density and water absorption of the concrete. Mechanical properties were determined in terms of compressive and splitting tensile strengths.

3.8.1 Workability

The workability of the concrete was determined through slump test. The slump measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. Slump test was conducted in accordance with provision of BS 1881-102 (1983) as shown in Figure 3-4.

Figure 3-4: Determination of slump as per BS 1881-102 (1983)

3.8.2 Water Absorption Test

The water absorption test was conducted on hardened concrete for all mixes. Three cube specimens of each concrete mix were cured for 28 days before testing. After the 28 days curing, the specimens were placed in a drying oven of temperature 100°C for a period of 72hrs conforming to specification of BS 1881-122 (1983). Upon removal from the oven, the specimens were cooled for 24hrs. After cooling, specimens were weighed and immediately immersed completely in a tank of water for 30 minutes. Specimens were removed from the tank and dried with a cloth to remove bulk of the water from the surface and then weighed. Water absorption was then calculated as the increase in mass resulting from immersion and was expressed as a percentage of the mass of the dry specimen.

3.8.3 Compressive Strength Test

For the determination of the compressive strength, 3 cube specimens of 150 X 150 X 150mm of each mix were tested at 7 and 28 days of curing using a Universal Testing Machine (UTM) as specified in BS 1881-115 (1983) shown Figure 3-5. The compressive strength for each cube was calculated by dividing the maximum load applied to it by the cross-sectional area according to BS 1881-116 (1983).

Figure 3-5: Compression test of cubes

3.8.4 Splitting Tensile Strength Test

For the determination of the splitting tensile strength, 3 cylinders 100mm in diameter and 200mm long for each mix were tested at 7 and 28 days of curing as specified in BS 1881-117 (1983).

$$\textbf{\textit{Splitting tensile strength}}\ (\sigma_{ct}) = \frac{2P}{\pi x l x d} \text{ -------------------------------- } \quad \text{Equation } 3 - 7$$

Where P is the maximum load (in N), l is the length of the specimen (in mm), and d is the cross-sectional dimension of the specimen.

3.8.5 Density of Concrete Test

The concrete density was determined by dividing the mass of each cube by its volume as specified by BS 1881 – 144 (1983). Specimens were cured in water in accordance with BS 1881 – 111 (1983) for more than 3 days and were therefore assumed to be saturated to a constant mass for the test. The specimen were weighed on the scale balance and masses recorded in kilogram (kg). The volume of each specimen was calculated in cubic meter (m^3) and the density was computed in kilogram per cubic meter (kg/m^3).

4. RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter focuses on the results and discussion of findings obtained from investigating the effect of PKS and RHA on the physical and mechanical properties of NWC as partial replacements for coarse aggregate and OPC respectively. These effects are discussed in terms of workability, density, water absorption, compressive strength, and splitting tensile strength. The characteristics of PKS, RHA, OPC, Coarse Aggregate and Fine aggregates are also presented and discussed in this chapter.

4.2 MATERIALS CHARACTERISTICS

Characterization of PKS and coarse aggregate were in terms of PSD, water absorption, specific gravity, ACV, AIV, and bulk density. RHA was characterized in terms of specific gravity, particle size distribution (hydrometer analysis), and chemical composition. Fine aggregate was characterized in terms of PSD, water absorption, specific gravity, and fineness modulus.

4.2.1 Characteristics of Palm Kernel Shells, Coarse Aggregate, and Fine aggregate

4.2.1.1 Particle Size Distribution of Palm Kernel Shells and Coarse Aggregate

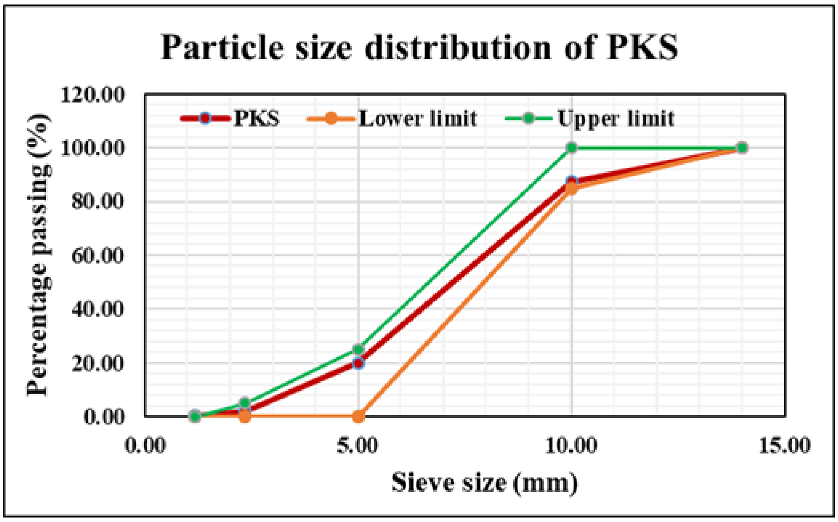


Figure 4-1: Particle Size Distribution of PKS

Results for the particle size distribution of PKS and coarse aggregate are presented in Figures 4-1 and 4-2 respectively. Figure 4-3 shows the particle size distribution of PKS and coarse aggregate. The maximum aggregate size for PKS was 10mm and 14mm for coarse aggregate as shown on Table 4 -1.

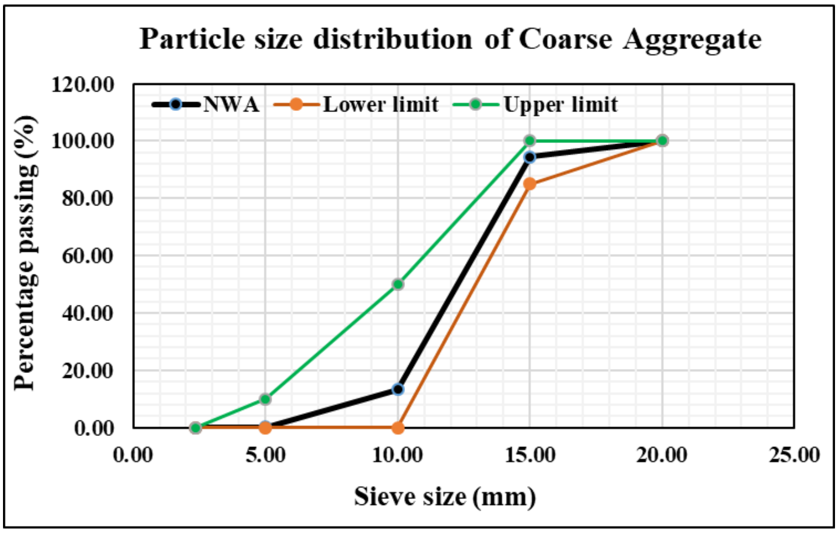


Figure 4-2: Particle Size Distribution of coarse aggregate

From Figure 4-1, it can be seen that about 60% of the PKS were between 5 mm – 10mm and about 20% were below 5mm. Also, Figure 4-2 shows that about 70% of the coarse aggregate was between 10mm – 15mm while less than 30% was below 10mm. From Figure 4-3, it can be seen that the particle sizes of PKS and coarse aggregate were between 5mm – 15mm which represented about 90% of the total aggregate.

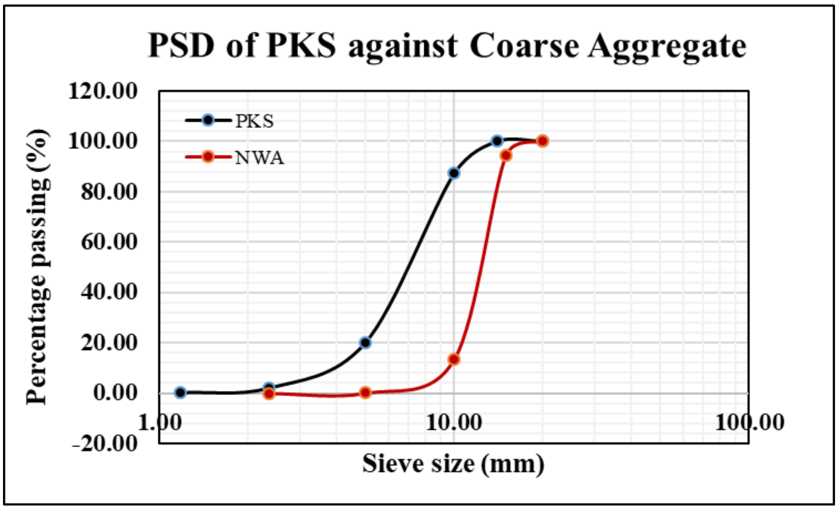


Figure 4-3: Particle Size Distribution of PKS and coarse aggregate

Hence it can be said that the PKS used in this research was finer than the coarse aggregate and therefore its substitution for coarse aggregate will increase the surface area of the aggregate which might lead to a high demand of cement paste for proper bonding. Holding all factors constant, PKS substitution for coarse aggregate will produce less workable concrete due to the increase surface area of PKS. With poor workability, compaction might also be poor which might lead to the production of concrete with voids that could reduce concrete strength, density, and durability as it may also result in increased level of water absorption.

Table 4-1: Characteristics summary of PKS, Coarse aggregate, and fine aggregate

Characteristic	PKS	Coarse aggregate	Fine aggregate
Maximum aggregate size (mm)	10	14	5
Specific Gravity	1.40	2.58	2.44
24 hr water absorption (%)	30.44	2.92	6.53
Bulk density (kg/m^3)	582.982	1,366.23	1,665.00
Loose Density (kg/m^3)	514.389	1,255.40	1,523.58
Aggregate Crushing Value, ACV (%)	2.15	17.42	-
Aggregate Impact Value, AIV (%)	4.63	7.635	-
Fineness modulus	-	-	2.68

Also from the figure, it can be seen that the coarse aggregate used was single size aggregate as about 80% of the aggregate was retained on sieve no. 10mm. Hence, the likely implication could be the formation of voids in the mixed due to the lack of smaller sizes to fill the voids. However, to avoid this situation, a large portion of fine aggregate is required to fill up those voids in order to produce durable concrete with less voids.

4.2.1.2 Particle size distribution of fine aggregate

The fine aggregate used was well graded as particles range from 0.15mm – 5mm in sizes. Hence, from Figures 4-4, it can be seen that the grading of the aggregates satisfied the requirements of BS 882 (1992), hence indicating uniformity in the concrete. Graded aggregate contributes to the quality of the concrete better than non-graded aggregate. Graded aggregate also increases the density of the concrete and reduces water permeability. It also leads to workable concrete with less voids and improves durability.

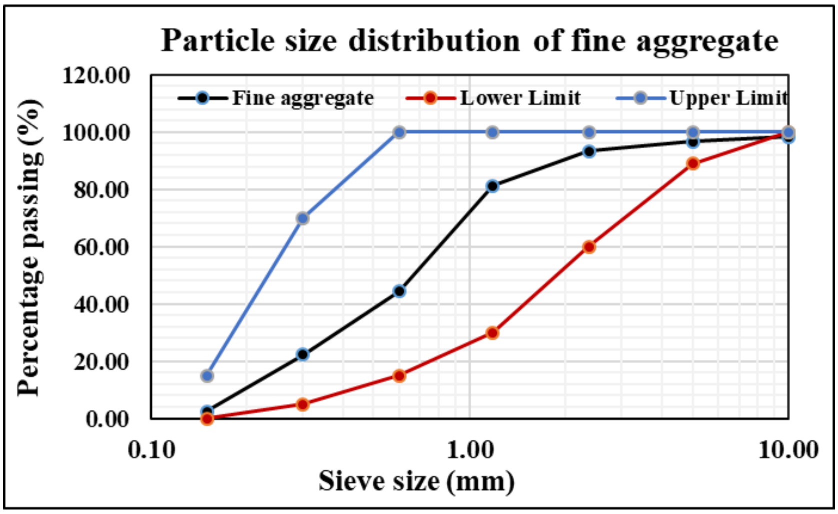


Figure 4-4: Particle Size Distribution of fine aggregate

Also, the figure shows that the particle size distribution satisfied ASTM C33 requirement for graded aggregate which requires that the fine aggregate be less the 45% retained on any one sieve. Too much material on one sieve means gap – grading, which will increase the cement – paste demand in the mix. ASTM C33 also suggested that the fineness modulus be kept between 2.3 and 3.1. This is due to the fact that a 'very fine' fine aggregate will increase water demand of the mix, while a 'very coarse' fine aggregate could compromise workability. Hence, the fineness modulus obtained was 2.68 which shows that the material was not very fine and not very coarse either, and therefore suitable for the production of concrete with high workability and finish-ability.

4.2.1.3 Water Absorption of PKS, Coarse Aggregate, and Fine AggSregate

The 24 hours water absorption for PKS, coarse aggregate, and fine aggregate obtained were 30.4%, 2.9%, and 6.5% respectively. Of the three aggregates, it can be seen that PKS had the highest percentage of water absorption. This high water absorption of the PKS can be attributed to the presence of micro tiny pores on the convex surface of the material. Though seems pretty high but still lower than other aggregates' water absorption such as pumice aggregates which have a 24hrs water absorption of 37% according to Hossain and Khandaker (2004).

Hence, it can be said that the high water absorption of PKS could lead to poor concrete workability as the quantified water for a given concrete workability might be absorbed by the PKS. This situation leads to poor compaction of concrete by creating voids that could compromise concrete strength and durability.

Also, due to absorptive characteristic of PKS, using PKS in concrete might serve as internal reservoirs as the absorbed water is stored in the concrete and hence enhance the gradual development of concrete strength as it is known that concrete strength continues to develop in the presence of moisture.

4.2.1.4 Specific Gravity of PKS, Coarse Aggregate and Fine Aggregate

The specific gravity for PKS, coarse aggregate, and fine aggregate recorded were 1.4, 2.58, and 2.44 respectively. From these results, PKS can be characterized as a light-weight aggregate (LWA) because Popovics (1992) stated that aggregates with specific gravity less than 2.4 are classified as LWA. Therefore, for this research, PKS was considered as a LWA.

Thus, due to the fact that PKS has been determined to be a lightweight aggregate, batching by weight will therefore mean that for the same masses of PKS and coarse aggregae, the volume of PKS will be about twice that of the coarse aggregate in the mix. This increases the surface area of PKS in the mix and increases the demand for cement paste. Hence, if the w/c ratio is held constant, concrete produced with PKS will have poor workability and strength than the concrete produced with the coarse aggregate. It can therefore be said that batching by volume works better than by weight for PKS aggregate and therefore batching by volume was adopted for this research.

Also, the low specific gravity of PKS might lead to the production of concrete with density below 2000kg/m^3. This might also cause the reduction in compressive strength as concrete density contributes significantly to the compressive strength. On the other hand, the low density of PKS concrete could bring about significant savings in construction cost as supporting members for the concrete can be of smaller sections because of the reduction in the dead load.

4.2.1.5 Aggregate Crushing Value of Palm Kernel Shells and Coarse Aggregate

The ACV for PKS and coarse aggregate were 2.15% and 17.42% respectively. BS 812 (1990) gave the maximum recommended ACV for aggregates for concrete production to 30%. This means that aggregate with higher ACV have poor resistance to compressive load while those with low ACV have good resistance to compressive load. Hence, from the results obtained, it can be seen that PKS has a lower ACV than the coarse aggregate and is therefore expected to perform better when being crushed under a gradually applied compressive load. In other words, it can be said that the material is more ductile than the coarse aggregate, and that the material can sustain stress without abrupt failure.

4.2.1.6 Aggregate Impact Value of Palm Kernel Shells and Coarse Aggregate

The AIV for PKS and coarse aggregate were 4.6% and 7.6% respectively. BS 882 (1992) specified limit for AIV for aggregates which are adequate for concrete with good impact resistance is 25%. As with the ACV, this also means that aggregate with higher AIV have weak impact resistance while those with low AIV have good impact resistance. Therefore, from the results obtained, PKS showed better impact resistance than the coarse aggregae.

Hence, it can be said that PKS is tougher than the coarse aggregate and can prevent crushing, degradation, and disintegration when stockpiled, fed through, and compacted with rollers without causing construction and performance problems. Table 4-1 shows the characteristic summary of PKS, coarse aggregate, and fine aggregate used in the research.

4.2.2 Characteristics of Rice Husk Ash and Ordinary Portland cement

The characteristics of RHA and OPC were determined in terms of their physical and chemical properties. The physical properties determined included, particle size distribution, specific gravity, and bulk density.

4.2.2.1 Physical Properties of Rice Husk Ash and Ordinary Portland Cement

Table 4-2: Physical properties of RHA and OPC

Property	**RHA**	**OPC**
Specific Gravity	1.77	3.11
Bulk Density (kg/m^3)	355.79	1396.67
Loose Density (kg/m^3)	267.59	1165.36
Mean particle size (mm)	0.15	-
Color	Grey	Grey

As shown in Table 4 – 2, the specific gravity of RHA and OPC used were 1.77 and 3.11 respectively, and hence it be said that the RHA used in this research was treated as a lightweight material since the specific gravity was below 2.4. However, though a lightweight, the material will not float in water since the specific gravity is greater than 1 and therefore mixing of the concrete can easily be achieved. Again, the low specific gravity of RHA can contribute significantly in the reduction of concrete density thereby bring a significant reduction in construction cost. On the other hand, if batching is done by weight and all other factors are held constant, for the same masses of RHA and OPC, the volume of RHA will be twice that of OPC as the specific gravity of OPC is almost twice that of RHA.

Also, it can be seen that the bulk density of RHA is just about 25% that of OPC. Hence it can be said that the OPC is about 4 times denser than the RHA, and therefore RHA can be said to contain more pores than the OPC. The most likely implication could be reduction of concrete workability as the quantified water for a particular workability will be absorbed into those pores.

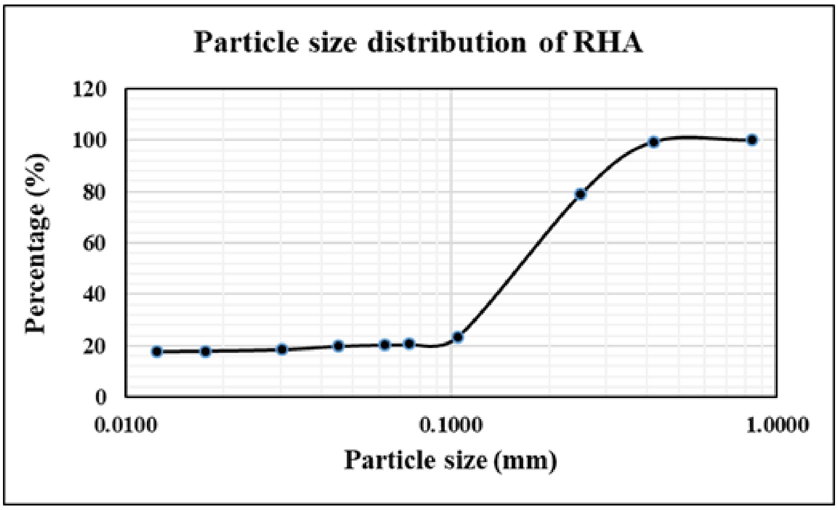


Figure 4-5: Particle size distribution of RHA

Figure 4-5 shows the particle size distribution of RHA using hydrometer analysis. It can be seen that about 50% of the particles were between 0.25mm (250µm) to 0.1mm (100µm), about 15% between 0.01mm (10µm) to 0.1mm (100µm), and about 15% below 0.01mm (10µm). The inclusion of particle sizes up 0.25mm was due to the fact that natural rice husk ash was considered for this research and hence no further grinding was done.

