INVESTIGATION OF PERFORMANCE OF LIME TREATED PALM KERNEL SHELL AND SUGARCANE BAGASSE ASH AS PARTIAL REPLACEMENTS OF COARSE AGGREGATE AND CEMENT RESPECTIVELY IN CONCRETE

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Investigation of Performance of Lime Treated Palm Kernel Shell and Sugarcane Bagasse Ash as Partial Replacements of Coarse Aggregate and Cement Respectively In Concrete

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DECLARATION

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

Signature : …………………………… Date : ……………………

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CE300-0015/17

This Thesis has been submitted with our approval as University Supervisors.

Signature: ……………………………… Date: …………………….

Dr. John N. Mwero

Signature: ……………………………… Date: …………………………….

Prof. (Eng.) Geoffrey N. MANG'URIU

DEDICATION

This thesis is first of all dedicated to the Almighty Allah for granting me this golden opportunity of life to pursue my Masters. It is also dedicated to my family for their unconditional love, care and support through this academic journey.

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ABSTRACT

This experimental research is focused on the effect of concrete made by incorporating lime treated Palm Kernel Shell (PKS) & Sugarcane Bagasse Ash (SCBA) as partial replacements of coarse aggregates and Ordinary Portland Cement (OPC) respectively. An experimental analysis for concrete grade 30 with a mix design ratio of 1:1.97:3.71 of cement: fine aggregates: coarse aggregates and a constant water to cement ratio of 0.5, was used. Physical tests such as workability on fresh concrete and water absorption on hardened concrete of each batch were carried out. Mechanical tests like compressive strength and split tensile strength were carried out on hardened concrete cubes (100mm × 100mm × 100mm) and cylinders (100mm × 200mm) at 7, 28, 45 and 90 days. The durability of the concrete, such as: weight loss, sulphuric acid attack, sodium hydroxide attack were carried out. The experimental results obtained in the study indicate the possibility of using up 15% of lime treated PKS and 10% of SCBA for production of structural concrete. But based on the target strength, the optimum value of lime treated PKS and SCBA should be determined in order to achieve the strength.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACI………………………………. American Concrete Institute

BS………………………………. British Standard

BS EN……………………………. British Standard European Norm

FAO………………………………. Food and Agriculture Organization

LWA………………………………. Light Weight Aggregate

LWC………………………………. Light Weight Concrete

MPa……………………………….. Mega Pascal

OPC……………………………….. Ordinary Portland cement

PKS………………………………… Palm Kernel Shell

SCBA…………………………..........Sugar Cane Bagasse Ash

CHAPTER 1: INTRODUCTION

1.1. Background of the Study

Concrete is a manmade composite material consisting of cement, aggregates and water, which is used in civil engineering construction and is preferred all over the world. It is used in roads, dams, buildings, retaining structures, airports, bridges stadiums, 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 and Maillard.,2007).

According to Ismall Mohamed A (2009), Its usage is around 10 billion tons per year, which is equivalent to 1 ton per every living person and 1.7 tons per person in the United States (Tinni and Arvo.,2013). About 50-80% of its volume are aggregates that consist of natural crushed stones and sand. Due to the depletion of natural resources, worry is gaining the place in the construction industry. In addition, since the bonding material in the concrete is cement, the high demand for this material has led to an increase in cost, making it the most expensive construction material. In view of the magnitude of these problems, combined with the problem of waste disposal, researchers decided to look for other ecological materials that could be used in the production of concrete. According to BS 5328 (1997), these 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.

The first concrete-like structures were built by the Nabataea traders or Bedouins who occupied and controlled a series of oases and developed a small empire in the regions of Southern Syria and Northern Jordan in around 6500 BC according to Nick Gromicko and Kenton Shepard (2006). 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.

Concrete offers so many advantageous properties such as good compressive strength, high mouldability, plasticity, durability, impermeability and fire resistant when hardened (Robinson et Michelle.,2015). The incorporation of agricultural waste material for its production can considerably reduce the cost incurred in buying coarse aggregate, which results in a potential reduction in the total cost of construction and will also reduce environment pollution.

Lack of waste management and recycling in third world countries has come to the attention of many organizations. Industrial production produces significant quantities of non-biodegradables solid waste. Most of this waste consist of: industrial waste (such as: sandpaper, chemical solvents, industrial by products, paints, paper products, metal and radioactive waste); municipal waste (such as plastics); and agricultural waste (natural fibers and such as palm kernel shell).

Palm kernel is the edible seed of the oil palm fruit. The fruit yields two distinct oils: palm oil derived from the outer parts of the fruit, and palm kernel oil derived from the kernel. The pulp left after oil is rendered from the kernel is formed into "palm kernel cake", used either as high-protein feed for dairy cattle or burned in boilers to generate electricity for palm oil mills and surrounding villages. Palm kernel cake is most commonly produced by economical screw press, less frequently via more expensive solvent extraction. Palm kernel cake is a high-fibre, medium-grade protein feed best suited to ruminants. Among other similar fodders, palm kernel cake is ranked a little higher than copra cake and cocoa pod husk, but lower than fish meal and groun dnut cake, especially in its protein value.

Considerable amount of waste in form of PKS are generated during oil extraction. A PKS are an interesting alternative for combating problems of overexploitation of conventional aggregates in concrete whose global production increases regularly. The effort of researchers is to achieve how to use that waste materials in concrete. The valorization of this biomass (PKS) makes it possible to produce a light concrete of density of less than or equal to 2, which leads to a considerable reduction in a dead load of buildings. There is also an improvement in the properties of concrete from the point of view of thermal comfort (Okereke et al., 2017).

1.2. Statement of the Problem

Concrete is a composite material made of aggregate (gravel and sand), cement, and water. Its constituent production come from the transformation of raw materials, which induce the over exploitation of our natural resources. A search for alternatives for combating problems of overexploitation of conventional aggregates in concrete whose global production increases regularly become important for researchers.

Africa, known for its enormous agricultural production produces a lot of waste product, during the processing of cash crops such as palm oil and sugar cane. One of the major waste materials in this production is PKS and SCB which have a negative effect on the general environmental appearance and become a menace to the environment. Hence, the aim of this research is to use PKS and SCBA waste material which has become one of the major environmental issues in developing countries as the partial replacement of coarse aggregates and cement in concrete.

1.3. Justification

According to the Food and Agriculture Organization of the United Nations (see in Appendix), 801,268 tons of PKS is produced in Africa each year. After extraction of oil from the palm kernel, the shell being a waste material pollutes the environment (Fig: 1.1). This study aims to reduce the amount of that waste material generated, and incorporate it in concrete production thus reducing environmental pollution. Abd et Asma (2014) ascertained that the used of Sugar Cane Bagasse Ash (SCBA): another agricultural waste material, improves the strength performance of concrete. Therefore, the combination of PKS treated with lime and SCBA might effectively replace coarse aggregate and cement respectively in concrete. Hence, the utilization of PKS treated with lime and SCBA will increase the preservation of the environment and will boost in the preservation of natural resources.

Furthermore, the alkali-silica reaction (ASR) is an expansive reaction between reactive forms of silica in aggregates and alkalis of potassium and sodium, mainly of cement, as well as aggregates, pozzolans, additives and water tempering. Reactivity is only potentially dangerous when it produces a significant expansion. In the interest of seeing the reaction of the PKS treated with lime in contact with the alkali-silica, it was decided to subject concrete to the condition of the medium alkali and medium acidity.

Figure 1. 1: PKS dump site

1.4. Objectives

1.4.1. General Objective

The aim of this study is to carry out an investigation of performance of lime treated PKS and sugar cane bagasse ash as partial replacement of coarse aggregate and cement respectively in concretre.

1.4.2. Specific Objectives

a) To determine the properties of PKS, SCBA, Coarse aggregate, Fine aggregate, Cement.

b) To assess the physical and mechanical properties of concrete made with lime treated PKS and sugar cane bagasse ash.

c) To assess the durability of concrete made with SCBA and lime treated PKS in an alkaline and acidic medium.

1.5. Scope of Study

This Study was focused on experimental investigation of the effect of SCBA and lime treated PKS as partial replacement of cement and coarse aggregate respectively. It was involved on determination of physical and mechanical properties of different percentages of SCBA and lime treated PKS. 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). SCBA and OPC were characterized in terms of chemical properties, PSD, and specific gravity. Concrete with lime treated PKS and SCBA were compared with NWC. Determination of the mechanical properties was at 7, 28, 45 and 90 days of curing. Also, the durability in chemical solution was checked for 45 and 90 days after 28 days of curing. The target strength was concrete grade C 30. The design mix used in this study was 1:1.97:3.71 for cement, fine aggregate and coarse aggregate and a water to cement ratio of 0.5 for all concretes.

Geographically, the study was conducted in Kenya at the Jomo Kenyatta University of Agriculture and Technology (JKUAT).

CHAPTER 2: LITERATURE REVIEW

2.1 Palm Kernel Shells

Palm kernel shells (PKS) illustrated in Figure 2.1, are the envelopes of Palm Kernel seeds. They are obtained after extraction of the fibers and crushing of the core. Palm kernel shells are hard, flaky and of irregular shape (Oti and Kinuthia 2015). The shape depends on how it breaks during the nut cracking. PKS is obtained as mashed pieces, varying in size from fine aggregates to coarse aggregates, after the mashing of palm kernel to remove the seed, which is used in the production of palm kernel oil (Olutoge, 2010). PKS are difficult in nature and do not readily deteriorate when used for concrete and therefore, do not contaminate or leach to produce toxic substances (Basri et al., 1999). PKS consists of about 65 to 70% of medium size particles in the range of 5 to 10 mm (Alengaram et al., 2010).

Figure 2. 1: Crushed palm kernel shells of different sizes (Alengaram et al., 2013)

2.1.1 Characteristics of Palm Kernel Shells

PKS has both physical and mechanical properties suitable for use as light weight aggregate. According to Okoroijwe et al.,(2014) the material physical and mechanical 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 of 18.73% (Shafigh et al.,2010). As presented in Table 2.1, the material bulk density ranges from 572 to 620 kg/m^3 (Itam et al.,2016;Alengaram et al.,2010). The material has been found to have a specific density of 1.34 (Williams, Ijigah, Anum, Isa, and Obanibi, 2014).

Table 2. 1: Properties of palm kernel shell

Author	Specific Gravity	Bulk Density (kg/m^3)	Shell Thickness (mm)	Water Absorption for 24 hrs (%)	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

2.1.2 Physical Properties of Palm Kernel Shell Concrete

PKS concrete is a lightweight concrete that uses PKS as partially or wholly replacement of the coarse aggregate thereby leading to a reduction in concrete cost. It can be classified as either Structural Light Weight Concrete (SLWC) when the 28-day compressive strength is 17 MPa and above or Insulating Light Weight Concrete when the 28-day compressive strength is below 17 MPa. PKS can be used as an aggregate for concrete production (Osei and Jackson, 2012). Saman Daneshmand (2011), stated that replacement of 10%, 20%, 30% and 40% crushed rock with PKS aggregate can be considered as a partial lightweight concrete but not a fully lightweight concrete.

2.1.3 Density of Palm Kernel Shell Concrete

For structural applications of Light Weight Concrete (LWC), the density is often more important than the strength (Rossignolo, Agnesini, and Morais, 2003). 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, Jumaat, and Mahmud (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, Muhit, and Jumaat, 2013). According to the American Concrete Institute (ACI) (2000), Structural

Light Weight Concrete is a concrete made with low density aggregate that has an air dry density of not more than 115lb/ft^3 (1840 kg/m^3) and a 28 day compressive strength of more than 2,500 psi (17 MPa), (ACI, 2000). Hardened density of PKSC as shown in Table 2-3 reported by researchers ranges from 1600 – 1960 kg/m^3 depending on the design mix.

Table 2. 2: Densities of hardened PKSC

Author	**Hardened Density (kg/m^3)**
Okafor, 1988	1753 - 1763
Okpala, 1990	1630 - 1780
Alengaram et al., 2010	1880
Shafigh et al., 2010	1937

2.1.4 Workability of Palm Kernel Shell Concrete

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. According to Alengaram, Jumaat, and Mahmud (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 studies summarized in Table 2-3.

Table 2. 3: 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

2.1.5 Water Absorption of Palm Kernel Shell Concrete

According to Basheer, Kropp, and Cleland (1987), 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% (Babu and Babu, 2003), and 14 – 22% according to Gündüz and Uğur (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, Mahmud, and Jumaat (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 2-2, which are responsible for the high water absorption of PKSC.

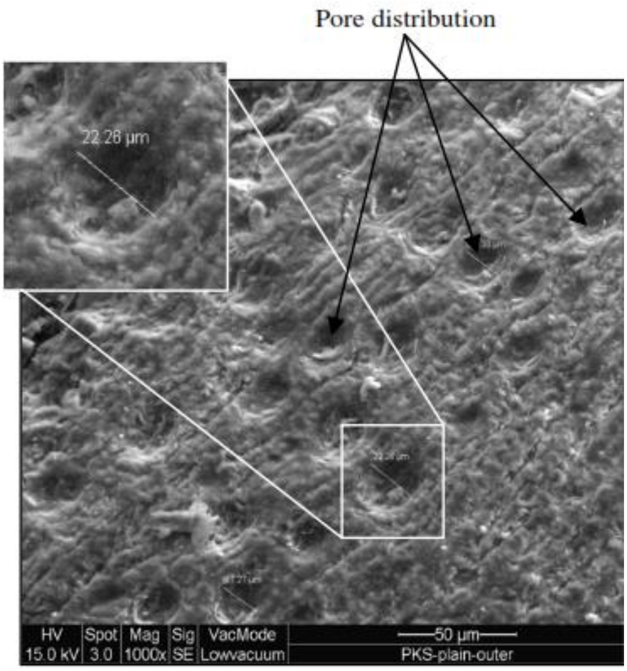


Figure 2. 2: Pores of the outer surface of PKS (Alengaram et al., 2011)

2.1.6 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.

2.1.7 Compressive Strength of Palm Kernel Shell Concrete

The compressive strength is the most commonly used parameter to describe the quality of concrete in practice (Wiegrink, Marikunte, and Shah, 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, Muhit, and Jumaat., 2013). According to Saman Daneshmand (2011), the compressive strength of PKSC is dependent on the amount of PKS aggregate in the concrete. Similarly, Olutoge, Quadri, and Olafusi (2012), stated that the strength increases with curing age and decreases with an increase in the percentage of the PKS aggregate. Depending on the mix design, percentage of PKS aggregate, and method of curing, different grades of PKSC have been reported by studies. Table 2-4 shows the compression strength of PKSC by various studies. Okpala (1990), reported a 28 days 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, Jumaat, and Mahmud (2011), incorporated steel fibers with PKSC 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 days compressive strength in a range of 39.34 – 44.95 MPa.

Table 2. 4: 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

2.1.8 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 MPa by varying water to cement ratio from 0.48 – 0.65. Shafigh, Jumaat, and Mahmud (2011), obtained the splitting tensile strength of 5.55 MPa by incorporating steel fibers. Table 2-5 shows a summary of splitting tensile strength reported by different studies.

Table 2. 5: Splitting Tensile Strength of PKSC by different Researchers

Author	**w/c**	**Mix Proportion**	**Splitting Tensile Strength (MPa)**
Okafor 1988	0.48	1:1.7:2.08	2.4
	0.65	1:2.1:1.12	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

2.1.9 Suitability of Palm Kernel Shell Aggregates for concrete production

PKS has been experimented in research as light weight aggregate (LWA) to produce light weight and cheaper concrete since 1984 (Alengaram, Muhit, and Jumaat, 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 cheaper and structural lightweight concrete. Also, it has been reported by Yap and Foong (2013), that PKS is suitable as replacement for natural granite 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% granite 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, Ijigah, Anum, Isa, and Obanibi (2014), produced a concrete with 100% replacement of granite 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 was 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, it is very workable, consistent and easily placed. Also, Itam et al (2016) investigated the feasibility of PKS as an aggregate replacement in lightweight concrete in terms of compressive strength, slump test, water absorption, and density. They indicated that using PKS for aggregate replacement increases the water absorption but decreases the concrete workability and strength. However, they concluded that results for PKS fall into the range acceptable for lightweight aggregate and hence there is a potential to use PKS as aggregate replacement for lightweight concrete. Therefore, with the so much research already conducted on PKS as lightweight aggregate, it can be seen that the material is suitable for the production of cheaper and lightweight concrete by replacing coarse aggregate. However, there is little information on the durability of the material especially for aggressive chemical environments.

2.2 Pozzolana

A pozzolan is a siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (calcium-silicate hydrate gel, calcium-alumino silicates, etc.).It has no alumino-silicates but its particles must be fine enough to provide a sufficient reactive surface area for the solid-state chemical reactions.

Recommended sizes of SCBA are 45 µm (micron) as the maximum particle size. Some studies specify a maximum of 10 µm. Regardless of the origin of the pozzolan, one must ensure the maximum particle size is 10 µm or less, or that at least more than 90% of the particles fulfill this requirement. It should also have low carbon contents (<1%).

2.2.1 Benefits of pozzolana

Pozzolans not only strengthen and seal the concrete, they have many other beneficial features when added to the mix, such as: Economic Savings, Higher Strength, Decreased Permeability, Increased Durability, Reduced Sulfate Attack, Reduced Volume, Reduced Alkali Silica Reactivity, Reduce Workability. Its chemicals compositions are presented in table 2.6. Common examples include Fly ash, ground granulated blast-furnace slag, silica fume, and natural pozzolans when used in conjunction with portland or blended cement, contribute to the properties of the hardened concrete through hydraulic or pozzolanic activity or both (Memphis., 1996).

