PAN AFRICAN UNIVERSITY

INSTITUTE FOR BASIC SCIENCES, TECHNOLOGY AND INNOVATION

The potential of dune sand for use in structural concrete

A Research Thesis submitted to the Pan African University, Institute of Science, Technology and Innovation, in partial fulfilment of the requirement for the award of the degree of Master of Science in Civil Engineering (Structural Option) of the Pan African University 2018.

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March 2018

Declaration

THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN SUBMITTED TO ANY EDUCATIONAL INSTITUTION OR UNIVERSITY FOR THE AWARD OF A CERTIFICATE.

Therefore, I declare that all the materials quoted in this thesis, which are not mine have been duly acknowledged.

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Dedication

I dedicate this thesis to:

- **My charming wife MOROMBAYE Salomé Marlène**
- **My lovely daughter DANEMBAYE Virginie Taryam**
- **To my dear Parents, Brothers and Sisters.**

For their permanent support for the accomplishment of this thesis.

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For their various contributions to the accomplishment of this thesis.

Abstract

The world population is about 7.4 billion but only about 1 billion live in desert areas which occupy 33% of the available land on earth. This poor demography in desert zone is essentially due to difficult living conditions including housing. To build in these areas which are generally distant from the main towns where construction materials are available and purchasable at reasonable cost, Contractors usually include some supplementary fees to cover the transport of materials. Dune sand represents about 20% of deserts worldwide.

The study focused on four (4) samples of dune sands randomly collected from Nyiri Desert(Kenya) and two (2) samples from Sahara Desert (Chad). After the assessment of chemical and physical properties of dune sand sampled, results showed that dune sand samples from Nyiri Desert contained 77.75% average particle size of less than 0.600mm while those of Sahara Desert had 97%. This study showed that the full replacement of ordinary sand by dune sand samples from Kenya and Chad, there were 22% and 41% average loss of compressive strength after 28 days respectively.

The cost estimation of dune sand concrete showed that when dune sand concrete is used for construction industry in desert environment from Kenya and Chad, that would result in an average cost and time reduction estimated at USD 30 and USD 66 per cubic meter respectively.

From the various studies carried out aimed at investigating the potential of dune sand for use in structural concrete, to ascertain the use of sand dune concrete in construction industries, it would be suggested that some further studies should be focused on durability over one year, splitting tensile strength and flexural strength tests.

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List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Code Institute
ASTM	American Standard of Testing and Materials
BS	British Standard
CA	Coarse Aggregate
CAC	Conventional Aggregate Concrete
CS	Compressive Strength
DS	Dune Sand
DSC	Dune Sand Concrete
E	Modulus of Elasticity (Young's Modulus)
f_c	The Specific Characteristic Strength
$f_{c28}^{`}$	Compressive Strength of Concrete at 28 days
f_m	The Target Mean Strength
FM	Fineness Modulus
HPC	High Performance concrete
JICA	Japan International Cooperation Agency
JKUAT	Jomo Kenyatta University of Agriculture and Technology
k	Constant
km	Kilometer
kN	Kilonewton
LWC	Light Weight Concrete

M	Lateral Contraction Coefficient
m	Meter
mm	Millimeter
mm^2	Square millimeter
MPa	Mega Pascal
N	Newton
n	The Number of Results
NCAC	Non-Conventional Aggregate Concrete
ND	Not Defined
NF	Norme Française
OPC	Optimum Portland Cement
OS	Ordinary Sand
pH	Potential of Hydrogen
RCAC	Reinforced Conventional Aggregate Concrete
RNCAC	Reinforced Non-Conventional Aggregate Concrete
S	Standard Deviation
SF	Silica Fume
SI	International System
SSD	Saturated Surface Dry
U.S. Standard	United State Standard
UTM	Universal Testing Machine
W/C	Water/Cement Ratio
x	An Individual Result

List of Nomenclatures

Ca	Calcium
Cr	Chromium
Cu	Copper
CO_2	Carbon Dioxide
Fe	Iron
Hg	Mercury
K	Potassium
Mn	Manganese
Ni	Nickel
Pb	Lead
Rb	Rubidium
SiO_2	Silicon Dioxide/Silica
SO_3	Sulfur Trioxide/Sulfate
Sr	Strontium
Ti	Titanium
Y	Yttrium
Zn	Zinc
Zr	Zirconium

Chapter 1: Introduction

1.1. Background

Concrete is a very common material used in construction sites over the world. It has been developed over thousands of years, its components were improved upon, combined with other materials and, ultimately, morphed into modern concrete.

The first concrete-like structures were built by the Nabataea traders or Bedouins who occupied and controlled a series of oases and developed a small empire in the regions of Southern Syria and Northern Jordan in around 6500 BC (Nick Gromicko and Kenton Shepard, 2002).

For having some specific high-quality concrete, the ratio of the aggregate should constitute about three-fourths of the total volume of the concrete (Ramachandran and Feldman, 1995). Therefore, the required performance of the concrete cannot be achieved without having proper ratios of the aggregates to be used in the concrete.

Therefore, using dune sand as materials might provide a good substitute for conventional materials, and decrease the cost of construction which is increasing along all the time.

Seen from space, the majority of the Earth’s surface is covered by oceans – that makes up 71% of the surface of the Earth, with the remaining 29% for land. Deserts make up 33%, or 1/3rd of the land’s surface area. That might sound like a surprisingly large amount, but that is based on the official definition of a desert. Desert are any region on Earth that can have a moisture deficit over the course of a year (less than 250mm of precipitation each year). In other words, they can have less rainfall in a year than they give up through evaporation.

More than 25 percent of Africa is desert. The Sahara Desert, the Kalahari Desert and the Namib Desert are the main deserts found in Africa. (Strahler *et al*, 1987).

The Sahara, the largest hot desert in the world, covers 3.3 million square miles and is in the northern part of Africa. The Kalahari Desert, located in southern Africa, covers 362,500 square miles. The Namib Desert, the world's oldest desert, is found in the south-western portion of the continent and covers 100,000 square miles. (*Wright, John W., 2006*).

Kenya’s land area is about 582,646 kilometers squared, of which 2.2 per cent is surface water. A huge proportion of Kenya’s land area is desert, arid or semi-arid lands (ASALs), accounting for over 80 per cent of the total area (*Survey of Kenya 2003, NLPS 2007, WRI and others 2007*).

Nyiri Desert, also called The Nyika, Taru Desert is a desert in southern Kenya. It is located east of Lake Magadi and between Amboseli, Tsavo West and Nairobi National Parks. High proportion of Kajiado County's land area is of Nyiri Desert. Its aridity is caused by rain shadow of the Kilimanjaro. For this study, samples of dune sands were mainly collected from Nyiri Desert(Kenya) and Sahara Desert (Chad).

Sand dune is any accumulation of sand grains shaped into a mound or ridge by the wind under the influence of gravity. Sand dunes are comparable to other forms that appear when a fluid moves over a loose bed, such as subaqueous “dunes” on the beds of rivers and tidal estuaries and sand waves on the continental shelves beneath shallow seas. Dunes are found wherever loose sand is windblown: in deserts, on beaches, and even on some eroded and abandoned farm fields in semiarid regions such as northwest India, some parts of the southwestern United States and most parts of Africa.

1.2. Statement of the Problem

Due to the high cost of construction mainly in desert and semi desert areas in Africa, the economy is affected. This is justified by the fact that in most arid zones in Africa, the infrastructure of transport is precarious, and the populations live in the extreme poverty. To build in these areas which are generally distant from main towns where construction materials are available and purchasable at reasonable cost, construction enterprises include most of the time some supplementary cost to cover the transport of materials such as aggregates, sand, cement, water, and so on.

Finding an alternative way of using common materials becomes meaningful due to the rare occurrence of ordinary materials (American Society of Civil Engineers,2009). The world population is about 7.4 billion. About 1 billion live in desert and semi desert areas. This huge variation in terms of demography is related to tough living conditions including housing. The difficult housing conditions are mainly caused by the cost of materials which is very high and so there is need to try to find a way to use materials such as dune sands which are readily available in desert and semi desert areas for buildings.

Ordinary sand for concrete is obtained along some rivers, lakes, streams, oasis, sea and so on. The quantity recommended for a specific work is not always reached or contains some toxic components inadequate for concrete mixing therefore manufacturers produce them to compensate the lack which entails crushing of rocks and boulders. From the crushing of rocks and boulders, another major phenomenon results, the propagation of large quantity of carbon dioxide into the atmosphere is causing the destruction of ozone layer where the earth warming is originated from.

In addition to that aspect, local people within desert area are struggling at the end of every rainy season to get a portion of land along the oasis, rivers, streams, and so on to fabricate some clay bricks to construct semi durable buildings. It is known that the available quantity of clay cannot supply the overall population. Therefore, the cost of clay bricks is very high to be purchased by an individual who lives under the level of poverty which is the case of more than 80% of the population (Shepherd *et al*,2013).

Facing all these challenges of housing wherever in the African continent, particularly in Chad and Kenya, it is necessary to look for other approaches to solve the unavailability of adequate and reliable construction materials by using what is readily available. One of these approaches is to use dune sands which are readily available and environment friendly as part of durable and semi durable constructions in desert and semi desert areas to reduce meaningfully the cost of construction to enhance Africa's economy through some of its major countries which are Chad and Kenya, which are severely threatened by one of the significant dilemmas of the third millenary which is housing (UN-Habitat, 2007).

1.3. Objectives

1.3.1. General Objective

The general objective of this study was to investigate the potential of dune sand for use in structural concrete.

1.3.2. Specific Objectives

1- To assess the chemical and physical properties of dune sand;

2- To evaluate the effect of dune sand properties on concrete;

3- To investigate the effects of silica fume as partial replacement of OPC on dune sand concrete;

4- To determine the cost reduction of using dune sand as concrete component for construction in desert environment.

1.4. Research Questions

1. What were the physical and chemical properties of dune sands?
2. What was the influence of dune sands on the mix design and the concrete properties?
3. What were the adequate ways to minimize or compensate the weaknesses due to the physical and chemical properties of dune sands?
4. What were the advantages of using dune sand concrete in desert and semi desert areas as compared to ordinary concrete?

1.5. Justification

The main target of this study was to provide a significant and durable means of construction in desert and semi desert areas by using dune sands as one of the major concrete components. They would therefore reduce the cost of construction in arid and semi-arid areas which were mostly inhabited by the populations extremely poor. This type of construction would also help to mitigate the impact of desert which threatens increasingly the overall humanity during these last decades.

The pollution that comes from dune sands and the risks arising from normal aggregates manufacturing will be reduced. Hence the carbon dioxide propagation should be reduced when there is a substitute solution to the problem. Instead of crushing rocks and boulders, using dune sands which are readily available is necessary. It would protect the environment and compensate the lack of materials specifically fine aggregates which create disputes among arid populations who have been using up to now river clays which are insufficient to provide suitable housing.

The study focused on various samples of dune sands coming from different places located in Kenya as well as Chad. Some studies were carried out to understand their behavior to use them in priority as concrete component in desert and semi desert areas. The results of the above studies were compared to those of conventional concrete so that some specifications are provided to serve as guidelines in the use of such materials.

1.6. Scope

The main scope of this study was to show the usefulness of dune sands as fine aggregates in concrete for constructions in desert and semi desert areas. Hence would emphasize on the technical and financial advantages of utilizing dune sands as concrete component in areas where they are available.

The prioritization of dune sand concrete would be then justified in this study for building in desert and semi desert zones. Furthermore, the investigation of the influence of physical and chemical properties of dune sands on the concrete to provide eventual ways to minimize or compensate weaknesses by using an additional material such as SF.

Finally, to show an average approximation in terms of cost reduction in the use of dune sand as concrete component for construction in desert environment.

Chapter 2: Literature Review

2.1 Theoretical Review

2.1.1 Properties and Classification of Soils

Physical property of soil refers to the relative percentages of the three types of soil particles, sand, silt and clay. The properties of soil are mainly classified into three groups as shown in the diagram below.

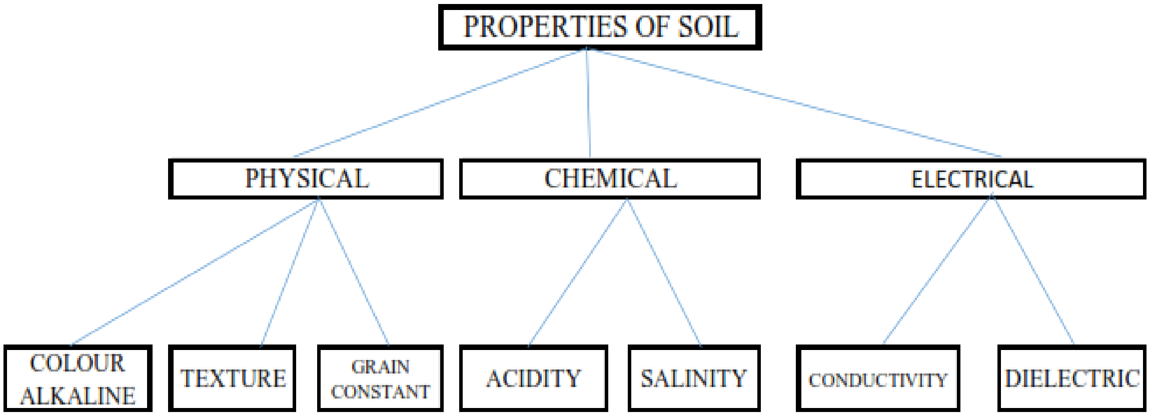


Figure 2.1:Diagram of classification of soil

(United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), *Colorado Soil Survey Program*, website: http://www.co.nrcs.usda.gov/technical/soil/).

Soil solid phase is characterized by:

1- Soil texture - size distribution of soil particles

2- Chemical and mineralogical properties

3- Shape and surface area of soil particles

4- Soil structure - arrangement of individual soil particles

i- Soil Texture

Soil texture is an intrinsic attribute of the soil and it is, therefore, often used to specify its physical composition. Soil texture refers to the size range of the solid particles in the soil resulting from the weathering of parent stocks.

Soil particles are grouped into classes based on size, and the relative proportions of these classes characterize the texture of the soil. These classes often differ also in mineral composition. Both particle size and mineral composition largely determine the nature and behavior of a soil like porosity, interactions with solutes, soil compaction, soil strength, and so on.

i.1 Particle size distribution

The major method to measure the particle size distribution of a soil is the mechanical analysis. The results of this analysis can be presented as a particle size distribution curve which displays the complete array and distribution of the particle sizes, or in a textural triangle (See Figure 2.2 below) based on the relative amounts of the clay, silt and sand fractions.

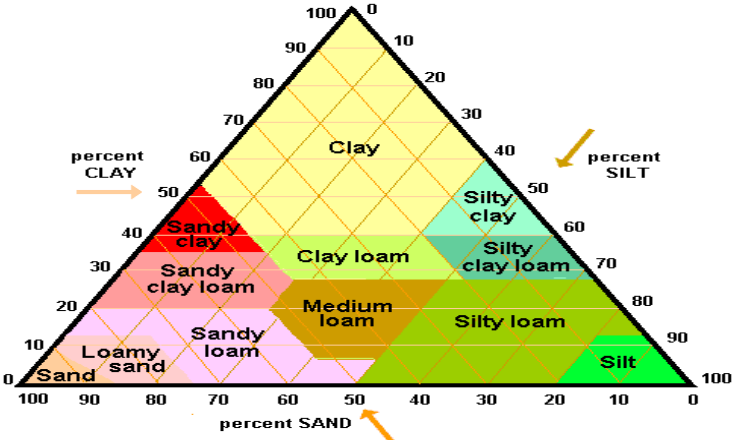


Figure 2.2:Textural triangle showing the sand, silt and clay compositions for various soil types (Foth and Henry, 1990)

ii- Chemical and Mineralogical Properties

Chemical properties of soil are mainly:

- Heavy metal content
- pH value
- Organic matter

Soil particles are separated into three main classes: clay, silt and sand; these can be subdivided depending on the classification system considered (Figure 2.3).

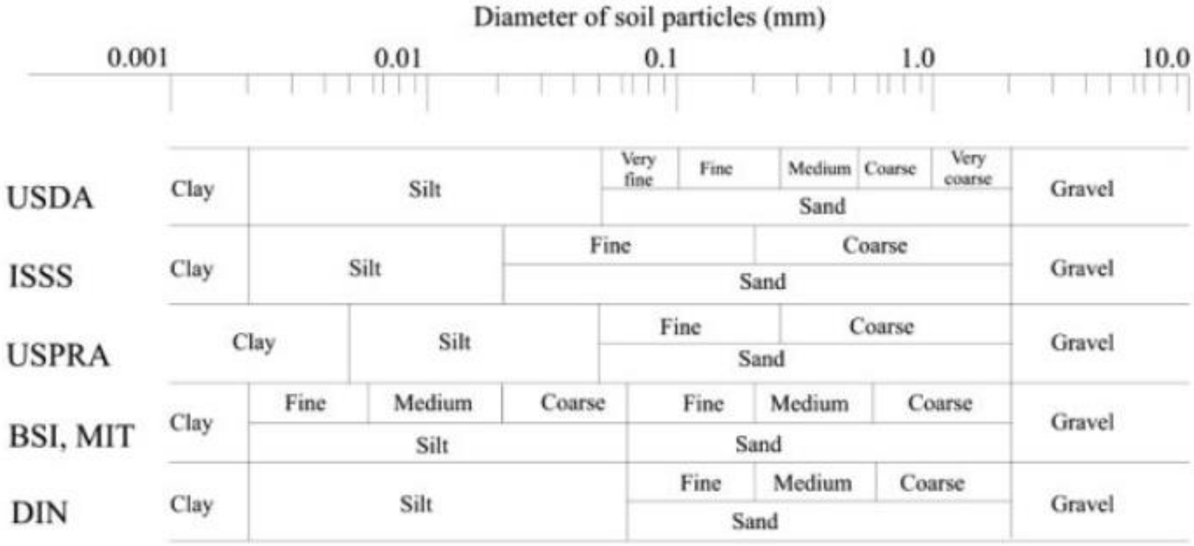


Figure 2.3:Classification of soil fractions by particle size diameter ranges (ASTM,1985)

ii.1 Types of soils

ii.1.1 Sand

The conventional definition of soil material includes particles up to 2mm in diameter and excludes larger particles such as gravel, stones, cobbles and even boulders with a diameter of several centimeters. The largest group of soil particles is sand with sizes ranging from 2mm to 0.05mm(USDA-classification) or to 0.02mm(ISSS-classification). This fraction is generally subdivided into coarse, medium and fine sand (Figure 2.2). Sand particles usually consist of quartz but may also contain fragments of other minerals such as feldspar, mica and occasionally heavy minerals such as zircon, tourmaline and hornblende, although the latter is rather rare (Mack *et al*, 1996).

ii.1.2 Silt

The silt fraction comprises particles between 0.002 and 0.05mm(USDA-Classification) or between 0.002 and 0.02mm (ISSS-classification). Silt particles have similar mineralogical and physical properties as sand, but because they are much smaller, they have a greater surface area per unit mass and are often coated with strongly adhered clay particles. Therefore, silt may exhibit to a limited extent some physicochemical properties of clay.

ii.1.3 Clay

Clay particles range in diameter from 0.002mm downward and constitute the colloidal soil fraction; they are plate or needle-like and belong mineralogically to the aluminosilicates. The clay fraction strongly affects soil behavior because of its great surface area per unit mass and physicochemical activity. A clay soil will usually exhibit a plastic behavior, is sticky when moist and hard when dry (Unikowski,1982).

Typical properties of some clay minerals are given in Table 2.1 below.

Table 2.1:Typical properties of selected clay minerals (WHO Geneva, 2005)

Properties	Clay mineral				
	Kaolinite	Illite	Montmorillonite	Chloride	Allophane
Planar diameter(um)	0.1-4	0.1-2	0.01-1	0.1-2	
Basic layer thickness	0.72	1	1	1.4	
(nm)	50	530	110	10-100	
Particle Thickness	5-20	80-120	700-800	80	
(nm)	3-15	15-40	80-100	20-40	40.7
Specific surface	0.25	0.5	1	0.5	1.2
(m2/g)					
CEC(me/100g)					
Area per charge(nm2)					

ii.1.4 Organic soil fraction

Humus particles are, like clay, negatively charged and form micelles capable to hydrate and to adsorb cations among other organic and inorganic constituents. Their charge results from the dissociation of organic carboxylic and phenol groups, and their cation exchange capacity(CEC) is due to the replacement of hydrogen, and thus pH dependent (Jain *et al*, 1997).

ii.1.5 Shape and Surface Area of Soils

Clay is the smallest mineral particle in soil. Clay particles are the active portion of a soil, because chemical reactions occur at their surface. Clay particles have about 1,000 times as much external surface area as the particles in an equal weight of sand. The effect of decreasing particle size on surface area can be illustrated with a deck of cards. Stacked together, the deck has only 16,129 mm^2 of surface area. When separated as individual cards, the deck has a surface area of nearly 645,160 mm^2 (Figure 2.4).