4.2.2.2 Chemical Analysis of Rice Husk Ash and Ordinary Portland Cement

Table 4-3: Chemical properties of RHA and OPC

Chemical composition	Content (%)	
	RHA	**OPC**
Silica (SiO_2)	80.00	22.00
Aluminum (Al_2O_3)	0.20	4.80
Calcium Oxide (CaO)	0.80	59.00
Magnesium Oxide (MgO)	0.14	0.75
Sodium Oxide (Na_2O)	0.12	0.28
Potassium Oxide (K_2O)	1.40	0.60
Iron Oxide (Fe_2O_3)	0.33	2.44
Manganese Oxide (MnO)	0.12	0.04
Titanium Oxide (TiO_2)	0.05	0.20
Loss of Ignition (LOI)	9.50	6.30

Table 4-3 shows the results of the chemical composition of RHA and OPC used in the research. From the table it can be seen that the combined percentage of silica (SiO_2), Iron Oxide (Fe_2O_3), and Alumina (Al_2O_3) for RHA was 80.5 thereby meeting the 70% minimum requirement of ASTM C618 for a good pozzolana. Also, the free lime content (CaO) of the OPC used was

59%. Therefore, the presence of silica, iron oxide, and alumina above the minimum requirement for a good pozzolana shows the ability of the RHA to form cementitious compound when mixed with the free lime of the OPC in the presence of moisture.

The Loss of Ignition (LOI) for the RHA recorded was 9.5 while it was 6.3 for the OPC. Though relatively high when compared to other pozzolanas but still below the 12% maximum standard as per ASTM C618 (2005). This high LOI could be due to the fact that the pyro processing was incomplete, and hence igniting the sample resulted in the evaporation of variety of components in the sample. For instance, carbonates could have been lost by the time the ignition was between 800 – 1000^{o}C. Hence, possible implication could be pre-hydration which could result in reduced workability, compressive strength, and might also increase setting time of the concrete.

The low calcium oxide (CaO) content of 0.8% for the RHA is also a good indicator for the production of durable concrete according to Shehata et al. (1999), who stated that low CaO content is good as it helps in the reduction of pore solution alkalinity.

4.3 EFFECT OF PALM KERNEL SHELLS AS COARSE AGGREGATE PARTIAL REPLACEMENT IN NORMAL WEIGHT CONCRETE

The effect of PKS as coarse aggregate partial replacement in concrete production was investigated for both fresh and hardened concretes. Effect was evaluated on the workability of concrete, density, compressive strength, splitting tensile strength, and water absorption of the concrete.

4.3.1 Workability of Palm Kernel Shell Concrete

The results obtained from the slump test for different percentages of PKS substitution for coarse aggregate are presented in Figure 4-6. With a constant w/c ratio, the concrete slump with 0% PKS was 39mm, 36mm at 25%PKS substitution, and 29mm at 50%PKS substitution.

Though the water absorption of PKS was taken into account, there was still a reduction in slump with increase in PKS content. Similarly, Danashmand and Saadatian (2011), and Williams et al., (2011) reported reduction in workability with increase in PKS content. This might have been due to the finer particle sizes of PKS (Figure 4 – 3) when compared to the coarse aggregate, hence increasing the surface area and demanding more water.

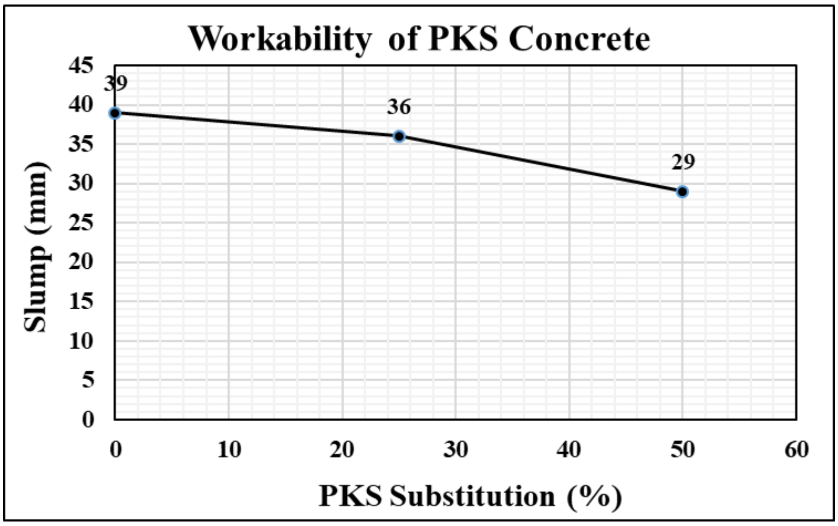


Figure 4-5: Workability of PKS concrete

Hence, decrease in workability with increase in PKS might require more compacting efforts which can lead to poor compaction. Poor compaction thus lead to leaving voids in the concrete which can caused reduction in concrete strength, density, and durability. Also, poor compacted concrete can increase the water absorption of concrete which affects concrete durability.

4.3.2 Density of Palm Kernel Shells Concrete

The difference in the density of the concrete with various PKS percentages is shown in Figure 4-7. The result shows the densities of 2459.9, 2311.9 and 2135.6 at 0%, 25% and 50% PKS substitutions respectively at 28days of curing. The figure also shows that the density of the concrete increases with curing age but decreases with increase in PKS content. Similar trend for PKS concrete density has been reported by Itam et al. (2016), Ikponmwosa et al., (2014), and Osei and Jackson (2012). This can be attributed to the low specific gravity of PKS (Table

4-1) when compared with coarse aggregate thus resulting in the reduction of concrete density as PKS percentage is increased in the mix. Also, it can be said that because of the reduction in slump, there must have been poor compaction which could have resulted in leaving voids in the concrete and hence reducing the density. However, up to 50% PKS substitution, the concrete density was still above the 2000kg/m^3 requirement for NWC as specified by BS 5328 -1 (1998) which contradicts with Ikponmwosa et al. (2014) findings that 50% PKS substitution led to a LWC which is below 2000kg/m^3. This can be attributed to the fact that batching by volume replaces equal quantity of coarse aggregae by PKS, which if by weight could mean twice the quantity of coarse aggregate for PKS for equal masses.

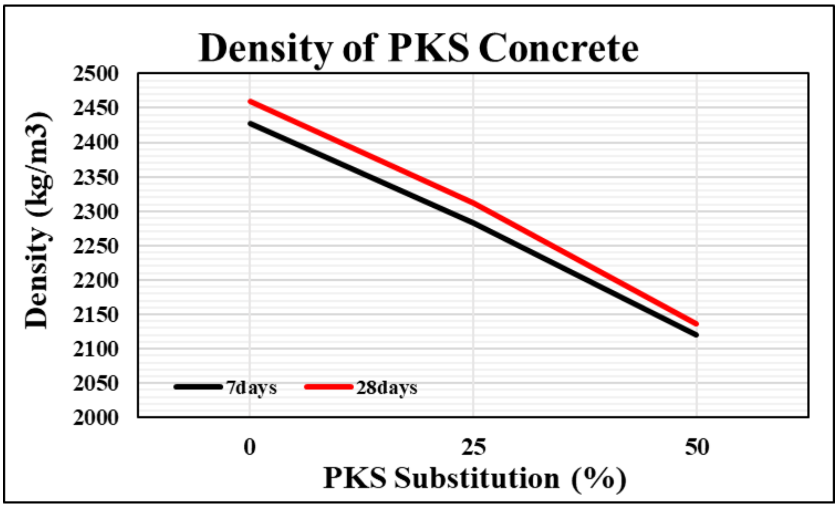


Figure 4-6: Density of PKS concrete

Hence, reduction in concrete density with increase in PKS content might result in the reduction of concrete strength as concrete density contributes to concrete compressive strength. Also, reduction in concrete density can lead to a significant reduction in construction cost as smaller sections for supporting members can be selected instead of larger ones as a result of the reduction in the dead load of the concrete.

Statistically, effect of PKS on the density of NWC was determined using a one-way analysis of variance (ANOVA). Result from the analysis (Appendix A1) shows that there was a significant effect on the densities of the concrete by the different PKS substitutions as was determined by a one-way ANOVA (F (2, 6) = 181.766, p = 0.000). Furthermore, a "post hoc test" was used to determine which substitutions were significantly different from each other. From the post hoc test, it is shown that at all levels of PKS substitution, there was a significant difference in the densities of the concrete at the 0.05 significance level.

4.3.3 Compressive Strength of Palm Kernel Shells Concrete

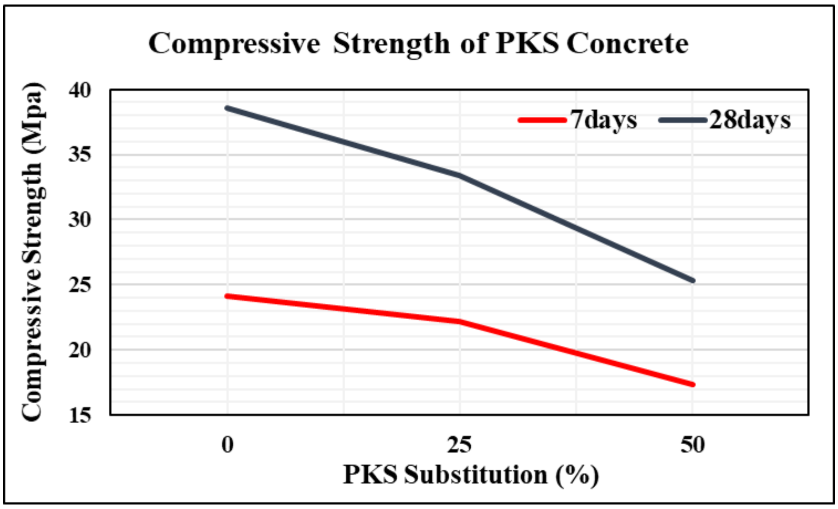


Figure 4-7: Compressive Strength of PKS concrete

The highest values obtained for the compressive strength at 7 and 28days of curing were 24.1MPa and 38.6MPa respectively for the control as shown in Figure 4-8. The compressive strengths obtained for 25% and 50%PKS substitutions were 22.2MPa and 17.3MPa at 7days of curing and, 33.4MPa and 25.3MPa at 28days respectively.

Hence, it can be seen that the compressive strength of concrete increases with days of curing but reduces with an increase in the PKS percentage in the concrete. Similar reports were made by Itam et al. (2016), Ikponmwosa et al., (2014), Daneshmand and Saadatian (2011), and Olutoge et al. (2012). Reduction in concrete compressive strength can be attributed to the poor workability of PKS concrete as was seen through the slump test (Figure 4-6). Reduction in workability might have resulted in poor compaction thereby compromising on concrete compressive strength. Also, the finer particle sizes of PKS (Figure 4-3) when compared to the coarse aggregate might have caused the reduction in the compressive strength as PKS had increased surface area thereby demanding more cement paste for proper bonding. Again, reduction in concrete density with increase in PKS content might have contributed to the reduction of compressive strength.

However, the compressive strengths obtained for all of the substitutions were above the 17MPa minimum requirement for structural concrete as specified by ACI 116R (2000). The concrete can therefore be used for the low cost construction of residential buildings.

Statistically, the effect of PKS as partial replacement of coarse aggregate on the compressive strength of NWC for the different substitutions was determined by a one-way ANOVA (Appendix A2). The analysis showed that there was a significant effect on the compressive strength of the concrete by the different substitutions PKS as was determined by a one-way ANOVA (F (2, 6) = 106.960, p = 0.000). The post hoc test conducted showed that there was a significant difference in the compressive strength of the concrete between all PKS substitutions at 0.05 significance level.

4.3.4 Tensile Splitting Strength of Palm Kernel Shells Concrete

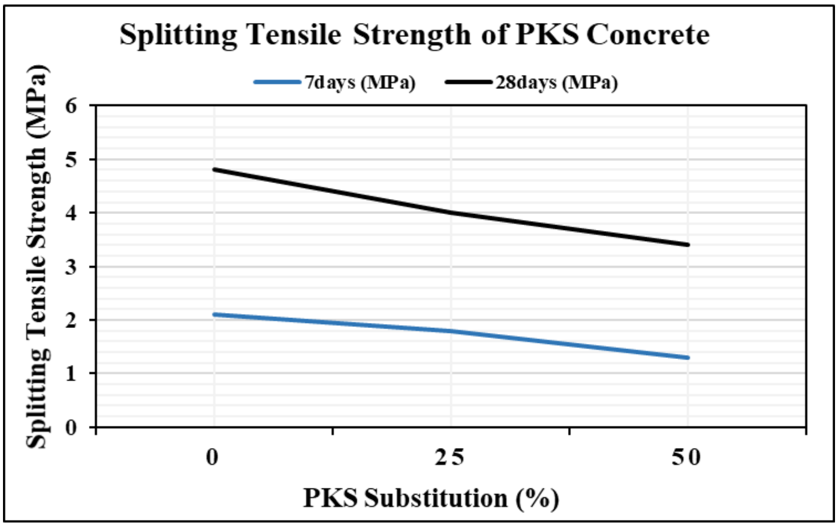


Figure 4-8: Splitting tensile strength of PKS concrete

The results for the splitting tensile strength at 7 and 28days of curing are shown in Figure 4-9. The trend of the splitting tensile strength curve is much similar to that of compression. As with the compressive strength, the tensile strength similarly reduces with an increase in PKS percentage but increases with curing age. Reduction in the splitting tensile strength can also be attributed to poor compaction, increased surface area of the PKS, and also reduction in concrete density with increase in PKS content. Hence failure was mainly due to bond failure between the aggregate and the cement paste.

From the figure, it can be seen that the splitting tensile strength reduces with increase in PKS content. Again, it was confirmed statistically (Appendix A3) that there was a significant effect on the splitting tensile strength of the concrete by the different PKS substitutions as was determined by a one-way ANOVA (F (2, 6) = 37.625, p = 0.000). However, from the post hoc test, it was shown that there was no significant difference between 25% and 50% substitutions, but there was a statistically significant difference in the splitting tensile strength between 0% and 25%, and also between 0% and 50% substitutions at the level of 0.05.

4.3.5 Water absorption of Palm Kernel Shells Concrete

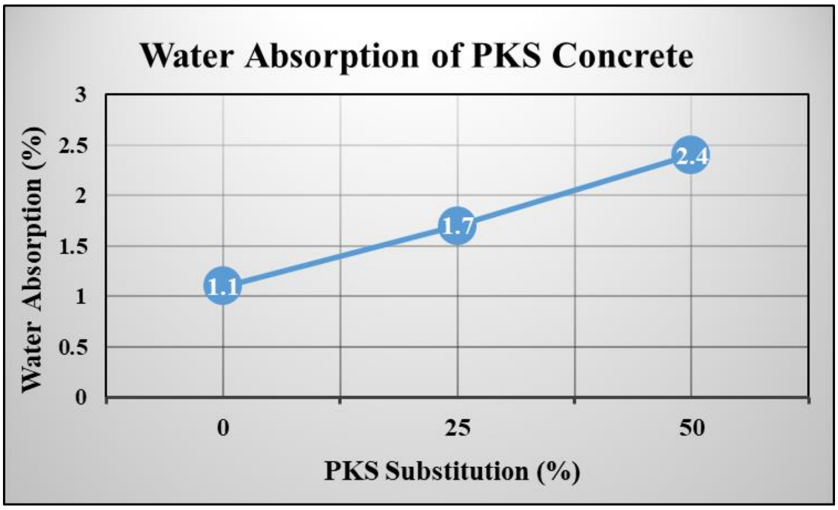


Figure 4-9: Water absorption of PKS concrete at 28 days of curing

The water absorption of PKSC at 28days is higher than that of the control concrete as shown in Figure 4-10. As oppose to the density, the water absorption of PKSC increases with an increase in PKS content in the concrete. Similar findings have been reported by Itam et al. (2016) and Olanipekun et al. (2006). This increase in water absorption with increase in PKS content can be highly attributed to the high water absorption of PKS (Table 4-1). Since PKS is highly absorptive, increasing its content in the mix will also increase the water absorption of the concrete. Also, increased in water absorption can partly be attributed to the reduction of concrete workability with increase in PKS content (Figure 4-6). Poor workability can result to poor compaction thus leaving voids in the concrete which might have increased the water absorption of the concrete.

Though higher than the control, but still considered lower when compared to other lightweight aggregate concrete such as expanded polystyrene concrete and pumice aggregate concrete with water absorption in the range of 14 – 22% according to Guduz and Ugur (2005). High water absorption can lead to less durable concrete especially in aggressive environments. On the other hand, the absorptive characteristic of PKS can be an advantage in concrete as it may serve as an internal reservoir thus enhancing the gradual development of strength.

Though the effect of PKS on the water absorption of NWC can be clearly seen on the graph, a one-way ANOVA was also conducted to ascertain the effect. It was also shown statistically (Appendix A4) that there was a significant effect on the water absorption of the concrete by the PKS percentages as was determined by a one-way ANOVA (F (2, 6) = 57.211, p = 0.000). From the post hoc test, it was shown that there was a statistically significant difference in the water absorption of the concrete between all PKS percentages. Hence, it can be said that PKS has a significant effect on the water absorption rate of NWC.

4.4 EFFECT OF RICE HUSK ASH AS PARTIAL REPLACEMENT FOR ORDINARY PORTLAND CEMENT ON NORMAL WEIGHT CONCRETE

The effect of RHA as partial replacement for Portland cement in concrete production was also investigated for both fresh and hardened states of the concrete. Effect of RHA on NWC have been determined through the workability of the concrete, density, compressive strength, splitting tensile strength, and water absorption of the concrete.

