# THE EFFECT OF SAND QUALITY ON THE STRENGTH OF SANDCRETE PRODUCTS – CASE STUDY OF SAND WON FROM ESRESO, APUTUOGYA AND ADAGYA IN THE ATWIMA KWAWOMA DISTRICT OF THE ASHANTI REGION

BY

MAAME ADWOA BENTUMAH SAGOE, BSc. (Hons)

KNUST

THESIS SUBMITTED TO THE DEPARTMENT OF PHYSICS, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
(Materials Science)

FACULTY OF PHYSICAL SCIENCES
COLLEGE OF SCIENCE
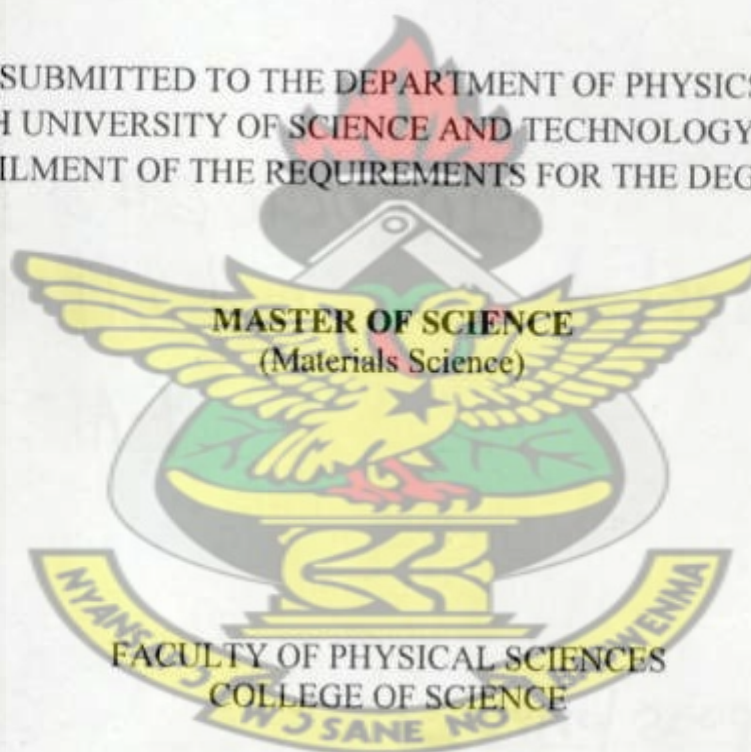
JUNE 2008

# DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the University except where due acknowledgment has been made in the text.

Signature......................................... Date...19./.09./.09......
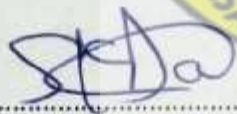
NAME: MAAME ADWOA BENTUMAH SAGOE

(STUDENT)

Signature......................................... Date...9/10/09..........

NAME: DR. A.B.C DADSON

(SUPERVISOR)

Signature......................................... Date...09/10/2009......

NAME: DR. S.K DANUOR

(HEAD OF DEPARTMENT)

i

## DEDICATION

I dedicate this work to the memory of my late mother, Comfort Happy Ahiekpor.

## ACKNOWLEDGEMENTS

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

## ABSTRACT

Sandcrete blocks are widely used in Ghana for various purposes such as laying of foundations and walling. The quality of blocks produced, however, differs from one manufacturer to the other due to the different methods employed in the production and the proper use of the constituent materials. This project focused on the effect of sand quality on the strength of sandcrete products using Ghacem cement. Sand was taken from Esreso, Aputuogya and Adagya in the Atwima Kwawoma district of the Ashanti region and were labelled as Esreso Plastering, Aputuogya all purpose and Adagya Plastering. The sand was used just as it was brought from the site (unsorted) and then sorted into fine and medium aggregates. Sandcrete blocks were mixed in the ratio 6:1 and 3:1. One batch of the sandcrete samples was air dried and the other batch was water cured for a period of 28 days, and tested for their compressive strengths and their water absorption. The sands were tested for their chemical content (chloride and sulphate) and organic matter content. Sand samples that were tested for their chloride and sulphate content recorded low values as compared to the ASTM requirements. For chloride and sulphate content in Esreso sand, the results were 0.065 mg/l and 0.5 mg/l respectively compared to the ASTM requirement of 500 mg/l. It was found that the mix ratio, the nature of the constituent materials and the presence of organic matter in the sand affected the quality of the sandcrete blocks. From the particle size analysis, it was found that, Esreso block and Adagya rough samples had a high amount of residue(weeds) and low compressive strengths, ie. 20.86% (4.97 MPa) and 28.97% (5.54 MPa)respectively. This project also confirmed that, generally air dried sandcrete blocks were better in strengths than water cured sandcrete blocks. Esreso Plastering samples of medium aggregates recorded strength of 20.09 MPa when air dried and 11.15 MPa when water cured. On the whole sandcrete blocks of medium aggregates gave higher strengths than sandcrete blocks of fine aggregates.

# CHAPTER ONE

## 1. GENERAL INTRODUCTION

The use of cement based products as a building material has gained such an international status that it is used as the standard measure of the suitability, in terms of its strength, durability and workability, compared with other building materials like bricks and laterite blocks for building construction.

However, the use of cement-based products sometimes require a specified period of time to set and a minimum strength before either the product could be used or any further work could be continued on it. In most cases the 28-day strength is the optimum strength which is used as the measure. This requirement sometimes becomes an impediment and causes delay of very important projects especially when the economics of the project is foremost in the minds of the contractor and the client. But since quality could not be sacrificed for other aspects, the curing period and attaining maximum strength should be adhered to.

Some works have been done on the possibility of accelerating the use of these products, without sacrificing quality, by way of enhancing the process of increasing the strength rapidly to its design requirements [1].

This project looks into the effect of sand quality on mortar cubes made from locally-made Portland cement (GHACEM), and determines its 28-day strength with a recommendation on the best type of sand and sand preparation needed in making sandcrete.

1

## 1.1    SAND

Sand is a product from the breakdown of larger rocks. The type of sand present, for example at a beach, is determined by the geological make –up of the region. When rocks or minerals are pulverized by any agencies, natural or artificial, the products may be classified as gravels, sands and mud or clays, according to the size of the individual particles. If the grains are so fine as to be impalpable (about 0 to 6mm. in diameter) the deposit may be regarded as a mud or clay. If many of them are as large as peas the material is a gravel. Sands may be uniform when they have been sorted out by some agency such as a gentle current of water or the wind blowing steadily across smooth arid lands, but usually they vary much both in the coarseness of their grains and in their mineral composition. The great source of natural sands is the action of the atmosphere, frost, rain, plants and other agencies in breaking up the surfaces of rocks and reducing them to the condition of fine powder; in other words sands are ordinarily the product of the agencies of denudation operating on the rocks of the earth's crust. Not all, however, are of this kind, for a few are artificial, like the crushed tailings produced in the extractions of metals from their ores; there are also volcanic sands which have originated by explosions of steam in the craters of active volcanoes [2].

A great part of the surface of the globe is covered by sand. In fertile regions the soil is very often of a sandy nature; though most soils are mixtures of sand with clay or stones, and may be described as loams rather than as sands. Pure sandy soils are found principally near sea-coasts where the sand has been blown inwards from the shore, or on formations of soft and friable sandstone like the Greensand. Accumulations of

2

sand are found also in some parts of the courses of our rivers, very often over wide stretches of the seashore, and more particularly on the sea bottom, where the water is not very deep, at no great distance from the land [2].

### 1.1.1 Constituents of sand

The most common constituent of sand, in inland continental settings and non-tropical coastal settings, is silica ($SiO_2$), usually in the form of quartz, which, because of its chemical inertness and considerable hardness, is quite resistant to weathering. However, the composition of sand varies according to local rock sources and conditions. Some locations have sands that contain magnetite ($Fe_3O_4$), chlorite ($ClO_2$), or gypsum ($CaSO_4.2H_2O$) [3].

### 1.1.2 Uses of sand

The economic uses of sands are very numerous. They are largely employed for polishing and scouring both for domestic and manufacturing purposes. "Bath bricks" are made from the sand of the river Parrett near Bridgewater. Sand for glass-making was formerly obtained at Alum Bay in the Isle of Wight and at Lynn in Norfolk, but must be very pure for the best kinds of glass, and crushed quartz or flint is often preferred on this account. One of the principal uses of sand is for making mortar with cement. For this purpose, any good clean sand free from salts is suitable; it may be washed to remove impurities and sifted to secure uniformity in the size of the individual grains. Moulding sands, adapted for foundry purposes, generally contain a

3

small admixture of clay. Sands are also employed in brick-making, in filtering, and for etching glass and other substances by blasting [4].