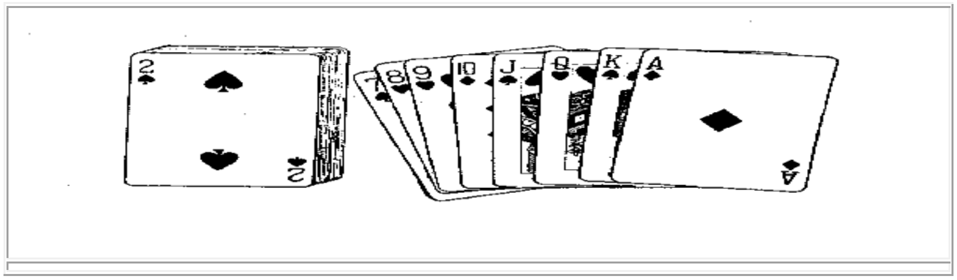


Figure 2.4:Subdivision of playing cards, like clay particles, increases surface size (Torrance et al,1995)

- **Soil Structure**

Soil structure refers to the arrangement of soil separates into units called soil aggregates. An aggregate possesses solids and pore space. Aggregates are separated by planes of weakness and are dominated by clay particles. Silt and fine sand particles may also be part of an aggregate. The aggregate acts like a larger silt or sand particle depending upon its size (Marshall & Holmes, 1979).

The arrangement of soil aggregates into different forms gives a soil its structure. The natural processes that aid in forming aggregates are:

1) wetting and drying,
2) freezing and thawing,
3) microbial activity that aids in the decay of organic matter,
4) activity of roots and soil animals, and
5) adsorbed cations.

Aggregates are important in a soil because they influence bulk density, porosity and pore size. Pores within an aggregate are quite small as compared to the pores between aggregates and between single soil particles.

ii.1.6 Other Physical Properties of Soils

The other physical properties of soils essentially important in civil engineering are particle density, bulk density, porosity, pore size and soil color.

2.1.2 Concrete

i- Definition and Constituents

The most popular artificial material on Earth isn't steel, plastic, or aluminum, it is concrete. The time during which concrete was first invented depends on how one interprets the term "concrete." Ancient materials were crude cements made by crushing and burning gypsum or limestone. Lime also refers to crushed, burned limestone. When sand and water were added to these cements, they became mortar, which was a plaster-like material used to adhere stones to each other. Over thousands of years, these materials were improved upon, combined with other materials and, ultimately, morphed into modern concrete (Nick Gromicko and Kenton Shepard, 2015).

Concrete is a composite material composed of coarse aggregate bonded together with a fluid cement that hardens over time. Most concrete is poured with reinforcing materials (such as rebar) embedded to provide tensile strength, yielding reinforced concrete (James, 2008).

Composition of concrete

- **Cement**

It is the matrix or binder. Portland cement is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar and many plasters. English masonry worker Joseph Aspdin patented Portland cement in 1824. It was named because of the similarity of its color to Portland limestone, quarried from the English Isle of Portland and used extensively in

London architecture. It consists of a mixture of calcium silicates (alite, belite), aluminates and ferrites compounds which combine calcium, silicon, aluminium and iron in forms which will react with water. Portland cement and similar materials are made by heating limestone (a source of calcium) with clay and/or shale (a source of silicon, aluminium and iron) and grinding this product (called clinker) with a source of sulfate (most commonly gypsum) (Nick Gromicko and Kenton Shepard, 2015).

- **Water**

Water is a part of the concrete, and it gives the liquid characteristic of the fresh concrete. The cement paste saves the amount of water on the surface of the grains of the cement and the grains of the aggregates to complete the hydration reaction of the cement components inside the concrete (Neville,1992). The w/c ratio is the response from the strength of the paste cement, so excessive water after the hydration was completed, it makes spaces on the surface of the aggregate and the cement (Nawy, 2008). Moreover, the water inside the fresh concrete may be described in two different ways. Free water which does not react with the cement and it is just for mixing the paste, bound water is the response from the reaction, in another word it provides the amount of water which will use to complete the chemical reaction (Kosmatka and Kirchhoff, 2002). Moreover, the water should be clean from the slate and any etch of chloride.

Combining water with a cementitious material forms a cement paste by the process of hydration. The cement paste glues the aggregate together, fills voids within it, and makes it flow more freely.

A lower water-to-cement ratio yields a stronger, more durable concrete, whereas more water gives a freer-flowing concrete with a higher slump. Impure water used to make concrete can cause problems when setting or in causing premature failure of the structure (Herring and Benjamin,2012). As the result, the ACI 318 set limits for the soluble chloride ion content by mass of cement in the reinforced concrete:

Table 2.2:Percentage of the soluble chloride ion in the reinforced concrete/mass of cement (ACI 318)

Pre-stressed concrete	0.06%
Reinforced concrete exposed to chloride in service	0.15%
Reinforced concrete that will be dry or protected from moisture in service	1.00%
Other reinforced concrete construction	0.30%

- **Aggregates**

Fine and coarse aggregates make up the bulk of a concrete mixture. Sand, natural gravel, and crushed stone are used mainly for this purpose. Recycled aggregates (from construction, demolition, and excavation waste) are increasingly used as partial replacements for natural aggregates, while a number of manufactured aggregates, including air-cooled blast furnace slag and bottom ash are also permitted (Herring and Benjamin,2012).

The size distribution of the aggregate determines how much binder is required. In this study where dune sands were used as fine aggregates, the surface area within the aggregates was much greater than for ordinary fine aggregates. Hence, more fine and strong binding elements were required to ensure correct adhesion within such a concrete which justifies the use of silica fume for both its high strength quality and fineness to fit in surface area to ensure good quality binding within dune sand concrete (U.S. Federal Highway Administration,2007).

❖ Mineral admixtures and blended cements

Inorganic materials that have pozzolanic or latent hydraulic properties are fine-grained materials added to the concrete mix to improve the properties of concrete (mineral admixtures), or as a replacement for Portland cement (blended cements). Products which incorporate limestone, fly ash, blast furnace slag, and other useful materials with pozzolanic properties into the mix, are being tested and used. This development is due to cement production being one of the largest producers (at about 5 to 10%) of global greenhouse gas emissions, as well as lowering costs, improving concrete properties, and recycling wastes.

Silica fume is a byproduct of the production of silicon and ferrosilicon alloys. It is like fly ash but has a particle size 100 times smaller. This results in a higher surface-to-volume ratio and a much faster pozzolanic reaction. Silica fume is used to increase strength and durability of concrete, but generally requires the use of superplasticizers for workability (U.S. Federal Highway Administration,2007).

ii- Properties of fresh concrete

❖ Consistency

Consistency is referred to as the resistance of a concrete to flow. Consistency of a concrete mix is a measure of the stiffness or sloppiness or fluidity of the mix. For effective handling, placing and compacting the concrete, consistency must be the same for each batch. It is therefore necessary to measure consistency of concrete at regular intervals. Slump test is commonly used to measure consistency of concrete (Neville, 1992).

❖ Workability

The workability of a concrete mix is the relative ease with which concrete can be placed, compacted and finished without separation or segregation of the individual materials.

Workability is not the same thing as consistency. Mixes with the same consistency can have different workabilities, if they are made with different sizes of stone – the smaller the stone the more workable the concrete (Neville, 1992).

It is not possible to measure workability but the slump test, together with an assessment of properties like stone content, cohesiveness and plasticity, gives a useful indication.

Workability can be measured by the concrete slump test, a simple measure of the plasticity of a fresh batch of concrete following the ASTM C 143 or EN 12350-2 test standards.

❖ Cohesiveness

Cohesiveness is referred to the capacity of materials to remain together. It is affected by the method of mixing, stiffness of the mix and the shape and surface texture of aggregates. Cohesiveness is described as the tendency not to bleed or segregate therefore its measure is mostly based on observation (Mehta *et al*, 2006).

iii- Properties of hardened concrete

Fully cured, hardened concrete must be strong enough to withstand the structural and service loads which will be applied to it and must be durable enough to withstand the environmental exposure for which it is designed. Below are the properties of hardened concrete:

- Strength
- Creep

- Durability
- Shrinkage
- Modulus of Elasticity
- Water Tightness

Strength:

Compressive strength or compression strength is the capacity of a material or structure to withstand loads tending to reduce size, as opposed to tensile strength, which withstands loads tending to elongate. In other words, compressive strength resists compression (being pushed together), whereas tensile strength resists tension (being pulled apart). In the study of strength of materials, tensile strength, compressive strength, and shear strength can be analyzed independently. Concrete compressive strength is generally measured in MPa (N/mm^2). Compressive strength mostly depends upon amount and type of cement used in concrete mix. It is also affected by the water-cement ratio, mixing method, placing and curing. Concrete tensile strength ranges from 7% to 12% of compressive strength. Both tensile strength and bending strength can be increased by adding reinforcement. The diagram below shows strength gaining of concrete with age (Neville, 1992).

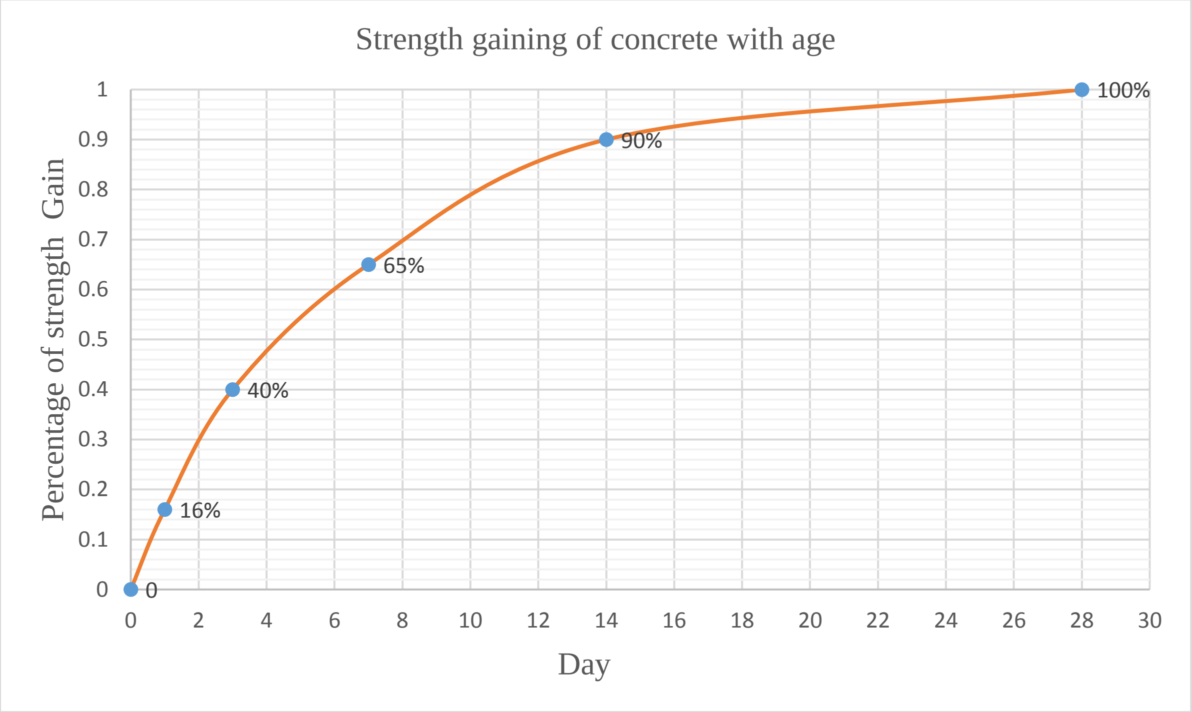


Figure 2.5:Strength gaining of concrete with age (Neville, 1992)

Creep:

When concrete is subjected to compressive loading it deforms instantaneously. This immediate deformation is called instantaneous strain. The main load maintained for a considerable period, concrete undergoes additional deformations even without any increase in the load. This time-dependent strain is termed as creep. Long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is applied.

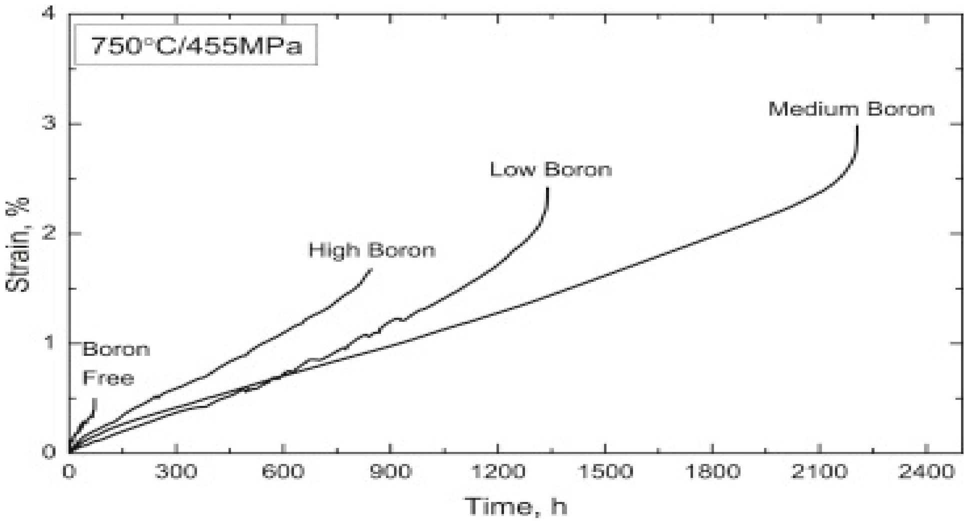


Figure 2.6:Strain-time curve due to creep at drying (Wittmann et al, 1982)

Durability:

Durability is defined as the ability to maintain satisfactory performance over an extended service life. The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years. Most concrete buildings are demolished due to obsolescence rather than deterioration. Different types of concrete require different degrees of durability depending on the exposure environment and properties desired. Appropriate concrete ingredients, mix proportions, finishes and curing practices can be adjusted based on required durability of concrete (Neville, 1992).

There are many types, but the major concrete durability types are:

- Physical durability
- Chemical durability

Durability of Concrete depends upon the internal factors (concrete system) and external factors (aggressiveness of the environment). The internal factors are cement content, degree of compaction, curing, cover and permeability (IS:456-2000).

- Cement content

Mix must be designed to ensure cohesion and prevent segregation and bleeding. If cement is reduced, then at fixed w/c ratio the workability will be reduced leading to inadequate compaction. However, if water is added to improve workability, water / cement ratio increases and resulting in highly permeable material.

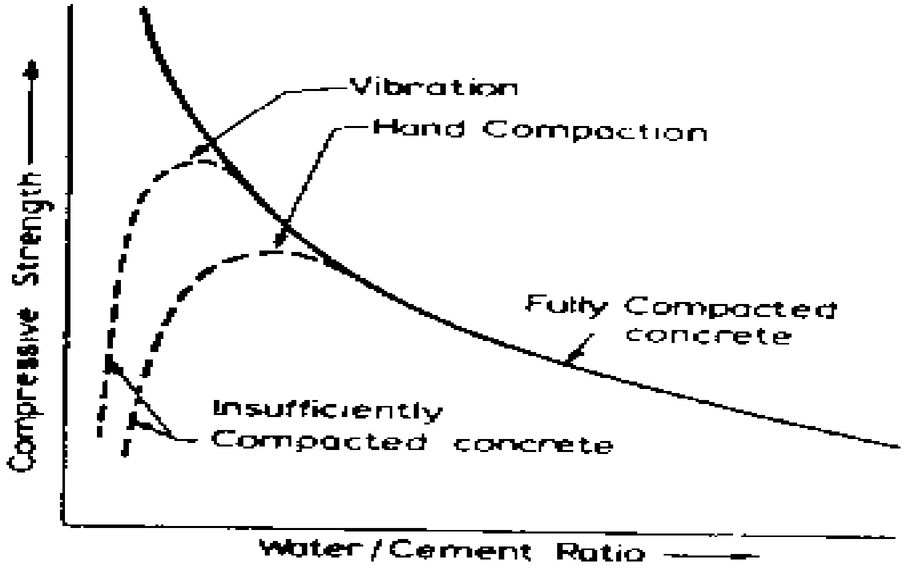


Figure 2.7:Relation between strength and water to cement ratio of concrete (Neville, 1992)

The strength that might be developed under the current circumstances is much dependent on the following factors: water to cement ratio, cement to aggregate ratio, maximum aggregate size, physical properties of aggregates, air content and admixtures. The major influencing factor is water to cement ratio as shown on Figure 2.7 above.

Duff Abrams in 1919 presented an equation that relates strength of concrete with water to cement ratio (Punmia et al, 2003).

$S=A/B^{w/c}$…………………………………………………………………...Equation2.1

S = strength of concrete

A and B are constants

w/c is water-cement ratio varies from 0.3 to 1.20

- Compaction

Compaction is a process of expelling the entrapped air. Compaction of concrete is an important component in the process of laying a concrete. If compaction is not carried out as required, a series of defects may become apparent and the concrete will suffer from significant loss of strength. Usually it is being governed by the compaction equipments used, type of formworks, and density of the steelwork.

- Curing

Curing plays an important role on strength development and durability of concrete. Curing takes place immediately after concrete placing and finishing, and involves maintenance of desired moisture and temperature conditions, both at depth and near the surface, for extended periods of time.

- Cover

Thickness of concrete cover must follow the limits set in codes.

- Permeability

It is considered the most important factor for durability. It can be noticed that higher permeability is usually caused by higher porosity. Therefore, a proper curing, sufficient cement, proper compaction and suitable concrete cover could provide a low permeability concrete.

Shrinkage

Shrinkage is the volume decrease of concrete caused by drying and chemical changes. In another word, the reduction of volume for the setting and hardening of concrete is defined as shrinkage. The various types of shrinkage are plastic shrinkage, drying shrinkage, autogeneous shrinkage and carbonation shrinkage.

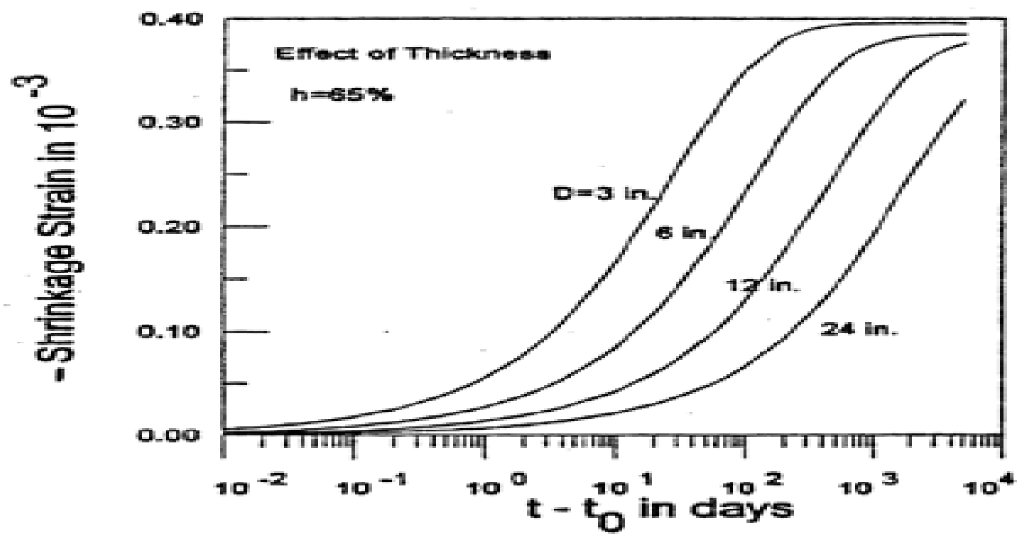


Figure 2.8:strain-time curve due to thickness effect (Wittmann et al, 1982)

Modulus of Elasticity:

The modulus of Elasticity of concrete depends on the Modulus of Elasticity of the concrete ingredients and their mix proportions. As per ACI code, the modulus of Elasticity to be calculated using following equation:

$Ec = 33\omega c1.5\sqrt{f'c}$ N/mm^2………………………………………………………Equation2.2

Where, ωc = unit weight of concrete, N/mm^2 (MPa)

f'c = 28 days compressive strength of concrete

For normal weight concrete ($9x10^{-7}$ N/mm^3 to $1.6x10^{-6}$ N/mm^3). It is assumed that

formula $Ec = 57000\sqrt{f'c}$

Water tightness:

Another property of concrete is water tightness. Sometimes, it is called impermeability of concrete. Water tightness of concrete is directly related to the durability of concrete. The lesser the permeability, the more the durability of concrete. The permeability of concrete is the capability of penetrating outer media into concrete. Outer media means water, chemicals, sulphate, and so on.

iv- Concrete Mix design

Concrete mix design is the process of finding the proportions of concrete mix in terms of ratios of cement, sand and coarse aggregates. For example, a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The concrete mix design proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass.