4.4.1 Workability of Rice Husk Ash Concrete

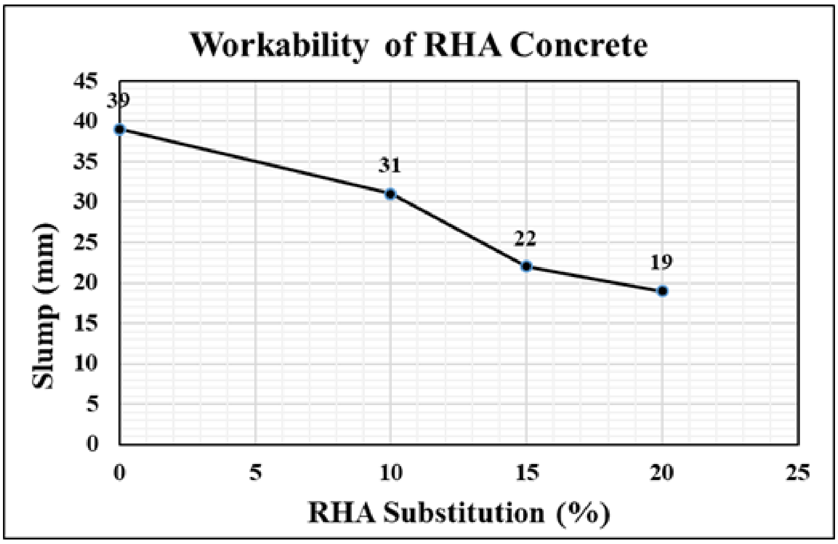


Figure 4-10: Workability of RHA concrete

With a constant w/c ratio, workability of concrete decreases as RHA percentage increases as shown in Figure 4 - 11. This can be attributed to the low bulk density and specific gravity of RHA (Figure 4-2) when compared to that of OPC. The low bulk density and specific gravity of RHA thus suggest that the material contains some pores which might be the reason why it is lighter than OPC. Hence, those pores might have absorbed some of the water quantified for the mix thereby reducing the workability of the concrete. Also, the high loss on ignition of RHA (Table 4-3) might have contributed to the reduction of concrete slump. Kartini (2011) reported that concrete containing RHA requires more water for a given constituency due to its absorptive characteristic of cellular RHA particles. Hence it can be said that more water is demanded for the workability of RHA concrete as RHA replacement for OPC is increased, and also suggesting that the lime pozzolana reactions require more water. Marthong (2012) also reported that the workability of concrete reduces with increase in RHA content.

Hence, poor workability of concrete could result into poor compaction producing concrete with so many voids. Concrete with voids as a result of poor compaction increases water absorption thus impeding on concrete durability.

4.4.2 Density of Rice Husk Ash Concrete

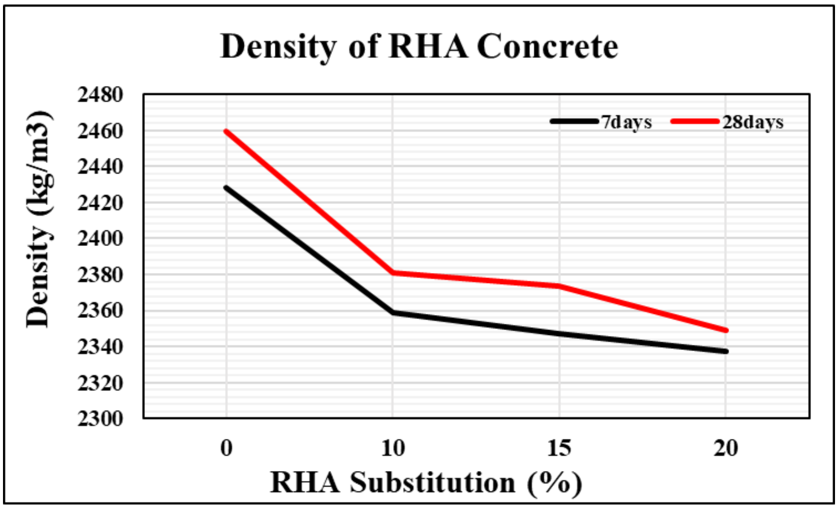


Figure 4-11: Density of RHA concrete

Results for the Densities of RHA concrete at 28 days of curing are presented in Figure 4-12. It can be seen that the density of RHA concrete increases with curing age but reduces with increase in RHA content. The increase in density with curing age might be due to the absorption of curing water in the pores of the concrete hence increasing its density. The formation of pores in the concrete might have been due to poor compaction as a result of the reduction in the concrete slump with increase in RHA content. The decrease in the density with increase in RHA content can be attributed to the low specific gravity of RHA (Table 4-2) when compared to that of OPC. Hence, increasing RHA content while reducing OPC content reduces concrete strength. Omondi (2013) also reported reduction in concrete density with increase in RHA content.

Hence, reduction in concrete density with increase in RHA content might result in the reduction of concrete strength as concrete density is significant in the determination of concrete compressive strength. Also, reduction in concrete density can lead to a significant reduction in construction cost as smaller sections can be selected instead of larger ones like those for NWC. However, though the density reduces with increase RHA content in the mix, the highest RHA replacement percentage of 20% recorded a density of 2349.2 which was about 95.5% of the control concrete and was within the range for NWC according to BS 5328 – 1 (1997). RHA concrete can therefore be used in the low cost construction of residential buildings.

From the statistical analysis (Appendix A5), there was a significant effect on densities of the concrete by different RHA percentages as was determined by a one-way ANOVA (F (3, 8) = 11.820, p = 0.003). Result from the post hoc test showed that there was a significant difference in the densities between 0% and 10% substitutions, 0% and 15% substitutions, and between 0% and 20% substitutions. However, there was no significant difference in the density between 10% and 15% substitutions, 10% and 20% substitutions, and between 15% and 20% substitutions.

4.4.3 Compressive Strength of Rice Husk Ash Concrete

Figure 4 – 13 shows the compressive strength of RHA concrete. The RHA concrete showed lower compressive strength in all the levels of substitution at 28 days of curing than the control concrete. This might have been due to the reduction in slump with increase in RHA content (Figure 4-11) resulting in poor compaction and hence affecting the compressive strength. Also, as there was a decrease in concrete density with increase in RHA content, the decrease in density might have contributed to the reduction of compressive strength. Finally, it could be

that since lime-pozzolana reactions required time, the 28 days of curing might not have been sufficient for the full strength development. Kartini (2011) also reported lower compressive strength of RHA concrete at 28days than the control concrete.

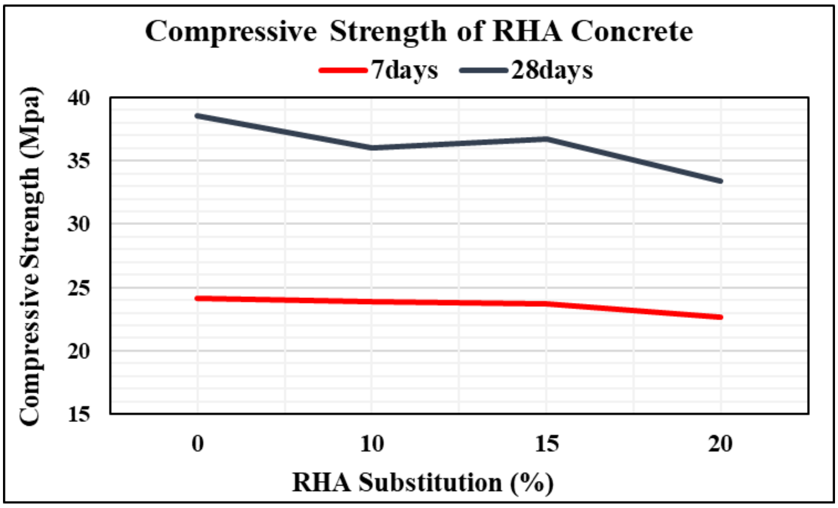


Figure 4-12: Compressive strength of RHA concrete

As can be seen from the graph, 15% RHA substitution for OPC shows the highest compressive strength at 28 days of curing beyond which there was a further decrease in strength of the concrete. This could be that, at 15% substitution, the silica content needed to have reacted with the free lime was at the optimum thereby showing a faster strength development rate than at 10 and 20% RHA contents. The further reduction in the compressive strength beyond 15% could have been due to an excess unreacted RHA particles hence acting as filler material thereby reducing the strength than the lower replacements. This also means that at 20% RHA content, the quantity of RHA present in the mix was higher than the amount required to combine with the liberated lime during the hydration process, thus leading to excess silica leaching out during the hydration process and hence causing the compressive strength to reduce. However, the compressive strengths for all of the substitutions obtained were above the 17MPa minimum requirement for structural concrete according to ACI 116R (2000). Therefore, up to 20% substitution of RHA for OPC by volume produce structural concrete and can be used for the low cost construction of residential buildings.

Statistical analysis (Appendix A6) also showed that there was a significant effect on the compressive strength of the concrete by the different RHA contents as was determined by one-way ANOVA (F (3, 8) = 13.556, p = 0.002). Result from the post hoc test showed that there was a statistically significant difference in the compressive strength between all RHA concretes except for 10% and 15% substitution in which there was no significant difference.

4.4.4 Splitting Tensile Strength of Rice Husk Ash Concrete

Figure 4-14 displayed results obtained for the splitting tensile strength of RHA concrete. As with the compressive strength, the splitting tensile strength also decreases with increase in RHA content at 7 days of curing. However, beyond the 7days, 15% substitution had the highest splitting tensile strength development rate. This could be due to the fact that beyond the 7days, the lime – pozzolana reaction might have started and that 15% RHA substitution had the optimum quantity of silica needed to have reacted with the free lime. Hence, at 20% RHA content, it can be said again that there must have been an excess unreacted RHA content which might have acted as a filler hence demanding more cement paste for proper bonding thus reducing the splitting tensile strength.

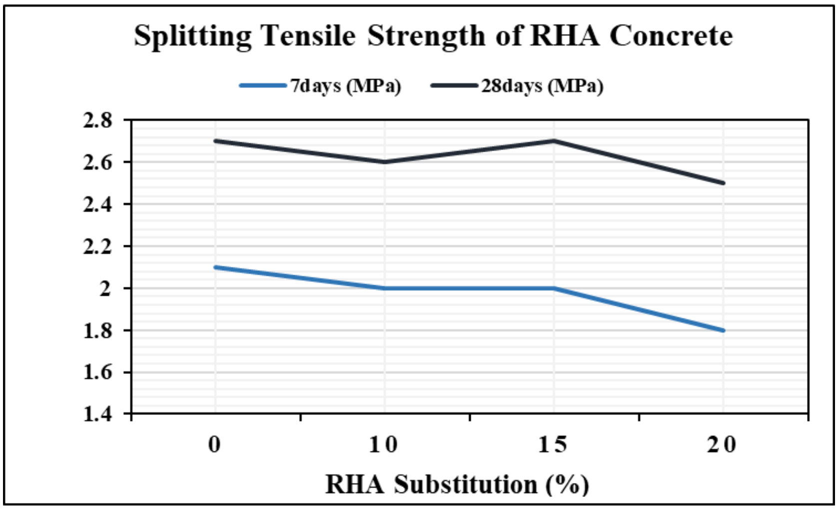


Figure 4-13: Splitting tensile strength of RHA concrete

From the one-way ANOVA (Appendix A7), it was determined that there was no significant effect on the splitting tensile strength of the concrete by the different RHA percentages as was determined by one-way ANOVA (F (3, 8) = 2.246, p = 0.160).

4.4.5 Water Absorption of Rice Husk Ash Concrete

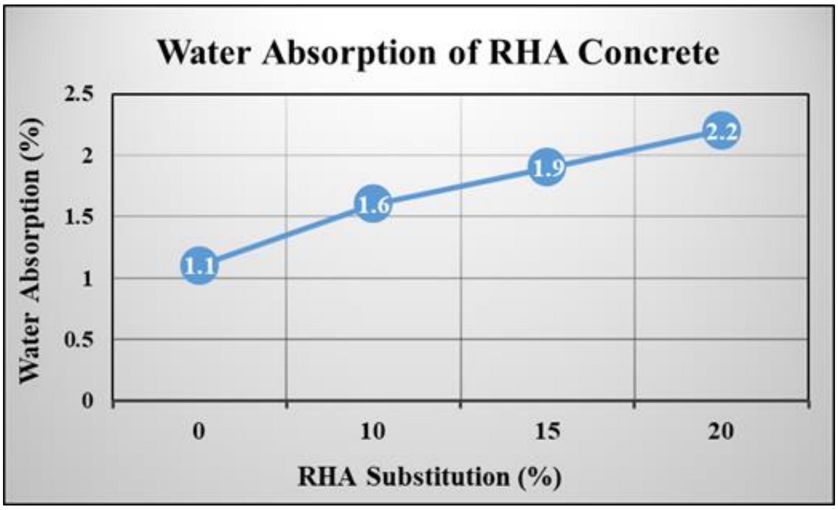


Figure 4-14: Water absorption of RHA concrete at 28 days of curing

Figure 4-15 shows the variation in water absorption with RHA contents. Test result shows that water absorption of RHA concrete increases with increase in RHA content. Concrete specimens containing RHA percentages depicted higher percentages of water absorption when compared to the control concrete at 28 days of curing. Ganesan et al. (2008) also reported higher water absorption percentage for RHA concrete at 28days than the control. Hence, increase in water absorption can be attributed to the absorptive characteristic of RHA (Kartini, 2011). Also, the reduction in the concrete slump (Figure 4-11) might have resulted in poor compaction thus leaving voids in the concrete that might have increased the water absorption of the concrete. High water absorption can lead to less durable concrete especially in aggressive environments. On the other hand, the absorptive characteristic of RHA can be an advantage in concrete as it may serve as an inner reservoir thus enhancing the gradual development of concrete strength.

From the statistical analysis (Appendix A8), it was determined that there was a significant effect on the water absorption of the concrete by the different RHA contents as was determined by one-way ANOVA (F (3, 8) = 41.684, p = 0.000). From the post hoc test, it was revealed that there was a significant difference in water absorption between all the various percentages of RHA at the level of 0.05.

4.5 EFFECT OF PALM KERNEL SHELLS AND RICE HUSK ASH AS PARTIAL REPLACEMENT OF COARSE AGGREGATE AND ORDINARY PORTLAND CEMENT RESPECTIVELY ON THE PHYSICAL AND MECHANICAL PROPERTIES OF NORMAL WEIGHT CONCRETE

The effect of PKS and RHA as partial replacements of coarse aggregate and OPC respectively have been investigated and the results are presented and discussed in this section. Effect on the mechanical properties was in terms of compression and splitting tensile tests, while effect on physical properties was in terms of workability, density of concrete, and water absorption.

4.5.1 Workability of Palm Kernel Shells and Rice Husk Ash concrete

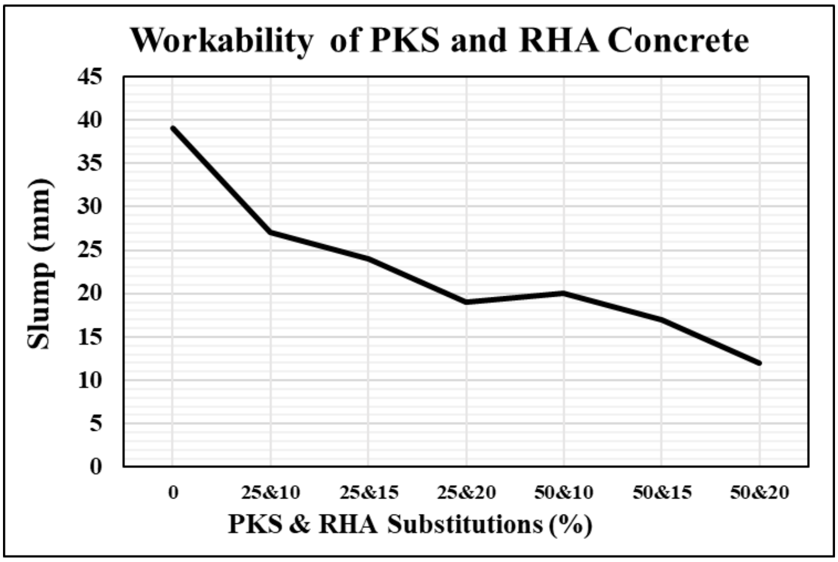


Figure 4-15: Workability of PKS and RHA concrete

Workability of PKS and RHA concrete is shown on Figure 4-16. As shown, the workability of the concrete reduces with increase in PKS and RHA content in the mix as compared to the control concrete. This can be attributed to the finer particle sizes of PKS (Figure 4-3) as compared to the coarse aggregate and hence demanding more water for a higher workability. Also, the absorptive characteristic of RHA according to Kartini (2011) might have contributed to the reduction in workability. That must be why there was a reduction in slump for all of PKS and RHA combinations than the control concrete. Again the high loss on ignition for RHA might have contributed significantly to the reduction in the workability of the concrete. High loss of ignition might have been due to the incomplete combustion process thereby containing some unburn elements that might have absorbed the water quantified for the mix and thus reducing the concrete slump.

From the graph, it appears like the RHA contributed more to the reduction in the slump than the PKS. It can be seen from the slump curve that when 25% PKS and 10% RHA were combined, the resulting slump was higher than for all other combinations. Hence, holding PKS at 25% while increasing the content of RHA to 20%, there was a further reduction of about 30%. When RHA was maintained at 10% and PKS increased to 50%, the reduction in slump was about 26%. This shows that RHA was more water demanding than the PKS which could be true since the water absorption of PKS was accounted for in the mix.

Hence, reduction in concrete slump might result in the production of porous concrete due to compaction difficulties. Porous concrete due to poor compaction leads to the reduction in concrete strength, reduced concrete density, and also increased water absorption that could compromise on the durability of the concrete.

4.5.2 Density of Palm Kernel Shells and Rice Husk Ash Concrete

The density of PKS and RHA concrete reduces with increase in PKS and RHA content but increases with curing age. As shown in Figure 4-17, the least density recorded was 2095.7 kg/m^3 when both PKS and RHA were at their highest percentages (50%PKS & 20%RHA). At their lowest percentages (25%PKS & 10%RHA), the highest density of 2276.3 kg/m^3 was recorded. Thus, the reduction in the density can be attributed to the low specific gravity of PKS (Table 4-1) as compared to coarse aggregate and also the low specific gravity of RHA (Table 4-2) as compared to OPC. Also, the reduction in the concrete slump (Figure 4-16) might have caused poor compaction and thereby produced porous concrete with a reduced density. On the other hand, the increase in the density of the concrete with curing age might have been due to the absorption of the curing water in the pores of the concrete.

