EFFECT OF CONSTITUENT MATERIALS ON THE QUALITY OF CONCRETE: A CASE OF MATERIALS IN KAKAMEGA COUNTY, KENYA

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CSE/G/01-52838/2018

A thesis submitted in partial fulfillment for the requirements of the award of the Degree of Master of Science in Structural Engineering of Masinde Muliro University of Science and Technology

November, 2023

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Declaration by the candidate

This thesis is my original work prepared with none other than the indicated sources support and has not been presented elsewhere for a degree or any other award.

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ACKNOWLEDGEMENT

I would like to give my warmest thanks to my supervisors Dr. B. Omondi and Prof. Eng. B. Sabuni who made this work possible through their motivation, enthusiasm, patience and immense knowledge. Their priceless and meticulous supervision at every stage of the work inspired me in innumerable ways. I would not have imagined having better supervisors for my Masters Study. Besides my supervisors, I would also like to thank Mr. Caleb Kibet and Levi for their assistance in the laboratory.

I also thank the postgraduate committee members for letting the progress presentation invaluable for their brilliant comments and suggestions. I would also like to thank my husband Mr. Jack Onyango and my kids Apphia Onyango and James Onyango for their tremendous support, encouragement and understanding while undertaking research and the writing of this thesis. Your love and prayers are what has kept me.

I would also like to thank my dear mom Mary Soo for her prayers and the motivation to keep me going. Finally, I would like to appreciate God for letting me through all the difficulties. I have experienced His guidance day by day. He is the one who let me finish my degree. I will keep on trusting Him forever.

DEDICATION

I dedicate this project to God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. I dedicate this research project to my mom for her great support even when things were so tough for, she constantly kept on encouraging me to work extra hard. To my friend Cate, for moral support and encouragement throughout my studies. To my colleagues and my manager for creating an enabling environment to carry out this project. I also dedicate this work to the entire engineering fraternity in Kenya.

ABSTRACT
The role of the quality of concrete in structural applications cannot be overemphasized. Quality of concrete in terms of workability, compressive strength and durability is influenced majorly by the properties and mix proportions of the individual constituent materials: cement, fine aggregates, coarse aggregates and water. The properties of aggregates are dependent on the parent rock formation which further depends on the geographical location resulting into a complex interaction in determination of quality of concrete. In order to address this complex interaction, there exist standards stipulating the required properties and the mix proportions of constituent materials for quality concrete. However, in Kenya, most building construction works are implemented based on materials which are sourced and used without characterization and/or modification. The practice leads to poor quality concrete in structural works and has been documented to be one of the reasons for building collapses. The aim of this research was therefore, to characterize the locally sourced concrete constituent materials and establish how they affect the quality of concrete. As a starting point, this research identified materials used for structural concrete in Kakamega County as the study area. The cement of different brands was sourced from local hardware stores while the fine aggregates were sourced from river beds, quarries and roadside. Furthermore, the coarse aggregates were sourced from two different quarries with significant spatial difference and difference in crushing methods: machine crushed and hand crushed. The materials were characterized to determine their properties. Each of the three-sourced fine aggregates were separately combined with the two-sourced coarse aggregates. Trial mixes were done using Portland Pozzolana Cement (PPC) and Ordinary Portland Cement (OPC) using mix designs that were developed based on the criteria outlined by British Research Establishment (BRE) for concrete classes C20/25 and C25/30 for OPC based concrete in conjunction with BS 8500 and BS EN 206-1 in order to accommodate the deficiencies of BRE in mix design of PPC. A total of 1008 concrete cubes were cast and cured under water for 7 days' intervals up to 98 days as quality tests were being conducted. The results showed that aggregates vary in their characteristics. Coarse aggregates had values of 2.28 and 2.02 for specific gravity and 1.58% and 12.72% for water absorption respectively. The fine aggregates were all well graded. For RS, QD and FS the silt contents were 12.82%,5% and 33.33% respectively and specific gravity values of 2.57,2.51 and 2.35 respectively. Three out of the four cement brands had characteristics that were within the recommended standards. The findings also showed that the characteristics of aggregates affects the mix ratios with the calculated mix ratios differing from the empirical ratios applied in the field case of C20/25 for FSCA2 that was 1:1.8:2 vs 1:2:3. Furthermore, it was shown that a high silt content present in roadside sand (FS) led to high water absorption and reduced the compressive strength of concrete. In terms of cement type, it was found that OPC based concrete had a slightly higher strength than PPC based concretes but they both continue to gain strength beyond 28 days. The results also showed that PPC combined with machine crushed coarse aggregate and quarried fines or

river sand can only be used to produce concrete class C20/25: higher concrete class is not feasible with the PPC. This is because it has a slower setting time hence the concrete may take more time before reaching its minimum characteristic strength. Further research on cylinder compressive strength and strength tests on aggregate should be carried out.

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LIST OF ABBREVIATIONS AND ACRONYMS

PPC	Portland Pozzolana Cement
OPC	Ordinary Portland Cement
BRE	British Research Establishment
EAS	East African Standards
DOE	Department of Environment
EN	European Norm
BS	British Standard
ACI	American Concrete Institute
IS	Indian Standards
NCA	National Construction Authority
CEM	Cement
PLC	Portland Limestone Cement
PPFAC	Portland Pulverized Fuel Ash Cement
MTIHUD&PW	Ministry of Transport, Infrastructure, Housing and Urban Development and Public Works
LOI	Loss on ignition
EAS	East Africa Standards
KS	Kenyan Standard
Al_2O_3	Aluminum Oxide
Fe_2O_4	Iron Oxide
BETA	Bottom-Up Economic Transformation Agenda
CEM	Cement
Mpa	Megapascals

CHAPTER ONE
INTRODUCTION

This chapter provides an introduction into the concrete composition, its rheological characteristics, the geological formations in Western, Kenya, various sources of coarse and fine aggregates and differentiating between Ordinary Portland Cement and Portland Pozzolana Cement. The chapter also explains the problem being tackled by this research, the objectives of the research, research questions based on the specific objectives and its significance to the stakeholders in the construction industry. It also highlights what the limitations of the research.

1.1 Background Information

The concrete structure is widely recognized as the predominant form of construction, undergoing continuous advancements and enhancements in order to align with global and environmental standards. This type of structure mostly consists of a composite material composed of cement, water, sand, and coarse aggregate. Nevertheless, cement is widely recognized as the most costly but pivotal component in the manufacturing of concrete.
Anciently, concrete quality was assessed primarily in terms of its compressive strength; it was assumed that making concrete "stronger" made it better in all respects. However, factors such as workability of fresh concrete, durability and compressive strength development also play a pivotal role in defining the quality of concrete (Czarnecki, 2008).

Rheology is defined as the study of the science of the flow and deformation of materials. In concrete study, the concept of rheology may be applied to analyse the hardened concrete deformation, the behaviour of cement pastes and slurries, handling and placing of mixed concrete in its fresh state (Yahia, 2016). The rheological qualities of concrete are contingent upon the quality of each ingredient employed in the combination, as well as the manner in which they interact with one another. The characteristics of newly mixed concrete have a significant impact on its mechanical strength, durability, and suitability for engineering purposes (Dengwu, 2017). According to Ting (2019), the rheological properties of cement pastes are significantly influenced by the fineness of cement.

The compressive strength, durability, workability, and other attributes of concrete are influenced by various factors, including the inherent characteristics of the constituent materials, the relative quantities of these materials in the mixture, and the quality of craftsmanship involved in the construction process. The compressive strength of concrete is contingent upon the specific type of cement utilized, as well as its inherent qualities. Blended Portland cements, specifically CEM 32.5, are widely utilized in developing nations as the predominant kind of cement. According to Victoria et al. (2017), these particular cements are more cost-effective, but exhibit reduced compressive strengths at the 28-day mark in comparison to Ordinary Portland cements. In previous years, Ordinary Portland cement (OPC) has been extensively employed in wide range of construction endeavors. Nevertheless, the synthesis of OPC necessitates a substantial quantity of energy. This renders the product financially inaccessible, particularly in regions with lower and middle economic statuses (Noor-ul, 2012).

Ordinary Portland Cement (OPC) is represented by the CEM codes 42.5N/42.5R and 52.5N/52.5R, whereas Portland Pozzolana Cement (PPC) is represented by the CEM codes 32.5N and 32.5R. The symbols "N" and "R" are used to represent normal early strength and rapid early strength, respectively. The performance of CEM 42.5 and CEM 52.5 is higher compared to that of CEM 32.5. The reason for this disparity is that CEM 42.5 and CEM 52.5 exhibit compressive strengths of 42.5 N/mm^2 and 52.5 N/mm^2, respectively, but CEM 32.5 demonstrates a compressive strength of 32.5 N/mm^2 after a period of 28 days (Joel, 2016).

According to Kazeem, (2015) unlike professional builders, roadside artisans do not perform quality assurance tests on concrete or conduct trial mixes to determine the optimal proportions of ingredients needed to produce a given concrete grade or strength class. The typical practice in Nigeria is to utilize a cement-fine aggregate-coarse aggregate mix ratio of 1:2:4, regardless of the specific strength class or grade of the cement. This approach is commonly employed due to a lack of awareness regarding the existence of several cement grades in Nigeria and their potential impact on the strength of concrete. Prior to the introduction of various cement strength classes in the Nigerian open market, roadside bricklayers commonly employed a 1:2:4 mix ratio as a general guideline.

The structure and characteristics of aggregates vary in different regions. This is due to the varied geological processes that leads to the formation of rocks in the area. These are such as: crystallization gives igneous rocks, erosion and sedimentation gives sedimentary rocks and metamorphism gives metamorphic rocks. The geology of Kenya may generally be grouped into the following five major geological successions: Archean (Nyanzian and Kavirondian), Kavirondian system: Mudstones, Sandstones, Conglomerates, Granitic intrusions, Nyanzian system: Shales, cherts, ironstones, Pyroclastics, Rhyolites, Andesites, Basalts (Norbert, 2013). Due to the difference in the type of rocks there is need to map out areas where aggregates are extracted and characterize them before use. The Nyanzian and Kavirondian system are most predominant in the Western part of Kenya. The durability of concrete can be influenced by variations in the constituent ingredients, namely cement, aggregates, and water, as described in previous studies. Aggregates comprise the majority of the volume of concrete, ranging from 65% to 80%. The compressive strength and durability of concrete are affected by the aggregates' type, proportion, composition, gradation, and quality Muhit,(2013) Therefore, aggregates are no longer considered as fillers but rather a major component of concrete.

Furthermore, it has been documented that the gradation/particle size distribution and proportion of coarse aggregates in the concrete mixture have an impact on both the compressive strength and workability characteristics of concrete. According to Obafaye (2020), the selection of suitable constituent elements for a certain concrete mixture is an essential requirement, yet it alone does not guarantee the creation of concrete of superior quality. It is imperative to ensure the appropriate proportioning of materials, followed by the proper mixing, placement, and curing of concrete. Additionally, meticulous quality control throughout the entirety of the concrete-making process necessitates the collaborative efforts of the materials supplier, builder, and engineer. The compressive strength of concrete exhibits a negative correlation with the increase in silt/clay content. The decrease in compressive strength can be attributed to inadequate bonding between silt and clay components, as well as the greater rate of water absorption in concrete containing elevated levels of silt and clay. The level of silt/ clay content in fine aggregates depends on the source and type of fine aggregates (Ayodele, 2020).

Hannah (2014), noted that the building sand being delivered in Nairobi City County and its surroundings contains silt and clay contents as well as organic pollutants that are beyond the permitted limits. A significant proportion of the samples, specifically 86.2%, did not match the silt and clay content thresholds specified in both BS 882 and IS standards. Additionally, 44.4% of the samples surpassed the limitations established by ASTM. In relation to the organic content, it was observed that 77% of the sand samples surpassed the permissible organic content levels advised for the manufacturing of concrete.

Victoria (2017), discovered that two out of the six brands of blended cement she had sampled did not reach the minimum compressive strength criteria at 28 days, lowering the caliber of the concrete made by those two brands. The application of blended Portland cements may therefore not be suitable for the manufacturing of structural concrete with a strength class of C 25 and above. This is due to the fact that none of the available cement brands were able to attain the desired compressive strength of 36.22MPa while maintaining a workable slump of at least 25mm.

Mohammed (2015), noted that proportions of coarse aggregates increase with the increase of its specific gravity. Nevertheless, an increased cement-water ratio results in a decreased density and weight of concrete. Consequently, the specific gravity is regarded as the primary determinant of both the quality and weight of concrete. The assessment of construction materials' quality holds significant importance. The primary aim of evaluating construction materials is to offer users a guarantee regarding the dependability and trustworthiness of those products. Construction materials testing laboratories play a significant role in national development by ensuring the quality of construction materials (Savitha, 2012). The main aim of this research is to investigate the effect of locally sourced constituent materials on the quality of concrete.

1.2 Statement of the Problem

Kakamega county is the second most populous county after Nairobi County (Ondiba, 2019). This implies an increased demand for housing units. This large population together with the implementation of the Housing agenda by the Bottom-Up Economic Transformation Agenda (BETA) provides proper justification for the need to come up with an affordable housing program that accommodates the large number of households. To achieve affordable Housing agenda, locally sourced materials are required for its implementation in Kakamega County.

Concrete which is the most commonly used material in construction in Kakamega County, is made from locally sourced fine aggregates, coarse aggregates and cement.

Fine aggregates within Kakamega county are sourced from rivers, quarries and road sides during rainy seasons while coarse aggregates are sourced from various quarries some that are hand crushed and sold by roadside vendors and others that are machine crushed and sold in licensed quarries. Most locally sourced aggregates in Kakamega County are used in the construction sites without determining their properties. Some of these materials, are not viable for use in manufacture of concrete yet most builders and contractors do not take this into consideration while casting various concrete elements. A high silt content in fine aggregates has been reported to cause cracking of walls which may lead to structural failure (Hannah, 2014).

Consumers of cement on the other hand, do not know the difference between Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) despite the fact that PPC has lower strength at 28 days in comparison with OPC (Kazeem, 2015). The use of PPC in British Research Establishment (BRE), a mix procedure designed for OPC has been reported to lead to lower concrete strengths and eventually lead to the failure of concrete structures.

This therefore, qualifies the need to investigate the effect of the locally sourced constituent materials on the quality of concrete in Kakamega County.

1.3 Research Objectives

To investigate the effects of locally sourced constituent materials on the quality of concrete using a case of Kakamega County.

1.3.1 Specific Objectives

i. To characterize the locally sourced cement, fine aggregates and coarse aggregates for concrete production.
ii. To evaluate the effect of the locally sourced cement, fine aggregates and coarse aggregates on the concrete mix design proportions.
iii. To evaluate the effects of cement, fine aggregates and coarse aggregates on workability and compressive strength of concrete.
iv. To compare the compressive strength development of concrete made using locally sourced cement, fine aggregates and coarse aggregates.

1.4 Research Questions

The research was based on the following research questions:

i. What are the characteristics of fine aggregates, coarse aggregates and cement commonly used within Kakamega county?
ii. What are the effects of locally available fine aggregates, coarse aggregates and cement on the concrete mix design proportions?
iii. What are the effects of locally available aggregates on the workability and compressive strength of concrete?
iv. How does the strength development of concrete made using locally sourced cement and fine aggregates and coarse aggregates compare?

1.5 Significance of the Study

The use of locally available aggregates in their original state may pose risk of failing to use the appropriate materials for the manufacture of concrete as prescribed in the standards. There is therefore need to characterize the fine and coarse aggregates before use. This will help in determining the extent at which the use of locally sourced materials in their original state on the quality of concrete. Individual properties of the aggregates such as silt content, specific gravity, grading and water absorption affect the workability and the strength development of the concrete.

The use of PPC in the Kenyan construction industry has become increasingly popular due to its economy and availability in the open market besides its lower carbon footprint. The builders and contractors mostly apply the DOE/BRE mix design with PPC in a mix procedure designed for OPC. This has been reported to lead to lower concrete strengths. Carrying out a mix design procedure based on DOE/BRE with BS8500 and BSEN 206-1 will help in coming up with mix proportions for the PPC based concrete.

The findings of the study will greatly assist concrete design mix engineers and contractors in applying the use of PPC with a greater confidence. It will also assist in enlightening the stakeholders in the building industry on the importance of characterizing aggregates, cement and water before use in manufacture of concrete. This will further enhance a smooth implementation of the Housing Agenda in BETA in Kakamega county and quality concrete. This will also assist in providing a solution to the problem of structural collapse of buildings as noted in the recent past.

The findings will add onto existing body of knowledge in academia on quality control of concrete made from locally sourced materials in Kakamega County.

1.6 Limitations of the Study

The research was limited to:

- The concrete classes to be covered are C20/25 and C25/30 since they are the commonly used concrete classes for medium to low rise buildings even though there are many other classes of concrete that are used for other construction activity.
- The aggregates used were all sourced within Kakamega County.
- The quality of concrete was limited to the study of workability, compressive strength and compressive strength development only. Durability was not studied.
- No aggregate strength tests were carried out.

1.7 Structure of the thesis

This thesis contains Five Chapters: Chapter one (Introduction), provides an introduction into the concrete composition, its rheological characteristics, the geological formations in Western, Kenya, various sources of coarse and fine aggregates and differentiating between Ordinary Portland Cement and Portland Pozzolana Cement. The chapter also explains the problem being tackled by this research, the objectives of the research, research questions based on the specific objectives and its significance to the stakeholders in the construction industry. It also highlights what the limitations of the research.