The choice of a concrete mix depends on the need of the project both in terms of strength and appearance and in relation to local legislation and building codes therefore the design begins by determining the requirements of the concrete. Many factors need to be considered, from the cost of the various additives and aggregates, to the tradeoffs between the "slump" for easy mixing and placement and ultimate performance. For a concrete to be used structurally, it is designed to have a characteristic strength more than 25/30 N/mm2. C25/30 is used for prestressed concrete or reinforced concrete subject to chlorides. Concretes of lesser strength are termed non-structural (Eurocode 2).

British Standard Method (BS)

The method of concrete mix design applied was in accordance to the method published by the Department of Environment, United Kingdom (BS EN 206-1).

According to the BS 5238: Part 2, the main two types of concrete mix are; design mix where the test of strength is essential, also the prescribed mix where the strength test is not required (McGinley and Choo, 1990). In addition, the main factor in the design of concrete mix is water cement (w/c) ratio, and it is usually between 0.45 to 0.6. On the other hand, the aggregate/cement ratio response from the workability when it is affecting on the water/cement ratio. Therefore, the steps of the were taken:

Step 1; the required strength leading to the w/c ratio was determined.

Step 2; the workability leading to the free water content was then determined.

Step 3; step1 and step 2 lead to determination of the cement ratio.

Step4; determination of the total aggregate content.

Step5; the selection of the fine and the course aggregate contents.

Selecting of the target W/C Ratio

The variability of the strength during the production brought the uncertainty in the selection of the proportions of the materials. The variation appeared in the quality of the used materials, mix proportions due to the production process, and due to sampling and testing. The previous studies have shown that the variation in the concrete due to the three groups as mentioned in normally distributed as in Figure 2.9 (Building research establishment report, 1988). The chart has two mathematical parameters, the mean (m) and the standard deviation (s). The standard deviation presents the measure of the variation according to the equation;

$$s = \sqrt{\frac{\sum(x-m)^2}{n-1}} \quad \text{……………………………………………………………………..Equation2.3}$$

Where x is an individual result.

n is the number of results.

m is the mean of the n results.

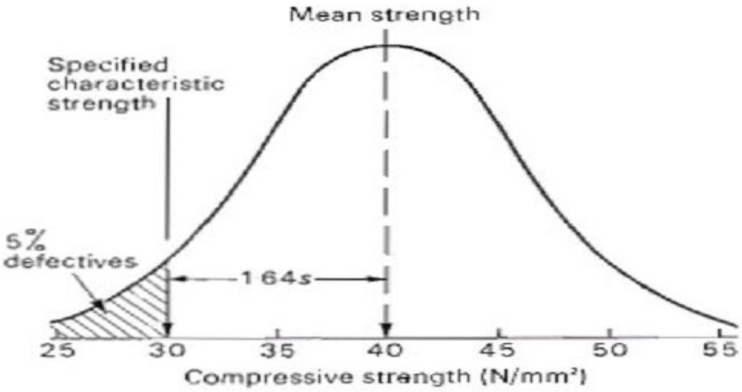


Figure 2.9:Normal distribution of concrete strength (Building research establishment report, 1988)

As the result, the variation leading to design for the mean strength greater than the specific strength, therefore, the differences in the two strengths represented in term of margin M;

$$f_m = f_c + M \quad \text{………………………………………………………………………Equation2.4}$$

Where:

- Margin M = k * s
- f_m is the target mean strength
- f_c is the specific characteristic strength
- s is the standard deviation

k is constant (10% defectives = 1.82, 5% defectives = 1.64, 2.5% defectives = 1.96, % defectives = 2.33).

The target mean strength of Figure 2.9 was used to determine the w/c ratio. Table 2.3 gives the strength depending on 0.5 w/c ratio, and type of the cement and the aggregate. This strength was plotted in the Appendix 1 to obtain the exact w/c ratio.

Table 2.3:Approximate compressive strength of concrete mixes made with a free w/c of 0.5 (BS, DEO Method)

Type of cement	**Type of coarse**	**Compressive strength (N/mm^2)**			
		Age (days)			
		3	**7**	**28**	**91**
Ordinary Portland(OPC)	Uncrushed	22	30	42	49
Sulphate Resistance Portland(SRPC)	Crushed	27	36	49	56
Rapid Hardening Portland(RHPC)	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

The same approach was used to obtain the free water contents in kilogram per unit volume to give different values for workability as in Table 2.4.

Table 2.4:Approximate free-water content(kg/m3) required to give various levels of workability (BS, DEO method)

Slump (mm)		**1 – 10**	**10 – 30**	**30 – 60**	**60 – 180**
Vebe time (s)		**> 12**	**6 – 12**	**3 – 6**	**0 – 3**
Maximum size of aggregate (mm)	**Type of aggregate**				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Therefore, the determination of the total aggregate contents followed the above step by using in Appendices 1, 2, 3, 4 and 5.

2.2. Experimental Background

A comparative study on strength properties of concrete made with river sand and dune sand from Sokoto (Nigeria) as fine aggregate carried by Yusuf *et al* (2015) with a concrete of nominal mix 1:2:4 using w/c ratio of 0.62 and concrete cubes 150mm x 150mm x 150mm reported that after 28 days hydration period dune sand can be utilized in concrete production since the average compressive strength of concrete cubes made with dune sand (fine aggregate, i.e. 22.68N/mm^2) is within the range stipulated in BS 8110 (1985) (i.e. 20 – 40N/mm^2).

From this experimental work carried by the author, the average compressive strength of the control mix obtained after 28days was 27.66 N/mm2 while the one of dune sand concrete was 22.68N/mm2 which entailed a loss of strength of 18%.

A study carried out by Azzouz (2009) entitled *"Study of concrete composed of dune sand"* aimed at assessing experimentally the influence of dune sands on physical-mechanical characteristics of deformation and durability of concrete composed of dune sands.

The dune sand concrete carried out was composed of natural dune sand, Portland cement with additive, coarse crushed aggregates, ordinary mixing water and admixtures. The materials used were originated from different places (Lichana region, Aïn Bennaoui region and Oued Djedaï region).

From the various experiments carried out, the author came out with the following:

- All the curves have the same shape; before 28 days, compressive strength increases very quick but from 28 days, the increase of compressive strength was relatively small
- The curves of concrete in which were included dune sand had the compressive strength at same ages smaller than the one made with normal sand from Oued
- Concrete composed of 50% SO + 50% SD1 gave compressive strength close to that of the control concrete (100% SO), the concrete made of (50% SO + 50% SD2) gave compressive strength much smaller to the control concrete
- The curve of concrete composed of 70% SO + 30% SD1 for the two cases of cement content was quite like the control curve (100% SO)
- After 60 days, the curve of concrete composed of 70% SO + 30% SD1 for the two cases of cement content crossed that of reference curve and the two curves became confounded

- The different curves in which were included SD2 for both cases of cement content, the compressive strength was very small comparatively to the reference curve
- Results proved that the increase of cement content 350 kg/m^3 à 400 kg/m^3 improved 6%. of compressive
- The compressive strength of concrete increases with the increase of admixtures (For instance 1% of superplasticizer increases 13% of compressive strength without incorporating admixtures)
- 8% of silica fume added to the concrete increased 30% of compressive strength for the two types of combination SD1 and SD2

From this experimental study carried out by Azzouz (2009) tiled “Study of concrete composed of dune sand” aiming at assessing experimentally the influence of dune sands on physical-mechanical characteristics of deformation and durability of concrete composed of dune sands.

The dune sand concrete carried out was composed of natural dune sand, Portland cement with additive, coarse crushed aggregates, ordinary mixing water and admixtures. The materials used were originated from various places. Some noxious elements were found during the chemical analysis precisely sulfate and sulphide.

A study executed in Qatar by Al-Harthy *et al* (2007) on the properties of concrete made with fine dune sand. Results of investigations of concrete made with dune sand showed that different control concrete mixtures using ordinary Portland cement (OPC) with a minimum design compressive strength of 40N/mm2 were prepared. The amount of fine aggregates constituted about 36% by weight of all the aggregates. The workability ranged from low of 16mm to a high of 122mm. For each control mix, other mixtures were prepared in which the fine aggregates were replaced by different percentages of dune sand ranging from 10% to 100%. The effect of dune sand on the workability, compressive strength, tensile strength, modulus of elasticity and initial surface absorption test (ISAT) was studied. Experimental results showed an improvement in the workability of concrete when fine aggregates were partially replaced by dune sand. An increase in slump was measured with increase in dune sand content. However, at high dune sand contents (above 50%), the slump started decreasing with an increase in dune sand. Generally, the strength values decreased with increase in dune sand replacement. The author concluded that the strength loss was not found considerable as the maximum reduction was less than 25% after full replacement.

A study carried out Euibae *et al* (2016) about Drying shrinkage cracking of concrete using dune sand and crushed. Experimental results were presented to evaluate the properties of drying shrinkage cracking of concrete using dune sand (DS) and crushed sand (CS) as fine aggregate (FA). Concrete mixtures were made to meet the target workability with the variation of DS to FA ratio (DS/FA ratio) and water content.

The results showed that the highest compressive strength and the highest tensile strength were shown in concrete mixtures of DS/FA ratio 20% and the strength decreased with the increase of DS/FA ratio when DS/FA ratio was over 20%. The lower water content led to higher net time-to-cracking. Also, the increase of DS led to decrease of CS and the increase of coarse aggregate (CA) in the mixture and this change led to decrease of the net time-to-cracking. It indicates that aggregate volume fraction could affect the drying shrinkage cracking under same total aggregate volume. Based on the changes of aggregate volume and the net time-to-cracking in this study, the restraint factor of CS could be calculated to minimum 54% of the restraint factor of CA and the restraint factor of DS could be less than that of CS.

2.3. Research gap

With reference to the literature review, dune sands have proven a suitable material in concrete as they can be used as full or partial replacement of ordinary fine aggregates. Though, the use of dune sands is associated with shortcomings of reduction in compressive strength and workability of concrete. From the recent researches carried on dune samples collected from places, results showed that some dune sand samples used as alternative materials to ordinary fine aggregate in concrete gave satisfactory compressive strength after 28 days (Al-Harthy *et al* 2007). Some dune sand concrete gave compressive strength greater than others. The variation of strength is due essentially to their chemical and physical properties (Neville, 1999). It would be important to carry out chemical, physical and mechanical studies on dune sand samples collected from Kenya (Nyiri Desert) and Chad (Sahara Desert) to investigate their potential for use in structural concrete and provide a mitigation measure to minimize weaknesses related to dune sand chemical and physical properties.

Chapter 3: Materials and Methods

3.1. Materials

3.1.1. Cement

The type of cement that was used in this study was Ordinary Portland Cement 42.5 locally manufactured. This cement has a wide range of applications from domestic building construction to large civil engineering projects. It has a minimum compressive strength of 42.5MPa at 28 days of curing and is manufactured to harmonize East African Standard KS EAS 18-1.

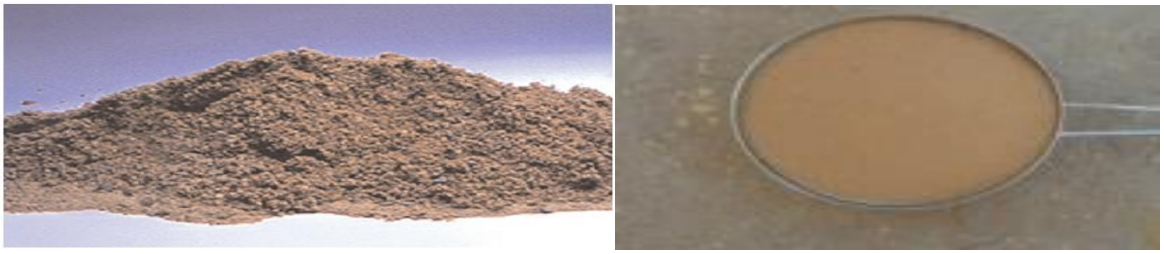
3.1.2. Water

In this study, portable water conforming to ASTM C1602 and BS EN 1008 standards was used for mixing the materials and curing the concrete samples. The water used in this research was obtained from general supply water system of JKUAT University.

3.1.3. Aggregates

i. Fine aggregates

The two types of fine aggregates used in this study were the conventional aggregate collected from Meru river (Kenya) and Chari Baguirmi river (Chad). In this study, sand conforming to BS 882:1992 was used. The fine aggregates that passed the 5.0mm BS 410 test sieve and containing no more coarser material were considered as sand for the study. The types of fine aggregates are shown on figure below.



a) Ordinary sand

b) A dune sand sample

Figure3.1: The two types of fine aggregates used

ii. Coarse aggregates

The coarse aggregates were obtained locally with a maximum size of 14mm and retained on a 5.0mm BS 410 test sieve, conforming to BS 882:1992 specification used in this study. The aggregates were first sieved then washed to remove dust and dirt and air dried to surface dry condition as shown in Figure 3.2.

Figure 3.2: Sample of coarse aggregates used in the study

3.1.4. Silica fume

In this work, the MasterRoc MS 610 was used. It is a high-quality silica fume powder for high performance concrete. It changes the porous structure of the concrete making it denser and more resistant to any type of external influence. It was delivered in powder grey color, with a density ranging between 0.55 and 0.7kg/l and a chloride content less than 0.1%. MasterRoc

MS 610 was added to the concrete during batching and the recommended dosage is 5 to 15% of the cement weight as shown on Figure 3.3.

Figure 3.3: Silica fume

3.2 Methodology

The collection of information from literature review available was used to state the usefulness of employing dune sand in concrete and the probable short comings of using such a material as concrete component and the potential solutions to mitigate those weaknesses.

Coming out with tangible and exhaustive information about the use of dune sand in concrete focused on the advantages and the disadvantages of using these materials in the concrete instead of the ordinary aggregates. The chemical components of the dune sand were evaluated to show their influence on the compressive strength of the hardened dune sand concrete and to provide eventual mitigation measures by using as silica fume as partial replacement of OPC.

The data collection was randomly done by picking samples from different places located in Nyiri desert(Kenya) and Sahara Desert(Chad), the dune sand samples were limited to four and two respectively. Accordingly, the influence of the dune sand in concrete was observed through the experiment by comparing the Non-Conventional Aggregate Concrete (NCAC) and the

Conventional Aggregate Concrete (CAC) in terms of consistency, workability, cohesiveness and compressive strength.

The study was executed in six steps:

1- Chemical and physical analysis of properties of the six samples of dune sand;
2- Carrying out normal concrete taken as control group from Kenya and Chad;
3- Replacement of 100% of ordinary sand by each sample of DS (Dune Sand: DS);
4- Replacement of 10% of Portland cement by silica fume in every Dune Sand Concrete (DSC);
5- Replacement of 15% of Portland cement by silica fume in every Dune Sand Concrete (DSC);
6- Cost analysis of various materials employed in DSC.

3.2.1. Characterization of Constituent materials

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

i. Physical tests carried out

i.1. Sieve Analysis and Fineness Modulus

Particle size distribution for fine (ordinary sand and dune sand) and coarse aggregates was determined by sieve analysis in accordance with BS 812-Part 103-1. Sampling of the aggregates to obtain a representative sample was done in accordance with the procedure described in clause 5 of BS 812:102: 1990 using the quartering method. From the finest sieve upwards, the cumulative percentage passing each sieve was calculated and used for plotting the grading curves. The grading curves were plotted on a semi-logarithmic graph showing the cumulative percentage passing on the abscissa while the sieve apertures plotted on a logarithmic scale.

From the sieve analysis tests, fineness modulus was computed for the fine aggregates by dividing the sum of the cumulative percentage retained on the standard sieves (150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 4.75 mm, 9.5 mm, 19.0 mm, 38.1 mm) divided by 100.

i.2. Specific gravity and Water absorption

Specific gravity of ordinary sand (OS), DS and coarse aggregates (CA) was determined from according to BS 812: Part 2: 1990. The water absorption and specific gravity were determined using a pycnometer and calculated equations 3.1 and 3.2 respectively.

Water absorption (in % of dry mass), $\mathbf{Wabs = 100\frac{(A-D)}{D}}$……………………... Equation 3.1

Relative Density, $\boldsymbol{\rho_s} = \frac{\mathbf{A}}{\mathbf{A-(B-C)}}$ in (ton/m3) ………………………………………Equation 3.2

Where: A- mass of the saturated surface-dry aggregate in air (g)

B- mass of the pycnometer containing sample and filled with water (g)

C- mass of the pycnometer filled with water only (g)

D- mass of the oven-dry aggregate in air (g)

i.3. Density

Densities of fine and coarse aggregates were obtained as per BS 812: Part 2: 1995 clause 5.7 and density of each material recorded.

ii. Chemical tests carried out

DS samples were taken for chemical testing at the laboratories of the Ministries of Mining and Transport in industrial area Nairobi. The chemical tests carried out were heavy metal content, pH value and organic impurities.

iii. Mix Design

Several trial mixes were made to come up with a conventional workable mix using OPC. The mix design ratio that was adopted in this study was 1:2:3 for OPC, fine aggregates and coarse aggregates respectively by weight with a water cement ratio of 0.5 as in accordance with BS 1881-125 (1990).

iii.1. Mix Proportions

From the adopted mix design, various calculations of OPC, fine aggregates, coarse aggregates and water were made for each mix. On completion of the initial mix proportion calculations, a control mix was first made of normal weight concrete without any additions or substitutions (100% OPC+100% OS+ 100% CA). Thereafter, a total of other 18 mixes were conducted. The mixes included full replacement of ordinary sand by 6 different samples of DS, replacement of 10% of OPC cement by SF in the 6 types of DSC and replacement of 15% of OPC cement by SF in the 6 types of DSC.

For each batch made, a slump test was performed on the fresh concrete, thereafter concrete cubes and cylinders were cast mechanical tests such as compressive strength (after 7, 14 and 28 days of curing) and concrete density.

iii.2. Batching, Mixing, Casting and Curing

iii.2.1 Batching and Mixing

In this study batching was done by weight. The batching procedure first entailed weighing all the individual material fractions as per the mix design calculations which included coarse aggregates, fine aggregates and OPC. This was followed by weighing of DS percentages of 100%. Then, weighing of SF of 10% and 15% of the cement weight. Finally, addition of the calculated quantity of mixing clean water made. After addition of water, mixing (shown in Figure 3.4) was extended for a further period of 3 minutes to obtain a homogenous mix.

Figure 3.4: Mixing of concrete to obtain a homogenous mix

iii.2.2. Casting

Before casting, all the cubic molds were cleaned and oiled properly. Cube steel mold dimensions of 150x150x150mm conforming to BS EN 12390-1:2000 were used for compressive and density. The molds were tightly screwed to ensure that there were no spaces left which could lead to a possibility of a slurry leakage. The cleaned and oiled molds for each category were filled with concrete in three layers using a poker vibrator up to when a cement slurry appeared on top of the molds as shown in Figure 3.5. The specimens were then left in the molds covered with a wet sack for 24hours.

Figure 3.5: Casting and compacting concrete into the concrete molds

iii.2.3. Curing

Open air curing was done for 24hours, after which the specimens were removed from the molds and then placed in the curing tank containing clean water before 7, 14 and 28 days mechanical testing.

iii.3. Workability

The workability of the concrete was determined using the slump test as shown in Figure 3.6 below. The slump test measures the consistency of fresh concrete before it sets. It is a test performed to check the workability of freshly made concrete. In this study, a slump test was carried out on each batch of freshly mixed concrete conforming to BS 1881 Part 102:1983.