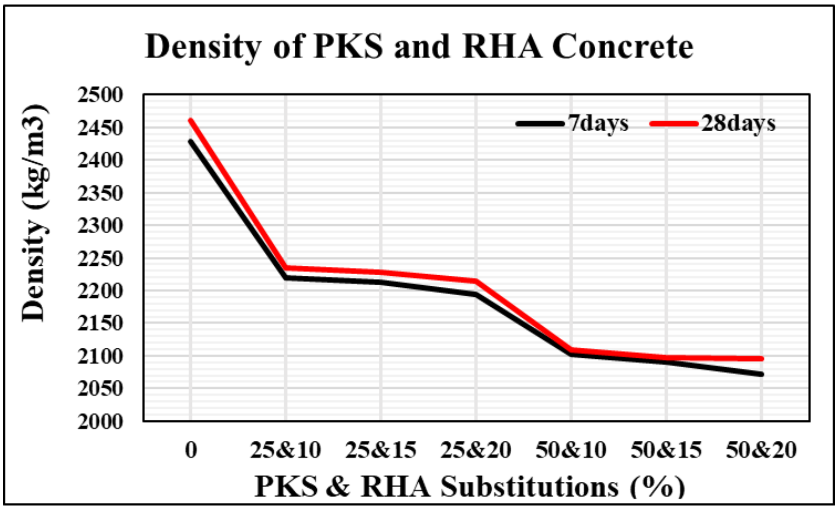


Figure 4-16: Density of PKS and RHA concrete

Again, it can be seen that though both PKS and RHA contributed in the reduction of the concrete density, bulk of the reduction was governed by the PKS content. The curve can be seen to have dropped significantly when PKS content was increased from 25% to 50% which was not the case for the increase in the content of RHA. This could be due to the fact that the specific gravity of PKS is lower than that of RHA and also PKS had a larger volume and a higher percentage in the mix than the RHA.

However, the lowest density from all of the combinations was above the 2000kg/m^3 minimum requirement for NWC according to BS 5328-1 (1997). Hence, PKS and RHA partial replacement for coarse aggregate and OPC respectively by volume produces concrete with density in the range of NWC. However, reduction in density can result in significant savings in construction cost as smaller sections for supporting members for the concrete can be selected. Nevertheless, reduction in concrete density might also lead to the reduction in the concrete strength.

Statistically, a factorial analysis (Appendix A9) was carried out to check the effect of PKS, RHA, and the interaction between PKS and RHA on the density of the concrete. It was determined that PKS ($p = 0.000$) had a significant effect on the density of the concrete, RHA ($p = 0.000$) also had a significant effect on the density of the concrete, but the interaction between PKS and RHA ($p = 0.135 > 0.05$) had no significant effect on the concrete density. From the post hoc test, it was shown that there was a significant difference in the density of the concrete between all of PKS substitutions. For RHA, though it had a significant effect on the concrete density, it was found that there was no significant difference in the density of the concrete between 10% and 15% substitutions, and also between 15% and 20% substitutions at 0.05 level of significance.

4.5.3 Compressive strength of Palm Kernel Shells and Rice Husk Ash Concrete

As shown in Figure 4-18, the compressive strength of PKS and RHA concrete reduces with increase in PKS and RHA content but increases with curing age. This can be attributed to the increased surface area of PKS as it was finer than the coarse aggregate (Figure 4-3) thereby resulting into weak bonding as more cement paste might have been demanded. It can also be attributed to poor compaction which might have resulted due to the reduction in the slump (Figure 4-16) creating voids that might have led to the reduction of the compressive strength. Also, the reduction in the concrete density with increased in PKS and RHA content (Figure 4-17) might have also contributed to the reduction in the compressive strength. Again, since lime – pozzolana reactions required time, it could be that the 28 days curing period was not sufficient for the full development of the strength and thus resulting in the reduction of the compressive strength.

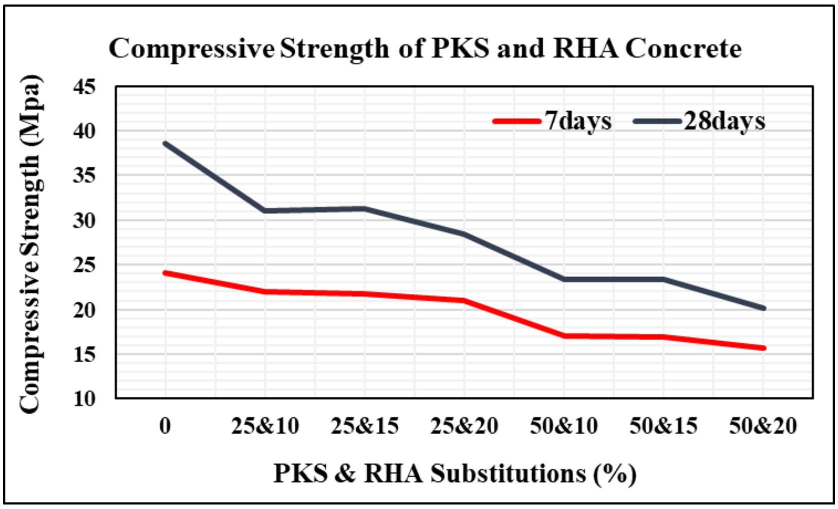


Figure 4-17: Compressive strength of PKS and RHA concrete

From the graph, the 25%PKS and 15%RHA combination is seen to have the highest compressive strength than any other combination at 28 days of curing. The reason for this might be that beyond the 7 days of curing, the lime – pozzolana reactions might have started and that the 15% RHA had the maximum amount of silica content needed to have reacted with the free lime and thus resulting in a faster strength development rate than the other substitutions. However, though compressive strengths for all of the combinations were lower than that of the control concrete, the least compressive strength obtained was yet still above the minimum compressive strength requirement of 2,500psi (17MPa) for structural concrete according to ACI 116R (2000). Hence, PKS and RHA can be used as partial replacement of coarse aggregate and OPC respectively to produce structural concrete for the low cost construction of residential buildings.

A factorial analysis (Appendix A10) was carried out to check the effect of PKS, RHA, and the interaction between PKS and RHA on the compressive strength of the concrete. It was determined that PKS ($p = 0.000$) had a significant effect on the compressive strength of the concrete, RHA ($p = 0.000$) had a significant effect on the compressive strength of the concrete, but the interaction between PKS and RHA ($p = 0.999 > 0.05$) had no significant effect on the concrete compressive strength. From the post hoc test, it was shown that there was a significant difference in the concrete compressive strength between all PKS levels of substitution. However, though RHA had a significant effect on the concrete compressive strength, it found that there was no significant difference in compressive strength between 10% and 15% substitutions at 0.05 level of significance.

4.5.4 Splitting tensile strength of Palm Kernel Shells and Rice Husk Ash Concrete

Figure 4-19 depicts the splitting tensile strength of PKS and RHA concrete. Similar trends as the compressive strength were observed with the splitting tensile strength. Increase in the percentage of PKS and RHA contents resulted in the reduction of the splitting tensile strength while there was an increase in the splitting tensile strength with curing age. Reduction in the splitting tensile strength with increase in PKS and RHA contents can also be attribute to the increase surface area of PKS which might have resulted in poor bonding. Reduction in the concrete slump (Figure 4-16) might have also caused poor compaction hence leading to porous concrete and the subsequent reduction in concrete strength. Also, the reduction in the concrete density (Figure 4-17) might have also contributed to the splitting tensile strength reduction of the concrete. Again, 28 days of curing might not have been sufficient for the full development of strength and hence resulting to a lower strength.

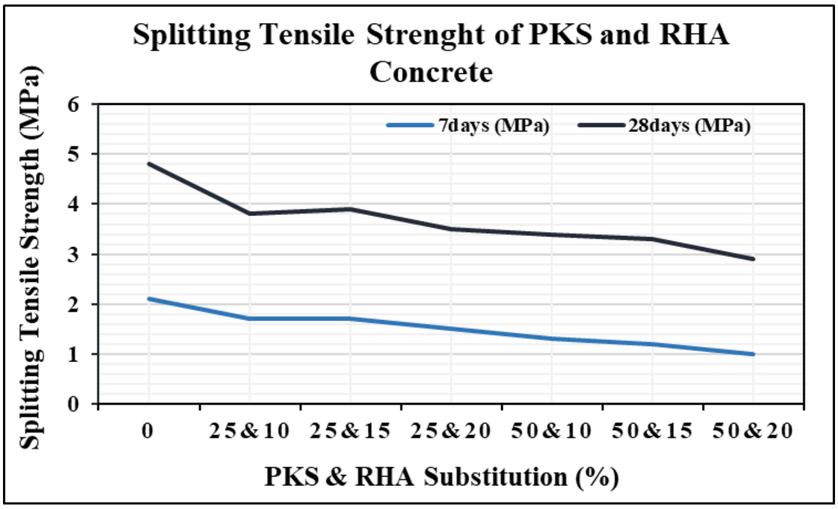


Figure 4-18: Splitting tensile strength of PKS and RHA concrete

A factorial analysis (Appendix A11) was carried out to determine the effect of PKS, RHA, and the interaction between PKS and RHA on the splitting tensile strength of the concrete. It was determined that PKS (p = 0.000) had a significant effect on the splitting tensile strength of the concrete, RHA (p = 0.012) had a significant effect on the splitting tensile strength of the concrete, but the interaction between PKS and RHA (p = 0.986 > 0.05) had no significant effect on the splitting tensile strength of the concrete. From the post hoc test, it was shown that though PKS had a significant effect on the splitting tensile strength of the concrete, there was no significant difference in the splitting tensile strength of the concrete between 25% and 50% substitutions. Similarly, it was found that there was no significant difference in the splitting tensile strengths between 0% and 10%, 0% and 15%, and also between 10% and 15% RHA substitutions at 0.05 level of significance.

4.5.5 Water absorption of Palm Kernel Shell and Rice Husk Ash Concrete

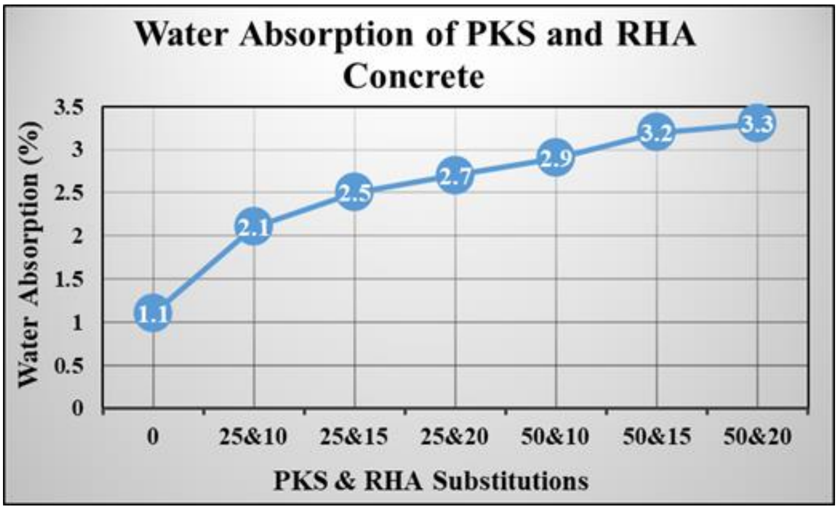


Figure 4-19: Water absorption of PKS and RHA concrete at 28 days

The water absorption of PKS and RHA concrete increases with increase in PKS and RHA content as can be seen in Figure 4-20. This can be attributed to the high water absorption of PKS (Table 4-1) as compared to coarse aggregate. Also, the absorptive characteristic of RHA according to Kartini (2011) might have also contributed to the increase in water absorption with increase in RHA content. Again, the reduction in the concrete slump (Figure 4-16) might have caused poor compaction that may have produced porous concrete and hence increasing the water absorption of the concrete.

The water absorption of the concrete with 25% PKS and all the percentages of RHA were lower than when PKS was increased to 50% with the same RHA percentages. Hence, it can be said that water absorption was chiefly governed by the PKS percentage in the mix. This can be attributed to the high absorption characteristic of PKS.

Though water absorption of PKS and RHA concrete is higher than the control concrete, but can be said to be low when compared to other lightweight aggregate concretes such as expanded polystyrene concrete and pumice aggregate concrete with water absorption in the range of 14 – 22% according to Guduz and Ugur (2005). High water absorption can lead to less durable concrete especially in aggressive environments. On the other hand, the absorptive characteristic of PKS and RHA can be advantageous as they may serve as inner reservoirs thus enhancing the gradual development of concrete strength.

A factorial analysis (Appendix A12) was conducted to determine the effect of PKS, RHA, and the interaction between PKS and RHA on the water absorption of the concrete. It was determined that PKS ($p = 0.000$) had a significant effect on the concrete water absorption, RHA ($p = 0.000$) had a significant effect on the concrete water absorption, but the interaction between PKS and RHA ($p = 0.485 > 0.05$) had no significant effect on the concrete water absorption. From the post hoc test, it was shown that there was a significant difference in the water absorption between all PKS substitutions, and also there was a significant difference in water absorption between all RHA substitutions at 0.05 level of significance.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the research conducted, the following conclusions have been made:

1. Characteristics of PKS and RHA:
    - PKS can be used as a replacement for coarse aggregate in the production of structural concrete.
    - RHA satisfies the requirement for a natural pozzolana and can therefore be used as a partial replacement for Portland cement in the production of concrete.
2. Effect of PKS on concrete:
    - The workability of PKS fresh concrete reduces with increase in PKS content. However, the problem can be handled by incorporating superplasticizers to produce the desired workability.
    - PKS in concrete reduces concrete strength. Low percentages produce higher strength than high percentages. 25% PKS content in the mix produces a more workable concrete, higher strength and density, and less water absorption than 50% PKS content in the mix as coarse aggregate replacement.
3. Effect of RHA on concrete:
    - Concrete workability decreases with increase in RHA content.
    - RHA in concrete as partial replacement for Portland cement reduces concrete strength, density, and increases water absorption at 28 days of curing. However, up to 15% RHA substitution produces workable and structural concrete.

4. Effect of PKS and RHA on concrete:
    - PKS and RHA in concrete as substitutes for coarse aggregate and OPC respectively reduce concrete workability, density, compressive and splitting tensile strength, and increase water absorption at 28 days of curing. However, 25% PKS and 15% RHA substitutions by volume produce workable and structural concrete.

5.2 RECOMMENDATIONS

The following recommendations have been made:

For possible applications:

1. PKS and RHA can be used in the production of structural concrete with good engineering properties, hence utilizing wastes and conserving the environment.
2. Based on the investigation, the lower the percentage of PKS in the mixed, the better the result of the concrete being produced. It is therefore recommended that the percentage of PKS in the mix be relatively low for better results.

For further research:

3. Pre-coating of PKS to reduce the high water absorption of the material can be investigated as it might improve on the properties of the concrete.
4. Further studies on the durability performance of PKS and RHA concrete should be carried out especially for aggressive environments due to the fact that PKS is a bio-degradable material.
5. The use of superplasticizers in PKS and RHA concrete should be investigated as they might improve on concrete engineering properties.

REFERENCES

Abdullah, A. A. A. (1984). Basic strength properties of lightweight concrete using agricultural wastes as aggregates, Proceedings of International Conference on Low-cost Housing for Developing Countries, Roorkee, India.

Abdullah, A. A. A. (1996). Palm oil shell aggregate for lightweight concrete. Waste material used in concrete manufacturing, Noyes Publication, pp. 624-636.

Abubakar, B. H., Ramadhansyah, P., and Hamidi, A. (2010). Malaysian rice husk ash Improving the durability and corrosion resistance of concrete. Concrete Research Letters, Vol. 1.

ACI 318 (1995). Building code requirements for structural concrete. American Concrete Institute.

ACI Committee 116 (ACI 116R-2000). Cement and Concrete Terminology. American Concrete Institute, armington Hills, Mich.,2000, 73 pp.

Alengaram, U.J., Jumaat, M.Z. and Mahmud, H. (2008). Influence of cementitious materials and aggregate content on compressive strength of palm kernel shell concrete. Journal of Applied Sciences, Vol. 8(18), pp. 3207-3213.

Alengaram, U. J., Mahmud, H., Jumaat, M. Z. and Shirazi, S. M. (2010). Effect of aggregate size and proportion on strength properties of palm kernel shell concrete. International Journal of Physical Science, Vol. 5(12), pp. 1848–1856.

Alengaram, U.J., Mahmud, H. and Jumaat, M.Z, (2011). Enhancement and prediction of modulus of elasticity of palm kernel shell concrete, Materials and Design, Vol. 32, pp. 2143-2148.

Alengaram, U.J., Abdullah, B A. M., and Jumaat, M. Z. (2013). Utilization of oil palm kernel shell as lightweight aggregate in concrete – A review. Construction and Building Materials, Vol. 38, pp. 161-172.

Antiohos, S. K., Papadakis, V. G., and Tsimas, S. (2014). Rice husk ash (RHA) effectiveness in cement and concrete as a function of reactive silica and fineness. Cement and Concrete Research, 61–62, 20–27. https://doi.org/10.1016/j.cemconres.2014.04.001

ASTM C33 (1999). Standard specification for concrete aggregates. USA: ASTM international.

ASTM C618 (2005). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. USA: ASTM International. www.astm.org/standards/C618.htm: pp. 1 – 623.

Azhagarsamy, S., and Jaiganesan, K. (2016). A Study on Strength Properties of Concrete with Rice Husk Ash and silica fume with addition of Glass Fiber, 1681–1684. International Research Journal of Engineering and Technology (IRJET). ISSN: 2395-0072. Volume: 03. www.irjet.net

Babu, K. G. and Babu, D. S. (2003). Behaviour of lightweight expanded polystyrene concrete containing silica fume, Cement and Concrete Research, Vol. 33(5), pp. 755–762.

Basheer, L., Kropp, J., and Cleland, D.J. (2001). Assessment of the durability of concrete from its permeation properties: a review. Construction Building Material, 15(2-3):93–103.

Basri, H.B., Mannan, M.A. and Zain, M. F. M. (1999). Concrete using oil palm shells as aggregate. Cement and Concrete Research, Vol., 29(4), pp. 619-622.

BS 812 Part 2 (1995). Testing aggregates. Methods for determination of density. British Standards Institution, London, UK.

BS 812 Part 103 (1990). Testing aggregates. Methods for determination of particle size distribution. British Standards Institution, London, UK.

BS 882 (1992). Specification for aggregates from natural sources for concrete. British Standards Institution, London, UK.

BS 1377 Part 2 (1990). Classification tests. Methods of test for soils for civil engineering purposes. British Standards Institution, London, UK.

BS 1881 Part 102 (1983). Testing concrete. Method for determination of slump. British Standards Institution, London, UK.

BS 1881 Part 111 (1983). Testing concrete. Method of normal curing of test specimens. Bristish Standards Institution, London, UK

BS 1881 Part 115 (1983). Testing concrete. Specification for compression testing machines for concrete. British Standards Institution, London, UK.

BS 1881 Part 116 (1983). Testing concrete. Method for determination of compressive strength of concrete cubes. British Standards Institution, London, UK.

BS 1881 Part 117 (1983). Testing concrete. Method for determination of tensile splitting strength. British Standards Institution, London, UK.

BS 1881 Part 122 (1983). Testing concrete. Method for determination of water absorption. British Standards Institution, London, UK.