Table 2. 6: Chemical composition

Component %	Sugarcane Bagasse	Silica Fume	Wheat straw	Rice husk	Metakaolin
Silica (SiO_2)	71.0	92.85	43.2	87.76	62.62
Alumina (Al_2O_3)	1.9	0.61	-	0.05	28.63
Ferric Oxide (Fe_2O_3)	7.8	0.94	0.84	0.06	1.07
Calcium Oxide (CaO)	3.4	0.39	5.46	0.31	0.06
Magnesium Oxide (MgO)	0.3	1.58	0.99	0.35	0.15
Potassium Oxide (K_2O)	8.2	0.87	11.30	1.4	3.46
Sodium Oxide (Na_2O)	3.4	0.50	0.16	0.1	1.57
Phosphorus Pentoxide (P_2O_5)	-	-	-	0.8	1
Manganese Oxide (MnO2)	0.2	-	0.02	-	-
Chromium (III) oxide (Cr2O3)	-	-	1.9	-	-
Loss on Ignition (LoI)	-	2.26	-	-	2.00

2.3 Bagasse Ash

Bagasse is the fibrous matter that remains after sugar cane or sorghum stalks are crushed to extract their juice. It is dry pulpy residue left after the extraction of juice from sugar cane (Babu,2017).

2.3.1 Physical Properties of Bagasse Ash concrete

2.3.1.1 Workability of SCBA concrete

The workability of concrete linearly increases with the increment in the SCBA content (Abdulkadir, Oyejobi, and Lawal 2014). This implies that the addition of SCBA content reduces the water demand in concrete for achieving a desired workability and hence improved performance of concrete. In cases where the workability of all mixes is to be kept constant, SCBA mixes will require lower water content, hence the compressive strength will be further improved. It is to be noted that reference mix normal concrete has higher slump, while all mixes have constant water content and dosage of super plasticizer. According to Mutua, Nyomboi, and Mutuku (2017), in order to achieve good workability, the best water cement ratio can be maintained at 0.6 where by the percentage content of sugar cane bagasse ash is 10% and glass content is maintained at 30%. Replacing cements with SCBA concrete mix provided better workability than the conventional one (Subramaniyan and Sivaraja., 2016).

2.3.2 Mechanical properties of Bagasse ash concrete

2.3.2.1 Compressive strength of SCBA concrete

SCBA shows an excellent performance when included in concrete as partial replacement for cement due to the high silica content present that simulates pozzolanic reactivity, and the ultra-fine particle sizes in it that significantly improve the microstructure that results in high early strength (Abd et al., 2014). SCBA being a pozzolan improves the strength of concrete over some period time. In a research conducted by Abd et al (2014), at the age of 28 days mixes made with 5, 10 and 15% SCBA showed 91, 88 and 84 MPa of compressive strength, respectively in comparison to 62 MPa, of the reference mix. In a similar study conducted by Modani and Vyawahare (2013), 10% replacement of cement with SCBA produced a good compressive strength. SCBA used to replace cement when used in glass concrete, however, showed a lower compressive strength than the control experiment, but significant increase up to 10% replacement of cement with sugar cane bagasse ash and 30% replacement of fine aggregates with crushed glass was noted (Mutua, Nyomboi, and Mutuku., 2017).

Excessive increase in SCBA percentage results in decreasing compressive strength along with significant fall in properties of fresh concrete. According to Abdulkadir

(2014), the compressive strength of the concrete cubes decreases as the SCBA content increases, 10% and 20% replacement of cement with SCBA was recommended for reinforced concrete with normal aggregates. Although, Subramaniyan and Sivaraja (2016) reported that as from 15% cement replacement, the strength starts to decrease at 28 days of curing, but was greater than conventional mix. Therefore, it can be concluded that 5 to 15% SCBA content is determined as optimum replacement for producing high strength concrete.

The optimum strength may however not be achieved at 28days of curing. In a study done by Abdulkadir, (2017). At 90 days compressive strength for 10% replacement showed clear developing strength which was about 96% of Ordinary Portland Cement (OPC) concrete while the other samples (15% & 20%) showed 85% strength development than Ordinary Portland Cement (OPC). Therefore, with the use of Sugar Cane Baggage Ash (SCBA) in partially replacement of cement in concrete, we can increase the strength of concrete while reducing the consumption of cement.

2.3.2.2 Tensile strength

According to Modani and Vyawahare (2013), the development of tensile strength of mixes decreases as the replacement of SCBA increases.

2.4 Research gaps

From the review of the literature, it was found that PKS is capable of replacing coarse aggregates up to 100% in concrete production, but the compressive strength decreases with an increase in PKS. In addition, it has been shown that SCBA is a pozzolana, and can be used in the production of concrete replacing cement. Although this material has proven to be suitable for many applications in the construction industry, there was limited information on viability, water absorption, compressive strength and tensile strength of SCBA in the cement mix with PKS treated with lime. Therefore, this research studied experimental investigation of concrete made with lime treated PKS and sugar cane bagasse ash.

2.5 Conceptual Framework

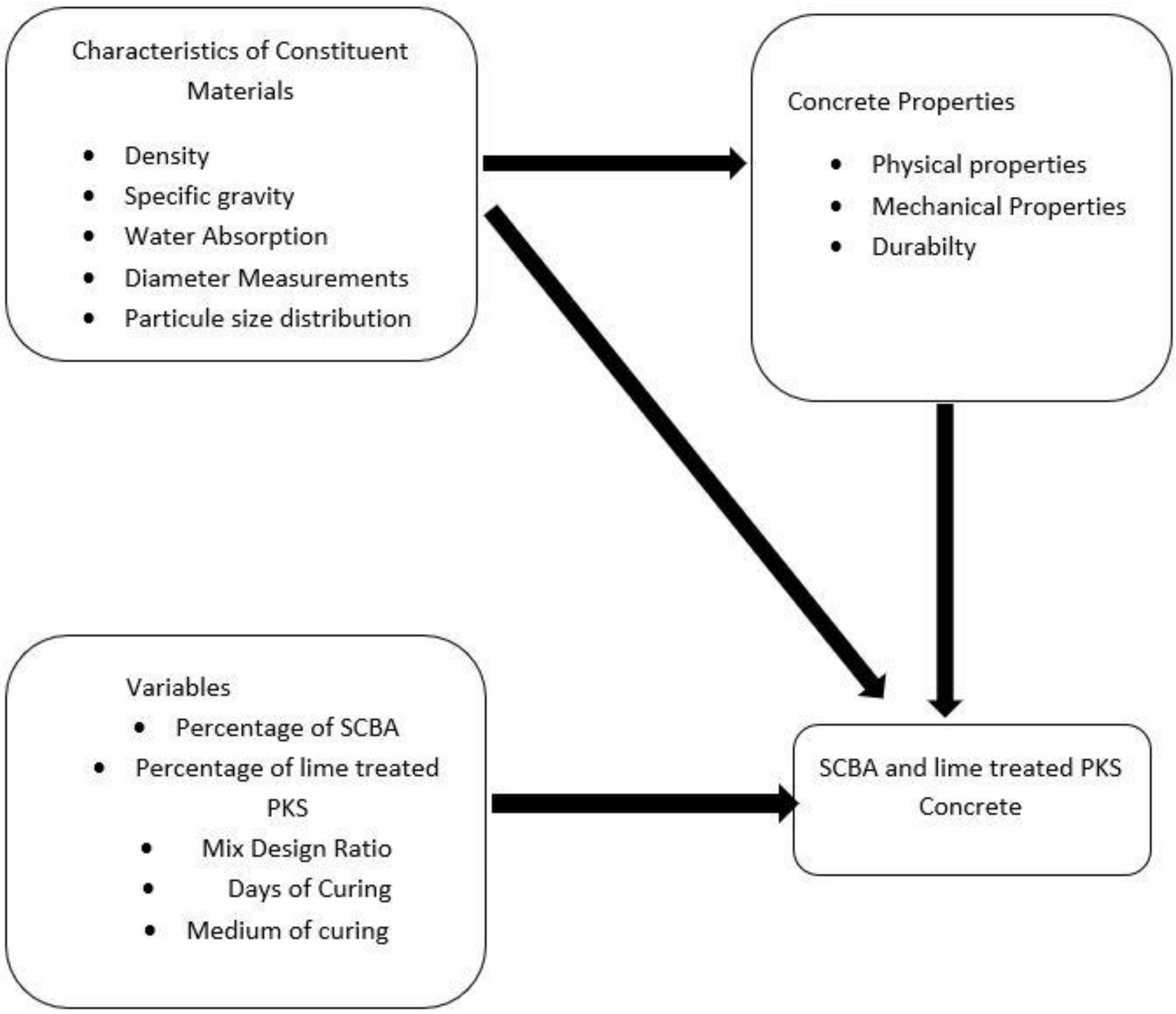


Figure 2. 3: Conceptual framework

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

This chapter deals with the methodology that was used in this research. This research focused on, experimental investigation of concrete made with lime treated PKS and sugar cane bagasse ash. The main parameters studied was compressive strength, spit tensile strength, durability, chemical attack, workability and water absorption of concrete.

3.2 Methodology Flow Chart

This research was progressed as presented in this figure.

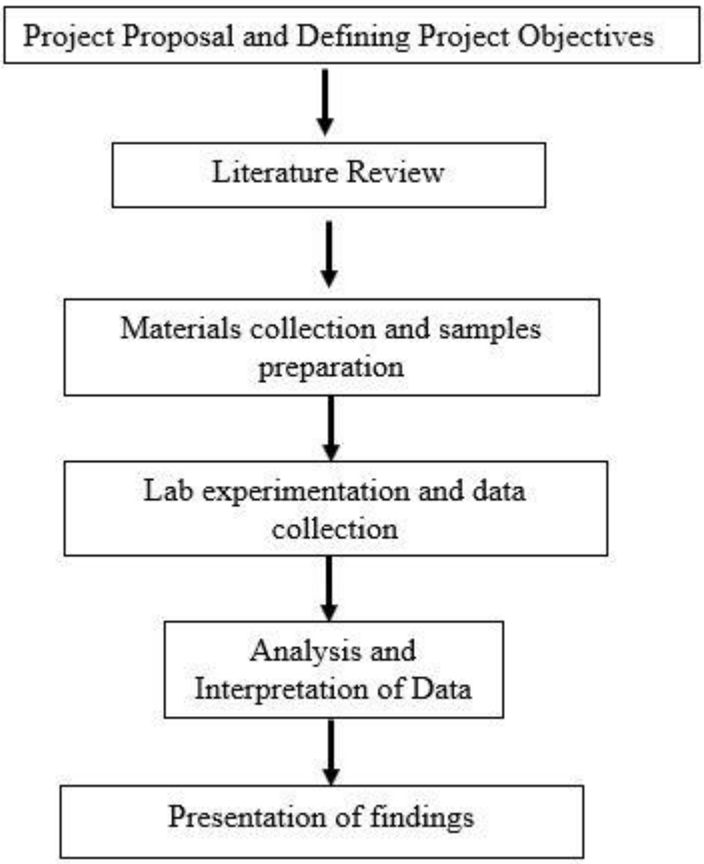


Figure 3. 1: Research Flow Chart

3.3 Materials and Preparation

3.3.1 Palm Kernel Shells

According to Traore et Yasmine (2015), the treatment of PKS with lime reduce the amount of it water absorption. Hence, the PKS obtained from Uganda at Kalangala island was treated with lime to make the shell less permeable. The treatment was done by putting PKS in lime solution (40g/l) for 2 hours (Appendix: Plate 1) follow by air dryied to obtain saturated surface dried such that the water cement ratio was not affected.

3.3.2 Coarse Aggregate

The coarse aggregate was obtained locally with the nominal size of 20mm and containing no finer, are known as coarse aggregates. It was conformed to ASTMC-33(2011). The aggregate was dried to a saturated surface condition to ensure that the water cement ratio was not affected.

3.3.3 Sugar Cane Bagasse Ash

Sugar Cane Bagasse Ash was used as a pozzolana to replace a portion of the OPC. It was locally obtained at sugar manufactor industry from Kakamega county, about 360 kilometers from Nairobi. The material was burned at a temperature of 600^{o}C (+/-50). The burnt ash was then heaped and was left to cool for 24hrs. It was prepared by sieving on 0.075 mm sieve to remove larger particles. Furthermore, hydrometer analysis as well as chemical composition of the material were also determined.

3.3.4 Fine Aggregate

Sand was obtained locally and did not contain any coarser material. It was sieved on test sieve 5.0mm to remove larger particles and dried on air saturated surface dried. Particle size distribution, specific gravity, fineness, and also water absorption was conducted before used.

3.3.5 Cement

The type of cement used in the research was Ordinary Portland Cement (OPC) class 42.5R conforming to EN 197-1 (2011) and obtained locally.

3.3.6 Water

Potable water used was tap water from laboratory, which was free from impurities.

3.3.7 Chemical solution

Sodium Hydroxide (NaOH) at pH 11 was used for alkali medium and Sulfuric acid (H_2SO_4) at pH 3 for acidic medium

3.4 Characterization of Constituent Materials

Tests that were done on the constituent materials can broadly be grouped into two categories namely: Physical tests and Chemical tests.

3.4.1 Physical characteristics

3.4.1.1 Hydrometer Analysis- Particle Size Distribution

Particle Size Distribution for SCBA was determined by hydrometer analysis test performed at the JKUAT (Transportation and Soils Laboratory). The hydrometer analysis is based on Stoke's Law, which gives the relationship between the velocities of fall of spheres in a fluid, the diameter of the sphere, the specific weights of the sphere and of the fluid, and the fluid viscosity. In equation form this relationship is:

$$\mathbf{v} = \frac{2}{9} \times \frac{(\mathbf{G_s} - \mathbf{G_f})}{\boldsymbol{\eta}} + \left(\frac{\mathbf{D}}{2}\right)^2 \text{...Equation 3.1}$$

Where: v-velocity of fall of spheres (cm/s)

G_s- Specific gravity of sphere

G_f- Specific gravity of fluid (varies with temperature)

η- Absolute, or dynamic, viscosity of the fluid (g/(cmxs)

D- Diameter of the sphere (cm)

Solving the equation for D and using the specific gravity of water, G_w, we obtain:

$$\mathbf{D} = \sqrt{\mathbf{18\eta v}/(\mathbf{G_s} - \mathbf{G_w})} \text{...Equation 3.2}$$

$$\mathbf{v} = \mathbf{L}/\mathbf{t} \text{ ....Equation 3.3}$$

$$\mathbf{A} = \sqrt{\mathbf{18\eta}/(\mathbf{G_s} - \mathbf{G_w})} \text{...Equation 3.4}$$

$$\mathbf{D} = \mathbf{A}\sqrt{\mathbf{L(cm}/\mathbf{t(min})} \text{.......where } 0.002\text{mm} \leq D \leq 0.2\text{mm} \text{............Equation 3.5}$$

3.4.1.2 Sieve Analysis

Particle size Distribution for fine and coarse aggregates was determined by Sieve analysis in accordance with (ASTMC-33 2011). Sieving was done by hand, from the finest sieve upwards. The material retained on each sieve was weighed and calculated as a cumulative percentage of the total sample mass passing each sieve.

3.4.1.3 Specific gravity and Water absorption

Specific gravity for SCBA was determined from the hydrometer analysis test, and, for PKS, fine and coarse aggregates was determined according to british standard. 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°C for 24 hours. The sample was cooled after oven drying and the mass weighed and recorded (mass D). The water absorption and specific gravity were calculated using equations 3.6 and 3.7 respectively.

Specific Gravity = $\frac{D}{A-(B-C)}$ -- Equation

3 – 6

Water Absorption = $\frac{100(A-D)}{D}$ --------------------------------------- Equation

3 – 7

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.

3.4.1.4 Aggregate Crushing Value

The aggregate crushing value was carried out on PKS, and coarse aggregate with reference to BS 812-110 (1990). The ACV value was calculated as;

$$\mathbf{ACV} = \frac{\mathbf{M_1}}{\mathbf{M_2}} \times \mathbf{100} \quad \text{…………………… Equation 3.8}$$

Where M_1- is the mass of the test specimen (in g)

M_2- is the mass of test specimen passing the 2.36mm sieve (in g)

3.4.1.5 Aggregate Impact Value

The strength of the aggregate may be measured in terms of crushing or impact tests. The aggregate impact value (AIV) gives a relative measure of resistance of an aggregate to sudden shock or impact. The AIV test was carried out with reference to BS 812-112 (1990).

AIV value was calculated as;

$$\mathbf{AIV} = \frac{\mathbf{M_1}}{\mathbf{M_2}} \times \mathbf{100} \quad \text{……………………..… Equation 3.9}$$

Where M_1- is the mass of test specimen passing the 2.36mm sieve (in g)

M_2- is the mass of the test specimen (in g)

3.4.1.6 Density

Densities of PKS, fine aggregates and the coarse aggregates were obtained.

3.4.2 Chemical characteristics

The objective of this test was to determine the chemical composition of SCBA and OPC, especially the silica content of SCBA 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. The Atomic absorption spectroscopy method was used to determine Al_2O_3, CaO, Fe2O_3, MgO, MnO_2 and CuO contents in the both samples. The test was done at the Ministry of Mining Laboratory in industrial area Nairobi for chemical analysis.

3.5 Mixing, Casting, Curing

The mix ratio of 1:1.97:3.71 was used for cement, sand, and coarse aggregate with a water cement ratio of 0.45. The mix ratio was used to produce sixteen types of concretes, as shown in Table 3-1. The control concrete consisted of aggregate, cement, and, sand.

Table 3. 1: Experimental matrix used for the research

PKS treated %	**SCBA% of Cement**			
	0	**10**	**15**	**20**
0	0%PKS + 0% SCBA	0%PKS + 10% SCBA	0%PKS + 15% SCBA	0%PKS + 20% SCBA
10	10%PKS + 0% SCBA	10%PKS + 10% SCBA	10%PKS + 15% SCBA	10%PKS + 20% SCBA
15	15%PKS + 0% SCBA	15%PKS + 10% SCBA	15%PKS + 15% SCBA	15%PKS + 20% SCBA
20	20%PKS + 0% SCBA	20%PKS + 10% SCBA	20%PKS + 15% SCBA	20%PKS + 20% SCBA

3.5.1 Mixing

Fine aggregates, coarse aggregates, PKS treated with lime, SCBA and cement was mixed according to our design mix ratio 1:1.97:3.71 for a target strength of concrete grade C30 calculated based on BS 56528 (1983). All mixing was done manually as show on (Appendix: Plate 2).