Figure 3.6: Slump test on concrete

iii.4. Compressive Strength

The compressive strength test for this research was determined using Universal Testing Machine (UTM) at JKUAT laboratory of civil engineering as specified in the test method BS 1881-Part 116,1983. Mean compressive strength was obtained by calculating the average of the three values that were calculated using Equation 3.3 for each mix. A total of 162 cubes were casted, cured and tested after 7, 14 and 28 days.

Compressive Strength was calculated by CS= $\frac{\mathbf{P}}{\mathbf{A}}$…………………………………… Equation 3.3

Where: P: Ultimate compressive load of concrete (kN)

A: Surface area in contact with the platens (mm^2)

iii.5. Density of Concrete

The density of concrete was determined with reference to BS 1881-114 using the 150x150x150mm cubes. The density (ρ) is the mass of a unit volume of hardened concrete expressed in kilograms per cubic meter as shown in equation 3.4. Density was carried out at both 7, 14 and 28 days of curing, three runs for each mix were made, and an average density was obtained.

$\boldsymbol{\rho = \frac{m}{v}}$……………………………………………………… ………………Equation. 3.4

Where: m- mass of the saturated specimen in air (in kg) v- Volume of specimen calculated from its dimensions (in m^3)

iii.6. Cost Analysis

Cost analysis is defined as the act of breaking down a cost summary into its constituents and studying and reporting on each factor. Construction material cost consists of material cost, shipping charges and taxes applicable if any. Cost estimates enables one to carry out financial appraisal, prepare a business plan, establish detailed budget, control spending, assess manpower requirements and perform many other management procedures. There is no specific standard for a cost analysis therefore the cost analysis was case basis. In this study, an estimation of all the components incorporated in the concrete were made. The maximum distance of transport was assumed to be 15 km. Chadian rule of the public markets as stipulated in Decree n° 555/PR/PM/MID/2017 stated that when a distance for transporting construction materials does not exceed 15km, the of cost of transport should not be included the final cost of a project. In this study, a safety factor of 10% was added to compensate or minimize any eventual contingency.

Chapter 4: Results and Discussions

4.1 Chemical properties of dune sand

4.1.1 Heavy Metal Content

Heavy metals are generally defined as metals with relatively high densities, atomic weights, or atomic numbers. It is important that the proportions of various metals present in a sample should be known to compare with the maximum allowable. Beyond a certain proportion, heavy metals become unfriendly to the environment. Babu and Aemere (2007) reported lead (Pb), zinc (Zn), Mercury (Hg), copper (Cu), nickel (Ni), iron (Fe) and chromium (Cr) were friendly with cement mortar up to 600 mg/L. Mindess and Young (2006) reported the tolerable limit of Cu, Pb, Zn, manganese(Mn) was 500 mg/L.

In addition to that aspect, some metals affect the compressive strength which would affect the durability of hardened concrete. B. Madhusudana Reddy and I. V. Ramana Reddy (2007) reported that the strength developments in reference and test specimens were the same for concentration of up to 100 mg/L. For the concentration of 500 mg/L, the observed decrease in compressive strength at 3 days was 2.4%. BS 3148 allows a maximal particle in suspension of 2000ppm.

Table 4.1 gives the different heavy metals present in the various samples of dune sand collected from Nyiri Desert(Kenya) which are sample A, sample B, sample C, sample D and those collected from Sahara Desert(Chad) that are sample 1 and sample 2.

Table 4.1: Heavy metal content

Element	Sample A	Sample B	Sample C	Sample D	Sample 1	Sample 2	Unit Conc'n
Potassium (K)	1.55 ± 0.21	1.09 ± 0.20	3.08 ± 0.34	3.11 ± 0.27	ND	ND	%
Calcium (Ca)	4.69 ± 0.24	7.01 ± 0.29	4.54 ± 0.24	3.48 ± 0.20	ND	ND	%
Titanium (Ti)	1.0 ± 0.06	0.907 ± 0.048	1.64 ± 0.09	0.931 ± 0.062	0 ± 0.06	0 ± 0.06	%
Manganese (Mn)	1327 ± 103	1072 ± 97	1244 ± 111	1215 ± 112	0.8 ± 0.06	1 ± 0.06	ppm
Iron (Fe)	6.95 ± 0.27	7.64 ± 0.23	5.28 ± 0.20	6.68 ± 0.29	40.0 ± 0.20	38.0 ± 0.20	ppm
Copper (Cu)	285 ± 24	330 ± 26	343 ± 30	315 ± 34	0.50 ± 20	0.60 ± 20	ppm
Zinc (Zn)	78.225	63.8 ± 6.06	83.2 ± 4.0	95.0 ± 10.2	1.10 ± 0.06	0.80 ± 0.06	ppm
Rubidium (Rb)	35.8 ± 4.0	18.5 ± 1.4	81.6 ± 5.5	89.3 ± 5.1	ND	ND	ppm
Strontium (Sr)	621 ± 17	494 ± 21	536 ± 16	287 ± 11	ND	ND	ppm
Yttrium (Y)	34.8 ± 2.3	25.6 ± 1.9	84.8 ± 6.5	54.6 ± 5.0	ND	ND	ppm
Zirconium (Zr)	689 ± 38	359 ± 21	3867 ± 174	575 ± 36	ND	ND	ppm
Lead (Pb)	25.4 ± 1.3	17.8 ± 1.8	34.5 ± 3.7	28.7 ± 10.0	2.0 ± 0.06	2.50± 0.06	ppm
Chromium(Cr)	ND	ND	ND	ND	3.0± 0.06	4.0± 0.06	ppm
Origin	Kenya	Kenya	Kenya	Kenya	Chad	Chad	

Results showed that samples collected from Kenya contain high proportion of Manganese which were beyond 500mg/L. All the heavy metal of samples collected from Chad remained less than the permissible proportion.

Regardless the various proportions of heavy metals contained in different samples collected, results of this study showed that the samples are friendly to the environment and will not affect the durability of concrete because of the proportions which fit in the allowable limits except the sample C with a high Zirconium (Zr) proportion. Zr is not toxic, the degree of its toxicity is low.

Human beings and plant possess numerous defense mechanisms to cope with its toxicity. It is extremely resistant to heat and corrosion contributing to reduce concrete temperature effects and to increase concrete strength (ISO 10270:1995; Shahid et al, 2013).

4.1.2 pH Value

pH (potential of hydrogen) is an approximate measure of acidity or alkalinity of a solution and is defined as the negative logarithm of the hydrogen ion (H +) concentration.

pH is the important parameter in studying the properties of concrete. Both low and high pH create problem in concrete in terms of corrosion and spalling. So, it is important to know the pH value of all the components of the future hardened concrete. The acidic state of concrete components will affect in terms of durability, acid destroys the protection layer of concrete resulting in loss of strength.

The test procedures are based on British Standard (BS) for testing of soils, aggregates and concrete as prescribed in BS1377: Part 3:1990(Chemical Tests).

The results obtained after testing are shown on the Table 4.2 below.

Table 4.2: pH value

Sample	pH	Origin
Sample A	8.83 ± 0.06	Kenya
Sample B	8.97 ± 0.06	Kenya
Sample C	8.63 ± 0.06	Kenya
Sample D	8.53 ± 0.06	Kenya
Sample 1	8.0 ± 0.06	Chad
Sample 2	7.80 ± 0.06	Chad

The results showed that the pH value ranges from 7.80 to 8.97 which means that all the samples were basic. Fereshte et al (2015) reported that the compressive strength of CEM cement improved in the presence of acidic and alkaline environments but alkaline environment showed the best results. Neville (1995) stated that pH range between 6.0 and 8.0 or even 9 have no significant effect on the compressive strength of concrete.

Results showed that, the pH value of all the samples remained slightly higher than the neutral state. These results ranging around neutral state were advantageous to the pH reduction of the future hardened because of the values which were neither too high nor too low.

4.1.3 Organic Impurities in dune sand samples

BS1377: Part 3:1990 and NPRA 014 test 14.445, Organic Content - Ignition Loss Method was used in this study to determine organic impurities. Testing of organic impurities in sand, BS1377: Part 3:1990 requires that the color of sodium hydroxide solution in sand should be lighter than the solution of sodium hydroxide mixed with tannic acid, both solutions having been preserved for 24 hours after mixing as detailed in BS 882. The permissible percentage of organic impurities in aggregates for concrete was 0.5%.

The Table 4.3 below gives the proportion of impurities after test conducted as per BS standard.

Table 4.3: Organic content of dune sand samples

Sample	**Organic content (% m/m)**	**Origin**
Sample A	0.040	Kenya
Sample B	0.054	Kenya
Sample C	0.094	Kenya
Sample D	0.081	Kenya
Sample 1	0.242	Chad
Sample 2	0.161	Chad

All the six dune sand samples tested indicated lighter color than the standard solution 24 hours after mixing. This indicated that all the collected were within the organic content limit as set in ASTM C40.

Results showed that organic content ranges from 0.040 to 0.242%. All the samples collected from Kenya showed small proportions of impurities meanwhile dune sand samples collected from Chad showed the highest proportions of organic content.

Although some samples contained some high proportions of impurities but, regardless permissible organic content, all the samples of dune sand were acceptable to be used as concrete component.

Ruiz *et al* (2010) established a precipitation threshold of 500mm per year below which vegetation is no longer associated with great moisture contents and soil status depends more on its physical and chemical properties. The high proportion of organic content in DS samples collected from Chad was related to their constituent properties and the high wind pressure from Sahara Desert that can carry huge quantity of particles in suspension.

4.2 Physical properties of dune sand and normal aggregates

4.2.1 Particle size distribution

The particle size distribution test was carried out according to BS1377: Part 2:1990. The particle size distribution of fine aggregates and normal aggregates are presented from Figure 4.1 to 4.8 below.

