COMPARATIVE PERFORMANCE OF PLASTER SANDS IN YOLA METROPOLIS

BY

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Declaration

I declare that the work in the dissertation report entitled "Comparative Performance of Plaster Sands in Yola Metropolis" has been done by me in the Department of Building, under the supervision of Prof. MuhammedM. Garba. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation report was previously presented for another degree at university.

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Certification

This is to certify that this dissertation entitled "COMPARATIVE PROPERTIES OF SANDS AS PLASTERING MATERIALS IN YOLA METROPOLIS" by USMAN, Suleman Yusuf, has been duly supervised, hereby approved and meet the regulations governing the award of the Masters Degree (MSc) in Construction Technology, Department of Building, Ahmadu Bello University, Zaria and is approved for it contribution to knowledge and literary presentation.

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Dedication

I wish to dedicate this dissertation tomy late father, Mallam Usman, Yusuf Alhaji and my mother, Hajiya Maimuna Usman Yusuf.

Acknowledgement

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Abstract

There is persistent argument constituting a serious problem as to which is better among the different sand types used for plastering mortars in Yola. Some are of the vague opinion that the cement and the water requirements for the sands are different and thus one is more economical than the other when used to produce plaster mixes. Moreover, as at now there seems to be no document specifying the properties of the two sands in question, thus the need to scientifically investigate as well as establish the suitability of the sands for plastering mortars in Yola. The results from this investigation will assist contractors, designers, builders, and other stakeholder in decision making as to which of the sands will be applied in different part of construction. It will also aid in placing the correct order for supply instead of falling under suppliers' mercy.This research thereforeis aimed at evaluating the properties of two plastering sands used in Yola with the view to establishing their major characteristics as plastering sands. A total number of 192 cubes and prisms were cast using nominal mix ratio of 1:3 with water cement ratio of 0.7 and tested for density, compressive and flexural strength at 7, 14, 28 and 56 days. Abrasion resistance, water absorption, sorptivity tests were carried out at 28 and 56days of curing age. The result showed that at 56 days the compressive strength was 16.48 N/mm^2 and 14.41N/mm^2, and flexural strength of 10.03 N/mm^2 and 10.11 N/mm^2 for samples A and B mortar respectively. This research concludes that the sample B mortar has higher flexural strength and durability properties than sample A mortar. The research recommends that where strength of mortar is the requirement, such as in mortar beds and joints, sample A should be used due to it higher compressive strength value and Sample B is a better option when it comes to durability as required in plastering and rendering due to its higher durability properties.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Plaster consists of mixture of lime or cement and sand, with the required quantity of water.Rough surface of concrete, masonry wall or concrete ceiling roofs are changed or covered to provide an attractive surface by plastering with a material called plaster. After the erection ofa building structure, plastering work has to take place in order to protect some of the building components such as walls, columns and beamsfrom the effect of weather, and to make the building look attractive(Michael & John, 2011). Plastering is the process of covering rough concrete surfaces, masonry walls and undulatting surface of buildings with a plastic material, called plaster, which is the mixture of lime or cement, sand and water (Satheesh, 2009; Weyer *et al.,* 2015). Mortars are spread over the block or brick works and then trowel is used to make the surface smooth to the required level. According toCorinaldesi, Moriconi & Naik(2005), plastering also increasesthermal and sound protection in the building.

The main aim of plastering a building is to provide strong and even surface that could be painted and give nice attractive appearance.Plasters are used for many reasons in a building. According to Adedeji (2007),the aimsof plaster include: protection of the underlying surface, allow or stop the migration of vapour or liquid moisture and air current, carrying the building loads, to give adequate fire resistance to the building system, provide sufficient sound and thermal insulation, provision of levelled and hygienic surface and abrasion resistance of the surface and accepts an attractive finishing. In addition, plaster improves the appearance of the wall by hiding the imperfections of rough work and

gives it an attractive texture compatible with the local environment (Houben & Guillaud, 1994).Very high humidity affects the masonry. Humidity may enter themasonry in different ways and forms, such as rain water, fog, rising damp, condensation.

If very hot weather enters the wall of a building, it should come outof the wall as quickly as possible, otherwise, it may cause several decay problems (Akkuzugil, 1997). At that point, plasters have an important role on 'breathing property' of the walls, by letting out the excess humidity (Szczerba& Jedrezejewska, 1998). Plaster in general, such as cement plasteris applied with 13mm thickness and sometimes it can be of 19mm thickness also. 19mm plaster is carried out in two stages. First layer is of 13mm and second is of 6mm thickness. After the first layer is set, cement slurry is spread on the surface beforethe second layer is applied. Besides walls, plaster is applied to the underside of upper floor decking which sometimes looks rough when the shuttering is removed. Many holes are found at various places under the decking, a 6mm plaster is applied in the ratio 1:3 cement to sand and then cured. The curing is carried out in the same method applied to the other plaster types on the finished surface.

As a weather preventing material, plaster arrangement is made of water preventing cement surface, a channel at the backof the plaster to control all water out of the plaster and a concealed moisture retaining barrier at the back of the arrangement. As a sound dampener and noise reducing element, both airborne and impact, plaster has historically served well. Plaster isbeing used in the construction of building as the oldest finishing materialsuch as those of Neolithic sites in the United Kingdom(Cessford, 2001). Acoustical plasters are laboratory tested to describe that these plasters can importantly increase Sound Transmission Class(STC) values of partitions. The hardness of plastering or rendering is

based largely on the material properties of the finishes and the material it is applied to, as well as the bond between the two materials (Abdurahman, 2014). The major components of plasters are the binder and filler also known as aggregates. Consequently all sort of filler materials are used as aggregates for plaster. However, Performance of the plaster is directly related to the properties of its components. In other words the components of plaster, such as mud, lime or gypsum as binder, different types of inorganic aggregates as filler, and organic and/or inorganic additives directly influence its performance. The characteristics of these components and their contributions to the performance should be well evaluated (Young & Miller, 2000).The most common types of plaster mainly contain either gypsum, lime, or cement with water and sand (Franz, 2012). All plasters must contain at least one cementitious material, generally lime, gypsum, or Portland cement.

Sand is used to increase capacity and to reduce shrinkage. Water is necessary to develop the plasticity of the cementitious material, and to assist in the chemical reactions involved in the hardening process.Care should be exercised in the selection of sand, the principal aggregate in plaster. Both the angular and globular types are satisfactory and may be either natural sand or ground rock. It should be composed of clean, hard, durable stone particles, free from objectionable matter, with an allowance of not more than 5 percent of loam, silt and clay. Sand for plaster should be graded to pass a No,3 or No. 4 sieve and at least 85 percent should be retained on a No.100 sieve. According to Singh & Singh (2006) an important requirement is that sand to be used for producing plastering mortar should be free of organic matter such as roots, seed, twigs and humus.

Plaster is usually produced as a dry powder and then mix together with the required amount of water to produce a stiff paste (mortar)before application.Cement plaster was

first introduced in American around 1909 and was named after the founder called adamant plaster. The cement plaster has a great advantage such as strength, hardness, quick setting time and durability which was noted at that time (Chudly & Greeno, 2008). Plaster has two major requirements such as workability and cohesive in the early stage and strong enough to hold paint and withstand local impact and abrasion, free of unsightly cracking, adequately bonded to the substrate, have an acceptable surface texture and accuracy (with reference to a plane or curved surface)which must occur at the hardened stage (Afrisam, 2008). The different sand types, Red (Sample A) and Black (Sample B) exist in Yola, which mainly used for plastering and rendering works. This research work intends to investigate and compare the engineering properties of these sands.

1.2 Statement of the Research Problem

A building can be considered or viewed aesthetically appealing when it is painted with selected paints colors, but painting takes place after rendering and plastering. Painting, rendering, and plastering are termed as finishes. However, because of the growth of population and of cities and the consequent increase in construction activities, this has led to an increase in the demand for plastering sand. According to Abukersh (2005), the large scale depletion of natural aggregates and the increase numbers of construction are causing significant damage to the society and causing serious problems denting the public and the environmentalist aspirations for a waste-free society. It is estimated that the annual consumption of sand is 40 billion tons globally (Beiser, 2015).

Importation of plastering sand may add to high cost of construction due to transportation. There is persistent argument constituting a serious problem as to which is better among the two abundant sand types used as plastering mortars in Yola. Some are of the vague

opinion that the cement and water requirements for the sands are different and thus one is more economical than the other when used to produce plaster mixes.As at now, there seems to be no documents specifying the properties of these sands in question, thus the need to scientifically investigate as well as establish the suitability of the different sand samples from Yola for producing plastering mortars.

1.3Justification for the Study

Since the different sands for making plastering mortars are widely available in Yola, this experimental study could establish the suitability or otherwise of using both sands for the production of plastering mortars. It could also establish the best of the two sand samples. Efforts wereplaced toward assessing the properties of the sands for plastering purpose. The result of this research would lead to determining the engineering properties of the sands and also could contribute to solving the argument over the sand samples. The results from this investigation will assist contractors, designers, builders, and other stakeholders in decision making as to which of the sands will be applied in different part of construction. It will also aid in placing the correct order for supply instead of falling under suppliers mercy.

1.4 Aim and Objectives

1.4.1 Aim

The aim of this research is to evaluate the properties of two plastering sands used in Yola with the view to establishing their major characteristics as plastering sands.

1.4.2 Objectives

The stated aim was pursued through the following objectives. These are to:

i. investigate the engineering properties of the research materials.

ii. establish fresh mortar properties for the sand samples.

iii. determine the strength characteristics of the hardened mortar produced with the sand samples.

iv. determine some durability properties of hardenedmortar produced with the plastering materials

1.5Scope and Limitations

1.5.1 Scope

In view of the fact that there exist two different plastering sands in yola, this research work therefore was restricted to laboratory experimental tests which focused on the physical, mechanical and durability properties of mortar (cubes and prisms) produced with the plastering sands, properties such as density, compressive strength, flexural strength, abrasion resistance, water absorption, and sorptivity only were investigated.

1.5.2 Limitation

The materials were picked during dry season, the moisture content could have changed which may invariably affect the bulk density.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Plaster

Plaster is a plastic material used in construction of building to prevent or provide an attractive appearance for concrete, masonry walls and concrete ceilings and for producing aesthetics elements (Weyer *et al.,* 2015). In English the plastic material used inside the surface of a building is called plaster, while render commonly means as external applications of the materials. Plaster is usually produced by mixing cement or lime, sand and the required quantity of water to produce a plastic workable material which is sprayed to the surface of a building (Henry, Alison & John, 2011). When the dry mix plaster come in contact with water reaction gives out heat through crystallization and the wet plaster becomes hardens.

2.1.1 History of Plaster

According to Goeke (2008) the use ofplaster started in a very long period of time since Around 7500 BC which is known as lime based plaster, the production of thelime plaster was by mixing the lime with unheated broken limestone which was used for finishing walls, floors, and hearths by the Ain Ghazal in Jordan in their buildings, aesthetics on the walls and floors were produced with red, finger-painted patterns and designs. Clay and gypsum plaster were used to produce an attractive surface over rough stone or mud brick walls at external finishing of the masonryin ancient India and China, while tombs, walls were finished with lime and gypsum plaster and the finished surface was often paintedin early Egyptian.

2.1.2 Types of plaster

The types of plaster that are generally used are produced with either gypsum, lime or cement and sand mixed together as a dry powder before the required amount of water is added, but the all work in similar way (Franz, 2012).

2.1.2.1 Cement Plaster

Cement plaster in this type of plaster a mixture of sand, cement and water is produced which is applied to the inside and outside the building to achieve a smooth surface. Gypsum plasters are sometimes used inside the surface of the buildings. Walls that are made with stock bricks are normally plastered while face bricks walls are not plastered. Different types cement based plasters are also used as provide spray fireproofing products. Vermiculite is usually used as lightweight material. For outside fireproofing of masonry buildings, pipe bridges and vessel skirts heavy types of such plasters are also used. Americaas the first country to used cement plasterwas introduce in America around 1909 and the plaster was named after the founder called Adamant Plaster. The great advantage of the plaster such as strength, hardness, the quick setting time and durability were discovered at that time (Franz, 2012).

2.1.2.2 Gypsum Plaster

Gypsum plaster: this type of plaster is also called plaster of Paris is the type of plaster that is manufactured through the process of heating gypsum to about 300^{o}F (150 ^{o}C) Lafarge.The dry plaster powder changeinto gypsum when mixed with water. After mixing the setting of the unmodified plaster usually take place from about 10 minutes and get endedin about 45 minutes; but not fully set after 72 hours.Hemihydrate is formed if the gypsum is heated beyond 266^{0}F (130^{o}C), which will also change to gypsum water is

added.Gypsumis also used to provide good appearance of surface of wood, stone, or metal on movie and theatrical set by the plasterer.

2.1.2.3 Lime Plaster

Lime plaster is the type of plaster that is manufactured by mixing calcium hydroxide and sand (fine aggregates). The Lime plaster set as a result of the Carbon dioxide in the atmosphere by changing the calcium hydroxide into calcium carbonate (limestone). In the process of making lime plaster limestone (calcium carbonate) is heated above approximately 850 ^{0}C to form quicklime (calcium oxide). Slaked lime (calcium hydroxide) is produced when water is added,that is also called as wet putty or white powder. Pastecan also be form when additional water is added prior to use and airtight container may be used stored the paste. The calcium hydroxide very slowly changes back in to calcium carbonate through reaction with atmospheric carbon dioxide when exposed to the atmosphere, causing increase in the strength of the paste. Lime plaster was the available material used for finishing of wall surfaces, whereby a series of wooden strips on studwork frame was finished with a wet plaster that hardened into a surface. Lime plaster is the plaster mainly used most in the construction of lath and plaster, which has curing time of about a month. Small amount of plaster of paris were added into the mix, in order to stabilize the lime plaster during the curing. In order to achieved large quantity of Plaster of paris mix water retardant admixture is added to the mix so as to regulate the setting.

2.1.2.4 Clay Plaster

Clay plaster this type of plaster is normally prepared by combining clay, sand and water in which certain amount of plant fibers are added provide tensile strength over wood lath. Clay plaster has been in used for very long period of time. American colonies used clay

plaster to finish inside part of their buildings. Internal plastering in the form of clay is used as a finishing to the buildings frame, and must have been seen in the inside of wattle filling in those olden days frame buildings in which wainscot had not been indulged. Afterthe introduction of lath and brick filling for the frame the used of clay was still in used (Mckee & Harvey, 2017). Otherbinders were used to replaced lime, where lime was not available or easily accessible.Mud plaster is made of clay or earth which is mixed with the required quantity of water to form a plastic material with adequate workability. If the mixture of the mud is very plastic it will lead to shrink, crack and distort on drying. It will also cause collapseof the wall.The excessive shrinkage which are form as a result of fine clay grains are controled by putting more fine and coarse aggregate in the mixed (Weaver & Martin, 1997). Straw or grass was added sometime with the addition of manure providing fiber for tensile strength as well as protein adhesive. Proteins in the manure act as binders (Chen&Quiling, 2000).

2.1.2.5 Heat Resistant Plaster

Heat resistant plaster is a type of plaster used in the construction of building that is manufactured to be used in a place where high temperature of above 50^{o}C is required such as walls and chimney breasts the main reason for producing this type of plaster is to replace the conventional gypsum plaster (Michaael & John, 2011).

2.1.3 Uses of Plaster

According to Abhimanyu, Dhruv, Ishwar, Rashid, Priyesh and Saurab,(2006) plaster is used in the construction of building for the following purposes: Plaster is applied to the surface of masonry providesprotection to the concrete or masonry structure of the building i.e. the block or the concrete units, from exposure to effect ofharsh weather element. It is

used as weatherproofing to prevent the penetration of water, to prevent the building against wind, rain and sun. It is used as a sanitary finishing, to provide cover holes that are form after the formwork are removed, so as to keep reptiles and insects out of the building structure. Plaster is used as a material to provide an even surface, to give walls and ceilings pleasing appearance either for their own aesthetic appeal or a base for application of paint and polishes. It is also a material for providing adequate defense against fire and plays important role in fireproofing a building.

2.1.4 Classification of Plaster

According to Frederick (2013) plaster can be classified as follows:

(a) the plaster isProduced by partial drying the moisture content of gypsum, the burning is usually carried at a temperature not above 190° C.

i. Plaster of Paris in this type of plaster the process of manufacturing it include calcination of a pure gypsum and no any extra materials being added either during or after burning.

ii. Cement plaster is the type of plaster that is produced by burning of gypsum containing certain natural impurities, or by addition to burned pure gypsum of certain materials which serve to reduce the set or render more plastic the product.

(b) Produced by the complete removal of water content of gypsum, the burning is usually carried out at temperatures above 190° C.

i. Flooring plaster is the type of plaster that is made by burning of pure gypsum.

ii. Hard finish plaster is manufactured by burning at a very high temperature or over of gypsum to which certain substances (usually alum or borax) have been included.

2.2Mortar

Mortars are the most widely used building materialsin construction of building structures, which normallyapplied to concrete or masonry surface as rendering and plastering systems to provide protection to the walls of the building (Swan, Rteil & Lovegrove,2011).Mortar are connecting stones, bricks, block, and plasters are used for rendering on the outside and inside of wall in the construction of building, the differences between mortar and plasters to take better finish, which depend to a very large extent on the type of sand used in the mix (Varghese& Charvard,2008).Mortar is a composite material made up of inert materials of varying sizes, which are bound together by a binding medium.According to Mitchell (2007) mortar consist mixtureof cement, lime, sand and water, adding a small percentage of lime to the cement mortar makes the mortar 'fat' or 'rich' which increases it workability. Mortar is also a plastic material that is used to bond building blocks such as stones, bricks and concrete masonry unit together, fill and cover the irregular openings between them and sometimes add aesthetical appearance or patterns in wall of buildings (Yang, Zhang & Qinglin, 2010). Mortar is produced as a mixtureof cement, sand in addition to water. Cement, water, and air are mixed to form a paste that put the aggregates together in the mortar. Thus, the mortar strength is completely based on the type of material used to produce the mortar(Abebe,2002).Mortar is one of the constituents of an isotropic masonry material.Spreading of uniform stress, corrections of openings on blocks and taking deformations connected to thermal expansions and shrinkageare all caused by mortar in a building system. In spite of this, mortar has been often abandon in terms of structural analysis of building structures, it is well known that it influences the final behaviour of building such as compressive and bond strengths, and deformability (Edgell

& Haseltine, 2005).It also provides protection against the passage of liquid through the joint in the masonry arrangement. Cement mortar becomes hard when its cures, resulting in a solid and rigid structure, however the strength of the mortar must be the same or less than that of the masonry unity, because the mortar is easier and less expensive to repair compared to the building unit. Mortar can be classified as lime mortar or cement mortar. Lime mortar is made of lime, sand and water, whereas cement (or cement lime) mortar is made of lime mortar mixed with Portland cement. When lime is mixed with aggregates (e.g. sand or gravel) and water, it becomes a mortar where it can be used in a plastic state and will harden to form a relatively durable material (Gibbons, Newsom, Scotland & Technical conservation, 2003).