3.5.2 Workability

The workability of the concrete was determined through slump test as shown in (Appendix: Plate 3). The slump test measures the consistency of fresh concrete before it sets. It is a test performed to check the workability of freshly made concrete; and therefore, the ease with which concrete flows. In this study, a slump test was carried out on every batch of freshly mixed concrete conforming to BS 1881-122 (1983) .

3.5.3 Casting

The cubes of 100 x 100 x 100mm and cylinders of 100 x 200mm were used to caste the concrete. After mixing of concrete, the cubes and cylinders were filled by three layers, and at each layer, it was vibrating, using pocker vibrator. Each mix casted a total of 21 cubes, 21 cylinders (Appendix: Plate 4) bringing the total of 336 cubes and 336 cylinders for the sixteen mixes.

3.5.4 Curing

Open air curing was done for 24 hours, after which the specimens were removed from the molds and then placed in the curing tank containing clean water (Appendix: Plate 5) before 7, 28, 45 90 days mechanical testing.

3.6 Physical characteristics of hardened concrete

3.6.1 Water Absorption Test

The water absorption test was carried out on hardened concrete for all mixes after 28 days conforming to specification of BS 1881-122 (1983). The cubes cured at 28 days, were placed in an oven at a temperature of 105^0C for 72 hours period. Upon removal, the cubes were cooled for 24 hours in a dry airtight vessel. After cooling, the cubes were weighed and immediately immersed completely in a tank of water for 30 minutes. The cubes were then removed from the tank and dried with a cloth to remove bulk of the water from the surface and then weighed. Water absorption was being calculated as the increase in mass resulting from immersion and was expressed as a percentage of the mass of the dry specimen as expressed by Equation 3.10. Water Absorption, percent = $\frac{(\mathbf{A-B})}{\mathbf{B}} \times \mathbf{10}$ ……………………………..…. Equation 3.10

Where: A= wet mass of unit in kg

B= dry mass of unit in kg.

3.7 Mechanical characteristics of hardened concrete

3.7.1 Compressive Strength

The compressive strength test for this research was determined using Universal Testing Machine (UTM) (Appendix: Plate 6) as specified in the test method BS 1881-116 (1983). It was obtained by calculating the average of the three values of each cube by dividing the maximum load applied to it by the cross-sectional area according to BS 1881-116 (1983).

3.7.2 Splitting Tensile Strength

A Universal Testing Machine (Appendix: Plate 7) was used to determine the splitting tensile strength by splitting 3 cylinders of each mix at 7, 28, 45, and 90days. The splitting tensile strength, σ_{ct}, in N/m^2 was calculated using Equation 3.11.

$$\boldsymbol{\sigma_{ct}} = \frac{\mathbf{2P}}{\boldsymbol{\pi} \times \mathbf{l} \times \mathbf{d}} \quad \text{...Equation 3.11}$$

Where *P* is the maximum load (in N),

l is the length of the specimen (in mm),

d is the cross-sectional dimension of the specimen.

3.8 Density of Concrete

The density of concrete was determined by dividing the mass of each cube by its volume as specified in BS 1881-114 (1983). The density was carried out at 28 days of curing, three (3) times for each mix that was made, and an average was obtained.

3.9 Durability test of Concrete

To test for the durability, 3 cubes and 3 cylinders of each mix was immersed in an alkaline medium of pH 11 and acidic medium of pH 3 for 45 and 90 days after gaining its maximum strength of 28 days. The specimen was tested for weight loss and mechanical strength to detect any reduction in strength (Appendix: Plate 8).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter focuses on the results and discussion of findings obtained from the effect of lime treated PKS and SCBA on the physical and mechanical properties of concrete 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, SCBA, OPC, coarse aggregate and fine aggregates are also presented and discussed in this chapter.

4.2 PROPERTIES OF PKS, SCBA, Coarse aggregate, Fine aggregate, Cement (OBJECTIVE 1)

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

4.2.1 Particle Size Distribution of Coarse Aggregate and Palm Kernel Shells

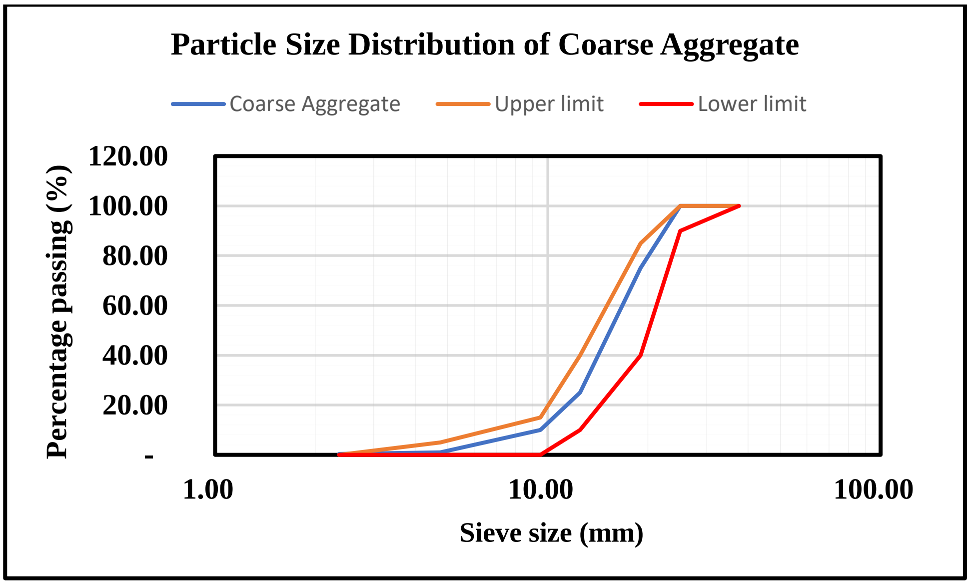


Figure 4. 1: Particle size distribution of coarse aggregate

From Figure 4-1 it can be seen that 50% of coarse aggregates were between 12.5mm and 25mm and about 25% were below 12.5mm. Also, Figure 4-2 shows that about 68% of PKS was between 9.5mm to 19mm while less than 20% was greater than 19mm.

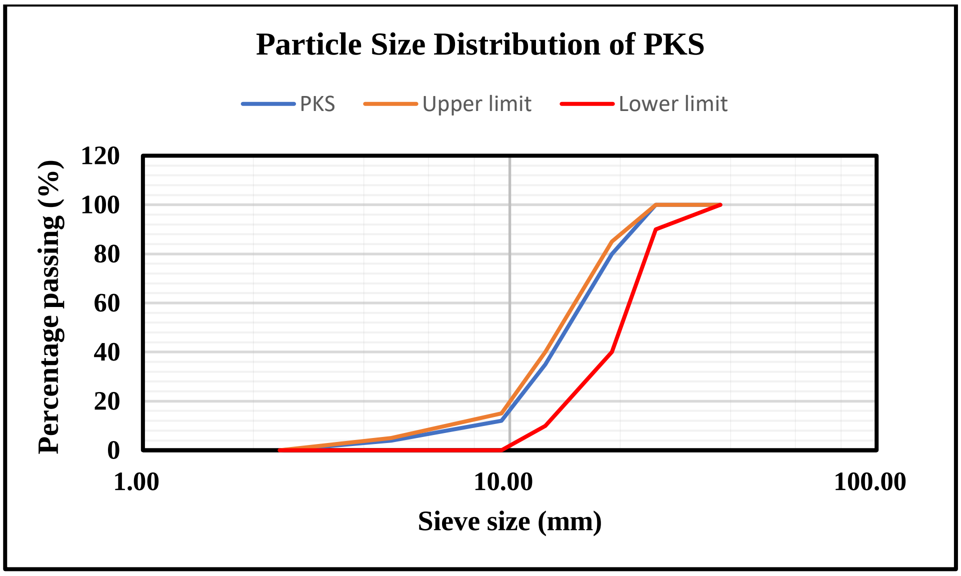


Figure 4. 2: Particle size distribution of PKS

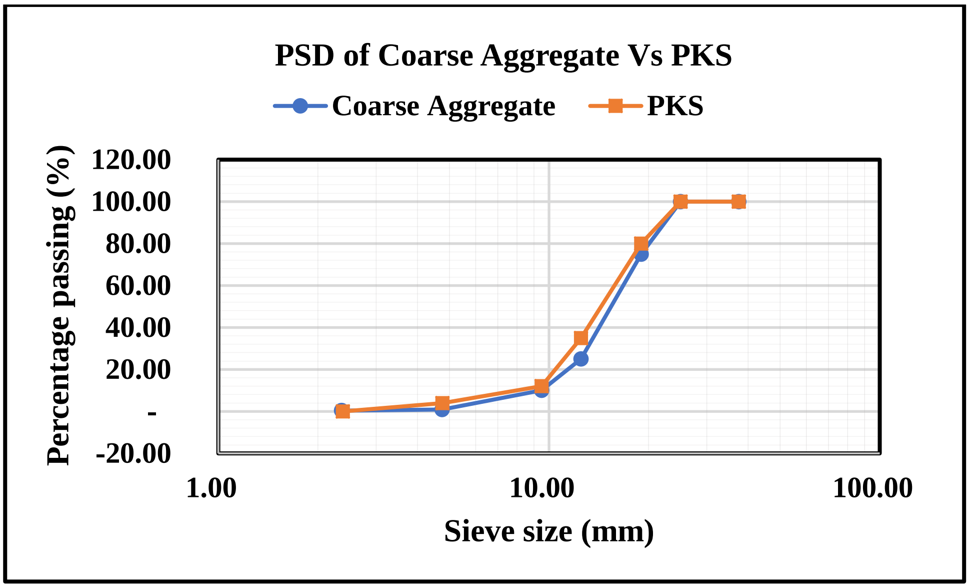


Figure 4. 3: Particle size distribution of coarse aggregate Vs PKS

Figure 4-3 shows that 90% of PKS and coarse aggregates sizes, were between 5mm to 25mm. Both of their curves were between upper and lower limit curve referenced in ASTMC-33 (2011). From the graph, it was noticed that the particle size of PKS are closer to upper limit envelope, which mean that the PKS has various bigger size of particles and can lead to the production of concrete with many voids, or the use of a larger portion of fine aggregate to fill those voids between the aggregates.

4.2.1 Particle Size Distribution of fine Aggregate

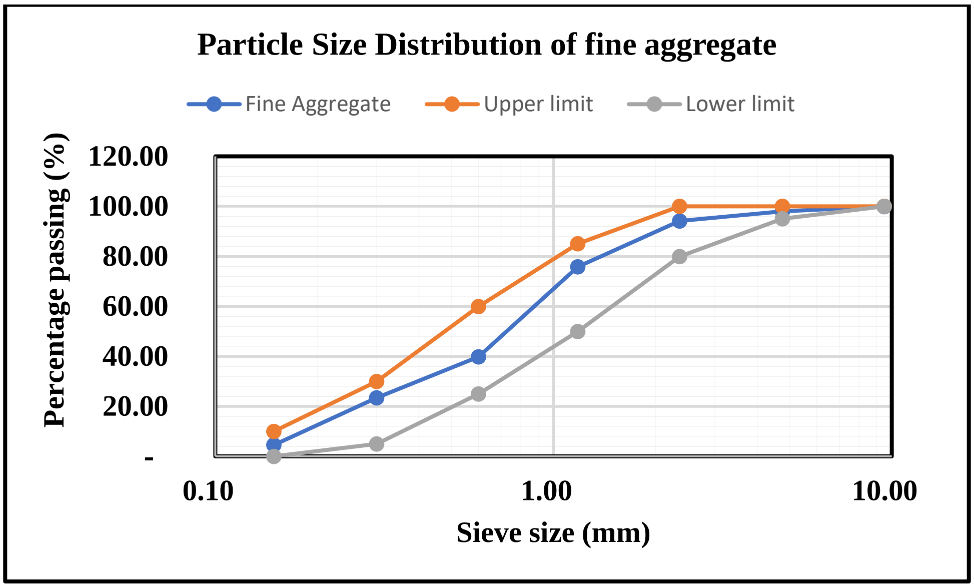


Figure 4. 4: Particle size distribution of fine aggregate

The fine aggregate used was well graded as particles range from 0.15mm – 4.75mm in sizes. Hence, from Figure 4-4, it can be seen that the grading of the aggregates satisfied the requirements of ASTMC-33 (2011), which requires that the fine aggregate be less the 45% retained on any one sieve. ASTMC-33 (2011) 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 on the mix, while a 'very coarse' fine aggregate could compromise workability. The fineness modulus obtained was 2.55 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.

Table 4. 1: Summary characteristics of PKS, coarse aggregate, and fine aggregate

Characteristic	Coarse aggregate	Untreated PKS	Treated PKS	Fine aggregate
Maximum aggregate size (mm)	20.00	19.00	19.00	5.00
Specific Gravity	2.49	1.09	1.01	2.45
24 hours water absorption (%)	3.27	35.64	30.41	5.26
Bulk density (kg/m^3)	1,292.05	553.81	554.51	1,593.25
Loose Density (kg/m^3)	1,177.05	480.52	481.42	1,474.83
Aggregate Crushing Value, ACV (%)	20.83	5.37	5.43	-
Aggregate Impact Value, AIV (%)	8.15	6.51	6.77	-
Fineness modulus	-	-	-	2.55

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

The water absorption of coarse aggregate, untreated PKS, treated PKS and fine aggregate obtained were 3.27%, 35.64%, 30.41% and 5.26% respectively. From these results, it can be seen that, although the water absorption of treated PKS is lower than untreated PKS, both are higher than the water absorption of aggregates. 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.

4.2.4 Specific Gravity of Coarse Aggregate, PKS, and Fine Aggregate

The specific gravity for coarse aggregate, treated PKS, and fine aggregate recorded were 2.49, 1.01 and 2.45 respectively. According to Popovics (1992), aggregates with specific gravity less than 2.4 are classified as light-weight aggregate (LWA). Hence, PKS can be categorized as a LWA since his specific gravity is less than 2.4.

4.2.5 Aggregate Crushing Value of Coarse Aggregate and PKS

The ACV for coarse aggregate, untreated PKS and treated PKS were 20.83%, 5.37% and 5.43% respectively. It can be noticed that their ACV satisfied BS 812-110 (1990) requirement since the maximum recommended ACV for aggregates was 30%. This implies that the PKS can be used for surface pavement.

4.2.6 Aggregate Impact Value of Coarse Aggregate and Palm Kernel Shells

The AIV for coarse aggregate, untreated PKS and treated PKS were 8.15%, 6.51% and 6.77% respectively. According to BS 812-112 (1990), the specified limit for AIV for aggregates which are adequate for concrete with good impact resistance is 25%. Therefore PKS and coarse aggreagate showed better impact resistance and are in adequation with BS 812-112(1990).

4.2.7 Characteristics of Sugarcane Bagasse Ash and Ordinary Portland cement

The characteristics of SCBA and OPC were determined in terms of their physical and chemical properties.

4.2.7.1 Physical Properties of Sugarcane Bagasse Ash and Ordinary Portland Cement

The specific gravity of SCBA and OPC used were 2.00 and 3.09 respectively. Due to the fact that the specific gravity was below 2.40, it can be said that the SCBA used in this research was lightweight material (Popovics 1992). The low specific gravity of SCBA can contribute in the reduction of concrete density.

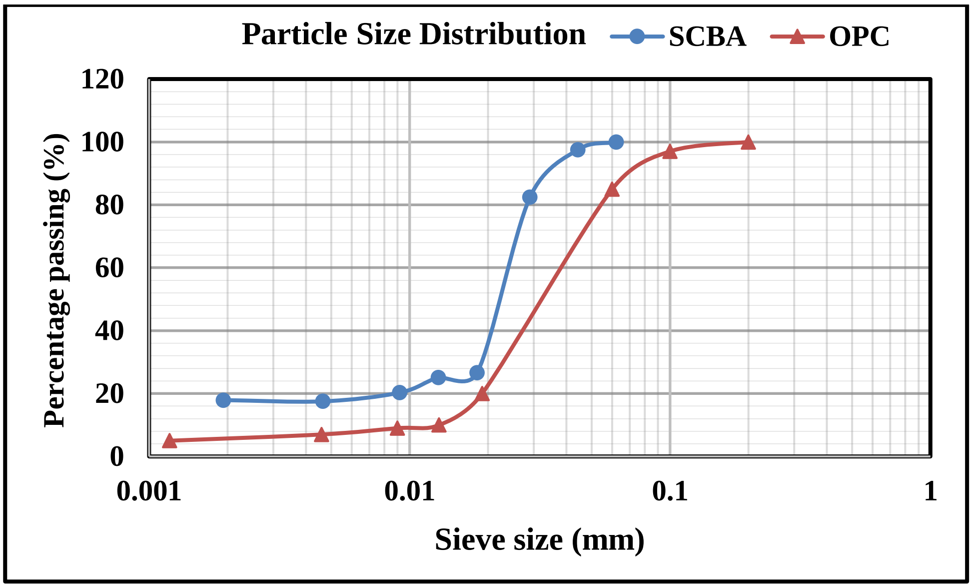


Figure 4. 5: Particle size distribution of SCBA and OPC

The hydrometer analysis of SCBA and OPC are presented on Figure 4-5. From the figure, it can be seen that the particle of SCBA are fine and closed to the one of OPC. About 28% of SCBA particles were between 0.002mm (2μm) to 0.02mm (20μm), and 72% between 0.02mm (20μm) to 0.065mm (65μm). Due to this finesse particle of SCBA, the surface area and water demand of SCBA increased as compare to OPC.

4.2.7.2 Chemical Analysis of Sugarcane Bagasse Ash and Ordinary Portland Cement

As shown in Table 4. 2, the silica (SiO_2) content of SCBA is 297% higher than that of cement while the free lime content (CaO) of cement is higher than SCBA by 94.86%. Despite this, we noted that the SCBA satisfied the minimum requirement of ASTM-C618 (2005) which required 70% for a good pozzolana.