Grading Zone As per IS:383   ZONE-II

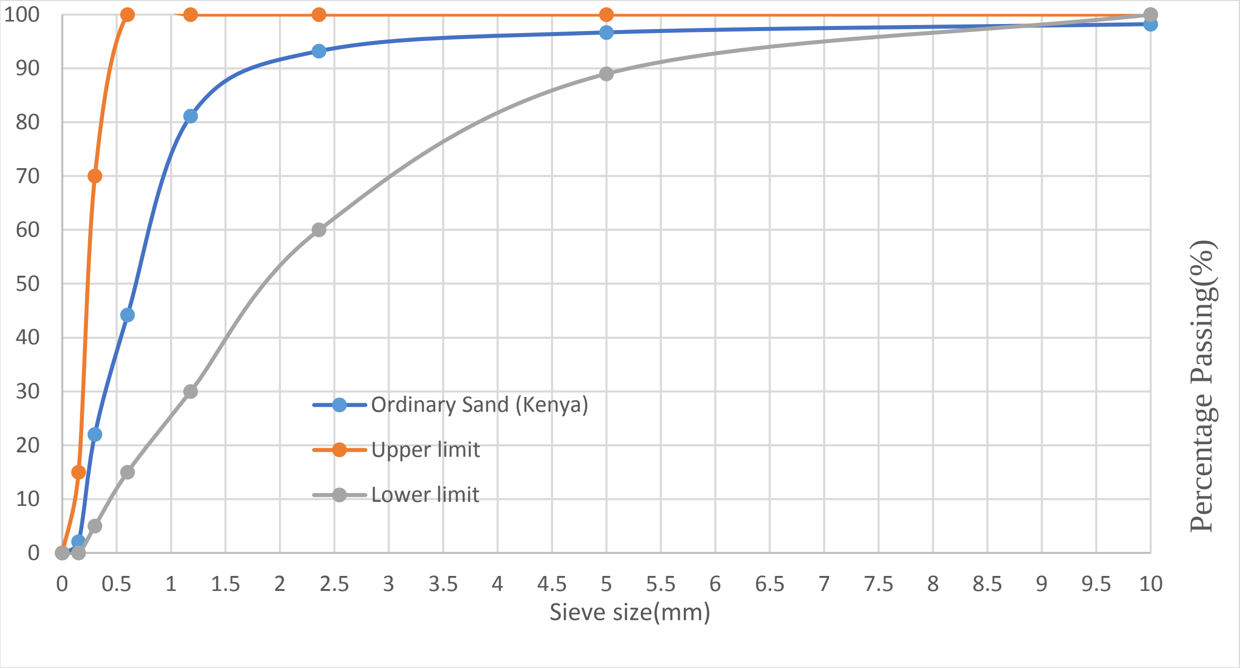


Figure 4.1: Sieve analysis graph of Ordinary Sand-Upper Limit-Lower Limit

Grading Zone As per IS:383   ZONE-IV

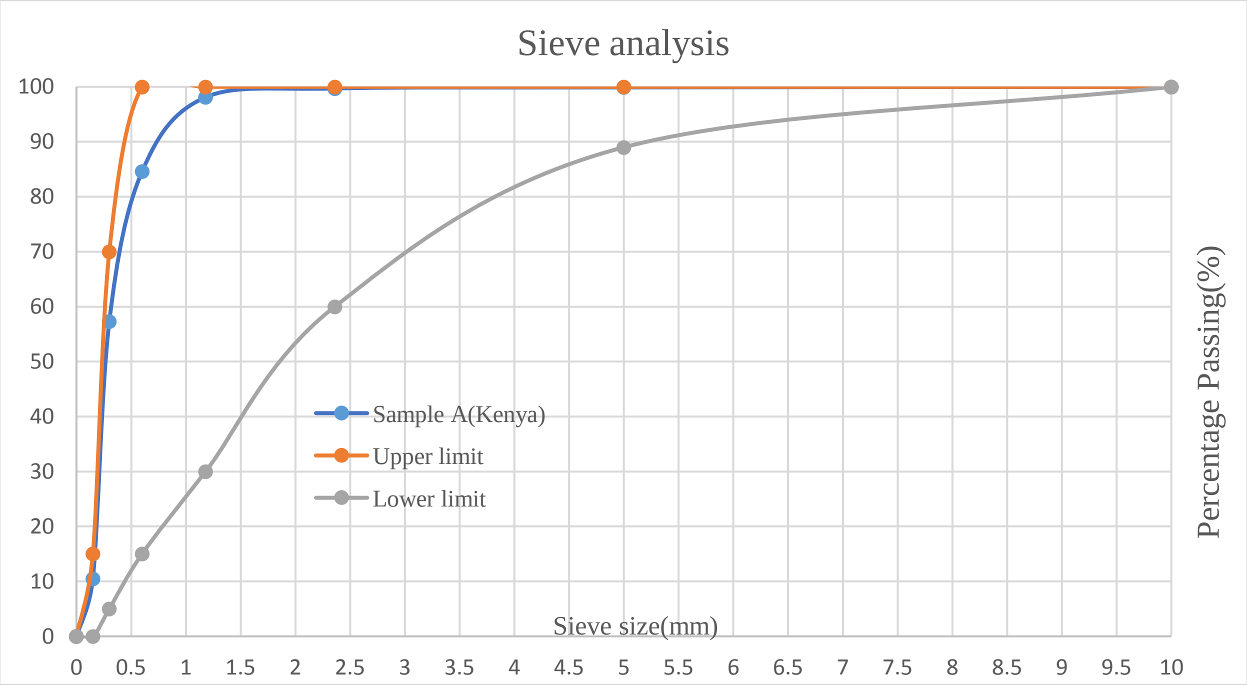


Figure 4.2: Sieve analysis graph of sample A-Upper Limit-Lower limit

Grading Zone As per IS:383 ZONE-IV

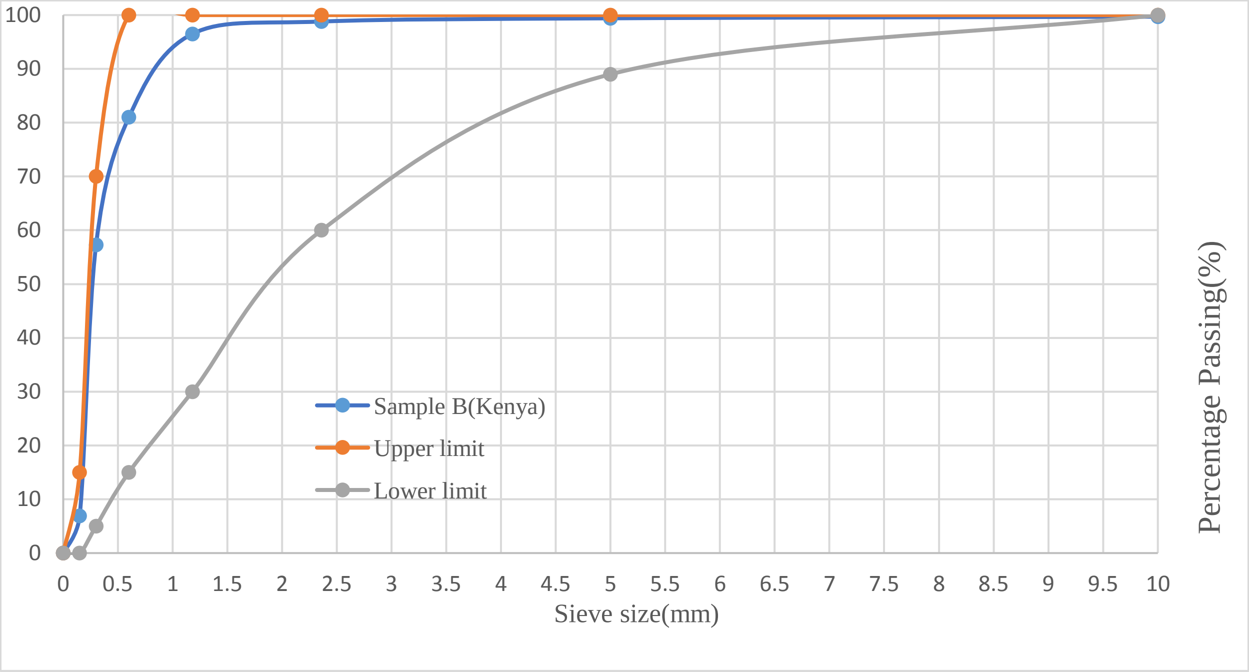


Figure 4.3: Sieve analysis graph of Sample B-Upper Limit-Lower limit

Grading Zone As per IS:383 ZONE-IV

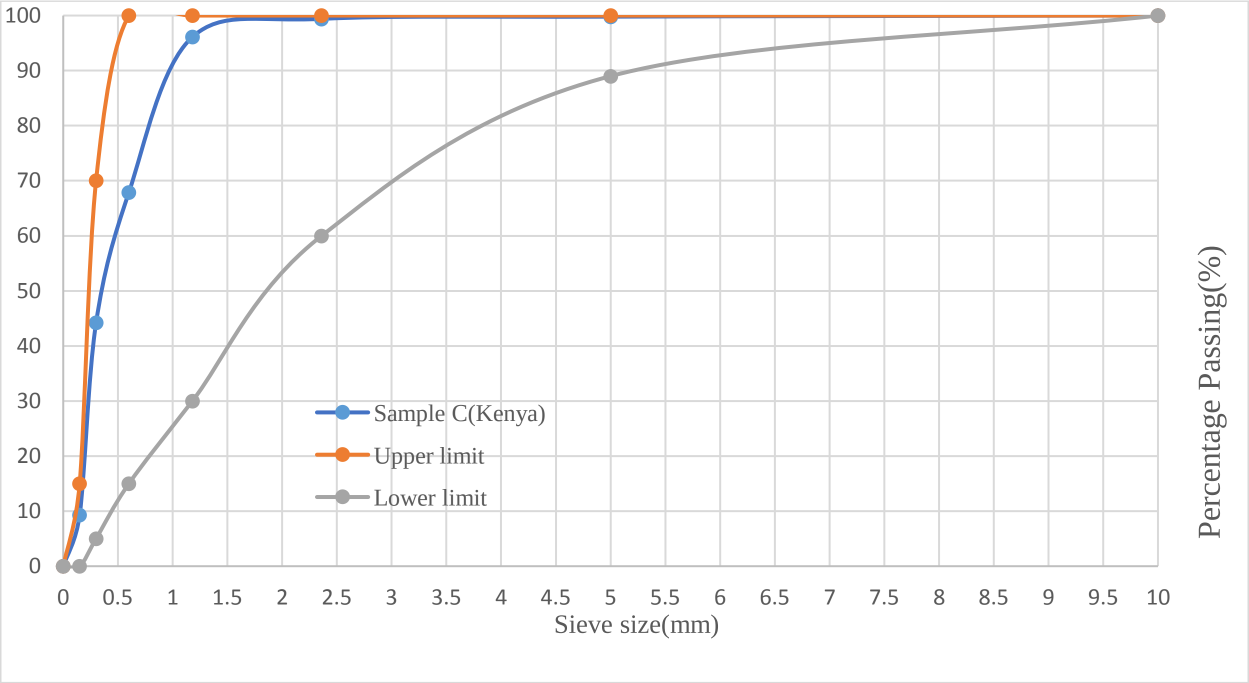


Figure 4.4: Sieve analysis graph of Sample C-Upper Limit-Lower limit

Grading Zone As per IS:383 ZONE-IV

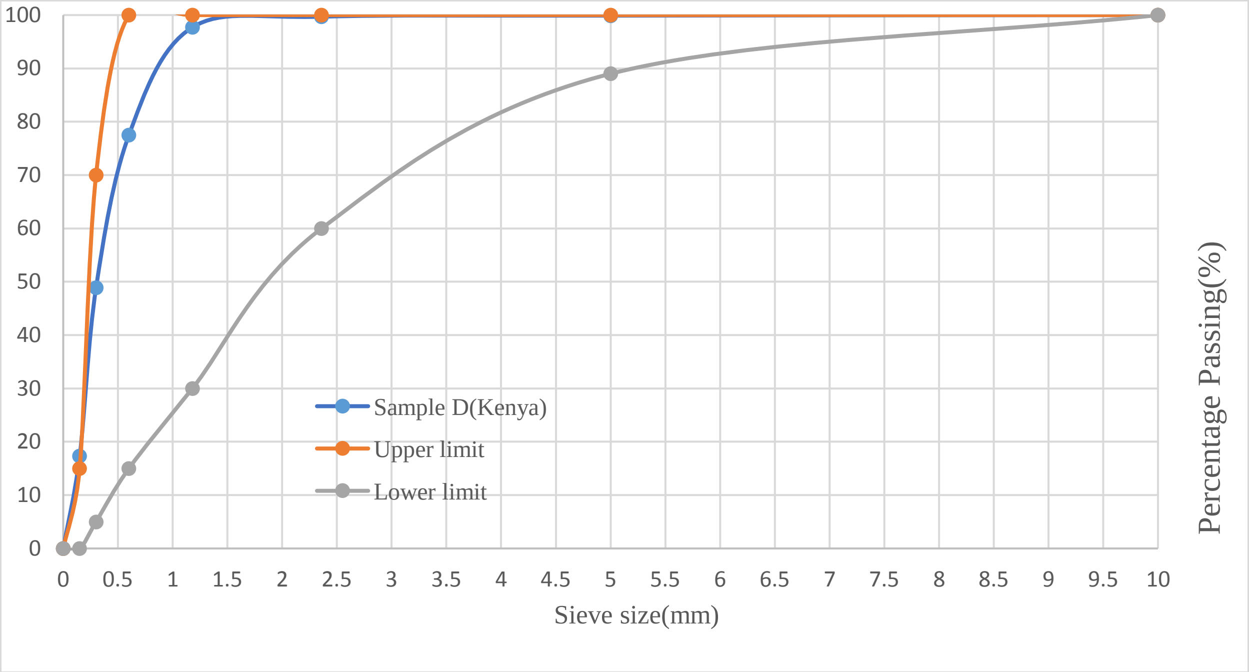


Figure 4.5: Sieve analysis graph of Sample D-Upper Limit-Lower limit

Grading Zone As per IS:383 ZONE-I

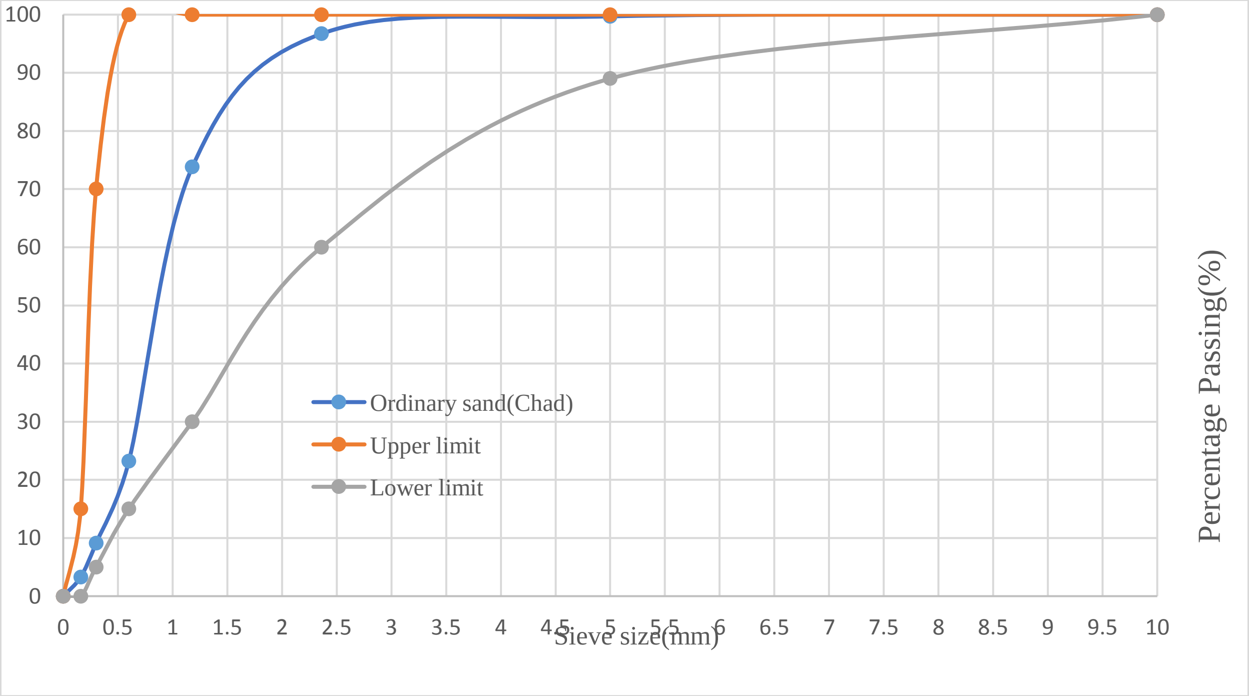


Figure 4.6: Sieve analysis graph of ordinary sand-Upper Limit-Lower Limit

Grading Zone As per IS:383 ZONE-IV

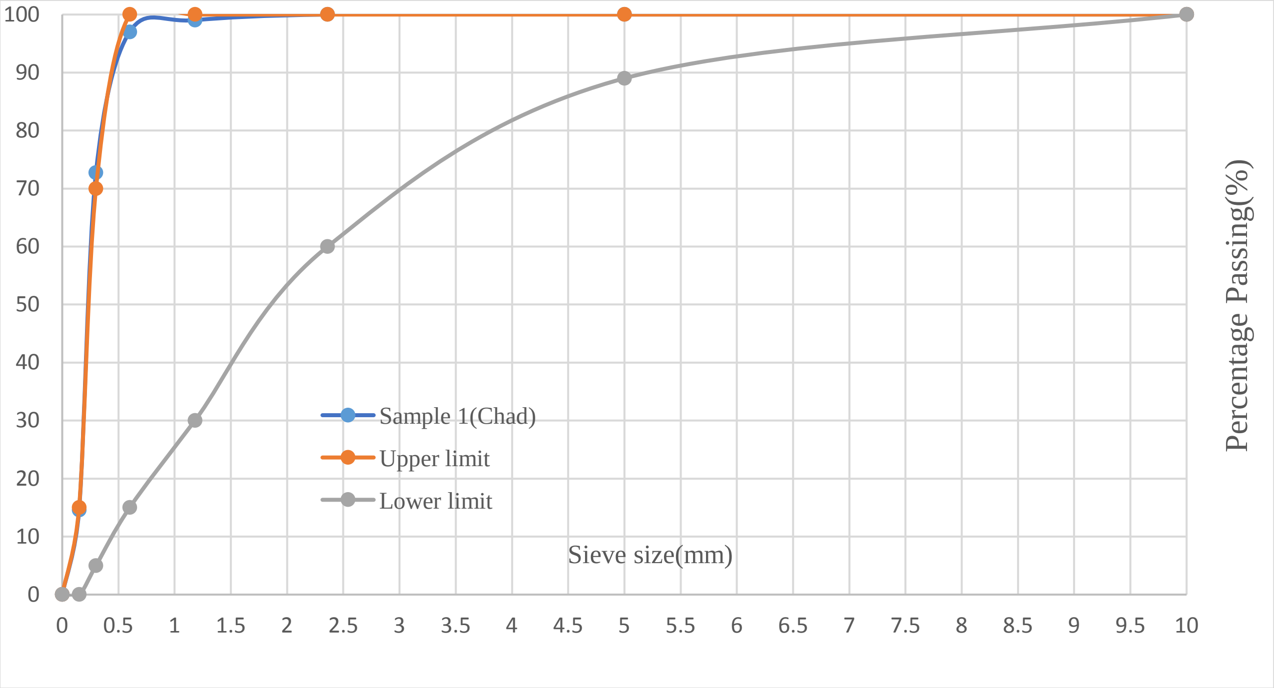


Figure 4.7: Sieve analysis graph of Sample 1-Upper Limit-Lower Limit

Grading Zone As per IS:383 ZONE-IV

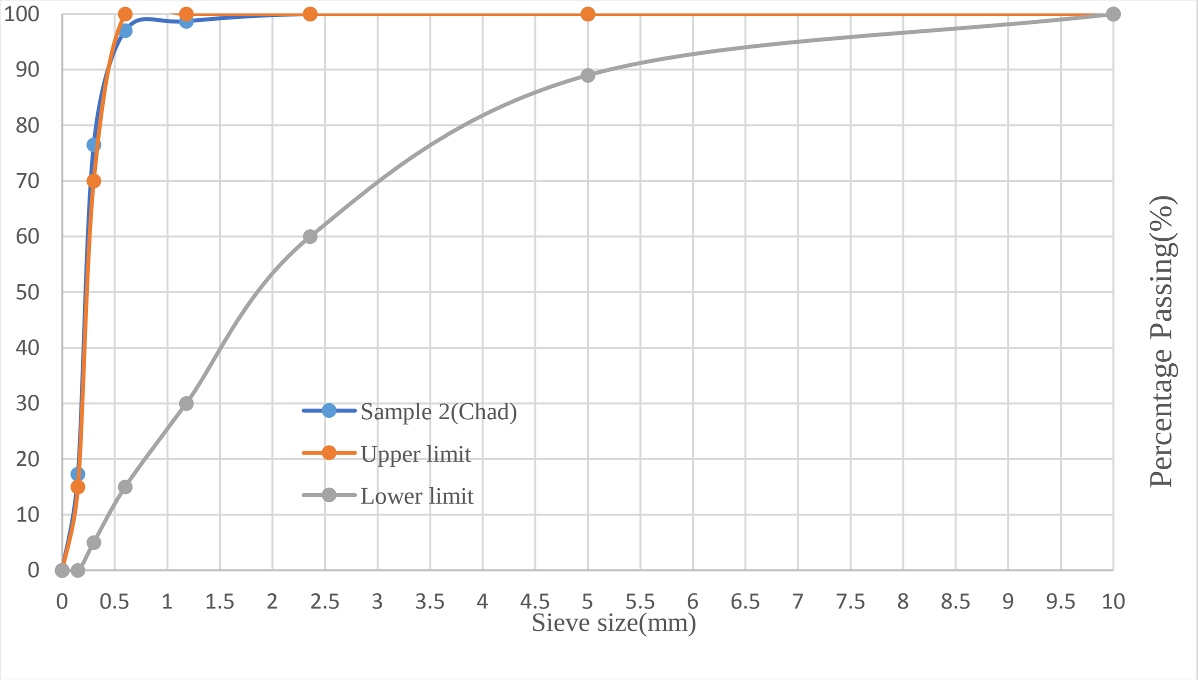


Figure 4.8: Sieve analysis graph of Sample 2-Upper Limit-Lower Limit

Particle size distribution of fine and micro-aggregate is known to strongly influence the microstructure of concrete. Sieve testing is one of the very fast methods of checking the quality of construction sand. Even though, the result of sieve test cannot be considered as the result to ensure the quality of sand.

The maximum ordinary fine aggregates size was 5mm for the OS from Kenya and Chad. While the maximum dune sand size was 5mm for the dune sand from Kenya and 1.18mm for the dune sand samples from Chad.

The average proportion of passing through the sieve size 0.600mm was 97% for the dune sand samples collected from Sahara Desert while the one of samples from Nyiri desert was an average of 77.75%. The difference in proportion was related to Sahara Desert originating from the various transgressions of Paleo-Chadian Sea and Nyiri Desert, the rain shadow of the Mount Kilimanjaro. The fineness of fine aggregates necessitated more bonding elements resulting in supplementary cost.

Describing an aggregate by its maximum and minimum size is not sufficient. It must be graded from its minimum to maximum size. IS-383 recommends some grading limit for fine aggregates.

The particle size distribution tests of all the samples as well as ordinary sand dune sands collected from Chad and Kenya were shown on the Figures and Tables above. After classification as per IS-383, the ordinary sand from Chad belonged to Zone-I meaning that the sand was coarse. Meanwhile the ordinary sand from Kenya belonging to Zone-II was normal sand. All the dune sand samples collected from Chad and Kenya after classification belonged to Zone-IV representing the finer sand in all the four zones.

From the particle size distribution curves shown in figures above, the gradings of only ordinary fine aggregates were observed to be within the upper and lower limit requirements of BS 882 (1992), indicating a uniformly graded particle size distribution of all the two types of aggregates. Meanwhile the ones of all the dune sand samples reached the lower limit grading.

In general, studies have shown that uniformly graded aggregate contribute more positively to the overall quality of concrete than gap-graded aggregates and desirable for efficient use of the paste (Chandra and Berntsson, 2002). Uniformly distributed aggregates lead to higher packing, resulting in concrete with higher density, less permeability, decreased cost of production, easy placement and enhanced overall quality of the concrete, and improved abrasion resistance (Mehta and Monteiro, 1993).

In this study, the fineness of DS samples necessitated the use of more bonding constituent (OPC and SF). The finer the aggregates, the more bonding component needed. The high fine proportions of DS sample affected all the properties of fresh and concrete leading to low workability and low compressive strength. All coarse aggregates passing through 5mm sieve size were excluded because they affected the properties of concrete additionally to DS effects.

4.2.2 Water absorption

The water absorption of aggregates is a key parameter in concrete mix design. The absorption is important in determining the net water-cement ratio in the concrete mix. The 24-hour water absorption obtained for all the aggregates are shown on the Table 4.4 below.

Table 4.4: Water absorption of aggregates

Sample	Water Absorption (%)	Origin
Ordinary Sand	6.53	Kenya
Coarse Aggregates	2.92	Kenya
Sample A	8.24	Kenya
Sample B	12.31	Kenya
Sample C	5.45	Kenya
Sample D	13.61	Kenya
Ordinary Sand	4.35	Chad
Coarse Aggregates	3.16	Chad
Sample 1	13.52	Chad
Sample 2	13.83	Chad

As shown above, the proportion of water absorption of all the samples were between 2.92 and 13.93%. The finer the aggregates, the higher the water absorption and inversely.

In general, most lightweight aggregates have higher water absorption values than normal weight aggregates. The high-water absorption properties of dune sands might be attributed to high porosity and large interconnecting pore structure of the aggregates. Since the water absorption of the dune sands is high, it is reasonable to conclude that the dune sand absorbs a greater amount of mixing water during concrete production. However, the high-water absorption of dune sands can be beneficial to the resulting hardened concrete. LWC with porous aggregates (i.e. high-water absorption) is less sensitive to poor curing as compared to NWC, especially in the early ages due to the internal water stored by the porous lightweight aggregates (Browning *et al*, 2011).

4.2.3 Specific gravity

Specific gravity is the density of a material at a certain temperature divided by the density of water at a certain temperature, the reference temperature is usually 20 degrees Celsius.

Balamurali Arumugam (2014) reported that the main cause in variation in weight of cube found to be specific gravity of coarse aggregate. It plays an important role in weight of concrete cube and specific gravity of an aggregate is a measure of strength or quality of material and specific gravity test helps in identification of stone.

The specific gravity test is prescribed by BS1377: Part 2:1990. The Table 4.5 below gives the different values of specific gravity according to each sample.

Table 4.5: Water absorption of aggregates

Sample	Specific gravity	Origin
Ordinary Sand	2.45	Kenya
Coarse Aggregates	2.58	Kenya
Sample A	2.39	Kenya
Sample B	2.29	Kenya
Sample C	2.4	Kenya
Sample D	2.04	Kenya
Ordinary Sand	2.52	Chad
Coarse Aggregates	2.6	Chad
Sample 1	1.85	Chad
Sample 2	1.78	Chad

The values of the specific gravities of the ordinary aggregates were from 2.45 to 2.60. These values are within the ranges for the specific gravity of aggregates from rock fragments (Olanipekun *et al*, 2006; Neville, 1995).

The specific gravity obtained for dune sands were from 1.78 to 2.40 which fall below the permissible values.

The high porosity of dune sands is likely to have contributed to the low specific gravity value compared to that of the ordinary sands. Generally, aggregates with specific gravity less than about 2.4 are classified as light weight while normal weight concrete aggregates have specific gravity around 2.6 (Popovics, 1992). The specific gravities obtained from the study were considered representative of lightweight and normal weight aggregate respectively.

4.2.4 Silt and clay Content

Silt and clay content is a fine material which is less than 150 microns. Usually, they are either silts or clayey silts, and are difficult to remove from the aggregate surface. They are unstable in the presence of water. Excessive quantity of silt and clay, not only reduces the bonding of cement and fine aggregates but also affects the strength and durability of concrete. The permissible Silt and clay content in sand percentage is only 6% (BS 12620:2013), IS:2686-1977 allows up to 8%.

Table 4.6: Silt content of aggregates

Sample	Silt content/clay (%)	Origin
Ordinary Sand	3.60	Kenya
Sample A	5.01	Kenya
Sample B	5.12	Kenya
Sample C	5.20	Kenya
Sample D	4.96	Kenya
Ordinary Sand	3.26	Chad
Sample 1	20.43	Chad
Sample 2	19.68	Chad

The proportion of silt and clay content of OS from Chad and Kenya were from 3.26 to 3.60 which are below the permissible limit as shown on Table 4.6.

From Table 4.6, the silt and clay contents of DS samples collected from Kenya ranged from 4.96 to 5.20% which are below the permissible silt content limit while the ones of the samples collected from Sahara Desert were from 19.68 to 20.43% which were beyond the permissible limits as stipulated by BS 12620:2013.

Shih-Wei (2013) reported that a decrease in durability occurs when the ratio of silt content to fine aggregate exceeds 5%. The compressive strength, however, when silt fine content is small than 5%, increases only 1 MPa. But decreases from 3MPa to 5 MPa when the silt content increases from 7% to 9%.

According to the French Standard NF EN 933-8, a sand with a silt and clay content within 30-40% is a clean sand with low percentage of fine clay adequate for high quality concrete. Therefore, the DS collected from Chad could be used successfully for high quality concrete.

4.2.5 Fineness Modulus(FM) of sands

FM is generally used to get an idea of how coarse or fine the aggregate is. In this study, FM of sands was determined using BS 812-103.1:1985, the amount of material passing the 75µm sieve shall not exceed the quantities of 2%. The higher the FM, the coarser the aggregate. Fine aggregate affects many concrete properties, including workability and finish ability. Usually, a lower FM results in more paste, making concrete easier to finish. For the high cement contents used in the production of high-strength concrete, coarse sand with an FM around 3.0 produces concrete with the best workability and highest compressive strength. Table 4.7 gives the FM of OS and DS used in the concrete mix.

Table 4.7: Fine Modulus of fine aggregates

Sample	Fineness Modulus	Origin
Ordinary Sand	2.68	Kenya
Sample A	1.53	Kenya
Sample B	1.74	Kenya
Sample C	1.83	Kenya
Sample D	1.59	Kenya
Ordinary Sand	2.89	Chad
Sample 1	1.20	Chad
Sample 2	1.10	Chad

ASTM C33 suggests that the fineness modulus be kept between 2.3 and 3.1. Very fine sand will increase the water demand of the mix, while very coarse sand could compromise its workability.

All the ordinary sands were within the allowable limits. The FM of the sand dune samples ranged from 1.10 to 1.83. All these values were below the permissible limit in terms of fineness of fine aggregates. In FM, the finer the material the more the water demand. FM is used for estimating the quantity of coarse aggregate to be used in the concrete mix design. The FM of fine aggregates should not be less than 2.3 or more than 3.1 or vary by more than 0.20 from batch to batch.