Chapter two (Literature Review), contains reviewed literature from various scholars in the field of concrete and its constituents. This chapter reviews rheology of concrete as construction material, characterization of concrete constituent materials, the practice of handling and placing concrete, testing of concrete and the concrete mix design that has been in practice in Kakamega County, Kenya. The intention was to report the effect of locally sourced materials on the quality of concrete thereby highlighting the research gaps.

Chapter three (Methodology), highlights the materials that were used and their various sources, the laboratory procedures followed to get their material properties and the relevant standards to determine their suitability for the manufacture of concrete. The procedure to get the concrete mix proportions is described in section 3.3.4. The constituents of concrete were hand mixed, tested for workability, cast in cubes, covered for 24 hours, demoulded and then cured in a curing basin for up to 98 days. The testing regimes were 14 of 7 days intervals. It also highlights the ANOVA method for data analysis.

Chapter four (Results and Discussion), reports and discusses the properties of cement, fine aggregates and coarse aggregates used in this study from laboratory experiments. Characterization of cement in this study involved determination of both physical and chemical properties of cement samples A, B, C and D (which was OPC). Aggregates were also subjected to tests to determine their properties that are relevant in the production of concrete.

It also discusses the results of workability and compressive strength of concrete and the compressive strength development in a bid to provide insights of the quality of concrete as affected by the characteristics of constituent materials.

Finally, chapter five (Conclusions and Recommendations), presents the conclusions and recommendations based on the results discussed in chapter four.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter reviews rheology of concrete as construction material, concrete mix design methods, characterization of concrete constituent materials, the practice of handling and placing concrete, testing of concrete and the concrete mix design that has been in practice in Kakamega County, Kenya. The intention was to investigate the effect of locally sourced materials on the quality of concrete thereby highlighting the research gaps.

2.2 Rheology of Concrete

Concrete is a frequently used construction material that primarily comprises a binder and a mineral filler. This particular construction material possesses the exclusive attribute of being the sole substance produced directly at the construction site or within a ready-mix concrete factory. Concrete has emerged as an essential construction element in contemporary society. Concrete is a composite material that consists of cement, mineral admixtures, water, aggregates, and chemical admixtures. The rheological qualities of concrete are contingent upon the quality of each constituent employed in the mixture, as well as the interactions between these constituents. The characteristics of newly mixed concrete have significant implications for its mechanical strength, durability, and suitability for engineering purposes (Dengwu, 2017).

The rheology of fresh concrete is investigated by looking at the characteristics of stability, compactibility, and mobility. Stability is dependent on the bleeding and segregation tendencies. Compactibility is related directly to relative density. Mobility is shown to be a function of the viscosity of the cement paste, cohesion of the mix and its angle of internal resistance to deformation (Ritchie, 1968). According to Ting (2019), the rheological properties of cement pastes are significantly influenced by the fineness of the cement. These characteristics of fresh concrete greatly influence the quality of concrete in fresh and hardened states. The rheological characteristics of new concrete, such as workability, encompass several factors such as stability, mobility, and compatibility. These parameters are crucial in assessing the appropriateness of a concrete mixture. Stability refers to a state in which the collective particles are uniformly dispersed inside the matrix, and empirical observations demonstrate consistent particle size distribution throughout the processes of transportation, placement, and compaction (Chaitanya, 2022). The mobility of fresh concrete refers to its capacity to exhibit fluid-like behavior when subjected to mechanical forces. The flow is constrained by cohesive, viscous, and frictional forces. The cohesive force arises as a result of the adhesion between the matrix and aggregate particles. The mobility and reorganization of aggregate particles inside the matrix are influenced by the viscosity of the matrix. Triaxial compression testing in the lab can be used to determine a concrete mix's mobility (Dengwu, 2017).

The compactibility of fresh concrete refers to its ability to be easily compacted. The process of compacting involves the removal of trapped air and the rearrangement of aggregate particles in order to create a dense mass, while ensuring that segregation does not occur. The compatibility measure is assessed using the compacting factor test, as described by (Ferraris, 2001).

The consistency of a concrete mixture is an indicator of its degree of stiffness, sloppiness, or fluidity. In order to ensure efficient handling, placement, and compaction of concrete, it is imperative that the consistency of each batch remains uniform. Hence, it is imperative to periodically assess the uniformity of concrete. The slump test is a widely utilized method for assessing the workability or consistency of concrete. The workability of a concrete mixture refers to the degree of ease with which the concrete may be effectively laid, compacted, and completed, while ensuring that there is no separation or segregation of its constituent ingredients (Danembaye, 2018). BS 8500-1 defines consistency in terms of slump number, flow number or slump-flow number. It is normally the responsibility of the user of the fresh concrete to make the selection of consistence and inform the specifier of the requirements.

The determination of concrete consistency is achieved by the utilization of a slump cone test. Excessive bleeding can occur as a consequence of an elevation in the water content. Therefore, an excess water content will not enhance the rheological qualities of concrete. Insufficient water content in concrete might result in decreased mobility and compactibility, hence posing challenges during the placement process. The rheological qualities of concrete are influenced by the shape, size, and texture of the aggregate. In order to achieve a greater degree of void filling, it is necessary to increase the proportion of fine aggregates and water content when dealing with rough and angular aggregates. Similarly, according to Ting (2019), angular fine aggregates will necessitate a greater amount of water content compared to natural sand.

Well-graded aggregates contribute to the enhancement of workability. The workability and void system of concrete can be influenced by the presence of aggregates of varying sizes or the absence of specific aggregate sizes. According to Chaitanya (2022), when there is an increase in coarse particles in a concrete mixture, the resulting mixture tends to become harsh and exhibit an increase in bleeding. Therefore, it is recommended that the aggregates be well-graded in order to preserve the workability of the mixture.

Admixtures such as plasticizers, superplasticizers, air-entraining agents, accelerators, and retarders have an impact on the rheological properties of concrete. The addition of plasticizers results in a decrease in water content by 10 percent, while maintaining the strength of the concrete. Super plasticizers enhance the flowability of the concrete, hence reducing the need for excessive compaction. When concrete is placed in corners and around densely packed reinforcing. The air-entraining agents possess the rheological characteristics of concrete. Figure 2.1 elaborates the factors affecting the rheology of concrete as discussed in this section of this thesis

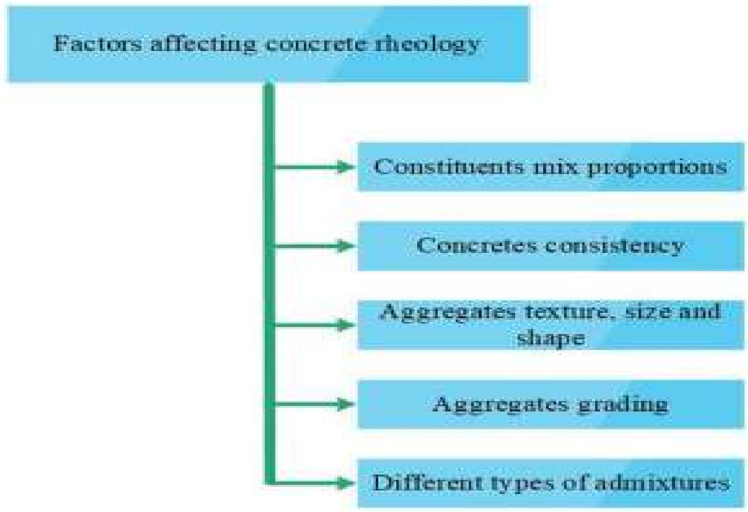

Figure 2. 1: Factors affecting concrete rheology

https://www.civilknowledges.com/rheology-of-concrete/

2.3 Characterization of Concrete Constituent Materials

In the recent past from 2016 to 2022, over 50 multi-storied houses have collapsed in Kenya because of various reasons resulting in loss of life and property (Kioko J. M., 2014). Kakamega County has not been exempted in the collapses as there has been 7 collapses within that duration. It was with this in mind that the Kenyan President launched an audit on buildings in January 2017. The reasons for the collapse of buildings were poor quality of concrete, inadequate designs and poor quality of other construction materials. Poor quality concrete can be attributed to low quality cement among other issues like the quality of sand, water and aggregates (Kiptum, 2018). This further qualifies the need to carry out the investigation of the effects of the constituent materials on concrete.

The compressive strength of concrete is influenced by various elements, including the chemical and mechanical qualities of the constituent materials, as well as the proportions of the concrete mix. Various cement brands, however, exhibit diverse chemical, physical, and mechanical properties. The presence of aggregates constitutes a significant portion, around 75%, of the overall volume of concrete. It is well accepted that the qualities of these aggregates play a crucial role in determining the quality of concrete in both fresh and hardened states.

The incidence of structural failure in reinforced concrete constructions has witnessed a notable rise in Kenya in recent times. Several factors have been cited as potential causes for the collapse of these buildings. These factors encompass issues such as incorrect concrete mix ratios, inadequate planking and strutting to support excavations, excessive spacing between columns, insufficient reinforcement, elevated slenderness ratios are cost-saving measures employed by contractors. According to the study conducted by Kioko et al. (2014), the alteration in the suggested composition of concrete can be ascribed to the utilization of Portland Pozzolana Cement with a strength of 32.5N/mm^2, as opposed to the Ordinary Portland Cement with a strength of 42.5N/mm^2, which is the recommended choice for the BRE mix design technique.

In a study conducted by Ogembo (2018), it was shown that defective building materials and inadequate craftsmanship are significant contributors to the majority of building collapses in Kenya. This phenomenon may be attributed to the utilization of Portland Pozzolana Cement (PPC) instead of Ordinary Portland Cement (OPC) in concrete mix design, as well as a lack of expertise in constructing concrete mixes.

Material testing is a must in all industries, especially in the building sectors. This is because an incorrect assessment of a material would be harmful to people and the environment. (Savitha, 2012) .Strength and permeability are the two important design parameters of concrete structures. For this reason, investigating the effect of the concrete constituents, like aggregates, on their mechanical and durability properties is of great importance. Aggregates make up between 60% and 80% of the volume of concrete, being surrounded by the cement paste. Aggregates are considered to be the most important factor affecting concrete strength (Mahmood Naderi, 2021).

2.3.1 Characterization of Aggregates

The aggregates used in production of concrete within Kakamega County are all sourced locally. The fine aggregates are found in rivers, quarries and roadsides while coarse aggregates are found in crushing quarries and roadside vendors who hand-crush the aggregates for use in production of concrete.

Most of the fine aggregates used in Kenya are river sand. While most of the river sand is of very good quality, it is common to find very silty sand especially during the rainy season. A case of sand with silt content as high as 30% being used are known. Sand merchants blend very silty sand with better quality sand before selling to unsuspecting customers. Indeed, sand merchants are known to sometimes mix red soil with sand to increase volume and thus more sales. Needless to say, no sieve analysis is carried out on such aggregates (Kamau, 2005)

The most commonly used coarse aggregate is crushed stone. Due to the high rate of unemployment, roadside crushing 'plants' have mushroomed in any place where there is construction going on and where there are boulders to be broken. The 'plant' constitutes of an individual armed with a sledgehammer for breaking up large boulders and a smaller hammer to break up small boulders to small pieces. Needless to say, the grading is done by eye. Equally the quality is also questionable as aggregate is sometimes made out of hardcore which is a by-product of natural stone quarrying which obviously infers that the stones are fairly soft because they can be dressed manually (crushing strength of less than 10 kPa). Also, since most of the boulders are actually small and are collected from the surface or excavated from shallow pits the bulk of the boulders are weathered on the outer surfaces and hence the aggregates obtained by crushing these boulders have high contents of weathered components (Kamau, 2005)

Aggregates shares characteristics with their parent rock, such as their chemical and mineral make-up, shape, roughness, degree of weathering, specific gravity, hardness, strength, physical and chemical stability, and pore structure (Li, 2017). Moreover, the effectiveness of concrete can be significantly impacted by factors such as mineral composition, surface area, surface texture, particle size and shape, elastic modulus, strength, grading, and water absorption (Mohammed S. M, 2010).

Mohammed (2010), found out that the coarse aggregate's composition, percentage with respect to the fine aggregate, and grain size distribution all have a significant impact on the concrete's compressive strength. When comparing high strength concrete to standard strength concrete, the effect of coarse aggregate properties and its grain size distribution on compressive strength is more obvious in the former. (Mohammed S. M, 2010)concluded that increasing the maximum size of the coarse aggregate increased the compressive strength of normal strength concrete.

In accordance with the findings of Fowler (2004), the utilization of effective grading techniques has the potential to yield improved outcomes by reducing the water demand necessary to achieve a desired consistency. Conversely, the grading of aggregates, as well as the proportioning method, the source of the aggregate, and the crushing operations, have a substantial impact on workability and slump.

Kiambigi (2018), determined that the compressive strength and various other characteristics of concrete are impacted by the physical, chemical, and mineralogical attributes of the fine aggregates employed, as well as the mix design, curing process, and manner of concrete installation. The author also stated that fine aggregates exhibit variations in their chemical, physical, and mineralogical characteristics, which are contingent upon the geographical origin, as well as the processes of weathering and crushing. Furthermore, it was shown that the compressive strengths of concrete made with natural river sand were higher compared to concrete made with alternative aggregates, assuming a consistent slump and water-to-cement ratio during the 28-day curing period.

The strength development in concrete is influenced by the amount of silt and clay, and it is important to ensure that these levels are kept within the specified limits. The presence of elevated levels of silt and clay in concrete can adversely impact its ultimate strength, leading to a failure to meet anticipated performance standards (Victoria, 2017)

According to the findings of Hannah (2014), it was determined that the sand present in Nairobi County and its surrounding areas exhibited elevated levels of silt and clay content, as well as organic contaminants. When these contaminants are present in concrete in excess of the allowable limits, the compressive strength of the material significantly decreases. If a designer wants to be sure that they get the desired concrete strength, it's a good idea to factor in the impact of impurities on the design mix.

Cho (2013) concluded that when silt content to fine aggregate ratio is greater than 5%, durability decreases. When the silt content was less than 5%, there was a small increase in compressive strength of 1 MPa. However, there was a drop in compressive strength from 3 MPa to 5 MPa when the silt concentration increased from 7% to 9%. The decrease in the slump was seen in conjunction with an increase in the silt content.

The assessment of compressive strength in concrete is influenced not only by the presence of silt, clay, and organic pollutants in sand, but also by the characteristics of particle sizes and shapes. The samples of unwashed sand displayed a variation in silt and clay content, ranging from 42% to 3.3%. Additionally, the organic impurities in these samples ranged from 0.029 to 0.738 photometric ohms. In the context of compressive strength, it was discovered that a significant proportion (38%) of the concrete cubes, which were manufactured using sand containing various impurities, failed to attain the prescribed design strength of 25 Mpa within the designated 28-day period. Hannah (2014) found that the inclusion of elevated amounts of silt and clay content, as well as organic pollutants, significantly reduces the compressive strength of concrete.

Additionally, Victoria (2017) asserted that the majority of fine aggregates employed at building sites fail to meet the minimum standards, resulting in a reduction in the compressive strength of concrete nationwide. Therefore, this presents a possible hazard of structural collapse for concrete constructions.

Specific gravity concerns the proportion between the density of a certain substance at a designated temperature and the density of water at a specific temperature, commonly established at 20 degrees Celsius. Pandey (2015), Oluwasola (2020) found in their respective studies that the results of the slump test demonstrated a decrease in workability with an increased percentage of flaky and elongated aggregates. In terms of water absorption, it has been observed that flaky aggregates have a higher capacity for water absorption when compared to elongated aggregates. The form of the aggregate used has a notable impact on the compressive strength of the concrete cube. The study revealed that a decreased proportion of flaky and elongated material corresponded to a comparatively better compressive strength, as opposed to instances when the percentage of such aggregate was elevated.

In a study conducted by Okumu (2017), it was shown that fine aggregates consisting of finer particles necessitated a greater amount of water in order to adequately wet their larger surface area. Additionally, the irregular form and rough texture of angular coarse aggregates were found to require a higher water demand compared to spherical aggregates. Additionally, she posited that the enhancement of concrete's strength is contingent not only upon the classification of the fine aggregates, but also upon the morphology and surface characteristics of such fine aggregates.

According to Newman (1960), it was observed that mixtures including saturated river gravel aggregates exhibit greater strengths and compacting factors compared to mixes that utilize dry stones, despite their apparent similarity. This implies that the geological formaton and weathering or crushing process impacts the strength of concrete.

The research conducted by Landgren (1964) substantiated the notion that the presence of substantial, externally exposed pores in lightweight aggregates is the primary factor contributing to challenges encountered in getting accurate measurements of water absorption in such aggregates. The existence of significant pores in concrete can be ascribed to the inclusion of cement paste and other fine constituents during the process of concrete mixing. Furthermore, the inside spaces of these holes may undergo partial water drainage due to surface-drying techniques.

The effect of changes in the angularity value of coarse aggregates on the workability of concrete exceeds the impact of adjustments in the flakiness of the aggregate. Based on the findings of Kaplan (1978), an increase in the angularity or flakiness of the aggregate is associated with a reduction in workability. It is crucial to acknowledge that these two impacts exhibit a cumulative characteristic.

Punkki (1995), discovered that when water absorbing lightweight aggregate was used in a dry condition, the workability of the concrete was significantly reduced by the water absorption of the aggregate. This effect was not present when prewetted aggregate was used. The water absorption by the lightweight aggregate also affected the early compressive strength of concrete. After one day, dry aggregate gave an the average 10 MPa higher compressive strength than did prewetted aggregate (Punkki, 1995).

In a research by Warda (2012),a well graded aggregate is defined as an aggregate gradation which is located in the zone-II of BS882 and the aggregate size distribution also falls within the 8-22 distribution .If any gradation does not meet both of these two criteria then it considered as not-well graded aggregate.