### 1.1.3 Range of grains
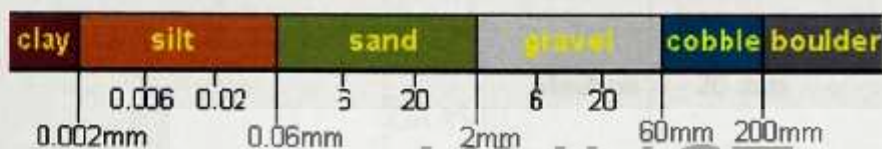


**Figure 1-1: Range of particle sizes**

The range of particle sizes encountered in soil is very large: from boulders with a controlling dimension of over 200mm down to clay particles less than 2µm. Some clays contain particles less than 1µm in size which behave as colloids, i.e. do not settle in water due solely to gravity.

In the British Soil Classification System, soils are classified into named Basic Soil Type groups, and the groups further divided into coarse, medium and fine sub-groups:

4

## Table 1-1: British Soil Classification System [5]

| | | | |
|---|---|---|---|
| Very coarse soils | BOULDERS | | > 200 mm |
| | COBBLES | | 60 - 200 mm |
| Coarse soils | G GRAVEL | Coarse | 20 - 60 mm |
| | | Medium | 6 - 20 mm |
| | | Fine | 2 - 6 mm |
| | S SAND | Coarse | 0.6 - 2.0 mm |
| | | Medium | 0.2 - 0.6 mm |
| | | Fine | 0.06 - 0.2 mm |
| Fine soils | M SILT | Coarse | 0.02 - 0.06 mm |
| | | Medium | 0.006 - 0.02 mm |
| | | Fine | 0.002 - 0.006 mm |
| | C CLAY | | < 0.002 mm |

Soils possess a number of physical characteristics which can be used as aids to size identification in the field. A handful of soil rubbed through the fingers can yield the following:

**Sand** particles are visible to the naked eye.

**Silt** particles become dusty when dry and are easily brushed off hands and boots.

**Clay** particles are greasy and sticky when wet and hard when dry, and have to be scraped or washed off hands and boots.

### 1.1.4   Shape of grains

The majority of soils may be regarded as either SANDS or CLAYS:

Sands include gravelly sands and gravel-sands. Sand grains are generally broken rock particles that have been formed by physical weathering, or they are the resistant components of rocks broken down by chemical weathering. Sand grains generally have a round shape.

Clays include silty clays and clay-silts; there are few pure silts. Clay grains are usually the product of chemical weathering of rocks and soils. Clay particles have a flaky shape.

There are major differences in engineering behaviour between SANDS and CLAYS (e.g. in permeability, compressibility, shrinking/swelling potential). The shape and size of the soil grains has an important bearing on these differences.

6

### 1.1.5 Shape characteristics of SAND grains

Sand and larger-sized grains are round. Coarse soil grains (silt-sized, sand-sized and larger) have different shape characteristics and surface roughness depending on the amount of wear during transportation (by water, wind or ice), or after crushing in manufactured aggregates. They have a relatively low specific surface (surface area). The following are some of the shapes sand particles could have:

**Rounded**: Water- or air-worn; transported sediments

**Irregular**: Irregular shape with round edges; glacial sediments (sometimes sub-divided into 'sub-rounded' and 'sub-angular')

**Angular**: Flat faces and sharp edges; residual soils, grits

**Flaky**: Thickness small compared to length/breadth; clays

**Elongated**: Length larger than breadth/thickness; broken flagstone

**Flaky & Elongated**: Length>Breadth>Thickness; broken schists and slates

### 1.1.6 Particle size tests



Figure 1-2: Sieves to measure the distribution of particle sizes

7

The aim of the particle size test is to measure the distribution of particle sizes in the sample. When a wide range of sizes is present, the sample will be sub-divided, and separate tests carried out on each sub-sample. Full details of tests are given in BS 1377 (Appendix A). Methods of test for soil for civil engineering purposes:

i. Wet sieving to separate fine grains from coarse grains is carried out by washing the soil specimen on a 60μm sieve mesh.

ii. Dry sieving analyses can only be carried out on particles > 60 μm. Samples (with fines removed) are dried and shaken through a nest of sieves of descending size.

iii. Sedimentation is used only for fine soils. Soil particles are allowed to settle from a suspension. The decreasing density of the suspension is measured at time intervals. Sizes are determined from the settling velocity and times recorded. Percentages between sizes are determined from density differences. [5]

## 1.2    THE DIFFERENCE BETWEEN CEMENT AND CONCRETE

Although the terms cement and concrete often are used interchangeably, cement is actually an ingredient of concrete. Concrete is basically a mixture of aggregates and paste. The aggregates are sand and gravel or crushed stone; the paste is water and portland cement. Concrete gets stronger as it gets older. Portland cement is not a brand name, but the generic term for the type of cement used in virtually all concrete, just as stainless is a type of steel and sterling a type of silver. Cement accounts for 10

to 15 percent of concrete mix, by volume. Through a process called hydration, the cement and water harden and bind the aggregates into a rocklike mass. This hardening process continues for years meaning that concrete gets stronger as it gets older [6].

## 1.3    PORTLAND CEMENT

Portland cement is the most common type of cement in general usage in many parts of the world, as it is a basic ingredient of concrete, mortar, stucco and most non-specialty grout. It is a finely-ground powder produced by grinding Portland cement clinker (more than 90%), a maximum of about 5% gypsum which controls the set time, and up to 5% minor constituents (as allowed by various standards). As defined by the European Standard EN197.1, "Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates ($3CaO.SiO_2$ and $2CaO.SiO_2$), the remainder consisting of aluminium- and iron-containing clinker phases and other compounds. The ratio of $CaO$ to $SiO_2$ shall not be less than 2.0. The magnesium content ($MgO$) shall not exceed 5.0% by mass." Portland cement clinker is made by heating, in a kiln, a homogeneous mixture of raw materials to a sintering temperature, which is about 1450°C for modern cements. The aluminium oxide and iron oxide are present as a flux and contribute little to the strength. For special cements, such as Low Heat (LH) and Sulfate Resistant (SR) types, it is necessary to limit the amount of tricalcium aluminate ($3CaO.Al_2O_3$) formed. The major raw material for the clinker-making is usually limestone ($CaCO_3$). Normally, an impure limestone which contains $SiO_2$ is used - the $CaCO_3$ content can be as low as 80%. Secondary raw materials (materials in the rawmix other than limestone) depend on the

9

purity of the limestone. Some of the secondary raw materials used are: clay, shale, sand, iron ore, bauxite, fly ash and slag.

## 1.3.1 Production of Portland Cement

Local rock (Limestone)   Corrective mineral

Raw mixture mill

Raw mixture silo

Rotating kiln

Clinker silo

Additional material Fly ash, blast furnace slag etc → Cement Mill

Packing and transport of cement to consumer.
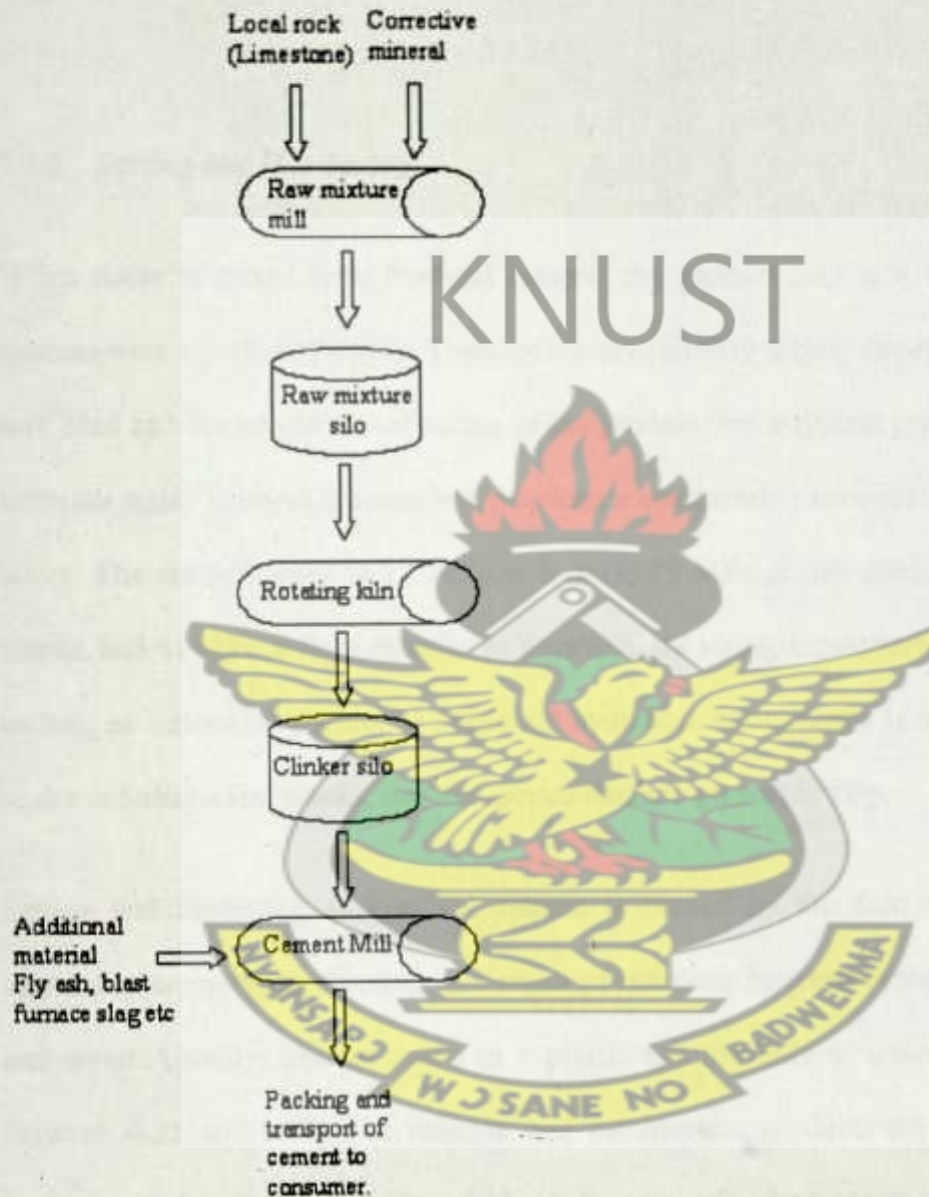
Figure 1-3: Schematic diagram on the production of Portland cement