Table 4. 2: Chemical properties of SCBA and OPC

Chemical composition	Content (%)	
	SCBA	**OPC**
Silica (SiO_2)	87.35	22.00
Aluminum (Al_2O_3)	1.97	4.80
Calcium Oxide (CaO)	3.03	59.00
Magnesium Oxide (MgO)	0	0.75
Potassium Oxide (K_2O)	4.46	0.60
Manganese Oxide (MnO)	0.24	0.04
Titanium Oxide (TiO_2)	0.18	0.20

Therefore, the presence of silica and alumina above the minimum requirement for a good pozzolana shows the ability of the SCBA to form cementitious compound when mixed with the free lime of the OPC in the presence of moisture. Calcium oxide is required for the formation of Tricalcium silicate and Dicalcium silicate which both reacts with water to form Calcium silicate hydrate which gives concrete its strength.

4.3 ASSESSMENT OF PHYSICAL AND MECHANICAL PROPERTIES OF CONCRETE MADE WITH LIME TREATED PALM KERNEL SHELL AND SUGAR CANE BAGASSE. (OBJECTIVE 2)

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

4.3.1 Workability of lime treated PKS and SCBA concrete

Workability in terms of slump test are presented in Figure 4-6; 4-7; & 4-8. From Figure 4-6, though the PKS was treated with lime to reduce the water absorption, there was still a reduction in slump with increase in PKS content. The workability reduced from 27mm for the control mix to 20mm for 20% addition of PKS. This might have been due to the finer particle sizes of PKS when compared to the coarse aggregate. From Figure 4-7, the presence of SCBA in the mix resulted in increased amount of fines as seen by the Particle Size Distribution curve of the SCBA concrete mix which increased the water demand for the mix. It confirms to the fact that pozzolanic reactions require more water as compared to normal concrete made with OPC. This finding is consistent with the research outcomes of Abdulkadir, Oyejobi, and Lawal (2014) which reported the reduction in slump with increase in percentage of SCBA.

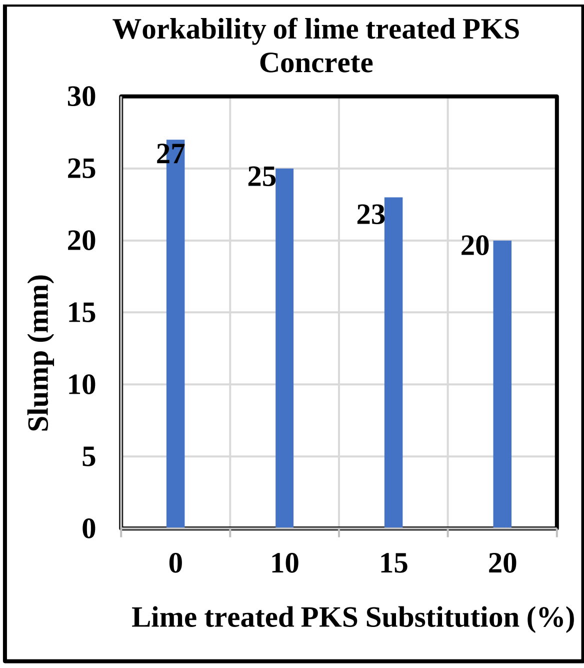


Figure 4. 6: Workability of lime treated PKS concrete

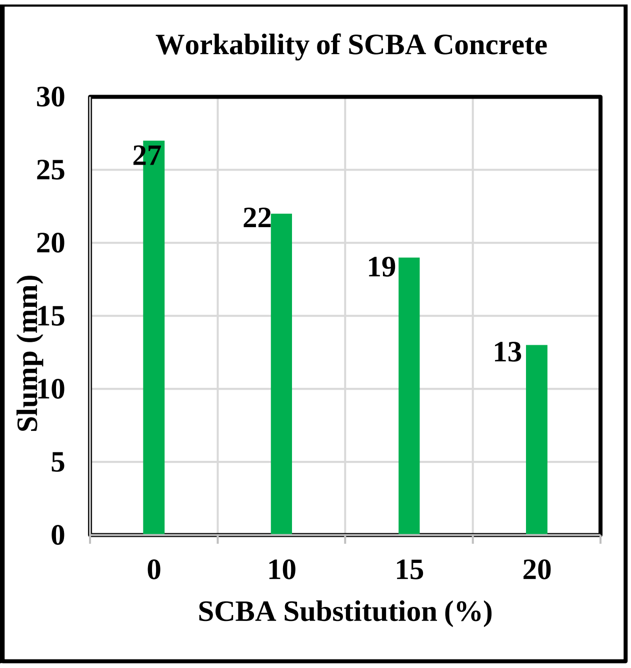


Figure 4. 7: Workability of SCBA concrete

As presented in Figure 4-8(a, b, c) it can be seen that the workability of lime treated PKS & SCBA concrete decreased at all mixes when compare to normal weight concrete. The lowest workability recorded falls in the very low range (0–25 mm). The decrease in workability of lime treated PKS & SCBA concrete can be seen to be linear and proportional to the percentages of lime treated PKS & SCBA added to the mix This can be attributed to high water absorption of PKS as compared to the coarse aggregate and hence demanding more water for a good workability. It can also be attributed to SCBA, as its particle sizes was very fine (75µ mm), hence increase in the amount of fines in the mix as compared to the OPC.

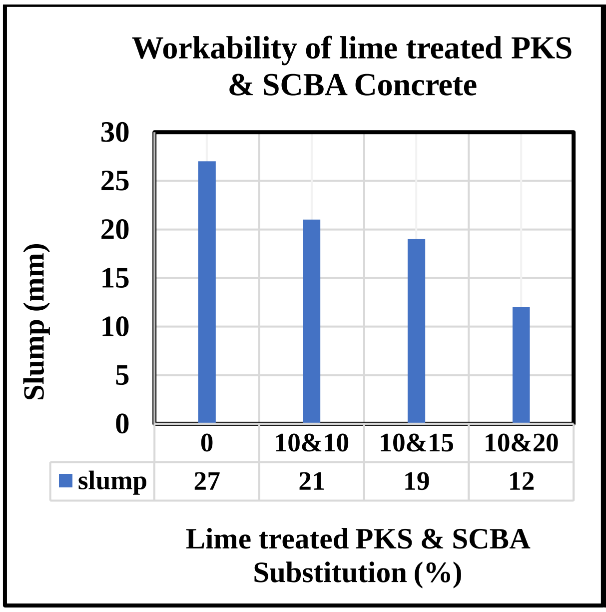


Figure 4. 8 (a)

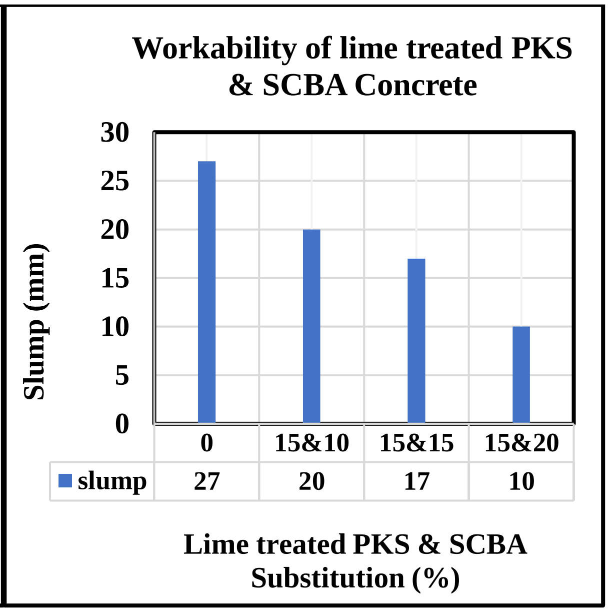


Figure 4-8 (b)

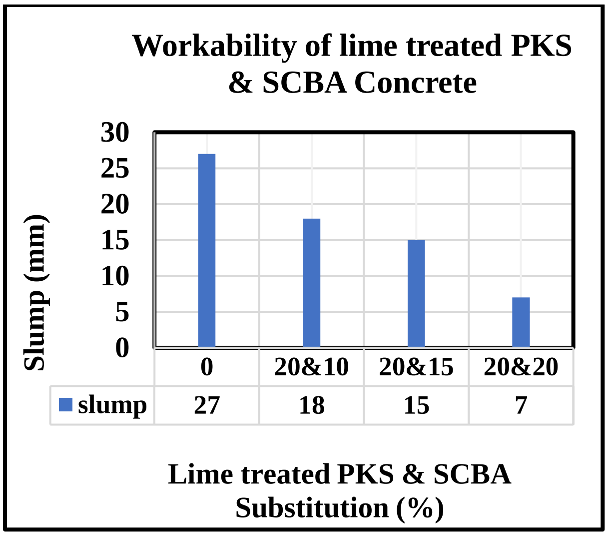


Figure 4-8 (c)

Hence, decrease in workability with increase in lime treated PKS & SCBA might require more compacting efforts which can lead to poor compaction. Poor compaction thus leads 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. Consequently, when using both lime treated PKS & SCBA, superplasticizers should be used in order to improve the workability of the concrete.

4.3.2 Water absorption of lime treated PKS and SCBA Concrete

The water absorption of lime treated PKS concrete increased slightly as the percentage replacement of lime treated PKS increase as shown in Figure 4-9. At 0% the water absorption was 1.72%, which increased to 3.74% at 20% PKS addition. This reduction in workability can be attributed to increase in the water absorption of the mix which must have resulted in the presence of voids in the hardened concrete. It is in order with the report of Olanipekun, Olusola, and Ata (2006). Similar result was obtained from

Figure 4-10 for SCBA concrete which shows a rise in the water absorption of concrete as the percentage of SCBA increases from 1.72% in the control to 2.80% at 20% SCBA content. This is due to the high absorptivity characteristic of SCBA as its particles was very fine.

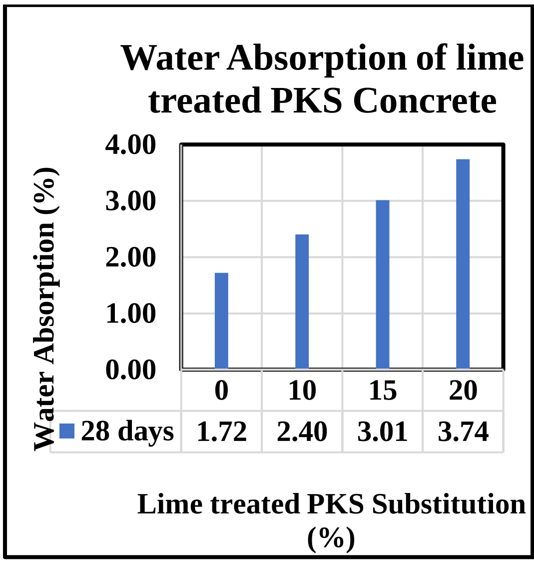


Figure 4. 9: Water absorption of lime treated PKS concrete

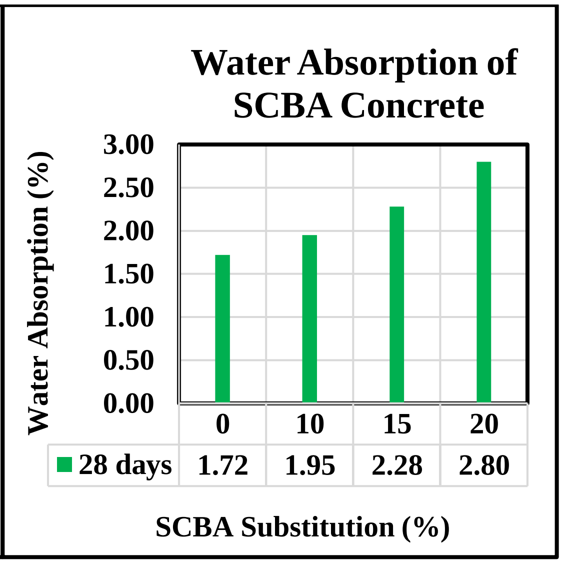


Figure 4. 10: Water absorption of SCBA concrete

As presented graphically in Figure 4-11(a, b, c), the results indicate that adding lime treated PKS & SCBA to concrete increases its water absorption. As recorded, there was a sudden increase in the water absorption of lime treated PKS & SCBA concrete from 1.72% to 7.40% noticed at 20% replacement of SCBA & PKS. This can be attributed to the combined high absorption characteristic of PKS & SCBA compared to coarse aggregate and OPC respectively. According to De Schutter and Audenaert (2004) the water absorption of concrete by immersion is an important property that gives an indirect indication of the pore structure of the concrete and durability performance in corrosive environment. Hence, high water absorption of lime treated PKS & SCBA can lead to less durable concrete. On the other hand, the absorptive characteristic of PKS and SCBA can be advantageous as they may serve as inner reservoirs thus enhancing the gradual development of concrete strength.

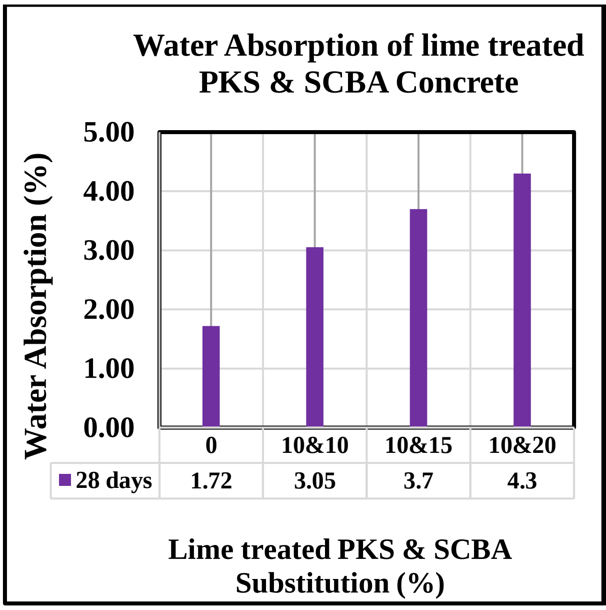


Figure 4. 11(a)

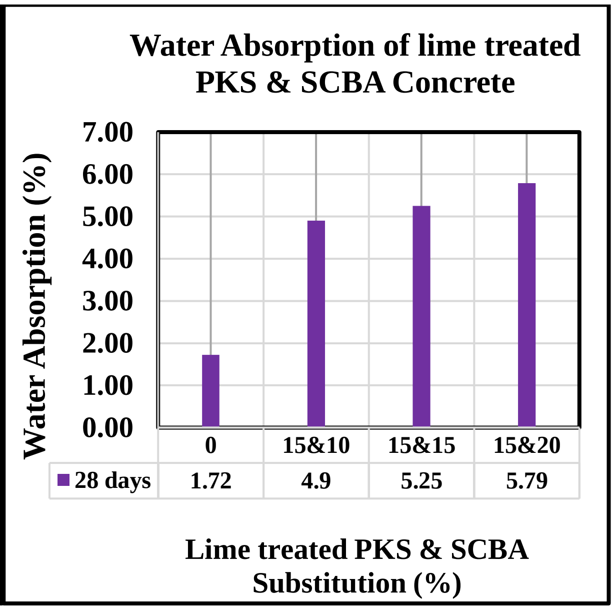


Figure 4-11(b)

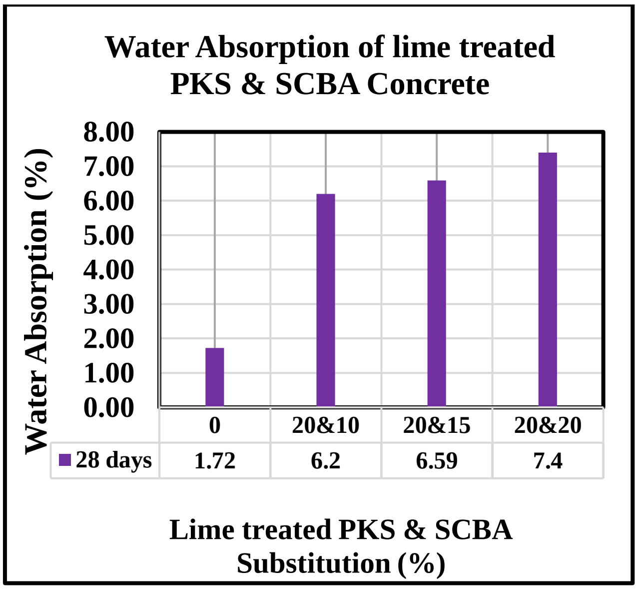


Figure 4-11(c)

4.3.3 Density of lime treated PKS and SCBA Concrete

The hardened bulk density of all lime treated PKS concrete and SCBA concrete prepared in this study are graphically presented in Figure 4-12 & 4-13. The density of lime treated PKS concrete increased from 7 days to 28 days while decreased as the percentage of substitution increased. This can be attributed to the low specific gravity of PKS when compared with coarse aggregate. Similar results were observed on density of SCBA concrete. It could be as a result that SCBA having a less bulk density of 554.13kg/m^3 as compared to that of OPC which was 1396.67kg/m^3. It is consistent with Abdulkadir, Oyejobi, and Lawal (2014) who reported, the average density of concrete decreases with increase in percentage replacement of SCBA with cement.

