COMPRESSIVE STRENGTH OF CONCRETE PRODUCED USING AGGREGATES FROM SELECTED TYPES OF ROCKS IN UGANDA

BY

KAWISO MICAH

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DECLARATION

I, Kawiso Micah do hereby declare that this research report contains the true record of my original work and no part of it has been submitted to any University or academic institution for the purpose of an academic award.

Signed:………………….

Date:…………………….

APPROVAL

This is to certify that this research report by Kawiso Micah was developed under our guidance and is hereby cleared for submission to the Board of Graduate Directorate and the Senate of Kyambogo University with our due approval.

Signed:…………………………………

Supervisor One: Prof. Obwoya Kinyera Sam

Date:……………………………………

Signed:…………………………………..

Supervisor Two: Enjiku Ben D.D

Date:……………………………………..

DEDICATION

This research report is dedicated to my wife and children.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This study was on determining the compressive strength of concrete made of granite, quartzite and sandstone aggregates of three aggregate sizes of 6.3 mm, 10 mm, and 14 mm and using three cement, sand and aggregate mixture ratios of 1:3:6, 1:2:4, and 1:1:2. This was to find out the effects of mixture ratios, aggregate sizes and aggregate types on compressive strength of the concrete. The samples of concrete were cured for 14 days and then a compression test machine was used to determine the compressive strength of the samples. The average compressive strength of granite concrete of mixture ratios 1:3:6, 1:2:4 and 1:1:2 were 8.56, 19.10 and 32.59 MPa respectively. The mean compressive strength of quartzite concrete of mixture ratios 1:3:6, 1:2:4 and 1:1:2 were 8.78, 17.57 and 31.22 MPa respectively. The average compressive strength of sandstone concrete of mixture ratios 1:3:6, 1:2:4 and 1:1:2 were 9.71, 20.75 and 33.58 MPa respectively. The mean compressive strength of granite concrete of aggregate sizes 6.3, 10, and 14 mm were 18.77, 19.62, and 21.87 MPa respectively. The mean compressive strength of quartzite concrete of aggregate sizes 6.3, 10, and 14 mm were 17.93, 18.95, 20.71 MPa respectively. The mean compressive strength of sandstone concrete of aggregate sizes 6.3, 10, and 14 mm were 19.49, 21.01, 23.21 MPa respectively. The results have revealed that the compressive strength of granite, quartzite and sandstone concrete increased with increase in cement aggregate ratio. Mixture ratio 1:1:2 produced the highest compressive strength of concrete and mixture ratio 1:3:6 produced the lowest compressive strength of concrete. The results have further revealed that compressive strength of the three rock types increased with increase in size of aggregate. The difference in the compressive strength for the three different types of rocks was negligible. Therefore, mixture ratios and aggregate sizes affect concrete compressive strength but rock types used did not affect the compressive strength of concrete samples. Builders and engineers who wish to construct structures should mind most about the aggregate size and mixture ratio than the granite, quartzite or sandstone aggregates used.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

The development of a country or a society can be judged by the quality and number of infrastructures the country or community has erected. The infrastructures can be to serve social and economic functions. The structures and facilities are erected to provide good shelter for domestic purposes and other economic activities. The economic related infrastructure comprises of roads, bridges and dams to ease transportation. Infrastructures like buildings are needed for carrying out trade. The housed equipment and machinery are meant for human activity that leads to human development. There are social infrastructures that provide shelter meant to house educational institutions, health centres, and banks.

A country's level of infrastructure development affects its level of economic development. It is clear from a comparison of the world's most industrialized nations that their infrastructure development and the expansion of their economic and social infrastructure are related. However, there isn't the same high standards of quality infrastructure in emerging or underdeveloped nations with their slow and low level of economic development. According to Vamsi (2020), India's economy was much far behind than those of many nations when it gained independence. The planners of India at that time prioritized infrastructure development and started spending about 50 percent of their budget to infrastructure development. In their first budget, 27 % went to transportation and communication, 13 % went to power, 10 % went to flood and irrigation control. India caught up with the rest of the globe thanks to investments made in infrastructure development since independence, and it is now one of the most promising nations in terms of development and growth.

The low infrastructure development in many developing nations showed the low level of economic growth and the low level of accomplishment of the Millennium Development Goals by 2015. The failure to realize the millennium Development Goals by 2015, made United Nations General Assembly again to formulate seventeen Sustainable Development Goals (SDGs) or Global Goals which were targeted to be achieved by 2030. One of the goals was aimed at building resilient infrastructure, promote industrialization, and foster innovation. The African

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Union Commission (AUC), in collaboration with the African Development Bank, the NEPAD Planning and Coordinating Agency, and the United Nations Economic Commission for Africa, was asked by the African Heads of State during the 12th General Assembly to create a Programme for Infrastructure Development in Africa (PIDA), which was formally introduced in Kampala, Uganda, in July 2010. The outcome of the work done was that for Africa to develop it had to invest in its regional infrastructure. Building the infrastructure required for transportation, energy, ICT, and trans-boundary water networks was a priority for Infrastructure Development in Africa in order to promote trade, spark growth, and generate jobs. Its implementation was to revolutionize business practices and contribute to the development of an interconnected and thriving Africa.

Africa is well positioned in the world and currently it is attracting many investors and developers for high growth market but is still experiencing challenges of inadequate infrastructure. Inadequate infrastructure has reduced productivity and increased production and transaction costs, which have hampered growth by making it more difficult for companies to compete and for governments to implement programs for economic and social development. Infrastructure shortcomings distinctly affect how competitive Africa is. Infrastructure is one of the main reasons why African nations, especially those south of the Sahara, are among the least competitive in the world. It has been discovered that poor infrastructure in modern-day Africa might reduce growth by as much as 2% annually.

Kampala the capital city of Uganda is for example more developed in terms of infra-structure, number of the structures and complexity of the structures compared to other towns because it has many more people who need the structures for different economic activities than those in the other towns in the country who have limited scope of economic enterprises. For the rest of Uganda to develop, the other towns have to increase and modernize their infrastructures to the level of Kampala. The increased and modernized infrastructure in other parts of the country will not only improve the numbers and standards of infrastructures but also enhance human interactions and business by catering for efficient communication, transportation and standard of living.

Much as Uganda has registered significant progress in the recent years on its infrastructure development, the percentage of 42.1% is still low. Roads continue to develop potholes and buildings continue to collapse due to; inappropriate mixing ratios, inappropriate building materials and untested strength of building materials. The quality and number of the built infrastructure like roads, bridges, drainage channels, pavements and buildings is still low According to the Uganda's ruling party, the National Resistance Movement (NRM Manifesto, 2021); Uganda has a total road network of about 159,366 kilometers with 20,854 km of national roads. By the end of 2019 Uganda government had tarmacked only 5,500 km of national roads, and rehabilitated 1,000 km of old tarmacked roads. The tarmacked roads because of much motor traffic they develop potholes easily and yet fixing them takes long. According to the 2019 Road User Satisfaction Survey, over 64 percent of the road users believe that, road agencies do not fix potholes in time while over 67 percent feel that agencies do not fix potholes to appropriate standards.

Another survey conducted by the New Vision in 2010 indicated that, Kampala city centre had roads with 2,489 potholes. The survey further shows that out of 89 roads in Kampala, 73 roads had potholes with Lumumba Avenue and Buganda road having the highest number of potholes with 249 and 245 respectively. The other most potholed city roads were Ben Kiwanuka, Old Port Bell, Makerere Hill Road, Upper Kololo Terrace, Seventh Street and Namuwongo Stage (Ocaido, 2019). However, the new Kampala City Council Authority (KCCA) has tried to fix the potholes in the city in the recent years. The bridge at Nile in Jinja district developed cracks when they had just finished constructing it. On the other hand, many of collapsed buildings have been reported in the media from time to time, the most recent one being a four storeyed building which was under construction in Kijampa zone in Makindye division in Kampala city (Saturday Vision, 29 September, 2020). According to Robert Ssekitoleko, the Chairperson of physical infrastructure committee in the 10th Parliament of Uganda, the cause for the collapse of Kijampa zone building was use of inappropriate materials. Also many of the storeyed buildings have been left incomplete due to use of inappropriate materials which puts the lives of the occupants at risk incase more levels are added on it since desired strength will be low. It is important that at every point of construction the strength of the building be tested, however some building engineers ignore this leading to the collapse of building. But there is a need for a scientific study to help building engineers improve the strength of structures leading to long lasting buildings or structures.

The construction of good infrastructure is possible when appropriate materials for building them are in place. There are natural and manmade materials that can be used in building infrastructures. Among the abundant natural material resources around us are water, sand and rocks. The man made materials include concrete, bricks, and tiles. Construction of infrastructure such as roads, highways, dams, bridges and houses require both natural and manmade materials like cement, sand, crushed rocks and water. Therefore, the natural and man made materials are used together to form composite materials. The widely used and produced composite material in the physical infrastructure construction is concrete. Concrete is used in construction of buildings, roads, electric poles, drainage channels, slabs, bridges, highways, pavements, dams and many other construction structures. In buildings, concrete is used in setting the foundations, columns, beams and slabs. For the case of roads it is used for paving them. The use of concrete is attributed to being affordable, structurally sound, and its wider application. Concrete is composite material comprising of cement, sand, aggregates and water. The type and grade of cement used in concrete production is important as it contributes greatly to concrete strength. Aggregate is another important component of concrete. This is because aggregates occupy approximately 66-78% of the volume of concrete (Don, 1978). Aggregates are classified depending on their sizes as fine or coarse aggregates. Coarse aggregate range from 4.75 mm to 50 mm and fine aggregate range from 75 μm to less than 4.75 mm. Fine aggregate (sand) can further be categorized as; very fine sand, fine sand, medium sand, coarse sand and very coarse sand. This categorization depends on the particle sizes of sand, for instance 0.0625 mm to 0.125 mm is for very fine sand, 0.125 mm to 0.25 mm is for fine sand, 0.25 mm to 0.5 mm is for medium sand, 0.5 mm to 1 mm is for coarse sand and 1mm to 2 mm is for very coarse sand. Significant production and utilization of aggregates started during the Roman Empire where the architects used aggregates to build their road network, bridges and aqueducts in form of arches. The idea to use aggregate in concrete brought about permanent demand for them up to date.

Aggregates are obtained from rocks after being crushed. There are many different types of rocks found in different regions of Uganda that are quarried and used to produce aggregates. For example granite is found in quarries like Laroo and Kidere in Gulu District, Peta in Tororo District, Ochuloi in Soroto District, Dokolo in Dokolo District, and Akiya in Lira District. Several locations in Mubende and Kiboga Districts also have granite rocks. Quartzites and slates are mined in several locations in the central region like Wakiso, Kampala, Lugazi, Mukono, and Luwero (Bukya, 2020). Marble occurs extensively in the northern region, particularly in Moroto District. Limestone is found in Tororo, Moroto, Hima, Muhokya, Kamwenge and the Lake George Basin about 30.5 m above the present level of Lake George. The limestone deposit at Hima is far more extensive and covers about 2.5 km^2 with an estimated reserve of 18-20 million tons and Muhokya limestone deposit had a total reserve of about 0.25 million tons as estimated in 1953 (Nagudi, 2011). Also according to Jennifer et al (2018) limestone and marble resources have been estimated at 14.5 million tons at Hima and Kasese, 11.6 million tons at Dura and Kamwenge and with over 300 million tons at Rupa, Koseroi, Tank Hill, Matheniko, Pule, Lolung in Karamoja. Estimations of resources at Muhokya in Kasese vary from 250,000 to 2 million tons. Each region uses the available rocks to obtain aggregates and use in the construction of roads or houses but what remains unclear is the trend of concrete strength from the different rock types.

The strength of concrete is however very important. It determines the life span and the stress the structure can withstand. The mix design, the quality, and the quantity of the ingredients used in the creation of concrete all affect the concrete's strength (Don, 1978). The concrete strength is measured in terms of grades. Lean concrete, regular concrete, standard concrete and high strength concrete are among the available concrete grades. The grades of concrete are produced by use of different mixture ratios of cement, sand, aggregate and water. The concrete grade chosen depends on the nature of the project in particular the load that concrete will be sustaining. Concrete with compressive strength of ten (M10) is used in types of projects where not very strong cement is needed. It’s used for smaller domestic or commercial projects like laying of garden pathways, using patio slabs. Here the load on concrete is relatively low. It is also suitable for projects that may need to be replaced in few years. It is not recommended for structural work. Concrete with compressive strength of twenty is very strong and it is good for bigger commercial or residential projects. It is useful in indoor flooring projects so long as the structure or the building is not too big. The type of floors best suited for this strength is floors in workshops or garages. It is also used for driveway that use few vehicles. Concrete grade with compressive strength of twenty five is standard concrete and good for foundations. It is very strong and it should be used in heavier structures especially in foundations that ensure the structure bears adequate support. Concrete grade with compressive strength of thirty is so strong and useful for roadways that experience a lot of motor traffic and footsteps in their daily use. This grade of concrete is used more in commercial projects and not domestic projects. It resists weather more effectively. Concrete grade of thirty five is much more durable and used in many commercial structures. The strength of this grade makes it suitable for many types of structural work in commercial buildings. It can withstand high pressure very well. Therefore, it is good for exterior walls, building of storeyed structures with sturdy foundations. Compressive strength of forty is taken as the most durable concrete with highest strength for high concrete strength. As a result it is suitable for construction of foundations of commercial buildings with multiple floors where large load is to be carried. This concrete grade is resistant to chemicals and cannot corrode easily. This makes it applied in areas where concrete is exposed to strong chemicals such as sanitation, and septic tank. The correct concrete grade ensures that concrete does not experience fatigue since it possesses the required strength. Therefore, while choosing a material for a particular application, engineers take strength into account as one of the key mechanical attributes (Duncan, 2007). Concrete being a composite material used to construct physical infrastructure, focus is on concrete strength and specifically compressive strength. This is due to the fact that it is a mechanical property of concrete that has undergone the most testing and is used to assess the strength and quality of concrete in structures.

1.2 Statement of the Problem of Study

Different types of rocks in Uganda are crushed into aggregates to produce concretes by builders and civil engineers in the construction of beams, columns, floors and pavements. Some of the concrete beams, columns and slabs have been found to be weak leading to collapsing of structures. The collapsing of structures as a result of weak concrete has been majorly attributed to poor cement quality and inappropriate mixture ratios of cement and sand, but little is mentioned about aggregate types, aggregate sizes and mixture ratios if they affect the strength concrete.

1.3 Purpose of the Study

The purpose of this study was to find out the compressive strength of concrete produced using aggregates from selected types of rocks in Uganda.

1.4 Conceptual Framework

The focus in this study was on the compressive strength. It is the dependent variable and it was chosen because it is one of the most tested mechanical properties in concrete. The independent variables were; the rock types, the mixing ratios and the aggregate sizes. Focus was on common rocks available that are crushed for making concrete using different sizes of aggregates and their contribution to strengthening structures. The moderating factors which contribute to strength of concrete are curing time, sand type, cement type, compacting pressure. In this research the moderating factors were kept constant for all the concrete samples. The relationship between independent variables, dependent variable and the moderating variables in the design of this study is diagrammatically shown in Figure 1.1.

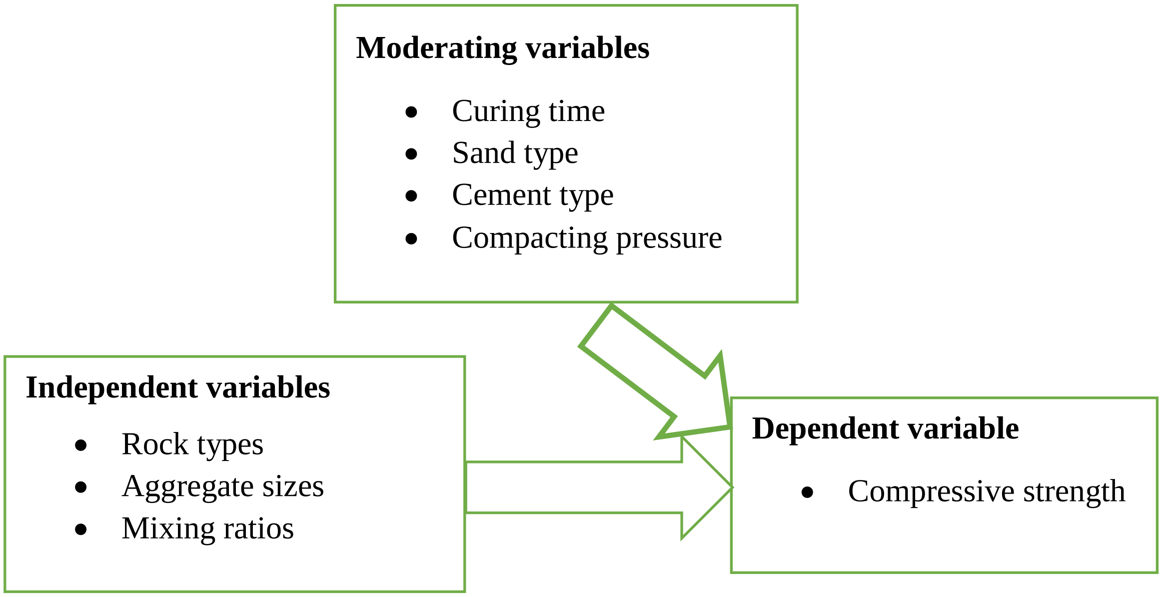

Figure 1. 1: A Block Diagram of the Variables considered in the study

1.5 Objectives of the Study

The specific objectives of the study were;

1. To determine the variation of compressive strength of granite, quartzite and sandstone concretes with mixture ratios.
2. To determine the variation of compressive strength of granite, quartzite and sandstone concretes with aggregate sizes.
3. To compare the variation between the compressive strength of granite, quartzite and sandstone concrete with mixture ratios.
4. To compare the variation between the compressive strength of granite, quartzite and sandstone concrete with aggregate sizes.

1.6 Research Hypothesis

The research objectives one and two were tested by the hypotheses that:

1. There is no variation of compressive strength of granite, quartzite and sandstone concrete with mixture ratios.
2. There is no variation of compressive strength of granite, quartzite and sandstone concrete with aggregate sizes.

1.7 Scope of the Study

The study focused on three rock types namely, granite, sandstone and quartzite. These rocks were chosen because they are among the most common and used rocks in production of aggregates for construction purposes. The study also used three coarse aggregate sizes of 6.3 mm, 10 mm, and 14 mm. These sizes are selected because they are the most produced mechanical sizes at quarry for the concrete works. Three mixture ratios of 1:3:6, 1:2:4, 1:1:2 (cement: sand: coarse aggregate) were used, because most of the daily concrete construction works are either ordinary concrete or standard concrete. Therefore the ratios chosen are the ones used to produce ordinary concrete and standard concrete. The study also used Ordinary Portland cement of grade 32.5, water, constant water cement ratios of 1.00, 0.66, and 0.45 for each mixture ratio and clean river sand.

1.8 Significance of the Study

The results have provided information to the construction industry, concrete practitioners, Uganda National Road Authority (UNRA), researchers and UMEME that rock types: granite, quartzite and sandstone aggregate does not affect the compressive strength of concrete. Mixture ratios and aggregate sizes affect concretes compressive strength. But aggregate sizes affect compressive strengths of concrete with only lower cement to aggregate ratio. Therefore, concrete produced from granite, sandstone and quartzite aggregates qualifies for construction purposes and can be accepted by Uganda National Bureau of Standards (UNBS) when properly made and cured.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

The strength of concrete has been reviewed in this chapter. The review covers the nature of cement, its behavior and their properties that contribute to strength gain. It also covers nature and properties of different types of rocks. The chapter further looked at the prefixed ratios that can be used to get different concrete grades, the types of concrete strength, the factors that affect the concrete strength and also reviewed the results of related researches about compressive strength.

2.2 Nature and Properties of Cement

Building materials like cement come in the form of finely ground powder. Cement is packed in sacks of 50 kg that are often made of paper and they are not water proof. Therefore, cement should be protected from water which can be absorbed slowly from the atmosphere or from the floor by keeping the cement in buildings on wooden stands and covered with a water proof material. The bags of cement should be checked regularly to remove lumps of hardened cement or discard cement if better one is available.