BS 1881 Part 125 (1983). Testing concrete. Method for mixing and sampling fresh concrete in the laboratory. British Standards Institution, London, UK.

BS 5328 Part 1 (1997). Guide to specifying concrete. British Standards Institution, London, UK.

BS EN 197 Part 1, (2000). Cement: Composition, specifications and conformity criteria for common cements, British Standard Institution, London, UK.

Budu, K., and Sarpong, D. (2013). Oil palm industry growth in Africa: A value chain and smallholders study for Ghana, In: Rebuilding West Africa's Food Potential, A. Elbehri (ed.), FAO/IFAD.

Chandrasekar, S., Satyanarayana, K.G., and Raghavan, P.N. (2003). Processing, Properties and Applications of Reactive Silica from Rice Husk — an Overview. Journal of Materials Science, 38:p. 3159.

Dadzie, D. K., and Yankah, J. E. (2015). Palm Kernel Shells as a partial replacement for Sand in Sandcrate block production. Chemistry and Materials Research, 7(10), 61–72.

Daneshmand, S., and Saadatian, O. (2011). Influence of Oil Palm Shell on Workability and Compressive Strength on high strength concrete. International Journal of Engineering. ISSN 1584-2665

ETSAP (2010). Energy Technology Systems Analysis Program, Joint Studies for New and Mitigated Energy Systems Final Report of Annex XI (2008-2010). https://iea-etsap.org/finreport/ETSAP-Annex-XI-final-report-final%20version-June-2012-v03.pdf

European Cement Research Academy (ECRA, 2009). Technical report ECRA-106/2009. https://www.ecra-online.org/fileadmin/redaktion/files/pdf/ECRA__Technical_Report_

CCS_Phase_II.pdf

European Concrete Platform ASBL. (2009). Sustainable Benefits of Concrete Structures. Concrete. http://www.sustainableconcrete.org.uk/main.asp?page=36

Food and Agriculture Organization (1996). Rome Declaration on World Food Security and World Food Summit Plan of Action. World food summit, 13-17 November 1996, Rome, Italy. http://www.fao.org/docrep/003/w3613e/w3613e00.HTM

Food and Agriculture Organization (2002). Rome: FAO Corporate Document Repository. Small-Scale Palm Oil Processing in Africa, ISBN 92-5-104859-2. http://www.fao.org/docrep/005/Y4355E/y4355e00.HTM

Gambhir, M.L. (2013). Concrete Technology Fifth Edition. Published by McGraw Hill Education (India) Private Limited, P-24, Green Park Extention, New Delhi 110 016.

Ganesan, K., Rajagopal, K., and Thangavel, K. (2008). Rice husk ash blended cement: Assessement of optimal level of replacement for strength and permeability properties of concrete. Construction and Building Materials 22 (2008) 1675 - 1683

Global Construction Perspective (2015). A global forecast for the construction industry to 2030, ENR Global Construction Summit 2015 New York – 10 September 2015. http://constructingexcellence.org.uk/wpcontent/uploads/2015/09/GCP_Conference_ENR_2030_WEB.pdf

Global palm oil conference (2015). Background Document: An overview of the palm oil sector: countries and companies. Bogota, Colombia 12-13 March, 2015. http://www.iuf.org/w/sites/default/files/Palm%20Oil%20Background%20document.pdf

Guduz, L. and Ugur, I. (2005). The effects of different fine and coarse pumice aggregate/cement ratios on the structural concrete properties without using any admixtures, Cement and Concrete Research, Vol. 35(9), pp.1859–1864.

Hossain, A., and Khandaker, M. (2004). Properties of volcanic pumice based cement and lightweight concrete, Cement and Concrete Research, Vol. 34(2), pp. 283–291.

Ikponmwosa, E. E., Salau, M. A., and Olonde, K. A. (2014). Suitability of crushed palm kernel shell as coarse aggregate in structural concrete. Current Advances in Civil Engineering, Volume 2, pp. 59 – 67.

Ismail Mohamed A. (2009). Study on the Properties of Palm Oil Fiber. Faculty of Civil Engineering Universti Teknologi Malaysia, 93.

Itam, Z., Beddu, S., Mohd Kamal, N. L., Alam, M. A., and Ayash, U. I. (2016). The Feasibility of Palm Kernel Shell as a Replacement for Coarse Aggregate in Lightweight Concrete. IOP Conference Series: Earth and Environmental Science, 32, 12040.

Kartini, K. (2011). Rice Husk Ash-Pozzolanic Material for Sustainability. International Journal of Applied Science and Technology, 1(6), 169–178.

Lun, L. T. (2015). Effectsof rice husk ash (RHA) produced from different temperatures on the performance of concrete. Faculty of Engineering and Green Technology, Universiti Tunku Abdul Rahman

Maeda, N., Wada, I., Kawakami, M., Ueda, T., and Pushpalal, G.K.D. (2001). Development of a New Furnace for the Production of Rice Husk Ash. The Seventh CANMET / ACI International Conference on Fly ash, Silica Fume, Slag and Natural Pozzolans in Concrete. Vol. 2, Chennai, India.

Mahmud, H. Jumaat, M. Z. and Alengaram, U. J. (2009). Influence of sand/cement ratio on Mechanical properties of palm kernel shell concrete, Journal of Applied Sciences, Vol., 9(9), pp. 1764 – 1769.

Mannan, M. A. and Ganapathy, C. (2001). Mix design for oil palm shell concrete. Cement and Concrete Research, Vol. 31, pp. 1323–1325.

Marthong, C. (2012). Effect of Rice Husk Ash (RHA) as Partial Replacement of Cement on Concrete Properties. International Journal of Engineering Research & Technology (IJERT). ISSN: 2278-0181. Vol. 1.

Mehta, P.K. (1992). Rice husk ash—a unique supplementary cementing material. Proceedings of the International Symposium on Advances in Concrete Technology, CANMET/ACI, Athens, Greece, pp. 407–430

Ndoke, P. N. (2006). Performance of palm kernel shells as a partial replacement for coarse aggregate in asphalt concrete. Leonardo Electronic Journal of Practices and Technologies, Vol. 5(9), pp. 145-52.

Okafor, F. O. (1988). Palm kernel shell as a lightweight aggregate for concrete. Cement and Concrete Research, Vol. 18(6), pp. 901–910.

Okoroigwe, E. C., Christopher, M. S., and Pascal, D. K. (2014). Characterization of palm kernel shell for materials reinforcement and water treatment. Journal of Chemical Engineering and Materials Science, 5(1), 1–6. https://doi.org/10.5897/JCEMS2014.0172

Okpala, D. C. (1990). Palm kernel shell as a lightweight aggregate in concrete. Building Environment, Vol. 25(4), pp. 291–296.

Olanipekun, E. A., Olusola, K. O., and Ata, O. (2006). A Comparative study of concrete properties using cocunut shell and palm kernel shell as coarse aggregates. Building and Environment 41 (2006) 297 – 301.

Olutoge, F. A. (2010). Investigations on Sawdust and Palm Kernel Shells as Aggregate Replacement, Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences, Vol. 5(4), pp. 7-13.

Olutoge, F. A., Quadri, H. A., and Olafusi, O. S. (2012). Investigation of the Strength Properties of Palm Kernel Shell Ash Concrete. Engineering, Technology & Applied Science Research, 2(6), 315–319.

Omondi, O. B. (2013). Investigation into the Cementitious Properties of a Mixture of Rice Husk Ash with Building Lime. Department of Civil and Construction Engineering, University of Nairobi.

Osei, D. Y., and Jackson, E. N. (2012). Experimental study of palm kernel shells as coarse aggregate in concrete. International Journal of Scientific and Engineering …, 3(8), 1–6.

Oti, J. E., and Kinuthia, J. M. (2015). The use of palm kernel shell and ash for concrete production. International Journal of Civil, Structural, Construction and Architectural Engineering Vol:9, No:3, 2015

Ponmalar, V., and Abraham, R. A. (2014). Study on effect of natural and ground rice husk ash concrete. KSCE journal of civil engineering (0000) 00 (0): 1 – 6. Doi: 10.1007/s 12205 –

014 – 2019 – 4.

Popovics, S. (1992). Concrete Materials Properties, Specifications and Testing, 2nd Edition, Noyes Publications, New Jersey, USA.

Population reference bureau (2016). 2016 World Population Data Sheet http://poppov.org/Home/Publications/Datasheets/2016/2016-world-population-data-sheet.aspx

Rao, P. P., Kumar, A. P., and Singh, B. B. (2014). A Study on Use of Rice Husk Ash in Concrete. International Journal of Education and Applied Research, 33, 75–81.

Rossignolo, J. A., Agnesini, M.V.C. and Morais, J. A. (2003). Properties of high-performance LWC for precast structures with Brazilian lightweight aggregates. Cement & Concrete Composites, Vol. 25, pp. 77-82.

Salas, A., Delvasto, S., Gutierrez, R. M., and Lange, D. (2009). Comparison of two processes for treating rice husk ash for use in high performance concrete. Cement and Concrete Research, 39 (2009) 773 - 778

Shafigh, P., Jumaat, M. Z., and Mahmud, H. (2010). Mix design and mechanical properties of oil palm shell lightweight aggregate concrete: A review. International Journal of the Physical Sciences, 5(14), 2127–2134.

Shafigh P., Jumaat Z. M., and Mahmud, H. (2011). Oil palm shell as a lightweight aggregate for production high strength lightweight concrete. Constr Build Mater:1848–53.

Shehata, M. H., Thomas, M. D. A., and Bleszynski, R. F. (1999). The effects of fly ash composition on the chemistry of pore solution in hydrated cement pastes. Cement and Concrete Research 29 (1999) 1915–1920.

Shetty, M. S. (2005). Concrete technology theory and practice, India, S. Chand & Company Ltd., India.

Shivaram, M.S. (2014). Measures to Contain Pollution Caused Due to Cement Productions:-A review. International Journal of Emerging Technology and Advanced Engineering, 4(11).

Smith, T., and Maillard, P.-L. (2007). The Sustainable Benefits of Concrete Pavement.

Stanley, C., and Bond, G. (1999). Concrete Through The Ages. https://doi.org/ISBN 0 7210

1547 6.

Teo, D. C. L., Mannan, M. A. and Kurian, V. J. (2006). Structural Concrete Using Oil Palm Shell (OPS) as Lightweight Aggregate, Turkish Journal of Engineering and Environmental Science, Vol. 30, pp. 1–7.

Teo, D. C. L., Mannan, M. A., Kurian, V. J. and Ganapathy, C. (2007). Lightweight Concrete Made From Oil Palm Shell (Ops): Structural Bond And Durability Properties. Building and Environment, 42, 2614-2621.

Trend in Global Carbon Dioxide Emission (TGCE, 2015). PBL Netherlands Environmental Assessment Agency. http://edgar.jrc.ec.europa.eu/news_docs/jrc-2015-trends-in-global-co2-emissions-2015-report-98184.pdf

United States Geological Survey (USGS, 2015). Mineral Commodity Summaries, January 2015. https://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf

Wiegrink, K., Marikunte, S., and Shah, S. P. (1996). Shrinkage Cracking of High-Strength Concrete. ACI Materials Journal, 93(5). https://doi.org/10.14359/9844

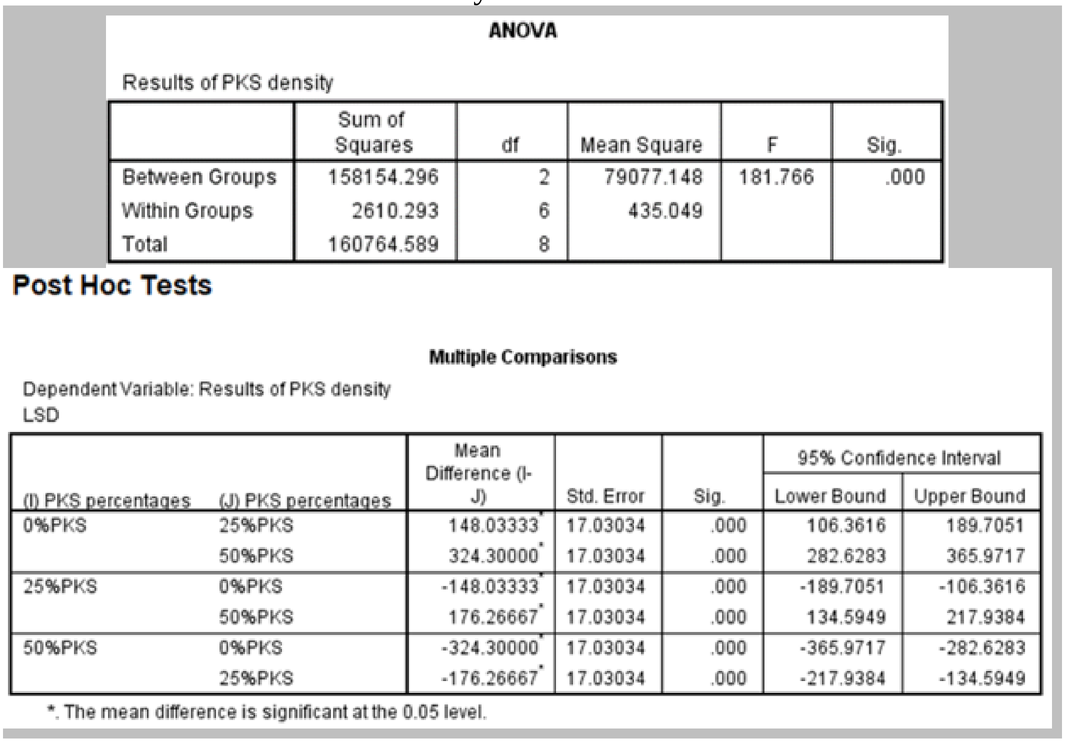
Williams, F.N1, Ijigah, E.A1 Anum, I2, Isa, R.B1 and Obanibi, A. O. (2014). Suitabilty of Palm Kernel Shell As Coarse Aggregate In Lightweight Concrete Production. Civil and Environmental Research, 6(7), 55–60.

Yap, S., Alengaram, U. J., Jumaat, M. Z., and Foong, K. Y. (2013). Waste Materials in Malaysia for Development of Sustainable Concrete: A Review. Electronic Journal of Structural Engineering, 13(1), 6

APPENDICES

APPENDIX A: Statistical analysis on the effect of PKS and RHA on the properties of c concrete

Appendix A1: Effect of PKS on the density of concrete



ANOVA

Results of PKS density

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	158154.296	2	79077.148	181.766	.000
Within Groups	2610.293	6	435.049		
Total	160764.589	8			

Post Hoc Tests

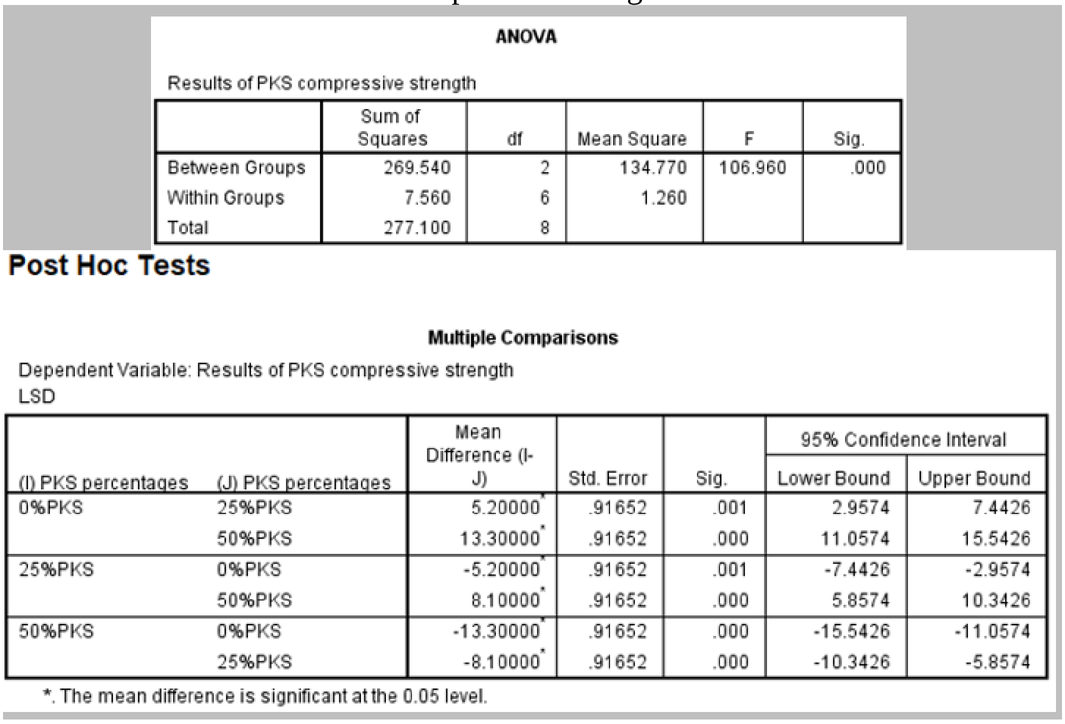
Multiple Comparisons

Dependent Variable: Results of PKS density
LSD

(I) PKS percentages	(J) PKS percentages	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0%PKS	25%PKS	148.03333*	17.03034	.000	106.3616	189.7051
	50%PKS	324.30000*	17.03034	.000	282.6283	365.9717
25%PKS	0%PKS	-148.03333*	17.03034	.000	-189.7051	-106.3616
	50%PKS	176.26667*	17.03034	.000	134.5949	217.9384
50%PKS	0%PKS	-324.30000*	17.03034	.000	-365.9717	-282.6283
	25%PKS	-176.26667*	17.03034	.000	-217.9384	-134.5949

*. The mean difference is significant at the 0.05 level.