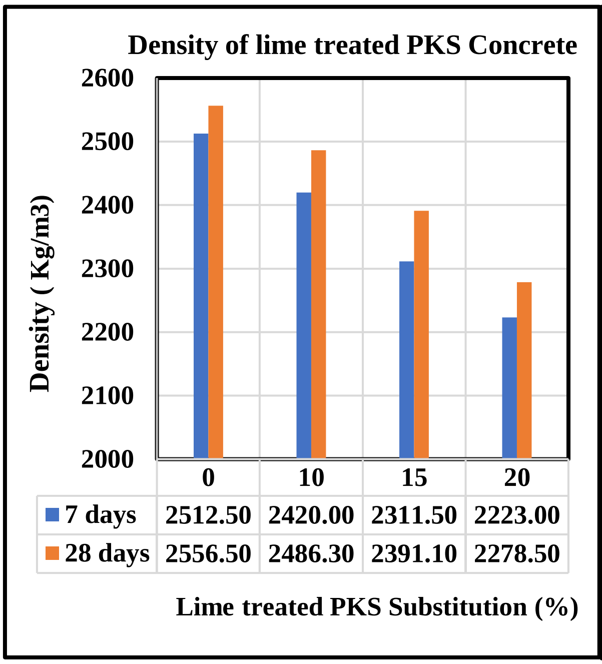


Figure 4. 12: Density of lime treated PKS concrete

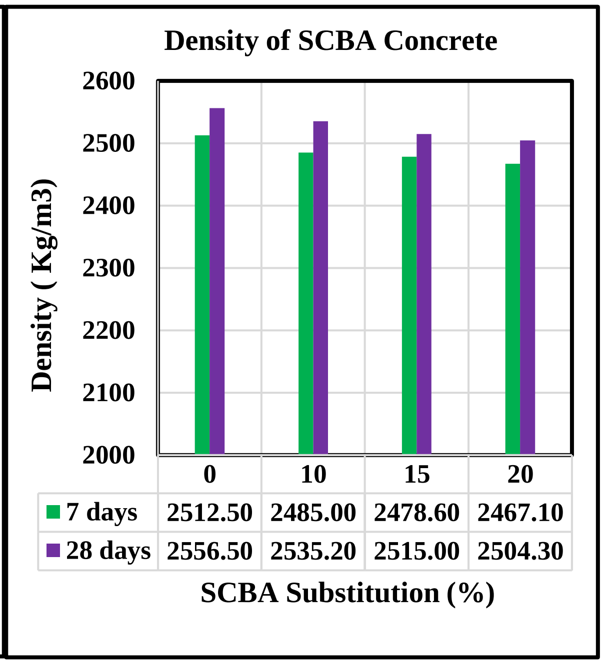


Figure 4. 13: Density of SCBA concrete

From Figure 4-14(a, b, c), the hardened density of lime treated PKS & SCBA concrete increased from 7 to 28 days, although a decrease was noticed with increase in the percentage replacement. This reduction is expected as the constituent materials were observed to be lighter than their replacements. Also, it can be said that because of the reduction in slump, there must have been poor compaction which could have resulted in voids in the concrete and hence reducing its density. This observed reduction in concrete density might result in a lower concrete strength, as concrete density contributes to concrete compressive strength. The lime treated PKS & SCBA concrete can be classified as normal weight concrete as the highest density is (2556.50kg/m3) while the lowest is (2201.90 kg/m3), which is outside the range of structural lightweight concrete.

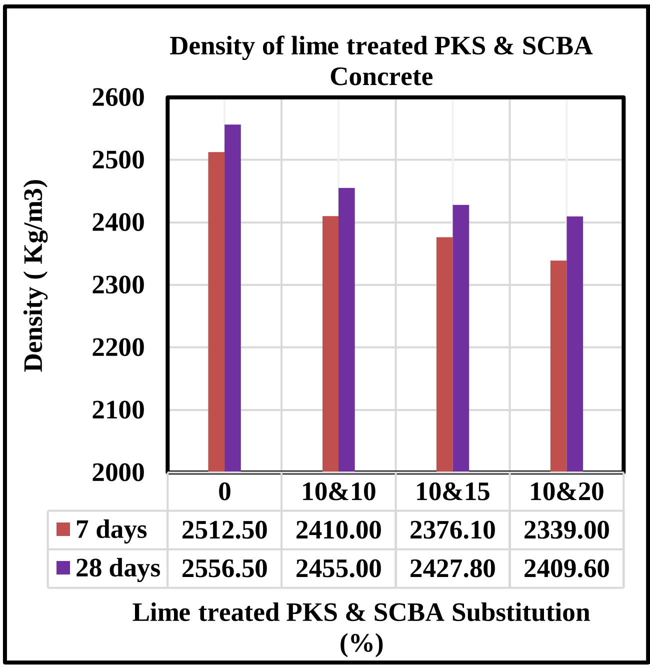


Figure 4. 14(a)

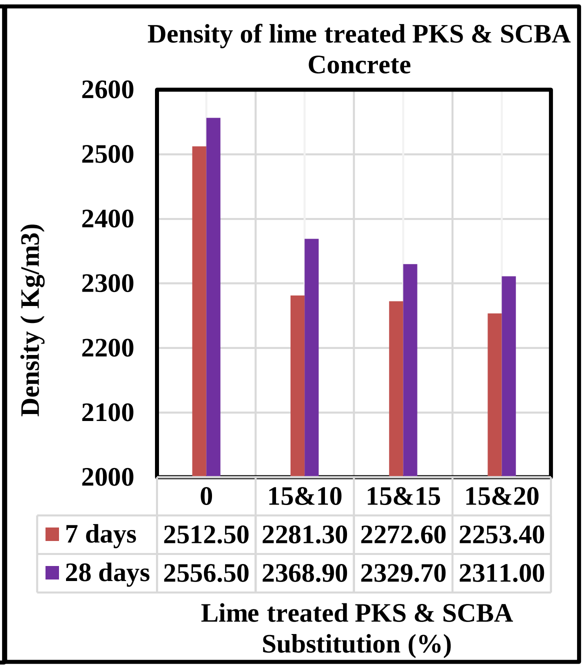


Figure 4-14(b)

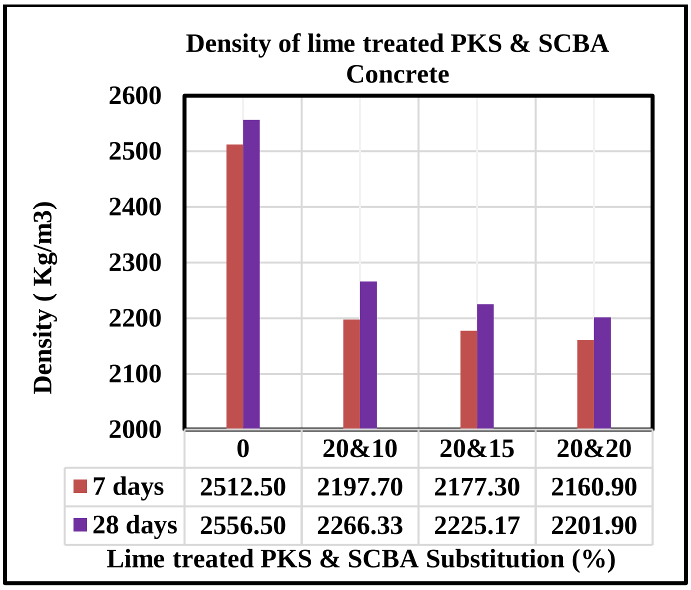


Figure 4-14(c)

4.3.4 Compressive strength of lime treated PKS and SCBA Concrete

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications, concrete is used primarily to resist compressive stresses. The compressive strength of lime treated PKS concrete (Figure 4-15) showed that the concrete gains strength with an increase in the curing age but decreases with an increase in PKS replacement. This could be due to the fact that the PKS has lower concrete density as compare to control. The compressive strength decreased at respective percentages of 11.19%,31.37% and 40.57% for 10%, 15% and 20% respectively compare to the control.

From Figure 4-16, the reduction in compressive strength of SCBA concrete can be attributed to the significantly low calcium oxide content of bagasse ash (3.03%) compared to that of cement (59.0%). As the SCBA is a pozzolanic material, it reaction occurs between calcium hydroxide ($Ca(OH)_2$), and silicic acid (H_4SiO_4) (Takemoto 1980).

$Ca(OH)_2 + H_4SiO_4 \rightarrow CaH_2SiO_4 \cdot 2\ H_2O$

The Calcium oxide is required for the formation of Tricalcium silicate and Dicalcium silicate, which both reacts with water to form Calcium silicate hydrate and gives concrete its strength.

Tricalcium silicate + Water--->Calcium silicate hydrate + Calcium hydroxide + heat

Dicalcium silicate + Water--->Calcium silicate hydrate + Calcium hydroxide +heat

The reaction of Tricalcium silicate is fast as it is responsible for most of the early 7days strength. From Figure 4-16 the reaction gave concrete 74.39%,73.67% and 73.81% of the 28days strength for 10%, 15% and 20%. Dicalcium silicate reacts more slowly and contributes only little to the strength at later times. Similar reduction in compressive strength of SCBA concrete was reported by Abdulkadir, Oyejobi, and Lawal (2014); Modani and Vyawahare (2013).

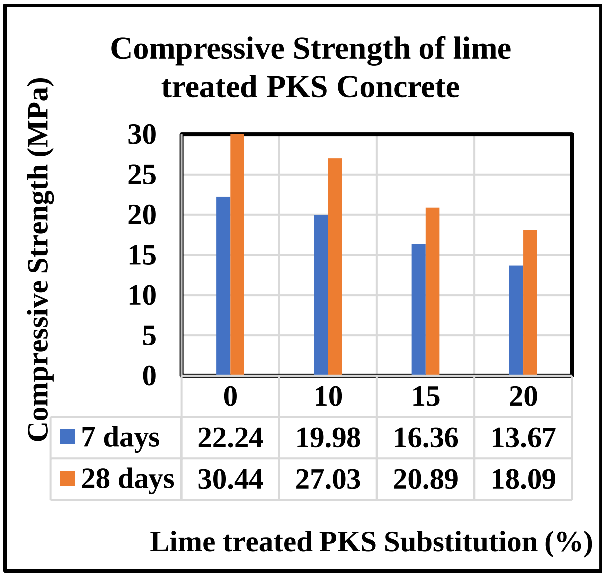


Figure 4. 15: Compressive Strength of lime treated PKS concrete

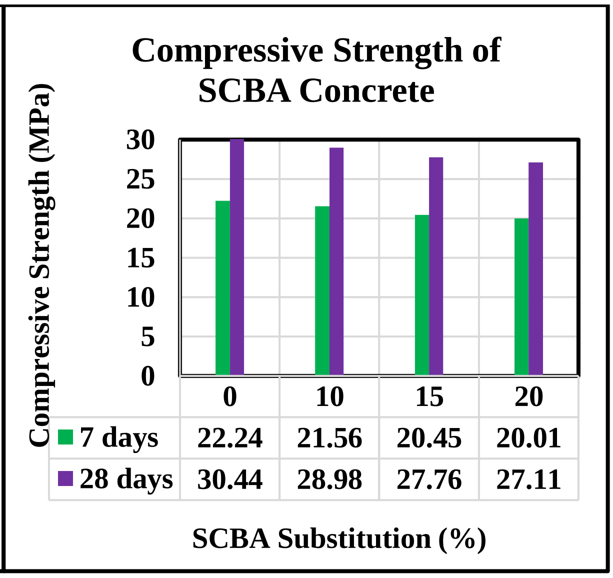


Figure 4. 16: Compressive Strength of SCBA concrete

As presented in Figure 4-17(a, b, c), for each curing age and increasing PKS & SCBA content in concrete mix, the result shows a decreasing compressive strength value below that of the control. At 28 days, the compressive decreased from 30.44MPa to 15.43MPa for 20% PKS & SCBA incorporation. The reduction can be attributed to the increased surface area of PKS as it was finer than the coarse aggregates thereby resulting into weak bonding as more cement paste might have been demanded. 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. According to MacGregor et al. (1997) a compressive strength within the range of 20 to 45 MPa is classified as good for normal weight concrete. Hence up to 15% of lime treated PKS and 10% of SCBA can be used as partial replacement of coarse aggregate and OPC respectively in production of structural concrete.

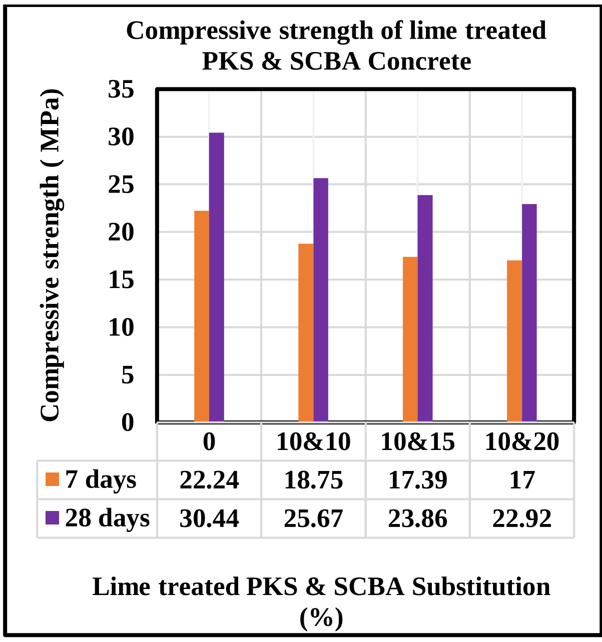


Figure 4. 17(a)

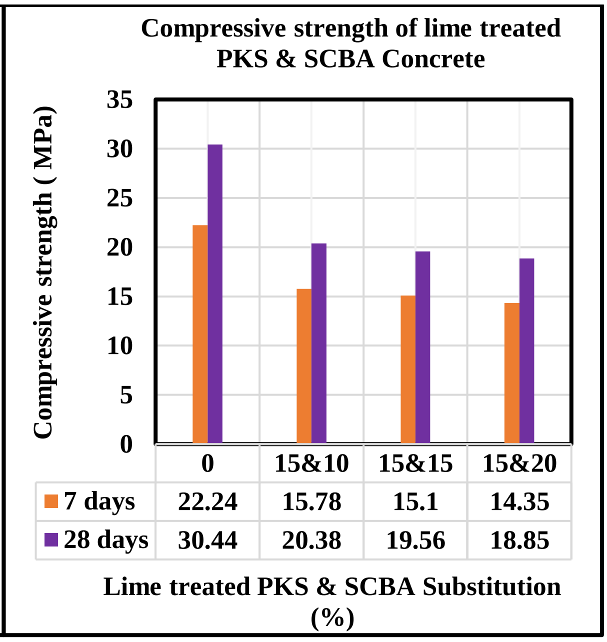


Figure 4. 17(b)

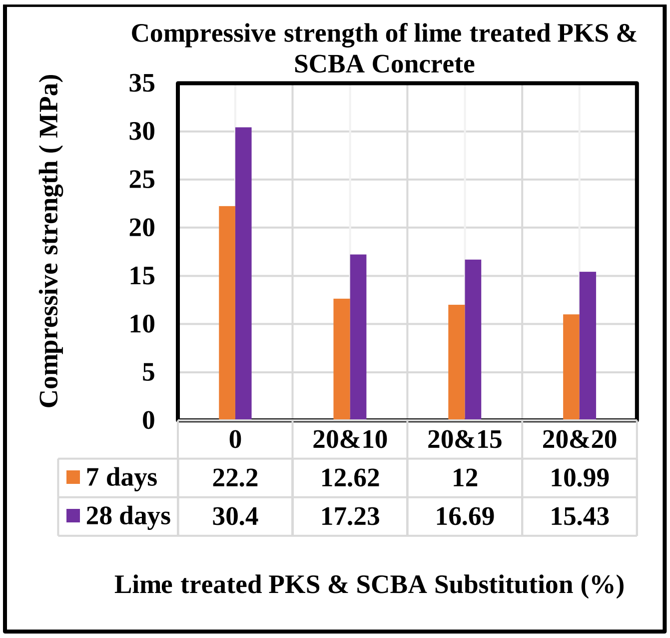


Figure 4. 17(c)

4.3.5 Splitting tensile strength of lime treated PKS and SCBA Concrete

The tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures. Concrete develops cracks when tensile forces exceed its tensile strength. A tensile strength is a measure of the ability of material to resist a force that tends to pull it apart. It is expressed as the minimum tensile stress (force per unit area) needed to split the material apart. As portrayed in Figure 4-18 & 4-19 the evolution of Splitting tensile strength, the experimental results show a trend that resembles the compressive strength results. The Splitting tensile strength of lime treated PKS concrete and SCBA concrete decreased as increased in percentage replacement while increased in curing age. This reduction can be attributed to poor compaction, increased surface area of the lime treated PKS, reduced bonding properties of SCBA in constituent materials in concrete as compared to the cement. This is in concordance with result reported by Modani and Vyawahare (2013).

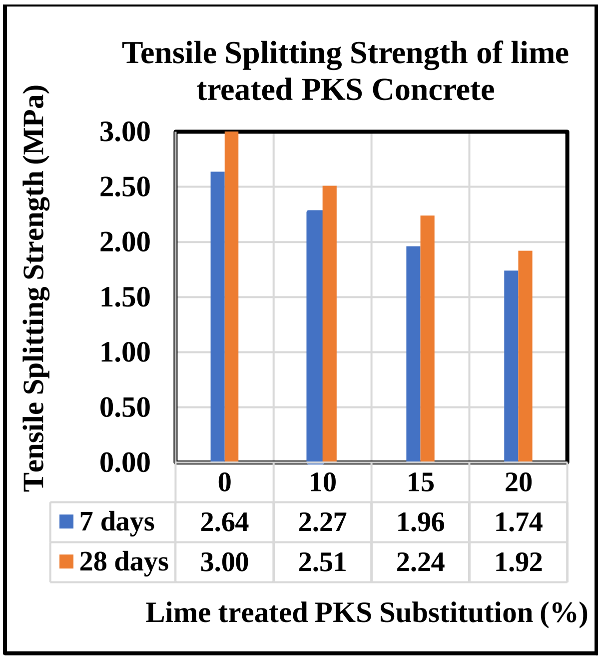


Figure 4. 18: Tensile splitting Strength of lime treated PKS concrete

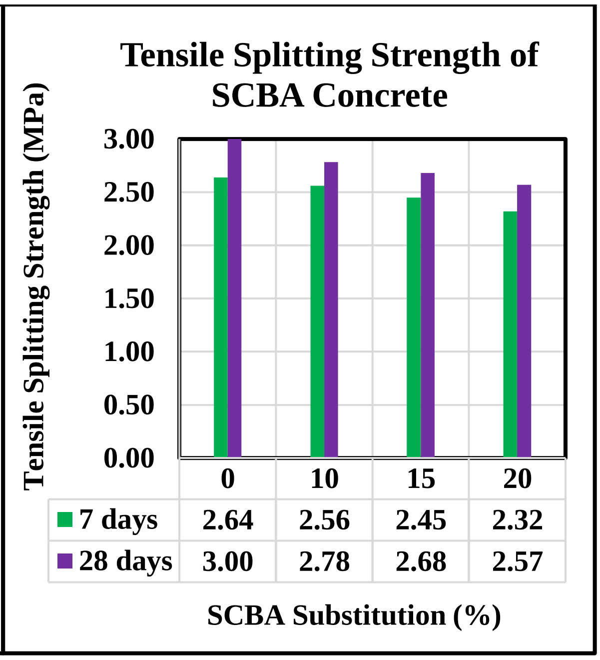


Figure 4. 19: Tensile splitting Strength of SCBA concrete

From Figure 4-20(a, b, c), the splitting tensile strength decreased from 3.00 MPa for the control to 1.77 MPa for 20% PKS &SCBA. Increase in the percentage of lime treated PKS & SCBA contents resulted in the reduction of the splitting tensile strength while there was an increase in the splitting tensile strength with curing age. This reduction can be caused by high water absorption characteristics of PKS and SCBA which lead to poor workability by creating voids in concrete. It is also due to lower specific gravity of PKS and SCBA which lead to lower concrete density as compare to control.