Sand and aggregates are mixed together with cement. This is achieved by mixing water and cement together with sand and aggregates in appropriate ratios. The chemical reaction known as hydration begins to take place which causes the cement particles and water molecules to bind sand and aggregate particles. The mixture becomes stiffer and harder to manipulate as the particles bind together. Eventually the bond becomes so strong that it forms a hard solid mass. At this point, it is said to have set. Cement mixed with water is called cement paste, when sand is added to the cement paste it produces mortar which is used to hold aggregates together since it becomes a hard, stone-like material when it dries (Duncan, 2000). Cement paste and sand act as fillers that occupy the empty spaces within the aggregates. Hydration of cement and water produces heat and in large masses of concrete such as dams the heat generated during hardening can be a problem. The heat generated during hydration is affected by presence of silicates and aluminates like Tricalcium silicate (C_3S) and Tricalcium aluminate (C_3A) respectively in cement. Cement hardens and gains strength faster because of early hydration caused by Tricalcium silicate (C_3S) and low contents of C_2S makes cement gain strength late after sometime like one year. Gypsum helps to minimize the heat generated during the early phases of C_3A hydration, which is where C_3A contributes little to the development of strength but makes cement sulfate resistant.

There exists different types of cement. The original type of cement was pozzolana cement, which was made by finely grinding burnt clay tiles or lime and volcanic ash. The volcanic ash or tiles have active silica and alumina which combines with the lime to produce this type of cement. Later Roman cement and Portland cement were produced (Don, 1978). At the moment it is mostly Portland cement that is being produced. Clay that is both silica and alumina rich is combined with lime and heated to a high temperature of about 1450 ^{0}C to create Portland cement. Lime is also known as calcareous material or calcium oxide which can be obtained from limestone, oyster shells or chalk. Sand, shale or blast furnace slags can be used for the extraction of silicon and alumina. Mechanically crushed clay and lime are subsequently stored in silos. These raw materials are weighed out in the proper ratio before being processed either wetly or dryly in a grinding mill. The slanted kiln receives the ground materials. The raw materials are heated until they melt in the kiln with temperatures between 1400 °C and 1650 °C, turning them into cement clinker. After cooling, the clinker is kept in storage. To control the cement's setting time, modest amounts of gypsum are added when the clinker is crushed in to fine powder. The final product is the cement which is stored in sacks (Mamlouk & Zaniewski, 2011).

Portland cement is made from clay and lime, two basic ingredients that contain iron oxide, silica, and alumina. They mix during heating in the kiln to form four complex chemical compounds. These are: tricalcium silicate ($3CaO \cdot SiO_2$), dicalcium silicate ($2CaO \cdot SiO_2$), tricalcium aluminate ($3CaO \cdot Al_2O_3$), and a tetra-calcium alumino ferrite ($4CaO \cdot Al_2O_3Fe_2O_3$) which are denoted as C_3S, C_2S, C_3A, and C_4AF respectively. Where C stands for calcium oxide (lime), S for silica, A for alumina, and F for iron oxide. Along with various alkalis, uncombined lime and magnesia are also present in minor concentrations. The alkali content in cement is determined by the quantity potassium oxide and sodium oxide. (Neville, 2011). Too much amounts of alkali contained in cement can make regulation of setting time of cement difficult. According to the national standards the requirement for alkali content in cement calculated by $Na_2O + 0.658\ K_2O$ should not be greater than 0.60% (Haimei, 2011). Many different types of Portland cement, such as ordinary Portland cement, Portland pozzolana cement, rapid hardening Portland cement, ultra high early strength Portland cement, low heat Portland cement, sulfate resistant Portland cement, blast furnace Portland cement, white Portland cement, and slag Portland cement, can be produced due to the ability to alter the percentage of compound composition of C_2S, C_3S, C_3A, C_4AF, $CaSO_4$, free CaO, and MgO during cement production. (Neville, 2011). Different types of cement are needed for different concrete applications. Cement with rapid strength growth is needed in several applications to complete construction projects quickly. Cement with low heat of hydration is needed in other applications in order to regulate volume variations brought on by shrinkage and cracking. In some circumstances, sulfate resistant cement is required to prevent concrete from degrading when exposed to sulfates. Fortunately, the ratios of the compounds of cement can be varied to produce cement of different types. Because rapid hardening cement contains a lot of calcium oxide (lime), it can quickly reach high strengths. This type of cement is utilized in concrete when the framework needs to be removed early because lime absorbs atmospheric carbon dioxide (CO_2) to generate calcium carbonate, which then hardens the cement (CaO). When work needs to be completed quickly, such as in static and running waters, ultra-high early strength cement is used. Low heat cement, on the other hand, has reduced amounts of C_3A and is used to create large concrete structures, such as for dams (Mamlouk & Zaniewski, 2011). Type I, Type II, Types III, Type IV, and Type V cement types are categorized by the American Society for Testing and Materials (ASTM) as normal, moderate sulfate resistance, high early strength, low heat of hydration, and high sulfate resistance, respectively, in the United States. When other types of cement don't need particular qualities, Type I is excellent for regular concrete work. It is applied in construction of floors, reinforced concrete structures, pavements etc. A mild sulfate exposure of 0.1% to 0.2% weight water soluble sulfate in soil is protected by Type II for concrete (sea water). Large piers, substantial abutments, and retaining walls can be built using this type, provided that the concrete is put during the warm months. Type III is used in construction when moulds are to be removed immediately or structures are to be used so soon. Type IV is used in construction of massive structure like large dams where heat of hydration is controlled. Type V shields concrete from exposure to soils containing 0.2% to 2.0% weight of water soluble sulfate (Mamlouk & Zaniewski, 2011). Other nations classify cement according to the compressive strength reached after 28 days. Some cement attains compressive strength of 33, 43 and 53 MPa after 28 days of casting. These are referred to as grades of cement. Cement of grade 33 is normally used for general purposes and in areas where low compressive strength of 20 MPa and below is needed. Cement grade of 43 is used to make concrete with compressive strength between 20 and 30 MPa. Cement grade of 53 is used in construction of dams, bridges and highways where higher strength and durability is needed. It's hydration rate is higher compared to other grades and develops strength very fast. (readcivil.com, 2018).

One of the important physical properties that must be carefully controlled is the fineness of cement. It is about the size of cement particles which have to lie betweeen 0.045 mm to 0.09 mm, with an average diameter of 0.01 mm. Smaller cement particles have larger surface area which enables it to hydrate faster and to also develop strength quickly. However, production costs and concrete quality may be detrimental when the fineness of cement is increased beyond the requirements. According to ASTM C 204, the Blaine air permeability apparatus, the surface area of the cement particles is determined in cm^2/g by obtaining a cement sample, measuring its air permeability, and comparing it to the standard air permeability, or using ASTM C 430, the Blaine air permeability apparatus, where the percentage passing on the 0.045 mm sieve or N0. 325 is determined (Mamlouk & Zaniewski, 2011).

The specific gravity is another property of cement needed for proportioning of concrete ingredients. Cement with no voids between particles has specific gravity of about 3.15 and is determined by using ASTM C 188. The bulk density of cement with voids in between the particles varies depending on how it is handled and stored. For example, bulk density of cement is increased by vibration and consolidation during transportation. Therefore, to measure quantities of cement for a given mix weight method is preferred than volume (Mamlouk & Zaniewski, 2011).

Setting of cement refers to cement paste becoming stiff or changing state from plastic to solid. During setting, cement develops some strength. Setting is not the same as hardening. Hardening is when the already set cement paste gains strength. There are two types of cement setting: initial setting and final setting. Concrete can be handled and put during the initial setting period before stiffening. The time for final setting ensures normal hydration of cement. Setting of cement is affected by the amount of gypsum added during manufacture, fineness of cement particles, water-cement ratio, admixtures and humidity during storage. Humidity causes false set to occur by making cement stiffens within few minutes after the mix and release of less heat. False set is eliminated by remixing cement paste vigorously without adding water so that it's plasticity is restored and to let it to set normally without losing strength. A rapid and a flash set are different from a false set since the former has the solution of remixing while the latter does not (Mamlouk & Zaniewski, 2011).

When the volume of cement paste is preserved after setting, the cement is said to be sound. Unsound cement expands after setting and is caused by slowed or delayed hydration. ASTM uses autoclave expansion C151 code to test the soundness of the cement paste. Soundness of cement is measured by subjecting bars of cement paste to heat and high pressure and according to ASTM C150 the autoclave expansion should not exceed 0.8% (Mamlouk & Zaniewski, 2011).

2.3 Rocks and Rock Types

The majority of the earth's crust is made up of rocks, which are defined as solid aggregates containing one or more rock minerals. Some rocks have only one mineral type and other rocks contain two to five major mineral types in addition to several other minor mineral types. The clay minerals, feldspar, quartz, calcite, dolomite, olivine, pyroxene, amphibole, and mica are minerals that make up most of the rocks in the Earth's crust (Thompson, 1997). The aggregate minerals forming the rock are held together by chemical bonds. The shapes of minerals, the sizes of minerals in the rocks and the arrangement of minerals in rocks determine many of the properties of rocks such as texture and rock bonding strength. The texture and types of rocks are primarily determined by the manner in which the rock was formed.

Rocks formed by the solidification and cooling of magma are called igneous rocks while sedimentary rocks are formed by compaction and cementation of sediments like sand, clay and silt in tectonic basins, and topographical sinks and rocks formed by variations in temperature and pressure on the protolith within the earth are called metamorphic rocks. Intrusive and extrusive igneous rocks are distinguished by their textures, colors, and mineral makeup. Intrusive rocks forms when magma crystalizes within the earth's crust. Magma cools slowly resulting into coarse grained and crystalline rocks. Intrusive rocks are grouped into two types namely; hypabyssal rocks which cools near to the earth's surface and have medium or large crystals set in beds of finer crystals like granophyre, porphyrie, dolerite and plutonic rocks which cools slowly at a great depth and have large crystals like granite, gabbro, peridotite and diorote. Granite, however, is the most prevalent intrusive rock found on the earth's surface. When lava rises and rapidly cools and solidifies in the open air after reaching the earth's surface due to changes in temperature and pressure, extrusive rocks, also known as volcanic rocks, are created. These rocks are fine grained and include basalt, rhyolite, obsidian, andesite, trachyte and pumice. Sedimentary rocks are formed by the accumulation and cementation of sediments like sand, clay and silt that are deposited by running water, wind or moving ice. Sedimentary rocks occur in layers and are classified according to their mode of origin as mechanically formed (like sand, silt, clay or gravel), organically formed (coral, limestone and coal) and chemically formed (rock salt). Igneous or sedimentary rocks that go through physical or chemical transformation are known as metamorphic rocks. These changes are caused by heat and pressure or both due to earth’s movement like folding and warping. A rock like granite can undergo physical and chemical change to a rock called gneiss, limestone to marble and sandstone to quartzite (Mibei, 2014).

The creation of concrete with the appropriate attributes, such as strength and durability, depends critically on the use of good rocks for high-quality coarse particles. Ideal construction aggregates should be clean, strong, with a rough texture and free from organic materials, dust and impurities such as salt. The dust prevents the concrete mix from bonding together to make a solid material. If aggregates are found to be dirty they should be cleaned first before being used. The quick method of knowing that aggregates are dirty is by carrying some in the hand, if the aggregates stain the hand, then they will be dirty. Aggregates suitable for making quality concrete are gravels and crushed stones but not friable and chert aggregate. Friable aggregates split easily while chert aggregates have low weathering resistance. Flaky and elongated aggregates are not good for concrete production but rather angular or irregular or cuboidal shaped aggregates. Coarse aggregate size of 20 mm and below are the commonly used sizes in the concrete construction. Coarse aggregates with absorption capacity of more than 10% of their weight after immersion in water for 1 day are porous and therefore unfit for concrete production. (Madeh, 2020). Hot aggregates contribute to the temperature in the concrete mix which reduces on the final strength. Aggregates of different sizes and stock should be piled separately to avoid mixing. Aggregates suitable for concrete production from igneous rocks are; granite, andesite, basalt, diorite, dolerite, gabbro, rhyolite and tuff, sandstone and limestone from sedimentary rocks and quartzite, gneiss, schist and hornfels from metamorphic rocks.

2.4 Concrete and Concrete Strength Determination

Cement, sand, water, and aggregate make up the main components of the composite material called concrete. Sometimes reinforced bars and admixtures are added for specific purposes such as strength enhancement and acceleration or retardation of setting and hardening of concrete respectively (Don, 1978).

According to Kisan et al. (2000) different grades of concrete can be produced by using two mix designs: nominal mix and design mix. Simple and compact structures are built using nominal mixture. The ratios of cement, sand, and aggregates in this sort of mix are predetermined and regulated. The quantities of concrete ingredients: cement, sand and aggregate are batched by volume method. Design mix is used in constructions very strong and storeyed structures. This type of mix design has no prefixed mixture ratios and the ratios are determined by the engineers after analysis of some properties in concrete ingredients like cement fineness modulus and specific gravity are first tested in the laboratory. Concrete ingredients are batched by weight method. Table 2.1 shows the nominal mixture ratios of cement, sand and aggregate used to achieve some grades of concrete, their corresponding compressive strength and the type of concrete.

Table 2. 1: Relationship of Grades of Concrete, Mixture Ratios and Compressive Strength (Kishan, 2018).

S/No	Mixture ratios	Grades of concrete	Compressive strength/MPa	Concrete types
1	1:5:10	M5	5	Lean concrete
2	1:4:8	M7.5	7.5	
3	1:3:6	M10	10	Ordinary concrete
4	1:2:4	M15	15	
5	1:1.5:3	M20	20	
6	1:1:2	M25	25	Standard concrete
7	1:0.75:1.5	M30	30	
8	1:0.5:1	M35	35	
9	1:0.25:0.5	M40	40	
10		M45	45	
11		M50	50	
12		M55	55	
13		M60	60	High strength concrete
14		M65	65	
15		M70	70	
16		M75	75	
17		M80	80	

A notation of M15 is a grade of concrete where M means mix proportion and 15 the compressive strength in MPa for 150 mm cube after 28 days of curing. The British/European Standards designate the various concrete grades as C10, C15, C20, C25, etc. The letters C stand for class of concrete strength, while the numbers (10, 15, 20, and 25) represent the characteristic compressive strength in N/mm^2 after being tested with a 150 mm x 300 mm cylinder mould in a direct compression test machine for 28 days. The grades of concrete can also be denoted as C 15/20, C 20/25, C 25/30 etc. C still means class of concrete strength and the numbers refers to the compressive strength when tested with a cylinder mould of 150 mm x 300 mm or with a cube mould of 150 mm x 150 mm x 150 mm respectively.

Lean concrete, standard concrete, ordinary concrete, and high strength concrete are the four types of concretes. The different concrete grades are used for different purposes. Lean concrete (M5 to M7.5) is used in foundation concrete to provide uniform surface and to prevent the direct contact from the soil. Ordinary concrete (M10 to M20). Plain Cement Concrete (PCC) is what M10 and M15 are used for, and it's great for building leveling courses, concrete roadways, and bedding for footing. M20 is utilized as Reinforced Cement Concrete (RCC) and is used to build slabs, beams, columns, and footings that will only be exposed to mild weather. Standard grade of concrete (M25 to M55), M25 up to M35 are used as RCC and are good for construction of slabs, beams, columns, footings and among others. For runways, concrete roads (PQR), pressurized concrete girders, RCC columns, and pressurized beams, M40 and M50 are also utilized as RCC. Pressurized concrete girders and piers play a vital role in M55 utilized as RCC. Projects requiring higher compressive strength, such as storeyed buildings, long span bridges, and ultra-thin white toppings, high strength concrete utilized as RCC is required.

Concrete strength is a general term that indicates concrete’s ability to resist breaking or bending under stress. Concrete strength types are tensile strength, compressive strength and flexural strength. Compressive strength refers to the ability of the concrete sample to withstand squeezing force. This force tends to shorten the size of the material. Compressive strength is a performance indicator that engineers use when designing structures. It is determined by dividing the breaking force with the cross sectional area usually after twenty eight days of casting. The SI unit of compressive strength is Mega Pascals denoted as MPa. Compressive strength of concrete for residential structures varies from 17 MPa to 28 MPa and higher for commercial structures.

Compressive strength of 70 MPa and above is needed for specified applications. Tests of compressive strength are carried out to determine whether the quoted concrete mixtures meet the specified compressive strength denoted as f'c in the job specification and also for quality control and acceptance of concrete. According to ASTM C 39, it provides Standard Compressive Strength Test Method for Cylindrical Concrete Specimens. Three or more concrete samples can be tested for a certain test age. The test ages used are 3, 7, 14 and 28 days. The specified strength is used by design engineers to design structural elements and is among the information put on the contract documents. The concrete design engineer develops a mixture ratio which produces average compressive strength (f'cr) greater than the specified strength (fc) such that the chances of concrete failing to meet the specified strength are avoided. Higher strength is obtained by applying the following acceptance criteria; the specified strength should be equal or less than the average of three consecutive tests and no single strength test should be less than the specified strength by more than 3.45 MPa or by more than 10 % of specified strength (f'c) when f'c is above 35 MPa. However, when a single strength test falls below the specified strength (f'c), it does not necessarily mean failure to attain the specified strength. However, failure may result from improper cylinder batching, handling, curing, and testing, particularly if these actions are not carried out in line with the prescribed protocols (Spring, 2003).

The other type of concrete strength is the tensile split strength which refers to concrete's ability to withstand forces tending to elongate it. It is measured by obtaining the maximum stretching or pulling stress that concrete can withstand before breaking. Tensile strength is a measurement of the force required to pull concrete to the point where it breaks.

Another type of concrete strength is flexural strength. Flexural strength is the capacity of concrete to resist bending forces when loaded. It's the maximum stress concrete experiences at the time of breakage. Flexural strength is also known as modulus of rapture/ bend strength/ fracture strength or transverse strength. Determining flexural strength is an indirect way of measuring tensile split strength of concrete. It is measured using un-reinforced concrete beams or slabs. The dimensions of concrete beams used are 150 x 150 mm or 100 x 100 mm with a span length of at least three times the width. Flexural strength is also measured in MPa by Standard Test Methods ASTM C 78 (third-point loading) or ASTM C 293 (Centre-point Loading). The flexural strength of center point loading is greater than that of third point loading by about 15 %.

Flexural strength is important in designing of pavements. Pavements can be accepted or controlled in the field by using modulus of rapture. Very few designers use flexural strength for structural concrete but rather use compressive strength which is convenient and reliable in judging the quality of the concrete. The concrete mixtures for pavements are stiff and slump ranges between 25 mm to 75 mm. The design mix can be obtained by carrying out flexural strength tests or by using past experience to select the material content for the needed design. The samples are consolidated by vibrations as per ASTM C 31 and the sides tapped to release entrapped air. Before the sample is tested it is immersed in water for at least 20 hours. Specifications and investigation of apparent low strengths should take into account the higher variable flexural strength results. Standard deviation for concrete with flexural strength of atmost 5.5 MPa should range from 0.3 to 0.6 Mpa. There could be testing problems or moisture differences for concrete with standard deviation of over 0.7 Mpa. Low strength is caused by testing issues or moisture discrepancies in a concrete beam as a result of premature drying. Core strength by ASTM C 42 is utilized for compressive strength to check against the desired value using the ACI 318 criteria of 85 percent of specified strength for the average of three cores. Flexural strength and compressive strength can be correlated in the laboratory. It is not scientific to saw beams in the laboratory to test flexural strength as this practice greatly reduces the beam's flexural strength and it should be avoided. Testing for flexural strength is so sensitive to how the samples were prepared, handled and cured. Handling and transporting of very heavy beams from the jobsite to the testing laboratory damages them easily. Testing beams after drying them lowers their strength. Failure to cure beams in a standard manner also affects the strength. Due to the difficulty of meeting all these standards on a construction site, the flexural strength values are unstable and low. Compressive strength has replaced flexural strength as the preferred method for task control and concrete paving quality assurance by road agencies. Compressive strength is used to order and accept the concrete, whereas flexural strength is used for design purposes. Both compressive and flexural testing should be performed when creating trial batches so that a correlation may be found for field control (NRMCA, 2015).