For this specific case of dune sand concrete mix design, it would be important to have a very small proportion of fines in coarse aggregates since more water or superplasticizer is required because of high surface area to have a good workability. Water content is one of the key factors affecting the compressive strength of concrete as it is more required for DSC, it negatively influenced the strength, so it was important to adjust the grading of coarse aggregates to minimize the loss induced. The finer the fine aggregates the coarser the coarse aggregates demand.

4.3 Fresh Concrete Testing

The potential strength and durability of the future hardened concrete is relatively dependent on the degree of its compaction. It is therefore important that the consistency of the mix be in such that, the fresh concrete can be transported, placed and finished early enough to reach the target strength and durability. Fresh concrete testing involved slump test and compacting factor test. Slump tests were conducted to determine workability and consistency of each concrete mix.

4.3.1 Slump Test

The slump test is prescribed by BS 12350-2: 2000. For the control concrete mix design, the specified slump was from 10-30mm. The control concrete mix design was 1:2:3 while the water/cement ratio was 0.5 and the cement content 380kg/m^3. These factors above remained constant for all the mixes as well as DSC. DS samples were then used as full replacement of OS for the assessment of physical and chemical properties of DS on concrete. Finally, SF was used as an additive to OPC to evaluate the effect of SF on DSC.

The slump test results are shown on Table 4.8 below.

Table 4.8: Slump Test of concrete

Sample	Slump(mm)	Origin
Control	26	Kenya
Sample A	19	Kenya
Sample A (10%)	5	Kenya
Sample A (15%)	0	Kenya
Sample B	13	Kenya
Sample B (10%)	4	Kenya
Sample B (15%)	0	Kenya
Sample C	10	Kenya
Sample C (10%)	6	Kenya
Sample C (15%)	0	Kenya
Sample D	10	Kenya
Sample D (10%)	3	Kenya
Sample D (15%)	0	Kenya
Control	23	Chad
Sample 1	9	Chad
Sample 1 (10%)	5	Chad
Sample 1 (15%)	0	Chad
Sample 2	8	Chad
Sample 2 (10%)	4	Chad
Sample 2 (15%)	0	Chad

Slump test results showed values ranging from 0–26 mm. The concrete mix design had a specified slump ranging from 10-30mm. All the control mixes slump fell within the expected limits. When DS was fully replaced by OS, Samples A, B, C and D had slumps which remained within the specified limits while the ones of Samples 1 and 2 were below the specified slump. This variation in slump was due to the aggregate size(fineness).

The Figures (4.9-4.14) below show the variation of slump in function of DS and SF replacement.

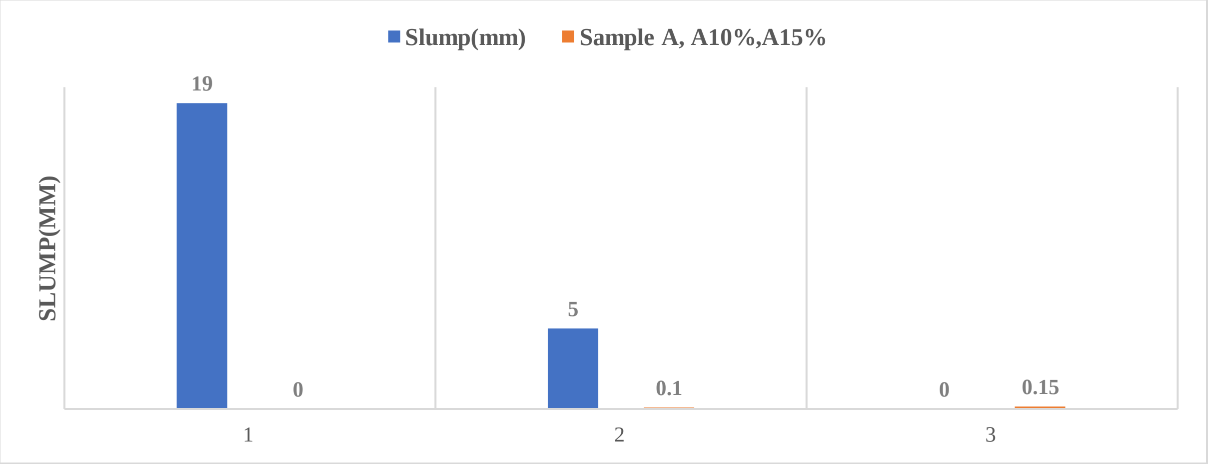


Figure 4.9: Variation in slump of Sample A

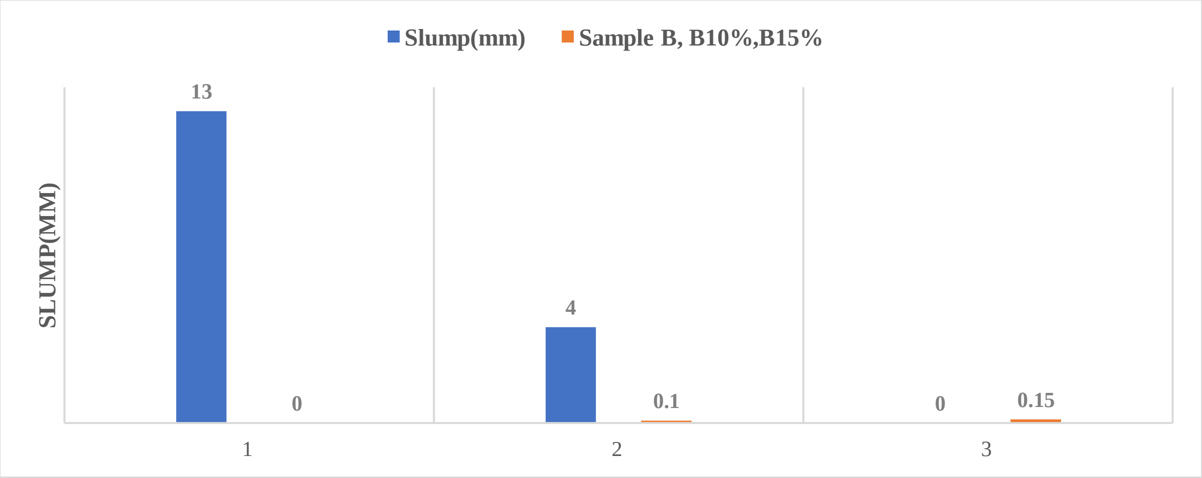


Figure 4.10: Variation in slump of Sample B

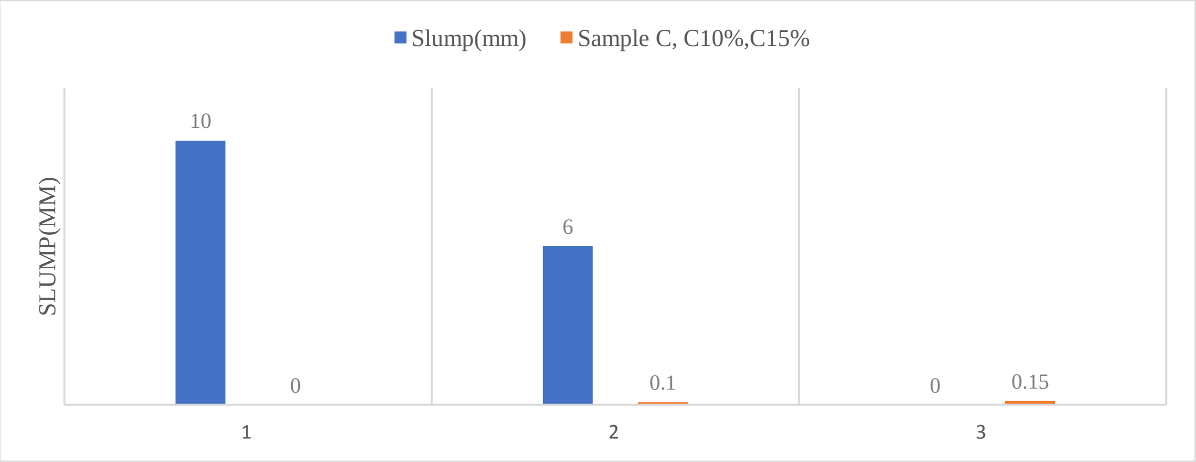


Figure 4.11: Variation in slump of Sample C

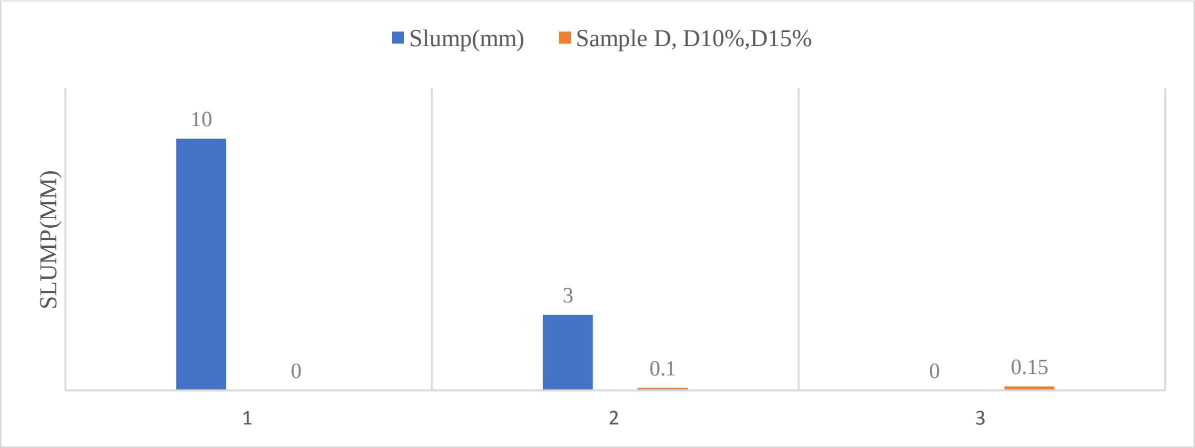


Figure 4.12: Variation in slump of Sample D

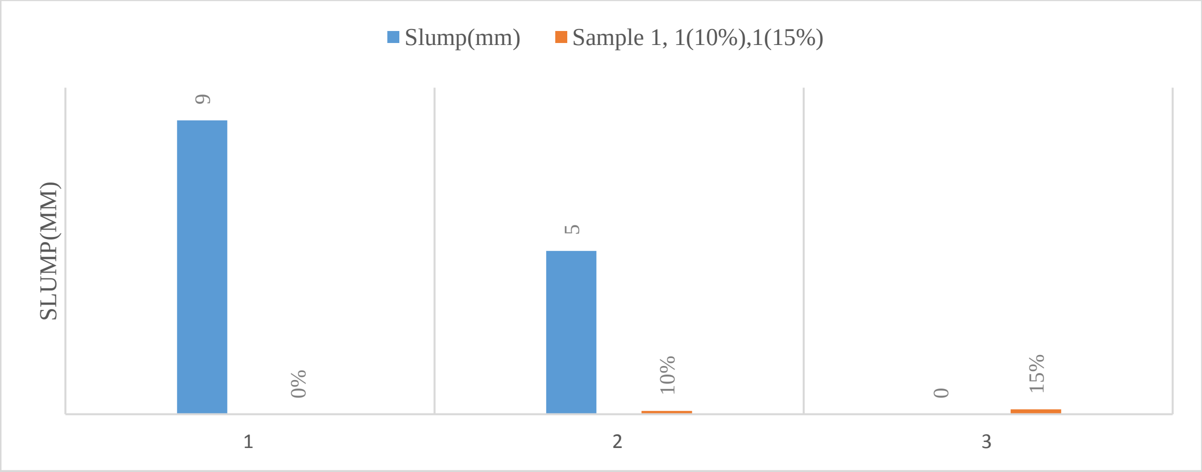


Figure 4.13: Variation in slump of Sample 1

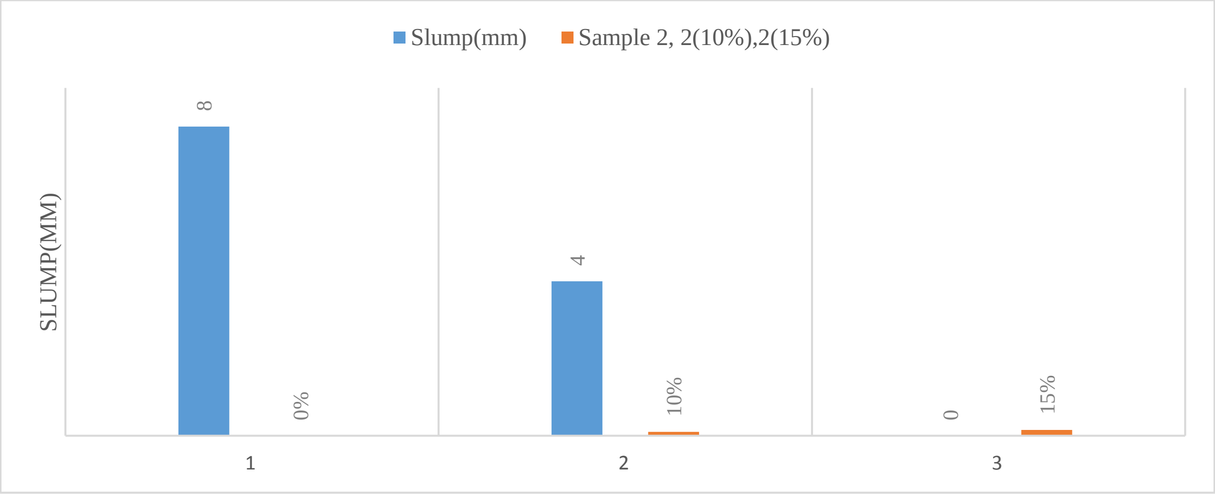


Figure 4.14: Variation in slump of Sample 2

When SF was added as a partial replacement of OPC, the slump started decreasing. At 10% replacement, the slump varied from 2-6mm. When the proportion of SF was increased to 15%, the slump was 0mm for all the samples. These results were justified by the increase of surface area due to the fineness of silica fume and the high-water absorption of both DS samples and SF.

4.4 Concrete Density

The concrete is prescribed as per BS EN 1991-1-1 which specifies densities, self-weight and imposed loads.

One of the most important properties of a good quality concrete is low permeability, especially one resistant to freezing and thawing. A concrete with low permeability resists ingress of water and is not as susceptible to freezing and thawing. Water enters pores in the cement paste and even in the aggregate.

Dorf and Richard (1996) reported that the density of normal concrete is 2400 kg/m^3 and the density of lightweight concrete is 1750 kg/m^3.Table 4.9 shows the average density saturated surface dry of the various concrete mixes.

Table 4.9: Concrete density(SSD)

Control	**Concrete Density(kg/m^3), Saturated Surface Dry**	**Origin**
Control	2515	Kenya
Sample A	2588	Kenya
Sample A (10%)	2546	Kenya
Sample A (15%)	2455	Kenya
Sample B	2607	Kenya
Sample B (10%)	2590	Kenya
Sample B (15%)	2538	Kenya
Sample C	2520	Kenya
Sample C (10%)	2514	Kenya
Sample C (15%)	2545	Kenya
Sample D	2567	Kenya
Sample D (10%)	2502	Kenya
Sample D (15%)	2603	Kenya
Control	2447	Chad
Sample 1	2309	Chad
Sample 1 (10%)	2347	Chad
Sample 1 (15%)	2372	Chad
Sample 2	2364	Chad
Sample 2 (10%)	2346	Chad
Sample 2 (15%)	2285	Chad

The design density was 2320 kg/m3. The Table 4.9 above shows that almost all the concrete samples have a density beyond the average density of 2400 kg/m^3. The average concrete density SSD was between 2285 and 2607 kg/m^3. Only the Samples 1 and 2 showed average concrete density below 2400 kg/m^3. These variations in density was related to different proportions of constituent aggregates. It was noticed that all the samples collected from Kenya had density SSD highly beyond 2400 kg/m^3 which was due to high porosity of DS samples.

4.4 Hardened Concrete Testing

Compressive strength of concrete cube test provides an idea about all the characteristics of concrete. It is the most important parameter used in the design of concrete structures.

In this study, the hardened concrete test conducted was compression strength test. It was conducted to control the quality of the concrete and to check specification compliance using the Universal Testing Machine. This is because it is easy to perform and shows strength correlation between the compressive strength and many desirable properties, (Mamlouk *et al*, 2006).

Test for compressive strength is carried out either on cube or cylinder. Various standard codes recommend concrete cylinder or concrete cube as the standard specimen for the test. American Society for Testing Materials ASTM C39/C39M provides Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

During this study, all the compressive strength tests were carried out with cube specimens of 15cm x 15cm x 15cm. These specimens were tested by compression testing machine after 7, 14 and 28 days curing. Three cubes were crushed using the Universal Testing machine for each sample at the crushing day, the average compressive strength was then adopted for the concerned sample.

4.5.1 Effect of dune sand properties on the Compressive Strength

Figure 4.15 below gives the variation of compressive strength in function of samples collected from Kenya. The four dune sand samples were collected randomly from Nyiri Desert in an average radius of 50 km.

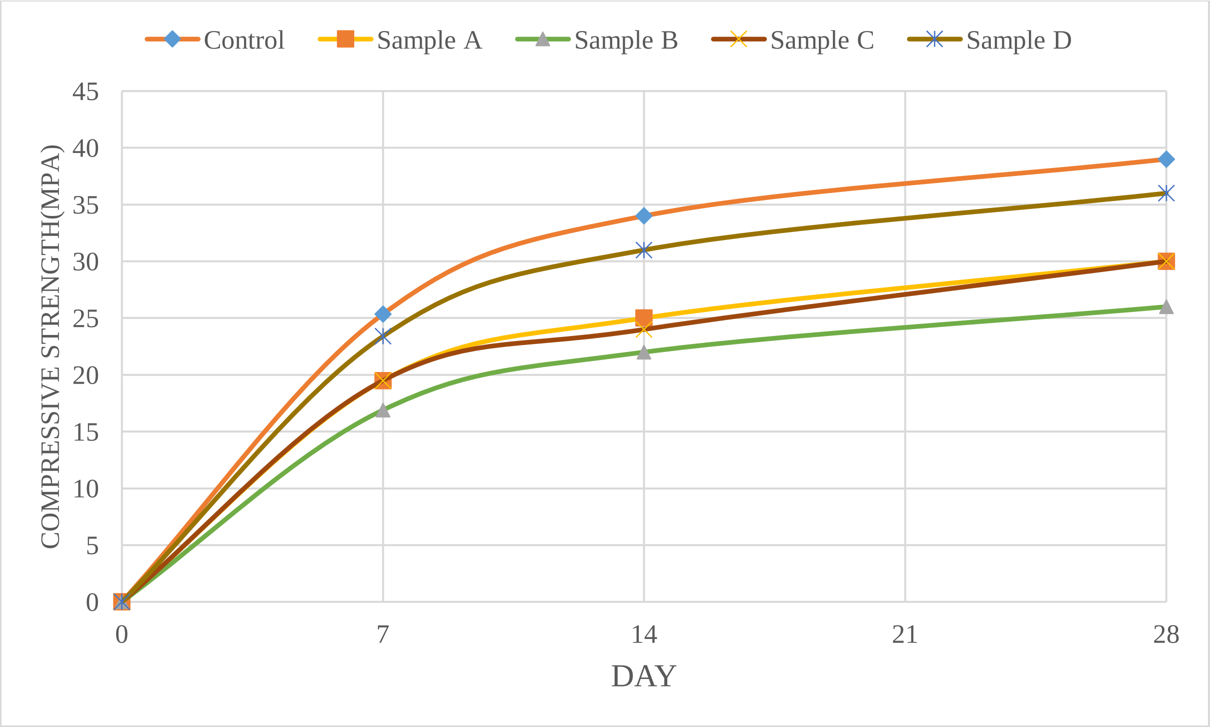


Figure 4.15: Variation of compressive strength with time in function of sample

The results above obtained from various samples collected from Kenya showed the average compressive strength obtained after 7, 14 and 28 days. The proportions of concrete mix in terms of ratios of cement, sand and coarse aggregates were determined using BS DEO Method. The parameters used for the determination of concrete mix were those of ordinary fine and coarse aggregates. The control mix design obtained was 1:2:3, the cement content was 380kg/m3 and the water to cement ratio was 0.5.