2.2.1 History of Mortar

Mortar is among the oldest and the most widely used building materials for their compliance and their easy adaptability to the morphological needs of the construction work. In human history different types of mortars were invented. From a modern chemical point of view it is possible to divide them into two general groups: mortars based on hydraulic or non-hydraulic chemical components. The term historical mortar is used basically for all types of mortars which have been used before the Portland cement invention in 19th century. The first mortars were made of mud and clay. According to research of Roman Ghirshman, mortar was first introduced in Pakistan at Mehrgarh of Baluchistan, built of sun-dried bricks bounded by clay in 6,500 BC. Additional progress was achieved with the invention of lime. In the middle ages the use of mortars went through many researches and the first mortars based on hydraulic reaction were invented. These mortars were composite material formed by a binder (hydraulic or aerial lime) and

variety of inert materials (silicate, dolomite or carbonate sand) and some additives mentioned further. Historical and monumental buildings represent the culture and stories of the people who built and lived in them. This makes the places with well-preserved cultural heritage very attractive for tourists, which has a huge positive impact on the popularity and economy of these regions. For this reason, preservation and restoration of historic masonry structures is usually supported by the governments or organizations. Most famous organization to preserve cultural heritage, but not only for this purpose, is United Nations Educational, Scientific and Cultural Organization, UNESCO, a specialized agency of the United Nations. UNESCO has195 member states around the whole world, it was founded in 1946 and the location of the major mansion is in Paris, France. Inappropriate attempts to recondition can cause enormous damage, and therefore authorities for cultural heritage have introduced numerous demands on techniques and materials used for the protection and repairs of these structures. Among the most important historical structures could be regarded: Hagia Sofia in Istanbul, Turkey; Cathedral of the Holy Cross and Saint Eulalia in Barcelona, Spain; St Peter's Basilica in Rome, Italy; Monastery SanVicente de Fora in Lisbon, Portugal; or Byzantine monuments on the island of Crete, Greece (Moropoulou, Cakmak, Biscontin, G. Bakolas and Zendri, 2002).

2.2.2 Classification of Mortar

According to Duggal (2008) mortars are classified on the basis of their bulk density, kind of binding material and application sand, physical and mechanical properties.

2.2.2.1 On the Basis of Bulk Density

The classification of mortar on the basis of bulk density is show in table 2.1.

Table 2.1: Types of Mortar, Bulk Density and Aggregate.

Types of Mortar	Bulk Density (kg/m^3)	Aggregate
Heavy Weight	>1500	Heavy quartz or sand
Light Weight	<1500	Light porous sand from pumice, tuffa, and slags.

Source: Duggal (2008)

2.2.2.2On the Basis of Building Material

The major factor in choosing a particular type of mortar for a given structure will based on the desired strength of masonry, resistance to passage of rain water, immediate and long period appearance, hardening temperature, expected working conditions of the building and cost.

For most practical purposes, a building mortar will fall in one of the following classes:

i. Cement Mortars: this type of mortar is prepared from cement, sand and the required quantity of water.
ii. Lime Mortars: consist of air hardening lime or hydraulic lime, sand and a required amount of water.
iii. Gypsum Mortars: is the type of mortar form from gypsums or anhydride binding materials.
iv. Mud Mortars: this is the type of mortars that consist of clay nodules and are used in construction of houses for poor temporary construction works.
v. Composite Mortar: this mortarmay be surkhi-mortar (surkhi, lime and water), lime-surkhi-sand mortar, cement lime mortar and cement clay mortar.

2.2.2.3 On the Basis of Application

i. Brick Laying Mortars: this type of mortar is produced for the purpose of brick work.

ii. Finishing Mortar: it manufactured as an architectural or ornamental parts, application of decorative layer on walls and panels.

iii. Special Mortars: they are the type of mortar produced for the purpose of sound, X-ray shielding, plugging concrete at oil fields.

2.2.2.4 On the Basis of Physical and Mechanical Properties

The basis of this classification is the strength of mortar which underlies the durability of mortar. Building mortars are subdivided into grades on the basis of compressive strength from 0.4 to 30.0N/mm^2.

2.2.3 Composition of Mortar

It is very important to understand the fundamental composition of a mortar. Beside, mortar has been said to be a composite material made by mixing three essential ingredients; fragment of fine aggregate (sand), cement, and water. The composition of mortar is designed by the volume or weight of material or by the relative amount of materials with the amount of binding materials taken as unit. A typical mortar mix would be 1 part cement to 3 parts washed, well graded, sharp sand based on the theory that the voids of empty space between the sand particles account for a 1/3 of the volume of the sand (Allen *et al.*, 2003). For example mortar composed of one kind of binding material and containing no mineral admixtures (e.g. cement mortar), the composition will be designated, say 1:4 i.e. one part of binding material (cement) and four (parts) of sand (Duggal, 2012). In order to obtain a strong, durable and financial viable mortar mix, it is crucial to understand the characteristics and behaviour of the ingredients. The ingredient of concrete can be classified into two groups, mortar contains three materials: cement, sand and water. If recognize that the water will be adjusted with every batch to meet job site conditions, it see

that one of the key tasks of batching mortar properly is accurately and consistently proportioning the amount of sand relative to cement. This sound simple, but many factors come in to play and we need to know what they are. For instance, sand volume changes in moisture. Oven dry sand saturated sand each occupies less volume than moisture in intermediate ranges. At 4% to8% moisture content, sand fluffs up or bulks. To aid in correction batching of sand, sand piles should be maintained in damp, loose condition. This might entails covering them to prevent or even sprinkling them with a hose in hot or windy condition.Allen *et al.,* (2003) argued that optimum and consistent performance of mortar requires correct constituent proportions.

2.3.3.1 Fine Aggregate(sand)

Aggregates are defined as granular materials used in construction that may be natural, manufacturedor recycled (BS EN 13139- 2002). According to Jackson and Dhir (1996) Aggregates are much cheaper than binder therefore using as much aggregate as possible in mortar will ultimately be more cost effective. Aggregates must be chosen carefully as they can comprise 50 to 75% of the total volume of mortar. Their type, size and physical properties will affect the material and construction process (Allen *et al.,* 2003).

Generally, aggregates such as natural sands and gravels are used in mortars but other materials such as crushed shell, crushed rocks, sandstone are also frequently adopted for specific purposes (Gibbons & Newsom, 2003). Aggregates can considerably improve the stability and durability of the resulting mortar, and must ideally be free from silt and clay to eliminate the possibility of failure (Allen *et al.,* 2003).River sand is the most commonly used fine aggregate. Sand is either round or angular grains and is often found mixed in various grading of fineness at different zones. The four zones of river sands are used for

the preparation of mortar cubes. Though its contain impurities is has to be cleaned and well sieved so the mortar will not affect the structure.

2.3.3.2 Cement

Cement is a binder, a substance that sets and hardens independently, and can bind other material together. The most important use of cement in the production of mortar and concrete to bind natural or crushed aggregate to produce a strong building material that isdurable in the face of normal environment effect. Cement is considered as the main constituent of mortar in terms of strength development. Gupta and Gupta (2012) defined cement as a material having adhesive and cohesive properties which makes it capable of bonding material fragments in to a compact mass. Cement and water constituents of mortar chemically react to form a binding medium (Garba 2014). When cement paste hardens, it binds the aggregate in to an artificial stone-like material called mortar.

2.3.3.3 Water

Water is one of the most important ingredients in mortar production as it actively takes placedin the chemical reaction with cement. Water plays an integral role in the manufacture of mortars. It is essential for the hydration reaction to occur in the material but is fundamentally required to achieve suitable workability characteristics. Water that is included to a designed mix that goes beyond that required for full hydration will result in the development of the pore structure. Water therefore has a significant influence on the development of the physical properties of the material i.e. compressive strength, permeability. The function of water in the hydraulic reaction is to enable dissolution and precipitation reactions to occur. The quality of water can affect the setting and strength of mortar (Allen, 2003). The water must be clean and free from suspended solids

anddissolved salts. In general, water fit for drinking such as tap water is acceptable for mixing mortar. Plenty dirty in mixing water affect the setting time, mortar strength and may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability of the mortar mix.

2.2.4 Types of Mortar

2.2.4.1 Cement Mortar

Cement Mortar is the mixture of cement, sand and water in desired proportion, Portland cement and blast furnance slag cement produced good mortar for wall built with bricks, stones and large block. Pozzolana Portland cement and sulphate –resisting cement produced mortar which are used for building constructions exposed to harsh and waste water, cement mortar are used for plastering, rendering smooth finishes and damp proof courses. The mix proportion of cement mortar depend on the type of work to be carried out e.g. masonry work 1:4 cement to sand, plastering for interior and exterior work 1:4, reinforced brick work 1:3 and damp proof courses 1:2. In the preparation of the mix the mortar may be mixed with mechanical mixer or manually, while mechanical mixers may be used for large quantities. For manual mixing, fine aggregate is sieved, cleaned with water to remove dirt, dust and dried. This dried fine aggregate is laid uniformly, on a pucca platform, over which cement is uniformly spread. The whole material is then thoroughly mixed with spades till it becomes uniform in colour. A depression is then made in middle of the mix and required quantity of water is added. The dry mix produced on the sites is transported and placed on the edges of the depression formed till the water is finally drained by the mix. The wet mix is then turn by usingmanually with spades until a uniform consistency of the mortar achieved. For mechanical mixing, the calculated quantity of

cement, sand, and water are fed in to the cylindrical container of the mixer, a rotor with blades, inside the container, rotates and thoroughly mixes the ingredients (Dungal, 2012).

2.2.4.2 Lime Cement Mortar

Lime cement mortars consist of small amount of cement and sand which are mixed dry. Lime putty is dissolved in water and added to the dry mix, the material is then mix thoroughly manuallyuntil uniform colour is obtained. For high lime content lime cement mortar is manufacture in the mills, lime and sand are first mixed separately in the form of paste for the entire day's requirement. Then cement is mixed with lime mortar in batch to be consumed in some hours' time.According to Forster 2002; Banfill and Forster (1999)in terms of design, lime mortar is more permeable than cement thus allowing a building to 'breathe' by not trapping moisture in a structure's fabric. The lime cement mortar has some great advantages due to increased water retentivity, workability, bonding properties and frost resistance. When lime cement mortar is used for plastering it provide good and smooth plaster finish and is used in buildings. The mix proportion for lime cement mortar for different types of work are outside wall 1:1:6 (cement, lime and sand) and 1:2:9 for art or tile wallsand inside walls respectively.

2.2.4.3 Mud Mortar

Mud mortars are generally used in traditional constructions, since 1900s, they are cheapest type of mortar producedwith local ingredients and are used for masonry works, surface floors and plastering wall surface in low cost buildings. In the process of mud mortar product, the top soil (from 150 to 200mm layer of earth) is removed from the ground are wetted and allowed to mature for some days (Duggal, 2012). Sometime clay is added to cement mortar to increase its workability, improve resistance to rain water, the plaster

surface is sometimes sprayed with bituminous material. This mortar showshigh frost resistance and strength more than cement sand mortar. Mud mortar is generally used for low cost buildings and protection from rain water; it is also used for temporary construction.

2.2.4.4 Lime Mortar

Lime mortar is the type of mortar that is prepared by mixing lime, sand and water. Lime used for mortar may be fat lime or hydraulic lime. Fat lime contain large amount of calcium oxide content. The hardening of this type of mortar depends on loss of water and absorption of carbon dioxide from the atmosphere and possible recrystallization in due course. Hydraulic lime has small content of silica, alumina and iron oxide. When the mixedcome in contact with water it produced putty or mortar having the property of setting and hardening under water. Slaked fat lime is used to make plastering mortar, while hydraulic lime is used for building construction and is suitable for construction of chimneys and lightly loaded walls above the foundations of buildings. Lime and sand in required quantities are placed on an impervious floor with spades. Water is added and mixed thoroughly with spades till mortar of uniform color and consistency is achieved before applied to the surface.The mix proportion of lime mortar for differenttypesof work are fat lime 1:2 lime to sand for plastering work, hydraulic lime 2:1for masonry work. Sand in lime mortar is an adulterant, and reduces its shrinkage (Hughes & Valek, 2003). Lime mortar forms holes allowing air to enter and helps the mortar in hardening. Lime mortar is not used for swampy areas and damp situations.

2.2.4.5 Surkhi Mortar

Surkhi is a material which is used as a replacement for sand for concrete and mortar, and has almost the same function as of sand but it also put some strength and hydraulicity. Surkhi is produced by grinding burnt bricks, brick-bats or burnt clay in to powder; under-burnt or over-burnt bricks and bricks containing high proportion of sand should not be used (Ashish & Rinku, 2012). When clay is especially burnt for producing surkhi, 10 to 20 per cent of quick lime is added to improve its quality; small clay balls are made for burning.Surkhi for plaster may be prepared from slightly under-burnt bricks, and ground very fine; this will increase the hydraulicity of fat lime. Mixing of Surkhi should be made in a mortar-mill with a certain quantity of lime added to the mix. (When conducting the test for under- burnt-bricks it should not dissolve in water). More strength can be achieved in Surkhi by submerging the material in water. The used of surkhi plaster in an exposed weather and very hot conditions may lead to a bad surface finishing.Surkhi should be grounded to pass through 4.75mm sieve and about less than 15 percent through 150 micron sieve. Sand is also added sometimes (Ravi, 2017). The mix proportions of surkhi mortar are 1:2 lime to surkhi for masonry and foundation work and 1:1:1 lime, surkhi to sand for masonry and foundation work.

2.2.4.6 Special Mortar

Duggal (2012) stated that somemortars can be used under special circumstances such as:

i. *Mortars for Filling Joints between Prefabricated Reinforced Concrete Components*:Theyare prepared with Portland cement and quartz sand with a mobility of 70 to 80mm. the grade of the mortar should be the same as that of concrete and in no case less than M-10. Cement sand and cement paste injection mortar intended for filling grooves inside prestressed concrete components should

have a grade not less than M-40 grade or more is preferred. Sulphate alcohol vinasse or naphetene soap is added in amount up to 0.2 percent of the weight of cement to reduce viscosity.

ii. *Packing Mortar:* these are the types mortarsused for packing oil wells they may be mixture of cement- sand, cement- loam and cement- sand- loam. Slag Portland cement, puzzolana and sulphate resisting cements are used in an area of harsh water and stackingof Portland cement when water pressure is expected. These mortars should have homogeneity, water resistance, predetermined setting time, adequate water yield under pressure and ability to form soil water –proof plugs in cracks and voids of rocks. Cement-sand-loam mortar with 5 percent calcium chloride is especially suitable for tunneling.

iii. *Damp-Proofing-Mortars*: these are prepared using high grade sulphate-resisting Portland cement or sulphate-resistance puzzolana cement as binding material and quartz sand or sand from crushed solid rock. An approximate composition of the mortar is 1:2:5 or 1:3:5. Water-proof seams and joints are produced from damp-proofing mortars made with expanding cement.

iv. *Sound Absorbing Mortars:* these type of mortars are prepared with Portland cement, slag cement, lime or gypsum as binding material, caustic magnesite and single size fraction sand (3.5mm) from lightweight porous materials such as pumice, cinders, ceramsite, etc. they have a bulk density of 600-1200kg/m^3 and used as sound absorbing plaster to reduce the noise level.

v. *Fire Shielding Mortars*: they are mortars used for setting refractory bricks in the furnance linings where the temperature is too high for ordinary mortar. Aluminous

cements and finely powdered fire bricks in the ratio 1:2 give excellent fire resisting mortars.

vi. *X-Ray Shielding Mortars:* These types of mortar are of heavy weight with bulk density or more than 2200kg/m^3 are required for plastering wall and ceilings of x-ray cabinets. The binding materials are Portland cement and slag cement, the aggregate are from heavy rocks in the form of sand (up to 1.25mm) and dust. Admixtures containing light weight elements (hydrogen, lithium, cadmium) are added to enhance the protective properties.

2.2.5 Uses of Mortar

Michael and John (2011) state that mortars are used for the following reasons:

i. for binding building unitsay like, bricks, stones, into a solid mass.
ii. serving as a seating and leveling material for the units
iii. it is also used in forming joints of pipes.
iv. during the maintenance process, mortar is used to fill up the cracks detected in the structure.
v. it is used to carryout pointing and plastering work on expected surfaces of masonry.
vi. it is also used for the improvement of general appearance of the structure.

2.2.6 Characteristics of Good Mortar

The major properties of hardened mortar are strength, development of good bond with building units, resistance to weathering and those of green mortar mixes are mobility, placeability and water retention(Papayianni, 2005& Henriques, Charola, Groot, Forster & Auras,2004**).** The mortar in addition, should be cheap and durable and should not affect the

durability of building units in contact. The joints made with mortar should not develop cracks.

2.2.6.1 Strength

The strength of a building depends largely upon both the mortar and the building unit. A very strong mortar with weak building units will be of little use. It is also of a great advantage to consider whether full strength is required within a short period of time. In cold weather, when the strength of cement mixes is develops slowly, this is likely to affect the choice of mix. According to Papayianni (2005) Strong cement mortars are most likely to lead to shrinkage crack and should therefore be avoided except where high strength is essential requirement. On the other hand the use of much weaker mortar such as, 1:10 cement to sand mortar is not adequate since reduction in cement content leads to less workability of the mortar, less cohesion and will provide opened joints of low resistance to frost. Strength of hardened mortar depends on the activity of binding materials, the water-cement ratio, consumption of binding material and the quality of sand.

2.2.6.2 Mobility and Placeability

The mobility of mortar is the process in a mortar can flow under the work of dead weight and outside force. Fluidity is indicated by “sinking degree”, which is determined by the consistency of mortar. The higher the degree of sinking for mortar, more better the mobility of the mortar.

The mortar mobility should be chosen based on the building types, construction conditions, and weather (Duggal 2008). The placeability of mortar is the process with which the mortar mix can be used with a low cost in a thin and uniform layer on the surface of a building. Depending on the composition a mortar may have a constituency ranging from

stiff to fluid. Mortar for masonry finishes and other works are made sufficiently mobile. The placeability of mortar mix depends on the mobility of the mortar mix. Mortars prepared from Portland cement lone are frequently deficient in cement paste, stiff and non-placeable and often plasticizers are added.

2.2.6.3 Water Retention

This is characterized by the ability of mortar not to stratify during transportation and to retain adequate humidity in a thin layer spread over a porous bed. Masonry such as bricks may suck water from mortar if not wetted sufficient depending upon the porosity of the units. This may lower the water cement W/C ratio of the mortar and consequently its strength. A mortar mix of low water retention will show the defects after hardening. Mortar may lose so much water that the amount left may be insufficient for its hardening and required strength. Mineral and organic plasticizing agents may be added to enhance water retention.

2.2.6.4 Resistance to Penetration of Rain

Plastering mortar should provide adequate protection to the masonry joints and units by forming an impermeable sheet. A satisfactory bond between the building units, mortar and plaster should be ensured.