10

There are three fundamental stages in the production of Portland cement:

i. Preparation of the raw mixture

ii. Production of the clinker

iii. Preparation of the cement

## 1.3.2 Setting and Hardening

When water is mixed with Portland cement, the product sets in a few hours and hardens over a period of weeks. These processes can vary widely depending upon the mix used and the conditions of curing of the product, but a typical concrete sets (i.e. becomes rigid) in about 6 hours, and develops a compressive strength of 8 MPa in 24 hours. The strength rises to 15 MPa at 3 days, 23 MPa at one week, 35 MPa at 4 weeks, and 41 MPa at three months. In principle, the strength continues to rise slowly as long as water is available for continued hydration, but concrete is usually allowed to dry out after a few weeks, and this causes strength growth to stop.

Setting and hardening of Portland cement is caused by the formation of water-containing compounds, forming as a result of reactions between cement components and water. Usually, cement reacts in a plastic mixture only at water/cement ratios between 0.25 and 0.75. The reaction and the reaction products are referred to as hydration and hydrates or hydrated phases respectively. As a result of the reactions (which start immediately), a stiffening can be observed which is very small in the beginning, but which increases with time. The point in time at which it reaches a certain level is called the start of setting.

11

Stiffening, setting and hardening are caused by the formation of a microstructure of hydration products of varying rigidity which fills the water-filled interstitial spaces between the solid particles of the cement paste, mortar or concrete. The behaviour with time of the stiffening, setting and hardening therefore depends to a very great extent on the size of the interstitial spaces, i. e. on the water/cement ratio. The hydration products primarily affecting the strength are calcium silicate hydrates ("C-S-H phases"). Further hydration products are calcium hydroxide, sulphatic hydrates (AFm and AFt phases, and related compounds, hydrogarnet, and gehlenite hydrate. Calcium silicates or silicate constituents make up over 70 % by mass of silicate-based cements. The hydration of these compounds and the properties of the calcium silicate hydrates produced are therefore particularly important. Calcium silicate hydrates contain less CaO than the calcium silicates in cement clinker, so calcium hydroxide is formed during the hydration of Portland cement [6].

### 1.3.3   Hydration of Portland cement

Soon after Portland cement is mixed with water, a brief and intense hydration starts (pre-induction period). Calcium sulfates dissolve completely and alkali sulfates dissolve but not completely. Short, hexagonal needle-like ettringite crystals form at the surface of the clinker particles as a result of the reactions between calcium- and sulphate ions with tricalcium aluminate. Further, originating from tricalcium silicate, first calcium silicate hydrates (C-S-H) in colloidal shape can be observed. Caused by the formation of a thin layer of hydration products on the clinker surface, this first hydration period ceases and the induction period starts during which almost no

12

reaction takes place. The first hydration products are too small to bridge the gap between the clinker particles and do not form a consolidated microstructure. Consequently the mobility of the cement particles in relation to one another is only slightly affected, i. e. the consistency of the cement paste turns only slightly thicker. Setting starts after approximately one to three hours, when first calcium silicate hydrates form on the surface of the clinker particles, which are very fine-grained in the beginning. After completion of the induction period, a further intense hydration of clinker phases takes place. This third period (accelerated period) starts after approximately four hours and ends after twelve to twenty four hours. During this period a basic microstructure forms, consisting of C-S-H needles and C-S-H leafs, platy calcium hydroxide and ettringite crystals growing in longitudinal shape. Due to growing crystals, the gap between the cement particles is increasingly bridged. During further hydration, the hardening steadily increases, but with decreasing speed. The density of the microstructure rises and the pores are filled. The filling of pores causes strength gain. The nature of the chemical action of water on cement compounds may perhaps be more clearly illustrated if we anticipate some of the later discussions and consider the hydration of $3CaO.SiO_2$. The hydration of this compound may be represented as:

$$3CaO.SiO_2 + water \rightarrow Ca(OH)_2 + xCaO.ySiO_2.aq \ .................. (1.0)$$

This action does not stop when the solution is saturated with calcium hydroxide but hydration continues and the further lime liberated by the reaction is deposited as crystals of calcium hydroxide [7]

13

### 1.3.4 Uses of cement

The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element. Users may be involved in the factory production of pre-cast units, such as panels, beams, road furniture, or may make cast-*in-situ* concrete such as building superstructures, roads, dams. These may be supplied with concrete mixed on site, or may be provided with "ready-mixed" concrete made at permanent mixing sites. Portland cement is also used in mortars (with sand and water) only for plasters and screeds and in grouts (cement/water mixes squeezed into gaps to consolidate foundations, road-beds, etc) [6].

### 1.4 STATEMENT OF PROBLEM

In Ghana, sand is being put to good use especially in areas such as in the building construction. Brick manufacturing plants use sand as an additive with a mixture of clay and other materials for manufacturing bricks. Previous studies have been carried out on sand in the areas of quality control practices in sandcrete blocks production. The use of sand for building has been practiced for many years in the developing countries. The persistence in the use of these sands in the building industries has been attributed to several factors. Ghana has a population of about 21 million, with the urban population growing at an estimated annual rate of 4.1% compared with the overall population growth of 3% [8]. With the urban population growing at this rate, building of houses and other recreational facilities are going to increase and the use of

14

sand with cement is also going to be on the rise. This might lead to the practice of using any sand for making sandcrete and concrete.

## 1.5 STATEMENT OF OBJECTIVES

### 1.5.1 General objective:

The main objective of this project is to ascertain the effect of sand quality on the strength of sandcrete products from winning sites in Atwima Kwawoma district in the Ashanti Region and more importantly recommend the type or best sand to use for optimum results.

### 1.5.2 Specific objectives:

1. Classification of sand particles into different particle sizes (medium and fine).

2. To find the effect of chloride, sulphate and organic matter content in the sand and how they affect the strength of the sandcrete products.

3. The effect of the sand quality on the strength of sandcrete products (for).

4. To investigate the effect of washed and unwashed sand on the strength of sandcrete products.

### 1.5.3 Justification of objective:

In Ghana, sand is being put to good use especially in the building construction. Sand used to reduce shrinkage also reduces plasticity. It is in view of these uses of sand that this project is being undertaken to investigate the effect of sand quality on the strength

15

of sandcrete products. The justification of this project is to see if the sand quality (sulphate, twigs, particle size) really affects quality of cement products.

Ghacem cement is the most widely used binding agent in aggregate (different particle sizes) for buildings both in the urban and the rural areas. It also sought to investigate the ratio of sand to cement mixture and its corresponding cold crushing strength (C.C.S).

# CHAPTER TWO

## 2. LITERATURE REVIEW

## 2.1 INTRODUCTION

Various methods have been devised and these are either by elevating the temperature of the water when curing or by introducing come chemical additives in the mortar mix [1].

Aggregates are generally divided into two groups: fine and coarse. Fine aggregates consist of natural or manufactured sand with particles sizes up to 5 mm. It consists of inert natural sand conforming to BSI, BS 882 (refer appendix B). It does not contain more than a total of 5% by weight of the followings: shale, silt and structurally weak particles [9].