True Slump refers to a general drop of the concrete mass evenly all around without disintegration.Shear Slump indicates that the concrete lacks cohesion. It may undergo segregation and bleeding and thus is undesirable for the durability of concrete.Collapse Slump indicates that the concrete mix is too wet, and the mix is regarded as harsh and lean. Zero slump is the indication of very low water-cement ratio, which results in dry mixes.

2.3.2 Characterization of Cement

Cement is a binding agent mostly composed of calcium, silica, aluminium, iron, and trace amounts of other substances. The materials used in the manufacturing of concrete, known as hydraulic cements, undergo a process of setting and hardening upon their combination with water.

According to a study conducted by Ehikhuenmen (2019), there was evidence to suggest that increasing the particle fineness of cement has a noticeable beneficial effect on the compressive strength of concrete. This observation provides evidence for the importance of granulometry, specifically mechanical activation or advanced grinding, in promoting the efficient and complete hydration of cement by generating $Ca(OH)_2$. This compound is formed during the cement hydration process and enhances its pozzolanic activity. Hence, the limitations of the positive attributes of concrete in the immediate term can be mitigated through the implementation of mechanical activation of cement, namely by enhancing its fineness. The researcher also reached the conclusion that the degree of fineness of cement plays a crucial role in the hydration process of the mixture. Specifically, a higher degree of fineness results in a larger surface area of cement particles in contact with water, leading to faster and more thorough hydration. Consequently, this leads to a reduction in the time required for the cement to set.

The duration required for cement to set is reduced in proportion to the increase in fineness of cement particles. This phenomenon can be attributed to the fact that coarse cement particles necessitate a lesser amount of hydration in order to attain a similar level of setting compared to finer cement particles. According to a study conducted by Ehikhuenmen (2019), there is a positive correlation between the fineness of cement and the workability of concrete.

The compressive strength of brick aggregate concrete exhibits an upward trend when the cement content is elevated, regardless of the aggregate size. Nevertheless, the magnitude of the development rate is more conspicuous when the cement quantity is equivalent to or less than 250 kg/m^3, whereas it becomes comparatively less substantial when the cement content surpasses 250 kg/m^3. There is a direct relationship between the compressive strength of brick aggregate concrete and the nominal size of the aggregate, particularly when the cement concentration is 150 kg/m^3. According to a study conducted by Hossain (2015), it was observed that the compressive strength of concrete with a cement concentration of 200 kg/m^3 and above exhibits an increasing trend with aggregate size up to 25 mm. However, beyond this threshold, the compressive strength tends to decrease as the aggregate size increases.

According to Pandey (2015), there is a positive correlation between specific gravity and the proportions of concrete, indicating that as the specific gravity increases, so does the proportion of concrete. However, an elevation in the ratio of cement to water leads to a reduction in the density and mass of concrete. Additionally, it was observed that there was an increase in the ratio of cement to water in the cement and water mixture. Therefore, the specific gravity is considered to be the principal factor influencing both the characteristics and mass of concrete.

Chemical analysis is a crucial aspect in the classification of cements, since it enables manufacturers to anticipate the material's response to its surroundings upon mixing (Akanni, 2014).

The Loss on Ignition (LOI) technique is utilized by the cement industry to evaluate the moisture content and/or carbonation levels in cement, as these variables can adversely affect its overall quality. A substantial decrease in the ignition loss can serve as an indication of pre-hydration and/or carbonation, which can occur due to insufficient and lengthy storage or contamination during shipping or transfer by suppliers (Akanni A. O., 2014). The term "insoluble residue" pertains to a component found in Portland cement that lacks the ability to exhibit cementitious capabilities. According to Akanni A. O. (2014), the inclusion of residual material has a notable influence on the properties of cement, specifically its compressive strength. The ASTM standard mandates that the non-cementing material content in Portland cement be regulated, with a maximum allowable insoluble residual of 0.75% (Kraiwood, 2000).

In addition, the increased strength of concrete can be attributed to the higher concentration of C_3S and C_2S in ordinary Portland cement (OPC), which are primarily responsible for the development of strength (Rahhal, 2005).

The study conducted by Victoria (2017) established a clear correlation between the compressive strength of concrete and the compressive strength of the cements employed during a 28-day duration. Therefore, it is crucial to utilize specific concrete mix proportions for different types of cements in order to maximize their individual characteristics. The below par quality of in-situ concrete in Kenya can be ascribed to the practice of substituting higher strength ordinary Portland cements with more cost-effective and readily available blended Portland cements. This substitution has been attributed to be a cause of the structural failure of concrete buildings (Victoria, 2017).

Kiptum (2018) posits that the accelerated cement setting witnessed at the building site can be ascribed to the comparatively diminished quantities of CaO and the heightened quantities of Al_2O_3 and Fe_2O_3. In addition, he argued that the significantly high amounts of insoluble residues were a causative element in the observed deficiency of binding properties displayed by the cement. The absence of proportionality in the amalgamation of the concrete constituents led to a substantial quantity of them falling short of the predetermined standards. The cement had a propensity for rapid setting and exhibited relatively low strength, hence leaving it inappropriate for utilization in construction applications. According to the expert's recommendation, it is imperative for customers to conduct cement testing before its application to minimize the potential hazards linked with the use of inferior cement. The risks encompass potential consequences such as the loss of human life, damage to property, and harm to the reputation of the construction team engaged.

On average, the compressive strength of 32.5N cement differs from that of 42.5N cement by 7.5 MPa over a 28-day period. When utilizing these two types of cements in the process of casting concrete, it has been noticed that the average difference in compressive strength of the concrete across different strength categories is 8.35 MPa (Victoria., 2017). This finding illustrates a clear relationship between the compressive strength of concrete and the compressive strength of the cements used after a 28-day duration. Therefore, it is crucial to utilize specific concrete mix ratios for different types of cements in order to maximize their individual characteristics. The manifestation of this phenomena becomes evident when multiple categories of cements are utilized during the process of casting concrete, while keeping the mix ratios consistent. In such cases, it has been discovered that the incorporation of blended Portland cement leads to a decrease in compressive strengths across all specified strength categories (Okumu, 2017).

Okumu, (2017) added that in every case, despite the cements meeting the minimum compressive strength criteria and the experiment being done in controlled working conditions, none of the cements achieved the intended concrete strength after 28 days when combined in a ratio of 1:1.5:3. This finding indicates that the selected mix design ratio was inappropriate for the cements, leading to the production of subpar concrete when blended Portland cements were employed. As a result, this has the potential to contribute to the structural failure of concrete buildings in Kenya.

For the majority of load-bearing structural elements in buildings, the strength class known as C20/25 is the suggested bare minimum. This research also shows that utilizing Nigerian Portland-limestone cement grade 32.5 requires a mix ratio of 1:1.5:3 to achieve a desired strength class of C20/25. The study also found that grade 32.5 of Nigerian Portland-limestone cement is insufficient for making concrete that meets the class C25/30 specification, which calls for a minimum cube compressive strength of 30MPa. The low compressive strength of 1:1:2 concrete made with Nigerian Portland limestone cement grade 32.5 is to blame for this disparity. As a result, it falls short of the required 30MPa for C25/30 concrete (Kazeem, 2015).

According to Kazeem (2015), a rich concrete mixture than the standard 1:1:2 mix ratio is required during the production of concrete of class C25/30, resulting in a less cost-effective final product.

A research study was undertaken to examine the impact of substituting Ordinary Portland Cement (OPC) with Portland Pozzolana Cement (PPC) on the compressive strength of concrete in Nigeria. The study's results indicated that the concrete mixture made with blended cements, particularly PPC Cement, demonstrated similar quality to that of OPC, except for variations in the water-cement ratio. The researchers made an observation that the heat of hydration of Portland Pozzolana Cement (PPC) was comparatively lower than that of Ordinary Portland Cement (OPC). Additionally, the cement content achieved for blended cements was slightly higher. Hence, it can be deduced that the incorporation of blended cements in the manufacturing of concrete can be optimized by the application of suitable quality control protocols and on-site monitoring. Yathish (2014) asserts that the proposed solution will satisfy the requirements of workability, strength, and durability.

2.3.3 Practice of Handling and Placing Concrete

Mixing is done by hand and generally on bare earth. Coarse and fine aggregates are mixed by turning them over and over to one side without any water being added. Cement direct from cement bags is spread over the mixture and water is added as the mixing proper starts. Generally, a batch consists of up to six cubic metres. As the mixing continues, it is not rare to find generous scoops of earth in the mix picked up by shovels. Water is not always acknowledged as a material that needs the same careful attention that the other ingredients of good concrete demand. Water used for most construction works is very often dirty and more often than not stored in underground tanks open to the sky, thus prone to contamination. There is also a misguided belief on most construction sites in Kenya that water is good for concrete and a drop more than necessary does no harm to the mix, but, in fact the wrong quantity can have disastrous effects (Kamau, 2005).

Kamau (2005), asserted that depending on the proximity of the mixing location to the building under construction, the concrete will be shovelled onto wheelbarrows and placed directly at the point where it is required. In storied buildings, the concrete is lifted by shovels from one level to another on wooden platforms (each lift is about 1.5m high) Sometimes the concrete is lifted up to 18m high thus resulting to segregation due to over handling. Tamping of wet concrete is quite common. This is done using an improvised tool generally consisting of a thin wooden pole with a piece of 150mm x 50mm and about 400mm long nailed to one end. The amount of compaction achieved depends on the experience of the operator. This piece of equipment is used on slabs while sharpened poles are used for beams and columns.

2.3.4 Tests on Concrete

Kamau (2005), added that tests on concrete are hardly carried out off and on site and everything is left to the artisan to certify the quality of the finished product.

2.4 Concrete Mix Design

The concrete mix design process entails the determination of appropriate proportions for cement, water, fine particles, and coarse aggregates. The objective of this particular excerpt is to develop a concrete mixture that is economically feasible while also possessing the desired characteristics in both its fresh and hardened states. According to Al-M., Hamid et al. (2018), the concrete mix design process entails the meticulous selection of suitable components and the establishment of their respective proportions. The fundamental objective is to attain optimum workability, optimum strength, and optimum durability while simultaneously minimizing expenses.

2.4.1 British Research Establishment method (BRE)

This methodology is appropriate for the formulation of traditional concrete blends that possess a 28-day compressive strength of no more than 75 MPa. This method also offers guidelines pertaining to the design of both lightweight and heavyweight concrete. The evaluation of the compressive strength of cured concrete is commonly performed using two distinct testing methods: the 150 mm cube test carried out after a duration of 28 days (referred to as f_{ck}, cube), and the 150 mm diameter by 300 mm cylinder test, also undertaken at the 28-day mark (referred to as f_{ck}, cylinder). The outcomes of both examinations are denoted in N/mm^2 units. The determination of water content to attain the desired workability takes into account the kind of aggregates, namely crushed and uncrushed, along with the maximum size of the coarse aggregate. The determination of air content is not relevant for concrete that does not include air entrainment. In the context of air-entrained concrete, there exists a provision specifying the minimum overall air content, which is complemented by a provision allowing for the maximum overall air content to exceed the aforementioned minimum requirement by up to 4%.

To ensure adequate protection, BS 8110 requires the use of concrete with higher strength ratings as the severity of exposure increases. In addition, it specifies the minimum amounts of cement and the maximum ratios of free water to cement, which are subject to variation based on the level of exposure. The presence of chlorides in aggregates or admixtures intensifies the problem of corrosion. The specification pertaining to limits can be located in the British Standard (BS) 882 and BS 8110. It is advisable to employ materials that conform to these prescribed standards.

This approach entails determining the total aggregate content by utilizing the wet density of concrete, as derived from the specified value outlined in the approved standard. The wet density of concrete is determined by the specific gravity of the particles when they are in a saturated surface dry state. When faced with a lack of pertinent information, individuals may employ the concept of specific gravity as a means of analysis. The density of uncrushed aggregate is recorded as 2.60, whereas the density of crushed aggregate is documented as 2.70. The determination of the proportion of fine aggregate is based on either the specifications provided or by referencing the data outlined in the applicable standard. The percentage of the total aggregate is utilized to attain the appropriate consistency of the fresh concrete. The selection is determined by the grading of the fine aggregate, the maximum size of the coarse aggregate, and the ratio of free water to cement. The determination of the quantities of fine and coarse aggregates is predicated upon the relative proportions of fine and coarse aggregate within the overall aggregate composition.

2.4.2 Limitations of BRE

i. CEM 32.5 is not taken into consideration in the outlined mix design procedure based on BRE.

ii. The assumption is made that a class 42.5 sulfate-resisting Portland cement exhibits a rate of strength development equivalent to that of a class 42.5 Portland cement.

iii. The scope of this study excludes the consideration of unique materials or special concretes, such as lightweight aggregate concrete, as well as the analysis of flowing or pumped concrete.

iv. The fine aggregates content determined by the BRE approach frequently yields larger values, leading to mixtures with excessive sand content in comparison to the ACI method.

v. The adjustment of fine aggregate content is not feasible for varying cement contents.

vi. The BRE approach fails to consider the influence of surface texture and flakiness of aggregate on sand and water content, despite its ability to differentiate between crushed stone aggregates and natural aggregates.

2.5 Research Gaps

Mohammed, S. M., (2010) asserted that compressive strength of the normal strength concrete increased when increasing the maximum size of coarse aggregate. He however did not use a constant maximum particle size of coarse aggregate.

Kiambigi M., (2018), found out that the Compressive strength of concrete is influenced by the properties of the fine aggregates used, the mix design, curing and the concrete placement method. He did not study if the coarse aggregates properties affected its compressive strength.

Okumu, V., (2017), discovered that high silt and clay content has an effect on the resultant concrete as it will not achieve the expected strength but did not study other properties of fine aggregates if they affected concrete.

Kazeem, K. A., (2015), The general use 1:2:4 for C20 cement-fine aggregate-coarse aggregate mix ratio irrespective of the strength class/grade of the cement does not result to the desired concrete strength but did not carry out a concrete mix design.

According to the findings of Hannah (2014), it was determined that the sand present in Nairobi County and its surrounding areas exhibited elevated levels of silt and clay content, as well as organic contaminants. The researcher did ot sample sand/fine aggregates in Kakamega County.

2.6 Conceptual Framework

The conceptual framework in Figure 2.2 represents the relationship between the variables in this study. The dependent variable in this research was the quality of concrete.

From the reviewed literature, the independent variables are type of cement (OPC or PPC), the characteristics of fine aggregates and characteristics of coarse aggregates. The intervening variables were: aggregate combinations and mix proportions. Furthermore, the mediating variables were: workability and compressive strength.

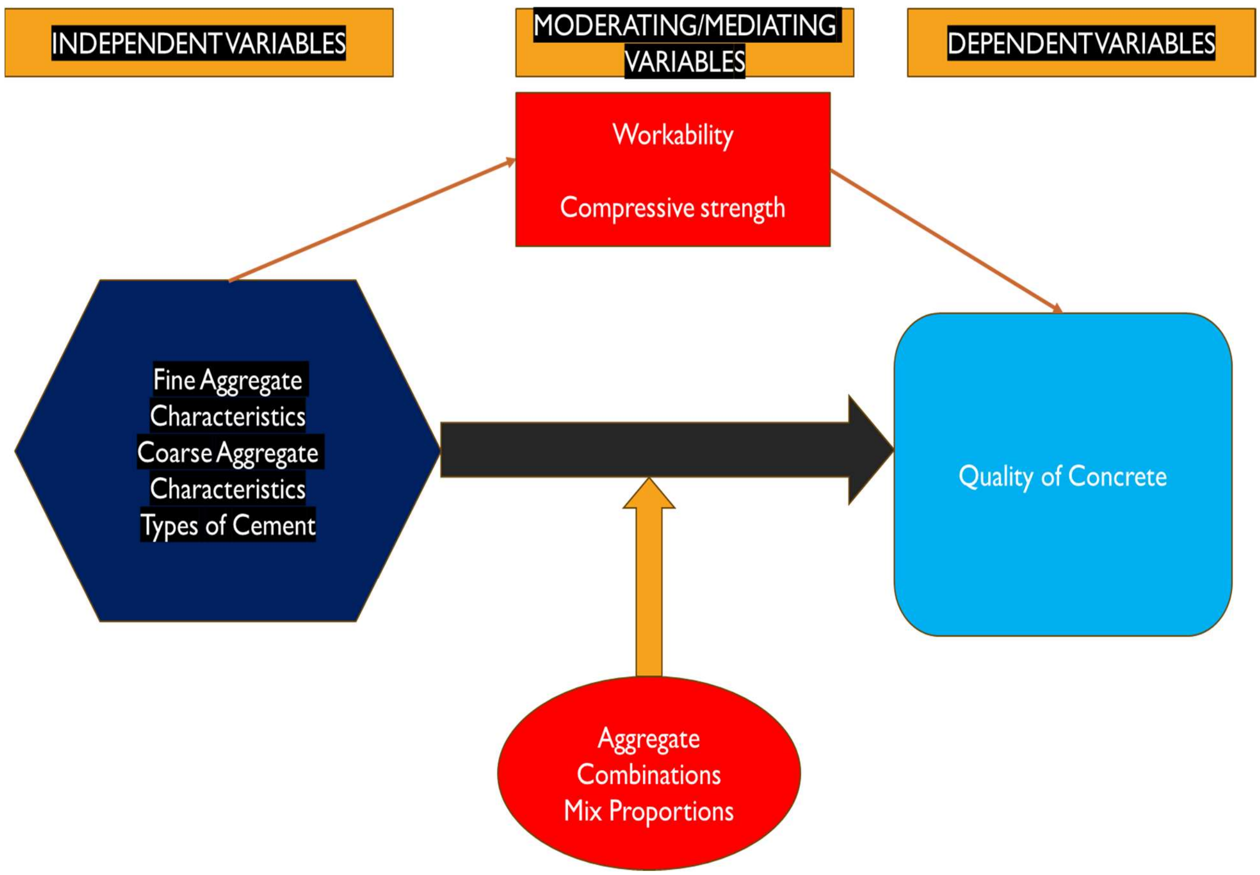

Figure 2. 2: The conceptual framework

CHAPTER THREE
METHODOLOGY

3.1 Introduction

This chapter highlights the materials that were used and their various sources, the laboratory procedures followed to get their material properties and the relevant standards to determine their suitability for the manufacture of concrete. The procedure used to get the concrete mix proportions is described in section 3.3.4. The specimens were hand mixed, cast in cubes, covered for 24 hours, demoulded and then cured in a curing basin for up to 98 days. The testing regimes were 14 of 7 days intervals.