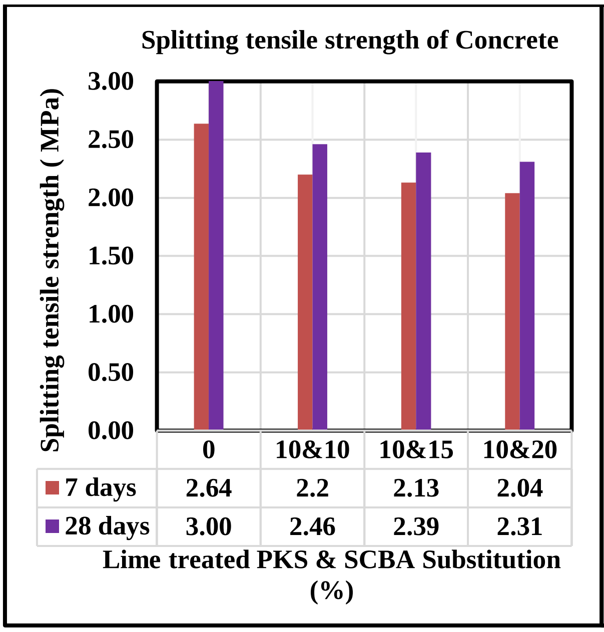


Figure 4. 20(a)

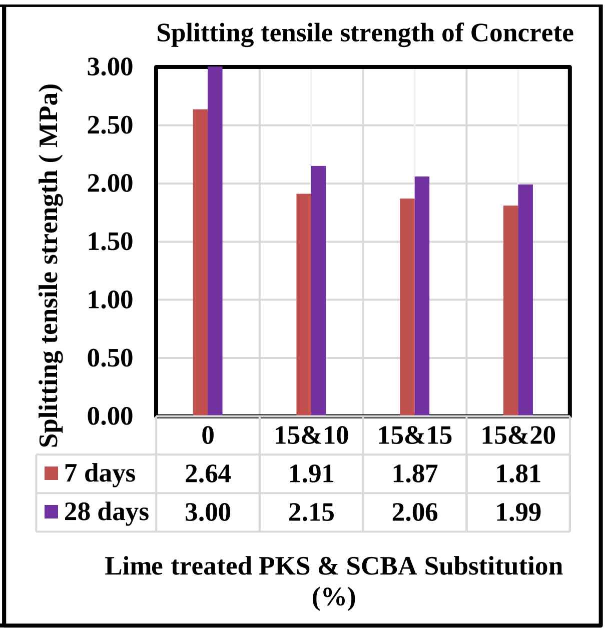


Figure 4. 20(b)

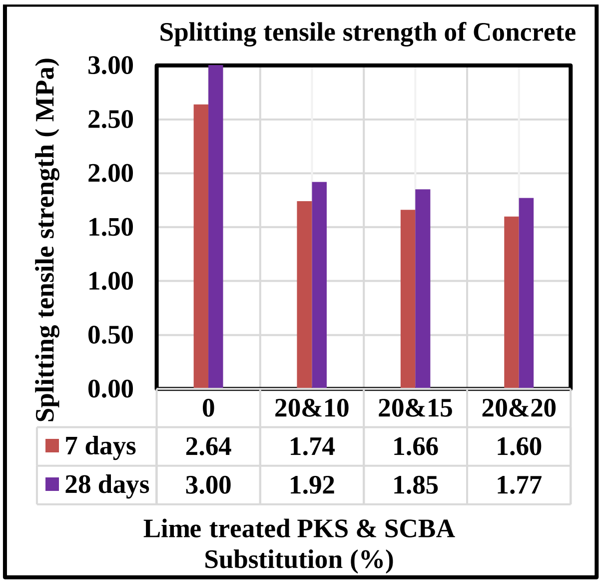


Figure 4. 20(c)

4.4 ASSESS OF DURABILITY OF CONCRETE MADE WITH SCBA AND LIME TREATED PKS IN AN ALKALINE AND ACIDIC MEDIUM. (Objective 3)

The durability of lime treated PKS and SCBA as partial replacements of coarse aggregate and OPC respectively has been investigated and the results are presented and discussed in this section. For the durability, the mechanical properties in terms of compression and splitting tensile tests were determine at 45 and 90 days, while for the chemical attack, the compressive strength and weight loss were evaluated.

4.4.1 Compressive strength of lime treated PKS and SCBA Concrete

From the Figure 4-21, It can be seen that the compressive strength increases with curing age but decrease with increased in percentage replacement. However, 10% of lime treated PKS replacement gave 96.88% of strength of the control at 45days and 99.91% at 90days. This development in strength can be due to the absorptive nature of PKS as it may serve as internal reservoir in concrete. Similar results were observe by Philips, Mutuku, and Mwero (2017). Figure 4-22 shown the development in strength with curing age and increase in percentage replacement. At 90 days, the strength increases by 7.12%, 2.61% and 0.22% respectively at 10%, 15% and 20% as compared to the control. These results confirm the fact that the SCBA as pozzolanic material, react over time as the day of curing increase.

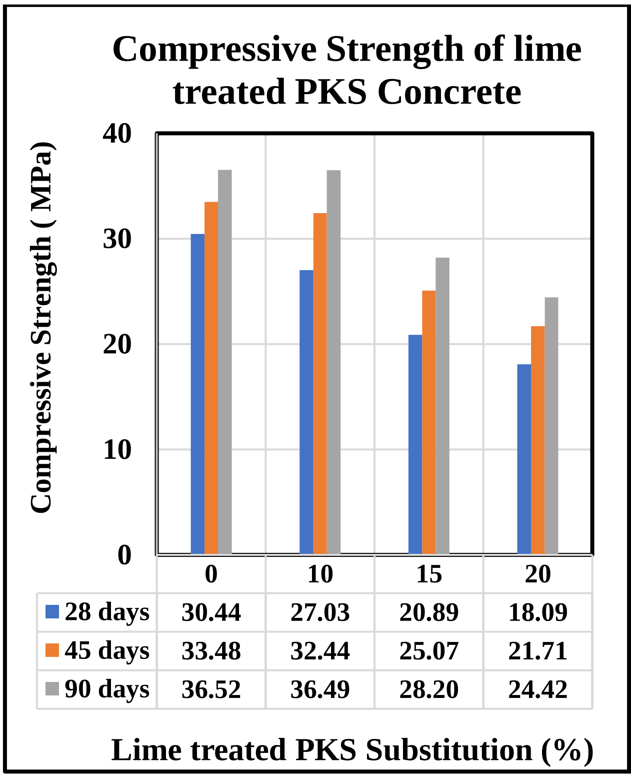


Figure 4. 21: Compressive Strength of lime treated PKS concrete

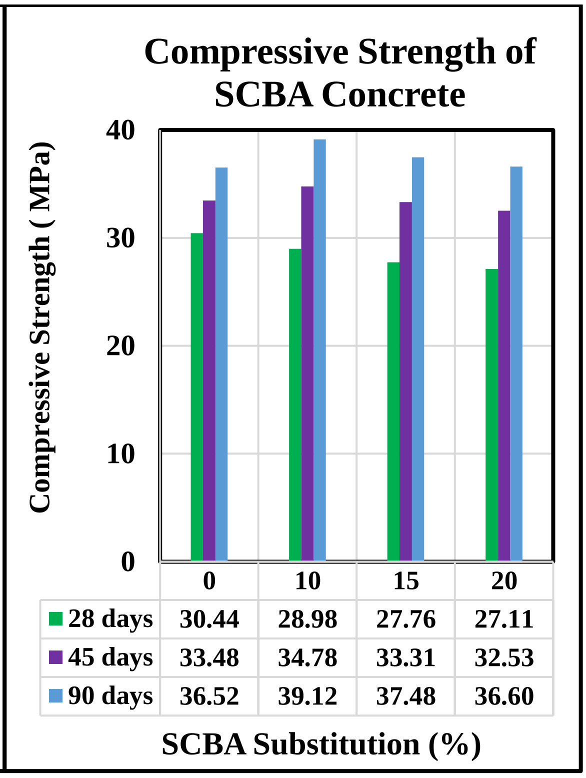


Figure 4. 22: Compressive Strength of SCBA concrete

From Figure 4-23(a, b, c), the combination of lime treated PKS and SCBA can be seen, all mixes decrease in strength as the percentage of replacement increase, except 10% lime treated PKS and SCBA combination which gave a better result. At 10% replacement lime treated PKS and SCBA combination, the strength increases by 2.40% at 90 days as compare to normal concrete. This development is in accordance with the result in Figures 4-21 & 4-22 which show the development of strength at 10% substitution of lime treated PKS and 10% substitution of SCBA. On combining them at the same percentage replacement, it can be seen that the lime treated PKS affect the strength by dropping down the development of strength of SCBA. This can be due to the fact that PKS have less specific gravity and weak bulk density as compare to coarse aggregate.

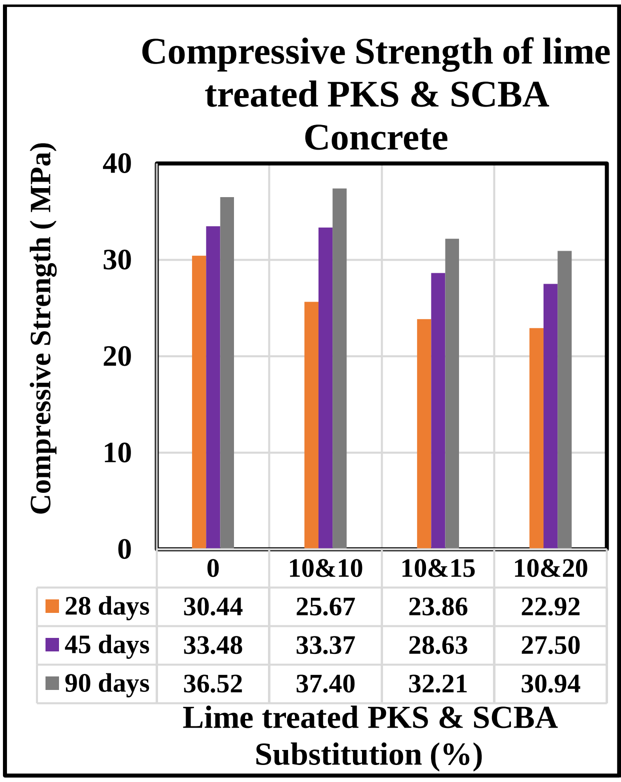


Figure 4. 23(a)

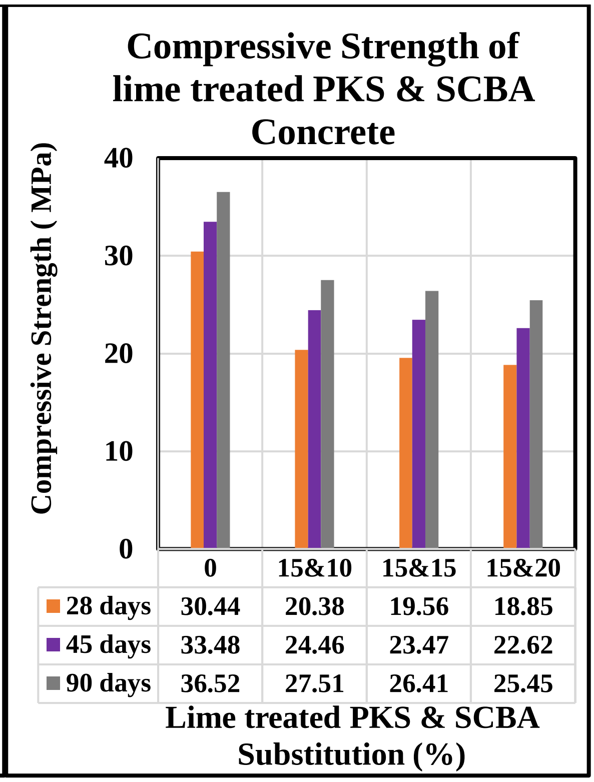


Figure 4. 23(b)

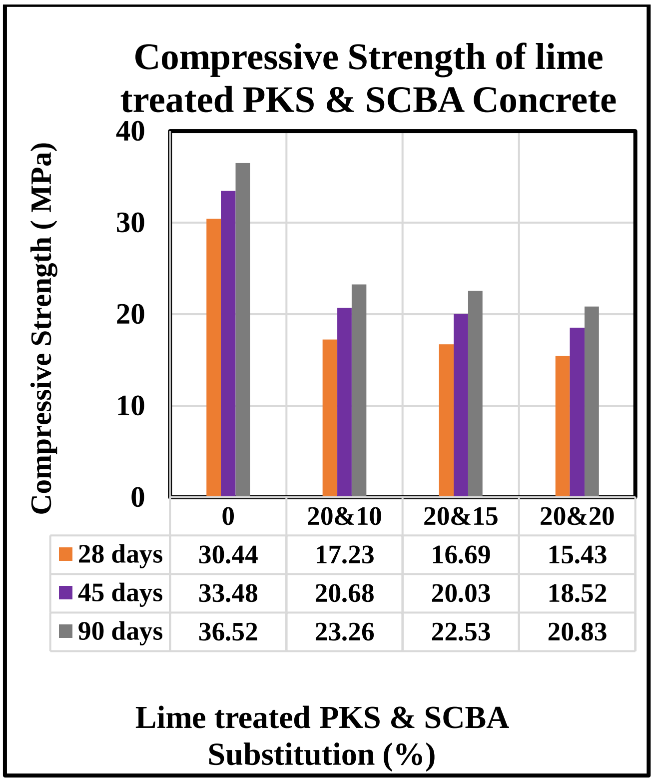
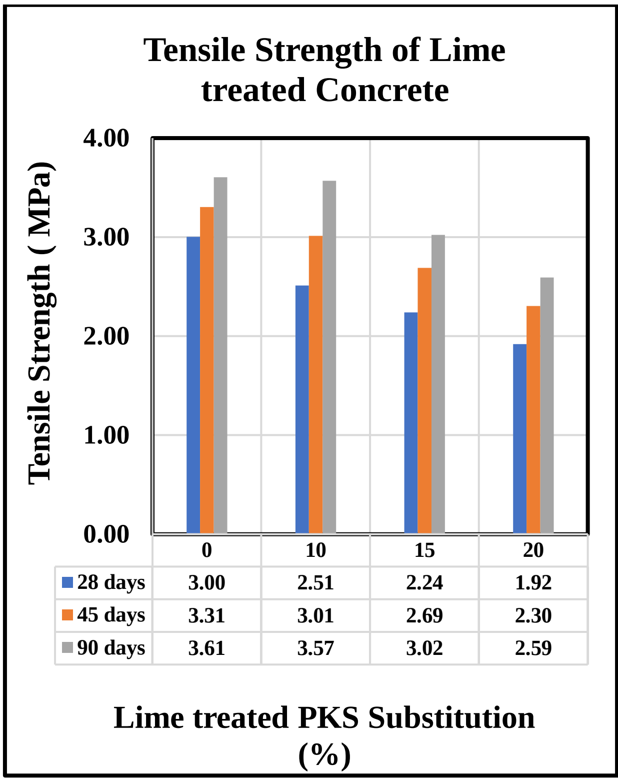


Figure 4. 23(c)

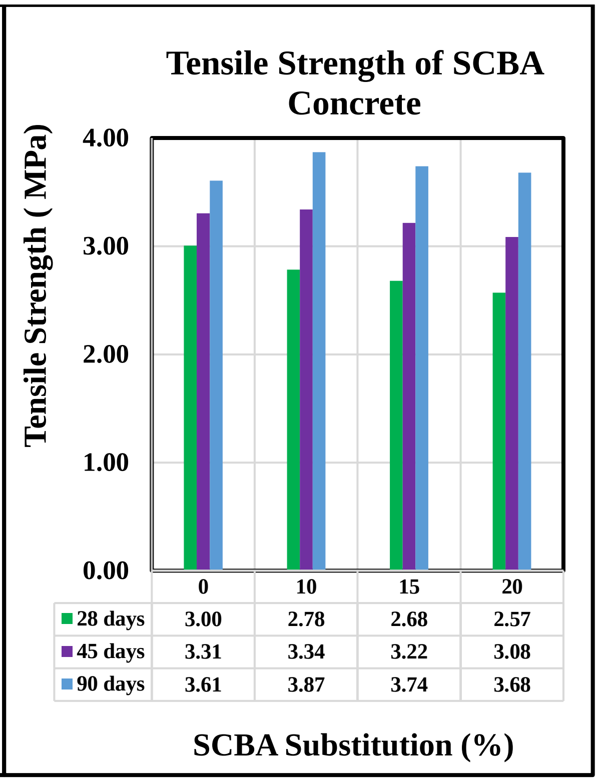
4.4.2 Tensile strength of lime treated PKS and SCBA Concrete

The tensile strength has a similar trend with compressive strength. In Figure 4-24 it can be seen that the tensile strength of lime treated PKS concrete decrease as the percentage replacement increase. At 10%, 15% and 20% substitution, it was noticed at 90 days that the tensile strength decreases by 0.99%, 16.13%, and 28.11% respectively compare to the control. This reduction in tensile strength might have been due to poor compaction, and increased surface area of lime treated PKS. The tensile strength of SCBA in Figure 4-25 illustrates the increment of strength with curing time. At 10%, 15% and 20% replacement, the tensile strength increases by 7.33%, 3.73% and 2.06% respectively at 90 days compare to the control. This increase in tensile strength might be due to the large amount of SCBA particle in the concrete, as its particle was very fine and can fill the void between concrete. It can also due to the reaction of SCBA as it is a pozzolanic material. Its reaction occurs between calcium hydroxide ($Ca(OH)_2$), and silicic acid (H_4SiO_4) (Takemoto, 1980). The Calcium oxide is required for the formation of Tricalcium silicate and Dicalcium silicate, which both reacts with water to form Calcium silicate hydrate and gives concrete its strength.