2.2.7 Durability of Mortar

Durability of mortar may be defined as its ability to endure aggressive conditions during its design life(Zahedi *et al.*,2015).The influence of climate has a major effect on the functionality, life span, environmental performance and durability of mortar (Uyeda,2009). A number of potentially destructive influences may interact with the mortar: these include water, frost, soluble salts and temperature change. In general, as the cement content

increases so will durability. Air entrainment of mortars improves resistance to freeze-thaw damage(Hughes &Valek, 2003). Soluble sulfates may be present in the masonry units, the soil, and the atmosphere or may be introduced extraneously. When the masonry becomes wet the sulfates may dissolve and can then react with the mortar. The sulfates in solution may then combine with compounds in the cement and result in expansion and crumbling of the mortar. In certain situations it may be necessary to use a mix with adequate sulfate resisting properties. The durability must be adequate for the situation in which the mortar is used. A mortar of lesser durability may be suitable for internal walls but could weather very badly on exposed chimneystacks, for example. Where a mortar of lower strength than the masonry units is used any water flow will tend to take place preferentially through the mortar joint. If any degradation occurs due to freezing and thawing this is less important than damage to the units themselves, as the mortar joint may be replaced relatively easily. In contrast, if a relatively dense and impermeable mortar is used with more permeable masonry any flow of water that takes place will tend to pass preferentially through the masonry unit rather than through the mortar joint. This may lead to salt crystallisation (efflorescence) on the surface of the masonry and/or degradation of the masonry unit due to freezing and thawing. Schroder & Ogletree (2009) indicate that high temperatures during curing may cause high stress in the freshly applied mortars that interrupts the carbonation process. More importantly, rapid dehydration of the mortar in these conditions is well understood to lead to partial hydration. This results in a low strength, poorly performing mortar.Mechanicalstrength and raise the risk of mortar failure by shrinkage fracturingand leaching, reducing durability is caused as a result of too much water in the mortar mix. There is often a requirement to test mortar for durability, but satisfactory tests

are difficult to develop in practice and most suggested regimes are either too lengthy and complicated or do not relate sufficiently well to site practice.

2.2.8 Properties of Fresh Mortar

Fresh or plastic mortar is a freshly mix material which can be moulded in to any shape.The quality of hardened mortar can be said to be dependent on the properties at its fresh stage, is therefore, important that fresh mortar is checked and certified adequate before use. The properties of mortar are to a great extent influenced by the water/cement ratio (w/c) ratio of the mixture; that is; this factor exercises most control over the concluding properties of mortar. Selection of a w/c ratio gives the engineer control over two opposing, yet advantageous properties, compressive strength and workability. According to Gambhir (2006) workability of fresh mortar depends on the properties of the constituent materials, mixed proportion, and environment conditions. Good workability and water retentivity are essential for maximum bond. A mortar that has a high cement content will be stronger, but may produces less bond conversely, mortar with moderate cement content will not be strong, but will have better bond strength. Mortar bonds masonry unity together. Good bond strength will significantly contribute to a masonry wall's integrity and weather resistance. The compressive strength of mortar has only a small effect on the strength of the wall, but gives it durability.Other properties of mortar: durability, workability, adhesion, resistance to penetration of rain water and appearance.

2.2.8.1 Workability of Fresh Mortar

The workability of fresh mortar refers to the comprehensive properties of mortar ease for construction and good for quality, including mobility and water retention (Chen & Qiling,

2000). Workability may also be refers as the action of a mortar mix in respect of all the properties neededduring its application, subsequent working and finishing. The workability of mortar is greatly influenced by flow properties of the mix, its cohesiveness and its retention of moisture against the suction of the building to which is applied. The mortar with good mobility is easy to be paved thinly and evenly on bricks and bonded with floor well. Besides, workability of mortars hasan important role on the construction process of building structures. According to Sabbatini (1984), the workability may be considered as one of the most important properties of the mortar because it directly influences the bricklayer's work.

If mortar is ‘harsh’ that is of poor workability, the output of craftsmen will be reduced. Picking up and spreading will be slow and difficulties will be experienced in placing the cross or perpendicular joints and in obtaining a good finish. Panarese, Kosmatka & Randall (1991) considers the workability as an assembly of several properties such as, consistency, plasticity and cohesion. Given the fact that plasticity and cohesion are difficult to measure in-situ, consistency is frequently used as the measure of the workability, thefactors affecting workability are mix proportion, water content, used of admixture and grading of aggregates.

Test for workability

Flow table test

This is the most commonly used method of measuring the consistency of mortar which can be employed either in the laboratory or at site work (Gambhir, 2006). Figure 2.1 shows the flow table apparatus.

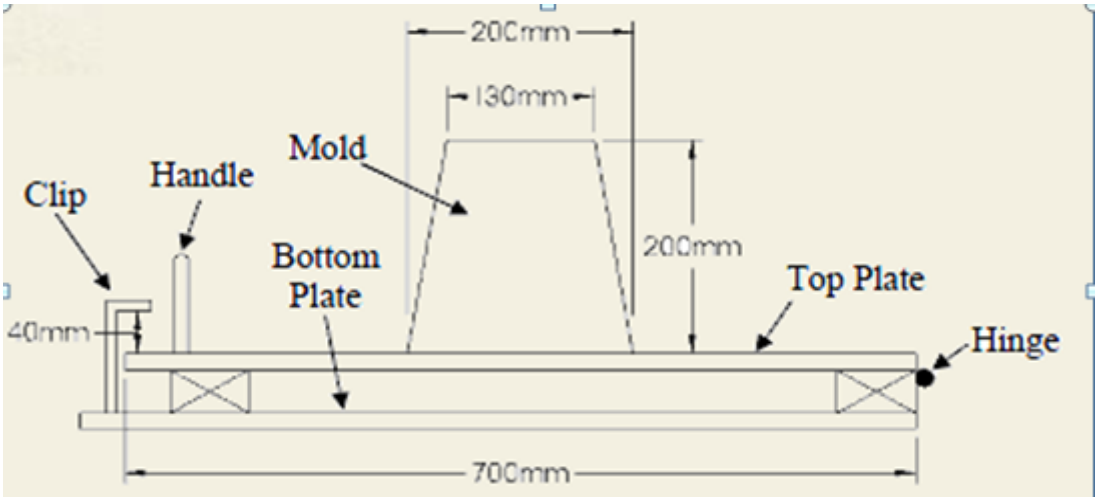


Figure 2.1 Flow Table Test Apparatus

Source:Matest(2017)

A mortar with good workability will have the following properties:

i. ease of use, i.e. the way it adheres or slides on trowel.

ii. ease of spread on the masonry unit.

iii. ease of extrusion between courses without excessive dropping or smearing.

iv. ease of positioning of masonry unit without movement due to its own weight and the weight of additional courses.

2.2.8.2 Bulk Density of Fresh Mortar

This is defined as weight of mortar held by container of unity volume when fill or compacted under defined condition. It is expressed in kg/m^3 or g/cm^3, bulk density is usually specified as loose or compacted. Bulk density of a given mortar depends on the grading of materials used such as the moisture content, degree of compaction, and texture.

The bulk density is determined by weighing amount of mortar required using equation (2.1).

$$\text{Bulk density (D)} = \frac{\text{Mass of mortar required to filled the container}}{\text{Volume of the container}} \quad \textbf{(2.1)}$$

$$\text{Bulk specific Gravity} = \frac{\text{Bulk Density}}{1000} \quad \textbf{(2.2)}$$

2.2.9 Curing

Mortar cures by hydration in which the chemical bonding in between binder and water take place (Ward-Harvey, 2009). It is important to provide adequate moisture (water) until its required strength is achieved (Allen & Iano 2009). Curing can take place over long period of time; more than 365 days depending on the water/lime ratio, climate exposure (including temperature, humidity and pressure), carbonation rate, time and mortar thickness (Taylor, 2002). Hanley & Pavia (2008) however suggest that 56 days is sufficient enough to study lime mortar early strength. Unfavourable curing condition will create a number of problems that will affect the quality of mortar. In hot weather, rapid evaporation could expel the water needed for hydration process, causing premature shrinkage on mortar. The quantity of mixing water should be increased to accommodate the high rate of evaporation. Conversely, curing in cold weather will increase the possibility of frost attack as the water in the mortar will expand (about 9%) to form ice (Allen *et al.*, 2003 and French, 2007). No chemical reaction (hydration) will occur because ice has no capability to hydrate the lime binder. It was suggested by Arnold (2003) that curing protection is important to maximize the hydration process thus maximizing the mortar strength and characteristics. It can be achieved by protecting the structure maintaining the

requiredmoisture levels and temperature during and in the infancy of the placement of the fresh materials (Taylor, 2002).

2.2.10 Properties of Hardened Mortar

The work of mortar in a structure is when it becomes hardened in the finished structure is to transfer the compressive, tensile and shear stresses between the units and it must be adequately durable to continue to do so over the service life of the structure. The strength and durability requirement of a mortar largely based on the type of service the masonry is required to perform. Wall which will be subjected to relatively severe stresses or exposure condition will need to be laid using a stronger and mortar then is required for general purpose applications.

2.2.10.1 Density

Density is defined as mass per unit volume of both solid material and the pores volume inside a single aggregate. For any pure sample or the same mixture, density is an intensive quantity, which means that its value is the same no matter how much of the sample is present. Density shows the proportional relationship between mass and volume of the sample. In order to get the density of a sample, the mass and volume of the sample material must be well known. In general, density can be transformed by altering either the pressure or the temperature.The density of a material improved always with the increase in the pressure within the material. Density improved with an improvement in the weather conditions, but there are notable exceptions to this generalization. The optimization of mortar density to improve structural efficiency (the strength to density ratio), reduce transportation costs, and also enhance the hydration is accomplished by replacing part of the normal-density aggregates (coarse aggregate, fine aggregate, or both) with comparable

amounts of low-density aggregate (Hoff, 2002).The density of a material is calculated using equation (2.3):

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \quad \textbf{(2.3)}$$

2.2.10.2 Compressive Strength

Investigation of many specifications gives the impression that compressive strength is the most important property of mortar. However, as workability and bond are also of great significance this may not also be truth. According to Shetty (2006) because it is relatively easy to measure compressive strength is frequently highlighted in specifications. Adequate mortar strength is an important factor to be considered but the mortar should not be stronger than the concrete or masonry unit on which the mortar is to be applied. The amount of cement content should not be too high in mortar whichwill produce a more rigid mortar, that may result in causing cracks passing through units and mortar joint as stresses are imposed. The compressive strength of mortar is the most common measure for determining the quality of masonry and the strength of mortar is based on the 28days cube strength. Compressive strength of mortar is usually determined through the use of mortar cubes. The compressive strength of light weight mortar depends on the density (Neville, 1995).The compressive strength is determined on the cube using a compression jig in a universal testing machine.The compressive strength is given by the equation (2.4)

$$F_m = \frac{F}{A_m} \quad \textbf{(2.4)}$$

Where

F_m= compressive strength, in MPa (N/mm²);

F = maximum load at failure, in N;

A_m is the cross-sectional area of the specimen on which the compressive force acts, calculated from the designated size of the specimen (see EN 1015-11) or from measurements on the specimen if tested according to Annex B, in mm^2.

2.2.10.3 Flexural Strength

Traditional building construction tended to be massive when compared to modern structures, typically with very thick walls. This meant that the mass or bulk generally resisted the various forces applied to the building (Mtabllib & Marke, 2010). The developments of modern building units and advances in mortar technology have led to production of moreslender structures which are more vulnerable to lateral force e.g. wind loads. BS 5628 part 1 provides guidance on the characteristic flexural strength of masonry, this is based on the type of masonry unit and the designation of the mortar. The flexural strength (F) is calculated from equation (2.5)

$$F = 1.5 \frac{Pl}{bd^2} \quad \textbf{(2.5)}$$

Where:

P = maximum flexural load

l = is the distance between the supports

b =Width of test beam, (mm)

d = Depth or thickness of tested beam, (mm)

Figure 2.2 shows the relationship between flexural and compressive strength of mortar.

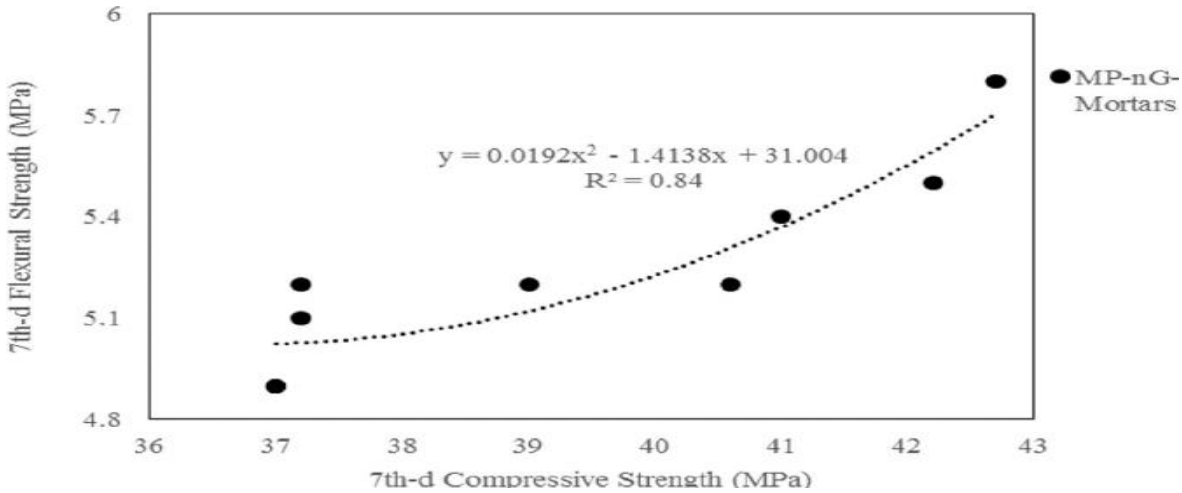


Figure2.2: Relationship between Flexural and Compressive Strength of Mortar

Source:Kirgiz(2013)

2.2.10.4 Water Absorption

Absorption is the process whereby a liquid is drawn into the mortar tending to fill the permeable pore spaces. It is generally quantified by monitoring the increase in mass as the liquid penetrates the pore structure. Water absorption is considered as ingest of water into mortar from all directions, the test of which, is a measure of the swelling potential of mortar.Water absorption is measure of permeability of mortar (Giannotti da silva, Liboio, & Helene 2008; Long, 2008). This is the ability of mortar to absorb and retain water. It is described by the amount of water absorbed by an initially dry material fully immersed in water. The higher the water absorption capacity of a mortar, the higher it's swelling characteristics and consequently, the higher the measure of shrinkage level of the mortar that results into the development of cracks. Mortar should be dense to minimize absorption, sound and adequate cured. The percentage of water absorption is calculated using equation (2.6).

%Water absorption = $\frac{W2- W1}{W_1}$ x 100_ **(2.6)**

2.2.10.5 Abrasion Resistance of Mortar

It can be used as a measure of an aggregate's suitability for use in mortar because higher loss values often indicate undesirable softness of an aggregate (Snyder, 2006).Wear on mortar surface can be generated by number of factors including skidding, scraping or sliding of objects on the surface, foot and tire traffic. It can also be affected by test conditions, type of abradant, pressure between the specimen and abradant, selection of mortar making materials (mixture proportions, curing and finishing procedures), type, kind or amount of treatment materials and abrasion by high velocities of water may leads to creating cavitation on mortar surface (Bakke, 2006). Additional loss occurs for recycled aggregates in this test, dependent on the amounts of adhered mortar, due to the weakness of mortar-to-aggregate bond strengths (Amorim, Brito &Evangelistta, 2012).

2.2.10.6 Sorptivity

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn in to the body of the material (Hall, 1989; Ganesan, Rajagopal&Thangavel, 2008).This is the rise or depression of a liquid in a small passage such as a tube of small cross-sectional area and the openings in a porous material. Capillarity, opined by Hausksbee (2013), is the result of surface, or interfacial forces of attraction between the molecules of water and glass walls, for example, and among the molecules of water themselves. These attractive forces balance the force of gravity of the column of water that has risen to a characteristic height. The narrower the bore of the capillary tube, the higher the water rises.Capillarity or capillary action explained by Touchette (2013), is the amazing, gravity-defying scientific phenomenon that makes liquids to flow upwards.

Capillary action depends on dissimilar, substances interacting with each other, one a liquid and the other a solid. The water molecules are attracted to the inner portion of the solid. Cohesion explains the way molecules of a single substance stick together. Water has very strong cohesion. Smaller opening, allow for more water cohesion and adhesion to the surface of the solid and is another force to reckon with.

2.3Fine Aggregate

Fine aggregate is defined as aggregates passing through 4.75mm sieve, they may be natural sand deposited by rivers, and crushed stone sand obtained by crushing stones and crushed gravel sand (Duggal,2008). The smallestsize of fine aggregate (sand) is 0.06mm. Depending upon the particles size, fine aggregate are described as fine, medium and coarse sands. On the basis of particles size distribution, the fine aggregate are classified into four zones; the grading zones being progressively finer from grading zone I to grading zone IV (BS 882:1973).

The structural integrity and longevity of a plaster depends on the quality of the materials. Quality assurance of construction materials is the assessment of its various properties in order to ascertain performance of the materials (Jackson &Plur, 1988). The condition under which the material is to serve depends on the quality, its characteristic features and suitability for that particular application in construction. In addition, Matawal (2011) stated that the durability of a structure cannot be evaluated if it is considered as isolation independent of the quality of the materials and service conditions for the materials. According to Neville and Brooks (2007) quality is determined by the chemico mineralogical composition, external appearance, texture structure and a combination of many properties by which a material differs from another. Fine aggregate, often called

sand BS 882: (1992), is not larger than 5mm in size and coarse aggregate comprises material at least with a of size of5 mm. In the United States, aggregate is divided by No.4 ASTMsieve is 4.75 mm in size (Neville, 2003).Fine aggregates as a construction material occur naturally as drifts in marine and/or fluvial environment (Usman, Idsuyi, Ojo& Simon, 2012).The composition of soil (sand) is highly variable, depending on the rock which the aggregate is sources and conditions used for the blasting and transportation. The study of individual grains can give much historical information as to the origin and kind of transport of the grain. Some fine aggregates are produced from by– product of quarrying. A uniform sand, consist of coarse, medium or fine aggregates.Fine aggregates used in building construction as 10% or more clay content while a grit sand has low clay content and have greater proportion of large grain sizes (BS 7533: Part 3).BS 882 recommends 3% clay or silt for sharp aggregates. BS 812 (1975), maintained that aggregates contain a number of constituent such as silt, dust, clay, soft particles. More so, silt is a material between 2mm to 60mm reduced by natural process of weathering.According to Akor, Usman, Bulus andGambo, (2008) aggregates are building materials obtainable in granular form.Neville (2000) observed that aggregates were originally seen as an inert material dispersed throughout the cement paste mainly for economic reasons.Robinson, Menzie and Hyun, (2004), described the term aggregates as an industrial commodity in terms sand, gravel, and crushed rock materials, in their natural or processed state, that are used to provide bulk, strength, and wear resistance in construction applications. The realization of the usefulnessand effect of fine aggregate on the strength of materials in building and construction industries had put into the minds of engineers and researchers to emphasis into the study of the engineering properties and its usefulness (Adeoti,

2001).Aggregates are inert filler in a mix, they are usually between 70% to75%volume of the whole mix. Sand is essentially quartz whereas clay is made of many other chemically active minerals like illite and kaolinite. Sand between 4.75mm (about 5mm) and 0.105mm in size is called fine aggregate. It used for making mortars plasters and concrete. Natural sand is available from local river beds or pits. An examination should be made on the fineness of the available sands and depending on its fineness. It should then be planned to be used for the different items of the construction (Varghese& Charvard 2008).It noted that manufactured sand, natural sand and gravel are the most used materials in the world after water, with almost 25 billion tons aggregate used per year, at an average of 4 tons per person. Robinson *et al.,* (2004) described fine aggregate as an industrial commodity in their natural or processed state thatare to provide bulk strength, and wear resistance in construction applications. Fine aggregate is generally natural sand and is graded from particles 5mm in size to the finest particles but excluding dust (Alexander & Sydney, 2005).Aggregates passing through a No. 4 (4.75mm) sieve and predominately retained on a No. 200 (75 µm) sieve are classified as fine aggregate. River sand is the most commonly used fine aggregate.In addation, crushed rock fines be used as fine aggregate. However, the finish of plaster with crushed fines is not as good as that with river sand (Zongjin, 2011).