All the materials utilized in this investigation were obtained exclusively from Kakamega County as shown in Figure 3.1 below. Kakamega County is situated in the old Western Province of Kenya and shares boundaries with Vihiga County to the South, Siaya County to the West, Bungoma and Trans Nzoia counties to the North, and Nandi and Uasin Gishu counties to the East. The capital and main urban center of the region under discussion is Kakamega. The county under consideration has a population of 1,867,579 individuals and spans an area of 3,033.8 square kilometers. It ranks second in terms of population size among all counties in Kenya, following Nairobi, and boasts the greatest rural population.

Figure 3. 1: Map of Kakamega County in Kenya

3.2 Materials

The materials used in the production of concrete are cement, fine and coarse aggregates.

3.2.1 Cement

The cement used in this study are the three most common brands are Portland Pozzolana Cement 32.5N and Ordinary Portland Cement 42.5N. They were sourced in hardware shops in Kakamega, and they conform with *KS EAS 18-1*. (2001) which is an adoption of the European Norm EN 197 cement standards. The brands were labelled as Sample A, Sample B, Sample C and Sample D, where sample D was the OPC.

3.2.2 Fine Aggregates

The fine aggregates were sourced from three different occurring sites namely: river beds with a sample denoted as RS, quarries with a sample denoted as QD and roadside with a sample denoted as FS.

3.2.3 Coarse Aggregates

Furthermore, the coarse aggregates were sourced from two different quarries with significant spatial difference and difference in crushing methods: machine crushed denoted CA1 and hand crushed denoted as CA2.

3.2.4 Aggregate Combination

The materials were characterized to determine their properties. Each of the three-sourced fine aggregates were separately combined with the two-sourced coarse aggregates as shown in Table 3.1. This was done to ensure that for every fine aggregate and coarse aggregate that may end up in a site for concreting, its behaviour will have been studied in the experimental research. The proportions of the constituents of concrete used are indicated in Table 3.7.

Table 3. 1:Aggregate combination

Aggregate Fine/Coarse	RS (River Sand)	QD (Quarry Dust)	FS (Roadside Sand)
CA1(Machine Crushed)	RS CA1	QD CA1	FS CA1
CA2(Hand Crushed)	RS CA2	QD CA2	FS CA1

3.3 Methods

The cement sampled was subjected to various physical and chemical tests to determine their properties in the sampled brands. The fine aggregates were tested for presence of silt, gradation and specific gravity. The coarse aggregates were tested for gradation, specific gravity in oven dry state, saturated surface dry state and apparent specific gravity, water absorption and sodium sulphate soundness tests.

3.3.1 Characterization of Cement

The brands that were selected for analysis underwent a series of physical and chemical tests. The subject of inquiry in EAS 148-6 pertains to the examination of cement through various testing methodologies. Specifically, this standard focuses on the determination of the fineness of cement. The determination of cement fineness was conducted using the sieving technique in order to ascertain the proportion of cement weight that successfully passed through the 90-micron sieve as shown in Plate 3.1.

The Vicat device was used to determine consistency, with measurements taken from the bottom to determine penetration. The subject of inquiry in EAS 148-3 specifically focuses on the determination of its setting time and soundness. The initial setting of the cement in the study was established. Initial setting time referred to the duration starting from the moment water is introduced to the cement until the Vicat square needle reaches a depth of 33-35 mm from the top (specifically 5 to 7 mm from the bottom) of the mould within the Vicat Apparatus. The final setting time referred to the duration from when water is introduced to cement until the point at which a 1 mm needle creates an indentation in the paste within the mould, while a 5 mm attachment fails to produce any impression.

The Le-Chatelier test was utilized for the detection of unsoundness specifically caused by the presence of free lime. The chemical analysis of cement was conducted in accordance with EAS 148-2. The determination of loss on ignition involved subjecting a cement sample to thermal treatment at temperatures ranging from 900 to 1000°C (1650 to 1830°F) until a stable weight is achieved. The determination of weight loss resulting from the application of heat to the sample was then conducted. The method of insoluble residue testing was employed to assess the durability of aggregates in the face of potential loss when subjected to a hydrochloric acid solution. The acid solution has the ability to dissolve carbonate compounds.

Plate 3. 1: Determining cement fineness

3.3.2 Characterization of Fine and Coarse Aggregates

The characteristics of the fine and coarse aggregates used in this study were investigated through the following tests:

3.3.2.1 Determination of Silt Content of Fine Aggregates

The apparatus used consists of graduated cylindrical jar, water, pinch of salt and sand specimen. The samples were soaked in the mix of salt and water in a graduated cylindrical jar and left to settle for 30 minutes. Silt content in the fine aggregates was determined as follows:

Eq. 1. $$Percentage\ of\ Silt\ Content\ = \left(\frac{V1}{V2}\right) x\ 100$$

V1 - Volume of silt layer

V2 - Volume of sand layer

This procedure was conducted in accordance to EN 12390-7/BS882.

3.3.2.2 Determination of Specific Gravity for Coarse Aggregates

The basket, containing aggregate, was fully submerged in water for a duration of 24 hours. Weighing was done with the basket and aggregate submerged in water kept between 22 and 32 degrees Celsius. Following the removal from the water, the basket and pebbles were dried with a dry absorbent cloth.

Eq. 2. $$Bulk\ Specific\ Gravity = G_{sb} = \frac{A}{(B-C)}$$

Eq. 3. $$Bulk\ SSD\ Specific\ Gravity = \frac{B}{(B-C)}$$

Eq. 4. $$Apparent\ Specific\ Gravity = G_{sa} = \frac{A}{(A-C)}$$

Three different masses are recorded during the test. Their symbols are:

A = mass of oven-dry sample in air (g)

B = mass of SSD sample in air (g)

C = mass of SSD sample in water (g)

The method followed the standards set forth in EN 12390-7/ BS882.

3.3.2.3 Determination of Specific Gravity for Fine Aggregates

The specific gravity of fine aggregate was determined through a test called the fine aggregate specific gravity test, which involved weighing a set volume of aggregate and comparing that to the weight of the same volume of water. The pycnometer method was used to accomplish the goal.

This procedure was conducted in accordance to EN 12390-7/BS882.

3.3.2.4 Determination of Water Absorption for Coarse Aggregates

The process of water absorption provides valuable insights into the interior composition and structure of aggregates. This procedure was conducted in accordance to EN 12390-7/BS882. The maximum allowable water absorption should not exceed 0.6 per unit by weight. The basket, containing aggregate, was fully submerged in water for a duration of 24 hours. Weighing was done with the basket and aggregate submerged in water kept between 22 and 32 degrees Celsius. Following removal from the water, the basket and pebbles are dried with a dry absorbent cloth. After surface drying, the aggregates were put on a scale to see how much lighter they are.

The aggregates were carefully arranged within a shallow tray and subjected to a controlled heating process within an oven, where temperatures ranging from 100 to 1100℃ are maintained for a duration of precisely 24 hours. Subsequently, the substance is subjected to a cooling process and subsequently measured in a hermetically sealed receptacle.

The calculation of water absorption was determined using the following formula:

Eq. 5. $$Water\ Absorption\ (Percent\ of\ dry\ weight) = (W_B - W_A)/W_A\ X\ 100\%$$

Where W_A is dry weight of aggregate

W_B is weight of aggregate immersed in water

Aggregates with higher absorption rates exhibit greater porosity.

3.3.2.5 Determination of Particle Size Distribution for Coarse and Fine Aggregates

The particle size distribution of the aggregates was determined using the guidelines outlined in the British Standard BS EN 1097-6-2013/BS882. The classification of aggregates was denoted by the proportion, represented as a percentage, of weight that remains on a sequence of sieves. The test sieves employed for the classification of concrete aggregates were characterized by square apertures, which are defined by their respective dimensions.

the aggregate sample was carefully positioned on the sieve with the biggest mesh size. The sieve was then securely covered, and thereafter subjected to a predetermined duration of vigorous shaking. During the process of shaking, the particles underwent a series of sieving stages where they traversed through progressively smaller sieves until they reached a point where they were unable to pass through the sieves due to their size.

The varying ratios of fine aggregate that have successfully traversed a sieve with a 600-micron aperture facilitated the categorization of aggregates into distinct zones, as outlined in the table 3.2 as provided by the British Standard 882.

Table 3. 2: Aggregate placement in different zones

Zone	Percentage
Zone I	15% to 34%
Zone II	34% to 59%
Zone III	60% to 79%
Zone IV	80% to 100%

3.3.2.6 Determination of Sodium Sulphate Soundness of Coarse Aggregate

The process of evaluating the soundness of aggregates in sodium sulfate or magnesium sulfate solutions involved subjecting them to multiple cycles of soaking, drying, and rehydration. This methodology aimed to replicate the detrimental effects on aggregates induced by the natural freeze-thaw activity. The process involved the deposition of salts into empty voids during the soaking phase, followed by the subsequent crystallization of these salts following drying. Additionally, it was observed that these crystals expanded during rehydration. This provided insight into the chemical resistance exhibited by aggregates in concrete. This procedure was conducted in accordance to EN 12390-7/BS882.

3.3.3 Mix design process

The process of concrete mix design involved the careful selection of appropriate materials and the determination of their relative amounts in order to provide optimal workability and optimal strength in the most cost-effective manner. The study selected sample A, which was PPC cement with the most favorable physical and chemical qualities, for investigation. As a control, sample D, which was OPC cement, was utilized to cast cubes. The combination of all the aggregates that had been characterized was to be performed, as shown in Table 3.2 above.

A constant w/c ratio was maintained for each of the strength classes of concrete.

A typical mix design procedure using RSCA1, Cement sample A for C20/25 was as follows:

Step 1: Specification the characteristic strength of the concrete which was C20/25

Step 2: Selection of the limit the proportions of the defective to 5%

Step 3: Determination of the standard deviation in relation to the characteristic strength using Fig. 3 of BRE which gives 8N/mm^2 for C20/25

Step 4: Calculation of the margin C1 = (k*s. d), k=1.64, C= 1.64*8=13 N/mm^2

Step 5: Calculation of the target mean strength = characteristic strength + the margin= 20+13=33N/mm^2

Step 5: Determination of the cement strength class: 42.5/52.5 (BRE does not specify working with 32.5)

Step 6: Selection of coarse aggregate type: Crushed

Step 7: Selection of fine aggregate type: uncrushed

Step 8: Free water/cement ratio was obtained from figure 4 of BRE in this case it was 0.63 as outlined as Fig 3.1 in this study

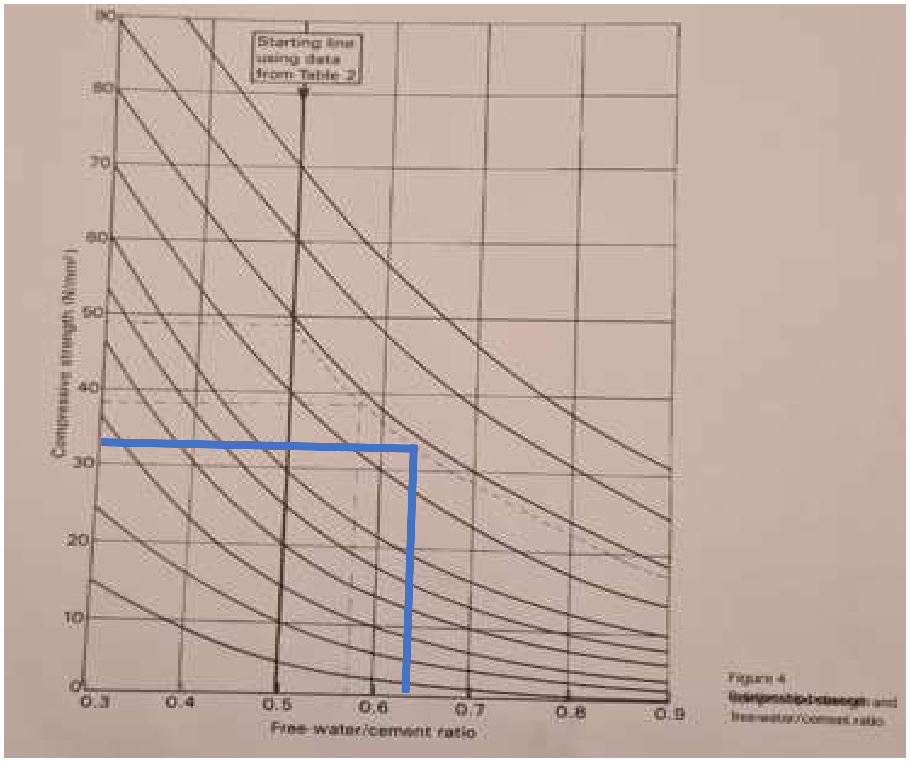

Figure 3. 1: Relationship between water cement ration vs compression strength

Step 9: Get the maximum free -water /cement ratio Table F1 of BSEN 206-1 or Table A.4 of BS 8500-1-2006 (here defined as Table 3.3) which is 0.65.

Step 10: We choose the lower value of the two (8/9) in this case it is 0.65 hence we use the lower value which is 0.63

Table 3. 3: Limiting value for composition and properties of concrete

Table F.1 — Recommended limiting values for composition and properties of concrete

	Exposure classes																	
	No risk of corrosion or attack	Carbonation-induced corrosion				Chloride-induced corrosion						Freeze/thaw attack				Aggressive chemical environments		
						Sea water			Chloride other than from sea water									
	X0	XC 1	XC 2	XC 3	XC 4	XS 1	XS 2	XS 3	XD 1	XD 2	XD 3	XF 1	XF 2	XF 3	XF 4	XA 1	XA 2	XA 3
Maximum w/c	—	0,65	0,60	0,55	0,50	0,50	0,45	0,45	0,55	0,55	0,45	0,55	0,55	0,50	0,45	0,55	0,50	0,45
Minimum strength class	C12/15	C20/25	C25/30	C30/37	C30/37	C30/37	C35/45	C35/45	C30/37	C30/37	C35/45	C30/37	C25/30	C30/37	C30/37	C30/37	C30/37	C35/45
Minimum cement content (kg/m^3)	—	260	280	280	300	300	320	340	300	300	320	300	300	320	340	300	320	360
Minimum air content (%)	—	—	—	—	—	—	—	—	—	—	—	—	4,0[a]	4,0[a]	4,0[a]	—	—	—
Other requirements												Aggregate in accordance with EN 12620 with sufficient freeze/thaw resistance					Sulfate-resisting cement[b]	

[a] Where the concrete is not air entrained, the performance of concrete should be tested according to an appropriate test method in comparison with a concrete for which freeze/thaw resistance for the relevant exposure class is proven.

[b] When SO_4^{2-} leads to exposure Classes XA2 and XA3, it is essential to use sulfate-resisting cement. Where cement is classified with respect to sulfate resistance, moderate or high sulfate-resisting cement should be used in exposure Class XA2 (and in exposure Class XA1 when applicable) and high sulfate-resisting cement should be used in exposure Class XA3.

Step 11: Slump is taken from Table 3 of BSEN 206-1(here defined as Table 3.4), consistence classes defined in table A.15 of BS 8500-1-2006 our slump class is S2

Table 3. 4: Slump classes

Table 3 — Slump classes

Class	Slump tested in accordance with EN 12350-2 mm
S1	10 to 40
S2	50 to 90
S3	100 to 150
S4	160 to 210
S5[a]	≥ 220

[a] See Note 1 to 5.4.1.

Step 12: The maximum aggregate size was determined by the grading test results, namely 20mm. It was also influenced by factors such as the minimum cover to reinforcement, minimum section dimension, and spacing between bars. Refer to BS 8500-1-2006 Table A.7 (here defined as Table 3.5). The minimum cement content was 260kg/m^3.

Table 3. 5: Minimum cement and combination content with maximum aggregate sizes other than 20mm

Table A.7 — *Minimum cement and combination contents with maximum aggregate sizes other than 20 mm*

Limiting values given for 20 mm maximum aggregate size		Maximum aggregate size		
Maximum w/c ratio	**Minimum cement or combination content kg/m³**	**≥40 mm**	**14 mm**	**10 mm**
0.70	240	240	260	280
0.65	260	240	280	300
0.60	300	280	320	340
0.60	280	260	300	320
0.55	300	280	320	340
	320	300	340	360
0.50	320	300	340	360
	340	320	360	380
0.45	340	320	360	360
	360	340	380	380
0.40	380	360	380	380
0.35	380	380	380	380

Step 13: the free water content was gotten from Table 3 of the BRE which is 225kg/m^3 (here defined as Table 3.6)

Table 3. 6: Approximate free water contents (kg/m3) required to give various levels of workability

Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	0–3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Note: When coarse and fine aggregates of different types are used, the free-water content is estimated by the expression:

$$\frac{2}{3} W_f + \frac{1}{3} W_c$$

where W_f = free-water content appropriate to type of fine aggregate
and W_c = free-water content approporiate to type of coarse aggregate.