Aggregates make up or occupy 60% to 80% of concrete volume making its selection highly important [10]. Aggregate should consist of particles with adequate strength and resistance to exposure condition and should not contain materials that will cause deterioration of concrete. All natural aggregate particles originally formed a part of a larger parent mass. This may have been fragmented by natural processes of weathering and abrasion or artificially by crushing. Thus, many properties of the aggregate depend entirely on the properties of the parent rock, for example chemical and mineral composition, petrologic character, specific gravity, hardness, strength,

17

physical and chemical stability, pore structure and colour [11]. Fine aggregates provide support function to the finer solids producing voids of a size which do not contain or support the finer particles. Particle shape affects the behaviour of the water because harsh angular aggregates do not pack well and result in high void content [12]. Such aggregates may have a high surface area, but because of a lack of contact between the particles, it does not effectively control the finer particles. Smooth rounded aggregates have the disadvantage that, although theoretically it should pack together and produce low voids, this situation does not necessarily occur in a graded material of this type.

Aggregates for mortar must be clean, sharp and free from salt and organic contamination. Most natural aggregates contain a small quantity of silt or clay. A small quantity of silt improves workability. Marine and estuarine aggregate should not be used unless washed completely to remove the magnesium and sodium chloride salts which are deliquescent and attract moisture [13]. The most suitable aggregate would appear to be one that is well graded with a balance between rounded and angular particles and a surface texture that is not too smooth. In practice it has been found that a natural river aggregate with a grading complying with BSI, BS 882 (refer appendix B) is the most suitable.

The realization of the usefulness and effect of fine aggregate on the strength of concrete and sandcrete in the building and construction industry has put into the

18

minds of engineers and researchers to lay more emphasis on the study of the Civil Engineering properties and its usefulness [14].

The structural world is more used to concrete blocks and clay bricks. Thus, literature on structural walling relates to either concrete blocks or clay bricks. Another viable option for walling is sandcrete blocks. Sandcrete blocks, which are formed from sand, cement and water, are peculiar to Africa and Asia. In Ghana, sandcrete blocks have an appeal to the construction industry due mainly to its ease of manufacture and the availability of sand, the main component, in Ghana [15].

There is a need to study methods of increasing the compressive strength of sandcrete blocks. A new research aimed at improving the compressive strength of sandcrete blocks by introducing coarse aggregates has begun. If coarse aggregates are introduced, the new constituents of the sandcrete blocks will then become fine aggregates, coarse aggregates, cement and water. Since the new constituent is the same as for concrete blocks, the major difference between the new sandcrete block and concrete block lies in the method of manufacture. Sandcrete blocks have relatively lower water content than concrete blocks. The lower water content implies a relatively shorter curing period. [15]

## 2.2 TESTING OF SANDS FOR CIVIL ENGINEERING WORKS

There is no question that there are great advantages in using cement in mortars, for example, it is easier to control the hardening process. At the same time there are

19

serious disadvantages to a cement mortar, and unfortunately the advantages are often overstated. Generally large amounts of cement are not needed for strength, and in some cases adding cement may produce more disadvantages than advantages [16].

### 2.2.1 Choice of mortar

When choosing a mortar, strength is not the only consideration. The interaction between the masonry units and the mortar is at least as important. For good interaction, the mortar must be smooth and easily worked.

The mortar should have about the same strength as the masonry units. If the mortar is much stronger there is always a risk for cracking. When choosing a mortar, one should do the following:

i.   Decide a suitable strength.

ii.  Adjust the mortar to the absorbency of the masonry units [16].

### 2.3   SOIL-CEMENT AS A CONSTRUCTION MATERIAL

The combination of soil with cement under controlled conditions of moisture and density produces a material of distinct physical and engineering characteristics. These properties depend on four main factors.

i.   Nature of soil

ii.  Preparation of soil, cement and water in the mixture

iii. The compactive energy used for the moulding of soil-cement.

20

iv.    Physical conditions such as the curing temperatures and the age of the soil cement mixes.

### 2.3.1  Volume change

It is generally observed that an increase in cement content tends to reduce the shrinkage of clay, due to the intergranular cohesion produced by the hydration of cement. It may, however be pointed out that in using soil-cement an optimum quantity of cement is required to cut down the shrinkage to a minimum. Normally, high concentrations of cement tend to produce shrinkage cracks in the soil-cement and sometimes these are detrimental for example to the strength of pavement [18].

### 2.3.2  Strength characteristics

The compressive strength, flexural strength and modulus of elasticity of a soil-cement mix increases with the concentration of cement. In addition the strength of soil-cement with the same concentration of cement is higher in a soil with a better grading. The curing temperatures and period of curing have pronounced effect on the increase in strength of soil-cement mixes [18].

### 2.4  THE NEW SCHOOL AND THE OLD SCHOOL OF MAKING CONCRETE

In just the last 20 years, the industry based on cement binder technology has undergone major changes that shake the very foundation of the old school way of thinking. Not long ago, concrete and mortars were going through their "brute strength" era. Strength was the primary concern and portland cement was king. The

21

common wisdom of the time held that many concrete and mortar problems could be solved simply with the addition of more cement.

The old school thinking reasoned that a higher compressive strength meant a better quality of material. Strength has an important role to play, but it isn't the only actor in the play. In fact, it may no longer be playing the lead role.

A very good example of this can be found in the specification for non-shrink grout. In the past, all too often non-shrink grouts were selected solely on compressive strength. The highest strength got the nod. But over time we've learned this about cement aggregate systems (including structural grouts): as the cement content is increased the compressive strength goes up, but the system also becomes more brittle. This can be very problematic in systems that are exposed to dynamic loads [20].

## 2.5    THE ECONOMICS OF CEMENT

ACI 302 actually suggests that since there is no direct correlation between compressive strengths and water/cement ratio, the two should not be combined in specification for interior floors. This statement means that, a given water/cement ratio will not necessarily produce the same compressive strength using raw material from different sources. Specifications that are strength-driven may require a different amount of cement than those that are water/cement ratio driven. If both are specified, there is a good chance that more cement may be used than is needed.

It has long been known that as the cement content increases, drying shrinkage becomes more of a problem. The importance of optimizing cement content for maximum performance is now being learnt. In other words, more about the economics of cement is being learnt.

In the area of concrete repair, the high strength brute can also lead us astray. Here again, all too often the brute gets the specification nod. Yet, when selecting a repair material, not only must strength be considered, but also bonding capability and the compatibility of the repair mortar with the substrate that is being repaired [20].

## 2.6 SAND FOR MORTAR

In National Specification System of Australia (NATSPEC's) specification of sand for mortar, it draws upon the work of others, with the main innovations being the way in which information is arranged and the insights that are drawn from that exercise. The aim is to promote the use of sand for mortar which:

- Enables mortar to be made without recourse to "doping" – the on-site (i.e. uncontrolled) addition of inappropriate quantities or combinations of cement, water or mineral or chemical plasticisers, all of which are deleterious if used in excess.

- Facilitates the making of mortar that is reasonably tolerant of variations in materials, preparation and environment – thus minimising the need for on-site manipulation of composition.

- Facilitates the making of mortar that can be placed, compacted and finished easily and quickly.

23

- Enables long term in-situ durability criteria to be met. (Or ensures satisfactory long term in situ performance).

The subject of this note is sand for cement-based mortar, principally for bedding masonry and tiles, for plastering and for monolithic toppings to concrete. It does not include sand for sand/lime mortars. It is hoped that it will facilitate the development of similar recommendations for sand used for concrete. The performance of mortar, in both fresh and hardened states, is particularly dependent on sand quality, more so than is that of concrete. Also, sand which is functionally optimal for mortar may not be so for concrete.

The term mortar is used to describe a class of cement-based materials of which the primary components are sand, cement and water. Hydrated lime is a near – primary component. Mortar can also be defined as a sub-class of concrete, differing only in that it has no coarse aggregate. Mortar for bedding masonry and tiles, and for plastering, is normally placed and finished by hand [21].

## 2.6.1 Guidelines for using higher contents of aggregate microfines in Portland cement concrete

The "particle size" method of classification has been influential – leading to the frequent removal of microfines from sand, regardless of its physical or compositional attributes, or end-use. In itself, this practice is frequently both wasteful and

24

environmentally undesirable. It has an important functional consequence; microfines overlap the particle size range of cement, and by definition, form part of the paste.

Traditional 1:3 mortar, the volume of microfines contributed by the sand may be as much as half that of the cement. It follows that microfines affect, to a similar or even greater degree than cement, the rheological behaviour of fresh mortar – a vital attribute of a material that is placed and finished by hand. When they are removed, the tradesperson has little option but to replace them. Typically this is done by increasing the volume of the paste and/or by improving the rheological behaviour of the paste. The former is normally done by adding cement and water. If this is done to excess, it leads to unacceptable shrinkage cracking [22].