Sand is a granular material that occurs naturally composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. Sand can also refer to a textural class of soil or soil type; i.e. a soil containing more than 85% sand-sized particles by mass (Beiser, 2015). The composition of sand varies, depending on the local rock sources and conditions.

Construction industry is responsible for extracting a large quantity of sand and gravel from rivers, for use as aggregates for production of mortars and concrete, causing a great environmental damage. In Brazil only, the aggregate consumption is estimated at 320 million cubic meters per year (Bastos,2006). In the whole world, the needs for housing are estimated at more than two million units and some construction materials like sand are becoming rare (Kenai, Benna&Menadi,1999). Due to natural reserves reduction and increase in monitoring by environmental authorities, sand extraction occurs now at each more distant and less accessible places, which increases its cost and diminishes the quality of sand.

The use of crushed fine aggregates resulting from production of coarse aggregates has been introduced in the market as an alternative to natural sands. Although crushed fine aggregates is already being used in construction since 1940 (Ohashi, 2006), there are still many doubts about its behavior. Among the main features of crushed fine aggregates particle shape, grain size distribution and chemical composition should be pointed out.

Aggregate characteristics can alter workability and mechanical properties of mortar (Lanas, Perez, Bello & Alvarez, 2004). Their particle shape harms its packaging, demanding an increase in fine content or in water quantity or the use of additives to ensure proper mortar workability. Typically, 10% to 25% of microfines are generated during production of crushed fine aggregates (Namshik, 2000). The high content of microfines in crushed fine aggregates facilitates mortar application and can collaborate to increase resistance. On the other hand, growing amounts of microfines increase the necessary amount of water to adequately wet particle surfaces and to maintain the specified

workability (Celik & Marar 1996), which may result in the appearance of cracking due to shrinkage.

2.3.1 Specification for Plastering Sand

According to IS 1542: 1992 plastering sand can be specified as given below:

Quality of Sand:

The sand shall consist of natural sand, crushed stone sand or crushed gravel sand or combinaion of any of these. The sand shall be hard, durable, clean and free from adherent coating and organic matter and shall not contain clay, silt and dust more than 5% in accondance with IS 2386-2: 1963.

Deleterious Materials: The sand shall not contain any harmful impurities, such as iron pyrites, alkalis, salts, coal, mica, shale, or similar laminated materials, soft fragments, sea shells and organic impurities in such quantities as to affect adversely the hardening, the strength, the durability of the appearance of the plaster or applies decoration or to cause corrosion of metal lathing or other metal in contact with the plaster.Plate I shows a sand profile.

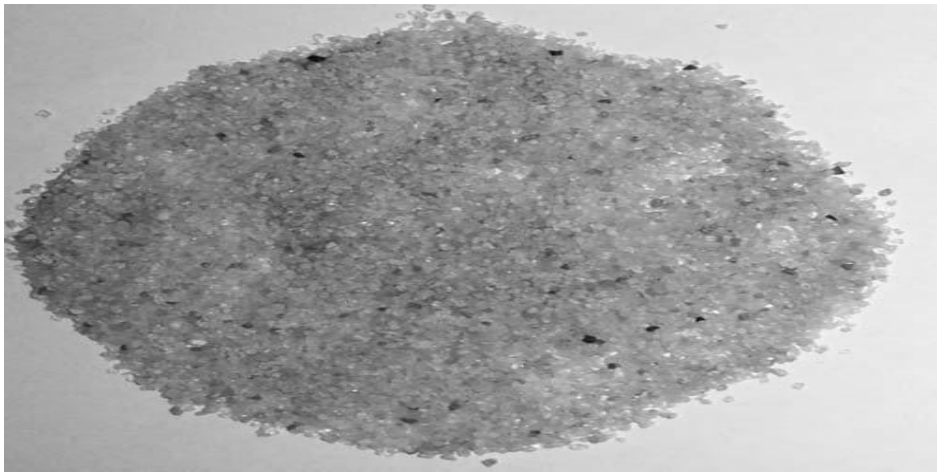


Plate I: Profile of Fine Aggregate (Sand)

Source: Zongjin(2011)

2.3.2Basic Characteristics of FineAggregates

A good fine aggregate should produce desired properties in both fresh and hardened mortars. Evaluation of the properties of fine aggregate are important and an understanding of its strength, and its effect upon the materials relative volumetric stability, porosity, relative density and chemical reactivity are essential.

Fine aggregate shape and surface texture can alter the properties of mortar in both early and later states. These out behaviour may be study by observation of the aggregate particles and classification of their particle shape and texture in accordance to BS EN 933-3 (1997). The classification is somewhat subjective due to visual analysis and identification of mineral components. However, the particle shape may also be study by direct measurement of the aggregate particles to in order to obtain the flakiness, elongation and angularity.

2.3.3 Properties of Fine Aggregate and it's Function in Mortar.

Properties of Fine Aggregate:

The characteristics of sand particles define the properties of sand. Properties can be further described by the physical, Mechanical and Chemical characteristics, (Meininger & Nichols, 1990). Determining if sand is suitable for particular application is characterized by several particles in accordance to different criteria such as its advantages and uses.

Functions of Fine Aggregate:

Sand is the most commonly used material as fine aggregate in mortar; it consists of small angular and rounded grains of silica. Generally, sand is used in mortar not only to add more strength its. Rather it is mainly used as an filling material to add more volume to themortar so as to provideeconomy, It subdivides cementing material into a thin film,

offers requisite surface area for film of cementing material to adhere and spread, Prevents shrinkage and cracking of mortar, Well graded sand provide density, it allows $Co_2$from the atmosphere to enter in some depth in the case of fat lime mortar and increase setting power, Some chemical reaction take place between silica (SiO_2) of sand grain and other cementing materials to form a hardened mass (Duggal, 2008).

2.3.4Requirements of Fine Aggregates:

Fine aggregate must contain coarse angular sharp and hard grains, It must be free from coatings of clay and silt, It should not contain any organic matter, It should be free from hygroscopic salt, It should be strong and durable and chemical inert.

2.3.5Available Grading of Fine Aggregates

The grading of an aggregate defines the proportions of particles in different sizes. The size of the aggregates particles normally used in construction varies from 37.5mm to 0.15mm. BS EN 12620 : (2002) places aggregates in three main categories; fine aggregates or sand (smaller than 5.00mm), coarse aggregate (larger than 5.00mm and combined aggregate (comprising both fine and coarse aggregates). The grading of an aggregate can have a considerable effect on workability and stability of mortar mix. Sieve analysis is used for determining the grading of an aggregate (BS EN 12620:(2002).Generally, it is considered that the fine aggregate used for mortar work should pass through a sieve of (3.2mm) and the sand for plaster and pointing must pass through a sieve of (2mm), (Varghese& Charvard, 2008). Another recommendation formortar and plaster work is that the material passing through the maximum sieve sizemust be 100%for mortar, [Indian Standard (IS) 2116 (1980)]and 80 to 100 percent for plasters, [Indian Standard (IS) 1542 (1977)]thus

enabling a wide variety of sand to be used for this purpose. The recommended grading of sand foris given in table 2.2.

Table **2.2: Grading of sand for masonry mortars and plasters**

IS Sieve	M_{IS}	P_{IS}	
4.75mm100		95-100	
2.36mm90-100		95-100	
1.18mm70-100		90-100	
150micron40-100			80-100
100micron5-70	20-65		
50micron0-15	0-50		

Source: Varghese &Charvard(2008)

Note: M_{IS} = IS 22116 – 1980 % passing;

Where:

M_{IS}=Mortar and P_{IS}= Plaster.

2.3.6 Classification of Fine Aggregate

According toBS EN 12620:(2002) fine aggregate may be described as coarse sand, medium sand and fine sand. However, depending upon their size, sand can be classified as:

1.*coarse Sand*:when a fineness modulus is between 2.90 to 3.20.

2.*medium Sand*:Sandwith a fineness modulus of 2.60 to 2.90.

3.*fine Sand*:With a fineness Modulus of 2.20 to 2.60.

b. According to its Grading

BS 882:(1973)specifications classify the fine aggregate into four types according to its grading as fine aggregate of grading Zone-1 to grading Zone-4.

c. *Based on Source*

i. *Natural Sand* –This is a type of fine aggregate that is form from natural disintegration of rock and which has been deposited by streams or glacial agencies.

ii. *Crushed Stone Sand* –this type sand is produced by braking hard stone in to the required sizes.

iii. *Crushed Gravel Sand* –crushed sand as the name imply is the type ofFine aggregate that is made by braking natural stone.

iv. *Blended Sand* –Blended sand is the sand that is manufactured by grinding natural sand and broken stone sand or broken gravel sand in suitable sizes.

Figure 2.3 shows the example of particles size distribution and cumulative surface area.

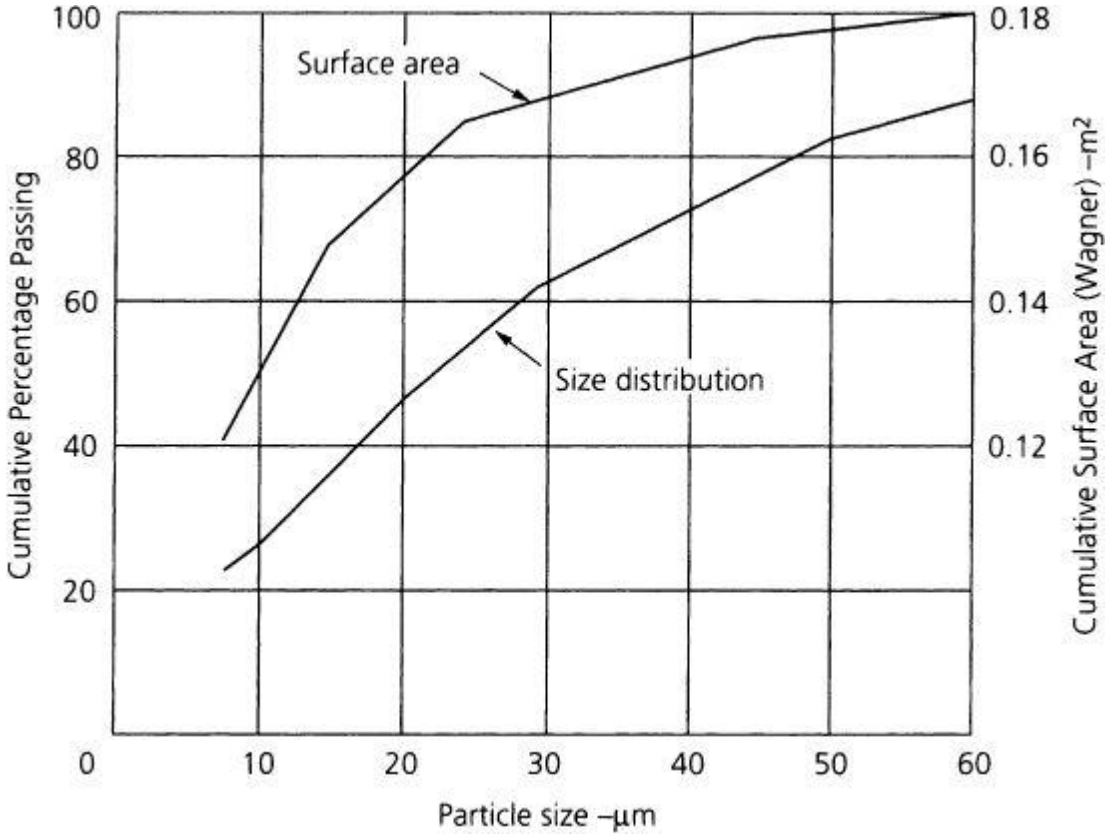


Figure2.3 Example of particle size distribution and cumulative surface area.

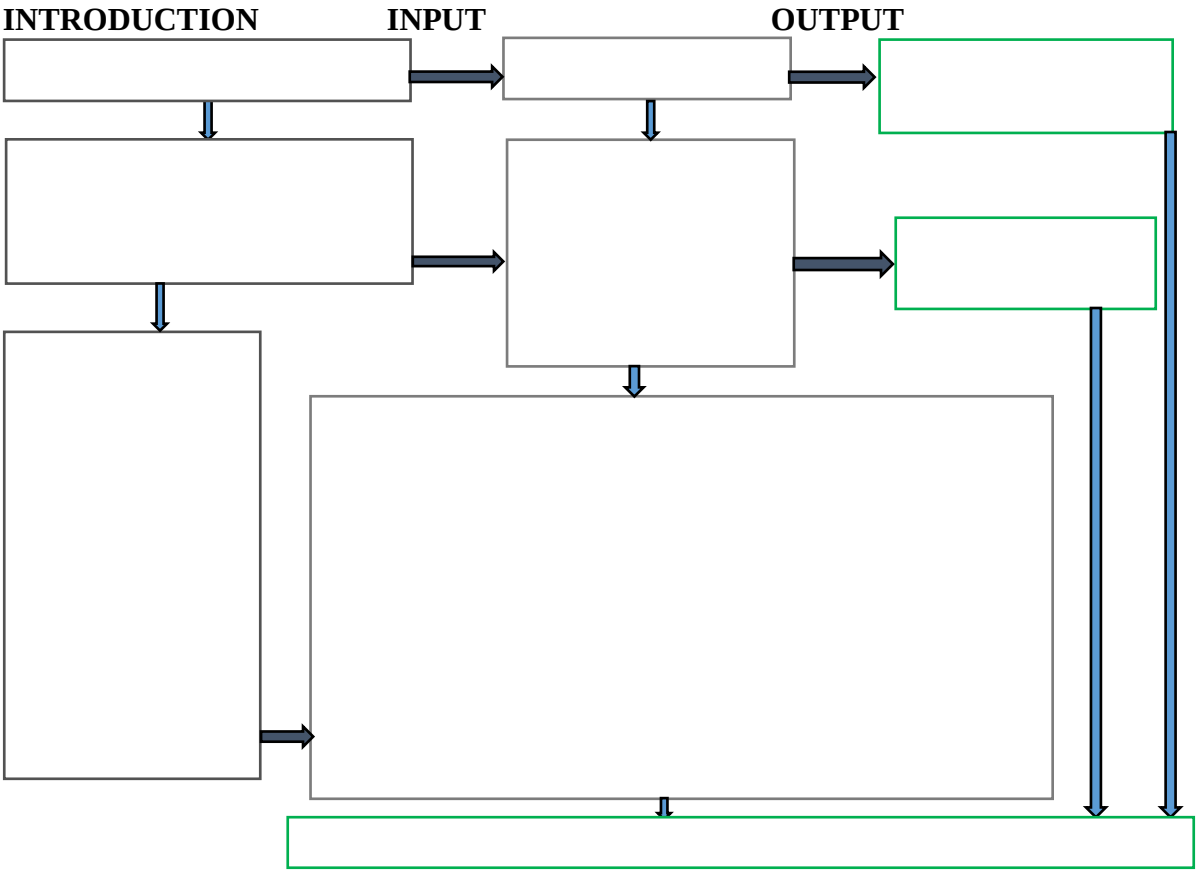
Source:Neville (2011)

CHAPTER THREE

3.0 METHODOLOGY

3.1 Research Design

The research carried out in this dissertation was designed in three stages as displayed in figure 3.1. The introductory stage consists of the formation of the research topic and giving it a proper tittle; highlighting the problem statement of the research; drafting of the aim and objectives of the dissertation and scoping the work. The input stage comprised of the main body of the work where the objectives were treated through laboratory experiments. The third stage is made up of discussion and interpretation of the research findings that lead to the conclusions.



[Adapted from Abdul-Azeez, 2012]

Figure3.1: Research Design

3.2 Research Materials and Methods

The research was carried out through the following methods:

3.2.1Materials

*3.2.1.1 Fine aggregate:*Clean and air-dried sands both sourced from Gerei local Government Area of Adamawastatewere used for the research work.

Plate II shows the satellite image of the site where the samples were obtained, the samples lies within co-ordinate A1 as shown.



Plate II: Satellite Image of Samples A and B Site

Plate III shows the pit of where sample A was picked



Plate III: Pit of Sample A

Plate IV shows the pitof where sample B was picked



Plate IV: Pit of Sample B

*3.2.1.2 Cement:*The cement used for the whole work was Dangote Cement,it was assumed to have complied with the requirements of BS EN 197-1 (1995) and was obtained from local dealers in Zaria.

*3.2.1.3 Water:*The waterused throughout the research work for mixing the mortars was pumped from the Ahmadu Bello University water works. The quality of the water conformed to the specification of BS EN 1008, (2002) which specifies that water to be used must be safe for drinking, free from odour, colour, taste and impurities.

3.3Tools, Apparatus and Equipment Used

The apparatus used in carrying out the various tests in the laboratory includes: head pan, hand scoop, weighing scale, shovel, wheel barrow, trowel, wire brush, tampping rod, mixing board, standard sieve, vicat apparatus, Le Charteliers apparatus and mould cube.

The equipment used in the course of carrying out the various experiments were:

i. Concrete mixing machine (CHONQING LIFAN-152 F)
ii. Compressive strength testing machine (STYE-2000)
iii. Flexural strength testing machine (STYE-2000)
iv. Weighing machine
v. Oven

3.4 Methods

The research was carried out through the following processes;

3.4.1Literature review

Relevant literatures were reviewed from different text books, journals, conference proceeding, seminars, published and unpublished research works, lecture notes, so as to articulate existing knowledge on the researchtopic.

3.4.2 Experimental Program

The experiments were conducted in two stages as follows:

A)Preliminary Investigations: Preliminary tests were carried out in accordance with the appropriate standards in order to check the quality of the two sands materials used for the experiment. The various preliminary tests carried out include: XRD Analysis, XRF Analysis, specific gravity, sieve analysis, determination of moisture content, bulk density, water absorption and siltcontent. Nominal mix proportion was adopted in order to estimate the quantity of material needed for the research work.