Step 14: The cement content was gotten by dividing the free water content gotten from step 13 by the w/c ratio from step 9 = 225/0.63=357 kg/m^3

Step 15: the minimum cement content from table F.1 above of BSEN 206-1 and use the greater value of step 13 and 14 which is 357 kg/m^3

Step 16: the relative density of the coarse aggregate in the saturated surface dry state (SSD) from the laboratory procedures. Which is 2.37 approx. 2.4

Step 17: the concrete density from Fig 5 of BRE (Herein defined as Fig.3.2) was 2180kg/m3

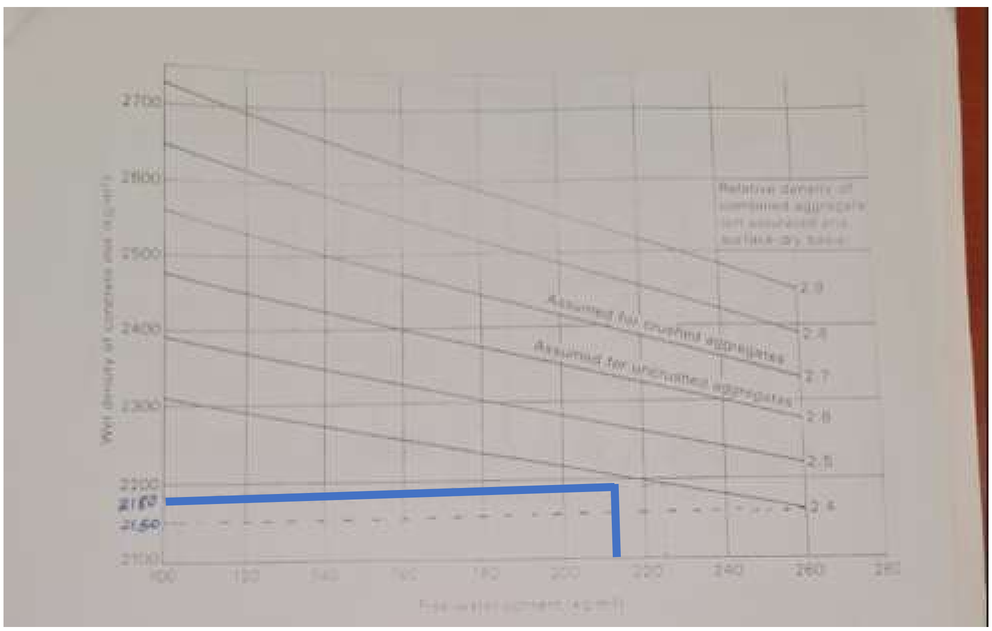

Figure 3. 2: Relationship between the specific gravity of aggregates in SSD and the free water content

Step 18: the Total Aggregate Content= Concrete density-cement content-water content

T.A.C = 2180kg/m^3-388kg/m^3-225kg/m^3=1567 kg/m^3.

Step 19: the percentage of fine aggregate passing 600-micron sieve was 59%.

Step 20: From Fig. 6 of BRE get the proportion of the fine aggregates 39%.

Step 21: Fine aggregate content (FAC)=proportion of fine aggregate*total aggregate content

FAC=39%*1567=611 kg/m^3

Step 22: Coarse aggregate content (CAC)=total aggregate content-fine aggregate content

$$CAC=1567 \text{ kg/m}^3-611 \text{ kg/m}^3=956 \text{ kg/m}^3$$

Step 23: The quantities gotten for cement, water, fine aggregate and coarse aggregate were to produce 1m^3 of concrete yet we needed 3 cubes of 150*150*150mm=0.010125m$^{3.}$ The quantities for each of the aggregate and cement combinations are now defined in Table 3.7.

Table 3. 7: Quantities for the constituents of concrete

Aggregate Combination	Concrete Class	Cement (Kg)	Water (Litres)	Fine aggregates	Coarse Aggregates
RSCA1 (PPC)	C20/25	3.95	2.28	4.81	10.73
	C25/30	4.15	2.28	4.76	10.59
RSCA1 (OPC)	C20/25	3.95	2.28	4.81	10.73
	C25/30	4.15	2.28	4.76	10.59
QDCA1 (PPC)	C20/25	3.95	2.28	6.99	8.56
	C25/30	4.15	2.28	6.89	8.45
QDCA1 (OPC)	C20/25	3.95	2.28	6.99	8.56
	C25/30	4.15	2.28	6.89	8.45
FSCA1 (PPC)	C20/25	3.95	2.28	7.29	8.25
	C25/30	4.15	2.28	7.19	8.15
FSCA1 (OPC)	C20/25	3.95	2.28	7.29	8.25
	C25/30	4.15	2.28	7.19	8.15
RSCA2(PPC)	C20/25	3.95	2.28	4.71	10.43
	C25/30	4.15	2.28	4.65	10.33
RSCA2 (OPC)	C20/25	3.95	2.28	4.35	9.67
	C25/30	4.15	2.28	4.30	9.57
QDCA2 (PPC)	C20/25	3.95	2.28	6.83	8.35
	C25/30	4.15	2.28	6.73	8.20
QDCA2 (OPC)	C20/25	3.95	2.28	6.33	7.75
	C25/30	4.15	2.28	6.23	7.59
FSCA2 (PPC)	C20/25	3.95	2.28	7.14	8.05
	C25/30	4.15	2.28	7.04	7.92
FSCA2 (OPC)	C20/25	3.95	2.28	6.58	7.44
	C25/30	4.15	2.28	6.48	7.34

3.4 Mixing of Concrete

The process of determining the proportions of the separate components of concrete was conducted based on their respective weights. The dry cement and aggregates were meticulously blended prior to the introduction of water. Following the addition of water, manual mixing was conducted for an additional duration of four minutes in order to get a uniform consistency of the concrete.

3.5 Concrete Slump test

The slump test is widely employed as the predominant technique for assessing the workability of freshly mixed concrete. The task was carried out in accordance with the specifications given in BS EN 12350-2:2019. The examination assessed the uniformity of the concrete mixture within a designated batch. The term consistency in relation to concrete pertains to its ability to flow, and so the test is employed to ascertain the level of moisture present. In practical terms, it may be observed that wet mixtures tend to possess more workability compared to dry mixes. The experimental setup comprises a metallic mold in the shape of a frustum of a cone, featuring open ends and equipped with two handles. The dimensions of the mold were approximately 305 mm in height, 203 mm in internal diameter at the bottom, and 102 mm in diameter at the top. Testing for slump is shown in Plate 3.2.

Plate 3. 2b: Slump test concrete (Zero Slump)

Plate 3. 3b: Slump test concrete (Collapse Slump)

3.5 Casting of Concrete Cubes

The metal cube moulds, measuring 150mm x 150mm x 150mm, were securely fastened and lubricated to prevent the concrete from seeping and adhering to the inner surfaces of the cubes, so facilitating the subsequent removal of the moulds. The homogeneous mixture that was obtained following the process of mixing was afterwards filled into each mould in a total of three layers. Following the placement of each layer, compaction was performed by administering 35 strokes using a tamping rod as shown in Plate 3.3. Following the third layer of compaction, the uppermost surface was smoothed using a flat trowel. The cubes were allowed to remain undisturbed for a duration of 24 hours. Three cubes were manufactured for each design mix in every class and for every testing regime. A total of 1008 cubes were cast.

Plate 3. 4: Casting of concrete cubes

3.6 Curing

Following the casting process, the moulds containing the compacted concrete were promptly enveloped with polythene sheets and allowed to rest for a duration of twenty-four hours. After a period of twenty-four hours, the cubes were removed from their moulds and subsequently submerged in fresh water. They were then maintained at the ambient temperature within the laboratory setting. The specimens were maintained in this state until shortly prior to the commencement of the testing phase as shown in Plate 3.4.

Plate 3. 5: Concrete cubes removed from a curing basin before testing for compressive strength

3.7 Compressive Strength Test

The curing process involved immersing the cubes in water, and their compressive strength was assessed at intervals of 7 days for a total of 14 testing periods spanning 98 days. Both PPC-based and OPC-based mixtures were evaluated using a universal testing machine with a loading capacity of 1500KN, following the guidelines outlined in BS 1881-116: 1983. A crushed specimen is illustrated in Plate 3.5.

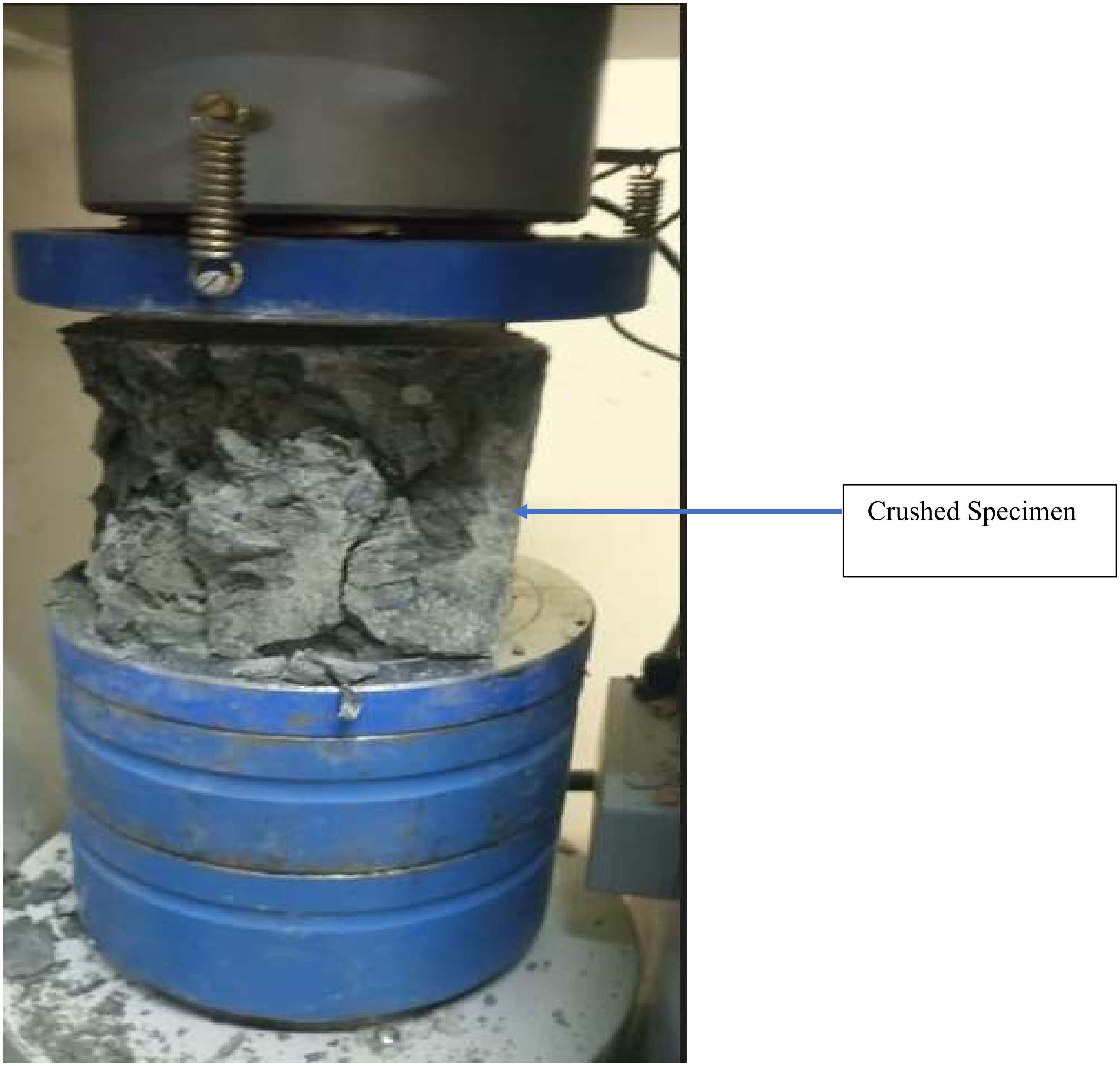

Plate 3. 6: Universal testing machine for testing the compressive strength of concrete cubes

3.8 Analysis of Data

The method used for data analysis was ANOVA. The dependent variable is the quality of concrete defined in terms of compressive strength and workability was continuous (interval or ratio) level of measurement. The independent variables were fine and coarse aggregate properties and the type of cement (OPC and PPC) The intervening and moderating variables were mix proportions and aggregate combinations in ANOVA must be categorical (nominal or ordinal) variables. The p value of the correlation of compressive strength of concrete and workability of fresh concrete was determined in relation to the aggregate combinations and type of cement. P- values greater than 0.05 showed that there was no significant difference in the correlation while values less than 0.05 showed a significant difference in the correlation.

Two-way ANOVA was chosen to know how two independent variables in combination affect the dependent variable.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

This chapter reports and discusses the characterization of cement, fine aggregates and coarse aggregates used in this study from laboratory experiments. Characterization of cement in this study involved determination of both physical and chemical properties of cement samples A, B, C and D (which was OPC). Aggregates were also subjected to tests to determine their properties that are relevant in the production of concrete.

It also discusses the results of workability and compressive strength of concrete and the compressive strength development in a bid to provide insights of the quality of concrete as affected by the characteristics of constituent materials.

4.2 Characterization of Constituents Materials of Concrete

4.2.1 Characterization of Cement

Tables 4.1 and 4.2 show results for physical and chemical properties of the sampled brands of cement.

Table 4. 1: Physical Properties of Cement Tests

	Physical Properties of Cement Tests Results BS EN197:2011						
	Property	**Sample A PPC**	**Sample B PPC**	**Sample C PPC**	**Sample D OPC**	**Upper limit BSEN 197:2011**	**Remarks**
1.	Cement fineness %	94.18	97.9	99.04	99	≥ 90	Ok
2.	Consistency mm (vicat penetration from the bottom)	6.5	7	8	6.6	5-7mm	Sample C not Ok
3.	Initial Setting Time	113 minutes	254 minutes	140 minutes	88 minutes	≥ 75 minutes	Ok
4.	Final Setting Time	120 minutes	264 minutes	206 minutes	180 minutes	≤ 600 minutes	Ok
5.	Soundness aerated (mm)	1.0	1.0	0.9	1.0	10	Ok
6.	Standard Consistence % H2O	34	35	37	30	25-35	Sample C not okay

From Table 4.1 it is seen that, all the samples passed the cement fineness test, initial and final setting time test and the aerated soundness test. A higher fineness will lead to a faster rate of strength development. This fineness property was found to be within the required limit of >90 minutes for all the sampled brands of cement.

Samples B and C had longer initial setting times making them inappropriate for faster placing due to the slow hydration process as a result of presence of pozzolana in PPC. All the samples were viable in the final setting time test because they set at less than 600 minutes which is the upper limit. The aerated soundness test showed the resistance of the cement to disintegration by weathering and, in particular, freeze-thaw cycles. Meaning the cement should be at minimum volume change after it gets hardened. All the cements sampled in this study were found to be below the required value of 10 in this test.

For consistency test and standard consistence, sample C had a value of 8mm and 37 respectively, which is greater than the limits of the EAS. A higher value than the recommended implies that more water is required for mixing that will give a higher workability but also lead to segregation, bleeding and will finally affect concrete strength.

Table 4. 2: Chemical Properties of cement samples tested

	Chemical Analysis of Cement Tests Results						
Sno.	**Property**	**Sample A 32.5N**	**Sample B 32.5N**	**Sample C 32.5N**	**Sample D 42.5N**	**Upper limit EAS**	**Remarks**
1.	Loss on ignition@900^0 C, %m/m	1.99	1.56	1.78	0.11	5.0	Ok
2.	Insoluble Residue, %m/m	1.46	1.42	1.25	2.2	5.0	Ok
3.	Magnesium Oxide as MgO, %m/m	1.39	1.22	1.41	1.76	5.0	Ok
4.	Sulphate as SO_3, %m/m	2.18	1.36	1.81	2.02	3.5	Ok
5.	Chlorides as Cl, %m/m	0.009	0.007	0.006	0.012	0.1	Ok

From Table 4.2, it is seen that, the LOI for all the samples was below the upper limit of 5%m/m. Although elevated levels of loss of ignition were evident in samples A, B, and C this may be ascribed to rehydration, indicating that the cement had been held for an extended duration (Kiptum, 2018).

All of the samples successfully passed the infrared (IR) test, despite the fact that the content in Sample D exhibited comparatively higher levels than the other samples. The adulteration of cement can be assessed by examining the insoluble residue, which is caused by impurities present in gypsum (calcium sulphate). Previous research conducted by J. Chai (2000) had demonstrated that higher levels of insoluble residue can lead to a reduction in the strength of cement.

The maximum allowable content of magnesium oxide (MgO) in regular Portland cement should not surpass 5%. All of the cement samples analyzed in this study met the specified standard. The presence of magnesium oxide in cement is responsible for both the coloration and the hardness characteristics exhibited by the final concrete. Concrete would develop fractures if the amount of magnesium oxide (MgO) exceeds 5 percent. The concentration of SO_3 in all cement brands were within the permissible range. Sulfur trioxide (SO_3) is responsible for regulating the rate at which cement sets, hence preventing the occurrence of flash set. A decrease in the setting rate leads to an increase in the compressive strength of the solidified material.

The chloride concentration inside regular Portland cement ought to be maintained at a level below 0.1%. All of the cement samples examined in this study met the specified criterion. Increased levels of chloride present in cement have a direct impact on the amount of chloride that becomes bonded inside the material. Consequently, this also affects the overall quantity of chloride available for electrochemical reactions, thereby influencing the corrosion process caused by chloride mechanisms. The physical and chemical characteristics of cements suggest that cement makers adhere to established standards during the production process. Given that sample A of Portland Pozzolana Cement (PPC) successfully passed all the physical and chemical analytical tests, it was selected for subsequent casting of cubes. Sample D, which represents Ordinary Portland Cement (OPC), was utilized as a control in this experiment.