Appendix A2: Effect of PKS on the compressive strength of concrete



ANOVA

Results of PKS compressive strength

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	269.540	2	134.770	106.960	.000
Within Groups	7.560	6	1.260		
Total	277.100	8			

Post Hoc Tests

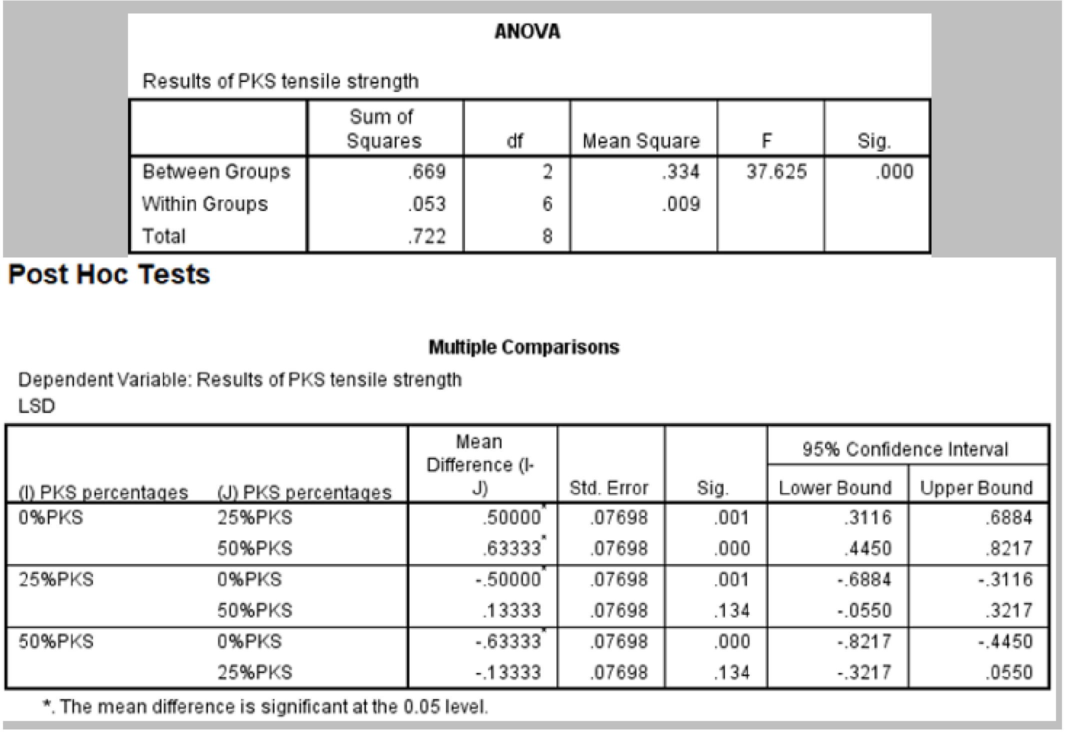
Multiple Comparisons

Dependent Variable: Results of PKS compressive strength
LSD

(I) PKS percentages	(J) PKS percentages	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0%PKS	25%PKS	5.20000*	.91652	.001	2.9574	7.4426
	50%PKS	13.30000*	.91652	.000	11.0574	15.5426
25%PKS	0%PKS	-5.20000*	.91652	.001	-7.4426	-2.9574
	50%PKS	8.10000*	.91652	.000	5.8574	10.3426
50%PKS	0%PKS	-13.30000*	.91652	.000	-15.5426	-11.0574
	25%PKS	-8.10000*	.91652	.000	-10.3426	-5.8574

*. The mean difference is significant at the 0.05 level.

Appendix A3: Effect of PKS on the splitting tensile strength of concrete



ANOVA

Results of PKS tensile strength

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.669	2	.334	37.625	.000
Within Groups	.053	6	.009		
Total	.722	8			

Post Hoc Tests

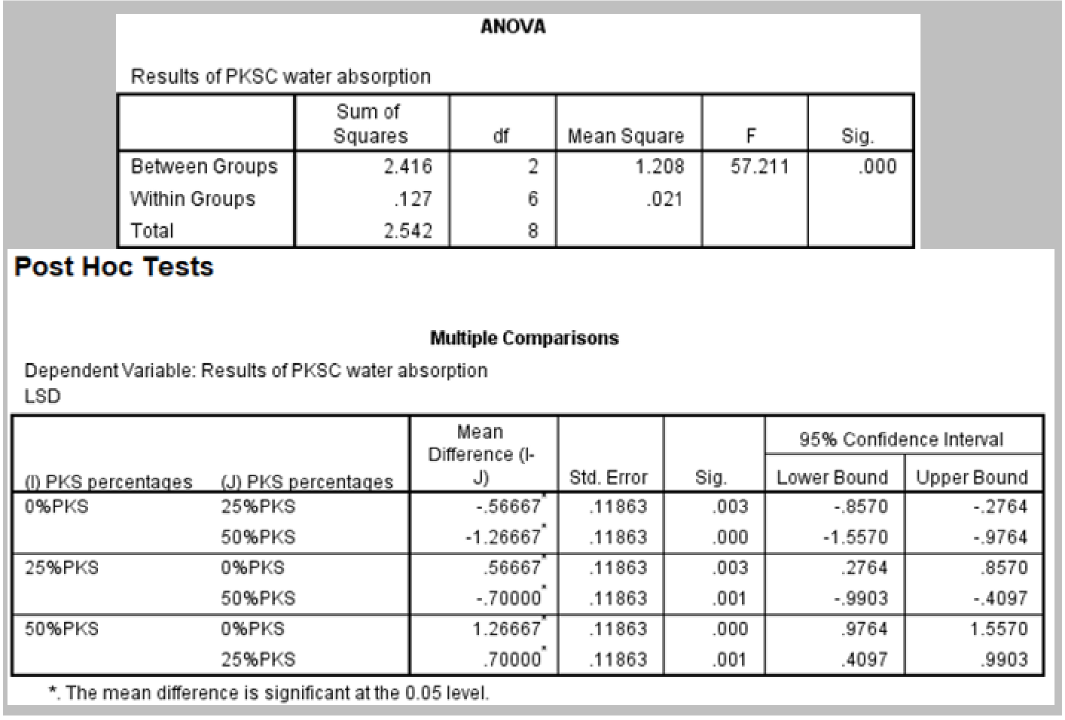
Multiple Comparisons

Dependent Variable: Results of PKS tensile strength
LSD

(I) PKS percentages	(J) PKS percentages	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0%PKS	25%PKS	.50000*	.07698	.001	.3116	.6884
	50%PKS	.63333*	.07698	.000	.4450	.8217
25%PKS	0%PKS	-.50000*	.07698	.001	-.6884	-.3116
	50%PKS	.13333	.07698	.134	-.0550	.3217
50%PKS	0%PKS	-.63333*	.07698	.000	-.8217	-.4450
	25%PKS	-.13333	.07698	.134	-.3217	.0550

*. The mean difference is significant at the 0.05 level.

Appendix A4: Effect of PKS on the water absorption of concrete



ANOVA

Results of PKSC water absorption

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.416	2	1.208	57.211	.000
Within Groups	.127	6	.021		
Total	2.542	8			

Post Hoc Tests

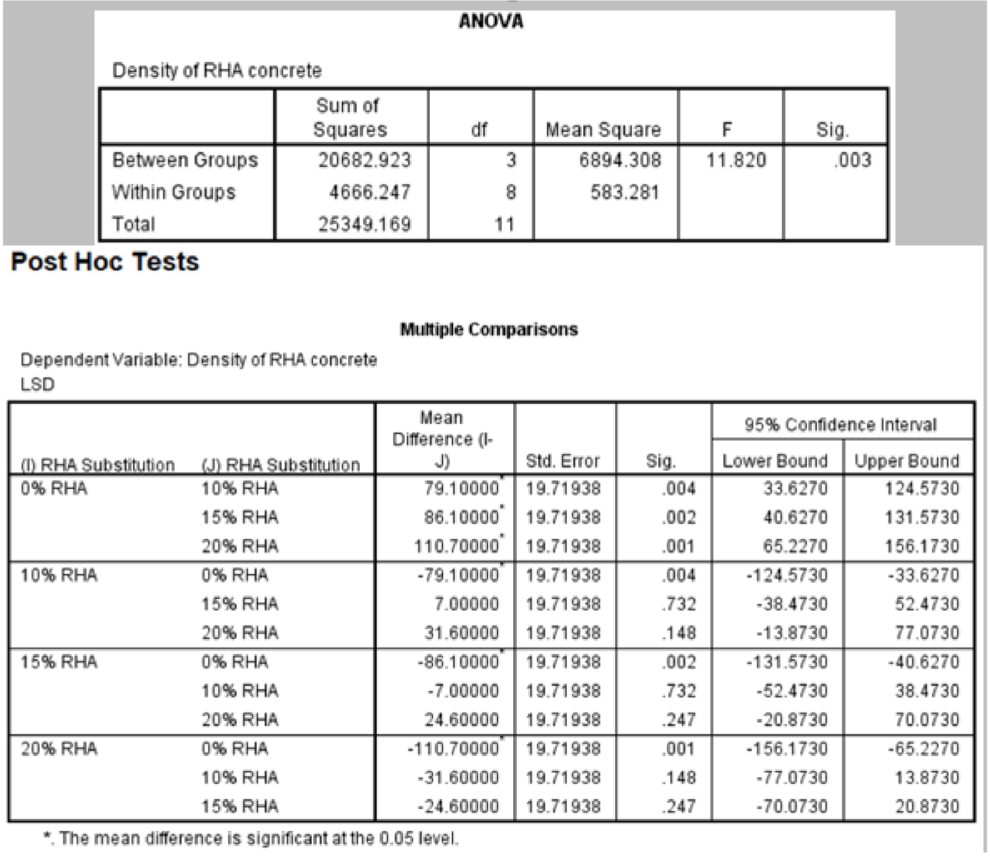
Multiple Comparisons

Dependent Variable: Results of PKSC water absorption
LSD

(I) PKS percentages	(J) PKS percentages	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0%PKS	25%PKS	-.56667*	.11863	.003	-.8570	-.2764
	50%PKS	-1.26667*	.11863	.000	-1.5570	-.9764
25%PKS	0%PKS	.56667*	.11863	.003	.2764	.8570
	50%PKS	-.70000*	.11863	.001	-.9903	-.4097
50%PKS	0%PKS	1.26667*	.11863	.000	.9764	1.5570
	25%PKS	.70000*	.11863	.001	.4097	.9903

*. The mean difference is significant at the 0.05 level.

Appendix A5: Effect of RHA on the density of concrete



ANOVA

Density of RHA concrete

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	20682.923	3	6894.308	11.820	.003
Within Groups	4666.247	8	583.281		
Total	25349.169	11			

Post Hoc Tests

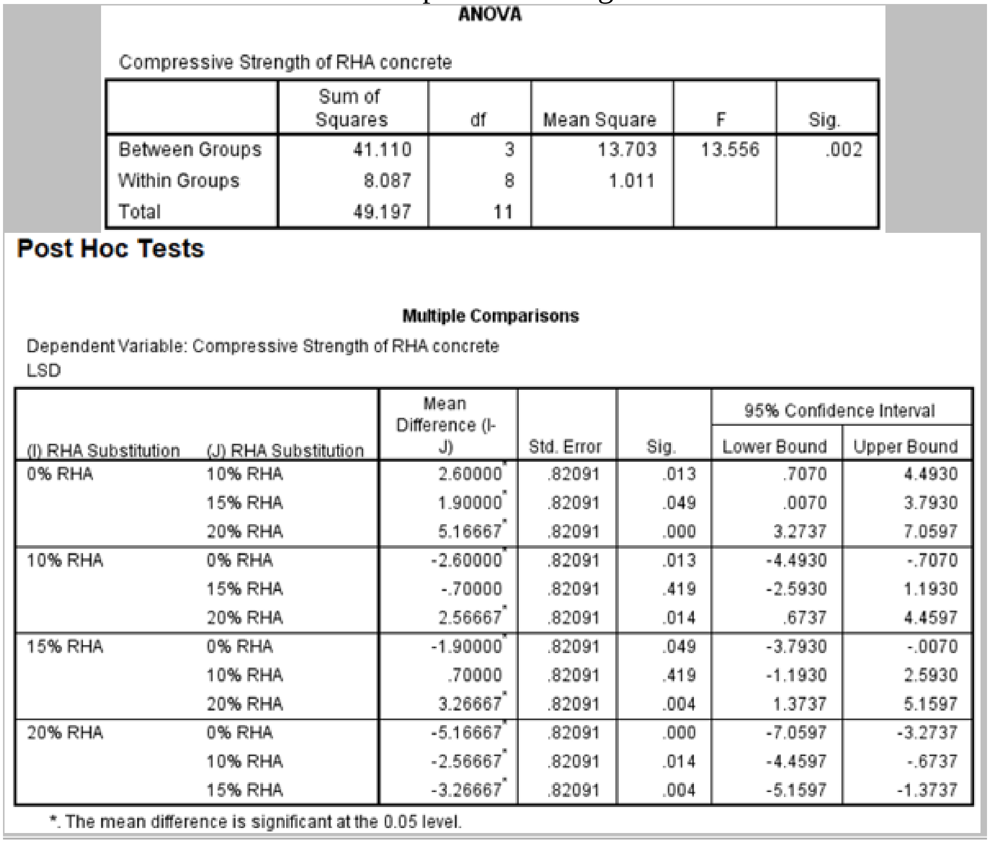
Multiple Comparisons

Dependent Variable: Density of RHA concrete
LSD

(I) RHA Substitution	(J) RHA Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% RHA	10% RHA	79.10000*	19.71938	.004	33.6270	124.5730
	15% RHA	86.10000*	19.71938	.002	40.6270	131.5730
	20% RHA	110.70000*	19.71938	.001	65.2270	156.1730
10% RHA	0% RHA	-79.10000*	19.71938	.004	-124.5730	-33.6270
	15% RHA	7.00000	19.71938	.732	-38.4730	52.4730
	20% RHA	31.60000	19.71938	.148	-13.8730	77.0730
15% RHA	0% RHA	-86.10000*	19.71938	.002	-131.5730	-40.6270
	10% RHA	-7.00000	19.71938	.732	-52.4730	38.4730
	20% RHA	24.60000	19.71938	.247	-20.8730	70.0730
20% RHA	0% RHA	-110.70000*	19.71938	.001	-156.1730	-65.2270
	10% RHA	-31.60000	19.71938	.148	-77.0730	13.8730
	15% RHA	-24.60000	19.71938	.247	-70.0730	20.8730

*. The mean difference is significant at the 0.05 level.

Appendix A6: Effect of RHA on the compressive strength of concrete



ANOVA

Compressive Strength of RHA concrete

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	41.110	3	13.703	13.556	.002
Within Groups	8.087	8	1.011		
Total	49.197	11			

Post Hoc Tests

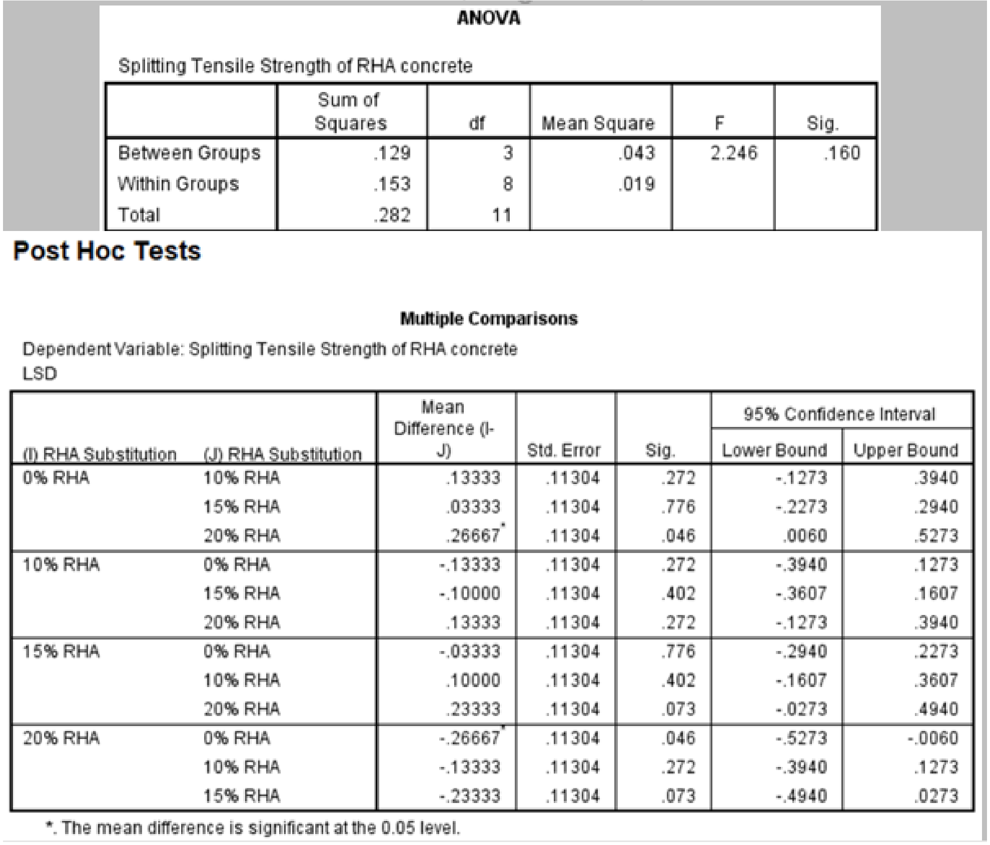
Multiple Comparisons

Dependent Variable: Compressive Strength of RHA concrete
LSD

(I) RHA Substitution	(J) RHA Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% RHA	10% RHA	2.60000*	.82091	.013	.7070	4.4930
	15% RHA	1.90000*	.82091	.049	.0070	3.7930
	20% RHA	5.16667*	.82091	.000	3.2737	7.0597
10% RHA	0% RHA	-2.60000*	.82091	.013	-4.4930	-.7070
	15% RHA	-.70000	.82091	.419	-2.5930	1.1930
	20% RHA	2.56667*	.82091	.014	.6737	4.4597
15% RHA	0% RHA	-1.90000*	.82091	.049	-3.7930	-.0070
	10% RHA	.70000	.82091	.419	-1.1930	2.5930
	20% RHA	3.26667*	.82091	.004	1.3737	5.1597
20% RHA	0% RHA	-5.16667*	.82091	.000	-7.0597	-3.2737
	10% RHA	-2.56667*	.82091	.014	-4.4597	-.6737
	15% RHA	-3.26667*	.82091	.004	-5.1597	-1.3737

*. The mean difference is significant at the 0.05 level.