The water-cement ratio, raw material quality, concrete age, concrete compaction, sand-aggregate ratio, temperature, relative humidity, and concrete curing all affect the strength of concrete. Quality of aggregate refers to its size, shape, texture and strength. Concrete that is well compacted and made from quality aggregates, its strength is governed by the water-cement ratio (Don, 1978). At a given water-cement ratio concrete strength may be different due to differences in aggregate size, grading, surface texture, shape, strength and the curing time of concrete (Kosmatka et al., 2002). Lower water cement ratio leads to higher strength and durability though the mix may be hard to pour and place, hence plasticizers or super-plasticizers may be used. The most commonly water cement ratios used range from 0.45 to 0.6. However, when very low little water is used in a mix, some cement paste remains un-hydrated since less mixing water is available leading to internal tension and development of weak bond in the concrete product. It is also important to know that very high water cement ratio results in segregation of the aggregates from the mortar. Unused water during hydration reaction evaporates from concrete as it hardens resulting into voids (bleeding) and shrinkage. It also causes internal cracks and visible fractures which reduce the final strength. According to Duncan (2000) both internal and external cracks however small it may be causes fracture in both brittle and ductile materials thus preventing it from having maximum strength. Therefore it is important for the mixture to have just enough water in the cement (cement paste) that surrounds and binds each aggregate particle and that the fresh concrete can be poured and placed.

Concrete compaction is a process of removing air entrapped in a flesh concrete. If this air is not expelled, it results into honey comb concrete and reduced strength. Previous studies show that strength of concrete reduces by approximately 6% when it contains 1% air. Compacting of concrete can be done in two ways; hand compaction and mechanical compaction. Compaction of concrete by hand is used in small and simple structures. Hand compaction uses rodding or ramming or tamping. Rodding is done by poking at the sharp corners and edges with a 2 m long and 16 mm diameter rod. Ramming is applied in plain concrete and ground floors but not in reinforced cement concrete (RCC) and upper floors. Tamping is done by hitting the top concrete surface with the wooden beam of cross sectional area 10 cm x 10 cm. This method is used in roofs, slabs and road pavements. Compaction of concrete by machines is a vibration that causes liquefaction so that air bubbles can move from the bottom to the top and then expelled. There are various types of vibration that can occur, including surface vibration, platform vibration, table vibration, and interior vibration. The most popular technique is internal vibration, which is accomplished by fastening eccentric weights to the shaft. When internal vibration cannot be used due to thin layers of concrete or concrete with significant reinforcing, external vibration is used. More power is consumed by external vibration than by interior vibration. When concrete is placed on a table in a lab and then vibrated, table vibration is used. Platform vibration is used extensively and takes the form of table vibration. Screed board is another name for surface vibration. The board is put on the vibrator, which causes vibration on the surface (Designbuildings.co.uk, 2020).

Concrete curing is the process of protecting concrete against water loss needed for hydration by keeping concrete within the recommended temperature ranges. Concrete is cured by keeping it in damp conditions until hydration is finished and strength attained. Concrete curing commences once concrete sets or after removing the frame work and continued as per the specified period of time. The methods used for concrete curing are; water, membrane and steam curing. These methods depend on the site constraints and type of structure. Water curing is carried out by sprinkling or spraying of water or curing agents over concrete surface. Membrane curing is carried out by wrapping concrete in an impermeable membrane compounds like wax, and acrylic. Water based liquids are sprayed over fresh concrete to create an impermeable membrane by plastic sheeting or formwork. Steam curing is done to accelerate the early hardening of concrete and mortar by exposing it to steam. It is commonly used for precast concrete plants where products are mass-produced and time for the formwork is quick (Namita, 2016). The compressive strength gain after different days of curing are indicated in the Table 2.2

Table 2. 2: Compressive Strength of Grades of Concrete after different days of Curing

Concrete grade	Compressive Strength/ MPa			
	3 days	7 days	14 days	28 days
M10	4	6.5	9	10
M15	6	9.75	13.5	15
M20	8	13	18	20
M25	10	16.25	22.5	25
M30	12	19.25	27	30
M35	14	22.75	31.5	35
M40	16	26	36	40
M45	18	29.25	40.5	45
M50	20	32.5	45	50

Proportioning is another factor that affects the strength of concrete. Proportioning is the method of ascertaining the quantity of cement, sand, aggregate and water in concrete mix to obtain the desired strength. Proportioning of ingredients in a concrete mix can be done by weight or volume method. Volume method, involves using either absolute volume method or dry loose bulk density or empirical method. The empirical method is easy to use and determine the amount of concrete ingredients required for the mix, but it is not quite accurate since it does not take into account the variation of density of sand and aggregates from different locations. It assumes density of cement to be 1440 kg/m^3, sand to be 1450 kg/m^3 and aggregates to be 1500 kg/m^3. It is also assumed that cement has negligible air voids, sand has 20% air and aggregate has 34% air hence total volume of air in a mixture is 54%. Therefore, to get 1m^3 of material you require 1.54 m^3 of dry material. The dry volume of concrete mixture is always greater than the wet volume (Sami, n.d.).

2.5 Review of Compressive Strength Values of Concrete

The impact of aggregate sizes on the compressive strength of concrete was examined by Roy et al., (2016). He used 9.5 mm, 13.2 mm, and 19.0 mm aggregate sizes, a continuous 1:2:4 mixing ratio, and a 0.5 water cement ratio. He also tested for slump. The results revealed that slump (workability) increases with aggregate size. After 7 days of curing, the workability of concrete formed with aggregates measuring 9.5 mm, 13.2 mm, and 19.0 mm was 10 mm, 13.5 mm, and 20 mm, respectively. The corresponding compressive strength was 15.34 MPa, 18.61 MPa, and 19.48 MPa. They came to the conclusion that compressive strength increases with aggregate size and workability is directly proportional to aggregate size. For a mixture ratio of 1:1.5:3 and a water cement ratio of 0.5, Sneka et al. (2018) evaluated the size influence of aggregate on the mechanical characteristics of concrete. He also used coarse aggregate sizes of 19 mm, 25 mm and 37.5 mm. Compressive strength of concrete cubes obtained were 20.17 MPa, 22.97 MPa and 23.13 MPa respectively. It was also found out that compressive strength of concrete increases with aggregate size. (Ajamu & Ige, 2018) also studied the effect of aggregate sizes on the compressive strength and flexural strength of concrete beams. They produced concrete cubes and beams in accordance with BS 1881-108 (1983) and ASTM C 293 respectively using different aggregate sizes of 9.0 mm, 13.2 mm, 19.0 mm, 25.0 mm and 37.5 mm. They used water cement ratio of 0.65, mixture ratio of 1:2:4 and a standard cube mould of dimensions 150 mm x 150 mm x 150 mm and a beam mould of dimensions 150 mm x 150 mm x 750 mm. Concrete samples produced were cured in a water tank for 28 days and then tested. Results of compressive strength were 21.26 MPa, 23.41 MPa, 23.66 MPa, and 24.31 MPa for aggregate sizes of 13.2 mm, 19.0 mm, 25.0 mm and 37.5 mm respectively. The results showed that as the aggregate sizes increases compressive strength also increases. Ogundipe et al., (2018) investigated the effect of aggregate sizes on the compressive strength of concrete produced from granite stone using two nominal mixture ratios of 1:2:4 and 1:3:6. He used aggregate sizes of 6, 10, 12.5, 20 and 25 mm and a constant water cement ratio of 0.55. The concrete samples were cured for 7, 21, 28 and 56 days. The results still showed that compressive strength is directly proportional to aggregate size and curing age for the two nominal mixes. He observed that aggregate size of 20 mm produced concrete with the highest compressive strength implying that there is an optimum size which gives the best results (20 mm for his case). Yaqub, M. & Bukhari (2006) studied the effects of coarse aggregate sizes on compressive strength of high strength concrete and found out that compressive strength increased as the aggregate size decreased . Aggregate sizes of 5 mm and 10 mm gave concrete with higher compressive strength than other sizes of 20, 25 and 37.5 mm. Woode (2015) determined the effects of different sizes of machine crushed gneisis in Ghana on the compressive strength of concrete. The coarse aggregate maximum sizes were 10, 14 and 20 mm. The compressive strength results showed that highest compressive strength and lowest slump were produced by the smallest coarse aggregate size.

Abdullahi (2012) focused on the effects of aggregate types on the compressive strength of normal concrete. The aggregate types he used were from granite, quartzite and river gravel. Fine sand was the normal sand obtained from a barrow pit. Nominal mixture ratio of 1:2:4 was used and concrete ingredients were obtained by absolute volume method. Aggregate's sieve analysis, bulky density and specific gravity were all determined. Compressive strength of concrete cubes were tested after 3, 7, 14, 21 and 28 days. Results showed that highest compressive strength of concrete at all ages was obtained from quartzite aggregates followed by river gravel and granite aggregates. Granite had the least compressive strength due to a bigger part of the gradation curve falling below the recommended range (below the lower limit). This implied that granite aggregate had much voids and needed greater paste to occupy all the voids. He concluded by observing that aggregate types have effect on the compressive strength of normal concrete. Wu et al., (2001) also studied the effects of aggregate types; quartzite, granite, limestone, and marble on the mechanical properties of high performance concrete. The study revealed that the strength of concrete at a given water cement ratio depends on the type of aggregate. Özturan & Çeçen, (1997) used basalt, limestone and gravel to produce normal and high performance concrete at 28 days. In high strength concrete, basalt produced the highest strength while gravel gave the lowest compressive strength. In normal strength concrete, basalt and gravel gave similar strength and limestone attained the highest compressive strength. Joseph et al.(2018) studied physio-mechanical properties of quart, sand stone and quartzite on comprehensive strength of the constituent concrete product using concrete mix design of M25 with nominal mix of 1:2:4 by absolute weight method and water cement ratio of 0.4. The strength of concrete was measured at three different intervals on all the three types of aggregates. The first measurement of strength was conducted after seven days; the second one was done after fourteen days and the third one after twenty eight days. At all ages of curing quartz aggregates gave the highest comprehensive strength followed by sandstone and quartzite. This was attributed to quartz stone being very strong, tough and having good irregular surface texture, less porous which enables proper bonding between the aggregate particles and cement paste. Quartzite had low comprehensive strength due to weak properties like high porosity, high moisture content, high permeability and lack of toughness. Therefore, concrete with stronger physio-mechanical properties gives higher comprehensive strength than concrete with lower physio-mechanical properties.

Prajapati & Karanjit (2019) used five different coarse aggregate types obtained from different sources, aggregate type A was extracted from Panauti, B from Melamchi, C from Chaukidada, D from Khopasi and E from Kaaldhunga in Kathmandu valley. Aggregate from Panauti were from limestone and marble rocks, gneiss rock from Melamchi, schist rock from Chaukidada, limestone from Khopasi and schist and quartzite from Kaaldhunga. Most of the aggregates used were angular in shape and graded to nominal maximum size of 40 mm. The mixture ratios used were 1:2:4, 1:2:3 and 1:1.5:3 and by use of weight method. The water cement ratio, the quantity of cement, sand and water were kept constant for each mixture ratio. The cubes of concretes of sizes 150 mm by 150 mm by 150 mm were used and cured for seven and twenty eight days. It was found out that concrete with aggregates from C, D and E had higher comprehensive strength compared to those from A and B. This implies that aggregates from different sources give different concrete strength.

CHAPTER THREE: METHODOLOGY OF THE STUDY

3.1 Introduction

The methodology that was adopted in this research included exploratory design to help in finding out the common types of rocks used in aggregate production, descriptive design to help in answering the research hypothesis and comparative research design to help in comparing the compressive strength of concrete of granite, sandstone and quartzite. Simple random sampling was used during selection of stones. Concrete ingredients were batched using the weight method. Concrete ingredients were mixed mechanically to form fresh concrete. Finally, compression test machine was used in determining the compressive strength of concrete samples and F-test at two levels of significance $\alpha=0.01$ and $\alpha=0.05$ was done to test the two hypothesis.

3.2 Design of the Study

The first part of the research was concerned with carrying out exploratory study to find out the major types of rocks used in producing aggregates for road and building construction. It also involved finding out the most used aggregate sizes, mixture ratios, mixing methods and tests normally done on concrete materials. It was done through extensive reading of the existing literature and consulting of the users of aggregates like the builders and civil engineers. After ascertaining the rocks mostly used, then the rocks were sampled and used to answer research hypothesis. Appropriate statistics and graphs were used to describe how compressive strength of concretes from different types of rocks vary with mixture ratios and aggregate sizes. The statistics that was used depended on the kind of data obtained.

3.3 Sampling and Sample Preparation

The granite, sandstone and quartzite rocks were obtained from the identified existing quarries. Granite was collected from Stirling Quarry in Mbalala, Mukono District, sandstone was also got from Mbalala, Mukono and quartzite from Katonga Quarry in Kiganda cell in Kireka. Granite was brought already crushed mechanically, sandstone and quartzite rocks were crushed manually at the quarry since there were no machines at the quarries that crush sandstone and quartzite mechanically. About three quarter of a sack of each aggregate size for the three rock types were taken to Ministry of Works and Transport, in Kireka. Each aggregate type was further sieved separately to obtain three different aggregate sizes of 6.3 mm, 10.0 mm, and 14.0 mm. Dry loose bulk density of each aggregate type and size was determined. Dry loose bulk densities of aggregates were got, so that their values are used in converting from volume to weight. River sand was collected and dried. Sand was dried so that the effect of bulking is overcome since sand contains some moisture which increases the volume of sand. River sand was obtained from Lwera. The silt content of river sand was determined to ensure that the sand used was clean, free from silt and organic matter. Tororo Ordinary Portland cement was used specifically Pozzolana Cement CEM II (B) 32.5 N. Tap water was used for mixing and curing of concrete.

3.3.1 Calculation of Quantities of Concrete Components

Concrete samples of granite, quartzite and sandstone were made from each uniform aggregate size of 6.3, 10, 14 mm using each of the three cement, sand and aggregate mixture ratio of 1:3:6, 1:2:4 and 1:1:2 respectively.

The quantities of concrete compositions; cement, sand, aggregates and water needed to produce concrete samples for each mixture ratio, aggregate size and rock type were calculated using the following steps.

1. For each concrete composition, the volume of cement, sand and aggregates needed to produce 1 m^3 of concrete was calculated by the equation (1)

$$Volume\ of\ concrete\ material = \frac{material\ part}{total\ material\ parts} \times 1.54 \tag{1}$$

2. Then the weight of each concrete material was calculated from the formular,

$$weight\ of\ concrete\ material = volume \times Dry\ loose\ bulk\ density\ of\ each\ material$$

The dry loose bulk density of each concrete ingredient obtained was recorded in Table 3.1 and quantities of concrete compositions for 1 m^3 of concrete were recorded in Table 3.2.

Table 3. 1: Dry loose bulk densities of cement, sand and aggregates

Bulk densities/ kgm^{-3}										
Cement	**Sand**	**Granite aggregates**			**Sandstone aggregates**			**Quartzite aggregates**		
		6.3 mm	**10 mm**	**14 mm**	**6.3 mm**	**10 mm**	**14 mm**	**6.3 mm**	**10 mm**	**14 mm**
1440	1615	1443	1461	1511	1362	1397	1427	1413	1440	1452

Table 3. 2: Quantities of Components to make 1 m^3 of Concrete.

Mixing ratios (Cement: sand: aggregates)	**Quantities**			
	Mass of cement/kg	**Volume of Sand/m^3**	**Volume of aggregates/m^3**	**volume of Water/litres**
1: 3: 6	221.76	0.46	0.92	17
1: 2: 4	316.80	0.44	0.88	17
1: 1: 2	554.40	0.39	0.77	17

3. The weight of cement, sand and aggregates for each concrete mix composition was then multiplied by 0.003375 m^3 (volume of the mould) and then multiplied by five, so that the fresh concrete is enough to cast four uniform concrete samples. .
4. The weight of cement, sand, aggregates and the volume of water used in each concrete mix composition was recorded in Tables 3.3, 3.4 and 3.5 for granite, sandstone and quartzite respectively.

Table 3. 3: Quantities of components used to make concrete samples from granite aggregates

Mixing ratios	Mass of cement/kg	Mass of Sand/kg	Mass of aggregates/kg			volume of Water/litres
			6.3 mm	10 mm	14 mm	
1 : 3 : 6	3.7	12.6	22.5	22.8	23.6	3.7
1 : 2 : 4	5.3	12.0	21.4	21.7	22.4	3.5
1 : 1 : 2	9.4	10.5	18.7	19.0	19.6	4.2

Table 3. 4: Quantities of components used to make concrete samples from sandstone aggregates

Mixing ratios	Mass of cement/kg	Mass of Sand/kg	Mass of aggregates/kg			volume of Water/litres
			6.3 mm	10 mm	14 mm	
1 : 3 : 6	3.7	12.6	21.3	21.8	22.3	3.7
1 : 2 : 4	5.3	12.0	20.2	20.7	21.2	3.5
1 : 1 : 2	9.4	10.5	17.7	18.2	18.5	4.2

Table 3. 5: Quantities of components used to make concrete samples from quartzite aggregates

Mixing ratios	Mass of cement/kg	Mass of Sand/kg	Mass of aggregates/kg			volume of Water/litres
			6.3 mm	10 mm	14 mm	
1 : 3 : 6	3.7	12.6	22.0	22.5	22.6	3.7
1 : 2 : 4	5.3	12.0	21.0	21.4	21.6	3.5
1 : 1 : 2	9.4	10.5	18.4	18.7	18.9	4.2

3.3.2 Production of Concrete Samples

Using the mass of cement, sand, aggregate and appropriate volume of water according to Tables 3.2, 3.3, and 3.4, four samples for each mixing ratio, aggregate size and rock type were produced in a mould of dimensions 150 mm x 150 mm x 150 mm shown in Figure 3.1 as follows.

Figure 3. 1: A picture of a compression testing Mould

The cement was mixed with river sand mechanically by a mixer until the mixture was thoroughly blended, then three-quarter volume of the tap water was added, mixed to form the cement paste. Coarse aggregate were added to the mixture and mixed properly until it was uniformly distributed throughout the batch and the remaining volume of water was finally added and mixed until the concrete appeared to be homogenous and of the desired consistency.

The moulds were oiled in order to prevent the adhesion of concrete and fresh concrete was then poured into the moulds in three layers and each layer was compacted by tamping 35 times from a height of 10 cm with a tamping rod of about 16 mm diameter and 60 cm long so as to have voids reduced.

Concrete above the rim of the mould was cut off by a straight edge and smoothened by the straight edge.

A piece of paper bearing the rock type, aggregate size, mixture ratio and curing date was attached on fresh concrete sample for easy identification and analysis.

The concrete samples were removed from moulds after one day and placed in water curing container for14 days.

The produced samples were then tested in moist conditions.

For each aggregate size, four samples were produced, resulting in 36 samples from three aggregate sizes and three mixture ratios and a total of 108 samples from the three rock types.

3.4 Measurement of the Sample Parameters

3.4.1 Measurements of Dimensions

Length (l) and width (b) were measured using a steel metre rule on each concrete sample as indicated by the arrows on Figure 3.2 and then the average value of length and width was calculated. Thereafter the average dimension of the samples l and b was used to find the cross sectional area as in equation (2).

$$cross\ sectional\ area = average\ length\ x\ average\ width \quad (2)$$

$$\mathrm{A} = l\ x\ \ b$$

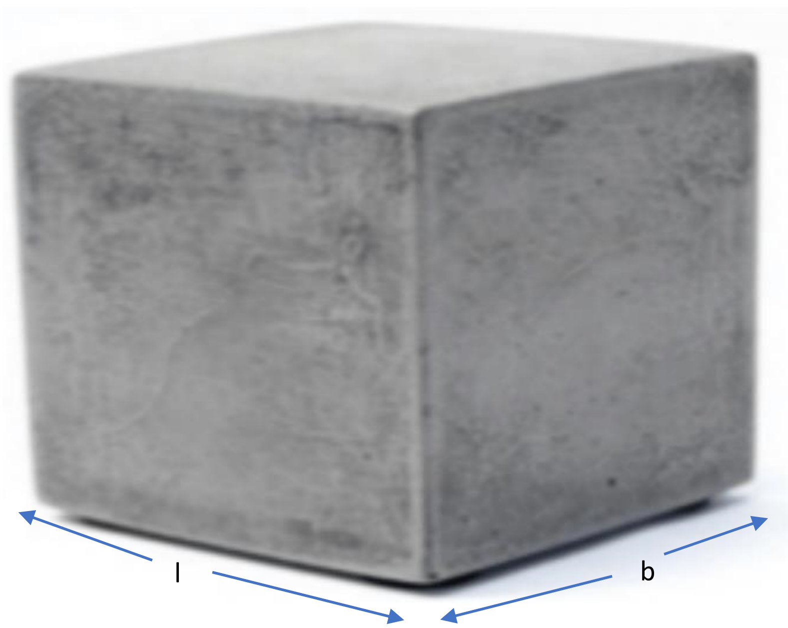

Figure 3. 2: Dimensions l and b of the Sample

3.4.2 Measurement of Compressive Strength of the Samples

The compressive test machine for measuring compressive strength was used on each sample, in accordance with ASTM C 39.