The control mix gave the compressive strength of 25, 34 and 39 MPa after 7, 14 and 28 days respectively. The ordinary sand was then replaced fully by each sample of dune sand. All the factors remained the same except the dune sand replacement. The Sample A mix gave the minimum compressive strength which was much smaller as compared to the control mix while the one of Sample D was close to the control mix.

Results showed that the Sample D had the smallest proportion of silt and clay content as compared to those of Samples A, B and C as showed on the Table 4.6 about silt and clay content. The high compressive strength of Sample D was related to its low silt and clay content, as the silt and clay content is one of the factors influencing the compressive strength of concrete.

Figure 4.16 below gives the variation of compressive strength in function of various samples collected from Chad. The two dune sand samples were collected randomly from Sahara Desert precisely in Hadjer Lamis constituency in an average radius of 50 km.

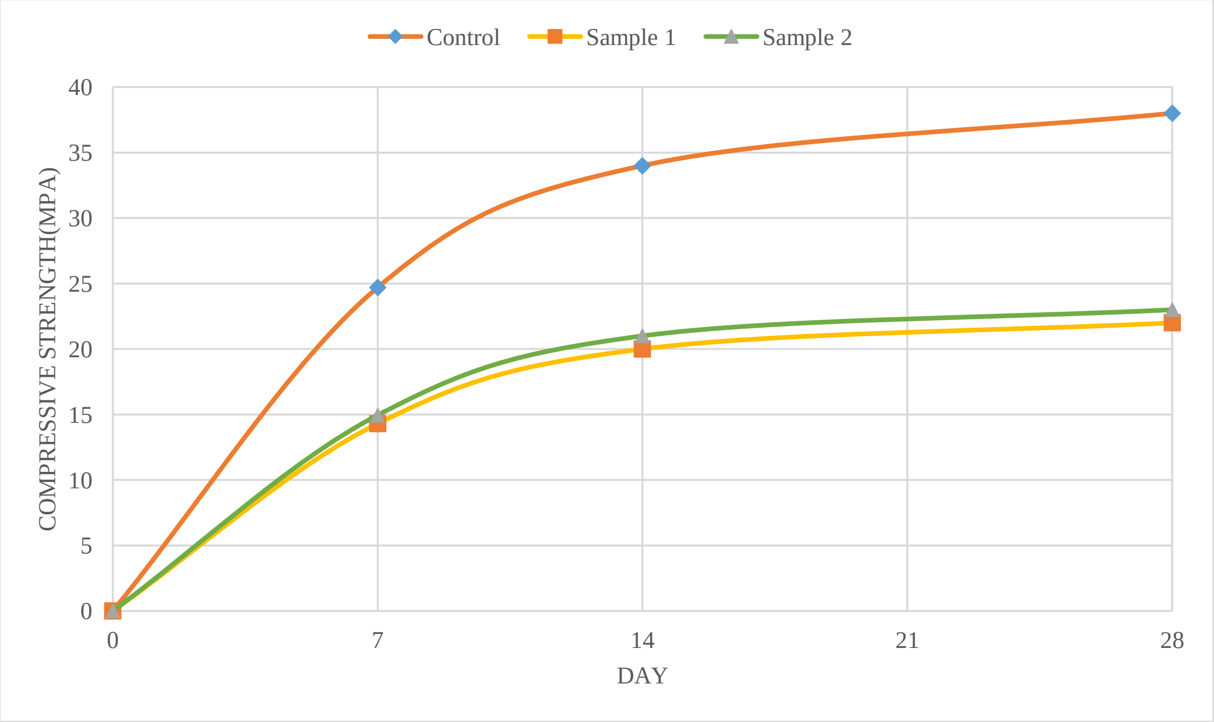


Figure 4.16: Variation of compressive strength with time in function of samples

Figure 4.16 showed the average compressive strength obtained after 7, 14 and 28 days. The proportions of concrete mix in terms of ratios of cement, sand and coarse aggregates were determined using BS DEO Method. The control mix design was 1:2:3, the cement content was 380kg/m3 and the water/cement ratio was 0.5.

The control mix gave the compressive strength of 25, 34 and 38 MPa after 7, 14 and 28 days respectively. The ordinary sand was then replaced fully by the two samples of dune sand for the two batches. All the factors remained the same except the dune sand fully replaced by the ordinary sand. The dune sand mixes gave compressive strength which were much smaller as compared to the control mix. The Sample 2 mix gave results which were better than those of Sample 1. The high compressive strength of Sample 2 was related to its less proportion in silt and clay as compared to that of Sample 1 as showed on Table 4.6 above.

4.5.2 Effect of Silica Fume on the Compressive Strength of dune sand concrete

SF also known as microsilica is an amorphous polymorph of silicon dioxide, silica. It is commonly known as a high strength cement used as a partial replacement of OPC in constructions. In this study, the proportions of SF chosen were 10 and 15%. The maximum allowable proportion of SF fixed by the production company was 15% beyond which it becomes unfriendly to environment.

- **Sample A**

Figure 4.17 below gives the variation of compressive strength of sample A collected from Kenya in function of SF replacement as compared to the control mix.

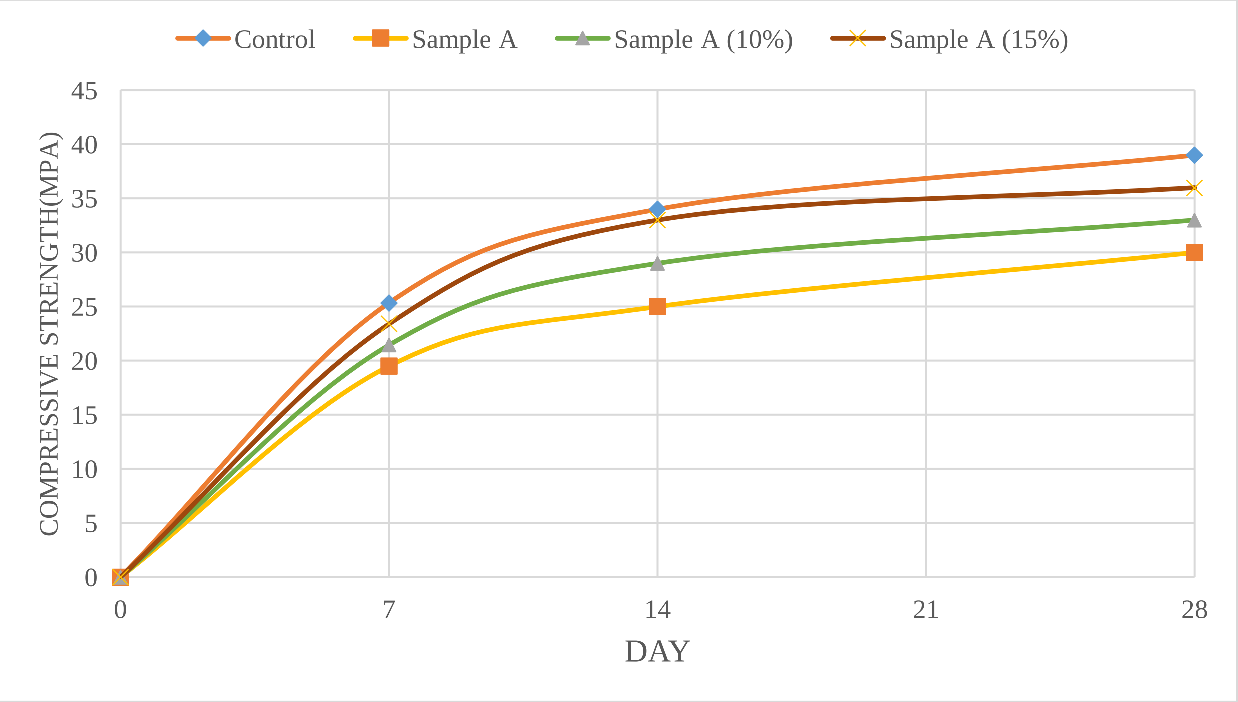


Figure 4.17: Variation of compressive strength with time of Sample A in function of SF replacement

Results above showed that when the ordinary sand was replaced by the Sample A, there was a loss of 23.08% compressive strength after 28 days. When 10% and 15% of OPC were replaced by SF, there were gains of compressive strength of 7.69% and 15.38% respectively after 28 days.

From the above, there was a loss of 23.08% after the full replacement of ordinary sand by Sample A. After the replacement of OPC by SF at 15%, there was a gain of 15.38%. Finally, after replacement of Sample A and treatment with SF, there was a loss of 7.7% compressive strength after 28 days. It means that the treatment was efficient but could not recover all the losses due to the influence of properties of Sample A.

❖ Sample B

Figure 4.18 below gives the variation of compressive strength of sample B collected from Kenya in function of SF replacement as compared to the control mix.

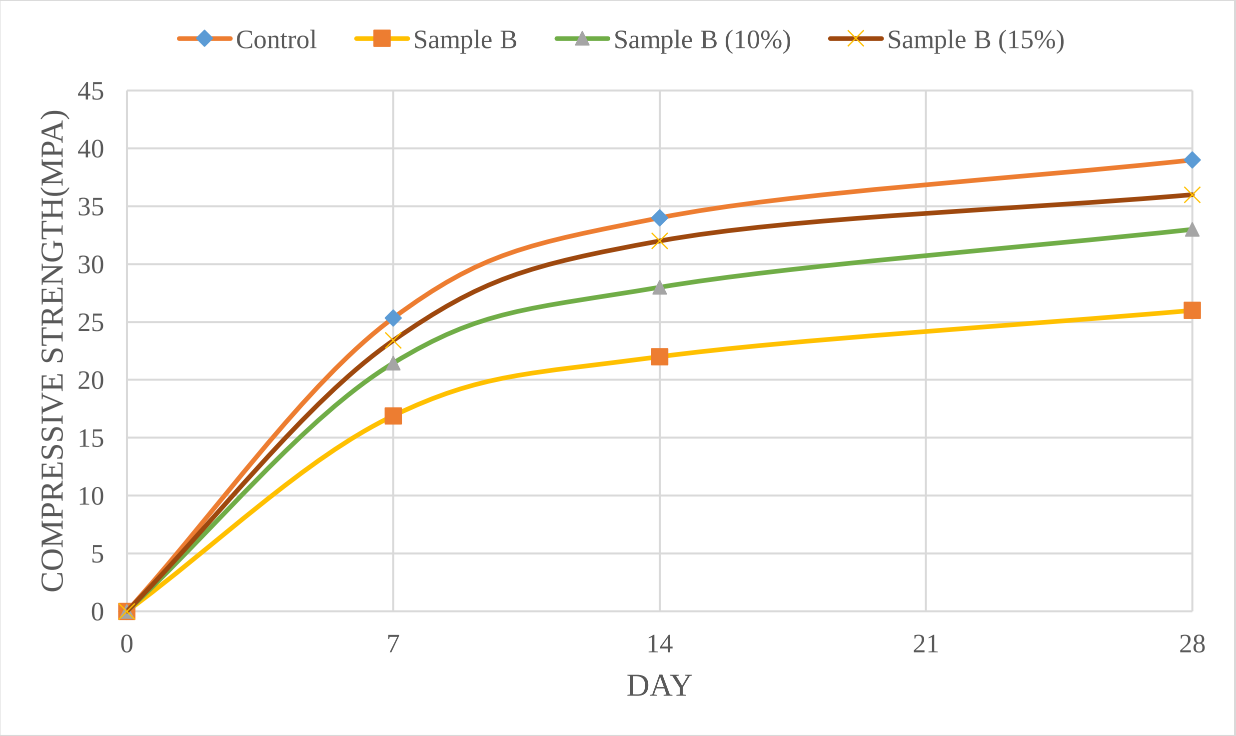


Figure 4.18: Variation of compressive strength with time of Sample B in function of SF replacement

Figure 4.18 showed that when the ordinary sand was replaced by the Sample A, there was a loss of 33.33% compressive strength after 28 days. When 10% and 15% of OPC were replaced by SF, there were gains of compressive strength of 17.95% and 25.64% respectively after 28 days.

Results showed a loss of 33.33% after the full replacement of ordinary sand by Sample B. After the replacement of OPC by SF at 15%, there was a gain of 25.64%. After full replacement of Sample B and treatment with SF, there was a loss of 7.69% compressive strength after 28 days. Therefore, the treatment was efficient but could not recover all the losses due to the influence of properties of Sample B.

- **Sample C**

Figure 4.19 shows the variation of compressive strength of sample C collected from Kenya in function of SF replacement as compared to the control mix.

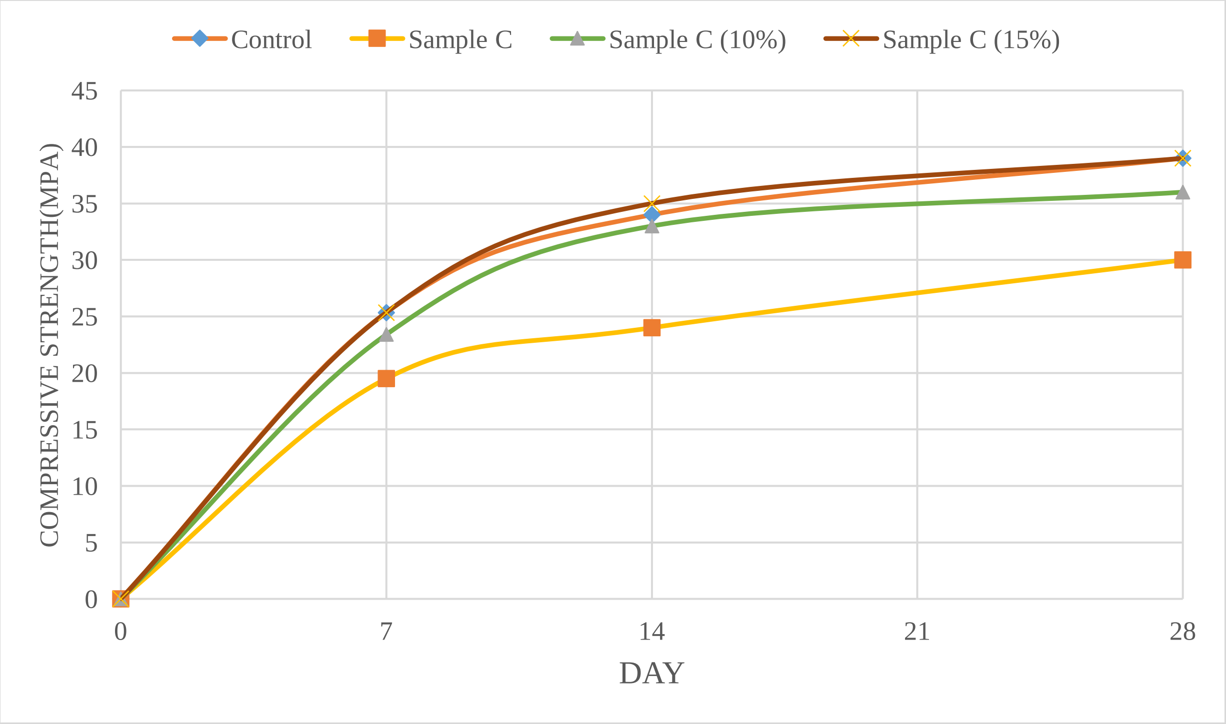


Figure 4.19: Variation of compressive strength with time of Sample C in function of SF replacement

Results obtained after testing showed that when the ordinary sand was replaced by the Sample C, there was a loss of 23.08% compressive strength after 28 days. When 10% and 15% of OPC were replaced by SF, there were gains of compressive strength of 15.38% and 23.08% respectively after 28 days.

Results showed a loss of 23.08% after the full replacement of ordinary sand by Sample C. After the replacement of OPC by SF at 15%, there was a gain of 23.08%. Sample C fully replaced and treated with SF gave no loss of compressive strength after 28 days. Results proved that the treatment was efficient and allowed to completely recover losses related to Sample C replacement.

❖ Sample D

Figure 4.20 gives the variation of compressive strength of sample D collected from Kenya in function of SF replacement as compared to the control mix.

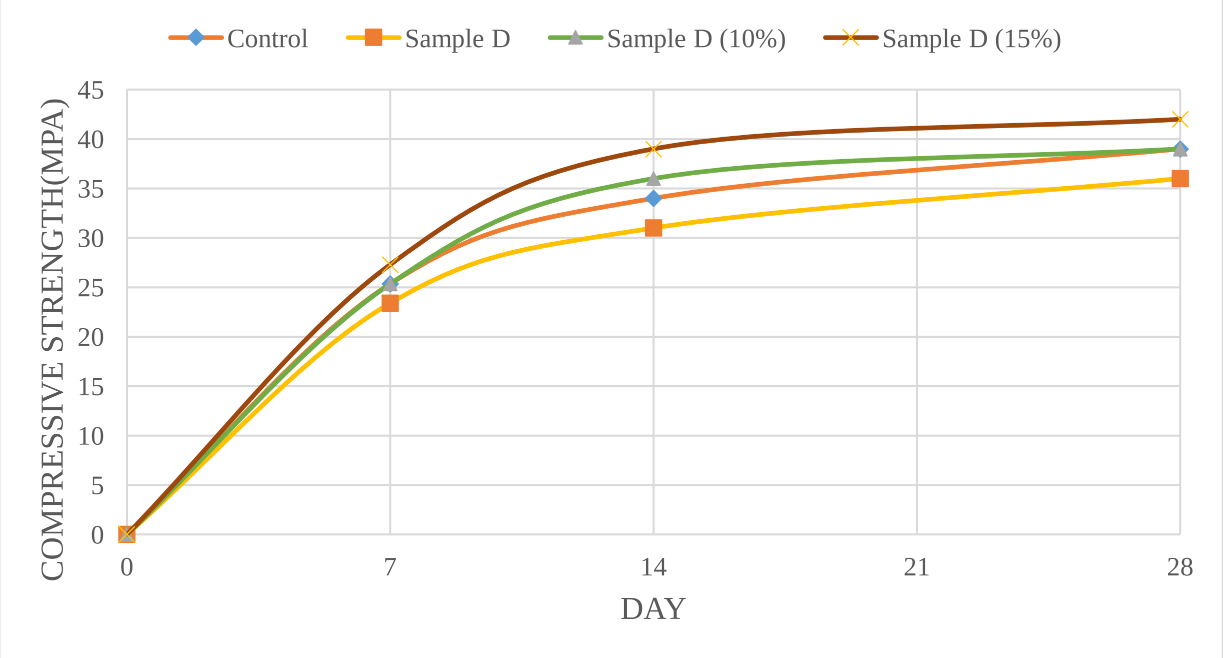


Figure 4.20: Variation of compressive strength with time of Sample D in function of SF replacement

Results obtained after testing showed that when the ordinary sand was replaced by the Sample D, there was a loss of 7.69% compressive strength after 28 days. When 10% and 15% of OPC were replaced by SF, there were gains of compressive strength of 7.69% and 15.38% respectively after 28 days.

Results showed a loss of 7.69% after the full replacement of ordinary sand by Sample D. After the replacement of OPC by SF at 15%, there was a gain of 15.38%. After full replacement of Sample D and treatment with SF, there were 7.69% gain of compressive strength after 28 days. The treatment was efficient and allowed to completely recover losses related to Sample D replacement and to have a compressive strength greater than the one of control mix.

❖ Sample 1

Figure 4.21 below shows the variation of compressive strength of sample 1 collected from Chad in function of SF replacement as compared to the control mix.