Appendix A7: Effect of RHA on the splitting tensile strength of concrete



ANOVA

Splitting Tensile Strength of RHA concrete

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.129	3	.043	2.246	.160
Within Groups	.153	8	.019		
Total	.282	11			

Post Hoc Tests

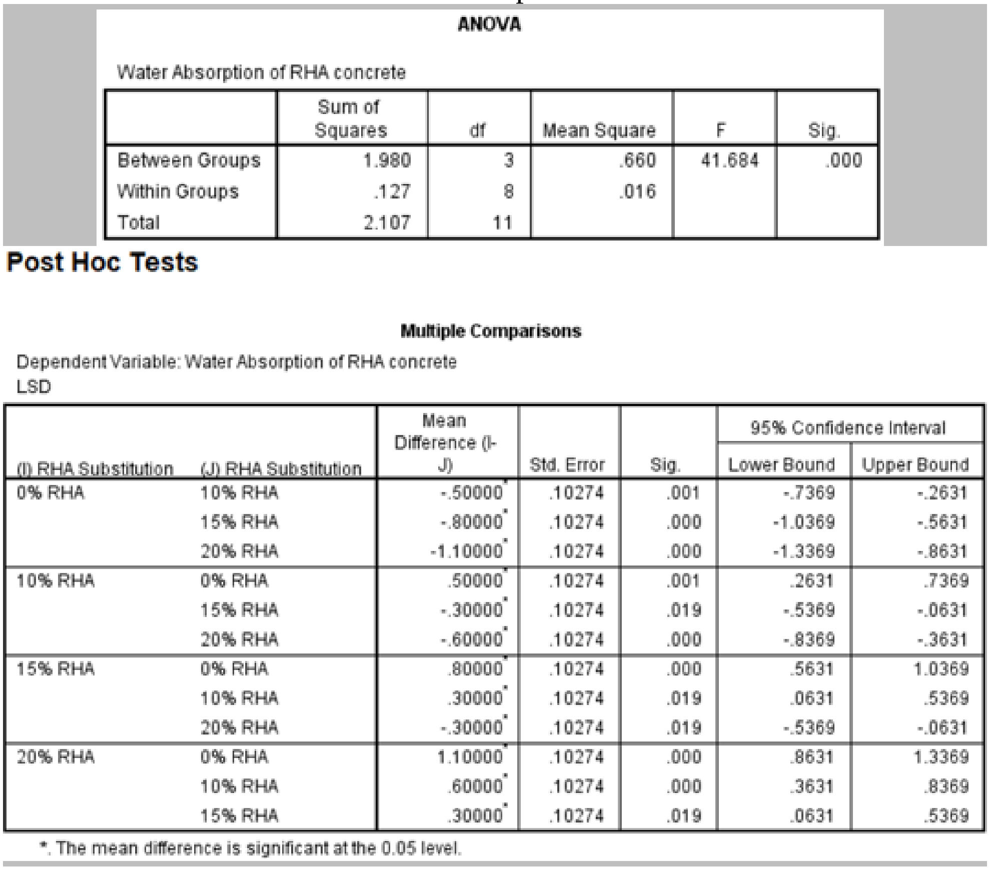
Multiple Comparisons

Dependent Variable: Splitting Tensile Strength of RHA concrete
LSD

(I) RHA Substitution	(J) RHA Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% RHA	10% RHA	.13333	.11304	.272	-.1273	.3940
	15% RHA	.03333	.11304	.776	-.2273	.2940
	20% RHA	.26667*	.11304	.046	.0060	.5273
10% RHA	0% RHA	-.13333	.11304	.272	-.3940	.1273
	15% RHA	-.10000	.11304	.402	-.3607	.1607
	20% RHA	.13333	.11304	.272	-.1273	.3940
15% RHA	0% RHA	-.03333	.11304	.776	-.2940	.2273
	10% RHA	.10000	.11304	.402	-.1607	.3607
	20% RHA	.23333	.11304	.073	-.0273	.4940
20% RHA	0% RHA	-.26667*	.11304	.046	-.5273	-.0060
	10% RHA	-.13333	.11304	.272	-.3940	.1273
	15% RHA	-.23333	.11304	.073	-.4940	.0273

*. The mean difference is significant at the 0.05 level.

Appendix A8: Effect of RHA on the water absorption of the concrete



ANOVA

Water Absorption of RHA concrete

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.980	3	.660	41.684	.000
Within Groups	.127	8	.016		
Total	2.107	11			

Post Hoc Tests

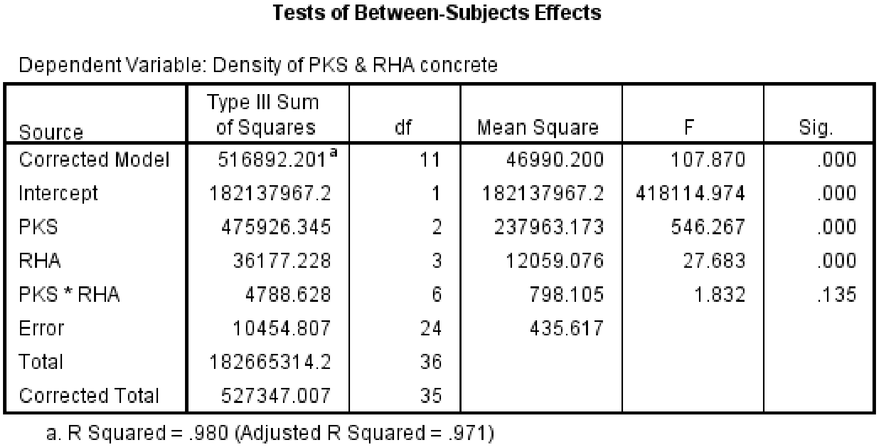
Multiple Comparisons

Dependent Variable: Water Absorption of RHA concrete
LSD

(I) RHA Substitution	(J) RHA Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% RHA	10% RHA	-.50000*	.10274	.001	-.7369	-.2631
	15% RHA	-.80000*	.10274	.000	-1.0369	-.5631
	20% RHA	-1.10000*	.10274	.000	-1.3369	-.8631
10% RHA	0% RHA	.50000*	.10274	.001	.2631	.7369
	15% RHA	-.30000*	.10274	.019	-.5369	-.0631
	20% RHA	-.60000*	.10274	.000	-.8369	-.3631
15% RHA	0% RHA	.80000*	.10274	.000	.5631	1.0369
	10% RHA	.30000*	.10274	.019	.0631	.5369
	20% RHA	-.30000*	.10274	.019	-.5369	-.0631
20% RHA	0% RHA	1.10000*	.10274	.000	.8631	1.3369
	10% RHA	.60000*	.10274	.000	.3631	.8369
	15% RHA	.30000*	.10274	.019	.0631	.5369

*. The mean difference is significant at the 0.05 level.

Appendix A9: Effect of PKS and RHA on the density of the concrete



Tests of Between-Subjects Effects

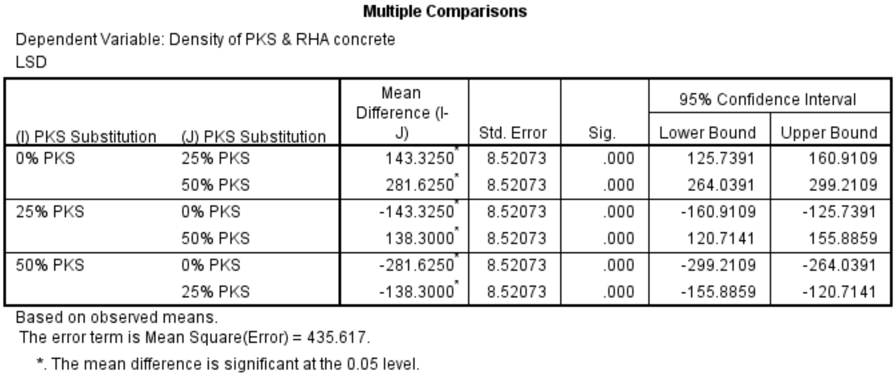
Dependent Variable: Density of PKS & RHA concrete

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	516892.201[a]	11	46990.200	107.870	.000
Intercept	182137967.2	1	182137967.2	418114.974	.000
PKS	475926.345	2	237963.173	546.267	.000
RHA	36177.228	3	12059.076	27.683	.000
PKS * RHA	4788.628	6	798.105	1.832	.135
Error	10454.807	24	435.617		
Total	182665314.2	36			
Corrected Total	527347.007	35			

a. R Squared = .980 (Adjusted R Squared = .971)

Post Hoc Tests

PKS Substitution



Multiple Comparisons

Dependent Variable: Density of PKS & RHA concrete
LSD

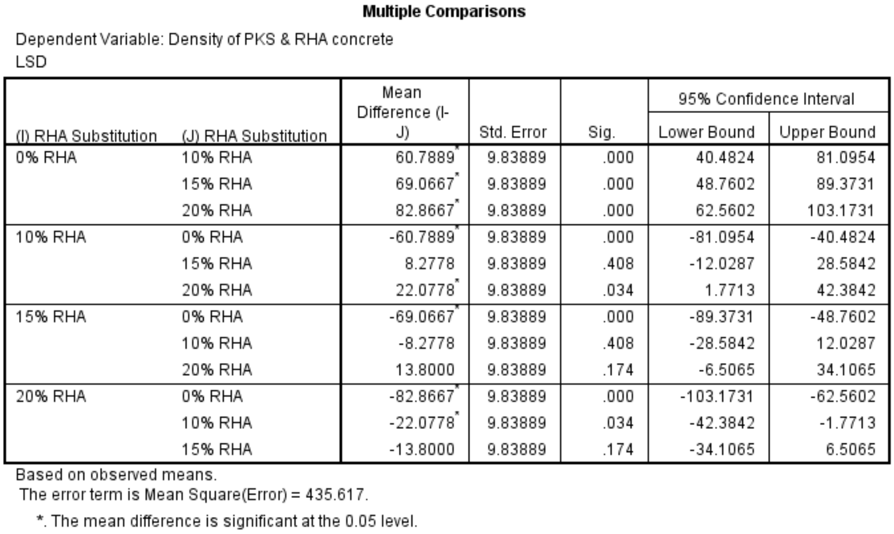
(I) PKS Substitution	(J) PKS Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% PKS	25% PKS	143.3250*	8.52073	.000	125.7391	160.9109
	50% PKS	281.6250*	8.52073	.000	264.0391	299.2109
25% PKS	0% PKS	-143.3250*	8.52073	.000	-160.9109	-125.7391
	50% PKS	138.3000*	8.52073	.000	120.7141	155.8859
50% PKS	0% PKS	-281.6250*	8.52073	.000	-299.2109	-264.0391
	25% PKS	-138.3000*	8.52073	.000	-155.8859	-120.7141

Based on observed means.
The error term is Mean Square(Error) = 435.617.

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

RHA Substitution



Multiple Comparisons

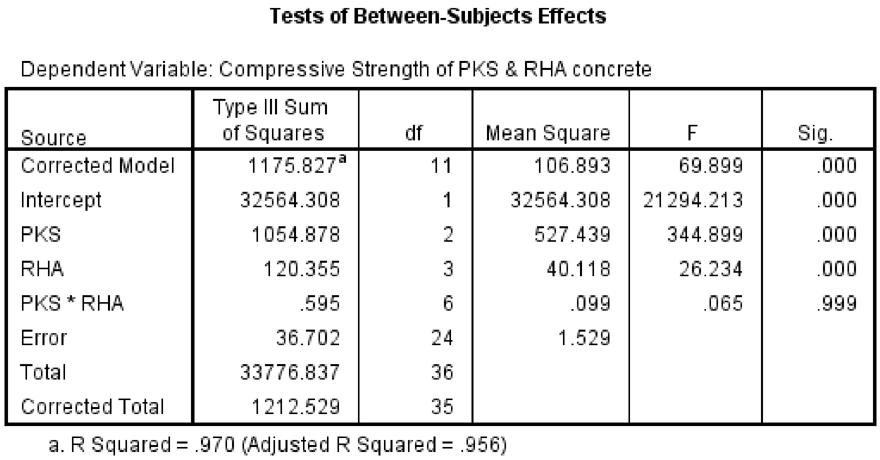
Dependent Variable: Density of PKS & RHA concrete
LSD

(I) RHA Substitution	(J) RHA Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% RHA	10% RHA	60.7889*	9.83889	.000	40.4824	81.0954
	15% RHA	69.0667*	9.83889	.000	48.7602	89.3731
	20% RHA	82.8667*	9.83889	.000	62.5602	103.1731
10% RHA	0% RHA	-60.7889*	9.83889	.000	-81.0954	-40.4824
	15% RHA	8.2778	9.83889	.408	-12.0287	28.5842
	20% RHA	22.0778*	9.83889	.034	1.7713	42.3842
15% RHA	0% RHA	-69.0667*	9.83889	.000	-89.3731	-48.7602
	10% RHA	-8.2778	9.83889	.408	-28.5842	12.0287
	20% RHA	13.8000	9.83889	.174	-6.5065	34.1065
20% RHA	0% RHA	-82.8667*	9.83889	.000	-103.1731	-62.5602
	10% RHA	-22.0778*	9.83889	.034	-42.3842	-1.7713
	15% RHA	-13.8000	9.83889	.174	-34.1065	6.5065

Based on observed means.
The error term is Mean Square(Error) = 435.617.

*. The mean difference is significant at the 0.05 level.

Appendix A10: Effect of PKS and RHA on the compressive strength of the concrete



Tests of Between-Subjects Effects

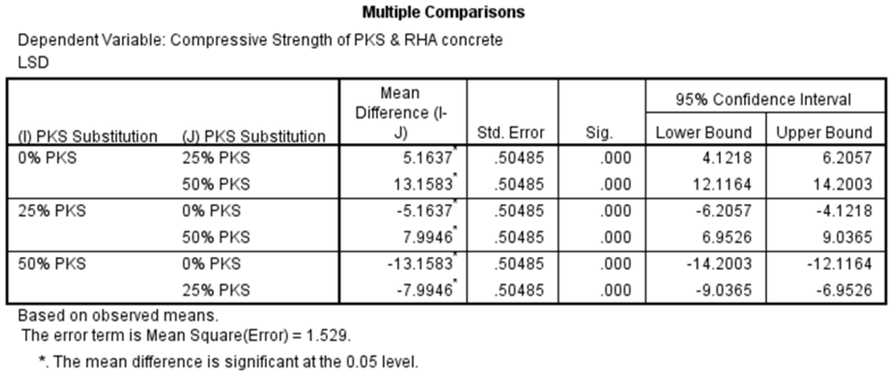
Dependent Variable: Compressive Strength of PKS & RHA concrete

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1175.827[a]	11	106.893	69.899	.000
Intercept	32564.308	1	32564.308	21294.213	.000
PKS	1054.878	2	527.439	344.899	.000
RHA	120.355	3	40.118	26.234	.000
PKS * RHA	.595	6	.099	.065	.999
Error	36.702	24	1.529		
Total	33776.837	36			
Corrected Total	1212.529	35			

a. R Squared = .970 (Adjusted R Squared = .956)

Post Hoc Tests

PKS Substitution



Multiple Comparisons

Dependent Variable: Compressive Strength of PKS & RHA concrete
LSD

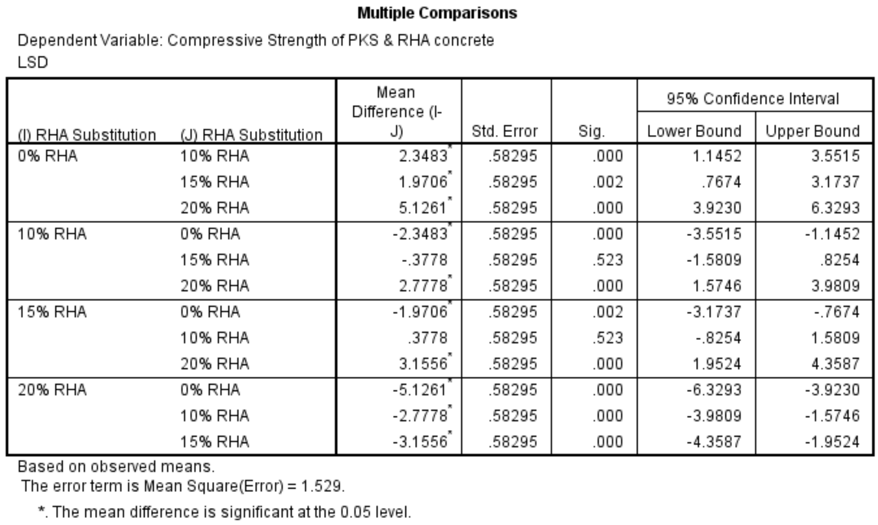
(I) PKS Substitution	(J) PKS Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% PKS	25% PKS	5.1637*	.50485	.000	4.1218	6.2057
	50% PKS	13.1583*	.50485	.000	12.1164	14.2003
25% PKS	0% PKS	-5.1637*	.50485	.000	-6.2057	-4.1218
	50% PKS	7.9946*	.50485	.000	6.9526	9.0365
50% PKS	0% PKS	-13.1583*	.50485	.000	-14.2003	-12.1164
	25% PKS	-7.9946*	.50485	.000	-9.0365	-6.9526

Based on observed means.
The error term is Mean Square(Error) = 1.529.

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

RHA Substitution



Multiple Comparisons

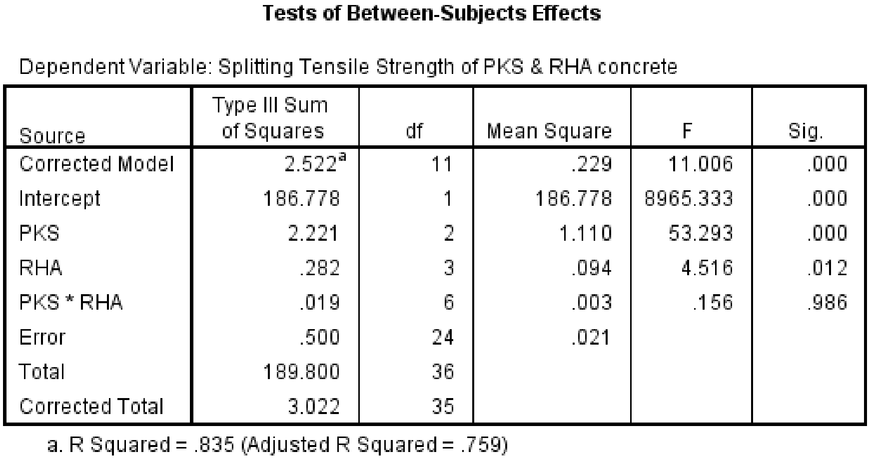
Dependent Variable: Compressive Strength of PKS & RHA concrete
LSD

(I) RHA Substitution	(J) RHA Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% RHA	10% RHA	2.3483*	.58295	.000	1.1452	3.5515
	15% RHA	1.9706*	.58295	.002	.7674	3.1737
	20% RHA	5.1261*	.58295	.000	3.9230	6.3293
10% RHA	0% RHA	-2.3483*	.58295	.000	-3.5515	-1.1452
	15% RHA	-.3778	.58295	.523	-1.5809	.8254
	20% RHA	2.7778*	.58295	.000	1.5746	3.9809
15% RHA	0% RHA	-1.9706*	.58295	.002	-3.1737	-.7674
	10% RHA	.3778	.58295	.523	-.8254	1.5809
	20% RHA	3.1556*	.58295	.000	1.9524	4.3587
20% RHA	0% RHA	-5.1261*	.58295	.000	-6.3293	-3.9230
	10% RHA	-2.7778*	.58295	.000	-3.9809	-1.5746
	15% RHA	-3.1556*	.58295	.000	-4.3587	-1.9524

Based on observed means.
The error term is Mean Square(Error) = 1.529.

*. The mean difference is significant at the 0.05 level.