3.4.2.1 X-ray diffraction analysis

The PHILIPS PW 1830 X-ray diffractometer at National Geoscience Laboratories (NGRL) Kaduna State, was used to analyse the two sand samples used for this work. 0.5g of the sand samples were prepared by compressing them into pellets which were labelled and placed in the X-ray diffractometer for analysis. The samples were analyzed between an angle of $5^{o}$to 55^{o} (2Θ) using the Cu K alpha radiation. The voltage and current of the X-ray tube were set at 40KV and 40mA respectively. Mineral phases were identified in XRD traces.

3.4.2.2 Chemical analysis

The chemical analysis of the two sand samples was determined using the X-ray fluorescence equipment (Spectro X-lab) at the Multi-User Laboratory at Department of Chemistry Ahmadu Bello University, Zaria. 4g of each sample was mixed with 0.09g of wax and then milled in a milling machine for 3 minutes to produce a homogeneous mixture. The mixture was poured into a disc and placed under a press pellet machine. The pellet machine produced a tab which was placed in a container. The container and its

content were fixed in the Spectro X-lab 2000 instrument for irradiation and finally to determine the chemical composition of the samples.

3.4.2.3 Particles Size Distribution Test of Fine Aggregate

The apparatus used for sieve analysis of the fine aggregate are weighing balance and BS sieve. 2kg of fine aggregate was weighed and the aggregate was then sieved using BS sieves of 10mm, 5mm, 2.5mm, 1.2mm, 600µm, 300µm, 150µm and pan.

The sieves were arranged with the sieve having the largest aperture at the top to bottom to decrease the aperture sizes with pan and lid in order to form a sieving column. The fine aggregate sample was then poured into the sieving column and shaken manually. Sieves were removed starting with the largest aperture sizes, and sieve shaken individually andmanually ensuring no material was lost. The retained material on each sieve was then weighed and recorded in accordance with BS 812-103, (1990).

3.4.2.4Specific Gravity Test

The specific gravity (Gs) for the two fine aggregates was determined by using pyknometer method. The apparatus used were density bottle and stopper, funnel, spatula and weighing balance.

The density bottle and its stopper was cleaned and dried. The weight of the bottle with stopper was then determined using weighing balance and recorded as W_1. A little quantity of the sand sample A was poured through a filter, using spatula into the density bottle. The density bottle was then covered using its stopper. The weight of the bottle, sand and stopper was recorded as W_2. Some quantity of water was then poured to cover the sand in the density bottle. The bottle was rotated in order to avoid air bubbles into the bottle, and then the stopper was used to cover the density bottle. The weight of the bottle, sand, water

and stopper was recorded as W_3. The density bottle was then emptied and properly washed and filled with water and stopper inserted. Precautions were taken to avoid air bubbles into the bottle. The body of the bottle was then wiped dry. The weight of the bottle, stopper and water (full) was recorded as W_4.The specific gravity denoted by Gs, was determined using equation (3.1).

$$Gs = \frac{W2 - W1}{(W4 - W1) - (W3 - W2)} \quad \textbf{(3.1)}$$

Where:

W_1= weight of the density bottle

W_2 = weight of density bottle + sand

W_3 = weight of density bottle + sand +water

W_4 = weight of density bottle + water (full)

The same procedure was used to determine specific gravity of other aggregate sample B.

3.4.2.5Bulk Density Test

Density is defined as weight per unit volume of both solid material and the pores volume inside a single aggregate. Bulk density is the weight of aggregate held by container of unit volume when filled or compacted under defined conditions. Aggregate bulk density is usually specified as loosed or compacted.The bulk densities of the sand samples were determined by transferring the fine aggregate to the box until it is about one third full, the surface was levelled with hand and the layer was evenly compacted with the required number of strokes (25) using tamping rod. Morefine aggregate was placed in the container until about two third full and again compacted as before. Finally the container was filled to over flow and compacted. The top of the container was levelled then the sand poured into the weighing balance, weighed and recorded as the mass (m) of the fine aggregate, volume

(v) of the box. The bulk densities (BD) of the aggregates was determined in accordance to BS 812-2(1995) using equation (3.2).

$$BD = \frac{M}{V} \quad \textbf{(3.2)}$$

Where:

BD = density of the aggregate in Kg/m^3

M= mass of aggregate in Kg

V= volume of the aggregate in m^3

3.4.2.6 Water Absorption capacity Test

This involved the determination of the moisture or water content in sand in a saturated and surfaced dry conditions. Two portions of the fine aggregate, 1kg eachwere weighed. Oneportion was placed in an oven maintained at $105^o \pm 5^oC$, and left for 24 hours in it. The second portion was completely submerged under water, for 24 hours, the sample in the oven was removed and weighed, also the socked sample was weighed after it has been completely dried. The wetted sample was then spread on a piece of paper under a blowing fan until completely surface dried. The percentage of water absorption capacity of the fine aggregate was computed using equation (3.3).

$$\%\text{Water absorption} = \frac{\text{Saturated surface dry weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100 \quad \textbf{(3.3)}$$

3.4.2.7 Silt Content Test

This involved the determination of the total amount of silt material in the fine aggregate. 50ml of an approximately 1% solution or 2.58g of salt was dissolved in water to form a solution and placed in a 250ml measuring cylinder. Sand, as received was added until the level reached the100ml mark, more salt solution was added until the total volume of the

mixture in the cylinder was 150ml. the cylinder was then covered with the palm of the hand, shaken vigorously, repeatedly turned down and then allowed to stand for 3 hours. The silt which becomes dispersed on shaken settled in a layer above the sand, and the height of this layer was expressed as a percentage of the height of sand using equation (3.4).

$$\%\text{Silt content} = \frac{\text{Height of silt}}{\text{Height of sand}} \times 100 \quad \textbf{(3.4)}$$

3.4.2.8 Moisture Content Test

The method covered the determination of moisture content which is the excess water that is contained in fine aggregate in a saturated and surface dry condition i.e. Absorption. As soon as the undisturbed sample from each pit was brought to the laboratory, sufficient number of containers were labeled, weighed and the weight of these were recorded. Small amount of each sample were put in three (3) different containers and reweighed with sample. The containers and their content were then placed in an oven maintained at a temperature of 105^{o}C to 110^{o}C for period of 24 hours. After, the sample is oven dried, the container with the dried sample were brought out of the oven and allowed to cool to the room temperature. Their final weights were recorded in accordance with BS 812-108 (1990).

$$\text{The moisture content (m)} = \frac{W_2 - W_1}{W_1 - W_3} \quad \textbf{(3.5)}$$

W_1 = Oven dry weight of sand

W_2= Air dry weight of sand

W_3 = Weight of empty container

B) Tests Undertaken on Hardened Mortar Samples:

The following were the tests carried out Density, Compressive Strength, flexural Strength, Abrasion Resistance, Water Absorption and Sorptivity.

All the mortar samples produced were cured in water for different periods of 7, 14, 28 and 56 days. Details of test types, mortar specimens and curing days are presented in Table 3.1.

Table 3.1:Production of Mortar Cubes and Prisms using Cement and Sands.

Type of Tests	**Sample Specimen A**				**Sample Specimen B**			
Curing Period (Days)	**7**	**14**	**28**	**56**	**7**	**14**	**28**	**56**
Density Test	5	5	5	5	5	5	5	5
Compressive Strength	5	5	5	5	5	5	5	5
Flexural strength	5	5	5	5	5	5	5	5
Abrasion Resistance	-	-	5	5	-	-	5	5
Water Absorption Test	-	-	5	5	-	-	5	5
Sorptivity Test	-	-	88-	-	88			

Source: Research Design (2018)

Total of 192 numbers of specimens were produced, for the strength tests, the samples were subjected to only compressive strength and flexural forces.

3.5Production and Testing of Mortar Specimens

3.5.1 Trial Mix

Trial mixes were prepared in order to test the appropriateness of the water/cement ratio and to check whether or not the particular aggregates or cement selected for use will behave as anticipated. The two sand samples were used for the trial test.

Mix proportion of 1:3 was used to cast 50mm x 50mm x50mm cubes which were used for the trials. Three different water-cement ratios were used; 0.5, 0.6 and 0.7. A water-cement

ratio of 0.7 was chosen, this is because the flow table value determined indicated 0.7 as the optimum.

3.5.2 Final mix proportion

The final mix entails the use of nominal mix method of mortar proportioning. A nominal mix proportion of 1:3 and a water-cement ratio of 0.7 were used for the production of the mortar specimens. Quantities of the materials were computed using absolute volume method. A total of 192 specimens were cast and cured for the ages of 7, 14, 28 and 56 days. The casting was carried out at concrete technology laboratory Department of Building, Ahmadu Bello University Zaria. The preparation of the mortar samples and assessment were carried out in accordance to BS EN 1015(1999) and EN 998 (2003).

3.5.3 Tests on Fresh Properties of Mortar

At the fresh stage, the mortar samples were tested forworkability using flow table andfresh mortar bulk density using steel mould and weighing balance. The tests were carried out in accordance with BS EN 1015 (1999).

3.5.3.1 Workability

Flow table test was carried out immediately after the mortar was thoroughly mixed to determine the workability of the mortar samples produced. To determine the workability or consistency of fresh mortar mix, the inside surface of the mould and the flow table were cleaned and oiled to prevent adherence of fresh mortar mix on the surfaces. The mould was placed (600 mm in height, internal base and top diameter of 200mm x 130 mm respectively) in the center of the flow table and filled in two layers each layer was tamped ten times with the tamper. The mould was held firmly in place during this operation. The excess mortar was removed from the top of the mould with the palette knife and the area

around the base of the mould cleaned with a cloth. A period of approximately 15seconds was allowed to elapse and the mould was then removed, the table was jolted 15 times at a rate of one jolt per second. The diameter of the spread mortar was measured in two directions at right angles to each other using calipers, results were recorded. The average of the both spread was taken as the flow value.



PlateV: Determination of Workability

3.5.3.2 Fresh Mortar Bulk Density Test

The determination of the bulk density of fresh mortar the inside surfaces of the moulds were cleaned and oiled to prevent adherence of fresh mortar on the surfaces, the mould was weighed and recorded as m_1. The mould was filled with mortar using a scoop until it was overflowing, then the edges of the mould was wiped clean with a damp cloth, the mould weighed and the mortar was recorded m_2. The fresh mortar bulk density (BD) was calculated using equation (3.7).

$$BD = \frac{m_2 - m_1}{V_v} \quad \textbf{(3.7)}$$

3.5.4 Casting of Mortar Samples

The mortar moulds (prism and cube) were cleaned from all dust and coated with oil as releasing agent in order to have smooth surface and to prevent sticking of mixed mortar to the moulds. The ingredients; cement, fine aggregate (sand) and water were measured using weighing balance. After that the weighed fine aggregate was first added to the cement and dry mixed for a minute manually. Then, water was added to the dry mixed mortarand thoroughly mixed for two more minutes. The mixed mortar was checked for workability and fresh mortar bulk density, then was placed in the mould in two layers and each of the layer wascompacted with the help of a poker vibrator for 30 and 45 seconds, the surface was levelled up by the means of a hand trowel. The mortars in moulds were kept undisturbed for 24 hours and protected against vibration, dehydration andshock. The cast mortarcubes and prisms were removed from the moulds and submerged in tank filled with water for curing to take place and until the testing age was reached.



Plate VI: Preparing Moulds for Casting of Mortar Cubes

3.5.5Curing of Mortar Specimens

After casting, the specimens still in their moulds were covered with polythene sheeting and kept under laboratory condition. Specimens were de-moulded at an age of one day after

which they were subjected to curing in watertank for 7, 14, 28 and 56 days, they were left completely uncovered in their particular curing environment.

3.6Tests on Hardened Mortar

After curing the mortar cubes and prisms produced were subjected to density, compressive strength, flexural strength, abrasion resistance, water absorption and sorptivity tests at 7, 14, 28 and 56 days of curing periods.

The details of various tests are presented as follows:

3.6.1 Density Test

The test was performed according to BS EN 12390-7 (2009). The density of mortars produced with aggregate samples A and Bwere determined. To achieve the saturation surfacedry condition, the samples were removed from the basin of water, wiped and left to dry in thelaboratory for one hour and then weighed using a scale with anaccuracy of 1 gram. Due tothe slight unevenness of the top surface of the samples, the volumes of the cubes were determinedusing the actual dimensions of each face. Basically, the density of the mortar was determinedasmass/volumein units of kg/m^3. This test was repeated when the samples were7, 14, 28, and 56 days old. Equation (3.8) was used tocalculate the density (D).

$$D = \frac{M}{V} \quad \textbf{(3.8)}$$

Where

M = the mass of the mortar cubes in kg

V = volume of the mortar cubes in m^3

3.6.2 Compressive Strength Test

Compressive strength was tested after curing the samples for different ages (days). In this research, compressive strength was determined after 7, 14, 28 and56 days of curing and based on the BS EN 1015-11 (1999). A STYE 2000 compressive testing machine was used for conducting the tests with a loading rate of 900 to 2000KN/sec. Plate III shows a typical testing arrangement for mortar compressive strength test. The machine has a maximum capacity of 250 KN. Initially, the samples were removed from the curing tank; the surface water was wiped off with a damp cloth and allowed to dry for 2 hours. Afterwards, the samples were weighed using weighing balance then placed in the machine and the loading cell was drawn down just before the surface of the tested samples.The average compressive strength of plastering mortar is 17 N/mm^2 according to BS EN 1015-11: 1999.

The samples were loaded in compression until they failed completely. Equation (3.9) was used to calculate the compressive strength (R_c).

$$R_c = \frac{F}{A} \quad \textbf{(3.9)}$$

Where;

F= Load at failure **(KN)**

A= Cross sectional area of the specimen on which compressive force acts.

Plate VII Shows a Failed Mortar Cubes Specimen



Plate VII: Failed Mortar Cube

3.6.3 Flexural Strength Test

The test was carried out in accordance with BS EN 1015-11 (1999), a testing machine capable of applying the load at standard rate was used. The test specimens after curring for the required aged were removed from the tank and surface dried, the specimens were wiped with a clean cloth to remove any loose grit or other material, the specimens were then weighed. Before testing the bearing surface of the rollers were cleaned and the specimens were placed with one of their faces (which were cast against the mould) on the supporting rollers. The load was applied without shock at a uniform rate and the maximum load applied was recorded. The flexural strength was calculated using equation (3.10).

$$F = 1.5 \frac{Pl}{bd^2} \quad \textbf{(3.10)}$$

Where:

P = maximum flexural load

l = distance between the supporting rollers

b = width of the specimen

d = depth of specimens

Plate VIII Shows a Failed Mortar Prism Specimen



Plate VIII: Failed Mortar Prism

3.6.4Abrasion Resistance Test

This was aimed at determining the abrasion resistance of the hardened mortar by rubbing action which causes attrition. The rubbing action results in the loss in initial weight per $1cm^2$ of the surface being abraded. Each specimen was weighed and the value recorded as W_1 before brushing its surface with a wire brush. Wire brush attached with 3.6kg weight was used to stroke the surface of each specimen up to 60 times at constant speed. The specimens were reweighted again and the value recorded as W_2. The loss in weight was calculated by subtracting the final weight from the initial weight (W_1-W_2). Abrasion resistance percentage was calculatedusing equation (3.11).

$$\%abraded\ material = \frac{W1 - W2}{W2} \times 100 \quad \textbf{(3.11)}$$

3.6.5 Water Absorption

This was carried out in accordance to ASTM C 642-97.The mortar cube specimens were heated in an oven for 72 hoursat105^{o}C and until a constant weight was attained, the cubes were then removed from the oven and allowed to cool gradually to room temperature for 3 hours, the weight of the cooled cubes is the initial weight and recorded as W_1. The final

weights were determined after the specimens were immersed in water for 30 minute, the cubes were removed and wet surface was wiped off excess water and re-weighed and recorded as W_2. Equation (3.12) was used to calculate the percentage of the water absorption.

$$\%\text{Water absorption} = \frac{W2-W1}{W1} \times 100 \quad \textbf{(3.12)}$$

3.6.6 Sorptivity Test

Thetest was performed in accordance with ASTM C 1585-04. The purpose was to determine the rate of absorption of water by unsaturated mortar. Sorptivity is a function of the increased mass of a specimen resulting from absorption of water, relative to the time that one surface is exposed to water. After pre-conditioning for 72 hours in an oven, the samples were weighed and their masses were recorded to the nearest 0.01g prior to application of sealant. In order to ensure the water flow only in one direction through the specimen without causing any effect of wicking action, the specimens were sealed on all sides other than the exposed face. The specimens were sealed with silicon sealant, tightly around the entire surface. The specimens were placed on a tabletop surface with the designated test surface face-down in order to keep it free of silicon sealant. Care was taken to ensure that the all imperfections, pits, and small dimples were filled with silicon sealant.The silicon sealant was allowed to dry for 24 hours forming a watertight and airtight seal. A second layer of silicon sealant was applied in the same manner to ensure that a proper seal was achieved. The masses of the prepared specimens were measured and recorded to the nearest 0.01g once more. This value form the initial mass value set for absorption calculations. A wedge was placed in the bottom of each container to ensure that the exposure to water was even across the exposed surface. Specimen was placed on the

support and the container was gently filled with tap water until it reached a level approximately 1 to 3 mm above the level of the exposed surface. The pressure head resulting from the 1 to3mm of immersion can be considered negligible. In this experiment, absorption was to be the result of capillary rise only. This simulates the behavior of most mortar structures in the field. A digital timer was initiated from the moment of the exposed surface came in contact with the water. The specimen masses were recorded at interval of 60 seconds, 5, 10, 20, 30, 60 minutes, 6 and 24 hours in accordance with the ASTM C 1585-04. Each specimen was quickly removed from the water, had its test surface wiped with towel to removed excess water and then placed on the scale upside-down such that the exposed face never come in contact with the scale, which could potentially allow water to be lost from the specimen. Water levels in the container were checked daily to ensure that the 1 to 3mm immersion range was maintainedat all times throughout the experiment. The absorption, *I*, was calculated as the change in mass divided by the product of the cross-sectional area test specimen (*a*) and the density of water (*d*). In accordance with the ASTM standard, for the purpose of the test, the temperature dependency of the density of water was neglected and a value of $0.001 g/mm^3$ was used. The unit of *I* is in mm. The absorption values were then plotted against time to produce absorption curves. The rate of change of the absorption curves at various times is called sorptivity; S. Soptivity values were then plotted against time to investigate changes in the rate of absorption.

Pate IXShows Mortar Subjected Sorptivity



Plate IX:Cubes arranged for sorptivity Test

3.7 Method of Data Analysis

The result of the various tests conducted were analysed using the arithmetic mean, or simple mean or average is the central tendency of a collection of numbers taken as the sum of numbers divided by the size of the collection. For the purpose of this research, the mean was used to analyse the result of the compressive and flexural strength at different curing periods by summing the strength of the cubes and prisms crushed on a particular day and dividing it by the number of cubes and beams respectively.