The sample was placed between two hardened blocks that is to say between the lower block and upper block and then a force was applied at constant rate of 0.6 MPa/s until the sample failed. The maximum force was read from the scale shown in Figure 3.3 for each sample and the results were recorded in the tables in the Appendix I, II and III for granite, quartzite and sandstone concrete respectively.

Figure 3. 3: A Picture of Compressive Test Machine and the Compressor

3.4.3 Calculation of Compressive Strength

Compressive strength of concrete of granite, sandstone and quartzite of different aggregate sizes and different mix compositions were computed using equation (3).

$$compressive\ strength = \frac{F}{A} \quad (3)$$

Where

F- is the failure load

A-is load's cross sectional area

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This study was concerned with determining the compressive strength of concrete made using aggregates from granite, quartzite and sandstone which are the rocks commonly found in Uganda. The compressive strength of granite, quartzite and sandstone concrete was determined using three aggregate sizes of 6.3 mm, 10 mm and 14 mm and three cement, sand and aggregate mixture ratios of 1:3:6, 1:2:4 and 1:1:2. The water cement ratios used for mixing the ingredient mixture ratios 1:3:6, 1:2:4 and 1:1:2 are 1.00, 0.66 and 0.45 respectively.

The first objective was to determine the variation of concrete's compressive strength with mixture ratios. The second specific objective was to determine how compressive strength of concrete produced varied with aggregate sizes. The third objective was to compare the compressive strength of granite, quartzite and sandstone concrete with ingredient mixture ratios. The last objective was to compare the compressive strength of granite, quartzite and sandstone concrete with aggregate sizes.

4.2 Variation of Compressive Strength of Concrete with Ingredient Mixture Ratios.

The first set of results was to obtain the compressive strength of granite, quartzite and sandstone concretes with ingredient mixture ratios.

4.2.1 Compressive Strength of Granite Concrete with Ingredient Mixture Ratios.

The compressive strength of granite concrete with ingredient mixture ratios of 1:3:6, 1:2:4 and 1:1:2 was determined for each aggregate size of 6.3 mm, 10 mm and 14 mm.

4.2.1.1 Compressive Strength of Granite Concrete of Aggregate Size 6.3 mm

The compressive strength of granite conrete with the three ingredient mixture ratios of aggregate size 6.3 mm were obtained as shown in Table 4.1. The table also shows the standard deviation and the maximum error of estimate at the two levels of significance $\alpha = 0.01$ and $\alpha = 0.05$.

Table 4. 1: Compressive Strength of Granite Concrete of Aggregate size 6.3 mm for the three Ingredient Mixture Ratios

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/MPa	7.96	17.04	31.29
Standard Deviation	0.28	0.17	0.49
Maximum Error of Estimate $at \propto = 0.01$	0.82	0.50	1.42
Maximum Error of Estimate $at \propto = 0.05$	0.45	0.27	0.77

To show the variation in compressive strength of granite concrete of aggregate size 6.3 mm, with the three ingredient mixture ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.1

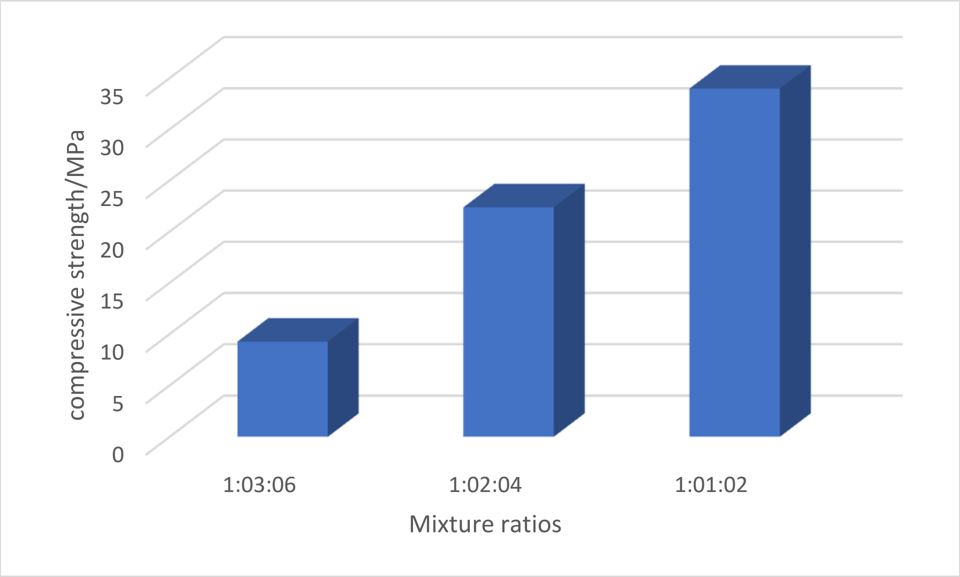

Figure 4. 1: Bar Chart of Compressive Strength of Granite Concrete of aggregate size 6.3 mm against Ingredient Mixture Ratios

To test if the compressive strengths of granite concrete of aggregate size 6.3 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated

F-value and the critical values at levels of significance α= 0.01 and α=0.05 obtained, as shown in Table 4.2.

Table 4. 2: The F-values for Granite Aggregate size of 6.3 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
4818.89	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios of aggregate size 6.3 mm are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of granite concrete of aggregate size 6.3 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 31.29 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 7.96 MPa was obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 29.9- 32.7 MPa and 30.5- 32.1 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 7.1- 8.8 MPa and 7.5- 8.4 MPa at α= 0.05. Mixture ratio of 1:1:2 had higher compressive strength than mixture ratio 1:3:6 after 14 days of curing. This is attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.3. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.1.2 Compressive Strength of Granite Concrete of Aggregate Size 10 mm

The compressive strength of granite concrete with the three ingredient mixture ratios of aggregate size 10 mm were obtained as shown in Table4.3. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 3: Compressive Strength of Granite Concrete of Aggregate Size 10 mm for the Three Ingredient Mixture Ratios

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/MPa	8.46	17.90	32.50
Standard Deviation	0.47	0.30	0.18
Maximum Error of Estimate $at \propto = 0.01$	1.38	0.88	0.52
Maximum Error of Estimate $at \propto = 0.05$	0.75	0.48	0.28

To show the variation in compressive strength of granite concrete of aggregate size 10 mm for the three ingredient mixture ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.2

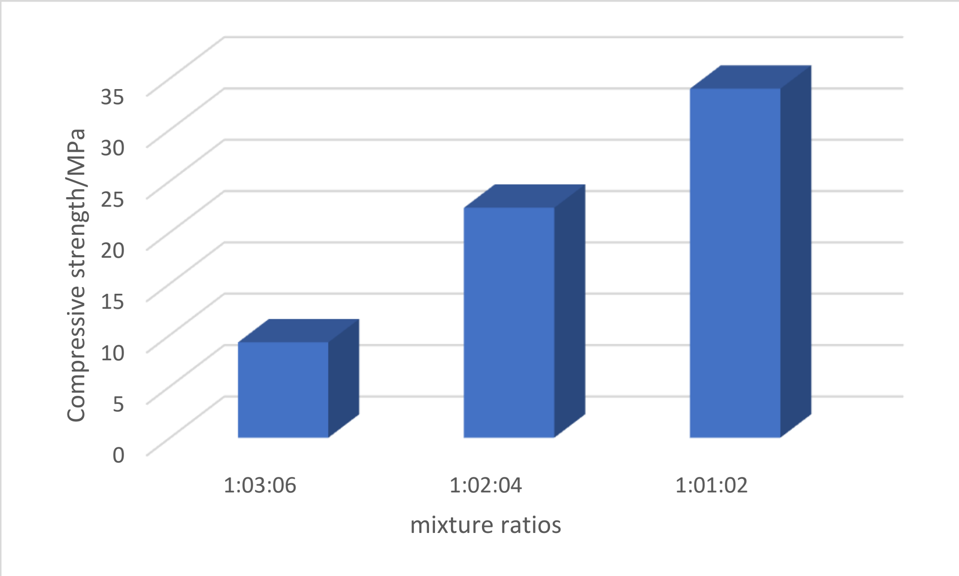

Figure 4. 2: Bar chart of Compressive Strength of Granite Concrete of aggregate size 10 mm against Ingredient Mixture Ratios

To test if the compressive strengths of granite concrete of aggregate size 10 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.4.

Table 4. 4: The F-values for Granite Aggregate size of 10 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
5080.47	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios of aggregate size 10 mm are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of granite concrete of aggregate size 10 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 32.50 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 8.46 MPa was obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 32.0- 33.0 MPa and 32.2- 32.8 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 7.1- 9.8 MPa and 7.7- 9.2 MPa at α= 0.05. Mixture ratio of 1:1:2 had higher compressive strength than mixture ratio 1:3:6 after 14 days of curing. This is still attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.3. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.1.3 Compressive Strength of Granite Concrete of Aggregate Size 14 mm

The compressive strength of granite concrete with the three ingredient mixture ratios of aggregate size 14 mm were obtained as shown in Table 4.5. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 5: Compressive Strength of Granite Concrete of Aggregate Size 14 mm for the Three Ingredient Mixture Ratios

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/MPa	9.26	22.37	33.97
Standard Deviation	0.27	0.41	2.14
Maximum Error of Estimate $at \propto = 0.01$	0.79	1.20	6.25
Standard Error of Estimate $at \propto = 0.05$	0.43	0.66	3.41

To show the variation in compressive strength of granite concrete of aggregate size 14 mm with the three ingredient mixture ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.3

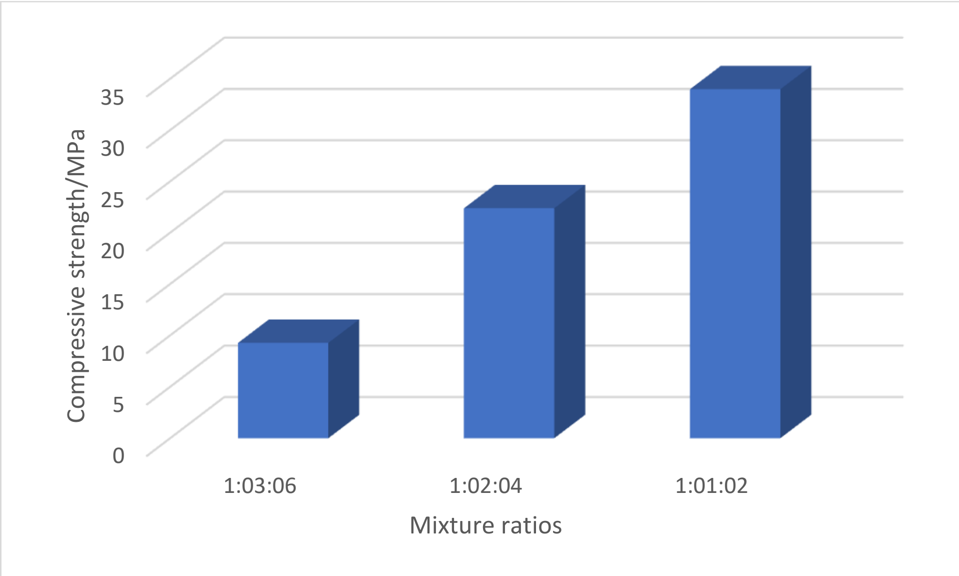

Figure 4. 3: Bar Chart of Compressive Strength of Granite Concrete of Aggregate Size 14 mm against Ingredient Mixture Ratios

To test if the compressive strengths of granite concrete of aggregate size 14 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated F-value and the critical values at two levels of significance $\alpha = 0.01$ and $\alpha=0.05$ obtained are shown in Table 4.6

Table 4. 6: The F-values for Granite Aggregate Size of 14 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
380.00	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios of aggregate size 14 mm are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of granite concrete of aggregate size 14 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 33.97 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 9.26 was obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 27.7- 40.2 MPa and 30.6- 37.4 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 8.5- 10.1 MPa and 8.8- 9.7 MPa at α=0.05. This is still attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.3. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.1.4 Comparison of Compressive Strength of Granite Concrete with Mixture Ratios for the three Aggregate Sizes

The compressive strength of granite concrete with mixture ratios for the different aggregate sizes was found to be different at both levels of significance α= 0.01 and α= 0.05. The highest value was obtained for the mixture ratio 1:1:2 and lowest value was obtained for the mixture ratio 1:3:6 for all cases as shown in the Table 4.7

Table 4. 7: Compressive Strength of Granite Concrete for Different Aggregate Sizes for the three mixture ratios

Aggregate Size/ mm	Compressive Strength/ MPa		
	Mixture Ratios		
	1:3:6	1:2:4	1:1:2
6.3	7.96	17.04	31.29
10	8.46	17.90	32.50
14	9.26	22.37	33.97

The values in the table indicate that compressive strength was increasing with the cement aggregate ratios for each of the three aggregate sizes and increased with aggregate sizes for each of the mixture ratios.

4.2.2 Compressive Strength of Quartzite Concrete with Ingredient Mixture Ratios

The compressive strength of quartzite concrete with ingredient mixture ratios of 1:3:6, 1:2:4 and 1:1:2 was determined for each of the aggregate sizes of 6.3 mm, 10 mm and 14 mm.

4.2.2.1 Compressive Strength of Quartzite Concrete of Aggregate Size 6.3 mm

The compressive strength of quartzite concrete with the three ingredient mixture ratios of quartzite aggregate size 6.3 mm were obtained as shown in Table 4.8. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 8: Compressive Strength of Quartzite Concrete of Aggregate Size 6.3 mm for the three Ingredient Mixture Ratios

Ingredient Mixture ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/ MPa	8.14	14.77	30.87
Standard Deviation	0.24	0.15	1.07
Maximum Error of Estimate $at \propto = 0.01$	0.71	0.45	3.12
Maximum Error of Estimate $at \propto = 0.05$	0.39	0.24	1.70

To show the variation in compressive strength of quartzite concrete of aggregate size 6.3 mm with the three ingredient mixture ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.4

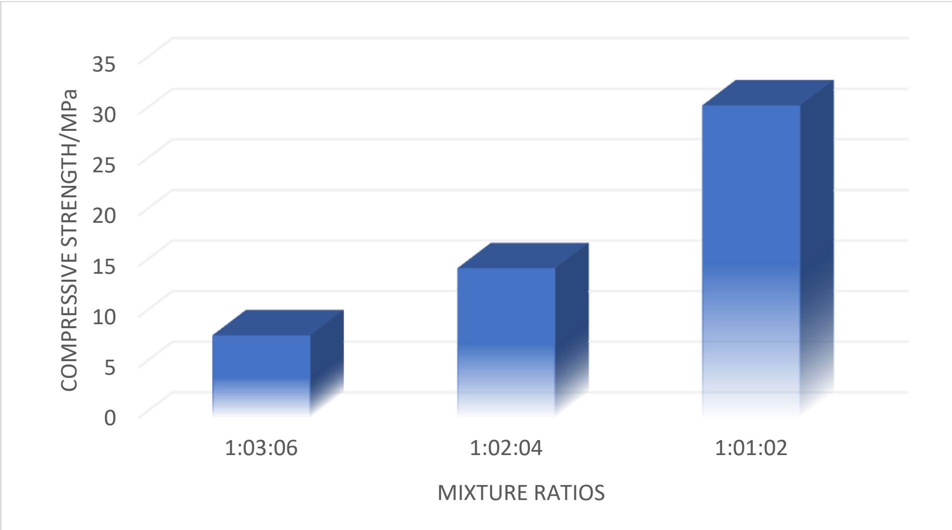

Figure 4. 4: Bar Chart of Compressive Strength of Quartzite concrete of Aggregate Size 6.3 mm against Ingredient Mixture Ratios

To test if the compressive strengths of quartzite concrete of aggregate size 6.3 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.9.

Table 4. 9: The F-values for Quartzite Aggregate Size of 6.3 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
1340.16	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios of aggregate size 6.3 mm are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of quartzite concrete of aggregate size 6.3 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 30.87 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 8.14 MPa obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 27.8- 34.0 MPa and 29.1- 32.6 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 7.4- 8.9 MPa and 7.8- 8.5 MPa at α= 0.05. This is attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.4. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.2.2 Compressive Strength of Quartzite Concrete of Aggregate Size 10 mm

The compressive strength of quartzite concrete with the three ingredient mixture ratios of aggregate size 10 mm were obtained as shown in Table 4.10. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 10: Compressive strength of Quartzite Concrete of Aggregate Size 10 mm for the Three Ingredient Mixture Ratios

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/MPa	8.58	16.98	31.28
Standard Deviation	0.30	0.75	0.47
Maximum Error of Estimate $at \propto = 0.01$	0.89	2.18	1.36
Maximum Error of Estimate $at \propto = 0.05$	0.48	1.19	0.74

To show the variation in compressive strength of quartzite concrete of aggregate size of 10 mm with the three ingredient ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.5

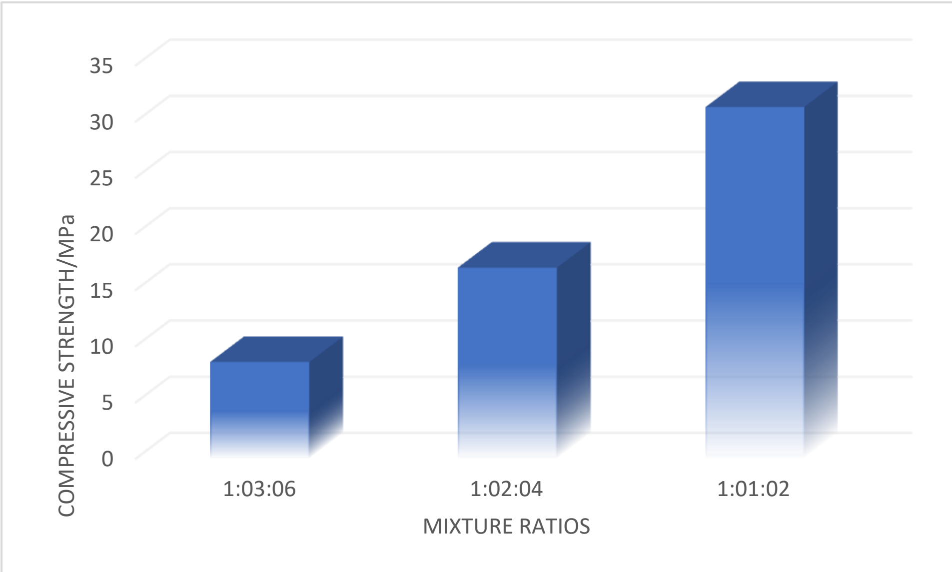

Figure 4. 5: Bar Chart of Compressive Strength of Quartzite Concrete of Aggregate Size 10 mm against Ingredient Mixture Ratios

To test if the compressive strengths of quartzite concrete of aggregate size 10 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.11.

Table 4. 11: The F-values for Quartzite Aggregate Size of 10 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
1822.44	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios were statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of quartzite concrete of aggregate size 10 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 31.28 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 8.58 MPa was obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 29.9- 32.6 MPa and 30.5- 32.6 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 7.7- 9.5 MPa and 8.1- 9.1 MPa at α= 0.05. This is still attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.4. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.2.3 Compressive Strength of Quartzite Concrete of Aggregate Size 14 mm

The compressive strength of quartzite concrete with the three ingredient mixture ratios of aggregate size 14 mm were obtained as shown in Table 4.12. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 001 and α= 0.05.