4.2.2 Characterization of Aggregates

Characteristics of fine aggregates studied in this research were: silt content, specific gravity and particle size distribution while the characteristics of coarse aggregates studied were: specific gravity, water absorption, sodium sulphate soundness and particle size distribution.

4.2.2.1 Silt Content of Fine Aggregates

Fig 4.1 shows the silt and clay content of the fine aggregates sampled for this study.

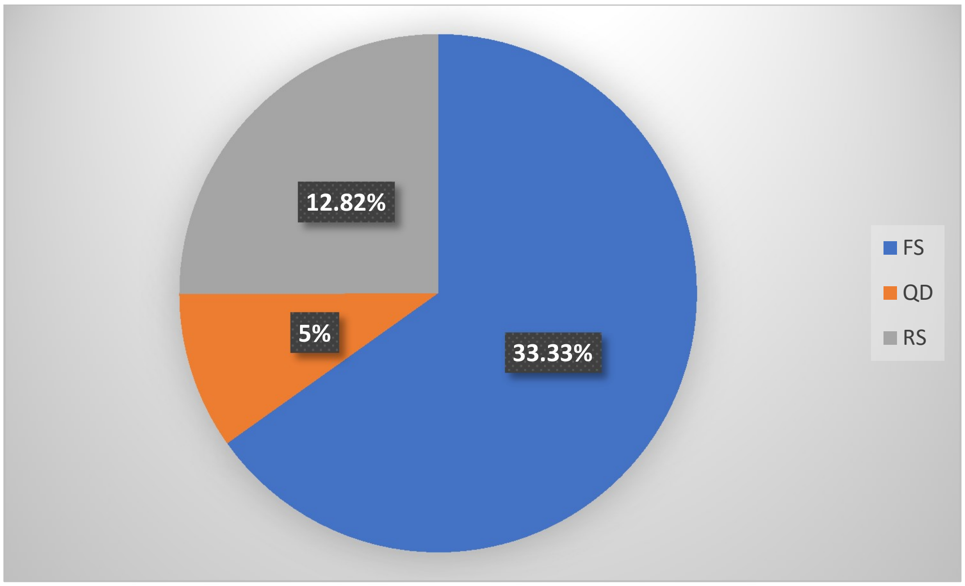

Figure 4. 1: Percentage of silt and clay content of sampled fine aggregates

All three categories of fine aggregates employed in this investigation exceeded the prescribed minimum requirement of 4% as stipulated in the British Standards. The silt contents of Samples QD, RS, and FS were determined to be 5%, 12.82%, and 33.33% respectively. The aforementioned discovery indicates that a considerable fraction of the fine aggregates employed in building sites exceeds the prescribed minimum criteria in terms of silt content.

The presence of silt particles in QD could be attributed to the very fine and dusty particles due to the grinding off rocks to produces quarry dust.

Silt and clay content in the RS and FS samples is due to clay particles found as run off in rivers and roadside drainages.

4.2.2.2 Specific Gravity Test in Fine Aggregates

Fig 4.2 shows the specific gravity of fine aggregates tested in this study.

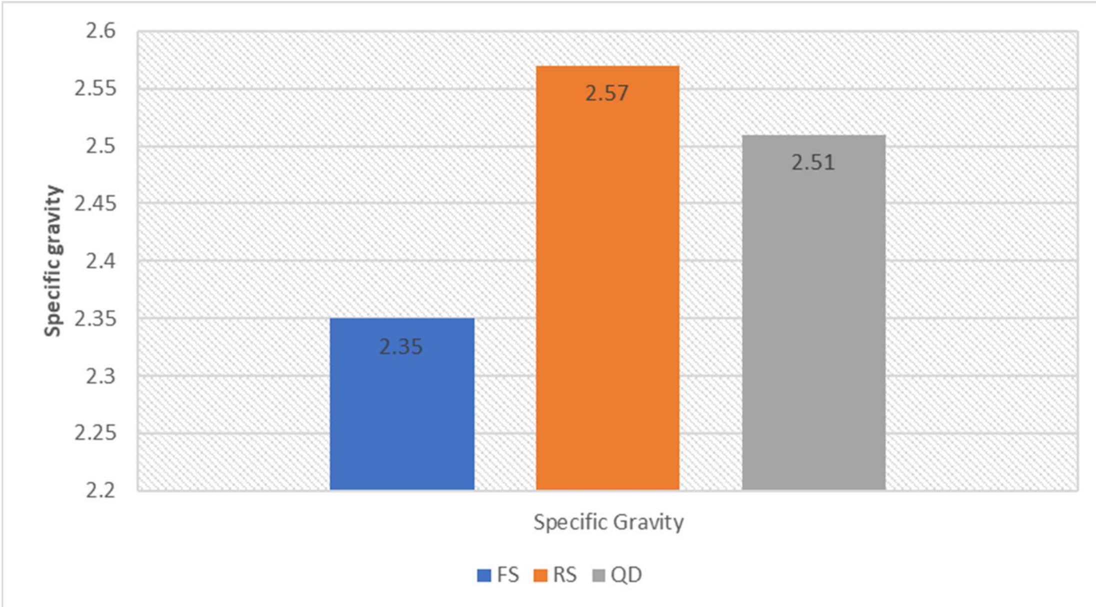

Figure 4. 2: The specific gravity of the fine aggregate samples

The specific gravity test demonstrates the viability of fine aggregate RS and QD with values of 2.57 and 2.51 respectively. However, fine aggregate FS collected from the roadside exhibits a comparatively lower specific gravity value of 2.35. Haque (2017) states that the specific gravity of aggregates commonly employed in construction typically falls between the range of 2.5 to 3.0, with an average value of roughly 2.68. The assessment of an aggregate's specific gravity is regarded as a reliable measure of the material's strength or quality. Generally, stones with lower specific gravity tend to exhibit weaker mechanical properties compared to stones with higher specific gravity value.

4.2.2.3 Particle size Distribution Test Curves for Fine Aggregates

The grading of the fine aggregates, namely FS, QD, and RS, utilized in this investigation was determined to conform to the grading envelopes outlined in BS 882. Fig 4.3 shows the particle size distribution for the fine aggregate samples.

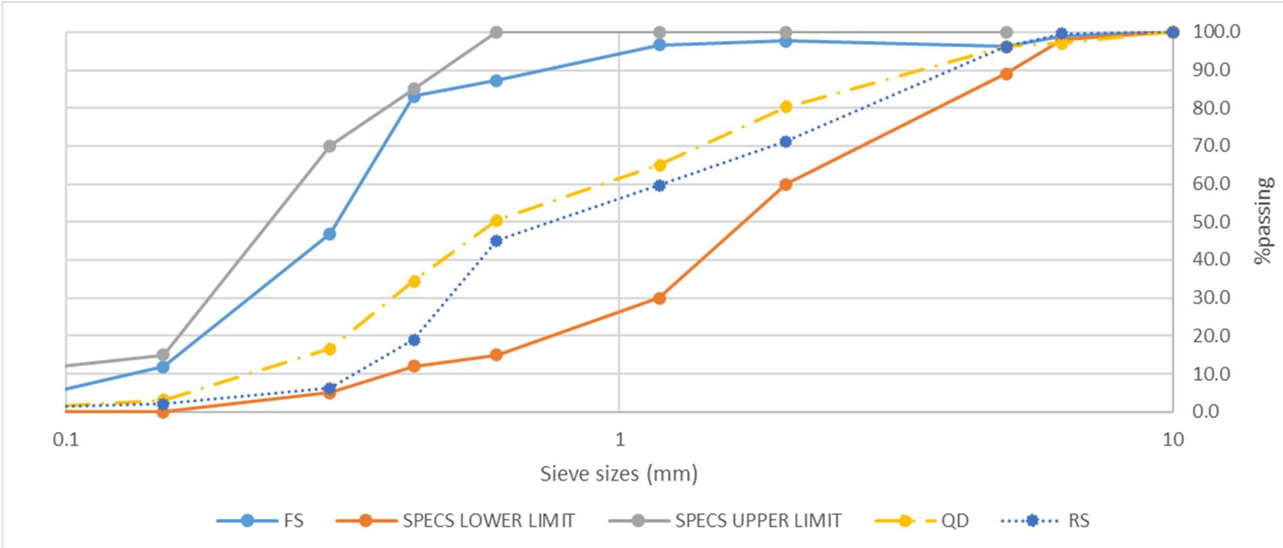

Figure 4. 3: Grading curves for fine aggerates

All the Fine aggregates RS, QD and FS grading curves were within the upper and lower specification limits of the British standard.

4.2.2.4 Particle size Distribution Test Curves for Coarse Aggregates

Fig 4.4 shows the particle size distribution for the fine aggregate samples.

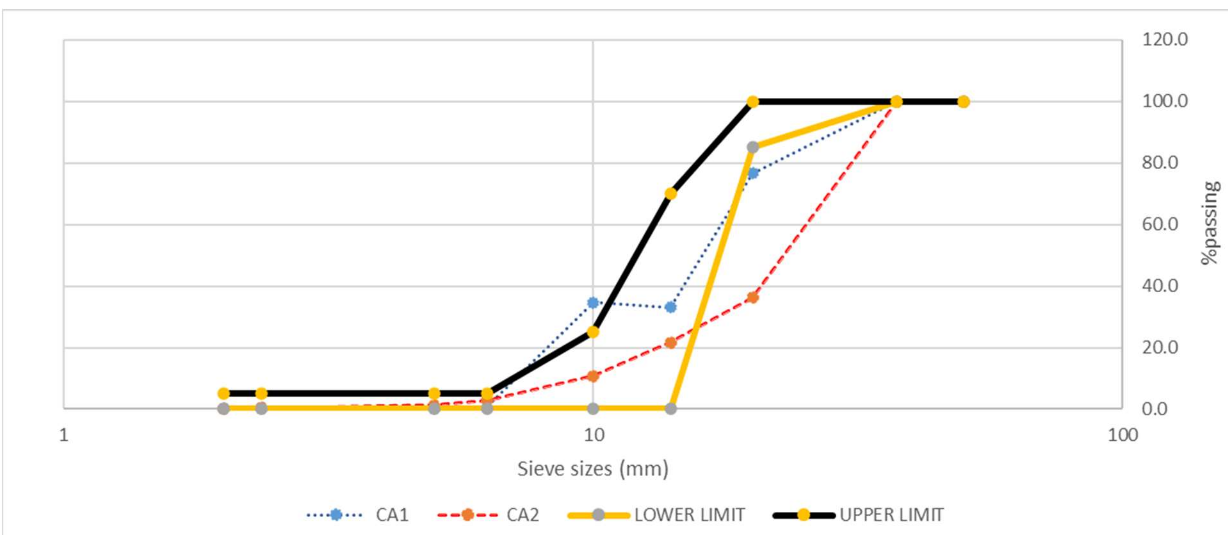

Figure 4. 4: Particle size distribution curves for coarse aggerates

The two coarse aggregate samples were out of range in some parts of the bracket. Both aggregate samples were gap graded with Sample CA1 having more small diameter particles while Sample CA2 has more large diameter aggregates. Gap grading gives a higher workability of concrete and high proneness to segregation as seen in Plate 3.2.

4.2.2.5 Sodium Sulphate Soundness Test in Fine Aggregates

Fig 4.5 shows the sodium sulphate soundness test results for the coarse aggregate samples.

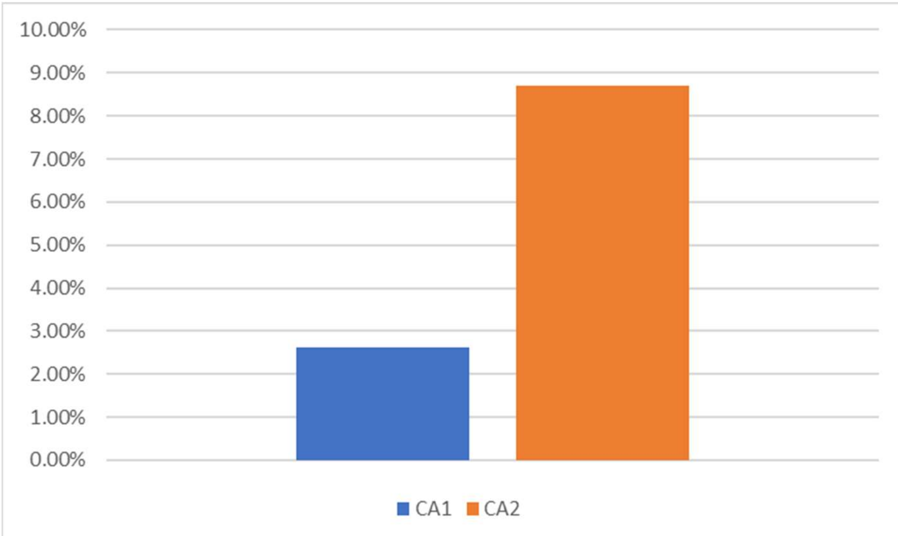

Figure 4. 5: Sodium sulphate soundness test results in coarse aggregates

Aggregate soundness test is a cyclical test that evaluates aggregates for durability and resistance to degradation from wetting and drying cycles. Figure 4.5 shows that aggregate CA1 sourced from machine crushers is more resistant with a value of 2.5 % than CA2 that is hand crushed with a value of 8.7%.

4.2.2.6 Specific Gravity Test for Coarse Aggregates

Fig 4.6 shows the specific gravity test results for the coarse aggregate samples.

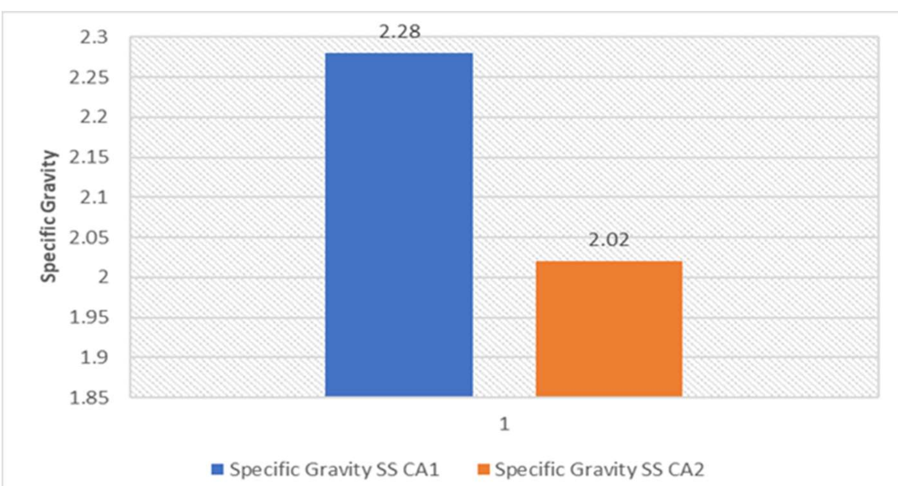

Figure 4. 6: The specific gravity test results for coarse aggregates

The specific gravity values of both aggregate CA2 and CA1 fall below the prescribed range necessary for construction purposes. According to Haque (2017), the typical range for the specific gravity of aggregates commonly employed in construction is between 2.5 to 3.0, with an average value of approximately 2.68. The determination of an aggregate's specific gravity is seen as an indicator of the material's strength or quality. Generally, stones with lower specific gravity values tend to exhibit weaker properties compared to those with higher specific gravity values. The difference in the values for specific gravity values for CA1 and CA2 are as a result of the difference in the geological formation of the rocks used in their production with values of 2.28 and 2.02 respectively. They were sourced from two different sub counties in Kakamega County.

4.2.2.7 Water Absorption Test for Coarse Aggregates

Fig 4.7 shows the water absorption test results for the coarse aggregate samples.

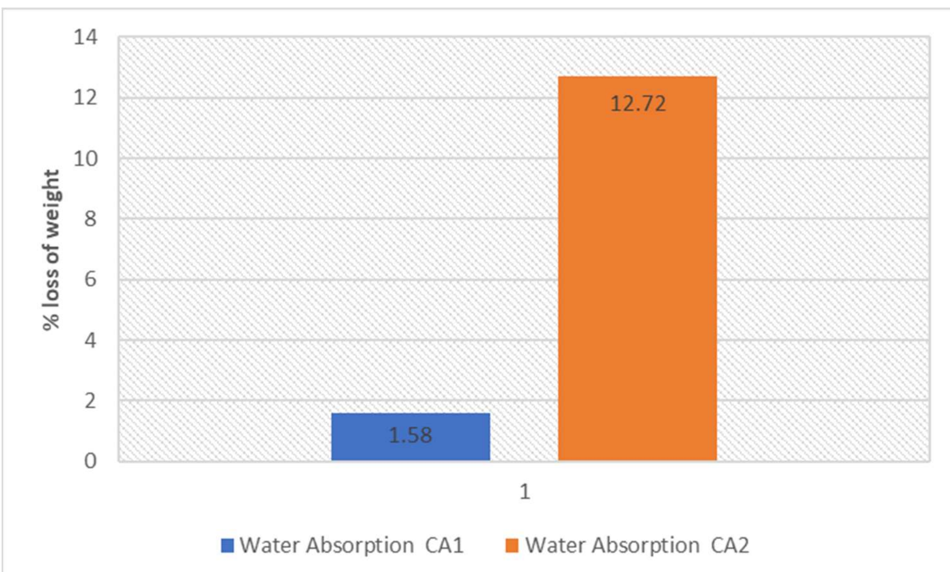

Figure 4. 7: The water absorption test results for coarse aggregates

Aggregate CA1 passed the water absorption rate with 1.58% while CA2 had an abnormally high absorption rate of 12.72%. The aggregate CA2 weathered upon soaking and pores were evident on its surface thus leading to the high absorption rate. The aggregate also had presence of fines on its surface which also led to water absorption. The upper limit for water absorption is 3%.