In this experiment the percentage was used to analyse the result of water absorption, capillarity (sobtivity), abrasion resistance and linear drying shrinkage tests by calculating the percentage of loss of weight and percentage of water absorption for entire mortar specimen. Graphs and tables were also used to presentsome results.

The result of the above tests are presented and analysed in chapter four of this research work.

CHAPTER FOUR

4.0 PRESENTATION OF RESULTS, ANALYSIS AND DISCUSSIONS

The results presented in this chapter are based on the tests carried out assess the physical and mechanical properties of mortar made with two different types of plastering sands used in Yola, Adamawa State.

4.1 Presentation of Results for Preliminary Test

The results include those of the physical and mechanical properties of the sands and the mechanical and physical properties of the mortar made with the sands.

4.1.1 Properties of Sands

Based on the X-ray diffraction (XRD) analysis, quartz and kaolinite were the minerals identified in the samples.Figure 4.1 and 4.2presents the percentage of minerals in each sample of sand, samples A andB.The diffraction peaks relative to quartz was more pronounced between 20 and 30θ as compared to the other phases. The detail of the results is shown in Table 16 of Appendix A11.

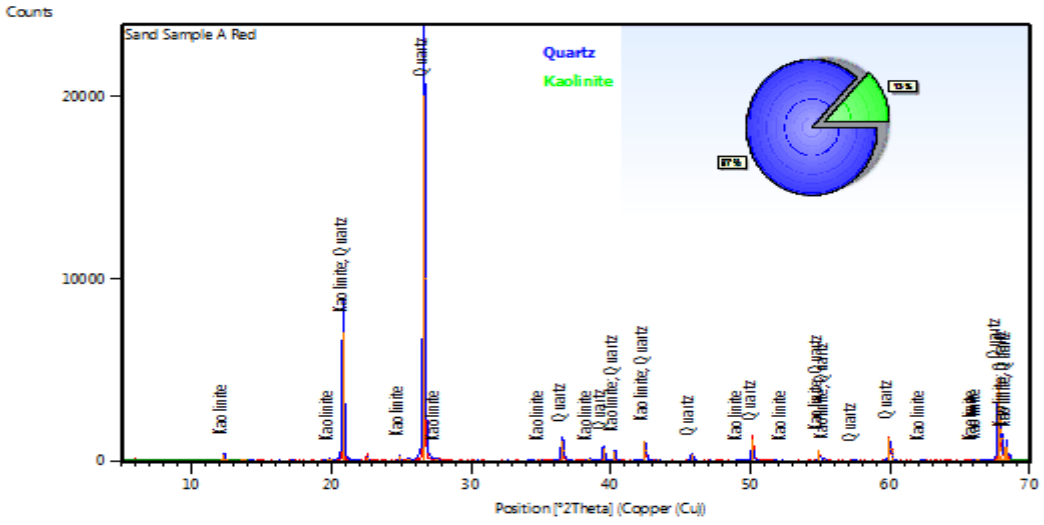


Figure 4.1: X-ray Diffraction Pattern of Sand Sample A

Source: Laboratory Research Work (2018)

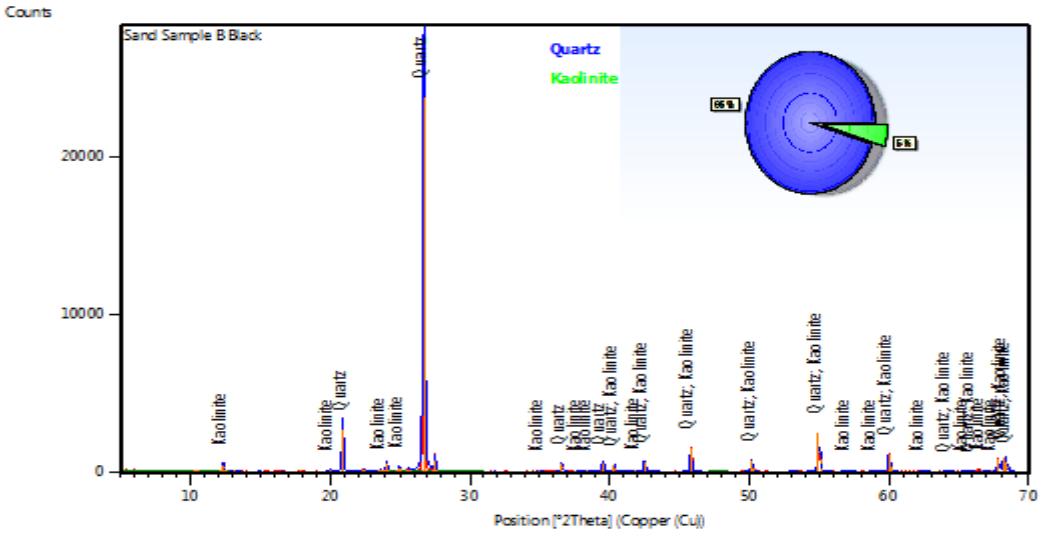


Figure 4.2: X-ray diffraction pattern of Sand Sample B

Source: Laboratory Research Work (2018)

Based on the X-ray fluorescence (XRF) analysis, the result shows that the X-ray fluorescence spectroscopy (XRF) machine was able to detect almost all the oxides. Table 4.1 presents the percentage of oxides in each of the samples, sand samples A and B have oxides sum of 100.002% and 100% respectively.The iron content of these materials could be responsible for the differences in colour with the sample A having iron content of 0.907% while the sample B has 1.707% which almost doubled the value of sample A.

Table 4.1Oxide Composition of Sample A and B

Elements	Sample A Concentration (%)	Sample (B) Concetration (%)
Na2O	0.045	0.000
MgO	0.289	0.452
Al2O3	13.181	16.696
SiO2	80.075	75.521
P2O5	0.414	0.252
SO3	0.534	0.473
Cl	0.031	0.023
K2O	1.734	2.318
CaO	1.382	1.072
TiO2	1.361	1.406
Cr2O3	0.002	0.004
Mn2O3	0.037	0.060
Fe2O3	0.907	1.707
ZnO	0.000	0.000
SrO	0.010	0.016

Source: Laboratory Research Work (2018)

4.1.1.1 Particle Size Distribution

Figure 4.3 presents the results of sieve analysis of fine aggregate samples A and B which was used to determine the fineness modulus of the sand samples as 2.65 and 3.58. Thedetails of the results are presented in Table 1 and 2 of Appendix A1. According to ASTM C 33 fineness modulus of fine aggregates ranges within 2.3 – 3.0 ($\pm$0.2) and sand sample A has fallen within the stated range while sample B is slightly out of the range. The percentages of the fine aggregates passing sieve 600 micron were found to be 55.1and 33.8. From the results it was clearly observed that sample A aggregate fall within the range of 35 - 90 which indicated that the aggregate fall within (Zone 2) as medium sand, sample B aggregate fall within the range of 15-34 which indicated that the aggregate fall within (Zone 1) as coarse sand.

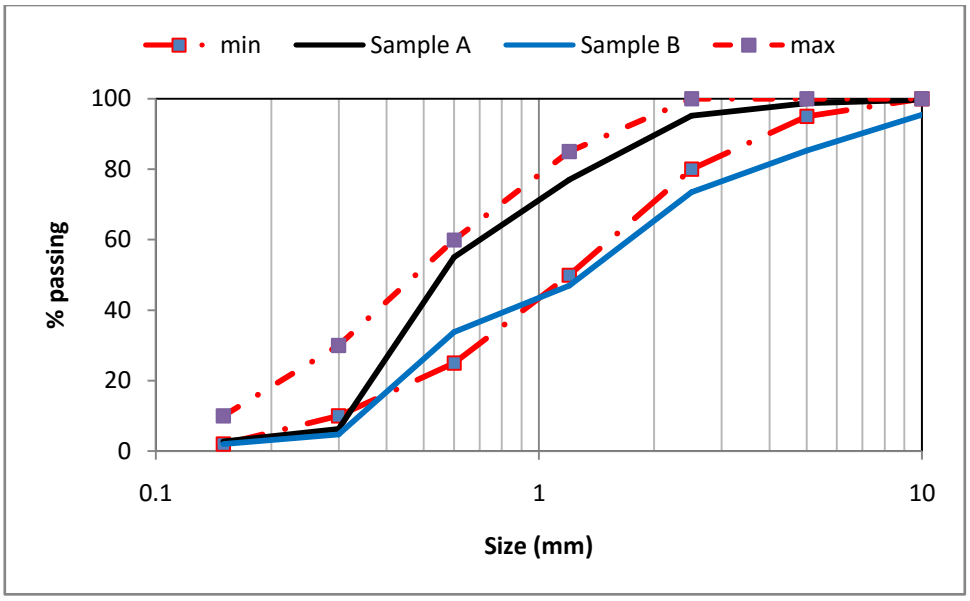


Figure 4.3: Particle Size Distributionfor Samples A and B

Source:Laboratory Research Work (2018)

4.1.1.2 Specific Gravity

Figure 4.4 presents the specific gravity of samples A and B aggregates, detail of the results are shown in Table 3 of Appendix A2. The specific gravity of samples A and B aggregates were found to be 2.61and 2.65 respectively.

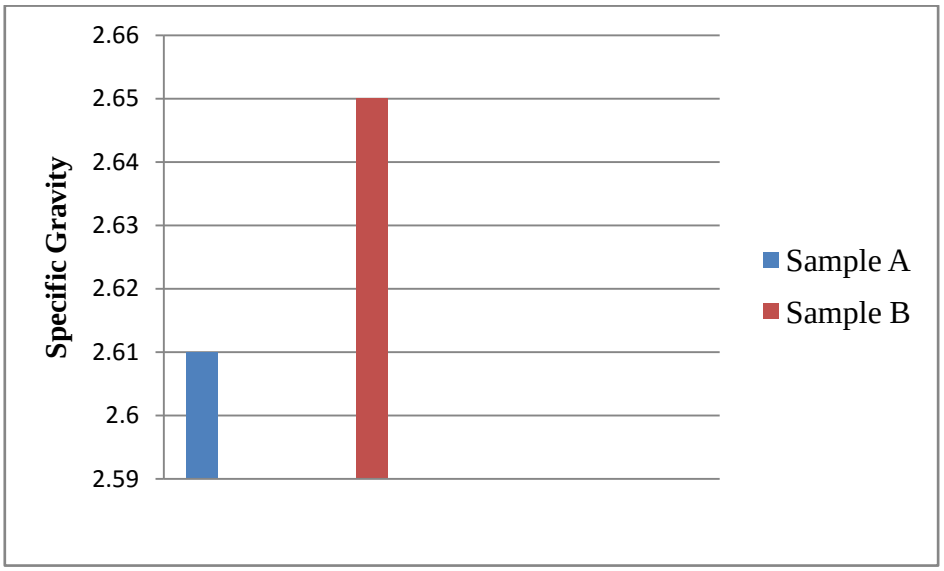


Figure 4.4: Specific Gravity forSamples A and B

Source:Laboratory Research Work (2018)

4.1.1.3 Bulk Density

Figure 4.5 shows the bulk density of the aggregate samples A and B they were found to be 1830kg/m^3 and 1690kg/m^3respectively which satisfy the requirements of BS 812 – 108 (1990) that states the range for normal weight aggregates to be between 1280kg/m^3 and 1920kg/m^3 (for bulk density). The detail of the result is presented in Table 3 of Appendix A2.

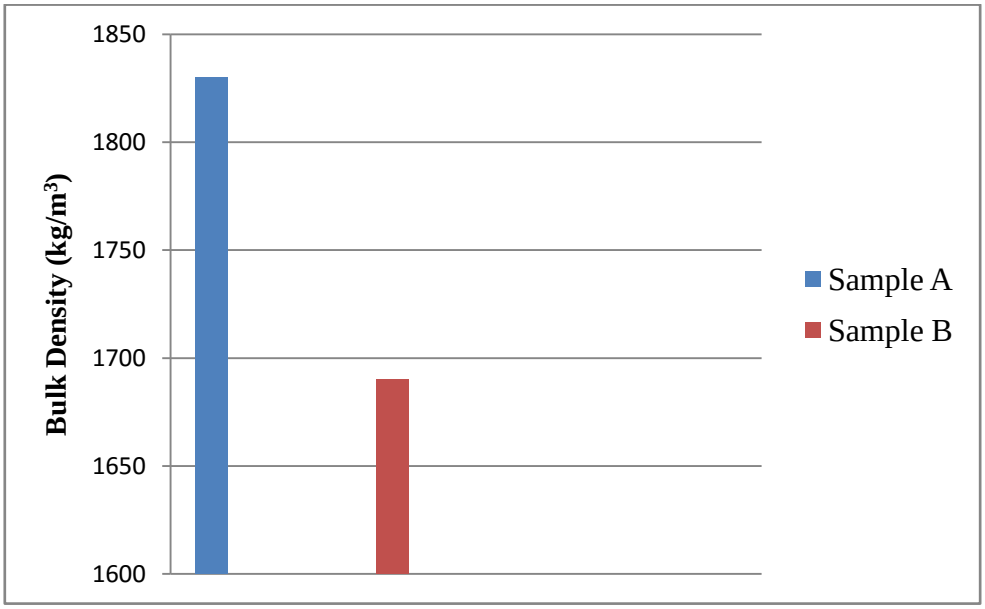


Figure 4.5: Bulk Density for Aggregate Samples A and B

Source:Laboratory Research Work (2018)

4.1.1.3 Water Absorption Capacity

Figure 4.6 presents the result of water absorption capacity of aggregate samples A and B, detail result is shown in Table 3of Appendix A2. It can be clearly seen from the result that sample B aggregate absorbed more water (6.00%)than that of sample A aggregate with (5.00%).

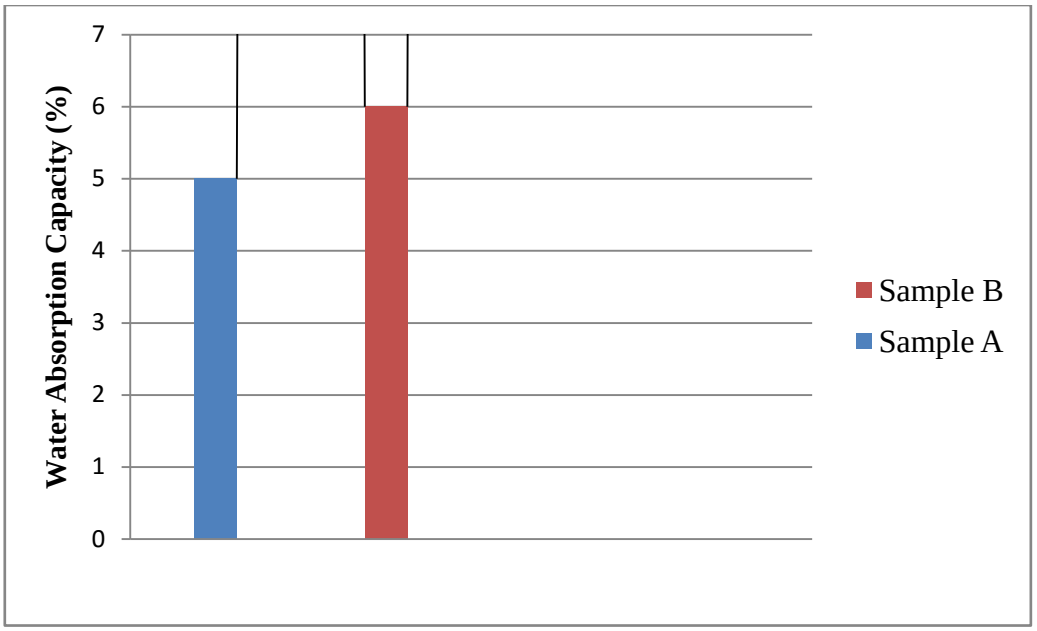


Figure 4.6: Water Absorption Capacityfor Samples A and B

Source:Laboratory Research Work (2018)

4.1.1.4 Moisture Content,

Figure 4.7 presents the result of moisture content for the samples A and B aggregates, which were found to be 1.12% and 1.14% respectively. Detail of the result is shown in Table 4 of Appendix A3. Based on the result obtained it indicated that aggregate sample B has a higher moisture content compared to aggregate sample A.

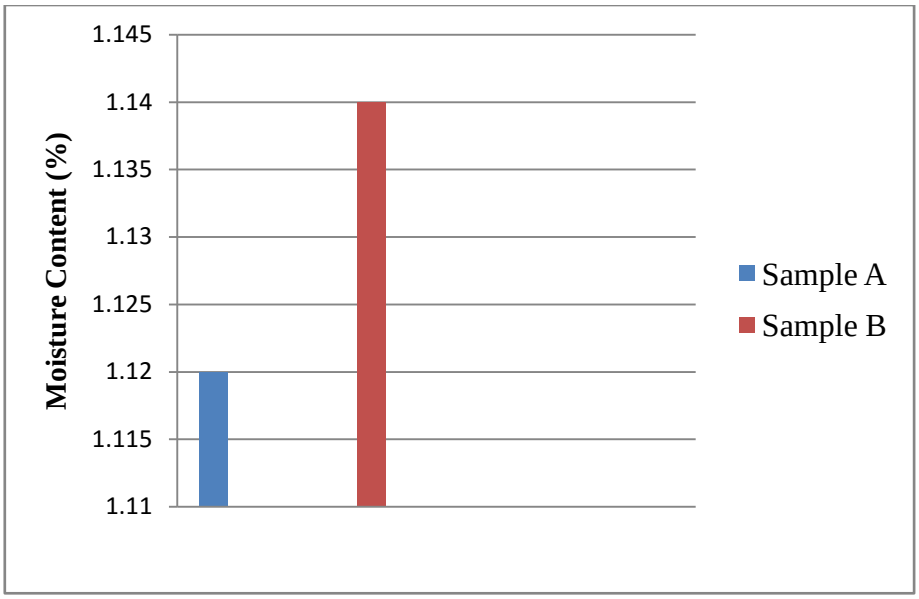


Figure 4.7: Moisture Content forSamples A and B

Source:Laboratory Research Work (2018)

4.1.1.5 Silt Content

Figure 4.8 shows the result of silt content for aggregate samples A and B, it was found to be 18.18% and 38.46% respectively. The detail of the result is presented in Table 4 Appendix A3, which clearly indicated that the content of silt in aggregate sample B is higher than that of sample A.