Table 4. 12: Compressive Strength of Quartzite Concrete of Aggregate Size 14 mm for the Three Ingredient Mixture Ratios

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/MPa	9.66	20.96	31.52
Standard Deviation	0.26	0.60	0.76
Maximum Error of Estimate $at \propto = 0.01$	0.75	1.75	2.21
Maximum Error of Estimate $at \propto = 0.05$	0.41	0.95	1.21

To show the variation in compressive strength of quartzite concrete of aggregate size 14 mm with the three ingredient ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.6

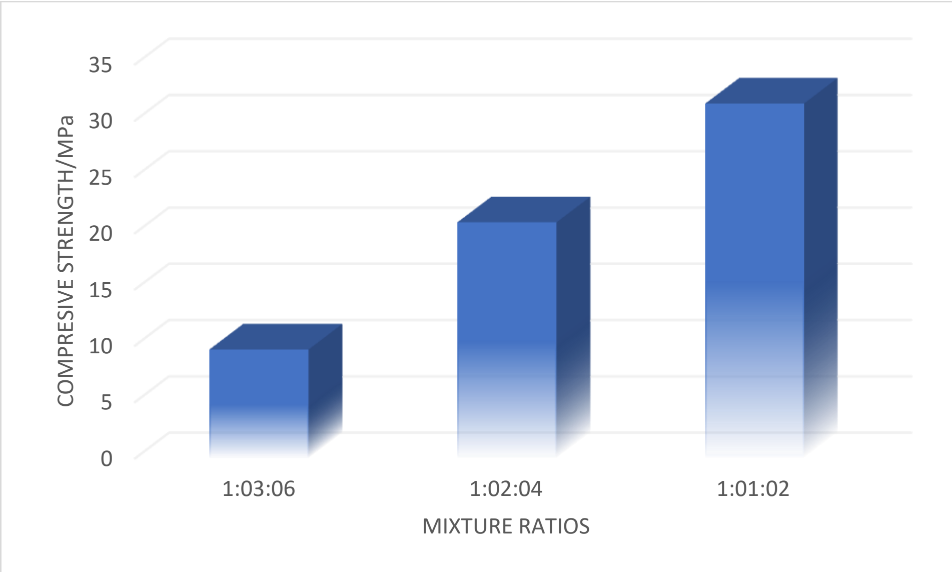

Figure 4. 6: Bar Chart of Compressive Strength of Quartzite Concrete of Aggregate Size 14 mm against Ingredient Mixture Ratios

To test if the compressive strengths of quartzite concrete of aggregate size 14 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.13.

Table 4. 13: The F-values for Quartzite Aggregate size of 14 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
1437.04	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios of aggregate size 14 mm are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of quartzite concrete of aggregate size 14 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 31.52 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 9.66 MPa was obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 29.3- 33.7 MPa and 30.3- 32.7 MPa at α= 0.05.

The lowest compressive strength at α= 0.01 is in the range of 8.9- 10.4 MPa and 9.3- 10.1 MPa at α=0.05. This is still attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.4. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.2.4 Comparison of Compressive Strength of Quartzite Concrete with Mixture Ratios

The compressive strength of quartzite concrete with mixture ratios for the different aggregate sizes was found to be different at both levels of significance α= 0.01 and α= 0.05. The highest value of compressive strength was obtained for the mixture ratio 1:1:2 and lowest value was obtained for ratio of 1:3:6 as shown in the Table 4.14

Table 4. 14: Compressive Strength of Quartzite Concrete of Different Aggregate Sizes for the three Mixture Ratios

Aggregate Size/ mm	**Compressive Strength/ MPa**		
	Mixture Ratios		
	1:3:6	1:2:4	1:1:2
6.3	8.14	14.77	30.87
10	8.54	16.98	31.28
14	9.66	20.96	31.52

The values in the table indicate that the compressive strength increased with cement aggregate ratios for the three aggregate sizes and increased with aggregate sizes for each mixture ratio.

4.2.3 Compressive Strength of Sandstone Concrete with Ingredient Mixture Ratios

The compressive strength of sandstone concrete with the three ingredient mixture ratios of 1:3:6, 1:2:4 and 1:1:2 was determined for each of the aggregate sizes of 6.3 mm, 10 mm and 14 mm.

4.2.3.1 Compressive Strength of Sandstone Concrete of Aggregate Size 6.3 mm

The compressive strength of sandstone concrete with the three ingredient mixture ratios of aggregate size 6.3 mm were obtained as shown in Table 4.15. The table also shows the standard deviation and the maximum error of estimate at the two levels of significance $\alpha = 0.01$ and $\alpha = 0.05$.

Table 4. 15: Compressive Strength of Sandstone concrete of Aggregate Size 6.3 mm for Three Ingredient Mixture Ratios

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/MPa	8.66	18.32	31.49
Standard Deviation	0.25	0.81	3.12
Maximum Error of Estimate $at \propto = 0.01$	0.73	2.35	9.11
Maximum Error of Estimate $at \propto = 0.05$	0.40	1.28	4.96

To show the variation in compressive strength of sandstone concrete of aggregate size 6.3 mm with the three ingredient ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.7

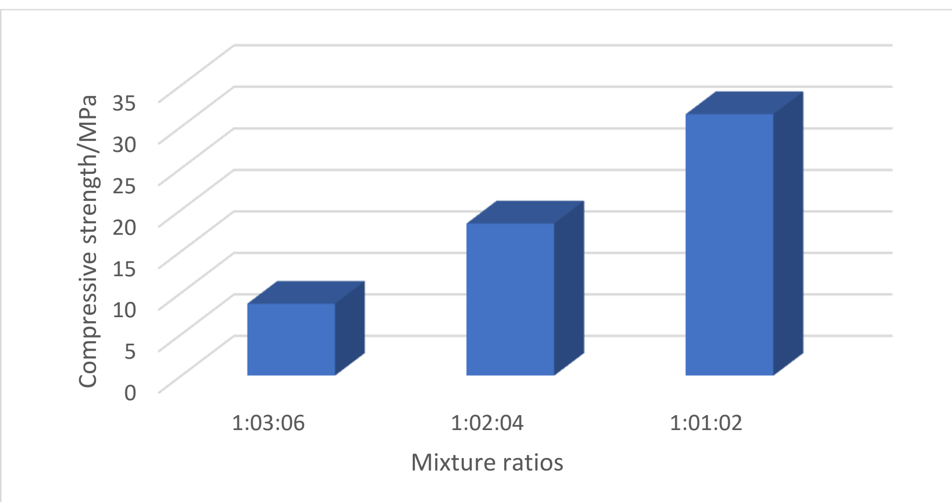

Figure 4. 7: Bar Chart of Compressive Strength of Sandstone Concrete of Aggregate Size 6.3 mm against Ingredient Mixture Ratios

To test if the compressive strengths of sandstone concrete of aggregate size 6.3 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.16.

Table 4. 16: The F-values for Sandstone Aggregate Size of 6.3 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
150.98	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios of aggregate size 6.3 mm are found to be statistically different. Therefore, the hypothesis that there is no variation of compressive strength of sands concrete of aggregate size 6.3 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 31.49 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 8.66 MPa was obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 22.4- 40.6 MPa and 26.5- 36.5 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 7.9- 9.4 MPa and 8.3- 9.1 MPa at α= 0.05. This is attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.5. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.3.2 Compressive Strength of Sandstone Concrete of Aggregate Size 10 mm

The compressive strength of sandstone concrete with the three ingredient mixture ratios of aggregate size 10 mm were obtained as shown in Table 4.17. The table also shows the standard deviation and the maximum error of estimate at the two levels of significance α= 0.01 and α= 0.05.

Table 4. 17: Compressive Strength of Sandstone Concrete of Aggregate Size 10 mm for Three Ingredient Mixture Ratios

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/MPa	9.76	20.39	32.88
Standard Deviation	0.15	0.16	1.93
Maximum Error of Estimate $at \propto = 0.01$	0.44	0.46	5.64
Maximum Error of Estimate $at \propto = 0.05$	0.24	0.25	3.07

To show the variation in compressive strength of sandstone concrete of aggregate size 10 mm with the three ingredient mixture ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.8

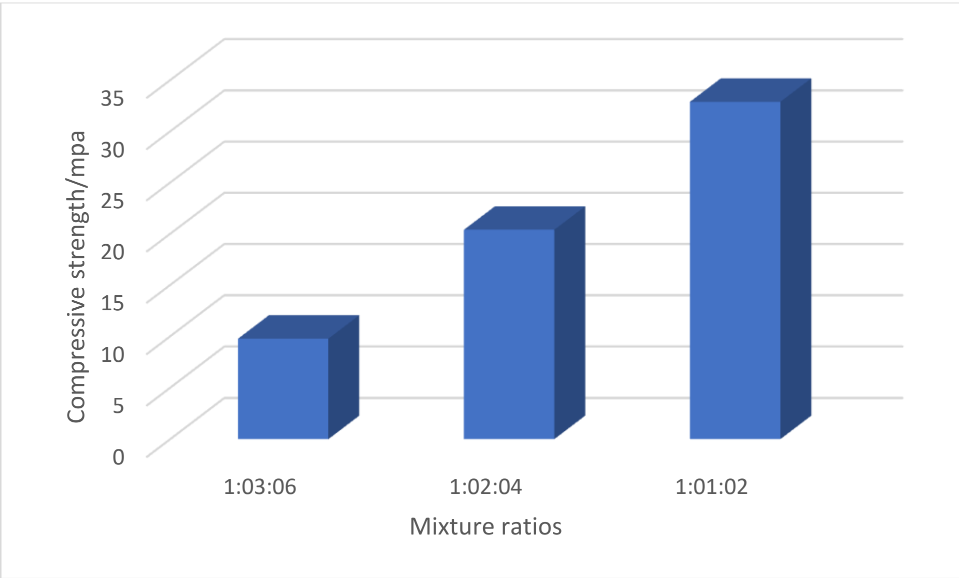

Figure 4. 8: Bar Chart of Compressive Strength of Sandstone Concrete of Aggregate Size 10 mm against Ingredient Mixture Ratios

To test if the compressive strengths of sandstone concrete of aggregate size 10 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated

F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.18.

Table 4. 18: The F-values for Sandstone Aggregate Size of 10 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
425.88	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios of aggregate size 10 mm are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of sandstone concrete of aggregate size 10 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 32.88 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 9.76 MPa was obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 27.2- 38.5 MPa and 29.8- 36.0 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 9.3- 10.2 MPa and 9.5- 10.0 MPa at α=0.05. This is still attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.5. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.3.3 Compressive Strength of Sandstone Concrete of Aggregate Size 14 mm

The compressive strength of sandstone concrete with the three ingredient mixture ratios aggregate size 14 mm were obtained as shown in Table 4.19. The table also shows the standard deviation and the maximum error of estimate at the two levels of significance α= 0.01 and α= 0.05.

Table 4. 19: Compressive Strength of Sandstone Concrete of Aggregate Size 14 mm for Three Ingredient Mixture Ratios

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Mean Compressive Strength/MPa	10.70	23.55	35.37
Standard Deviation	0.57	0.24	1.07
Maximum Error of Estimate $at \propto = 0.01$	1.68	0.69	3.13
Maximum Error of Estimate $at \propto = 0.05$	0.91	0.38	1.71

To show the variation in compressive strength of sandstone concrete of aggregate size 14 mm with the three ingredient ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.9

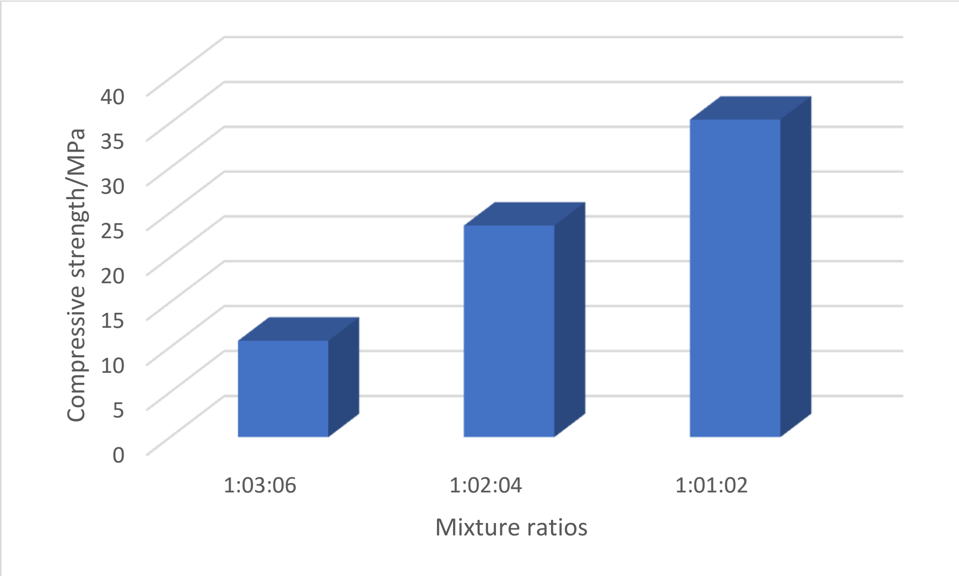

Figure 4. 9: Bar Chart of Compressive Strength of Sandstone Concrete of Aggregate Size 14 mm against Ingredient Mixture Ratios

To test if the compressive strengths of sandstone concrete of aggregate size 14 mm were statistically different or affected by the mixture ratios the F-test was performed. The calculated

F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.20.

Table 4. 20: The F-values for Sandstone Aggregate Size of 14 mm

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
1188.01	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three mixture ratios of aggregate size 14 mm are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of concrete of aggregate size 14 mm with mixture ratios is rejected. Different mixture ratios produce concrete with different compressive strengths. The highest compressive strength of 35.37 MPa was obtained for the mixture ratio of 1:1:2 and lowest compressive strength of 10.70 MPa was obtained for mixture ratio of 1:3:6. The highest compressive strength at α= 0.01 is in the range of 32.2- 38.5 MPa and 33.7- 37.1 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 9.0- 12.4 MPa and 9.8- 11.6 MPa at α= 0.05. This is still attributed to higher quantity of cement in the sand and aggregate mixture than that in the mixture of 1:3:6 as indicated in Table 3.5. Also ratio 1:1:2 had low water cement ratio that made concrete mixture workable than ratio 1:3:6 which had high water cement ratio and yet according to Abram's law, the lower the water cement ratio the higher the compressive strength and the vice versa.

4.2.3.4 Comparison of Compressive Strength of Sandstone Concrete with Mixture Ratios

The compressive strength of sandstone concrete with mixture ratios for the three aggregate sizes was found to be different at both levels of significance α= 0.01 and α= 0.05. The highest value of compressive strength was obtained for the mixture ratio of 1:1:2 and lowest value was obtained for ratio of 1:3:6 for all aggregate sizes as shown in the Table 4.21

Table 4. 21: Compressive Strength of Sandstone Concrete of Different Aggregate Sizes for the three Mixture Ratios

Aggregate Sizes/ mm	**Compressive Strength/ MPa**		
	Mixture Ratios		
	1:3:6	1:2:4	1:1:2
6.3	8.66	18.32	32.49
10	9.76	20.39	32.88
14	10.70	23.55	35.37

The values in the table clearly indicate that that compressive strength of sandstone concrete was increasing with the cement aggregate ratio just like granite and quartzite concretes for the three aggregate sizes and it was increasing with aggregate size.

4.3 Variation of Compressive Strength of Concrete with Aggregate Sizes.

The second set of results was to obtain the compressive strength of granite, quartzite and sandstone concretes with aggregate sizes.

4.3.1 Compressive Strength of Granite Concrete with Aggregate Sizes

The compressive strength of granite concrete with the aggregate sizes of 6.3 mm, 10 mm and 14 mm was determined for each ratio of 1:3:6, 1:2:4 and 1:1:2.

4.3.1.1 Compressive Strength of Granite Concrete with Ingredient Mixture Ratio 1:3:6

The compressive strength of granite concrete with the three aggregate sizes of mixture ratio 1:3:6 were obtained as shown in Table 4.22. The table also shows the standard deviation and the maximum error of estimate at two levels of significance $\alpha = 0.01$ and $\alpha = 0.05$.

Table 4. 22: Compressive Strength of Granite Concrete of Ingredient Mixture Ratio 1:3:6 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	7.96	8.46	9.26
Standard Deviation	0.28	0.47	0.27
Maximum Error of Estimate $at \propto = 0.01$	0.82	1.38	0.79
Maximum Error of Estimate $at \propto = 0.05$	0.45	0.75	0.43

To show the variation in compressive strength of granite concrete of ingredient mixture ratio 1:3:6 with the aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.10

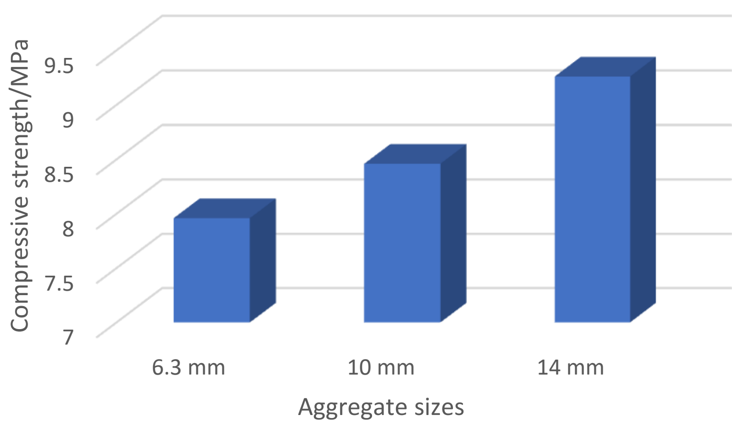

Figure 4. 10: Bar Chart of Compressive Strength of Granite Concrete of Ingredient Mixture Ratio 1:3:6 against Aggregate Sizes

To test if the compressive strengths of granite concrete of mixture ratio 1:3:6 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.23.

Table 4. 23: The F-values for Granite Mixture ratio of 1:3:6

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
13.63	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three aggregate sizes of mixture ratio 1:3:6 are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of granite concrete of mixture ratio 1:3:6 with aggregate sizes is rejected. Different aggregate sizes produce concrete with different compressive strengths. The highest compressive strength of 9.26 MPa was obtained for the aggregate size of 14 mm and lowest compressive strength of 7.96 MPa was obtained for the aggregate size of 6.3 mm. The highest compressive strength at α= 0.01 is in the range of 8.5- 10.1 MPa and 8.8- 9.7 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 7.1- 8.8 MPa and 7.5- 8.4 MPa at α= 0.05. The results reveal that big aggregates have higher compressive strength than small aggregates because they have higher surface area which enables better interlocking within the mixture and development of a strong bond. Also big aggregates may be well graded than small aggregates since big aggregates may contains some small aggregates in between them and this reduces on the voids hence increasing on the strength of concrete. These results are in agreement with findings of Roy et al. (2016), Sneka et al. (2018), Ajamu & Ige (2018), and Ogundipe et al. (2018), but contradicting with the findings of Yaqub and Bakhari (2006) and Woode (2015).

4.3.1.2 Compressive Strength of Granite Concrete of Ingredient Mixture Ratio 1:2:4

Compressive strength of granite concrete for the three aggregate sizes of ingredient mixture ratio 1:2:4 were obtained as shown in Table 4.24. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 24: Compressive Strength of Granite Concrete of Ingredients Mixture Ratio 1:2:4 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	17.04	17.90	22.37
Standard Deviation	0.17	0.30	0.41
Maximum Error of Estimate $at \propto = 0.01$	0.50	0.88	1.20
Maximum Error of Estimate $at \propto = 0.05$	0.27	0.48	0.66

To show the variation in compressive strength of granite concrete of mixture ratio 1:2:4 for the three aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.11

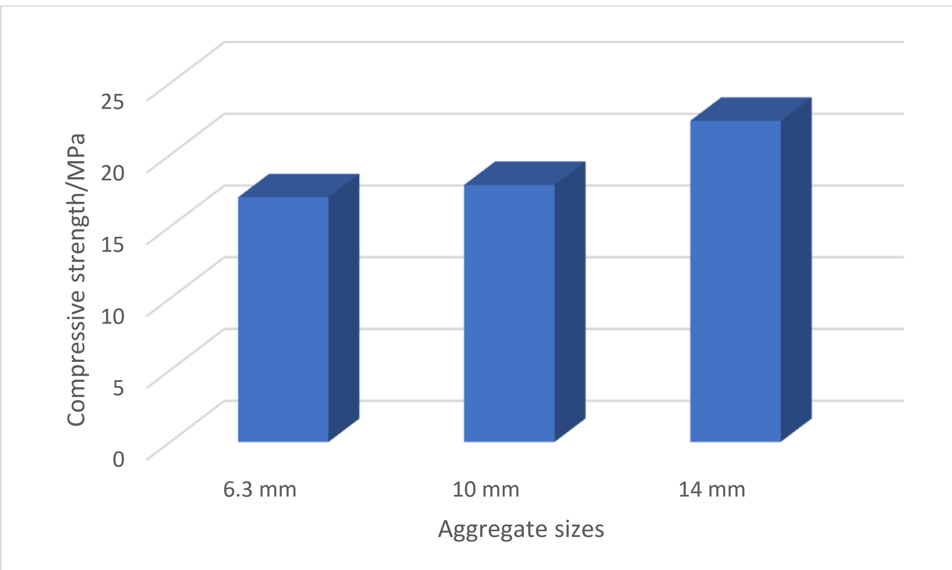

Figure 4. 11: Bar Chart of Compressive Strength of Granite Concrete of Ingredient Mixture Ratio 1:2:4 against Aggregate Sizes

To test if the compressive strengths of ingredient mixture ratio 1:2:4 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.25.