	0	10	15	20
28 days	3.00	2.51	2.24	1.92
45 days	3.31	3.01	2.69	2.30
90 days	3.61	3.57	3.02	2.59

Figure 4. 24: Tensile Strength of lime treated PKS concrete



	0	10	15	20
28 days	3.00	2.78	2.68	2.57
45 days	3.31	3.34	3.22	3.08
90 days	3.61	3.87	3.74	3.68

Figure 4. 25: Tensile Strength of SCBA concrete

Figure 4-26(a, b, c) shows the tensile strength of Lime treated PKS and SCBA. It can be seen that at all mix substitution, the tensile strength decreases as the percentage increased, except at 90 days, 10% of lime treated PKS and SCBA which increase by 1.23% of the control. This reduction at all mix except 10% substitution, can be caused by high water absorption characteristics of PKS and SCBA, which lead to poor workability by creating voids in concrete. It is also due to lower specific gravity of PKS and SCBA which lead to lower concrete density as compare to control.

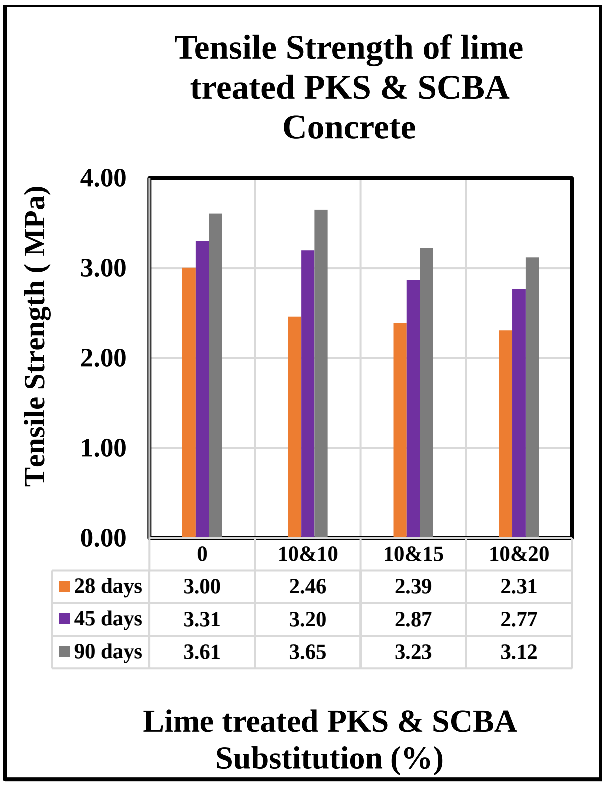


Figure 4. 26(a)

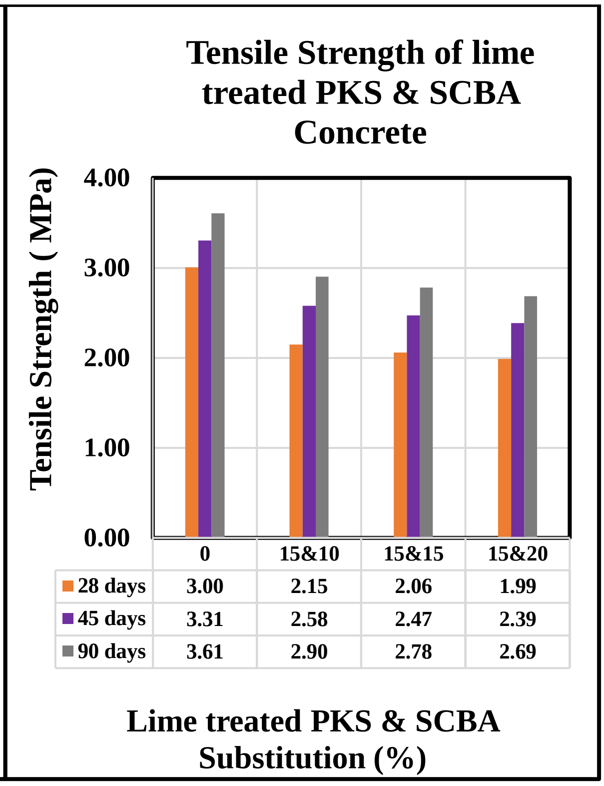


Figure 4. 26(b)

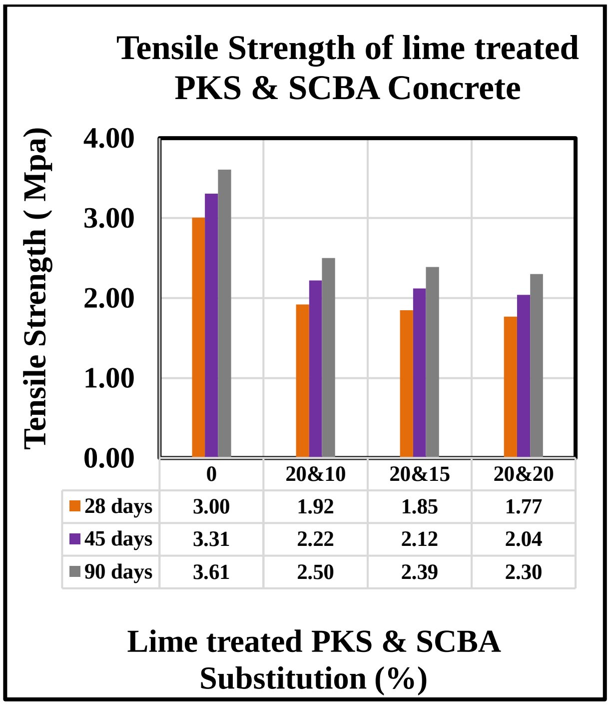
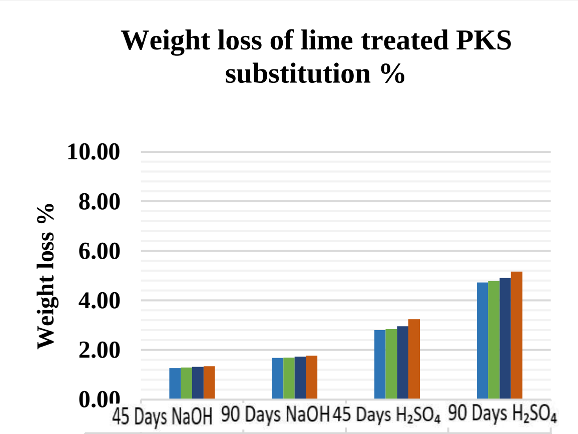


Figure 4. 26(c)

4.4.3 Chemical attack of lime treated PKS and SCBA Concrete

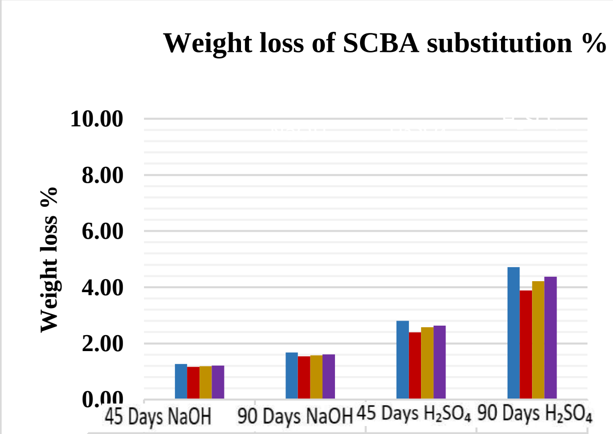
The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to these environment(Sivaraja et al. 2010). To assess the durability, chemical solution such as Sulphuric acid (pH 3) and sodium hydroxide (pH 11) were used.

4.4.4 Weight loss of lime treated PKS and SCBA Concrete at 45 and 90 days



	45 Days NaOH	90 Days NaOH	45 Days H_2SO_4	90 Days H_2SO_4
0	1.27	1.68	2.80	4.72
10	1.29	1.70	2.84	4.78
15	1.32	1.73	2.96	4.91
20	1.34	1.77	3.24	5.17

Figure 4. 27: Weight loss of lime treated PKS concrete



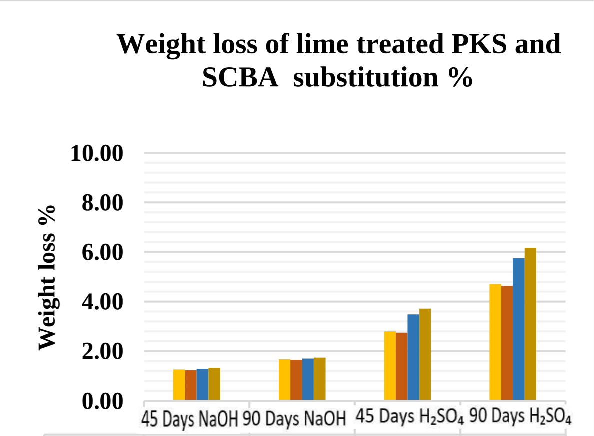
	45 Days NaOH	90 Days NaOH	45 Days H_2SO_4	90 Days H_2SO_4
0	1.27	1.68	2.80	4.72
10	1.16	1.54	2.40	3.89
15	1.18	1.57	2.58	4.21
20	1.21	1.61	2.63	4.38

Figure 4. 28: Weight loss of SCBA concrete

The weight loss was determined in accordance with ASTM C267-97. After 28 days of curing, the concrete specimens were immersed in two types of chemical solutions: sulfuric acid (H2SO4) pH of 3 and Sodium Hydroxide (NaOH) pH of 11. Before the compressive strength test, the effet of acid attack on weight was evaluated by measuring the mass loss (ML) of specimens, as follow:

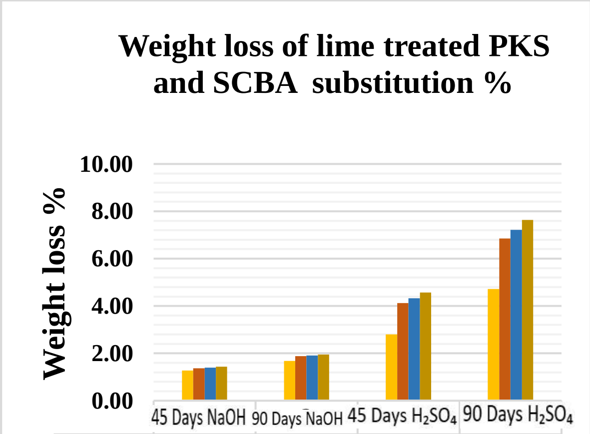
$$ML(\%) = \frac{Wr - Ws}{Wr} \times 100$$

where Wr is weight of the specimen before immersion and Ws is weight of the immersed specimen after test period. The result can be seen in Figure 4-27 & 4-28. From the graphs, we noticed that the concrete specimen resists better sodium Hydroxide attack than Sulphuric acid attack on weight loss. This reduction in weight of concrete specimen is due to the chemical reaction between the hydration products of concrete and the surrounding acid, which indues the loss of materials and surface irregularities.



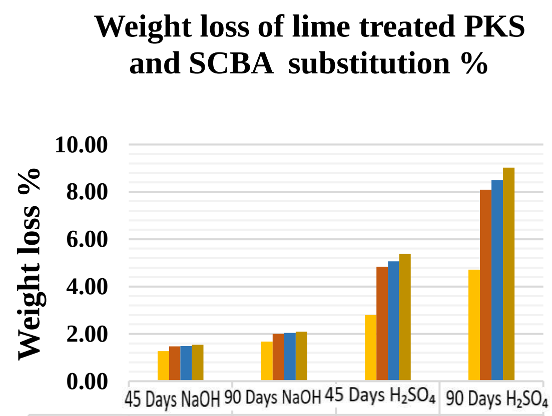
	45 Days NaOH	90 Days NaOH	45 Days H_2SO_4	90 Days H_2SO_4
0	1.27	1.68	2.80	4.72
10&10	1.24	1.66	2.75	4.64
10&15	1.30	1.71	3.49	5.76
10&20	1.34	1.75	3.73	6.18

Figure 4. 29(a)



	45 Days NaOH	90 Days NaOH	45 Days H_2SO_4	90 Days H_2SO_4
0	1.27	1.68	2.80	4.72
15&10	1.37	1.88	4.12	6.86
15&15	1.40	1.91	4.33	7.21
15&20	1.43	1.95	4.57	7.64

Figure 4-29(b)



	45 Days NaOH	90 Days NaOH	45 Days H_2SO_4	90 Days H_2SO_4
0	1.27	1.68	2.80	4.72
20&10	1.47	2.00	4.83	8.09
20&15	1.49	2.04	5.07	8.50
20&20	1.54	2.10	5.38	9.03

Figure 4-29(c)

From the Figure 4-29(a, b, c) similar result was observed. The concrete specimen lost more weight on sulphuric acid attack than sodium hydroxide attack. At 0% substitution on 90days, the concrete lost 4.72% of the weight in sulphuric acid solution while it lost 1.68% in sodium hydroxide. At 20% substitution of PKS and SCBA, the concrete lost 9.03% in sulphuric acid solution at 90 days, while 2.10% in sodium hydroxide. This indicates that the chemical solution attacked the hydration products of cement and produced the soluble corrosion products which affect the weight by reducing the specimen size.

4.4.5 Compressive strength of lime treated PKS and SCBA Concrete in sulphuric acid solution

In Figure 4-30 & 4-31 a reduction in strength was observed for lime treated PKS concrete and SCBA concrete. It has been found after 90 days of immersion in sulphuric acid solution that, the strength of PKS concrete retained 96.43%, 96.37%, 96.24% and

95.98% respectively at 0%, 10%, 15%, and 20% substitution compare to initial strength at 28 days, while at 0%, 10%, 15%, and 20% substitution, the strength of SCBA concrete retained 96.43%, 97.26%, 96.94% and 96.77%. This can be explained considering time, that the loss of strength of SCBA concrete is better than the PKS concrete. The reduction in strength is due to the irregularities in geometry across the height of the degraded concrete cubes which result in non-uniform distribution of stresses while applying the compressive load and subsequent reduction in compressive strength.

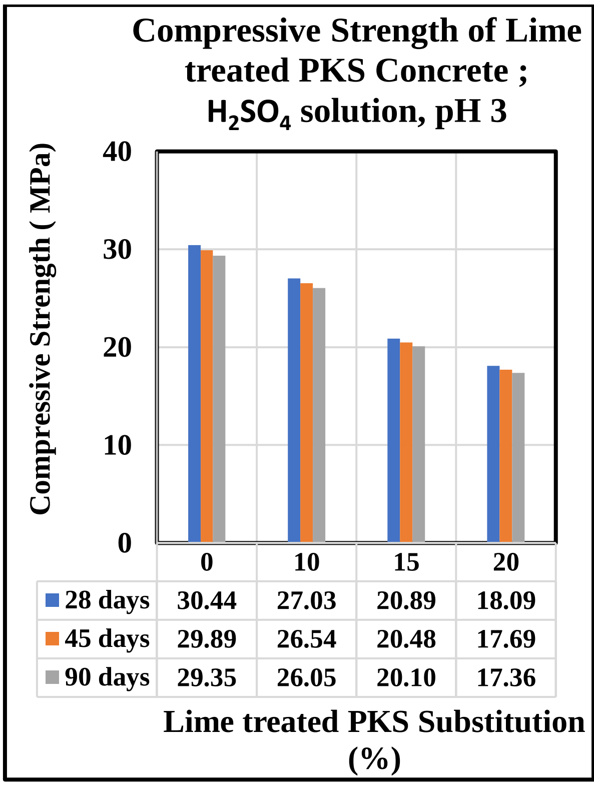


Figure 4. 30: Compressive Strength of Lime treated PKS Concrete; H2SO4 solution, pH 3

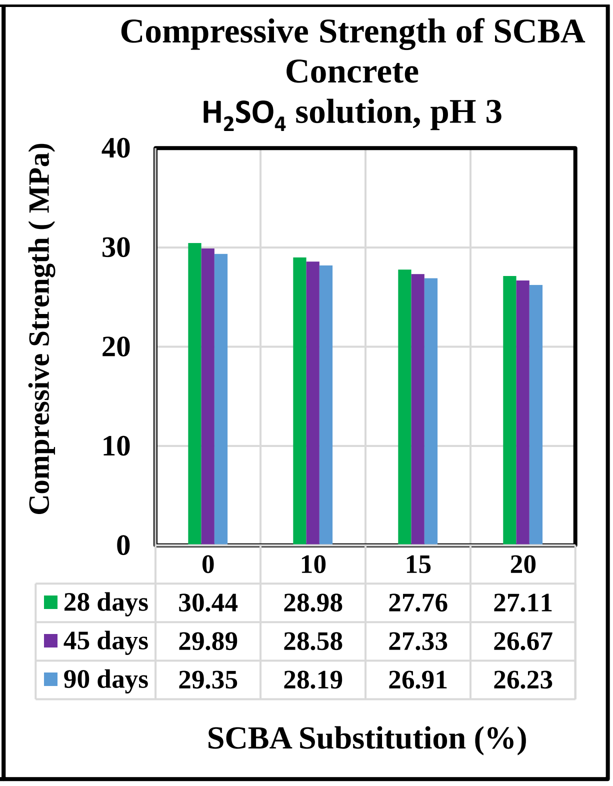


Figure 4. 31: Compressive Strength of SCBA concrete; H_2SO_4 solution, pH 3

Figure 4-32 despite the results, strength of lime treated PKS and SCBA concrete. At all mixes of substitutions, the compressive strength decreases as the percentage of substitution increases. At 90 days, the compressive strength decreased from 29.35MPa for control concrete to 14.21 MPa at 20% lime treated PKS and SCBA substitution. From the results, it is evident that the mix of lime treated PKS and SCBA concrete in terms of performance, had lower compressive strength than conventional concrete when exposed to sulphuric acid attack. This reduction in strength is due to the destruction of concrete structure as it appears that in the sulphuric acid attack, the early decomposition of calcium hydroxide and subsequent formation of layer amount of gypsum are attributed to the progressive deterioration accompanied by the scaling and softening of the matrix.