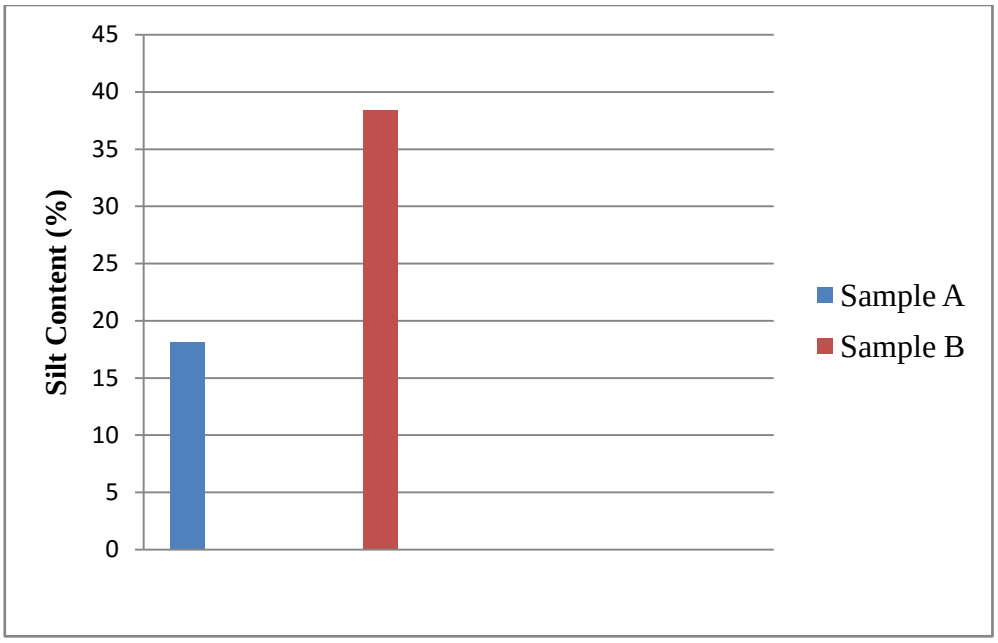


Figure 4.8: Silt Content for ASamples A and B

Source:Laboratory Research Work (2018)

4.2 Results of Tests on Fresh Mortar

4.2.1 Workability

Figure 4.9 presents the relationship between workability of mortars made with aggregate samples Aand B. The detail result is shown in Table 5 of Appendix A4.Sample A has a flow value of 595mm while sample B has a flow value of 345mm, which indicated that, mortar produced with aggregate sample A was more workable than the mortar produced with aggregatesample B, this could be due to the higher percentage of silt content in sample B. Based on the result obtained, it indicated that both mortars produced are soft mortar according to BS EN 1015-6 (1999).

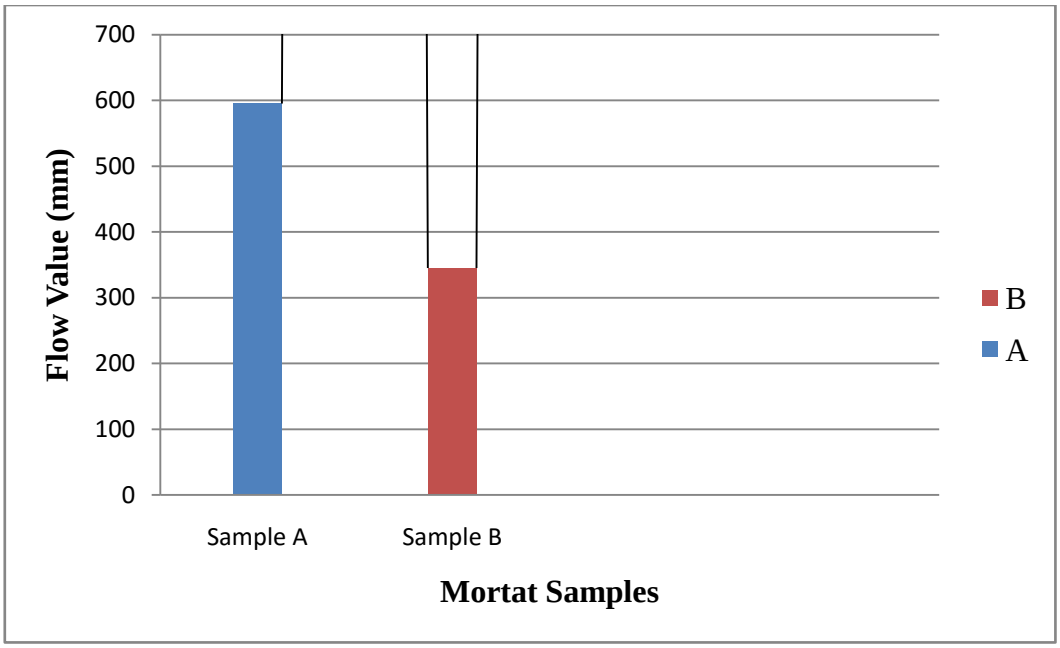


Figure 4.9: Workability of Mortar Sample A and Sample B

Source:Laboratory Research Work (2018)

4.2.2 Bulk Density

Figure 4.10 Presents bulk density of the fresh mortars produced with aggregates sample A and B. The results show that mortar produced with aggregate sample A has a bulk density of 2200kg/m^3 while that made with aggregate sample B has a fresh bulk density of 2030kg/m^3. The fresh bulk density test results show that mortar produced with aggregate sample A was heavier than the mortar produced with aggregate sample B. The details of the results are presented in Table 6 of Appendix A4.

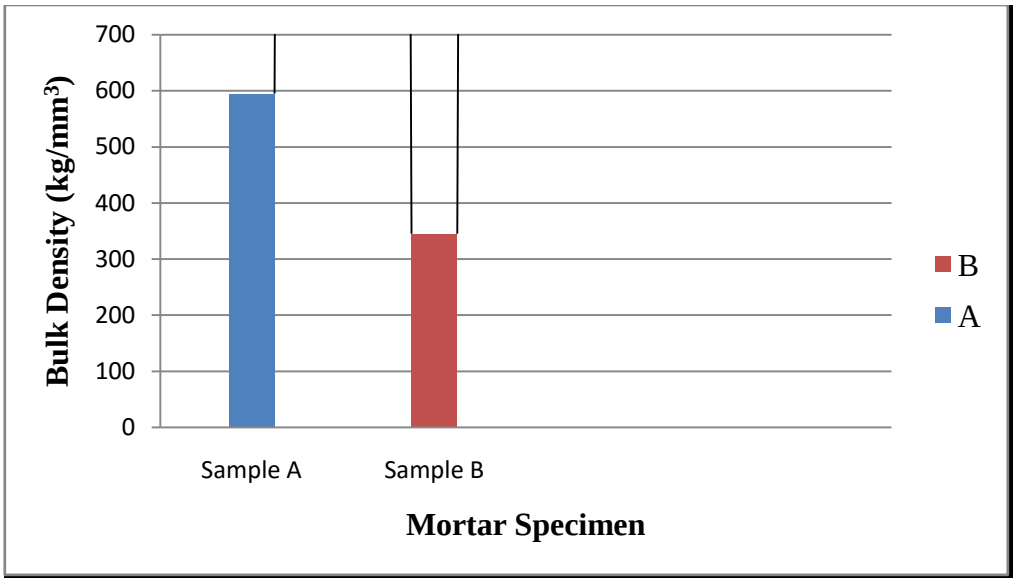


Figure 4.10: Bulk Density of Fresh Mortar Produced with Sample A and B

Source:Laboratory Research Work (2018)

4.3 Results of Tests on Hardened Mortar

4.3.1 Density of Mortar

Figure 4.11 shows the results obtained for the density measurements and details of the results are presented in Table7of Appendix A5. It can be seen that mortar produced with aggregate sample A exhibited lower densities than the mortar made with aggregate sample B for all ages of curing. This was expected, as the specific gravity of aggregate sample A, (2.61) is less than that for aggregate sample B, (2.65). However, the mortar made with aggregate sample B showed a slight increase in density at 28 and 56 days while a decrease in density was observed for the mortar made with aggregate sample A at 28 and 56 days.

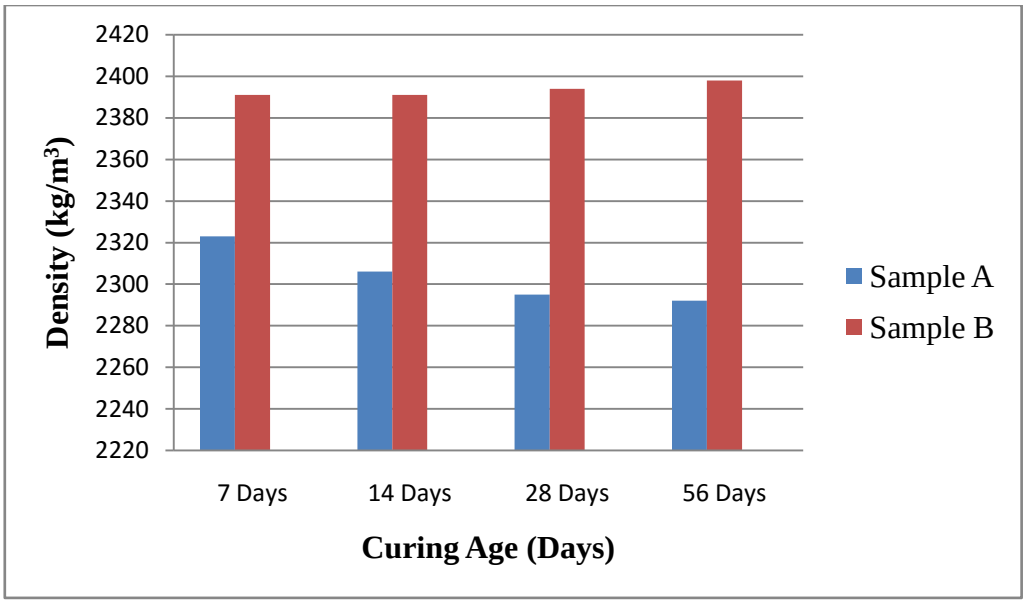


Figure 4.11: Density of Hardened Mortar Samples A and B

Source: Laboratory Research Work (2018)

4.3.2Compressive Strength of Mortar

Figure 4.12 presents the average compressive strength of mortar specimens produced with different types of plastering sands of Yola cured in normal water for 7, 14, 28 and 56 days prior to crushing.The detail result is shown in Table 8 of Appendix A5.The compressive strength of mortar produced with aggregate sample A for each of the four curing periods was higher than that of mortar produced with aggregate sample B.Thelowest compressive strength for both sands occurred at 7days which are 9.45N/mm^2 and 7.09N/mm^2 respectively while the highest strength for both sands occurred at 56days which are 16.48N/mm^2 and 14.41N/mm^2. The 28days strength for both sands, 15.82N/mm^2 and 12.03N/mm^2 respectively fall below the standard (BS EN 1015-11:1999). This could be due to the higher percentage of silica oxide content in aggregate sample A.

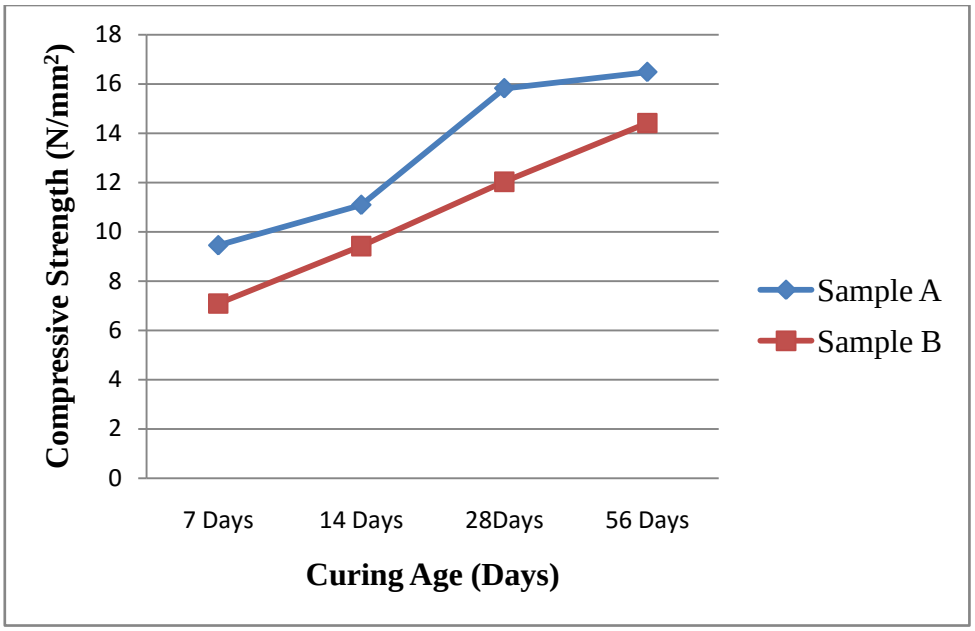


Figure 4.12: Compressive Strength of Hardened Mortar Samples A and B

Source: Laboratory Research Work (2018)

4.3.3 Flexural Strength of Mortars

Figure 4.13 shows the relationship between flexural strength of mortars made with aggregates sample A and B and age of curing, the detail results are in Table 9 of Appendix A6.Itcan be seen that at the early period of curing, the average flexural strength of mortar produced with aggregatesample B was greater than those of sample A in all of the curing periods 7, 14, 28 and 56 days respectively. The increase in flexural strength continued steadily throughout the curing periods. This could be due to higher percentage of quartz (95%) and fineness of aggregate sample B.

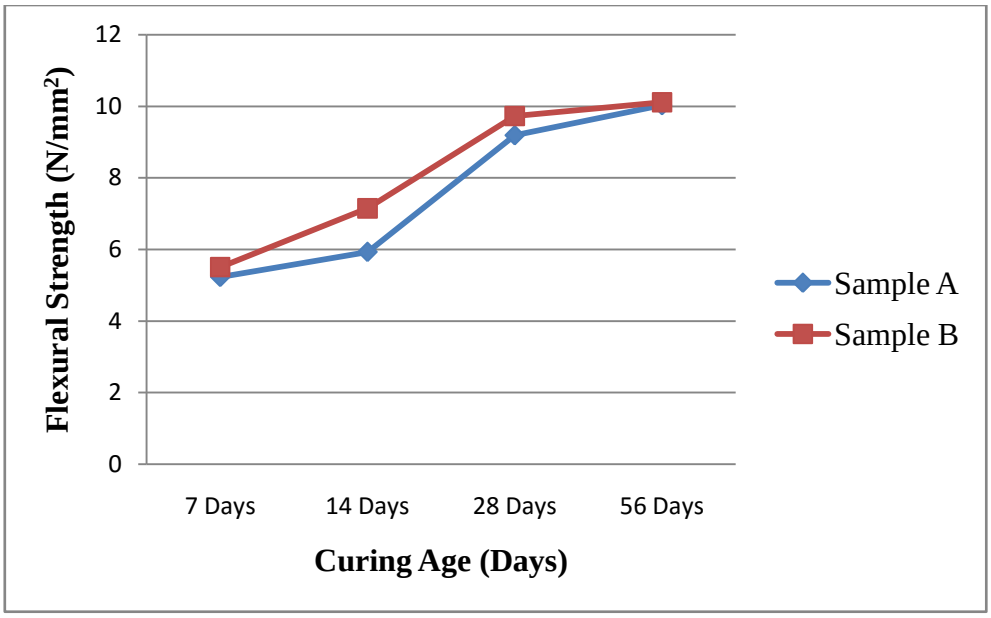


Figure 4.13: Flexural Strength of Mortar Produced with Samples A and B

Source: Laboratory Research Work (2018)

4.3.4 Water Absorption

Figure 4.14 presents water absorption test results for mortars produced with aggregate samples A and B.Mortar produced with aggregate sample B has lower water absorption rate than that made with sample A having water absorption of 3.53% and 3.14% for 28 and 56days respectively. The sample A mortar has water absorption of 5.39% at 28 days and 3.92% at 56 days, water absorption reduced with age as a result of improvement of the mortar pore structure with age.

From the result it can be clearly seen that, sample B mortar has less water absorption, which implies that it will have less susceptibility to permeability by liquid and of course stronger and durable than sample A mortar. This could be as a result of finer particles of sample B that results in filling the pores in the plastering mortar.

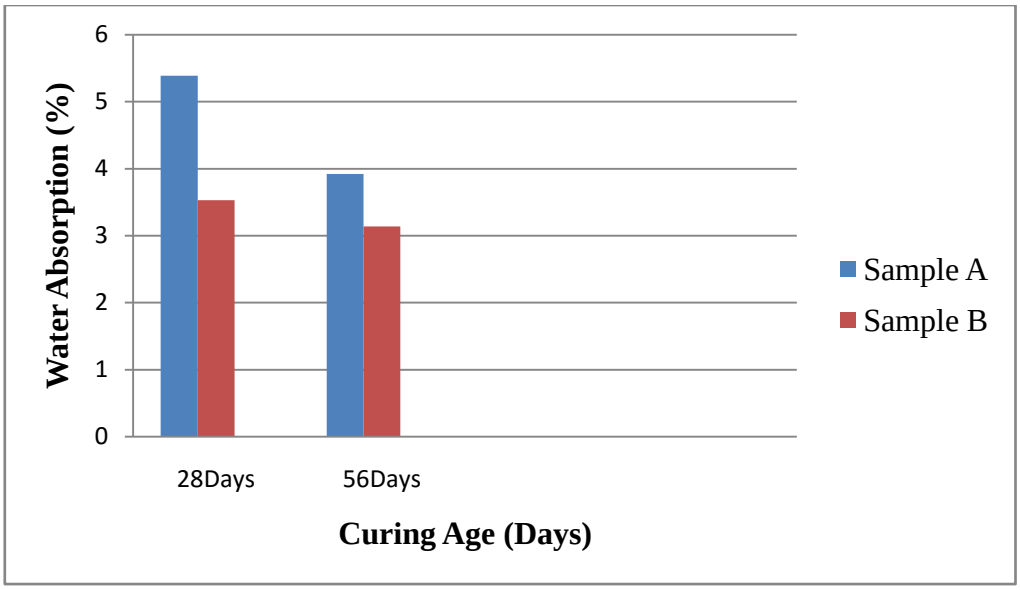


Figure 4.14: Water Absorption of HardenedMortar Samples A and B

Source: Laboratory Research Work (2018)

4.3.5 Abrasion Resistance

Figure 4.15: Shows the results of abrasion resistance ofmortars made with aggregate samples Aand B determined at the end of 28 and 56 days curing periods. The detail is shown in Table 11 of Appendix A7. The loss in weight of sample B mortar was less than that of sample A. This indicated that sample B mortar has higher resistanceto abrasion compared to sample A mortar. The percentage loss after abrasion at 28 and 56 days, the sample B mortar loss inweight of0.17% and0.29% while sample A mortar had loss in weight of 0.25% and 0.30%.From the result it can be observed that, the resistance to abrasion of the mortar samples increased with increase in curing days andsample B mortar resist abrasion more than that of A throughout the curing periods. This could be due to the aggregate size, its quantity and improvement in the pore structure of the mortar sample.