Table 4. 25: The F-values for Granite Mixture Ratio of 1:2:4

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
338.37	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three aggregate sizes of mixture ratio 1:2:4 are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of granite concrete of mixture ratio 1:2:4 with aggregate sizes is rejected. Different aggregate sizes produce concrete with different compressive strengths. The highest compressive strength of 22.37 MPa was obtained for the aggregate size of 14 mm and lowest compressive strength of 17.04 MPa was obtained for the aggregate size of 6.3 mm. The highest compressive strength at α= 0.01 is in the range of 21.2- 23.6 MPa and 21.7- 23.0 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 16.5- 17.5 MPa and 16.8- 17.3 MPa at α= 0.05. The results continue to reveal that big aggregates have higher compressive strength than small aggregates because they have higher surface area which enables better interlocking within the mixture and development of a strong bond. Also big aggregates may be well graded than small aggregates since big aggregates may contains some small aggregates in between them and this reduces on the voids hence increasing on the strength of concrete. These results are in agreement with findings of Roy et al. (2016), Sneka et al. (2018), Ajamu & Ige (2018), and Ogundipe et al. (2018), but contradicting with the findings of Yaqub and Bakhari (2006) and Woode (2015).

4.3.1.3 Compressive Strength of Granite Concrete of Ingredient Mixture Ratio 1:1:2

Compressive strength of granite concrete with the three aggregate sizes of ingredient mixture ratio 1:1:2 were obtained as shown in Table 4.26. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 26: Compressive Strength of Granite Concrete of Ingredient Mixture Ratio 1:1:2 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	31.29	32.50	33.97
Standard Deviation	0.49	0.18	2.14
Maximum Error of Estimate $at \propto = 0.01$	1.42	0.52	6.25
Maximum Error of Estimate $at \propto = 0.05$	0.77	0.28	3.41

To show the variation in compressive strength of granite concrete of mixture ratio 1:1:2 with the three aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.12

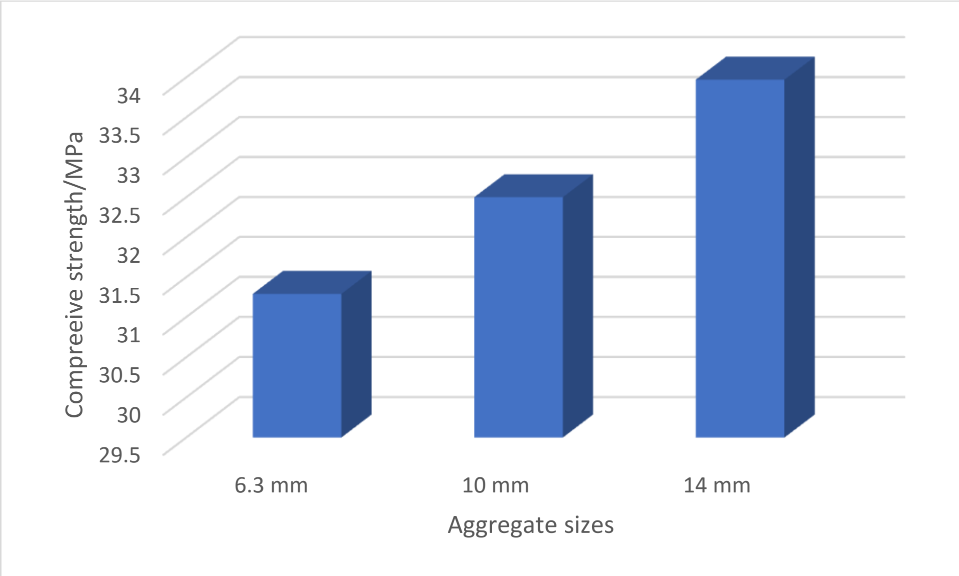

Figure 4. 12: Bar Chart of Compressive Strength of Granite Concrete of Ingredient Mixture Ratio 1:1:2 against Aggregate Sizes

To test if the compressive strengths of granite concrete of mixture ratio 1:1:2 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained are shown in Table 4.27.

Table 4. 27: The F-values for Granite Mixture Ratio of 1:1:2

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
4.44	8.02	4.26

Since the calculated F-value is less than the critical value at level of significance α= 0.01, the compressive strength for the three aggregate sizes of mixture ratio 1:1:2 are statistically the same at α= 0.01. Therefore, the hypothesis that there is no variation of compressive strength of granite concrete of mixture ratio 1:1:2 with aggregate sizes is accepted. Different aggregate sizes produce concrete with same compressive strengths of mixture ratio 1:1:2. The average compressive strength of 32.58 MPa was obtained for the three aggregate sizes. The average compressive strength for the ratio 1:1:2 at α= 0.01 for the three aggregate sizes was between 29.9-35.5 MPa. Mixture ratio 1:1:2, compressive strength was found not vary with the aggregate sizes. It may be due to the quantity of cement being too much in the sand and aggregate mixture. Therefore, it is possible that most of the strength is contributed by cement in the mixture.

At level of significance α= 0.05 the calculated F-value is almost the same as the critical value, the compressive strength for the three aggregate sizes are statistically the same at α= 0.05. The average compressive strength of 32.59 MPa was obtained for the three aggregate sizes. The average compressive strength at α= 0.05 was in the range of 34.1- 31.1 MPa. Mixture ratio 1:1:2, compressive strength was found not vary with the aggregate sizes. It may be due to the quantity of cement being too much in the sand and aggregate mixture. Therefore, it is possible that most of the strength is contributed by cement in the mixture.

4.3.1.4 Comparison of Compressive Strength of Granite Concrete with aggregate sizes with three Ingredient Mixture Ratio 1:1:2

The compressive strength of granite concrete with aggregate sizes was found to be different for only two mixture ratios of 1:3:6 and 1:2:4 at both levels of significance but same strength for mixture ratio of 1:1:2 at both levels of significance α=0.01 and α =0.05 as shown in Table 4.28.

Table 4. 28: Compressive Strength of Granite of different Ingredient Mixture Ratio for the three Aggregate Sizes

Mixture Ratios	**Compressive strength/ MPa**		
	Aggregate sizes/ mm		
	6.3	10	14
1:3:6	7.96	8.46	9.26
1:2:4	17.04	17.90	22.37
1:1:2	31.29	32.50	33.97

The values in the table indicate that compressive strength was increasing with aggregate sizes for the three ingredient ratios and with the cement aggregate ratio.

4.3.2 Compressive Strength of Quartzite Concrete with Aggregate Sizes

Compressive strength of quartzite concrete with the aggregate sizes of 6.3 mm, 10 mm and 14 mm was determined for each ingredient mixture ratio of 1:3:6, 1:2:4 and 1:1:2.

4.3.2.1 Compressive Strength of Quartzite Concrete of Mixture Ratio 1:3:6

The compressive strength of quartzite concrete with the three aggregate sizes of mixture ratio 1:3:6 were obtained as shown in Table 4.29. The table also shows the standard deviation and the maximum error of estimate at two levels of significance $\alpha = 0.01$ and $\alpha=0.05$.

Table 4. 29: Compressive Strength of Quartzite Concrete of Ingredient Mixture Ratio 1:3:6 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	8.14	8.58	9.66
Standard Deviation	0.24	0.30	0.26
Maximum Error of Estimate $at \propto = 0.01$	0.71	0.89	0.75
Maximum Error of Estimate $at \propto = 0.05$	0.39	0.48	0.41

To show the variation in compressive strength of quartzite concrete of mixture ratio 1:3:6 with the three aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.13

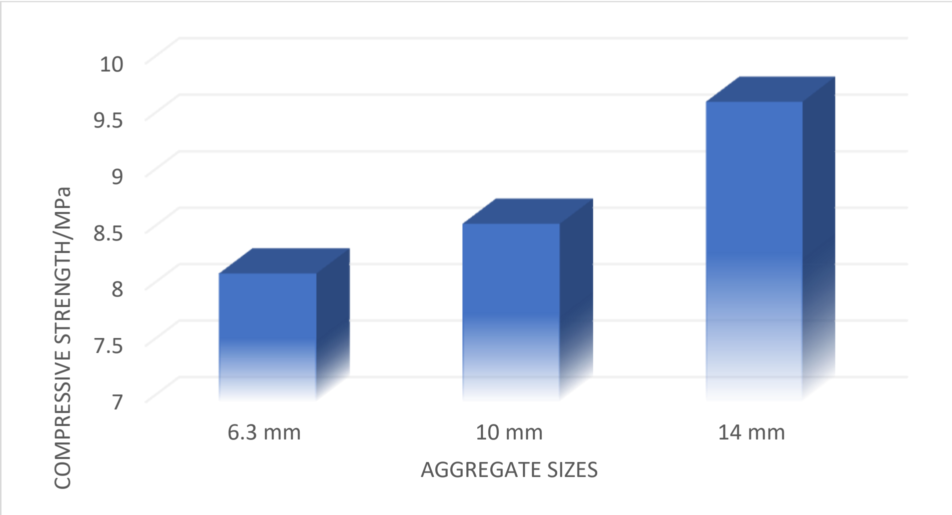

Figure 4. 13: Bar Chart of Compressive Strength of Quartzite Concrete of Ingredient Mixture Ratio 1:3:6 against Aggregate Sizes

To test if the compressive strengths of Quartzite concrete of mixture ratio 1:3:6 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.30.

Table 4. 30: The F-values for Quartzite Mixture Ratio of 1:3:6

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
33.83	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three aggregate sizes of mixture ratio 1:3:6 are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of quartzite concrete of mixture ratio 1:3:6 with aggregate sizes is rejected. Different aggregate sizes produce concrete with different compressive strengths. The highest compressive strength of 9.66 MPa was obtained for the aggregate size of 14 mm and lowest compressive strength of 8.14 MPa was obtained for the aggregate size of 6.3 mm. The highest compressive strength at α= 0.01 is in the range of 8.9- 10.4 MPa and 9.3- 10.1 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 7.4- 8.9 MPa and 7.8- 8.5 MPa at α= 0.05. When quartzite aggregates were used, the results continue to reveal that big aggregates have higher compressive strength than small aggregates because they have higher surface area which enables better interlocking within the mixture and development of a strong bond. Also big aggregates may be well graded than small aggregates since big aggregates may contains some small aggregates in between them and this reduces on the voids hence increasing on the strength of concrete. These results are in agreement with findings of Roy et al. (2016), Sneka et al. (2018), Ajamu & Ige (2018), and Ogundipe et al. (2018), but contradicting with the findings of Yaqub and Bakhari (2006) and Woode (2015).

4.3.2.2 Compressive Strength of Quartzite Concrete of Mixture Ratio 1:2:4

The compressive strength of quartzite concrete with the three aggregate sizes of mixture ratio 1:2:4 were obtained as shown in Table 4.31. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 31: Compressive Strength of Quartzite Concrete of Ingredient Mixture Ratio 1:2:4 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	14.77	16.98	20.96
Standard Deviation	0.15	0.75	0.60
Maximum Error of Estimate $at \propto = 0.01$	0.45	2.18	1.75
Maximum Error of Estimate $at \propto = 0.05$	0.24	1.19	0.95

To show the variation in compressive strength of quartzite concrete of mixture ratio 1:2:4 with the three aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.14

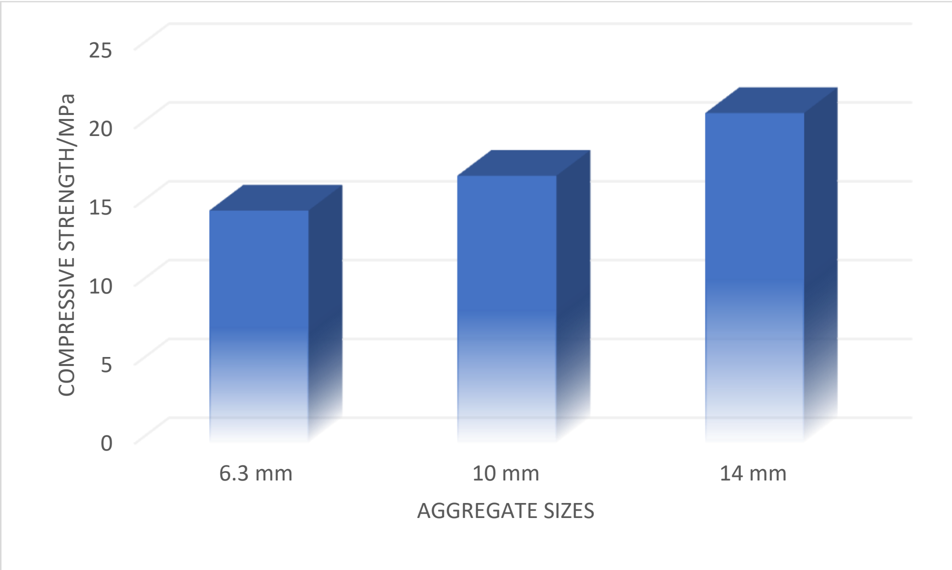

Figure 4. 14: Bar Chart of Compressive Strength of Quartzite Concrete of Ingredient Mixture Ratio 1:2:4 against Aggregate Sizes

To test if the compressive strengths of Quartzite concrete of mixture ratio 1:2:4 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.32.

Table 4. 32: The F-values for Quartzite Mixture Ratio of 1:2:4

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
125.62	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three aggregate sizes of mixture ratio 1:2:4 are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of quartzite concrete of mixture ratio 1:2:4 with aggregate sizes is rejected. Different aggregate sizes produce concrete with different compressive strengths. The highest compressive strength of 20.96 MPa was obtained for the aggregate size of 14 mm and lowest compressive strength of 14.77 MPa was obtained for the aggregate size of 6.3 mm. The highest compressive strength at α= 0.01 is in the range of 19.2- 22.7 MPa and 20.0- 21.9 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 14.3- 15.2 MPa and 14.5- 15.0 MPa at α= 0.05. The results continue to reveal that big aggregates have higher compressive strength than small aggregates because they have higher surface area which enables better interlocking within the mixture and development of a strong bond. Also big aggregates may be well graded than small aggregates since big aggregates may contains some small aggregates in between them and this reduces on the voids hence increasing on the strength of concrete. These results are in agreement with findings of Roy et al. (2016), Sneka et al. (2018), Ajamu & Ige (2018), and Ogundipe et al. (2018), but contradicting with the findings of Yaqub and Bakhari (2006) and Woode (2015).

4.3.2.3 Compressive Strength of Quartzite Concrete of Mixture Ratio 1:1:2

The compressive strength of quartzite concrete with the three aggregate sizes of mixture ratio 1:1:2 were obtained as shown in Table 4.33. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 33: Compressive Strength of Quartzite Concrete of Ingredient Mixture Ratio 1:1:2 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	30.87	31.28	31.52
Standard Deviation	1.07	0.47	0.76
Maximum Error of Estimate $at \propto = 0.01$	3.12	1.36	2.21
Maximum Error of Estimate $at \propto = 0.05$	1.70	0.74	1.21

To show the variation in compressive strength of quartzite concrete of mixture ratio 1:1:2 with the three aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.15

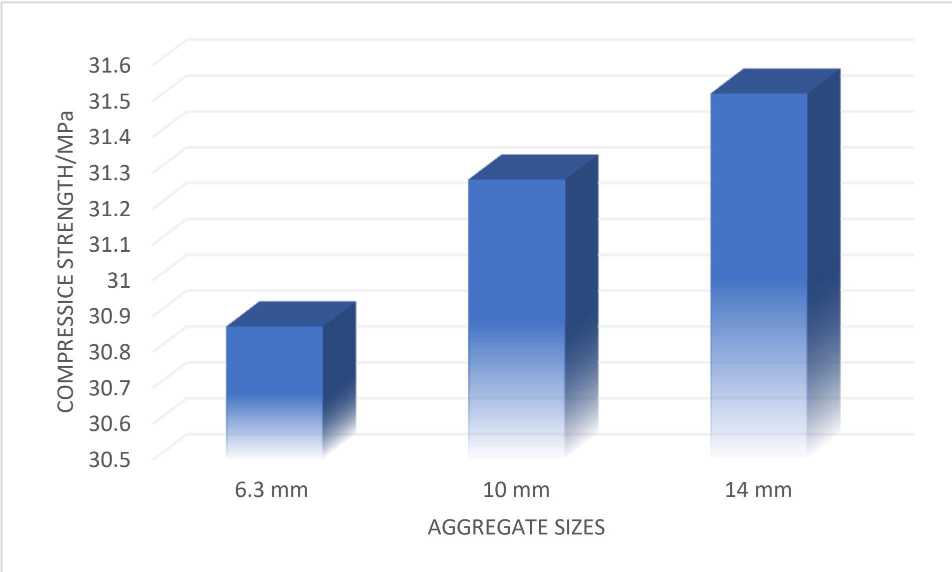

Figure 4. 15: Bar Chart of Compressive Strength of Quartzite Concrete of Ingredient Mixture Ratio 1:1:2 against Aggregate Sizes

To test if the compressive strengths of quartzite concrete of mixture ratio 1:1:2 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.34.

Table 4. 34: The F-values for Quartzite Mixture Ratio of 1:1:2

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
0.68	8.02	4.26

Since the calculated F-value is less than the critical values at both levels of significance, the compressive strength for the three aggregate sizes of mixture ratio 1:1:2 are statistically the same with the average compressive strength of 31.22 MPa. Therefore, the hypothesis that there is no variation of compressive strength of quartzite concrete of mixture ratio 1:1:2 with aggregate sizes is accepted. Different aggregate sizes of mixture ratio 1:1:2 produce concrete with same compressive strengths. The average compressive strength obtained for the ratio 1:1:2 at the level of significance α= 0.01 for the three aggregate sizes was between 28.9-33.5 MPa. The average compressive strength obtained for the ratio 1:1:2 at the level of significance α= 0.05 for the three aggregate sizes was between 30.0-32.4 MPa. The compressive strength of quartzite concrete for aggregate sizes of mixture ratio 1:1:2 did not vary. It may be due to the quantity of cement being too much in the sand and aggregate mixture. Therefore, it is possible that most of the strength is contributed by cement in the mixture.

4.3.2.4 Comparison of Compressive Strength of Quartzite Concrete with aggregate sizes for three Mixture Ratios

The compressive strength of quartzite concrete with aggregate sizes was found to be different at both levels of significance for only two mixture ratios of 1:3:6 and 1:2:4 and same strength for mixture 1:1:2 as shown in Table 4.35.

Table 4. 35: The Comparison of compressive Strength of Quartzite Concrete Obtained for each Ingredient Mixture Ratio

Mixture Ratios	Compressive Strength/MPa		
	Aggregate sizes/ mm		
	6.3	10	14
1:3:6	8.14	8.58	9.66
1:2:4	14.77	16.98	20.96
1:1:2	31.52	31.28	30.87

The values in the table indicate that compressive strength was increasing with aggregate sizes for the three mix proportions and with the cement aggregate ratio.

4.3.3 Compressive Strength of Sandstone Concrete with Aggregate Sizes

The compressive strength of sandstone concrete with the aggregate sizes of 6.3 mm, 10 mm and 14 mm was determined for each mixture ratio of 1:3:6, 1:2:4 and 1:1:2.