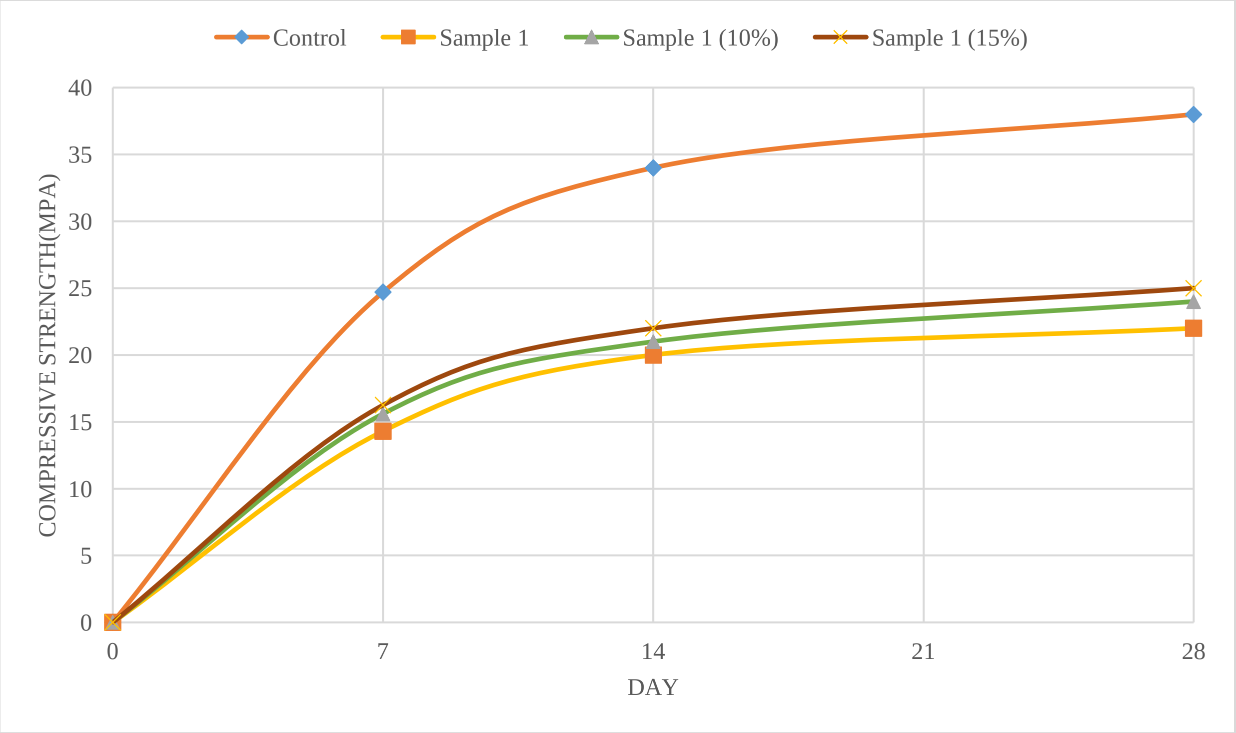


Figure 4.21: Variation of compressive strength with time of Sample 1 in function of SF replacement

Results above showed that when the ordinary sand was replaced by the Sample 1, there was a loss of 42.10% compressive strength after 28 days. When 10% and 15% of OPC were replaced by SF, there were gains of compressive strength of 5.26% and 10.53% respectively after 28 days.

From the above, there was a loss of 42.10% after the full replacement of ordinary sand by Sample 1. After the replacement of OPC by SF at 15%, there was a gain of 10.53%. Sample 1 fully replaced and treated with SF gave a loss of 31.57% compressive strength after 28 days. The treatment with SF was efficient but could not recover all the losses due to the influence of physical properties of Sample 1.

❖ Sample 2

Figure 4.22 below gives the variation of compressive strength of sample 2 collected from Chad in function of SF replacement as compared to the control mix.

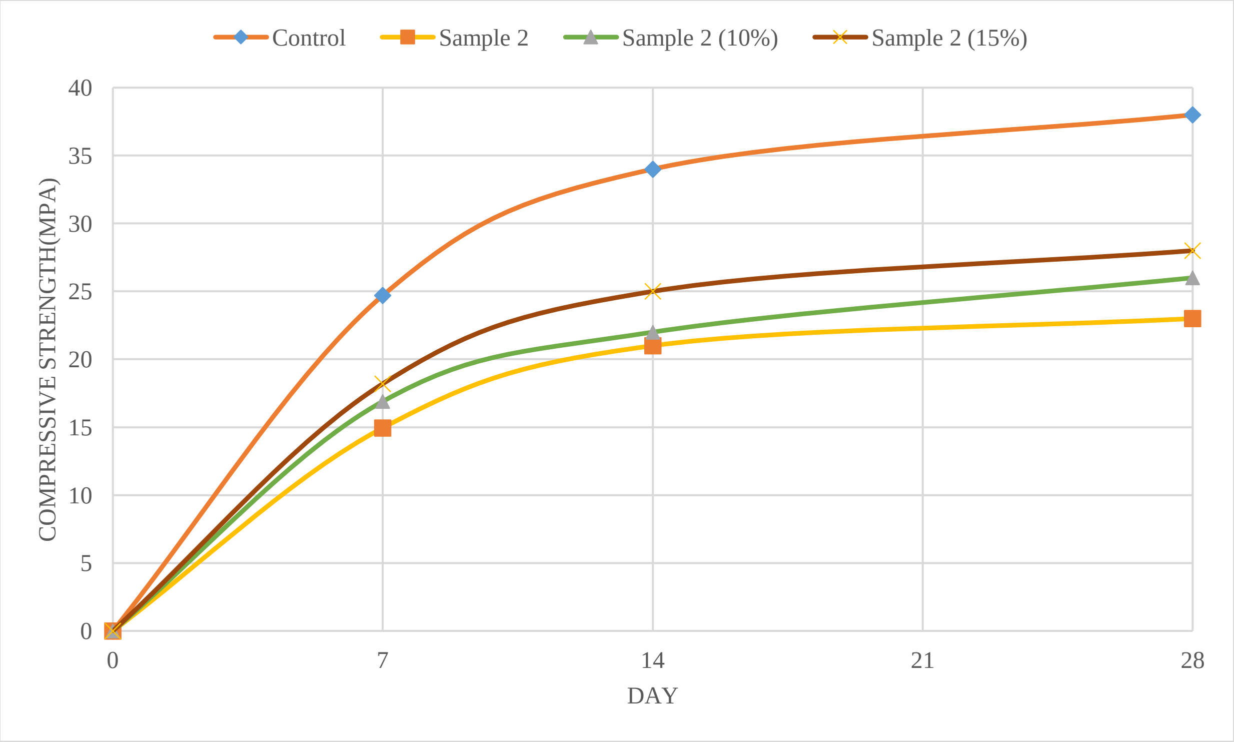


Figure 4.22: Variation of compressive strength with time of Sample 2 in function of SF replacement

Results above showed that when the ordinary sand was replaced by the Sample 2, there was a loss of 39.47% compressive strength after 28 days. When 10% and 15% of OPC were replaced by SF, there were gains of compressive strength of 7.89% and 13.16% respectively after 28 days.

Results showed a loss of 39.47% after the full replacement of ordinary sand by Sample 2. After the replacement of OPC by SF at 15%, there was a gain of 13.16%. After full replacement of Sample 1 and treatment with SF, there was a loss of 26.31% compressive strength after 28 days. The results showed that the treatment was efficient but could not recover all the losses due to the influence of properties of Sample 2.

4.5 Advantages of using dune sand concrete as alternative to ordinary concrete in desert area

The focus of a project contractor is to make profit by executing constructions according standards and within time while remaining in the budget. Time and cost management are of main concern of any contractor.

Constructing in desert areas is challenged by the non-availability of fine aggregates meanwhile, dune sands are readily available in those zones. Purchasing normal fine aggregates which are distant from the construction site demands more time and resources.

In this study, after assessing the influence of DS properties samples on DSC, results showed that Samples A, C and D could be used as full of replacement of OS in structural concrete ($fc_{28} \geq 25/30$). The control mix design determined and adopted by mass batching was 1:2:3 with a cement content of 380kg/m3 and a water to cement ratio of 0.5. These factors were kept constant in DSC.

The cost of estimate of this study was done on the average transport distance of ordinary fine aggregates of about 300km and 500 km from Kenya (Kajiado county) and Chad (Hadjer Lamis region) respectively. The choice was made based on the nearest place where ordinary fine aggregates can be found and transported to desert areas. The places where ordinary fine aggregates can be found are Meru (Kenya) and Ndjamena (Chad).

The Table 4.10 and 4.11 below give an estimation in cost reduction when dune sand concrete is used for construction in desert environment. It is well to know that the estimation does not include the treatment with Silica Fume.

Table 4.10: Cost estimate, first case study (Nyiri Desert, Kenya)

S/No.	Items	Unit	Price per unit(Ksh)	Price per unit(USD)
1	Concrete of class 25/30	m^3	21500	215
2	Dune sand concrete 25/30	m^3	18500	185
3	Average Cost benefit of using dune sand concrete in desert area	m^3	3000	30

Table 4.11: Cost estimate, second case study (Sahara Desert, Chad)

S/No.	Items	Unit	Price per Unit(XOF)	Price per Unit(USD)
1	Concrete of class 25/30	m^3	262500	471
2	Dune sand concrete 25/30	m^3	225000	405
3	Average Cost benefit of using dune sand concrete in desert area	m^3	37500	66

After the investigation of the few dune sand samples randomly collected from Nyiri and Sahara Deserts, results showed that when the choice of dune sand samples is fairly made, they can be used for an ordinary concrete without any treatment resulting then in time and cost reduction of projects in desert environment. The use of these materials can be extended to non-arid zones due to the unavailability of aggregates also, the over exploitation of ordinary fine aggregates which threaten the environment.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

The general objective of this study was to Investigate the potential of dune sand for use in structural concrete, the following conclusions can be made:

1. DS samples contained noxious heavy metal but remained within the permissible proportions, pH values were slightly basic and dune sands from Sahara Desert had more impurities than those of Nyiri Desert but remained within the allowable limits;
2. Dune sands from Nyiri Desert contained 77.75% average particle size of less than 0.600mm while those of Sahara Desert had 97%, dune sands from Nyiri Desert had an average FM of 1.67 while the ones from Sahara had an average of 1.15;
3. When the OS from Kenya and Chad were fully replaced by DS, there were average losses of compressive strength of 22% and 41% respectively as compared to control mixes;
4. When a choice of DS is well made, it can be used without any treatment for structural concrete with a control mix design of 1:2:3, a cement content of 380kg/m3 and a water to cement ratio of 0.5;
5. When 10% of OPC was replaced by SF in DSC, there was 81.63% average reduction in slump and when 15% Silica Fume was replaced by OPC in dune sand concrete, there was 100% reduction in slump; when 10% of OPC was replaced by SF in DSC from Kenya and Chad, there were 12.18% and 6.58% average gain of compressive strength after 28 days respectively, when 15% of OPC was replaced by SF in DSC from Kenya and Chad, there were 19.87% and 11.85% average gain of compressive strength after 28 days respectively;

6. When dune sand concrete is used for construction industry in desert environment from Kenya (radius of 300km) and Chad (radius of 800km), that would result in cost and time reduction estimated at USD 30 and 66 per cubic meter respectively;

5.2 Recommendations

From this work and its findings, the following recommendations will be suggested for eventual future study to ascertain the use of dune sand concrete in construction industry:

1. To extend compressive strength test after 90 days and 1 year to follow the strength development with time regardless compressive, splitting tensile and flexural tests;
2. To execute durability tests such as chemical resistance, freeze/thaw resistance, deep abrasion resistance, thermal shock resistance, warpage, wedging, bond strength, breaking strength, thermal expansion, and moisture expansion on dune sand concrete;
3. To evaluate the effect of superplasticizer on the compressive strength and durability of dune sand concrete and dune sand concrete treated with SF and to assess the workability of DSC made with coarse aggregates grading from 10-25mm/14-25mm;
4. To estimate the cost reduction of using dune sand concrete and dune sand concrete treated with SF as compared to ordinary concrete at wide scale;
5. To evaluate the impact of desertification resulting from the use of a certain quantity of dune sand in concrete over a defined period.

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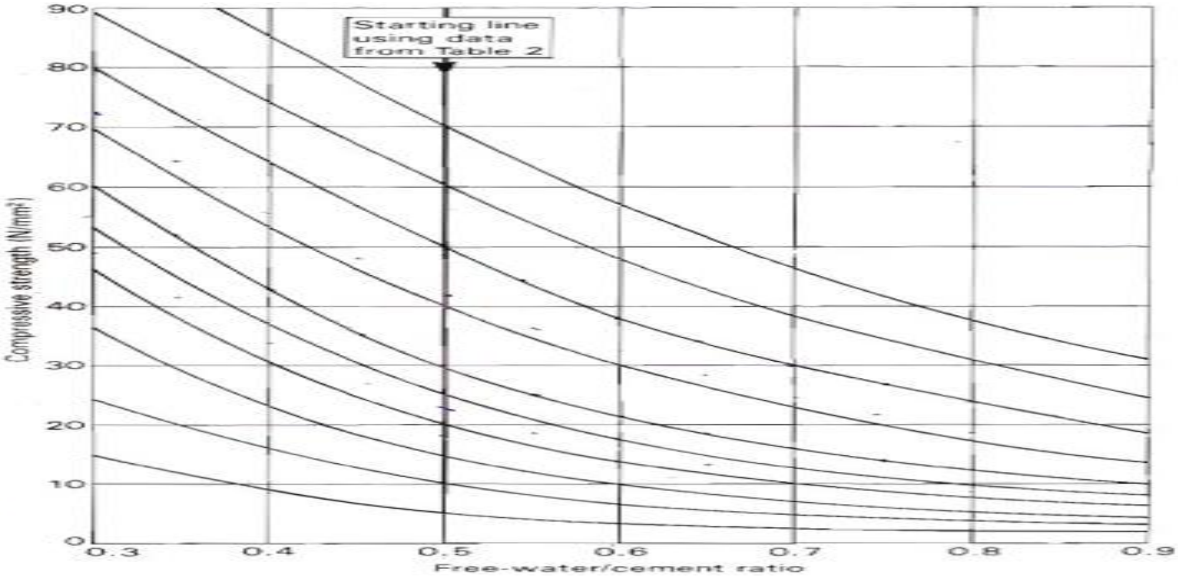
7. Appendices



Appendix 1: Relationship between the compressive strength and the water/cement ratio

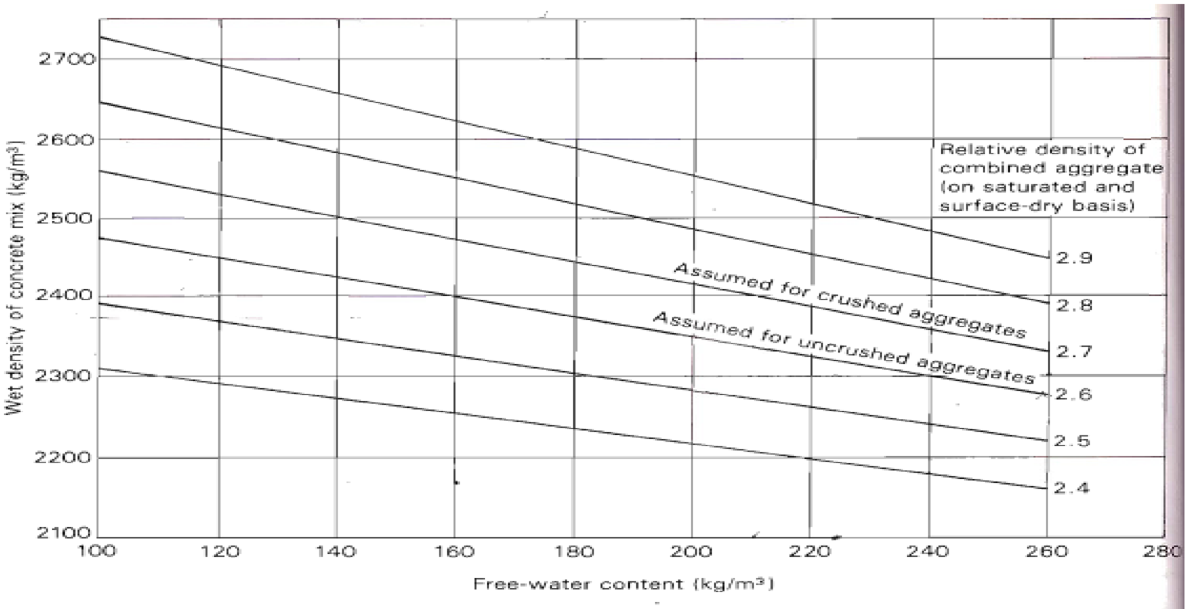


Figure 5 Estimated wet density of fully compacted concrete

Appendix 2: Relationship between the free-water content and the wet density of concrete mix

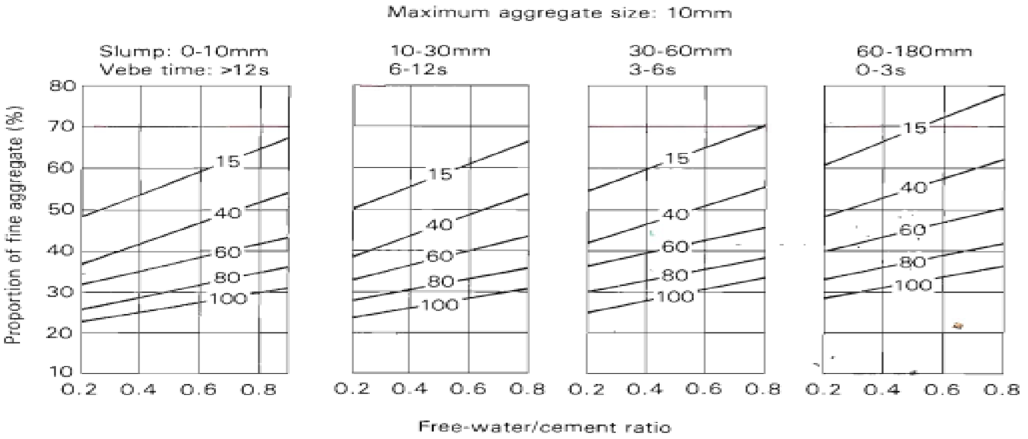
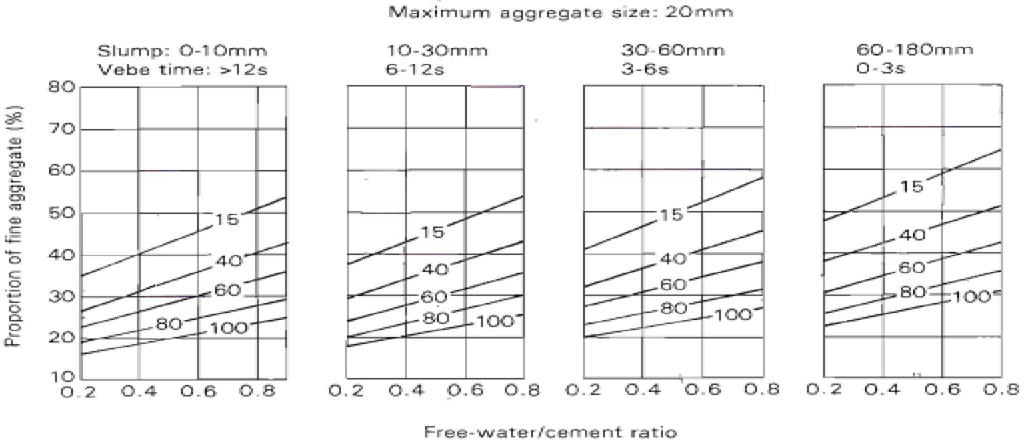
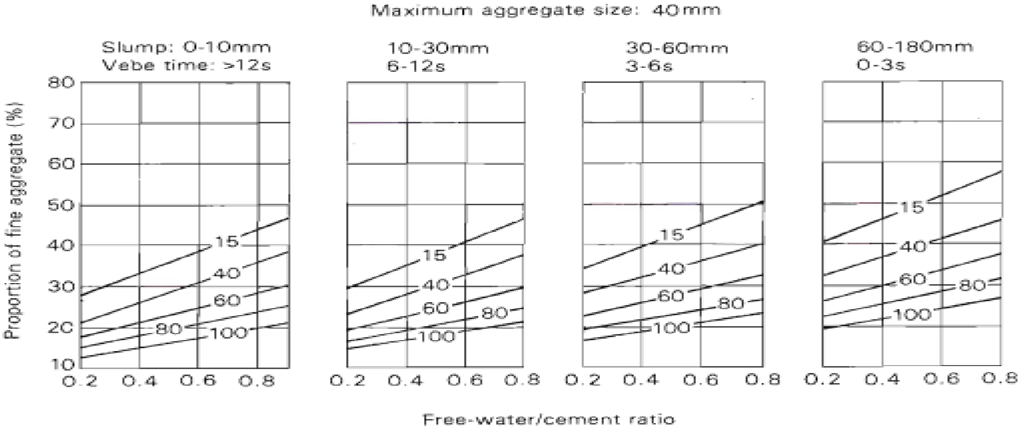


Figure 6 Recommended proportions of fine aggregate according to percentage passing a 600 μm sieve

Appendix 3: Free-water/ cement ratio and the proportion fine aggregate (%) for maximum size 10 mm



Appendix 4: Free-water/ cement ratio and the proportion fine aggregate (%) for maximum size 20 mm



Appendix 5: Free-water/ cement ratio and the proportion fine aggregate (%) for maximum size 40 mm