The guidelines for using higher contents of aggregate microfines show that if the uncompacted voids content of the total sand including microfines is 0.45%, and if the particle size distribution fits within a defined envelope, the sand will be adequate for plaster. An uncompacted voids content of 45% translates approximately to a compacted voids content of 40%. Sands with microfines contents ranging from 0 – 11% were investigated. Plaster is generally considered to be more sensitive to sand quality than mortar for bedding masonry units. Particle size distribution is not used as a primary descriptor. It is used only as a reference point for specifying uniformity. Particle shape is not used as a descriptor, it being assumed that this will be taken care of by the voids content criterion [6].

## 2.7 CHEMICAL AND PHYSICAL ATTACK OF SALTS ON CONCRETE

Mortar and concrete are two important construction materials widely used in both domestic and industrial construction. With increased incidences of salinity in urban developments, an understanding of how these materials interact with saline ground conditions will assist designers and builders in selecting appropriate building technologies. Chemical salt attack is caused by ingressing salts into cementitious materials, and the reactions with cement hydrates resulting in either the deterioration of the matrix or loss of corrosion protection of the steel reinforcement. Both the physical resistance of the materials against ingressing salts and the chemical resistance of the materials against deleterious reactions determine the performance of the material. Cement type and mix proportions are keys to the resistance of mortar and concrete against chemical attack. Physical salt attack is caused by the capillary suction of salts solution through a porous medium such as mortar, and subsequent crystallisation through drying. The process is repeated through cycles of wetting and drying. Crystallisation and re-crystallisation of certain salts can generate expansive force which results in the physical break down of the porous medium. The same phenomena also affects the exposed part of concrete foundation even though concrete is much less porous than mortar Salts may come into direct contact with bricks and mortars, or reach bricks and mortars through rising dampness (capillary suction & crystallisation process). It is generally believed that if the surface of the material is exposed to air, the main deterioration process is of physical attack due to expansion of salt in the pores of the materials. However, this mechanism is the least understood and research is currently undertaken to better understand this process [23]. In a moist environment where salts are dissolved in solution, a chemical attack can occur usually

26

due to the sulphate salts [24]. Sulphate can result in the loss of strength of bricks and concrete, or cracking of concrete.

The third deterioration mechanism is due to the corrosion of steel reinforcement in reinforced concrete structures. In this case, the main deleterious salt is chloride, which diffuses into concrete resulting in the lowering of the pH and activating the passivated steel to corrode. Corrosion leads to formation of iron products that expand, which may result in cracking of concrete around the steel reinforcement. This phenomenon is more commonly observed in reinforced concrete structures in marine environment [25] such as concrete wharf in tidal zone and buildings along the coastline.

### 2.7.1 Sulphates Attack.

The deterioration of mortar and concrete due to sulphate bearing soils has been well established. Naturally occurring sulphates of sodium, potassium or magnesium can chemically attack hardened cementitious materials in mortars and concrete, causing deterioration. To produce significant attack, aggressive chemicals have to be in solution and should be able to penetrate into the structure.

Sulphate attack is a complex process involving a sequence of different chemical reactions. There are mainly two mechanisms related to sulphate attack: ettringite and gypsum formation. In general, it is accepted that expansion and cracking are associated with ettringite formation. Strength loss and mass loss are associated with gypsum formation [26]. Also there is evidence that gypsum formation can cause

27

considerable expansion when formed in large masses [24,27]. However, gypsum formation is generally accompanied by a reduction in strength [24]. Also, a third mechanism could take place as a result of decalcification of calcium silicate hydrates (C-S-H), or even unhydrated $C_3S$ and $\beta$-$C_2S$ in the presence of sulphate ions [26,27].

Calcium ions are released to the pore solution and supply $Ca^{2+}$ to promote the formation of either ettringite or gypsum. It must be noted that the decalcification of C-S-H can also lead to loss of strength and elastic properties due to a reduction in binding capacity.

### 2.7.2 Attack due to Chloride Salts

There are two basic transport mechanisms for the penetration of chlorides, diffusion of chloride ions and transport of chloride ion combined with water transport. Two parameters govern the chloride diffusion and the related risk of corrosion:

(a) diffusion resistance of the concrete, which primarily depends on the pore size distribution and the chloride ion concentration gradient

(b) binding capacity of the concrete with respect to chloride ions (both physical and chemical binding) as this binding capacity influences both the penetration rate and the ratio of bound to free chloride ions in the pore water.

The diffusion resistance of concrete to chloride ions is important as it governs the rate of penetration of chloride ions. Superior diffusion resistance (lower diffusion coefficient) would imply that it will take longer for chloride ion concentration at

28

reinforcement to exceed a critical chloride concentration ($C_{cr}$), for which depassivation and corrosion of the steel can take place. Thus concrete structures with high resistance to chloride diffusion are expected to have longer service life. Also the binding capacity of concrete is critical as it is generally recognized that only the free chloride ions in the pore water influences corrosion of reinforcement.

### 2.7.3 Resistance of Concrete and Mortar to Physical Attack

There are many types of concrete structures that can be affected by saline environments: slabs on grade, footings, roads, concrete pipes, kerbs and gutters. Due to the different types of concrete used in these different applications, the extent and possible types of deterioration occurring could be different. The impacts of a saline environment manifest in different forms: efflorescence, scaling, progressive erosion of surface, cracking, crumbling and softening. Scaling is considered to be the effect of salt crystallisation with no impact due to chemical attack. It will occur when the rate of evaporation of water from the concrete surface is faster than the rate of water entering the system. The deterioration is progressive and leads to surface damage, which could possibly lead to further salts penetration. Physical attack by salt crystallisation could ultimately lead to crumbling concrete.

## 2.8 RESISTANCE OF MORTAR AND CONCRETE TO CHEMICAL ATTACK

### 2.8.1 Sulphate Salts

It has been found that the sulphate resistance of concrete depends of the chemical resistance of cement and the physical resistance of the concrete [28,29]. The chemical resistance is strongly influenced by the cement composition or cement type, whereas the physical resistance is controlled by the concrete mix proportions and in particular the water to cement ratio. Concrete with lower permeability has better physical resistance and thus would resist the penetration of sulphate ions and thereby improve the sulphate resistance of concrete.

The sulphate ion content of sand determined quantitatively in accordance with AS 1012.20 should be reported if in excess of 0.01 %. Sand should not be used which, when tested in accordance with AS 1012.20, contain sulphates (expressed as $SO_3$) in proportions which result in the sulphate content of the mortar exceeding 5.0% by mass of Portland cement.

### 2.8.2 Chloride Salts

The diffusion resistance of concrete to chloride ions is normally expressed in terms of chloride diffusion coefficient $D_a$. The lower the $D_a$, the better the resistance of concrete to chloride ions ingress. As mentioned before, diffusion is mainly influenced by the pore size distribution. The diffusion coefficient has been found to reduce with increase in the strengths and also with the addition of supplementary cementitious material (SCM) such as fly ash, slag and silica fume.

30

The chloride ion content of sand determined quantitatively in accordance with AS 1012.20 should be reported if in excess of 0.01 %. A combination of sands where the total chloride salt content (expressed as $Cl^-$) exceeds 0.04 % should not be used in reinforced mortar or mortar in contact with embedded metallic fittings. A combination of sands where the total chloride salt content exceeds 0.15 % should not be used in plain mortar.

### 2.8.3 Combined Effect of Chloride and Sulphate Salts

In saline environment, it is quite common for both sulphate and chloride to coexist. Studies on concrete in sea water indicate that the presence of chloride retards the attack by sulphate ions. Chlorides permeating into the concrete react with $C_3A$ to form chloroaluminate hydrates (Friedel's salt) and the quantity of $C_3A$ available to form expansive ettringite is reduced. Other studies confirm that the presence of chloride ions in sulphate environment mitigates the sulphate attack in plain and blended cements [30]. That is one of the possible reasons why, in some concrete buried in saline soils (normally containing chloride), sulphate attack was not observed.

The beneficial effect of chloride ions is not operative if magnesium attack is involved in the proces [31].
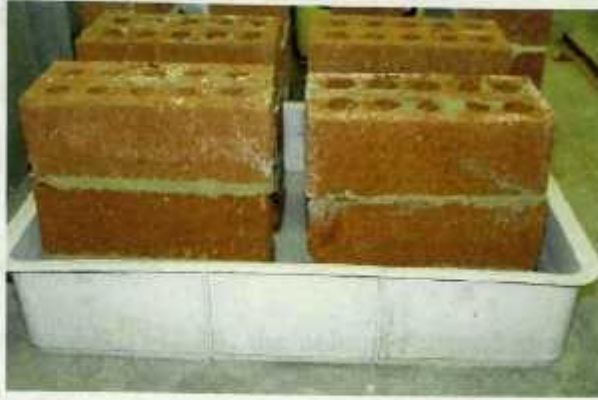
Figure 2-1: Experimental set-up for brick/mortar system study.