4.3 Effect of Constituent Materials on Concrete Mix Design Proportions

The concrete mix ratios were determined based on BRE, BS8500-1 AND BSEN206-1. The mix design empirical ratios do not match the mix design proportions from the mix design procedure carried out. This is due to the fact that the aggregates from a certain region vary in specific gravity and the fine aggregates vary in the proportion of fines.

Table 4. 3: Computed mix design ratios vs the empirical mix ratios

AGGREGATE COMBINATIONS	CONCRETE CLASS	CALCULATED MIX RATIOS	EMPIRICAL MIX RATIOS
RSCA1	C20/25	1:1.2:2.7	1:2:3
RSCA1	C25/30	1:1.5:2.6	1:1.5:3
QDCA1	C20/25	1:1.8:2.2	1:2:3
QDCA1	C25/30	1:1.7:2	1:1.5:3
FSCA1	C20/25	1:1.9:2.1	1:2:3
FSCA1	C25/30	1:1.7:2	1:1.5:3
RSCA2	C20/25	1:1.2:2.6	1:2:3
RSCA2	C25/30	1:1.1:2.5	1:1.5:3
QDCA2	C20/25	1:1.7:2.1	1:2:3
QDCA2	C25/30	1:1.6:2	1:1.5:3
FSCA2	C20/25	1:1.8:2	1:2:3
FSCA2	C25/30	1:1.7:1.9	1:1.5:3

The mix design ratios developed from the above procedure were different from the empirical mix ratios. This difference was due to the coarse aggregate specific gravity that was below the recommended values of between 2.5-3.0 which consequently affected the wet density of concrete. This could be attributed to the low specific gravity of both sampled coarse aggregates and the resultant density of concrete.

It is therefore important to carry out a mix design of concrete and do trials before carrying out any concrete works on structural elements and avoid over reliance on the empirical design ratios.

4.4 Effect of Locally Available Materials On The Workability of PPC and OPC Based Concrete Mixes

The workability of concrete describes the consistency and ability of fresh concrete to flow and be formed. The workability of concrete is measured using a concrete slump test and is often referred to as concrete slump according to DOE or the consistency of the concrete according to BS 8500-1.

The desired consistence class for concrete slabs is S2 which should be between 50-90mm for ease of placing and working.

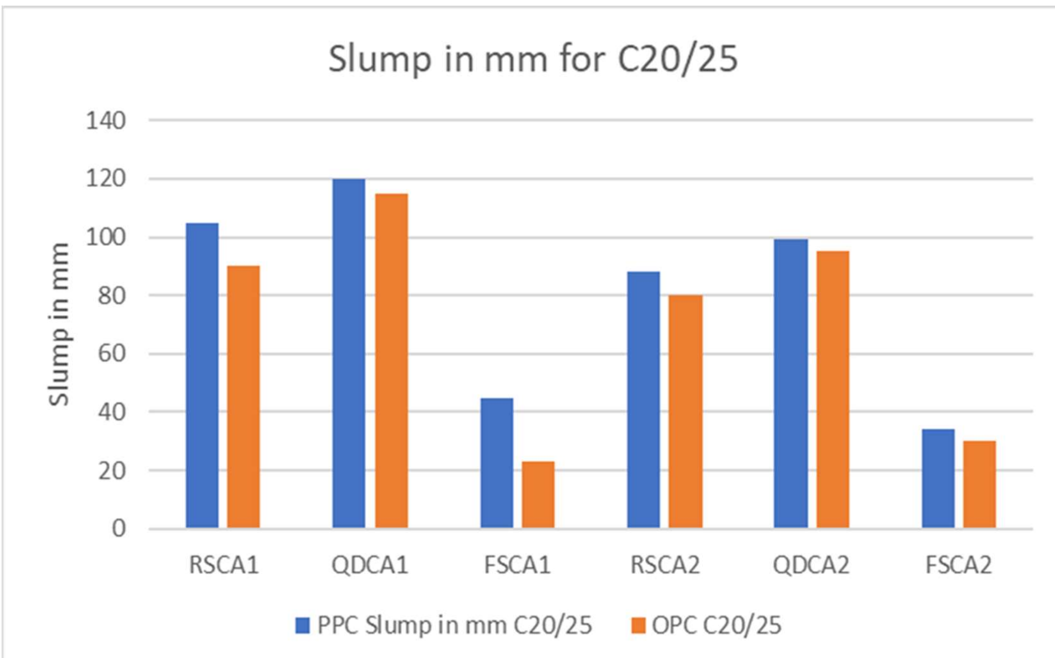

Figure 4. 8: Slump values for all the aggregate combinations for C20/25

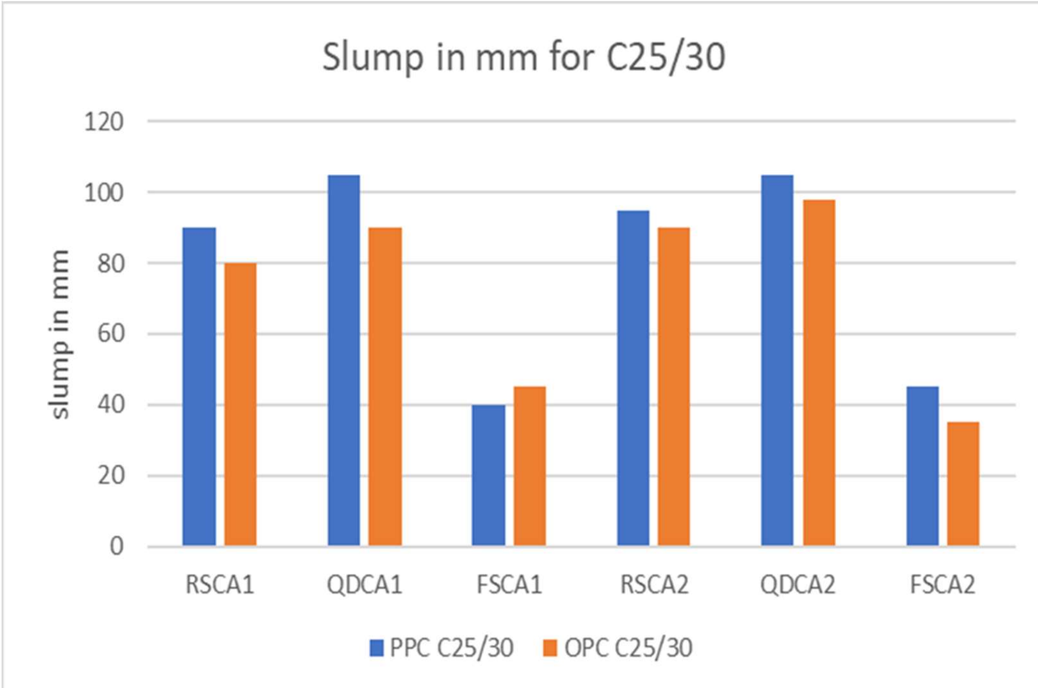

Figure 4. 8: Slump values for all the aggregate combinations for C25/30

Table 4. 4: ANOVA analysis for workability of OPC vs PPC based concrete

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	147	1	147	0.186548	0.674969	4.964603
Within Groups	7880	10	788			
Total	8027	11				

From Table 4.4, for C20/25 and C25/30 for OPC and PPC and all the aggregate combinations, the p value (>0.05) hence there is no statistically significant difference in the workability of both cements. Although there is no statistical difference in workability, the charts showed that PPC was more workable than OPC in concrete hence easy to flow more freely and fill up formwork hence its applicability in complex designs.

Aggregate CA2 exhibits a significantly higher water absorption rate of 12.82%, leading to a notable effect on the workability test results, resulting in a lower slump value when compared to aggregate CA1, which has a water absorption rate of 1.58%. The workability of concrete is notably diminished by the water absorption of coarse aggregate CA2, as it has pores that restrict the available water for mixing, resulting in decreased workability of the concrete. A lower slump means the mix is less fluid and less workable. Aggregate CA1 gives a high slump meaning the mixes were workable except for its combination with FS which had a high silt content.

The presence of a high silt content in fine aggregate FS of 33.33% also influenced the slump of concrete since silt absorbs lots of water reducing the amount of water in concrete and making the concrete less fluid and less workable. The effect of silt was also evident on the RS aggregate combinations and was least in the QD aggregate. Fine aggregate QD produced the most workable concrete.

4.5 Strength Development of PPC-Based Concrete Mix in Comparison to OPC-Based Concrete Mix

Concrete is a highly adaptable and multifunctional substance commonly employed in the field of building. The compressive strength is the most crucial characteristic of this material. A number of factors, including the calibre of the raw materials, the proportion of water to cement, the proportion of course to fine aggregate, the age of the concrete, the process of compaction, the temperature, the relative humidity, and the curing techniques used, all affect the development of concrete strength.

It is observed that the rate of strength development has a progressive pattern, with a more pronounced acceleration during the initial stages of the material's lifespan. However, this rate diminishes as the concrete ages. The compressive strength of concrete achieved with Portland Pozzolana Cement (PPC) exhibits a continued growth beyond the 28-day mark. The increase in strength for PPC based concrete is as a result of its slow rate of strength gain due to a slow hydration process.

Fig 4.9 shows the strength development curves for PPC and OPC for C20/25 and C25/30 using the three fine aggregate samples with each of the coarse aggregates CA1.

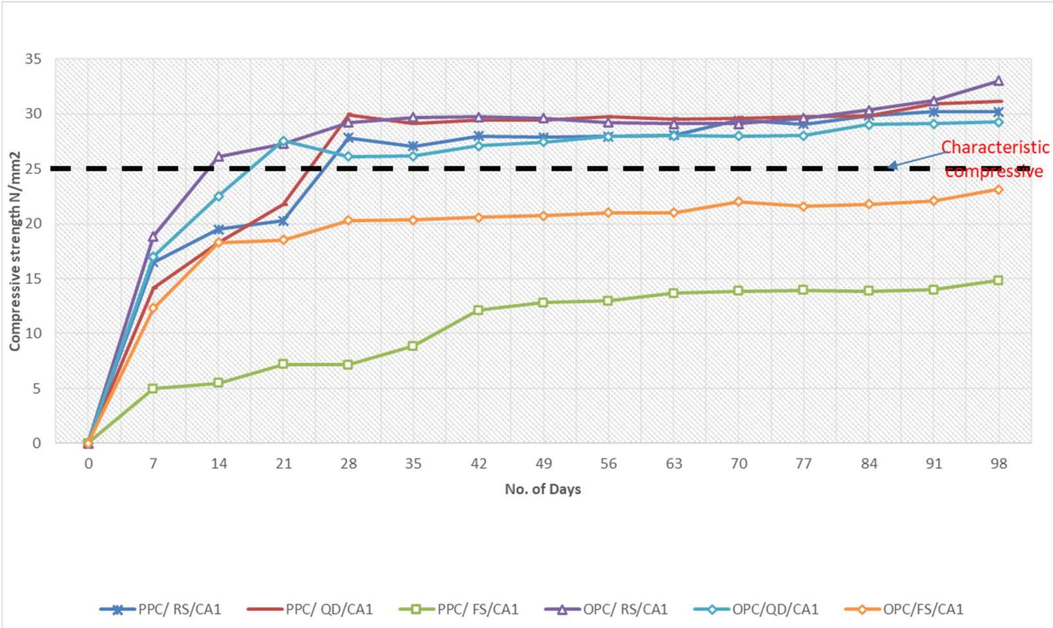

Figure 4. 9: Compressive strength vs aggregate combination for C 20/25 for PPC and OPC based concrete for aggregate CA1 Combinations with aggregates RS, FS and QD

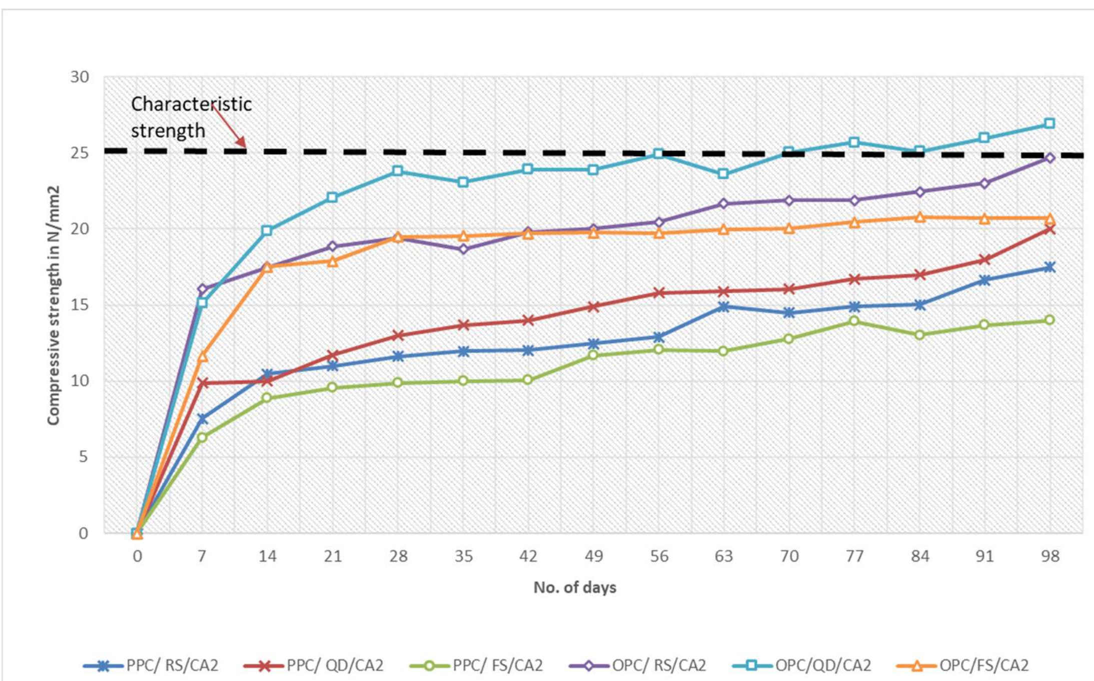

Figure 4. 10: Compressive strength vs aggregate combination for C 20/25 for PPC and OPC based concrete for aggregate CA2 combinations with aggregates RS, FS and QD

For C20/25 and aggregate CA1 with fine aggregates RS and QD, they achieved the minimum characteristic strength of 25N/mm^2 for both OPC and PPC at 28 days. The strength continues to increase beyond 28 days due to the slow hydration of cement.
FS did not achieve the characteristic strength with both OPC and PPC even at 98 days as shown in Fig 4.12.

For C20/25 and aggregate CA2 for RS, QD and FS, they did not achieve the minimum characteristic strength of 25N/mm^2 for both OPC and PPC at 28 days except for OPC and QD at 77 days which achieved the minimum characteristic strength as shown in Fig 4.13.

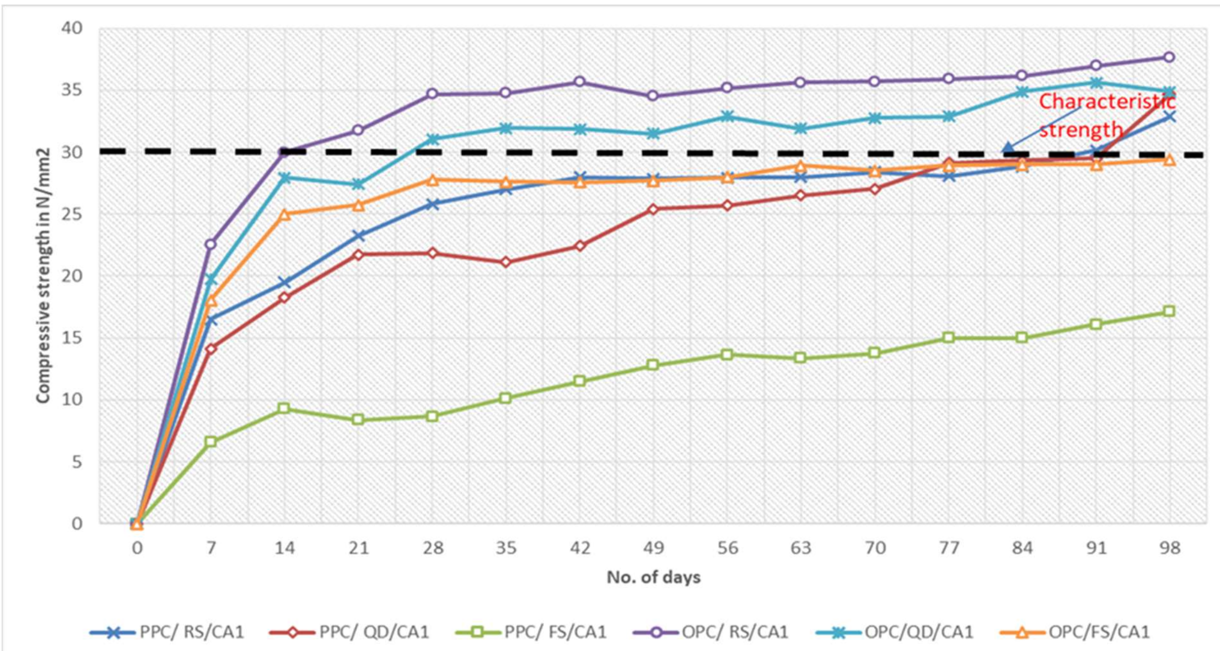

Figure 4. 11: Compressive strength vs aggregate combination for C25/30 for PPC and OPC based concrete for aggregate CA1 combinations with aggregates RS, FS and QD

Fig 4.14 shows that for C25/30 and coarse aggregate CA1 only OPC/RS AND OPC/QD achieves the minimum characteristic strength of 30 N/mm^2 at 28 days.
PPC/QD and PPC/RS achieves the minimum characteristic strength of 30 N/mm^2 at 91 days.
OPC/FS and PPC/FS do not achieve the minimum characteristic strength of 30 N/mm^2.