4.3.3.1 Compressive Strength of Sandstone Concrete of Mixture Ratio 1:3:6

The compressive strength of sandstone concrete with the three aggregate sizes of mixture ratio 1:3:6 were obtained as shown in Table 4.36. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 36: Compressive Strength of Sandstone Concrete of Ingredient Mixture Ratio 1:3:6 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	8.66	9.76	10.70
Standard Deviation	0.25	0.15	0.57
Maximum Error of Estimate $at \propto = 0.01$	0.73	0.44	1.68
Maximum Error of Estimate $at \propto = 0.05$	0.40	0.24	0.91

To show the variation in compressive strength of sandstone concrete of mixture ratio 1:3:6 with the three aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.16

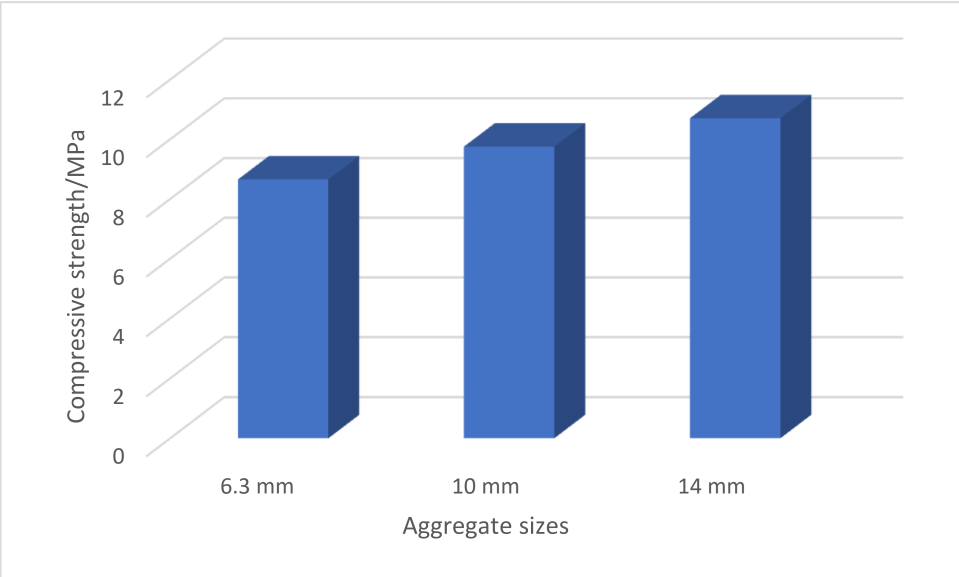

Figure 4. 16: Bar Chart of Compressive Strength of Sandstone Concrete of Ingredient Mixture Ratio 1:3:6 against Aggregate Sizes

To test if the compressive strengths of sandstone concrete of mixture ratio 1:3:6 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α=0.05 obtained as shown in Table 4.37.

Table 4. 37: The F-values for Sandstone Mixture Ratio of 1:3:6

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
30.37	8.02	4.26

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three aggregate sizes of mixture ratio 1:3:6 are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of sandstone concrete of mixture ratio 1:3:6 with aggregate sizes is rejected. Different aggregate sizes produce concrete with different compressive strengths. The highest compressive strength of 10.70 MPa was obtained for the aggregate size of 14 mm and lowest compressive strength of 8.66 MPa was obtained for the aggregate size of 6.3 mm. The highest compressive strength at α= 0.01 is in the range of 9.0- 12.4 MPa and 9.8- 11.6 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 7.9- 9.4 MPa and 8.3- 9.1 MPa at α= 0.05. When sandstone aggregates were used, the results revealed that big aggregates have higher compressive strength than small aggregates because they have higher surface area which enables better interlocking within the mixture and development of a strong bond. Also big aggregates may be well graded than small aggregates since big aggregates may contains some small aggregates in between them and this reduces on the voids hence increasing on the strength of concrete. These results are in agreement with findings of Roy et al. (2016), Sneka et al. (2018), Ajamu & Ige (2018), and Ogundipe et al. (2018), but contradicting with the findings of Yaqub and Bakhari (2006) and Woode (2015).

Compressive Strength of Sandstone Concrete of Mixture Ratio 1:2:4

The compressive strength of sandstone concrete with the three aggregate sizes of mixture ratio 1:2:4 were obtained as shown in Table 4.38. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 38: Compressive Strength of Sandstone Concrete of Ingredient Mixture Ratio 1:2:4 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	18.32	20.39	23.55
Standard Deviation	0.81	0.16	0.24
Maximum Error of Estimate $at \propto= 0.01$	2.35	0.46	0.69
Maximum Error of Estimate $at \propto= 0.05$	1.28	0.25	0.38

To show the variation in compressive strength of sandstone concrete of mixture ratio 1:2:4 with the three aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.17

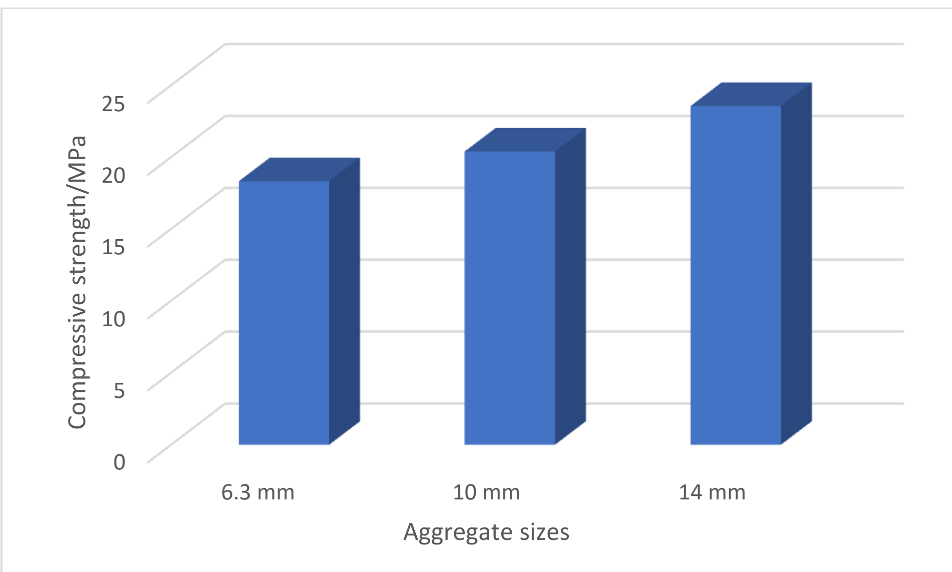

Figure 4. 17: Bar Chart of Compressive Strength of Sandstone Concrete of Ingredient Mixture Ratio 1:2:4 against Aggregate Sizes

To test if the compressive strengths of sandstone concrete of mixture ratio 1:2:4 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α= 0.05 obtained as shown in Table 4.39.

Table 4. 39: The F-values for Sand stone Mixture Ratio of 1:2:4

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
113.74	8.65	4.46

Since the calculated F-value is greater than the critical values at both levels of significance, the compressive strength for the three aggregate sizes of mixture ratio 1:2:4 are statistically different at both levels of significance. Therefore, the hypothesis that there is no variation of compressive strength of sandstone concrete of mixture ratio 1:2:4 with aggregate sizes is rejected. Different aggregate sizes produce concrete with different compressive strengths. The highest compressive strength of 23.55 MPa was obtained for the aggregate size of 14 mm and lowest compressive strength of 18.32 MPa was obtained for the aggregate size of 6.3 mm. The highest compressive strength at α= 0.01 is in the range of 22.9- 24.2 MPa and 23.2- 23.9 MPa at α= 0.05. The lowest compressive strength at α= 0.01 is in the range of 16.0- 20.7 MPa and 17.0- 19.6 MPa at α= 0.05. The results continue to reveal that big aggregates have higher compressive strength than small aggregates because they have higher surface area which enables better interlocking within the mixture and development of a strong bond. Also big aggregates may be well graded than small aggregates since big aggregates may contains some small aggregates in between them and this reduces on the voids hence increasing on the strength of concrete. These results are in agreement with findings of Roy et al. (2016), Sneka et al. (2018), Ajamu & Ige (2018), and Ogundipe et al. (2018), but contradicting with the findings of Yaqub and Bakhari (2006) and Woode (2015).

Compressive Strength of Sandstone Concrete of Mixture Ratio 1:1:2

The compressive strength of sandstone concrete with the three aggregate sizes of mixture ratio 1:1:2 were obtained as shown in Table 4.40. The table also shows the standard deviation and the maximum error of estimate at two levels of significance α= 0.01 and α=0.05.

Table 4. 40: Compressive Strength of Sandstone Concrete of Ingredient Mixture Ratio 1:1:2 for the Three Aggregate Sizes

Aggregate Sizes	**6.3 mm**	**10 mm**	**14 mm**
Mean Compressive Strength/MPa	31.49	32.88	35.37
Standard Deviation	3.12	1.93	1.08
Maximum Error of Estimate $at \propto = 0.01$	9.11	5.64	3.14
Maximum Error of Estimate $at \propto = 0.05$	4.96	3.07	1.71

To show the variation in compressive strength of sandstone concrete of mixture ratio 1:1:2 with the three aggregate sizes, a bar graph of compressive strength against aggregate sizes was plotted as shown in Figure 4.18

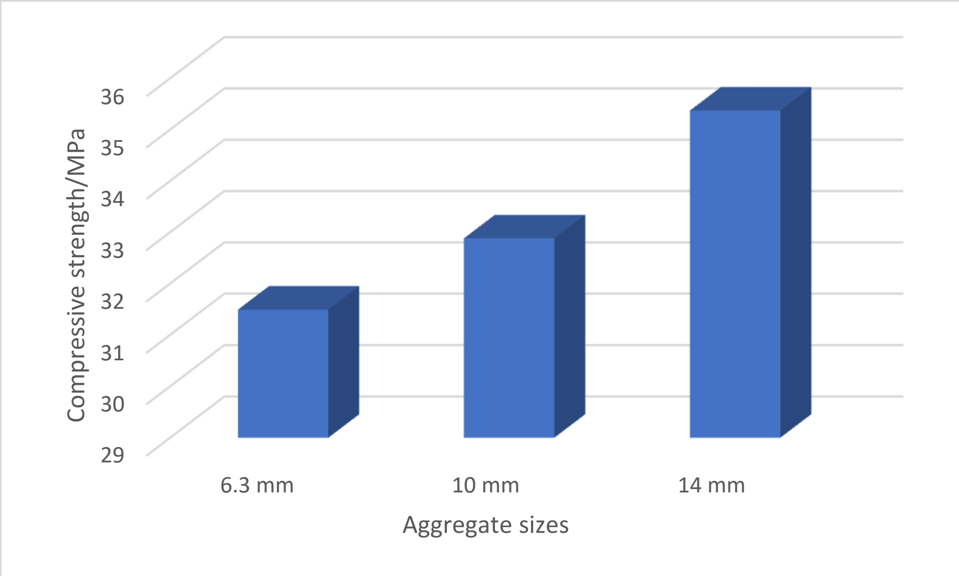

Figure 4. 18: Bar Chart of Compressive Strength of Sandstone Concrete of Ingredient Mixture Ratio 1:1:2 against Aggregate Sizes

To test if the compressive strengths of sandstone concrete of mixture ratio 1:1:2 were statistically different or affected by the aggregate sizes the F-test was performed. The calculated F-value and the critical values at two levels of significance α= 0.01 and α= 0.05 obtained as shown in Table 4.41.

Table 4. 41: The F-values for Sandstone Mixture Ratio of 1:1:2

Calculated F-value	Critical value at α= 0.01	Critical value at α= 0.05
3.18	8.65	4.46

Since the calculated F-value is less than the critical values at both levels of significance, the compressive strength for the three aggregate sizes of mixture ratio 1:1:2 are statistically the same with the average compressive strength of 32.25 MPa. Therefore, the hypothesis that there is no variation of compressive strength of sandstone concrete of mixture ratio 1:1:2 with aggregate sizes is accepted. Different aggregate sizes of mixture ratio 1:1:2 produce concrete with same compressive strengths. At level of significance α= 0.01 average compressive strength obtained for the three aggregate sizes for the ratio 1:1:2 is between 27.3- 39.2 MPa. At α= 0.05 the average compressive strength obtained for the three aggregate sizes for the ratio 1:1:2 is between 30.0-36.5 MPa. Mixture ratio 1:1:2, compressive strength was found not vary with the aggregate sizes. It is also attributed to the quantity of cement being too much in the sand and aggregate mixture. Therefore, it is possible that most of the strength is contributed by cement in the mixture.

4.3.3.2 Comparison of Compressive Strength of Sandstone Concrete with Aggregate Sizes for three Mixture Ratios

The compressive strength of sand stone concrete with aggregate sizes was found to be different for two mixture ratios of 1:3:6 and 1:2:4 at both levels of significance but same strength for mixture ratio 1:1:2 at both levels of significance as shown in the Table 4.42.

Table 4. 42: Compressive Strength of Sandstone Concrete of Different Mixture Ratios for three Aggregate Sizes

Mixture Ratios	**Compressive Strength/ MPa**		
	Aggregate sizes/ mm		
	6.3	10	14
1:3:6	8.66	9.76	10.70
1:2:4	18.32	20.39	23.55
1:1:2	31.49	32.88	35.37

The values in the table indicate that compressive strength of sand stone concrete was also increasing with aggregate sizes for the three mix proportions and with the cement aggregate ratio.

4.4 Comparison of Compressive Strength of Granite, Quartzite and Sandstone Concretes with Ingredient Mixture Ratio

The third set of results was to compare compressive strength of granite, quartzite and sandstone concretes with ingredient ratios for the three aggregate sizes.

4.4.1 Compressive Strength of Granite, Quartzite and Sandstone Concrete of Aggregate Size 6.3 mm

Compressive strength of granite, quartzite and sandstone concretes for the three ingredient mixture ratios of aggregate size 6.3 mm were obtained as shown in the Table 4.43.

Table 4. 43: Compressive Strength of Granite, Quartzite and Sandstone Concrete of Aggregate Size 6.3 mm for the three Ingredient Mixture Ratios.

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Compressive Strength of Granite /MPa	7.96	17.04	31.29
Compressive Strength of Quartzite /MPa	8.14	14.77	30.87
Compressive Strength of Sandstone /MPa	8.66	18.32	31.49

To show the variation in compressive strength of granite, quartzite and sandstone concrete of aggregate size 6.3 mm for the three mixture ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.19

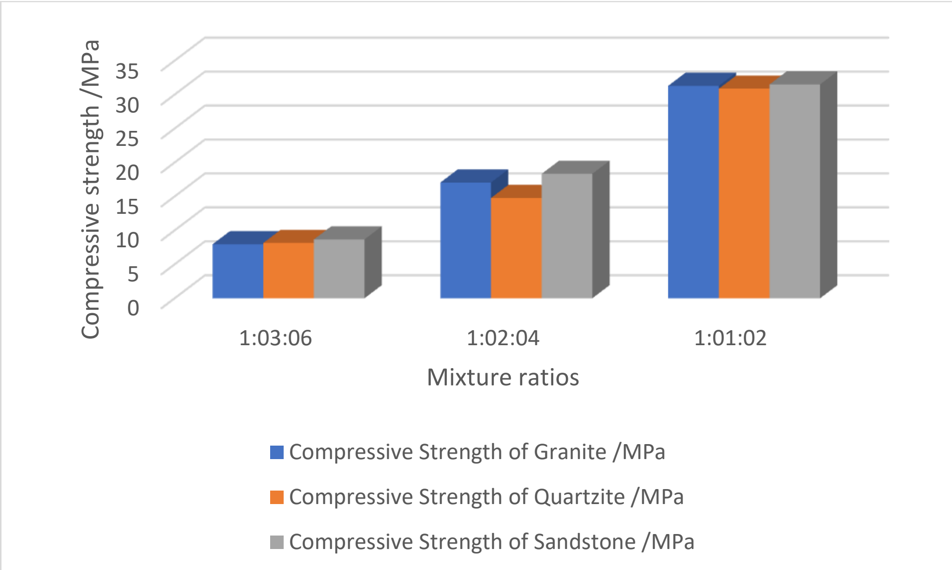

Figure 4. 19: Bar Chart of Compressive Strength of Granite, Quartzite and Sandstone Concrete of Aggregate Size 6.3 mm against Ingredient Mixture Ratios.

For the three mixture ratios of 1:3:6, 1:2:4 and 1:1:2, sandstone concrete gave the highest compressive strength. The difference in strength of concrete is attributed to different physio-mechanical properties possessed by the different aggregate types. The results continue to reveal that compressive strength of granite, quartzite and sandstone concretes of the same mixture produce concrete of the same class.

4.4.2 Compressive Strength of Granite, Quartzite and Sandstone Concrete of Aggregate Size 10 mm

Compressive strength of granite, quartzite and sandstone concretes for the three ingredient mixture ratios of aggregate size 10 mm were obtained as shown in the Table 4.44.

Table 4. 44: Compressive Strength of Granite, Quartzite and Sandstone Concretes of Aggregate Size 10 mm for the three Ingredient Mixture Ratios.

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Compressive Strength of Granite /MPa	8.46	17.90	32.50
Compressive Strength of Quartzite /MPa	8.58	16.98	31.28
Compressive Strength of Sandstone /MPa	9.76	20.39	32.88

To show the variation in compressive strength of granite, quartzite and sandstone concrete of aggregate size 10 mm for the three mixture ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.20

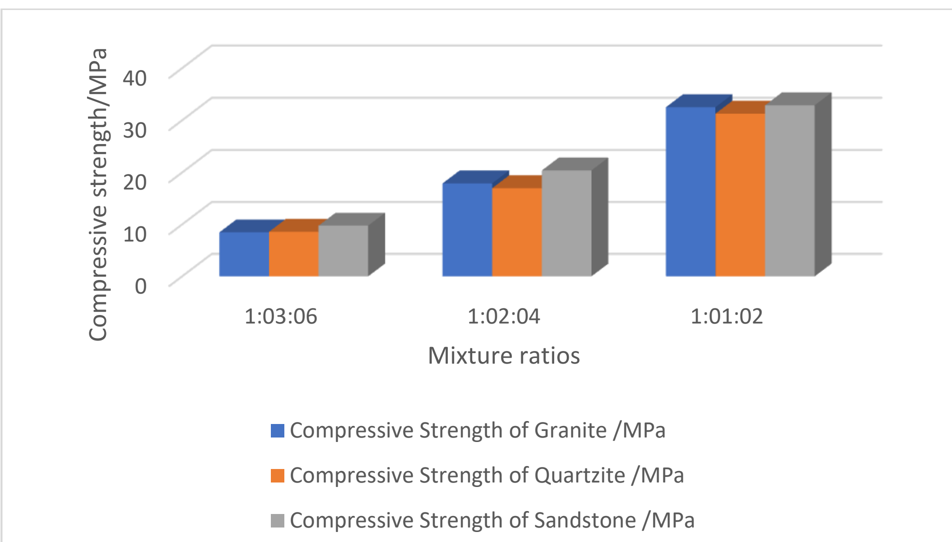

Figure 4. 20: Bar Chart of Compressive Strength of Granite, Quartzite and Sandstone Concrete of Aggregate Sizes 10 mm against Ingredient Mixture Ratios.

When aggregate size was changed to 10 mm, for the three mixture ratios of 1:3:6, 1:2:4 and 1:1:2, sandstone concrete gave the highest compressive strength. The difference in strength of concrete is still attributed to different physio-mechanical properties possessed by the different aggregate types. The results continue to reveal that compressive strength of granite, quartzite and sandstone concretes of the same mixture ratio produce concrete of the same class.

4.4.3 Compressive Strength of Granite, Quartzite and Sandstone Concrete of Aggregate Size 14 mm

Compressive strength of granite, quartzite and sandstone concretes for the three ingredient mixture ratios of aggregate size 14 mm were obtained as shown in the Table 4.45.

Table 4. 45: Compressive Strength of Granite, Quartzite and Sandstone Concrete of Aggregate Size 14 mm for the three Ingredient Mixture Ratios.