Figure 2-2: Appearance of the brick/mortar system after one cycle in NaCl solution



Figure 2-3: Appearance of the brick/mortar system after seven cycles in NaCl

## 2.9 IMPURITIES

Limits to impurities may be specified by reference to the relevant clauses of AS 2758.1, Section 9, from which most of the following is drawn:

### 2.9.1 Organic impurities

If sand is tested to AS 1141.34, the colour obtained should not be darker than the standard colour of the reference solution. The performance of any suspect sand may be evaluated by comparing its performance in mortar to that of a similar mortar manufactured using sand that is known to be satisfactory.

### 2.9.2 Soluble salts

Some soluble salts may cause efflorescence in mortar or adjacent concrete or masonry, corrosion of reinforcing steel or embedded metallic items (if such are used) or disintegration of the mass of the mortar. Permissible levels of soluble salts are generally expressed as the proportion of the relevant ion present in the mortar by mass of mortar or by mass of Portland cement.

Sand which contains other strongly ionized salts, such as nitrates, shall not be used unless it can be shown that they do not adversely affect mortar durability [21].

## 2.10 UTILISATION AND QUALITY OF CEMENT-STABILISED BUILDING BLOCKS

### 2.10.1 Definition of cement-stabilised building blocks

In this report the term "cement-stabilised building blocks" is used as a generic name to cover a wide range of building materials. A cement-stabilised building block is

33

defined here as one formed from a loose mixture of soil and/or sand and/or aggregate, cement and water (a damp mix), which is compacted to form a dense block before the cement hydrates. After hydration the stabilised block should demonstrate higher compressive strength, dimensional stability on wetting and improved durability compared to a block produced in the same manner but without the addition of cement. This definition includes a range from hand-tamped soil blocks containing only enough cement to enhance their dry strength a little (but not to achieve any long term wet strength) to close-tolerance high-density concrete blocks, mechanically mass produced and suitable for multi-storey construction without a render [32].

### 2.10.2 Current production of cement-stabilised building blocks: practices and problems

**Curing procedures**

The most detrimental practice seen in all of the countries surveyed was poor curing of the formed cement stabilised block. Once formed the blocks are frequently left out in the sun to "dry", large areas of sun-dried "curing" blocks were observed in every country surveyed [33]. Cement relies on the presence of water to hydrate, forming an interlocking skeleton of calcium silicate hydrate which gives the material its strength. If the block is allowed to prematurely dry then full hydration of the cement does not occur and consequently only part of the cement used contributes to the strength of the block. Experiments conducted by the DTU (Technology University of Denmark) at the University of Warwick have shown that the strength lost due to poor curing can easily reduce the final block bulk strength by 20%. As the block surfaces lose water

34

first, strength loss in these regions is still higher [34]. The loss of surface strength reduces both the handleability (edge and corner chipping during transport) and the durability of the blocks. If proper curing were implemented, maintaining the moulding water content for at least seven days, then both strength and durability improvements would be seen. Good curing practice is not followed for one of two reasons. Either the producer is not aware of the need for curing (instances in all countries surveyed) or it is felt that the cost of constructing a suitable curing area is not worth the potential increase in quality. In Kampala where sandcrete blocks are produced by "egg-laying" vibrating machines, producers observed that wet weather, provided heavy rain did not pit the newly moulded blocks, gave better curing. However they were reluctant to use cloths to increase humidity during curing and also indicated that shading the blocks would be unacceptably expensive, given the large area which would have to be covered. With conventional moulding methods the strength of the green blocks is not sufficient to allow stacking of the fresh blocks and hence a large sheltered curing area is required. Improved compaction produces higher density green blocks which may be stack cured, greatly reducing the area needed. Furthermore a higher density block loses water more slowly as a result of its reduced porosity and consequently is less susceptible to poor curing practice [35].

**Batching**

Cement hydration begins as soon as the cement comes into contact with water. Experiments conducted by the DTU confirmed a strength loss due to compaction delay but found it to be less pronounced, namely 20% loss after a two hour delay. The significance of batch time was not understood by field producers and consequently

35

batch times of two hours or more were common. In isolated instances batch times up to six hours were found [36] which would result in at least a 50% strength loss for blocks produced at the end of a batch. Batch times of 30 minutes are recommended and it is advisable that times do not exceed 1 hour.

**Optimum water content**

The amount of water added to the cement mix is also important for good compaction during moulding. Moulding at the optimum water content results in the densest block yielding the greatest strength. If too much or too little water is added the formed block will be less dense. This fact was not fully appreciated by any of the block manufacturers visited and consequently variable moisture contents were used at moulding. This fact also contributes to the argument for shortening batch-times, as water is progressively lost from the mix both in the hydration of cement and also by evaporation.

**Raw materials testing**

The material, either "soil" or "sand" to be stabilised is not adequately tested and the importance of the fine aggregate content is not understood. Thorough soil testing has always been advocated for soil-stabilisation but not for sand stabilisation. It has been found in the field that what is sold as sand, which should contain minimal quantities of material finer than fine sand (0.063mm) frequently, contains high quantities of such fines. CSIR in Pretoria, South Africa have found supplies of "building sand" composed of over 50% clay. More commonly contamination is in the order of 25%

fines, as observed in Zimbabwe, Kenya, Botswana and Ghana for unwashed pit sand. The proportion of silt and clay (the fines) present in the material to be stabilised plays an important role in determining the amount of cement needed for a given degree of stabilisation. It is the fines, particularly the clay fraction, which expand and contract on wetting and drying and consequently affect the durability of the cured block. Without an understanding of both the effect of the fines and the quantity present it is unlikely that the optimum use of cement will be made [36].

## Quality control

Quality control is usually not appreciated by the block manufacturer; in consequence there is a large degree of variation in quality, both between manufacturers and within the stock of a single manufacturer. For example, most Non Governmental Organizations projects had tested blocks at the start of production to determine the optimum cement content for the required strength but had not continued testing subsequently. Blocks produced in Kenya were recently tested for compressive strength by the Kenyan Standards office and found to be only half of the value expected 0.7 MPa compared to 1.5 MPa [21]. This is not surprising as the production of blocks had begun 12 years earlier, methodology was passed from operator to operator, degenerating over the years, and no quality testing had been implemented to monitor gradual changes. Testing of the density of green blocks would identify production problems at an early stage, allowing quick remedial action to be taken. Testing of representative sample blocks for cured strength would serve as both an overall check on the production system and a useful marketing tool, namely the adherence of the block to the local building regulations [37]. However although

37

building regulations exist in nearly all urban areas, defining the minimum allowable compressive strengths of walling materials, they are not effectively enforced for low rise construction. Botswana site inspectors rely on a purely visual assessment of the blocks [38].

Although the cement-stabilised production process is a simple one, it relies very heavily on tight quality control to achieve good results. The following is a summary of the factors which can cause block defects if not adequately monitored:

soil/sand composition may vary considerably even if dug from a single pit inadequate mixing can produce a highly uneven distribution of cement mixing too large a batch at one time can reduce strength due to premature cement hydration incorrect moisture content at the time of moulding adversely affects the efficiency of compaction variations in the volume of mix placed in the mould for compaction affects the final density of the block and can seriously damage the machine. Inappropriate curing will allow the block, in particular the block surface, to lose the water required for full hydration of the cement, causing low strength blocks with poor surface durability [38].