Fig 4.15 below shows that for C25/30 and coarse aggregate CA2 combined with all the fine aggregates do not achieve the minimum characteristic strength of 30 N/mm^2.

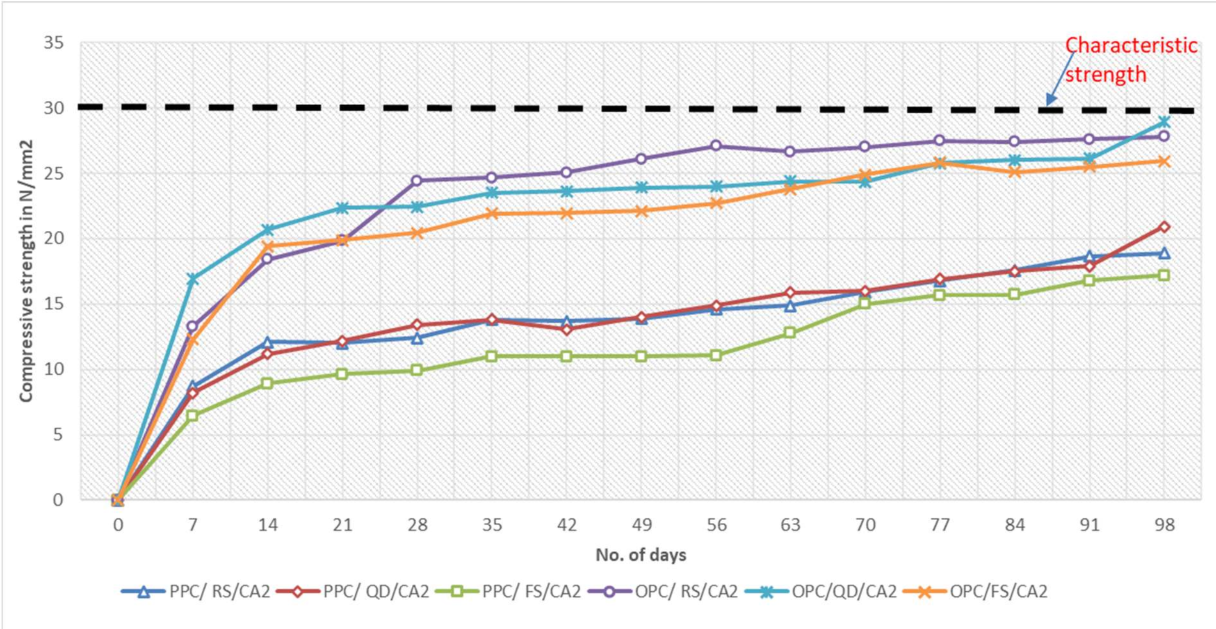

Figure 4. 12: Compressive strength vs aggregate combination for C 25/30 for PPC and OPC based concrete for aggregate CA2 combinations with aggregates RS, FS and QD

At 28 days, the OPC and PPC concrete achieves 99% of the compressive strength of concrete of 25N/mm^2. In both coarse aggregate and fine aggregate combinations PPC concrete compressive strength is less than that of OPC based concrete. The compressive strength of Ordinary Portland Cement concrete is higher by 9% than for Portland Pozzolana Cement concrete at 28 days. The strength values exhibited a steady increase in direct correlation with the duration of curing, suggesting a significant influence of curing age on the development of concrete strength. The level of strength exhibits a gradual increase from 77 days to 98 days, with a subsequent decrease in the rate of improvement in compressive strength.

Table 4. 4: ANOVA analysis for compressive strength of OPC vs PPC based concrete

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2180.07	2	1090.035	20.38736	6.49E-07	3.219942
Within Groups	2245.58	42	53.4662			
Total	4425.65	44				

From table 4.4, for C20/25 and C25/30 for all aggregate combinations there is a significant difference between the compressive strength development for OPC and PPC based concretes because p- value (<0.05).

Table 4. 5: ANOVA analysis for compressive strength for different fine aggregates with varying silt contents

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1262.554	1	1262.554	95.60291	3.38E-10	4.225201
Within Groups	343.362	26	13.20623			
Total	1605.916	27				

For both C20/25 and C25/30 for all the aggregate combinations with different percentages of silt contents the p-value (<0.05) there is a significant difference in compressive strength development. Fine aggregate QD produces a strong mix followed by RS and FS. This could be attributed to the fact that silt content has an impact on the compressive strength of a concrete mix since RS has a silt content of 12% followed by QD at 5% and FS at 33.33%. This is evident because of the low compressive strength of the FS mixes. The presence of silt in FS surrounds the aggregates reducing bonding between the aggregates and hence lowering the compressive strength of concrete. RS and QD gives better compressive strength because they have lower silt content as compared to FS.

Table 4. 6: ANOVA analysis for compressive strength for different coarse aggregates with varying specific gravities

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	653.6601	1	653.6601	60.42362	3.02E-08	4.225201
Within Groups	281.2669	26	10.81796			
Total	934.927	27				

For C20/25 and C25/30 for all aggregate combinations the p-value (<0.05) hence there is a significant difference in the compressive strength development for different specific gravities of coarse aggregates. Aggregate CA1 produces a bigger concrete density and therefore a higher compressive strength for the concrete. This is due to the fact that it has a higher specific gravity and is resistant to weathering action by the MgO present in the cement composition. Aggregate CA2 gives lower compressive strength for both OPC and PPC. The concrete cubes do not achieve the desired target compressive strength. The concrete cube density is also low due to the fact that it has a low specific gravity. The aggregate is also prone to weathering action by sodium sulphate and its surface is coated with dust particles.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusions and recommendations based on the results discussed in Chapter 4. The conclusions are presented in Section 5.2 and the recommendations are presented in Section 5.3.

5.2 Conclusions

The main aim of this study was to investigate the effect of constituent materials on the quality of concrete in Kakamega County. From the results obtained and discussed in Chapter 4, it can be concluded that:

1. The different cement brands had varying chemical and physical properties but were majorly within the permissible limits set in the standards BSEN 197:2011. All the fine aggregates used in the study did not meet the standard requirements of silt and clay content set in BS882 which consequently reduced the compressive strength of concrete whereas grading and specific gravity test results were within the recommended range in BS882. The coarse aggregates under this study did not meet the grading and specific gravity standard requirements in BS882 and the effect was a lower compressive strength of the concrete. The coarse aggregates were gap graded and therefore combining with other aggregates for continuous grading would be appropriate to avoid having close to zero slump in concrete. River sand and quarry dust performed better than roadside sand because of their higher specific gravity of 2.57 and 2.51 respectively and proper grading requirements that was within the grading envelopes set in BS 882. Machine crushed aggregate had a specific gravity of 2.28 higher than the hand crushed aggregate and its water absorption was 1.58% implying more strength and less porosity. The hand crushed aggregate performed poorly because of its lower specific gravity of 2.02 vis a vis the 2.5-3.0 that is recommended and high-water absorption rate of 12.72% vis a vis 3% recommended in BS882.

2. Materials to be used on structural concrete should be sourced from rivers and quarries for fine aggregates and machine crushing plants for coarse aggregates from Turbo area in Kakamega County. Appropriate blending of the machine crushed coarse aggregate to attain proper grading is also necessary to improve the quality of concrete achieved.

3. The workability of PPC-based concrete surpasses that of OPC-based concrete, rendering it highly suitable for the building of elaborate designs due to its ability to effectively fill complex formwork structures. The workability of concrete was notably hindered by the water absorption of the hand crushed coarse aggregate, as the presence of pores resulted in a decrease in the available water for the mixing process. The impact of high silt content in fine aggregates on the workability of concrete was also observed. The presence of silt in these aggregates resulted in water absorption, leading to a decrease in the workability of the concrete.

4. The concrete's compressive strength was reduced due to the combination of a substantial quantity of silt and clay in the tiny particles in FS, along with the comparatively low specific gravity of the coarse aggregates of CA2. The experimental results indicated that the specific gravity of machine crushed CA1 aggregate exhibited a greater value in comparison to that of hand crushed aggregate CA2.The concrete that was produced with the machine crushed aggregate and quarry dust/river sand for concrete C20/25 since it achieves the characteristic strength at 28 days but was not viable for C25/30. The blending of the machine crushed aggregate to achieve a well graded sample could help in achieving improved compressive strength. The hand crushed ungraded aggregate and

roadside sand should not be used for production of concrete due to their low specific gravity and high silt and clay content respectively.

5.3 Recommendations

The recommendations from this study are:

- There is need to carry out Impact value and Aggregate Crushing Value tests on aggregates to ascertain the strength of coarse aggregates to determine its impact on the compressive strength of concrete.
- There is need to study the effect of constituents of concrete using the cylinder compressive strength which is lower than the cube strength because Eurocode is based on cylinder strength of concrete hence necessary because of the shift to Eurocode Design.
- Coarse aggregates sourced from roadside vendors neighbouring Vihiga County and fine aggregates from roadside drains are not suitable for structural use.
- Durability as a component of the quality of concrete should be studied.

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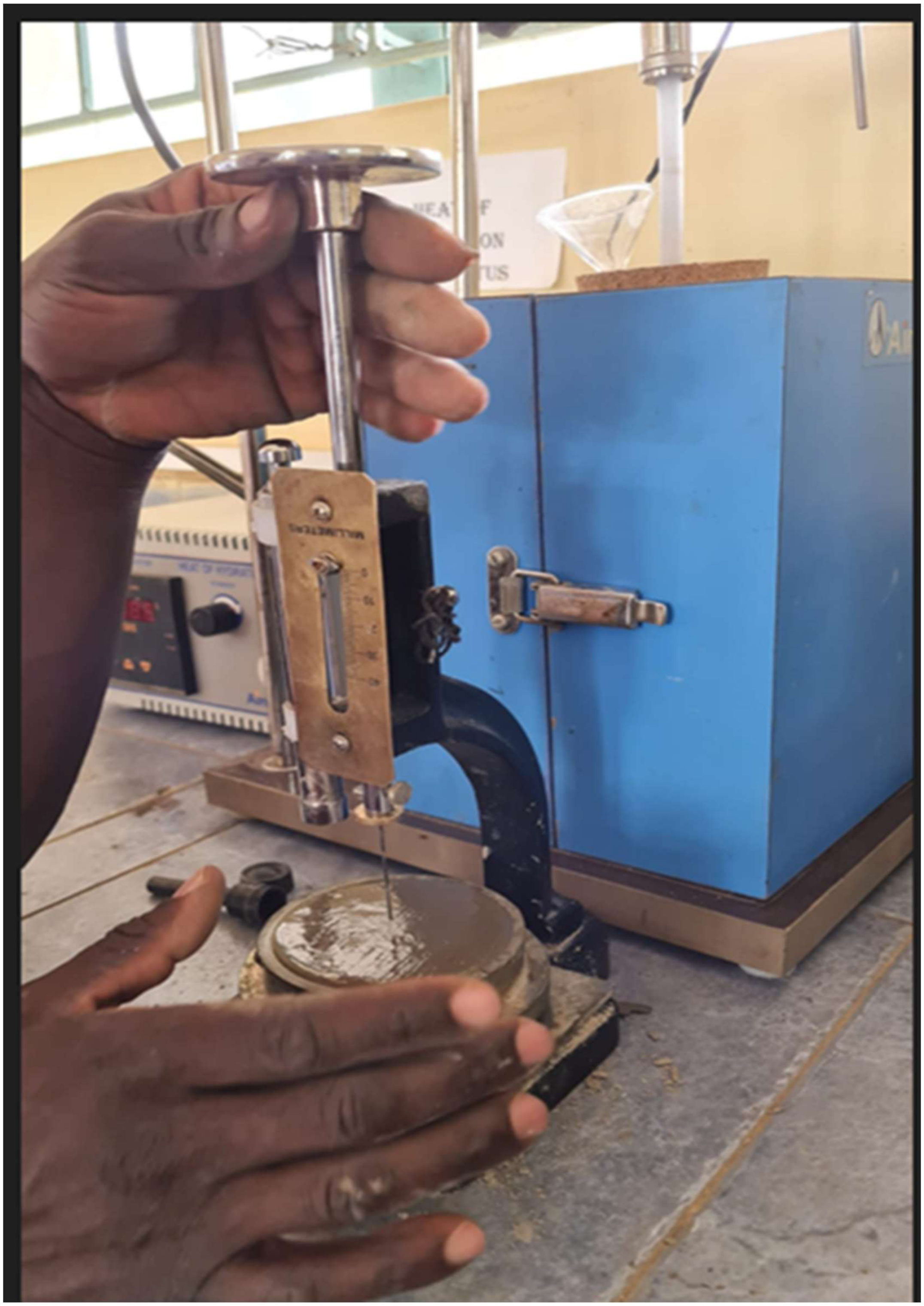
APPENDICES

Appendix 1: Plates describing laboratory tests

Appendix 2: Consistency of cement test of cement



Appendix 3: Aggregate particle size distribution test

Appendix 4: Aggregate soaked and removed from sodium sulphate solution

Appendix 5: Weathered particle from aggregates

Appendix 5: Oven dried aggregates

Appendix 6: Raw data from the compressive strength test procedure

QDCA1	26/7/2022	08/02/2022	7	200	2173.5	22500	328.7		25
QDCA1	26/7/2022	08/02/2022	7	200	2207.1	22500	317.2		25
QDCA1	26/7/2022	08/02/2022	7	200	2186.16	22500	308.7	14.14222	25
QDCA1	26/7/2022	08/09/2022	14	200	2218.7	22500	417		25
QDCA1	26/7/2022	08/09/2022	14	200	2343.8	22500	384.3		25
QDCA1	26/7/2022	08/09/2022	14	200	2188.3	22500	432.4	18.27704	25
QDCA1	26/7/2022	16/8/2022	21	200	2277.7	22500	528.2		25
QDCA1	26/7/2022	16/8/2022	21	200	2289.6	22500	482		25
QDCA1	26/7/2022	16/8/2022	21	200	2185.9	22500	456.9	21.73481	25
QDCA1	26/7/2022	23/8/2022	28	200	2296.15	22500	344.1		25
QDCA1	26/7/2022	23/8/2022	28	200	2225.1	22500	463.3		25
QDCA1	26/7/2022	23/8/2022	28	200	2194.7	22500	466.3	18.86963	25
QDCA1	26/7/2022	30/8/2022	35	200	2196.9	22500	466.3		25
QDCA1	26/7/2022	30/8/2022	35	200	2283.8	22500	448.5		25
QDCA1	26/7/2022	30/8/2022	35	200	2365.7	22500	443.6	20.12444	25
QDCA1	26/7/2022	09/06/2022	42	200	2280.9	22500	366.4		25
QDCA1	26/7/2022	09/06/2022	42	200	2179.5	22500	452.9		25
QDCA1	26/7/2022	09/06/2022	42	200	2187.1	22500	288.9	16.41778	25
QDCA1	27/7/2022	14/9/2022	49	170	2244	22500	558.6		25
QDCA1	27/7/2022	14/9/2022	49	170	2225.5	22500	648		25
QDCA1	27/7/2022	14/9/2022	49	170	2300.77	22500	508.9	25.41481	25
QDCA1	27/7/2022	21/9/2022	56	170	2285.1	22500	521.1		25
QDCA1	27/7/2022	21/9/2022	56	170	2278.1	22500	582.9		25
QDCA1	27/7/2022	21/9/2022	56	170	2311.5	22500	428.3	22.70074	25
QDCA1	27/7/2022	28/9/2022	63	170	2330.6	22500	245.6		25
QDCA1	27/7/2022	28/9/2022	63	170	2378.9	22500	456.4		25
QDCA1	27/7/2022	28/9/2022	63	170	2316.2	22500	548.3	18.52296	25
QDCA1	27/7/2022	10/05/2022	70	170	2110.19	22500	479.6		25
QDCA1	27/7/2022	10/05/2022	70	170	2343.14	22500	348		25
QDCA1	27/7/2022	10/05/2022	70	170	2356.39	22500	391	18.05333	25
QDCA1	27/7/2022	10/12/2022	77	170	2212.5	22500	642.4		25
QDCA1	27/7/2022	10/12/2022	77	170	2228.8	22500	625.3		25
QDCA1	27/7/2022	10/12/2022	77	170	2236.9	22500	698.9	29.13481	25
QDCA1	27/7/2022	19/10/2022	84	170	2246	22500	701.9		25
QDCA1	27/7/2022	19/10/2022	84	170	2213.9	22500	702.7		25
QDCA1	27/7/2022	19/10/2022	84	170	2221.5	22500	687.9	31	25
QDCA1	27/7/2022	26/10/2022	91	170	2278.6	22500	687.6		25
QDCA1	27/7/2022	26/10/2022	91	170	2267.9	22500	696.8		25
QDCA1	27/7/2022	26/10/2022	91	170	2245	22500	679.6	30.57778	25
QDCA1	27/7/2022	11/02/2022	98	170	2217	22500	709.5		25
QDCA1	27/7/2022	11/02/2022	98	170	2234	22500	656		25
QDCA1	27/7/2022	11/02/2022	98	170	2256	22500	700.7	30.61037	25