Ingredient Mixture Ratios	**1:3:6**	**1:2:4**	**1:1:2**
Compressive Strength of Granite /MPa	9.26	22.37	33.97
Compressive Strength of Quartzite /MPa	9.66	20.96	31.52
Compressive Strength of Sandstone /MPa	10.70	23.55	35.37

To show the variation in compressive strength of granite, quartzite and sandstone concrete of aggregate size 14 mm for the three mixture ratios, a bar graph of compressive strength against mixture ratios was plotted as shown in Figure 4.21

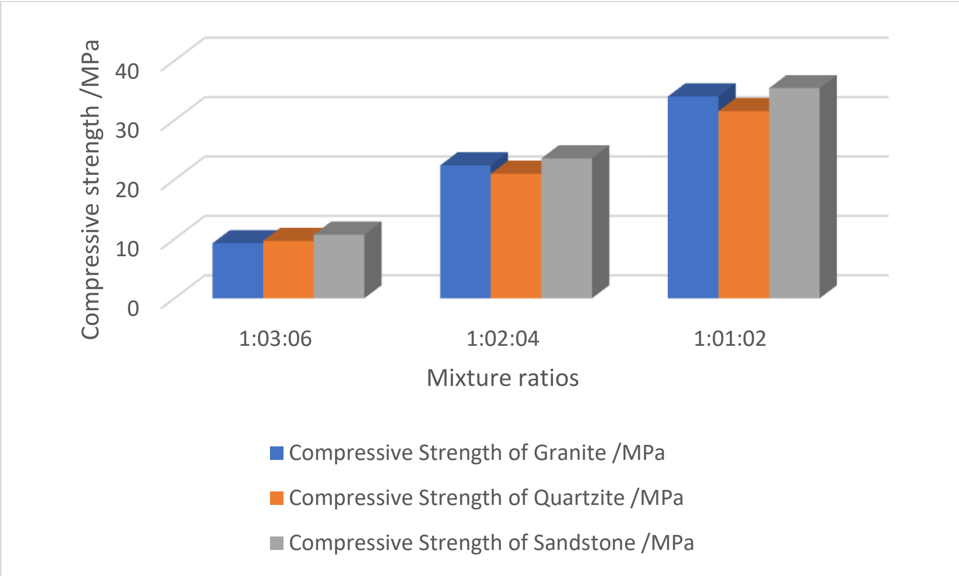

Figure 4. 21: Bar Chart of Compressive Strength of Granite, Quartzite and Sandstone Concrete of Aggregate Sizes 14 mm against Ingredient Mixture Ratios.

When aggregate size was made 14 mm, for the three mixture ratios of 1:3:6, 1:2:4 and 1:1:2, sandstone had the highest compressive strength of concrete. The difference in strength of concrete is still attributed to different physio-mechanical properties possessed by the different aggregate types. The results continue to reveal that compressive strength of granite, quartzite and sandstone concretes of the same mixture ratio produce concrete of the same class.

4.5 Comparison of Compressive Strength of Granite, Quartzite and Sandstone Concretes with Aggregate Sizes

The fourth and last set of results was to compare compressive strength of granite, quartzite and sandstone concretes with aggregate sizes for the three mixture ratios.

4.5.1 Compressive Strength of Granite, Quartzite and Sandstone Concrete of Mixture Ratio 1:3:6

Compressive strength of granite, quartzite and sandstone concretes for the three aggregate sizes of ingredient mixture ratio 1:3:6 were obtained as shown in the Table 4.46.

Table 4. 46: Compressive Strength of Granite, Quartzite and Sandstone Concrete of Mixture Ratio 1:3:6 for the three aggregate sizes.

Aggregate sizes	**6.3 mm**	**10 mm**	**14 mm**
Compressive Strength of Granite/MPa	7.96	8.46	9.26
Compressive Strength of Quartzite/MPa	8.14	8.58	9.66
Compressive Strength of Sandstone/MPa	8.66	9.76	10.70

To show the variation in compressive strength of granite, quartzite and sandstone concretes of mixture ratio 1:3:6 for the three aggregate sizes, a bar graph of compressive strength against aggregate size was plotted as shown in Figure 4.22

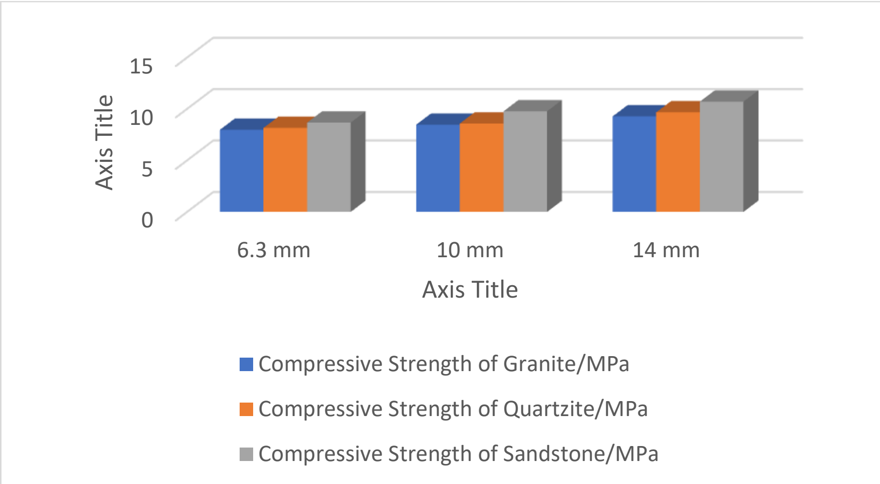

Figure 4. 22: Bar Chart of Compressive Strength of Granite, Quartzite and Sandstone Concrete of Ingredient Mixture Ratios 1:3:6 against Aggregate Sizes.

For the three aggregate sizes, sandstone produced concrete with the highest compressive strength and granite produced concrete with the lowest compressive strength. The difference in strength of concrete is still to different physio-mechanical properties possessed by the different aggregate types. The results continue to reveal that compressive strength of granite, quartzite and sandstone concretes of the same aggregate size produce concrete of the same class.

4.5.2 Compressive Strength of Granite, Quartzite and Sand stone Concrete of Mixture Ratio 1:2:4

Compressive strength of granite, quartzite and sandstone concretes with the three aggregate sizes of ingredient mixture ratio 1:2:4 were obtained as shown in the Table 4.47.

Table 4. 47: Compressive Strength of Granite, Quartzite and Sandstone Concrete of Mixture Ratio 1:2:4 for the three aggregate sizes.

Aggregate sizes	**6.3 mm**	**10 mm**	**14 mm**
Compressive Strength of Granite/MPa	17.04	17.90	22.37
Compressive Strength of Quartzite/MPa	14.77	16.98	20.96
Compressive Strength of Sandstone/MPa	18.32	20.39	23.55

To show the variation in compressive strength of granite, quartzite and sand stone concretes of mixture ratio 1:2:4 for the three aggregate sizes, a bar graph of compressive strength against aggregate size was plotted as shown in Figure 4.23

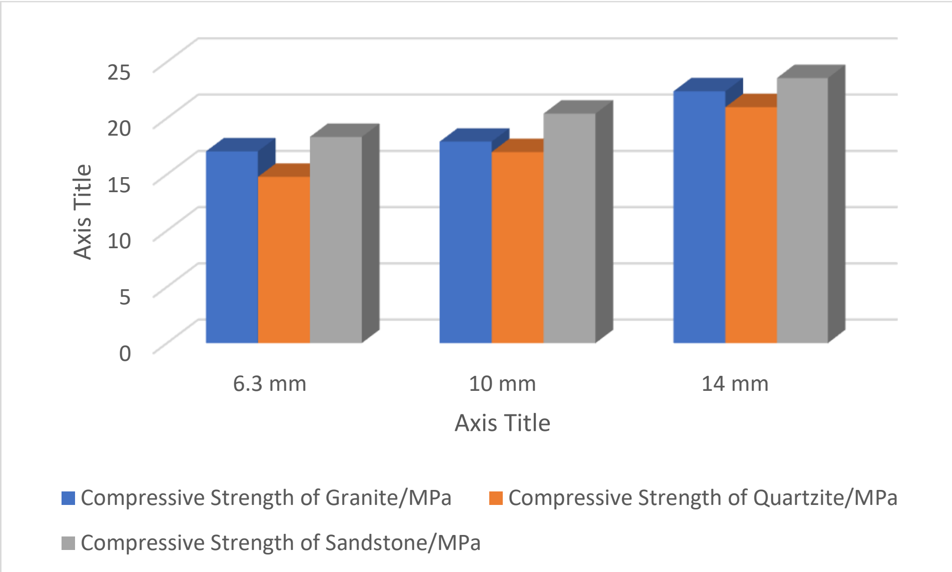

Figure 4. 23: Bar Chart of Compressive Strength of Granite, Quartzite and Sandstone Concrete of Ingredient Mixture Ratios 1:2:4 against Aggregate Sizes.

For the ingredient mixture ratios of 1:2:4, sandstone produced concrete with the highest compressive strength and quartzite concrete gave the lowest compressive strength unlike mixture ratios of 1:3:6 where compressive strength was highest in sandstone and lowest in granite concrete. The difference in strength of concrete is still attributed to different physio-mechanical properties possessed by the different aggregate types. The results continue to reveal that compressive strength of granite, quartzite and sandstone concretes of the same aggregate size produce concrete of the same class.

4.5.3 Compressive Strength of Granite, Quartzite and Sandstone Concrete of Mixture Ratio 1:1:2

Compressive strength of granite, quartzite and sandstone concretes for the three aggregate sizes of ingredient mixture ratio 1:1:2 were obtained as shown in the Table 4.48.

Table 4. 48: Compressive Strength of Granite, Quartzite and Sandstone Concrete of Mixture Ratio 1:1:2 for the three aggregate sizes.

Aggregate sizes	**6.3 mm**	**10 mm**	**14 mm**
Compressive Strength of Granite/MPa	31.29	32.50	33.97
Compressive Strength of Quartzite/MPa	30.87	31.28	31.52
Compressive Strength of Sandstone/MPa	31.49	32.88	35.37

To show the variation in compressive strength of granite, quartzite and sandstone concretes of mixture ratio 1:1:2 for the three aggregate sizes, a bar graph of compressive strength against aggregate size was plotted as shown in Figure 4.24

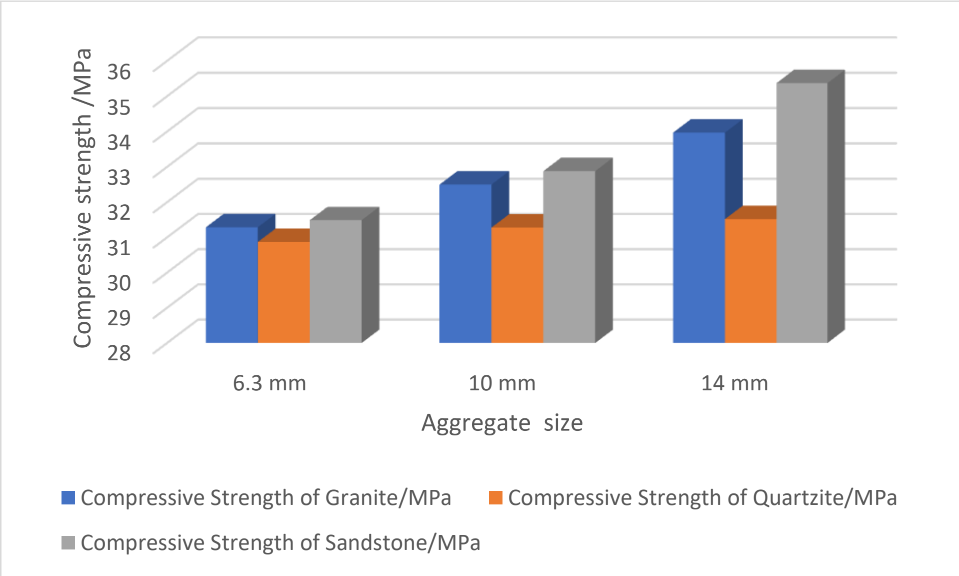

Figure 4. 24: Bar Chart of Compressive Strength of Granite, Quartzite and Sandstone Concrete of Ingredient Mixture Ratios 1:1:2 against Aggregate Sizes.

For the ingredient mixture ratios of 1:1:2, sandstone produced concrete with the highest compressive strength and quartzite with the lowest compressive strength just like mixture ratio of 1:2:4. The difference in strength of concrete is still attributed to different physio-mechanical properties possessed by the different aggregate types. The results continue to reveal that compressive strength of granite, quartzite and sandstone concretes of the same aggregate size produce concrete of the same class.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This study focused on two hypotheses. The first hypothesis was that the compressive strength of concrete produced does not vary with ingredient mixture ratios of 1:3:6, 1:2:4 and 1:1:2. This was established for three aggregate sizes of 6.3 mm, 10 mm and 14 mm and three rock types of granite, Quartzite and sandstone at two levels of significance α =0.01 and α =0.05. The second hypothesis was that the compressive strength of concrete made does not vary the aggregate sizes of 6.3 mm, 10 mm and 14 mm. This was done for three mixture ratios of 1:3:6, 1:2:4 and 1:1:2 and for three rock types of granite, quartzite and sandstone at two levels of significance α =0.01 and α =0.05.

5.2 Conclusion

The first assumption was that there was no variation of compressive strength of concrete with mixture ratios for the three aggregate sizes of granite, quartzite and sandstone rocks. However, compressive strength of concrete for the three rock types of granite, quartzite and sandstone for the three aggregate sizes of 6.3, 10 and 14 mm depended on the ingredient mixture ratios at both levels of significance α= 0.01 and α= 0.05. Therefore, the first hypothesis was rejected. Concretes with different mixture ratios have different compressive strength. Mixture ratio 1:1:2 produced concrete with the highest compressive strength and mixture ratio 1:3:6 produced concrete with the lowest compressive strength. The compressive strength of granite, quartzite and sandstone concretes for mixture ratio 1:3:6 was in the ranges of 7.96-9.26, 8.14-9.66 and 8.66-10.70 MPa. The compressive strength of granite, quartzite and sandstone concretes for mixture ratio 1:2:4 was in the ranges of 17.04-22.37, 14.77-20.96 and 18.32-23.55 MPa. The compressive strength of granite, quartzite and sandstone concretes for mixture ratio 1:1:2 was in the ranges of 31.29-33.97, 30.87-31.52 and 31.49-35.37 MPa. Comparison of granite, quartzite and sandstone concretes with mixture ratios for the three aggregate sizes of 6.3, 10, and 14 mm revealed that granite, quartzite and sandstone aggregates produced concretes of the same class.

The second assumption was that there was no variation of compressive strength of concretes with aggregate sizes for the three mixture ratios. But compressive strength of granite, quartzite and sandstone concrete for the two ingredient mixture ratios of 1:3:6 and 1:2:4 depended on the aggregate sizes at both levels of significance $\alpha = 0.01$ and $\alpha = 0.05$. The hypothesis was true for only two ingredient mixture ratios of 1:3:6 and 1:2:4 and false for mixture ratio of 1:1:2. Mixture ratios of 1:3:6 and 1:2:4, aggregate size 14 mm of granite, quartzite and sandstone produced concrete with the highest compressive strength and aggregate size 6.3 mm produced concrete with lowest compressive strength. Mixture ratio 1:1:2, compressive strength of granite, quartzite and sandstone concretes was found not vary with the aggregate sizes at both levels of significance $\alpha = 0.01$ and $\alpha = 0.05$. Comparison of compressive strength of granite, quartzite and sandstone concretes with aggregate sizes for three mixture ratios 1:3:6, 1:2:4 and 1:1:2, revealed that granite, quartzite and sandstone aggregates of the same aggregate size produce concretes of same class.

In summary, different mixture ratios of cement, sand and aggregate of 1:3:6, 1:2:4 and 1:1:2 each produced concrete with different compressive strength for granite, quartzite and sandstone aggregates. Aggregate sizes only affect mixture ratios of 1:3:6 and 1:2:4 which produce ordinary concrete but it does not affect mixture ratio of 1:1:2 which produces standard concrete. When granite, quartzite and sandstone aggregates are mixed in equal proportion and with same aggregate sizes, then concretes produced are of the same class.

5.3 Recommendations

Builders and engineers who wish to construct structures with high compressive strength should use granite, quartzite or sandstone aggregates of aggregate size of 14 mm and mixture proportions of 1:1:2. Then builders who wish construct structures with low compressive strength should use granite, quartzite or sandstone aggregates of aggregate size 6.3 mm and mixture ratio 1:3:6.

From this study, the following areas are suggested for further study;

Determination of compressive strength of concrete using aggregate sizes bigger than 14 mm, with the same mixture ratios of 1:3:6, 1:2:4 and 1:1:2 and same aggregate types of granite, quartzite or sandstone.

Also further research should be done on the determination of compressive strength of concrete using other types of rocks like basalt, limestone and marble found in Uganda using same mixture ratios and aggregate sizes.

Lastly future work can be done on determination of compressive strength of concrete using other types of cement for the same mixture ratios and aggregate sizes.

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APPENDICES

Appendix I: Test Results of Cross-Sectional Area, Breaking Force and Compressive Strength of Granite Concrete

Aggregate Size/ mm	**Area/ m^2**	**1:3:6**		**1:2:4**		**1:1:2**	
		Breaking Force/ KN	**Compressive Strength/ MPa**	**Breaking Force/ KN**	**Compressive Strength/ MPa**	**Breaking Force/ KN**	**Compressive Strength/ MPa**
6.3	0.0225	183	8.13	385	17.11	716	31.82
	0.0225	184	8.18	382	16.98	698	31.02
	0.0225	179	7.96	379	16.84	710	31.56
	0.0225	170	7.56	388	17.24	692	30.76
			7.96		**17.04**		**31.29**
10	0.0225	177	7.87	402	17.78	728	32.36
	0.0225	186	8.27	403	17.91	730	32.44
	0.0225	199	8.84	396	17.60	737	32.76
	0.0225	199	8.84	412	18.31	730	32.44
			8.46		**17.90**		**32.50**
14	0.0225	202	8.98	490	21.78	812	36.09
	0.0225	216	9.60	511	22.71	766	34.04
	0.0225	210	9.33	508	22.58	698	31.02
	0.0225	205	9.11	504	22.40	781	34.71
			9.26		**22.37**		**33.97**

Appendix II: Test Results of Cross-Sectional Area, Breaking Force and Compressive Strength of Quartzite Concrete

Aggregate Size/ mm	Area/ m^2	1:3:6		1:2:4		1:1:2	
		Breaking Force/ KN	Compressive Strength/ MPa	Breaking Force/ KN	Compressive Strength/ MPa	Breaking Force/ KN	Compressive Strength/ MPa
6.3	0.0225	191	8.49	328	14.58	688	30.58
	0.0225	180	8.00	336	14.93	707	31.42
	0.0225	182	8.09	331	14.71	719	31.96
	0.0225	179	7.96	334	14.84	664	29.51
			8.14		**14.77**		**30.87**
10	0.0225	200	8.89	383	17.02	709	31.51
	0.0225	185	8.22	405	18.00	695	30.89
	0.0225	190	8.44	366	16.27	716	31.82
	0.0225	197	8.76	374	16.62	695	30.89
			8.58		**16.98**		**31.28**
14	0.0225	220	9.78	480	21,33	721	32.04
	0.0225	212	9.42	452	20.09	690	30.67
	0.0225	224	9.96	481	21.38	700	31.11
	0.0225	213	9.47	473	21.02	726	32.27
			9.66		**20.96**		**31.52**

Appendix III: Test Results of Cross-Sectional Area, Breaking Force and Compressive Strength of Sand Stone Concrete

Aggregate Size/ mm	**Area/ m^2**	**1:3:6**		**1:2:4**		**1:1:2**	
		Breaking Force/ KN	**Compressive Strength/ MPa**	**Breaking Force/ KN**	**Compressive Strength/ MPa**	**Breaking Force/ KN**	**Compressive Strength/ MPa**
6.3	0.0225	189	8.40	399	17.73	747	33.20
	0.0225	201	8.93	439	19.51	784	34.84
	0.0225	191	8.49	404	17.96	675	30.00
	0.0225	198	8.80	407	18.09	628	27.91
			8.66		**18.32**		**31.49**
10	0.0225	219	9.73	455	20.22	681	30.27
	0.0225	216	9.60	463	20.58	733	32.58
	0.0225	224	9.96	457	20.31	776	34.49
	0.0225	219	9.73	460	20.44	769	34.18
			9.76		**20.39**		**32.88**
14	0.0225	224	9.96	536	23.82	767	34.09
	0.0225	238	10.58	523	23.24	804	35.73
	0.0225	247	10.98	530	23.56	824	36.62
	0.0225	254	11.29	530	23.56	788	35.02
			10.70		**23.55**		**35.37**