38
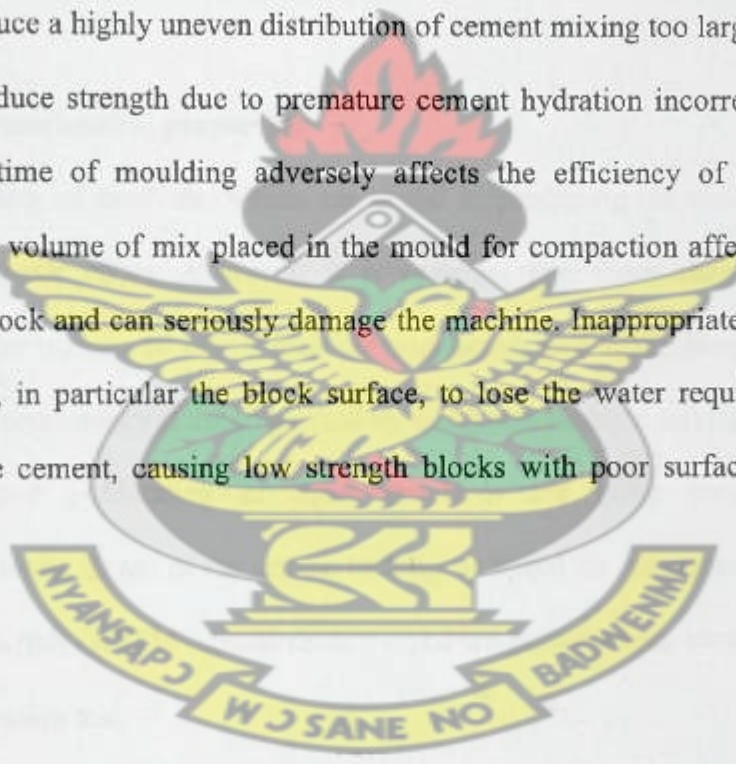
# CHAPTER THREE

## 3. EXPERIMENTAL THEORIES

Once a mortar cube material is prepared, its properties are evaluated and they are usually compared with the properties of a standard cube. Analysis of properties of the mortar cube is also important in determining the applications for which the material can be used. The various analytical and evaluative methods used to determine the compressive strengths and the chemical composition of the mortar cube are as follows:

### 3.1 Physico-mechanical properties

There are a variety of methods, which are useful in predicting physico-mechanical properties of mortar cubes. However, it is essential that there should be some consistency in the manner in which tests are conducted, and in the interpretation of the results. This consistency is accomplished by using standardized testing techniques. Establishment and publication of these standards are often coordinated by professional societies. Some of the testing techniques based on American Society for Testing and Materials (ASTM) standards employed are porosity test, water absorption test, and compression test.

## 3.2 POROSITY TEST

Porosity of a body is the total proportion of pores contained between the solid particles of which the body is composed [39].

Pores in a body are of two types: open pore and closed pore. Open pores are spaces into which water can penetrate and closed pores are spaces into which water cannot penetrate. Pores play a significant role in the mechanical behaviour of a material because they can provide stress concentration that far exceed the shear or fracture strength [39].

Porosity is also of two types: apparent porosity and true porosity. Apparent porosity is defined as:

$$Apparent\ porosity = \frac{Total\ open\ pore\ volume\ of\ a\ sample}{Bulk\ volume\ of\ a\ sample} \quad \text{.......................(3.1)}$$

The Bulk volume of a sample = True volume of a sample + Total pore volume of a sample

The Total pore volume of a sample = Total open pore volume + Total closed pore volume

Mathematically, the expression used to estimate the apparent porosity is as follows:

$$Apparent\ porosity = \frac{W_2 - W_1}{W_2 - W_3} \quad \text{.................................................(3.2)}$$

Where:

$W_1$ = Dry mass of sample in air

$W_2$ = Saturated mass of sample in air

$W_3$ = Saturated mass of sample in water [39].

## 3.3    WATER ABSORPTION TEST

Water absorption is the amount of water absorbed by a sample after soaking the sample in water for a certain period of time [40].

The amount of water absorbed by a sample is calculated from the formula:    The percentage water absorbed %WA is

$$\%WA = \left(\frac{W_2 - W_1}{W_1}\right) \times 100\% \dots\dots\dots(3.3)$$

## 3.4    COMPRESSION TEST

Compressive properties describe the behaviour of a material when it is subjected to a compressive load. Loading is at a relatively low and uniform rate. Compressive strength or compressive stress, compressive strain and compressive modulus are the most common values produced when a test sample is subjected to a compressive load. From the slope of the tangent to the initial straight line portion of the compressive stress- compressive strain curve, compressive modulus is computed [41].

Compressive strength, compressive strain and compressive modulus are calculated using the following expressions[41]:

41

$$Compressive\ strength = \frac{Maximum\ compressive\ load\ on\ a\ sample}{Average\ cross-sectional\ area\ of\ a\ sample} \quad\ldots\ldots\ldots\ldots (3.3)$$

KNUST

## 4. EXPERIMENTAL METHODS

The various methods used in the determination of the physico-mechanical properties as well as the chemical analysis of the sands are described below.

### 4.1 MATERIALS

Only one type of cement (GHACEM), produced in the country was chosen for this study. Sand used by local building and road contractors and ordinary tap water were the other materials used to prepare the test cubes. The sands were taken from winning sites in ESRESO, ADAGYA AND APUTUOGYA ABOATEM all in the Atwima Kwanwoma district in the Ashanti regions.

### 4.1.1 Curing equipment

The curing aluminium container used for the test had a size of 160cm by 124cm by 85cm. The container could contain almost all (about 450 cubes) at a particular time. The temperature of the water in the container was at room temperature.



Figure 4-1: Picture of samples in the curing water tank for the period of 28 days

43

## 4.2     SIEVING OF SAND

An amount of 20 kg of the sand was weighed and sieved into fine (≤0.5mm), medium (≤1.4mm) and rough (≤2mm) particles respectively. The different amount was weighed and converted into percentages, but the sand used for the mixes for all the sandcrete cubes were fine particles and medium particles only. Cement of fineness 2250 cm²/g and the sand were the mix design used for the moulding.



Figure 4-2: Picture of sieves with sizes of 0.5 mm, 1.4 mm and 2 mm respectively.

## 4.3     MIXING AND MOULDING OF SAND AND CEMENT

The mixing and moulding were done using natural silica sand. The sand -to- cement ratio was 6:1 and 3:1.

The amount of sand and cement (6 parts of sand to 1 part of cement) was measured by volume and put in the mixing bowl. The mixture was combined in the mixing bowl and mixed thoroughly. Then the needed water (ie.1.5 times the amount of cement used) was added until it became a paste (not too watery or the cement won't hold

44

together), it is mixed together with the sand and cement. The moulds were 100 mm by 100 mm by 100 mm which the inside was coated with oil for easy release of samples. The mixture is put in the mould and made sure it was filled up. The mould and their contents were then subjected to vibration for effective packing; after which the surfaces of the sand-cement mixture was smoothed at the brim of the mould. The cubes were taken out from the moulds after 24 hours. The cubes were divided into two batches. One batch was put in the tank to cure for 28 days before testing for compressive strengths and another batch was also air-dried for 28 days and tested for their compressive strengths.

The areas for each of the cubes were taken again after they were removed from the moulds (though a 100 mm by 100 mm by 100mm moulds were used before crushing for their compressive strengths). For each sample, three cubes were made; Sand from each winning site namely, Adagya, Esreso and Aputuogya was used in making a set of three cubes for sand-cement ratios of 6:1 and 3:1 by volume.

The sand used in the mixes was used as from the winning sites. The fine aggregates were mixed in the proportions 6:1 and 3:1 by volume and the medium aggregates were also mixed in the same proportions also by volume. The fine and medium sand particles used in the mixes were again formed in equal ratios, that is, 50% of fine and 50% of medium. The fine and medium sand particles were again formed by combining 75% of fine and 25% of medium sand particles. They were also formed in mixes by combining 75% of medium and 25% of fine.

Adagya sample was washed and dried to remove organic matter and most silt content from it and then formed in the proportion 6:1 and 3:1 respectively. The water content was the same for all the mixes.



Figure 4-3: Picture of the mixing bowl



Figure 4-4: Picture of a vibrator

Figure 4-5: Picture of cubes being kept in the mould to be demoulded after 24hours.