Appendix A11: Effect of PKS and RHA on the splitting tensile strength of the concrete



Tests of Between-Subjects Effects

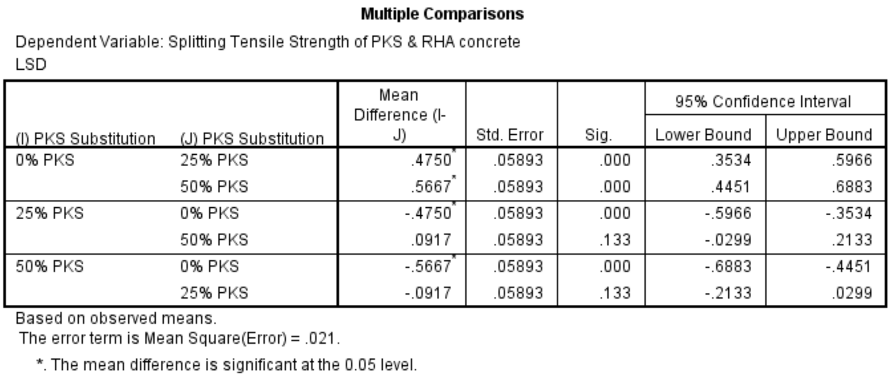
Dependent Variable: Splitting Tensile Strength of PKS & RHA concrete

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.522[a]	11	.229	11.006	.000
Intercept	186.778	1	186.778	8965.333	.000
PKS	2.221	2	1.110	53.293	.000
RHA	.282	3	.094	4.516	.012
PKS * RHA	.019	6	.003	.156	.986
Error	.500	24	.021		
Total	189.800	36			
Corrected Total	3.022	35			

a. R Squared = .835 (Adjusted R Squared = .759)

Post Hoc Tests

PKS Substitution



Multiple Comparisons

Dependent Variable: Splitting Tensile Strength of PKS & RHA concrete
LSD

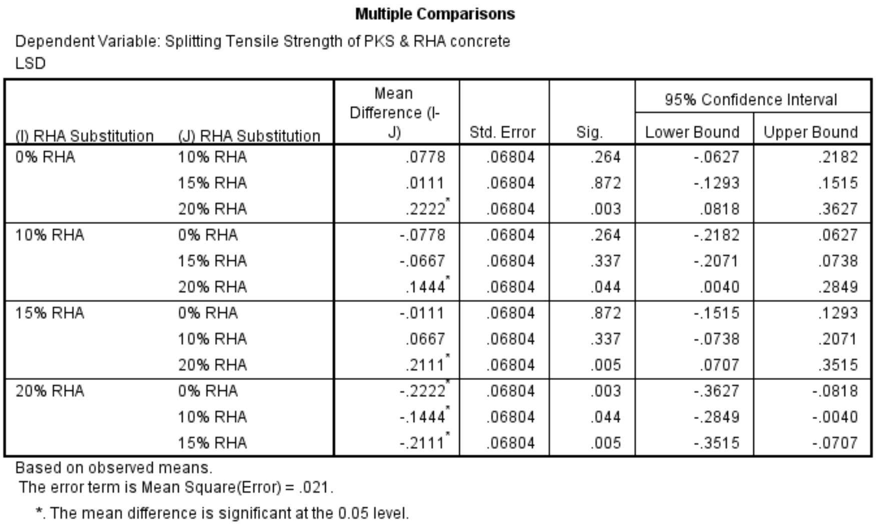
(I) PKS Substitution	(J) PKS Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% PKS	25% PKS	.4750*	.05893	.000	.3534	.5966
	50% PKS	.5667*	.05893	.000	.4451	.6883
25% PKS	0% PKS	-.4750*	.05893	.000	-.5966	-.3534
	50% PKS	.0917	.05893	.133	-.0299	.2133
50% PKS	0% PKS	-.5667*	.05893	.000	-.6883	-.4451
	25% PKS	-.0917	.05893	.133	-.2133	.0299

Based on observed means.
The error term is Mean Square(Error) = .021.

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

RHA Substitution



Multiple Comparisons

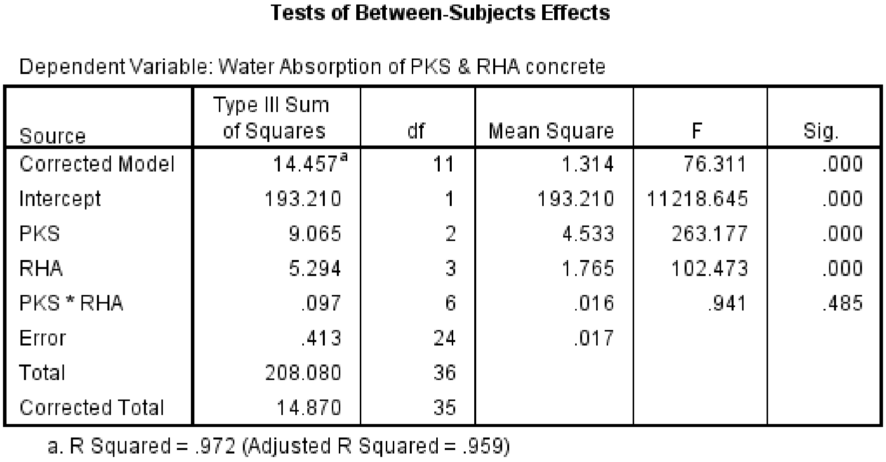
Dependent Variable: Splitting Tensile Strength of PKS & RHA concrete
LSD

(I) RHA Substitution	(J) RHA Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% RHA	10% RHA	.0778	.06804	.264	-.0627	.2182
	15% RHA	.0111	.06804	.872	-.1293	.1515
	20% RHA	.2222*	.06804	.003	.0818	.3627
10% RHA	0% RHA	-.0778	.06804	.264	-.2182	.0627
	15% RHA	-.0667	.06804	.337	-.2071	.0738
	20% RHA	.1444*	.06804	.044	.0040	.2849
15% RHA	0% RHA	-.0111	.06804	.872	-.1515	.1293
	10% RHA	.0667	.06804	.337	-.0738	.2071
	20% RHA	.2111*	.06804	.005	.0707	.3515
20% RHA	0% RHA	-.2222*	.06804	.003	-.3627	-.0818
	10% RHA	-.1444*	.06804	.044	-.2849	-.0040
	15% RHA	-.2111*	.06804	.005	-.3515	-.0707

Based on observed means.
The error term is Mean Square(Error) = .021.

*. The mean difference is significant at the 0.05 level.

Appendix A12: Effect of PKS and RHA on the water absorption of the concrete



Tests of Between-Subjects Effects

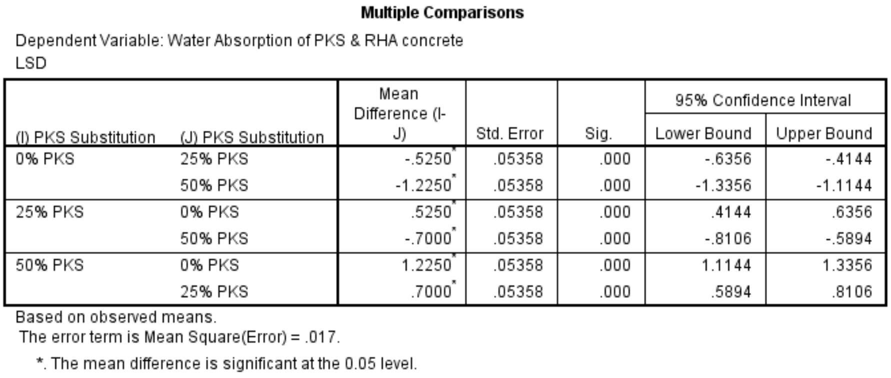
Dependent Variable: Water Absorption of PKS & RHA concrete

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	14.457[a]	11	1.314	76.311	.000
Intercept	193.210	1	193.210	11218.645	.000
PKS	9.065	2	4.533	263.177	.000
RHA	5.294	3	1.765	102.473	.000
PKS * RHA	.097	6	.016	.941	.485
Error	.413	24	.017		
Total	208.080	36			
Corrected Total	14.870	35			

a. R Squared = .972 (Adjusted R Squared = .959)

Post Hoc Tests

PKS Substitution



Multiple Comparisons

Dependent Variable: Water Absorption of PKS & RHA concrete
LSD

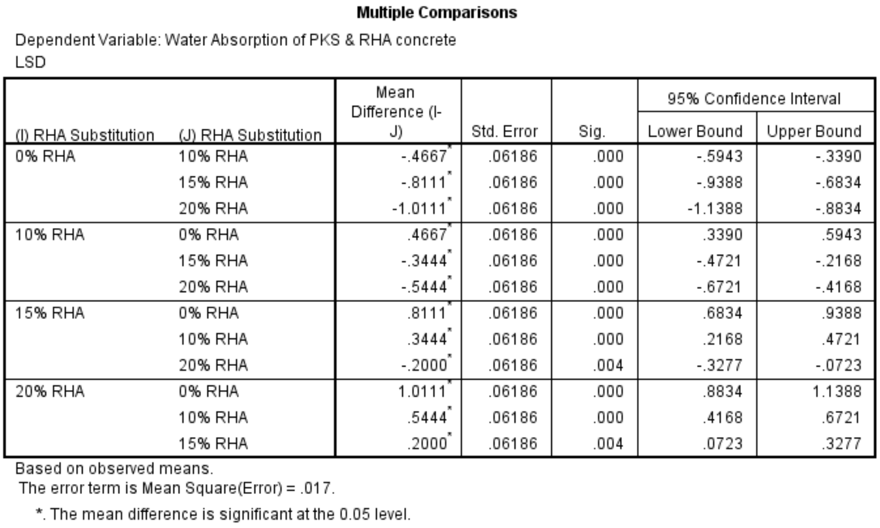
(I) PKS Substitution	(J) PKS Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% PKS	25% PKS	-.5250*	.05358	.000	-.6356	-.4144
	50% PKS	-1.2250*	.05358	.000	-1.3356	-1.1144
25% PKS	0% PKS	.5250*	.05358	.000	.4144	.6356
	50% PKS	-.7000*	.05358	.000	-.8106	-.5894
50% PKS	0% PKS	1.2250*	.05358	.000	1.1144	1.3356
	25% PKS	.7000*	.05358	.000	.5894	.8106

Based on observed means.
The error term is Mean Square(Error) = .017.

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

RHA Substitution



Multiple Comparisons

Dependent Variable: Water Absorption of PKS & RHA concrete
LSD

(I) RHA Substitution	(J) RHA Substitution	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0% RHA	10% RHA	-.4667*	.06186	.000	-.5943	-.3390
	15% RHA	-.8111*	.06186	.000	-.9388	-.6834
	20% RHA	-1.0111*	.06186	.000	-1.1388	-.8834
10% RHA	0% RHA	.4667*	.06186	.000	.3390	.5943
	15% RHA	-.3444*	.06186	.000	-.4721	-.2168
	20% RHA	-.5444*	.06186	.000	-.6721	-.4168
15% RHA	0% RHA	.8111*	.06186	.000	.6834	.9388
	10% RHA	.3444*	.06186	.000	.2168	.4721
	20% RHA	-.2000*	.06186	.004	-.3277	-.0723
20% RHA	0% RHA	1.0111*	.06186	.000	.8834	1.1388
	10% RHA	.5444*	.06186	.000	.4168	.6721
	15% RHA	.2000*	.06186	.004	.0723	.3277

Based on observed means.
The error term is Mean Square(Error) = .017.

*. The mean difference is significant at the 0.05 level.

APPENDIX B: Experimental results on the effect of PKS and RHA on concrete at 28 days

Appendix B1: Effect of PKS and RHA on the density of concrete

	RHA Substitutions (%)			
PKS Substitutions (%)	**0**	**10**	**15**	**20**
0	2431.5	2350.1	2353.9	2338.6
	2472.8	2378.7	2401.0	2348.8
	2473.5	2413.7	2366.6	2360.3
25	2296.0	2224.1	2204.4	2226.0
	2319.5	2271.8	2239.4	2207.5
	2320.5	2209.5	2242.5	2210.7
50	2116.5	2105.1	2096.2	2079.0
	2160.5	2108.3	2117.8	2101.9
	2129.9	2114.0	2079.0	2103.8

Appendix B2: Effect of PKS and RHA on the compressive strength of concrete

	RHA Substitutions (%)			
PKS Substitutions (%)	**0**	**10**	**15**	**20**
0	38.6	34.9	37.5	34.3
	39.7	35.8	36.7	33.4
	37.5	37.3	35.9	32.6
25	33.4	30.1	30.5	28.1
	31.8	30.6	31.2	26.8
	35.0	32.2	32.2	30.3
50	23.4	22.3	22.8	18.9
	27.3	23.3	23.0	20.4
	25.2	24.3	24.4	21.0

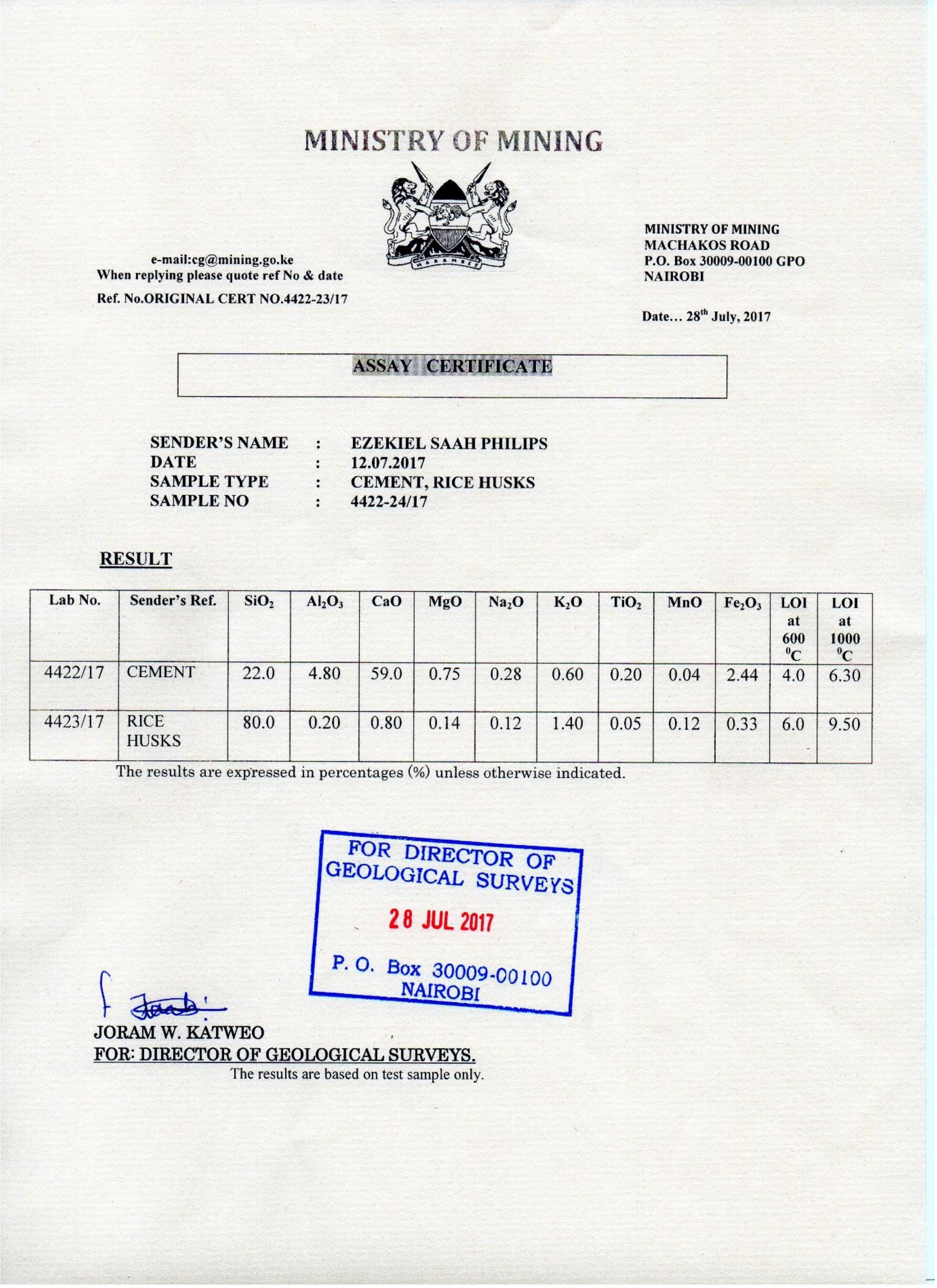
Appendix B3: Effect of PKS and RHA on the splitting tensile strength of concrete

	RHA Substitutions (%)			
PKS Substitutions (%)	**0**	**10**	**15**	**20**
0	2.6	2.5	2.7	2.5
	2.7	2.7	2.9	2.4
	2.9	2.6	2.5	2.5
25	2.2	2.1	2.2	2.0
	2.3	2.3	2.1	1.9
	2.2	2.0	2.3	2.2
50	2.1	2.3	2.1	1.7
	2.0	1.9	2.0	1.9
	2.2	2.1	2.3	2.1

Appendix B4: Effect of PKS and RHA on the water absorption of concrete

	RHA Substitutions (%)			
PKS Substitutions (%)	**0**	**10**	**15**	**20**
0	1.3 1.0 1.1	1.5 1.8 1.6	1.8 2.0 2.0	2.2 2.3 2.2
25	1.9 1.6 1.6	2.1 2.1 2.0	2.5 2.6 2.5	2.8 2.6 2.8
50	2.4 2.3 2.5	3.0 2.9 2.9	3.3 2.9 3.4	3.3 3.4 3.2

APPENDIX C: Result of the chemical analysis of RHA and OPC



MINISTRY OF MINING

e-mail:cg@mining.go.ke

MINISTRY OF MINING
MACHAKOS ROAD
P.O. Box 30009-00100 GPO
NAIROBI

When replying please quote ref No & date

Ref. No.ORIGINAL CERT NO.4422-23/17

Date… 28th July, 2017

ASSAY CERTIFICATE

SENDER'S NAME : EZEKIEL SAAH PHILIPS
DATE : 12.07.2017
SAMPLE TYPE : CEMENT, RICE HUSKS
SAMPLE NO : 4422-24/17

RESULT

Lab No.	Sender's Ref.	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	LOI at 600 ^{0}C	LOI at 1000 ^{0}C
4422/17	CEMENT	22.0	4.80	59.0	0.75	0.28	0.60	0.20	0.04	2.44	4.0	6.30
4423/17	RICE HUSKS	80.0	0.20	0.80	0.14	0.12	1.40	0.05	0.12	0.33	6.0	9.50

The results are expressed in percentages (%) unless otherwise indicated.

FOR DIRECTOR OF
GEOLOGICAL SURVEYS
28 JUL 2017
P. O. Box 30009-00100
NAIROBI

JORAM W. KATWEO
FOR: DIRECTOR OF GEOLOGICAL SURVEYS.

The results are based on test sample only.