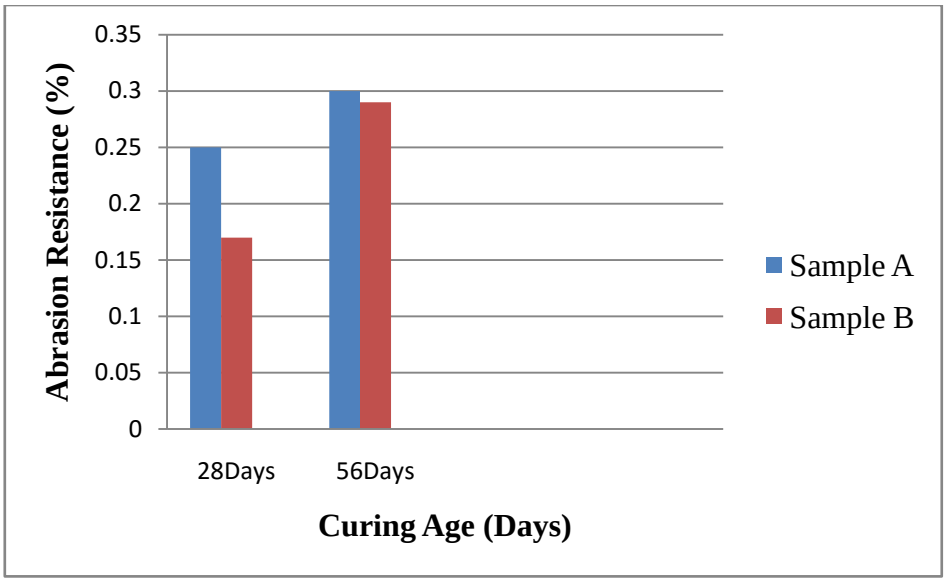


Figure4.15:Abrasion Resistance of Hardened Mortar Sample A and B

Source: Laboratory Research Work (2018)

4.3.6 Sorptivity

Figure 4.16 presents the results of Sorptivity for mortars produced with aggregate samples A and B and detail of the results is shown in Table 12 of Appendix A7. The sorptivity value of mortar cubes made with aggregate sample A increased over that of aggregate sample B at 28 and 56 days. The sorptivity of the cubes at 56 days are however lower than at 28 days. This could be due to the increase in calcium silicate hydrates (CSH) gels in the mortar.

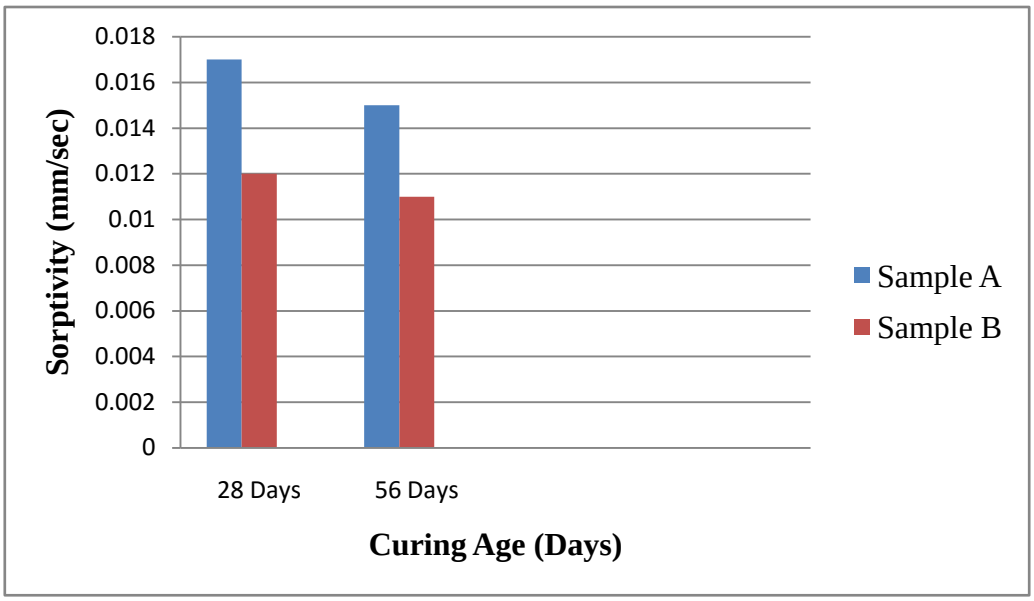


Figure 4.16:Sorptivity of Hardened Mortar Sample A and B

Source: Laboratory Research Work (2018)

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Major Findings

The research was experimentally aimed at evaluating the properties of different plastering sands used in Yola, with the view to establishing their major characteristics as plastering sands.

The highlights of the major findings are summarized as follows:

i. Sample A plastering mortar has higher flow value at fresh stage than sample B mortar by45% and also, the bulk density of the fresh mortar produced with sample A is higher than that of mortar made with sample B by8%.

ii. In terms of compressive strength, mortar produced with sample A has higher compressive strength than the mortar produced with sample B, by13% at 56 days.

iii. Sample B mortar has developed higher flexural strength than sample Amortar, by0.8% at 56 days.

iv. Mortar produced with sample B exhibited lower water absorption capacity than that made with sample A, by3.14% at 56 days.

v. The mortar produced with sample B offered more resistance to abrasion than that produced with sample A, by0.29% at 56 days.

vi. Mortar produced with sample B showed lower sorptivity than that produced with sample A, by9% at 56 days.

5.2 Conclusions

After carrying out experiments, observations, analysis and discussions, on the comparative properties of plasters made with two plastering sands, the following conclusions were drawn:

i. The two sand samples (A and B) have different engineering properties such as quartz content of 87% and 95% and silicondioxde content of 80.075% and 75.521% respectively. Specific gravity 2.61 and 2.65, bulk density 1830 and 1690kg/m^3, water absorption capacity 5% and 6%, moisture content 1.12% and 1.14%, and silt content 18.18% and 38.46%.

ii. Mortar made with sand sample A has higher flow table value than that of sample B by 42%, thereby making sample A a more workable plastering sand.

iii. With the compressive strength of sample A (16.41N/mm^2) higher than that of sample B (14.41N/mm^2), sample A is better than sample B in terms of compressive strength by 14%. While In the case of flexural strength, the maximum flexural strength obtained for sample B was 10.11N/mm^2 higher than that of sample A 10.03N/mm^2 at 56 days, sample B is better in terms of tension by 0.79 % thus, making sample B more susceptible to cracks.

iv. Based on analysis of the results obtained the sample B mortar offered higher durability such as abrasion resistance and also in terms of sorptivity sample B offered higher resistance to sorptivity than sample A.

5.3Recommendations

i. The sands can both be used for construction purpose as they belong to zone 1 and 2 (A and B) respectively as specified by BS 882 (1992).

ii. The research recommends that where strength of mortar is the requirement such as in mortar beds and joints, sample A should be used due to it higher compressive strength value.

iii. Sample B is a better option when it comes to durability as required in plastering and rendering due to it higher durability properties.

5.4 Recommendation for Further Studies

i. Further research should be carried out to assess the durability of mortar produced with the two sand samples in aggressive environment.

ii. Investigation should be carried out on fire resistance, permeability and drying shrinkage of mortar made with the two sand samples.

iii. The mortar produce with the samples should be subjectedto curing for longer periods to analyze the strength variations.

5.5 Contribution to Knowledge

i. The research has discovered that the two plastering sands of Yola, red and black are good construction aggregates because of their engineering properties which all fall within standards such as bulk density, flow table values and fineness modulus.

ii. The researchhas confirmed that sample B is the best sand when used appropriately for plastering and rendering works.

iii. From the flow table values of the two samples of mortar which were above 200mm, the mortar samples fall under the category of soft mortars that will required loose compaction methods as stated by BS EN 1015-6 (1999).

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APPENDIX A1

Table1: Sieve Analysis of Sample A Aggregates

BS Sieve Size (g)(g)	Weight retained retained (%)	Total Weight retained (g)	Cumulative Percentage (%)	Weight passing	Percentage passing
10	5	5	0.25	1995	99.75
5	20	25	1.25	1975	98.75
2.5	70	95	4.75	1905	95.25
1.2	365	460	23	1540	77
0.6	438	898	44.9	1102	55.1
0.3	977	1875	93.8	125	6.25
0.15	70	1945	97.25	55	2.75
Pan	55	-	-	0	0
Total		265.2			
Fineness modulus		2.65			

Source: Laboratory Research Work (2018)

Table 2: Sieve Analysis of Sample BAggregates

BS Sieve Size	Weight retained (g)	Total Weight retained (g)	Cumulative Percentage retained (%)	Weight passing (g)	Percentage passing (%)
10	90	90	4.5	1910	95.5
5	205	295	14.75	1705	85.3
2.5	235	530	26.5	1470	73.5
1.2	530	1060	53	940	47
0.6	265	1325	66.25	675	33.8
0.3	580	1905	95.25	95	4.75
0.15	55	1960	98.0	40	2
Pan	40	-	-	0	0
Total			358.25		
Fineness modulus			3.58		

Source: Laboratory Research Work (2018)

APPENDIX A2

Table3: Specific Gravity, Bulk Density and Absorption Capacity of Fine Aggregate

Properties	**Sample (A)**	**Sample (B)**
Specific gravity	2.61	2.65
Bulk density kg/m^3	1830	1690
Absorption Capacity (%)	5.00	6.00

Source: Laboratory Research Work (2018)

APPENDIX A3

Table 4: Moisture Content, Silt Content and Bulking of Fine Aggregates

Properties	Sample (A)	Sample (B)
Moisture Content (%)	1.12	1.14
Silt Content (%)	18.18	38.46

Source: Laboratory Research Work (2018)

APPENDIX A4

Table 5: Workability of Mortar Samples A and B

Type of Mortar	Flow Value(mm)
Sample (A)	595
Sample (B)	345

Source: Laboratory Research Work (2018)

Table 6: Bulk Density of Fresh Mortar Samples A and B

Type of Mortar	Bulk Density (kg/m^2)
Sample (A)	2200
Sample (B)	2030

Source: Laboratory Research Work (2018)

APPENDIX A5

Table 7: Density of Hardened MortarSamples A and B

Density (kg/m^3)				
Mortar Samples	7days	14days	28days	56days
Sample (A)	2323	2306	2295	2292
Sample (B)	2391	2391	2394	2398

Source: Laboratory Research Work (2018)

Table 8: Average Compressive Strength of Hardened Mortar Samples A and B

Compressive Strength (N/mm^2)				
Mortar Samples	7days	14days	28days	56days
Sample (A)	9.45	11.09	15.82	16.48
Sample (B)	7.09	9.42	12.03	14.41

Source: Laboratory Research Work (2018)

APPENDIX A6

Table 9: Average Flexural Strength of Hardened Mortar Samples A and B

Flexural Strength (N/mm^2)				
Mortar Samples	7days	14days	28days	56days
Sample (A)	5.23	5.93	9.19	10.03
Sample (B)	5.51	7.15	9.73	10.11

Source: Laboratory Research Work (2018)

Table 10: Water Absorption ofHardened Mortar Samples A and B

	Water Absorption (%)	
Mortar Samples	28days	56days
Sample (A)	5.39	3.92
Sample (B)	3.53	3.14

Source: Laboratory Research Work (2018)

APPENDIX A7

Table 11: Abrasion Resistance ofHardened Mortar Samples A and B

Abrasion Resistance (%)		
Mortar Samples	28days	56days
Sample (A)	0.25	0.30
Sample (B)	0.17	0.29

Source: Laboratory Research Work (2018)

Table 12: Sorptivity of Hardened Mortar Samples A and B

	Sorptivity (mm/√s)	
Mortar Samples	28days	56days
Sample (A)	0.017	0.012
Sample (B)	0.015	0.011

Source: Laboratory Research Work (2018)

APPENDIX A8

Table 13:Data Collected and Calculationson Hardened Mortar Sample A at 28Days

√Time		Mass	ΔMass	ΔMass/Area/Density	
Days	S	$S^{1/2}$	(g)	(g)	of Water =*I* (mm)
0	0	267	0.00	0.0000	
	60	8	267.25	0.25	0.1000
	300	17	267.75	0.75	0.3000
	600	24	267.75	0.75	0.3000
	1200	35	267.95	0.95	0.3800
	1800	42	268	1.00	0.4000
	3600	60	269	2.00	0.8000
	7200	85	271.5	4.50	1.8000
1	92220304279.5		12.5	5.0000	

Source: Laboratory Research Work (2018)

Table 14:Data Collected and Calculations on Hardened Mortar Sample B at 28Days

√Time		Mass	ΔMass	ΔMass/Area/Density	
Days	S	$S^{1/2}$ (g)		(g)	of Water =*I* (mm)
0	0	258.90.00		0.0000	
	60	8	259.5	0.60	0.2400
	300	17	259.5	0.600.2400	
	600	24	259.8	0.900.3600	
	1200	35	260.5	1.60	0.6400
	1800	42	261.52.601.0400		
	3600	60	262.5	3.601.4400	
	7200	85	265	6.10	2.4400
1	92220	304	268.5	9.603.8400	

Source: Laboratory Research Work (2018)

APPENDIX A9

Table 14:Data Collected and Calculationson Hardened Mortar Sample A at 56Days

√Time		Mass	ΔMass	ΔMass/Area/Density	
Days	**S**	**$S^{1/2}$**	**(g)**	**(g)**	**of Water =*I* (mm)**
0	0	269.50.00	0.0000		
60	8	270.25	0.75	0.3000	
300	17	270.5 1.00	0.4000		
600	24	270.65	1.15	0.4600	
1200	35	273.15	3.65	1.4600	
1800	42	273.15	3.65	1.4600	
3600	60	271.41.90	0.7600		
7200	85	2777.50	3.0000		
192220304278.5		9.00 3.6000			

Source: Laboratory Research Work (2018)

Table 15:Data Collected and Calculationson Hardened Mortar Sample B at 56Days

√Time		Mass	ΔMass	ΔMass/Area/Density	
Days	**S**	**$S^{1/2}$**	**(g)**	**(g)**	**of Water =*I* (mm)**
0	0	250	0.00	0.0000	
60	8	250.5	0.50	0.2000	
300	17	250.9 0.90	0.3600		
600	24	250.95	0.95	0.3800	
1200	35	251	1.00	0.4000	
1800	42	251	1.00	0.4000	
3600	60	251.75	1.75	0.7000	
7200	85	257.57.50	3.0000		
1 92220304		261	11.0	4.4000	

Source: Laboratory Research Work (2018)

APPENDIX A10

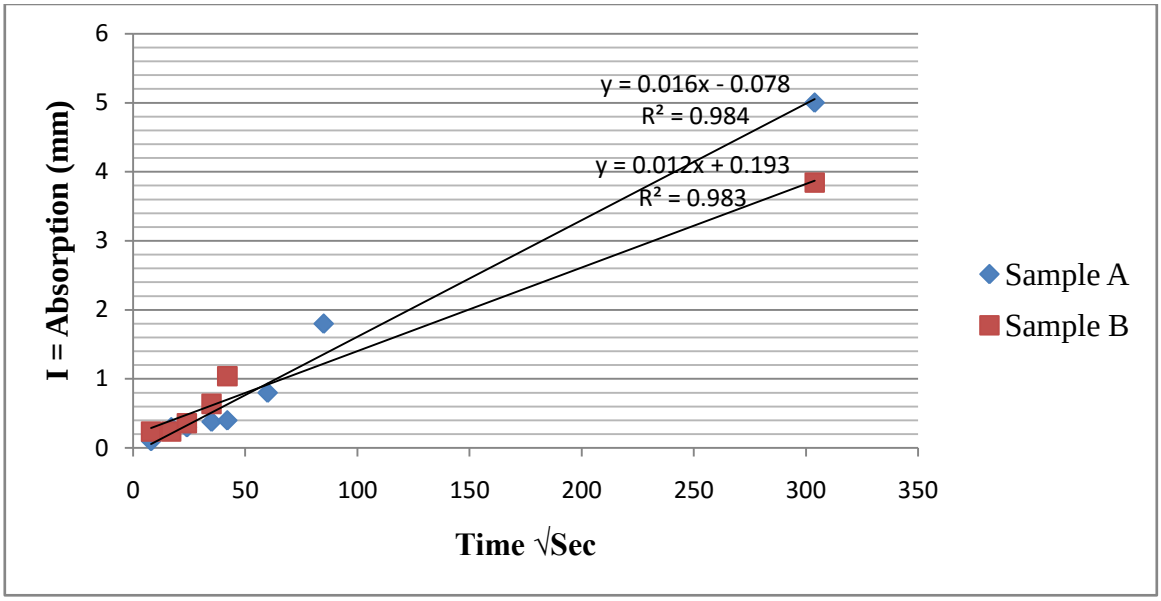


Figure1:Absorption of Hardened Mortar Samples A and B at 28 Days

Source: Laboratory Research Work (2018)

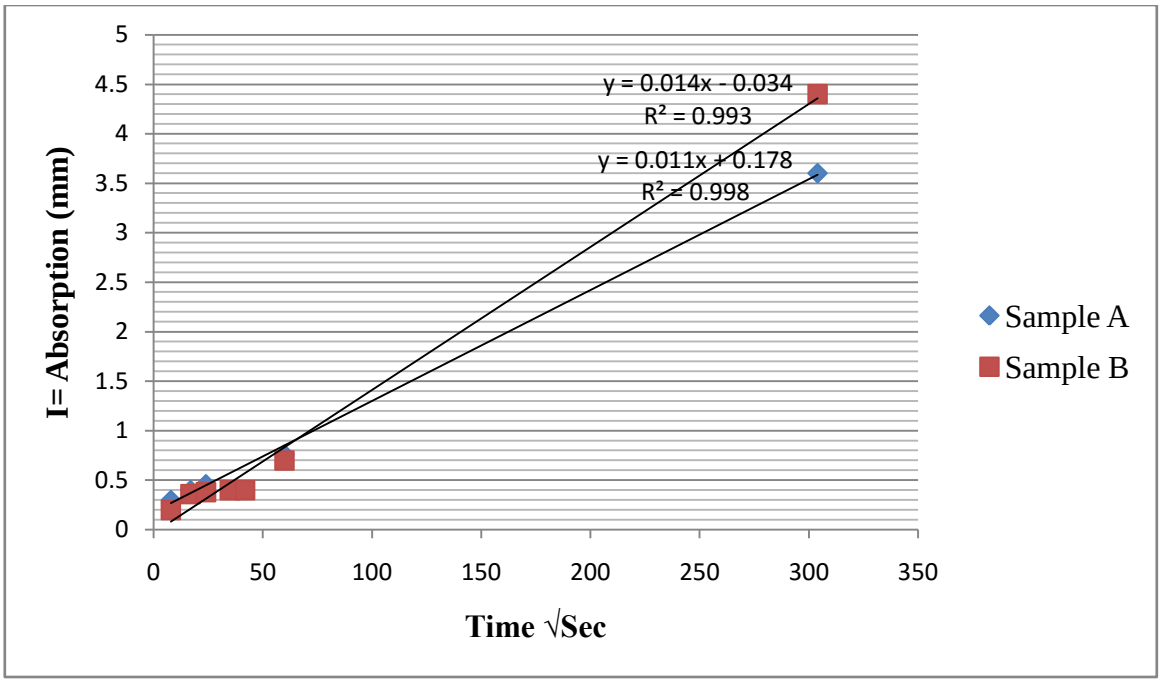


Figure 2: Absorption of Hardened Mortar Samples A and B at 56 Days

Source: Laboratory Research Work (2018)

APPENDIX A11

Table 16: Mineral Composition of Samples A and B

Mineral Name	**Sample A (%)**	**Sample B (%)**
Quartz	87	95
Kaolinite13		5

Source: Laboratory Research Work (2018)