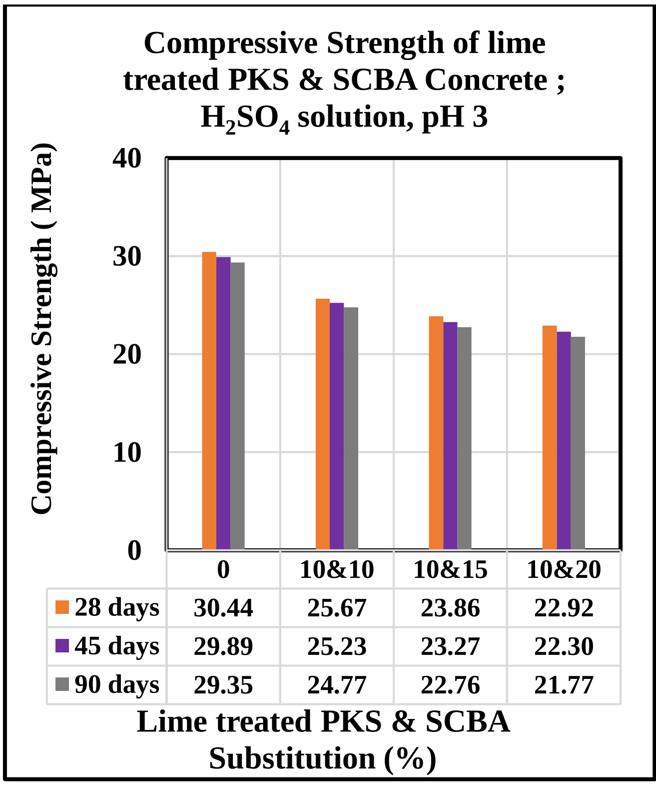


Figure 4. 32 (a)

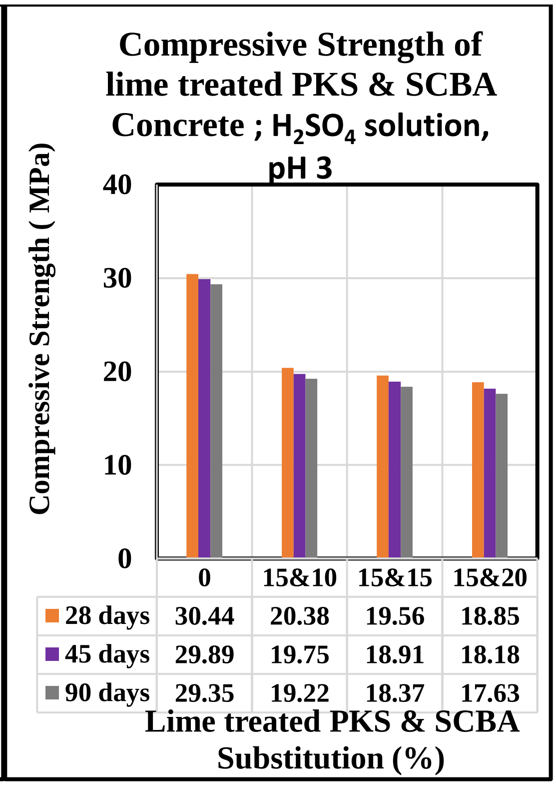


Figure 4-32(b)

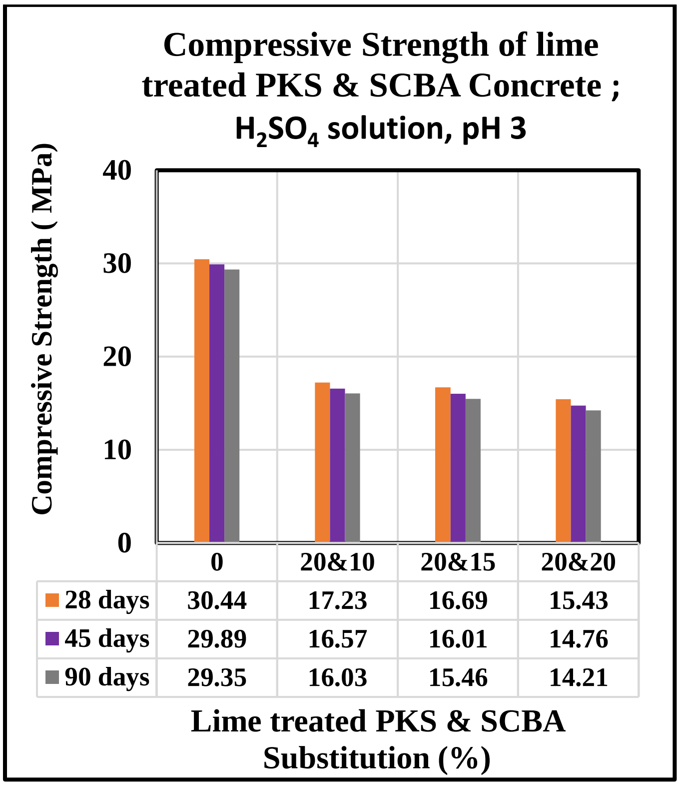


Figure 4-32(c)

4.4.6 Compressive strength of lime treated PKS and SCBA Concrete in sodium hydroxide solution

On Figure 4-33 & 4-34, A reduction in strength was observed for lime treated PKS concrete and SCBA concrete. It has been found after 90 days of immersion in sodium hydroxide solution, the strength of PKS concrete retained 99.30%, 99.28%, 99.25% and 99.21% respectively at 0%, 10%, 15%, and 20% substitution compare to the initial strength at 28 days, while at 0%, 10%, 15%, and 20% substitution, the strength of SCBA concrete retained 99.30%, 99.44%, 99.41% and 99.37%. This shown that, SCBA concrete resist to chemical attack better than PKS concrete. This less resistance of lime treated PKS concrete may be due to the fact that the lime treated PKS concrete has more voids (as it particles was bigger), allowing the chemical solution to penetrate into concrete mass and reducing the content of calcium hydroxide.

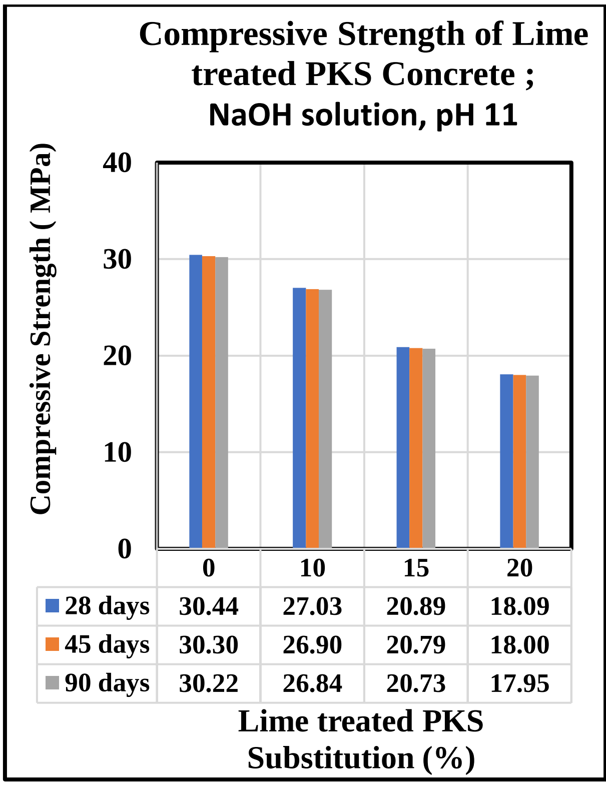


Figure 4. 33: Compressive Strength of Lime treated PKS Concrete; NaOH solution, pH 11

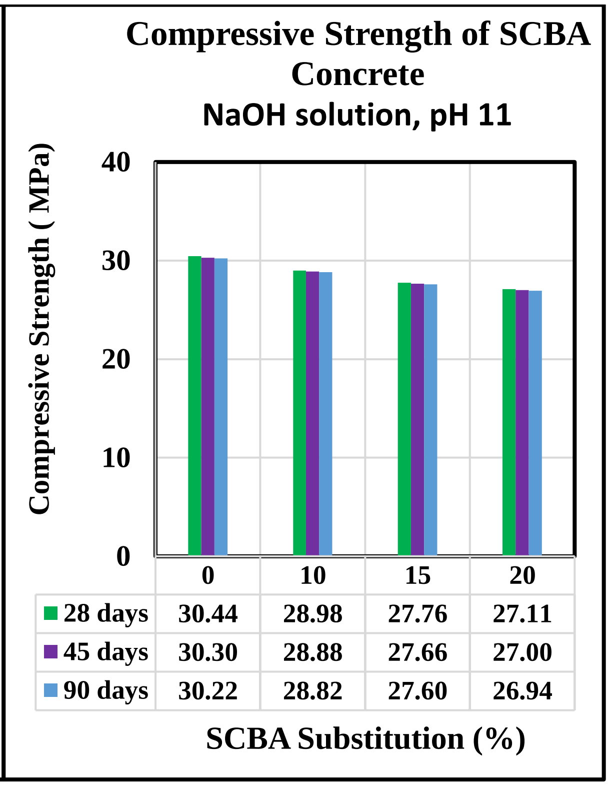


Figure 4. 34: Compressive Strength of SCBA concrete; NaOH solution, pH 11

Figure 4-35 despite the results strength of lime treated PKS and SCBA concrete. At all mix of substitution, the compressive strength decreases as the percentage of substitution increase. At 90 days, the compressive strength decreases from 30.22MPa to 15.26 MPa at 20% lime treated PKS and SCBA substitution. From the results, it is evident that lime treated PKS and SCBA concrete in terms of performance, had lower compressive strength than conventional concrete when exposed to sodium hydroxide attack. Similar trend was observed with concrete exposed to sulphuric acid which can be the result of a higher penetration of sodium hydroxide which results in the significant removal of the surface layer and therefore the reduction of compressive strength.

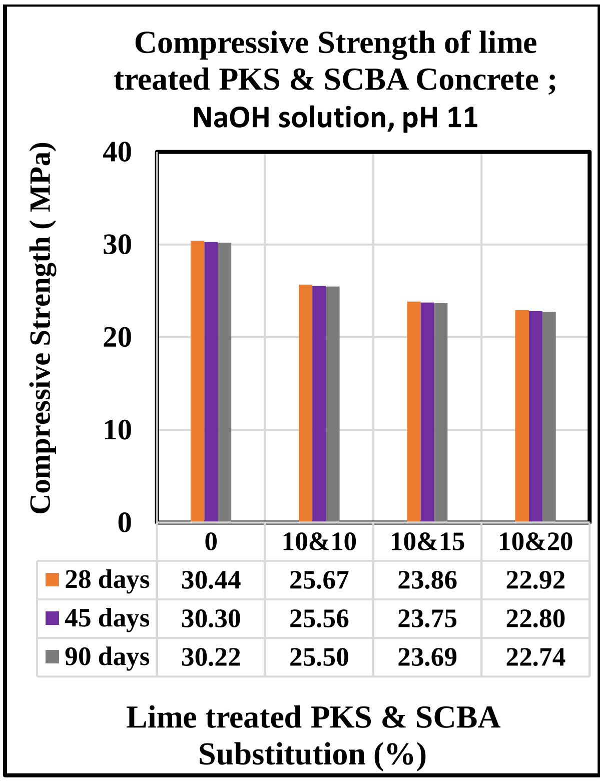


Figure 4. 35(a)

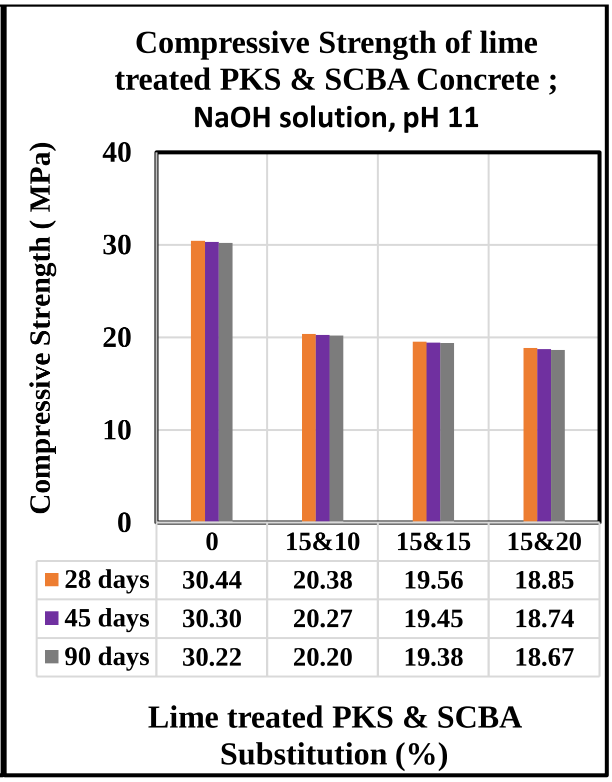


Figure 4-35(b)

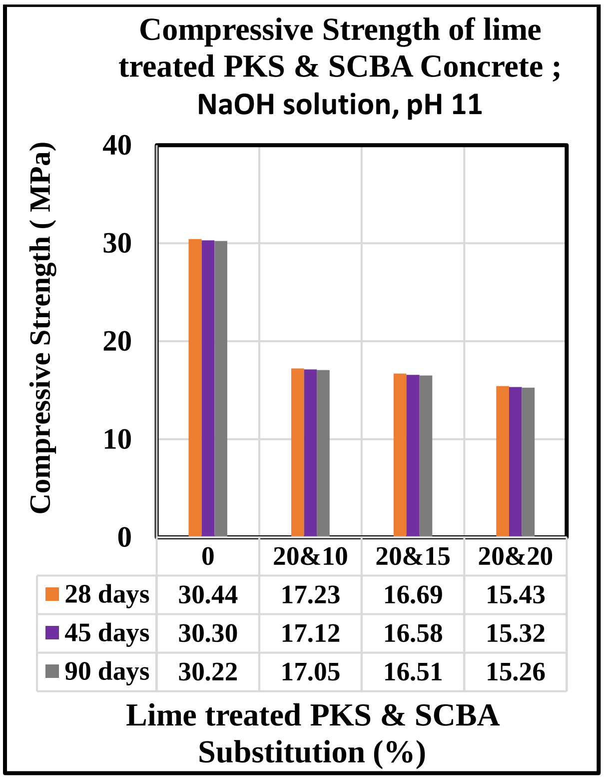

Compressive Strength of lime treated PKS & SCBA Concrete ; NaOH solution, pH 11
Compressive Strength (MPa)
40
30
20
10
0
0
20&10
20&15
20&20
28 days
30.44
17.23
16.69
15.43
45 days
30.30
17.12
16.58
15.32
90 days
30.22
17.05
16.51
15.26
Lime treated PKS & SCBA Substitution (%)

Figure 4-35(c)

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the experimental investigation of this research, the following conclusions have been made:

1. Characteristics of PKS and SCBA:
    a) The PKS satisfied the ASTM C-33 requirement in terms of particles size distribution and can be used as replacement of coarse aggregate in the production of structural concrete.
    b) The chemical composition of SCBA satisfied the requirement ASTM C618 for a good pozzolana and can be used as partial replacement of OPC in the production of concrete
2. Effect of lime treated PKS on concrete:
    a) The workability of lime treated PKS fresh concrete reduces with increase in lime treated PKS content.
    b) Lime treated PKS in concrete reduces concrete strength. Low percentages produce higher strength than high percentages. However, up to 15% lime treated PKS can be used in the mix as coarse aggregate replacement.
3. Effect of SCBA on concrete:
    a) Concrete workability decreases with increase in SCBA content.
    b) At 28 days, the strength of SCBA concrete as partial replacement for OPC is lower compare to the control while at 90 days the strength is

higher than the control. Up to 20% SCBA substitution can be used for structural concrete.

4. Effect of lime treated PKS and SCBA on concrete:
   a) Lime treated PKS and SCBA in concrete as substitutes for coarse aggregate and OPC respectively reduce concrete workability, density, compressive and splitting tensile strength, and increase water absorption. However, up to 15% lime treated PKS and 10% SCBA substitutions can be used for structural concrete.
   b) Based on the target strength (30MPa), up to 10% lime treated PKS and 10% SCBA substitutions is adviced to use, as it gave the optimum value.
   c) SCBA concrete resist better to chemical attack than lime treated PKS concrete. But combining them in the concrete, they have less resistance attack compare to the control.
   d) Lime treated PKS and SCBA the concrete resists better to sodium Hydroxide attack than Sulphuric acid attack on weight loss
   e) Utilization of lime treated PKS and SCBA in the concrete production help to conserve naturel ressources and preserve the environment.

5.2 RECOMMENDATIONS

The following recommendations have been made:

For possible applications:

1. Based on the investigation, the lower the percentage of lime treated 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.

2. The SCBA concrete should be used in production of structural concrete as partial replacement of cement, which will reduce the quantity demanded of cement production and will contribute to the preservation of our natural ressources.
3. Lime treated PKS and SCBA should be used in the production of structural concrete but the optimum value should be determined based on the target strength.

For further research:

4. The durability performance of PKS and SCBA concrete on other chemical solution should be carried out
5. The use of superplasticizers in PKS and SCBA concrete should be investigated as they might improve on concrete engineering properties.

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APPENDIX

Plate 1: Treatement of PKS

Plate 2: Mix of constituent material

Plate 3: Slump test on the concrete

Plate 4: Casted concrete

Plate 5: Curing concrete

Plate 6: Universal Testing Machine

Plate 7: Split tensile of cylinder

Plate 8: Curing concrete in chemical solution