## 4.4    CURING

This is a picture of cubes being air dried for a period of 28 days before they tested foe their compressive strengths.
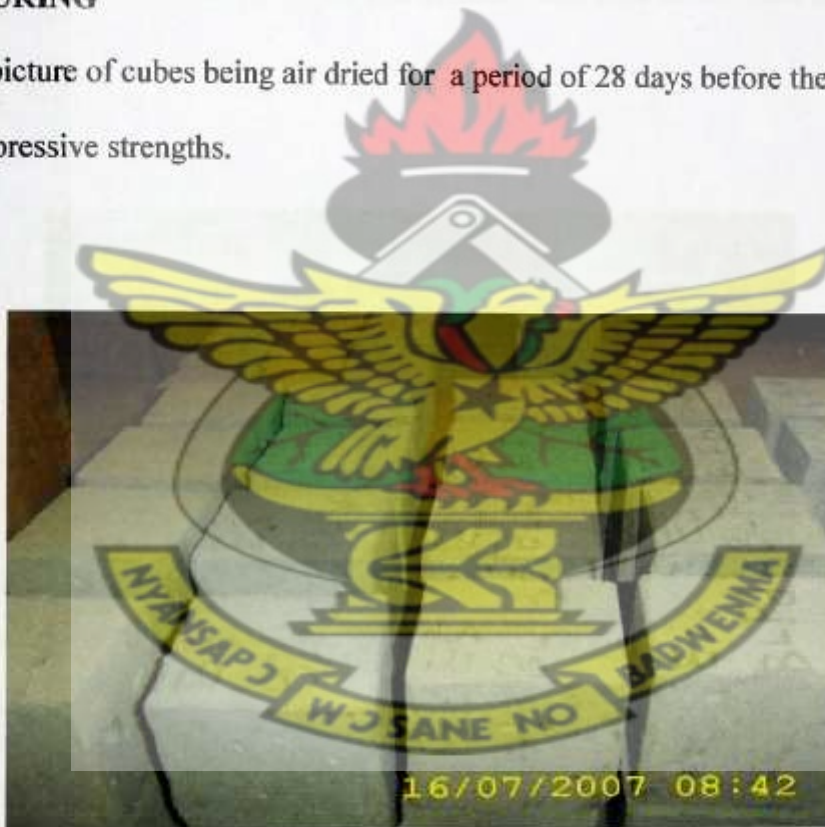


Figure 4-6: Picture of samples being air dried for a period of 28 days

## 4.5    COMPRESSION TESTS ON CUBES

Sand- Cement cubic samples (100 mm × 100 mm × 100 mm) with different cement ratio sample were used for the compression test. One side of the cube was marked facing the movable head of the compression testing machine (Fig 4-7). The average cross sectional area of the sides of the test sample which received the loads was measured before the application of the loads. The movable head of the compression testing machine was lowered until it came in contact with the test sample. The movable head was lowered until the test sample failed. Sandcrete blocks with different sand particle sizes that were also formed were crushed for their compressive strengths.



Figure 4-7: Picture of a sample being crushed in the compressive strength machine

## 4.6    POROSITY

This test was done after the 28-day curing period. All the samples were air-dried for 28 days, after which they were weighed in air. The cubes were then immersed in water at ordinary room temperature for a period of 48hours. After the 48hours, the saturated cubes were weighed in water and then weighed in air as well and the porosity was determined for the samples.

By using the water saturation method, the effective apparent porosity is a measure of the effective void volume of a porous medium and it is determined as the excess of bulk volume over grain volume.



Figure 4-8: Picture of a cube being weighed in air

Figure 4-9:Picture of saturated cube being weighed in water

## 4.7    CHEMICAL TEST

### 4.7.1   Sulphate test

Ten grams of the sand was dissolved and agitated in 100 ml of water for about 30 minutes to leach out the soluble sulphates. The solution was filtered through the filter paper and 10 ml of the sample was taken and sulfaver 4 powder pillow was added as a reagent. The prepared sample was put in the spectrophotometer for analysis. Readings of the sulphate content was recorded digitally. A spectrophotometer (model DR 2010) was used. This was done for all the sand samples.

### 4.7.2  Chloride test

Ten grams of the sand was agitated with 100 ml distilled water for 24 hours to bring soluble chloride into solution and then filtered. One hundred ml of the filtrate solution was titrated with the addition of silver nitrate (AgNO3) solution using potassium dichromate as an indicator and then weighed. This was also done for all the sand samples

CALCULATION:

Mg Cl/L= (A-B) x M x 35.45 x 1000/mL sample where:

A= mL titration for sample

B= mL tritation for blank

M= molarity of $AgNO_3$

### 4.7.3  Organic matter content

Twenty grams of sand sample was oven dried for 24 hours. Approximately 100 ml of prepared 6% $H_2O_2$ was added and stirred with the sand in a beaker. The beaker and its content were placed on a hot plate at about 600°C for about 24 hours and covered with a watch glass the contents stirred with a glass rod from time to time. At the end of the 24 hours a small quantity of $H_2O_2$ was added and if it caused further evolution gas bubbles another 100 ml of $H_2O_2$ was added. The process was repeated until no gas bubbles evolve. The sand was filtered and washed with hot distilled water, dried to a constant weight.

## CALCULATION:

Wb= weight of dried sand before test

Wf= weight of dried sand after test

Percentage of organic matter content = $(Wb-Wf)/Wb \times 100$

# CHAPTER FIVE

## 5. RESULTS AND DISCUSSION

The results of particle size analysis, compressive strength, porosity and chemical test of the sand and sandcrete for different winning sites in the Atwima Kwanwoma district in the Ashanti region are presented in this chapter. Esreso Red, Esreso Plaster and Esreso Block are names used by the sand winners for different purposes of the sand.

## 5.1 SIEVE ANALYSIS

Sand from Esreso, Adagya and Aputuogya were analysed into different particle sizes by sieving. The size particles were coarse ($\leq$2mm), medium ($\leq$1.4mm) and fine ($\leq$0.5mm).

### 5.1.1 Esreso red

All these samples are used in the making of sandcrete blocks. By visual inspection, sand from esreso (esreso red) was bright brown in colour, had too much organic matter which were mostly weeds. After sieving, the coarse ($\leq$2 mm) was 3.70% in the whole bulk of the sand. This was not enough for the purpose of making blocks (Fig 5-1)

### 5.1.1 Esreso block

These samples were brown in colour. The overall residue in Esreso red was (20.86%). Most of the residues were mainly stones and weeds. There were about (20%) of stones, mostly fine stones and the stones were mainly transparent like quartz. This is the cause of the weathering of rock from which the sand came from. After sieving, the medium (≤1.4 mm) was (52.59%), followed by fine (22.30%) and coarse (4.25%).

### 5.1.2 Esreso plaster

The sample was also brown in colour. The sample was so fine that after sieving the residue content was very little (0.31%). This could be seen as if there was no organic matter in it. It was very smooth when felt in between the fingers and when sieved the coarse particles (0.68%) were almost insignificant. The fine particles was (76.53%) after sieving.
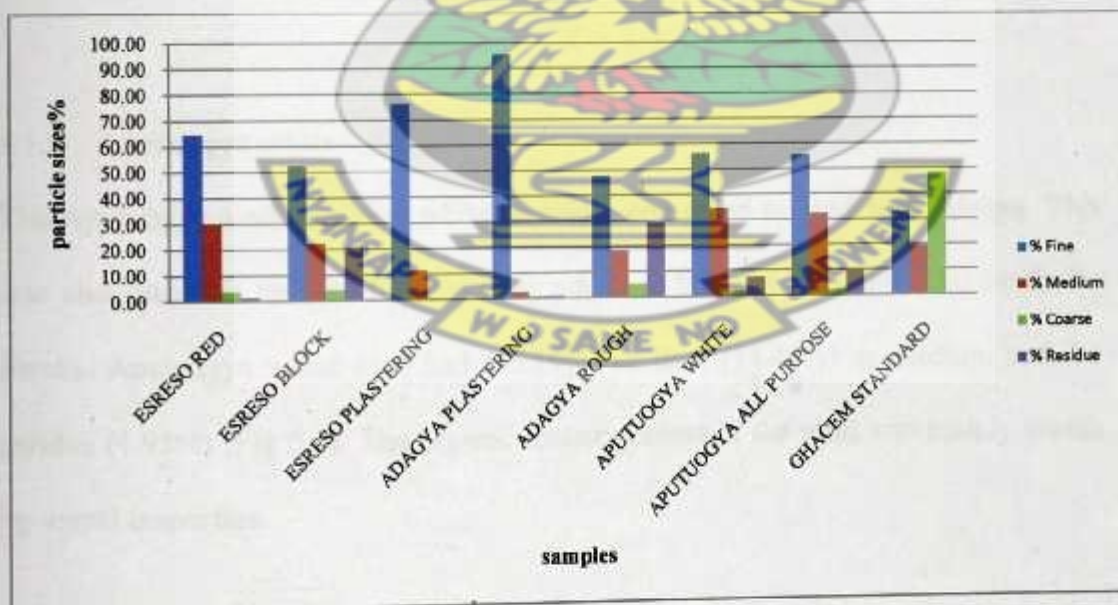


Figure 5.1: A graph showing the sieve analysis of the sand samples from different winning sites and their relative amount in percentages

54

### 5.1.4 Adagya rough

Adagya rough was off-white in colour. The organic matter content was (1.08%) compared to samples taken from Esreso. Compared to Esreso, aggregates of Adagya and Aputuogya were much bigger in size but mostly of stones and roots of plants. With Adagya rough, the sand had too much fine (47.56%) in it. The medium particle sizes was (18.29%) and with the coarse particles being (5.17%) (Fig 5-1).

### 5.1.5 Adagya plaster

This was also off-white in colour. As the name implies the Adagya plaster which is supposed to be used for plastering purposes was used in the making of sandcrete blocks had its fine particles rocketing at (95.37%) compared with the medium particles which had (2.51%) and the coarse particles which had a quantity of (1.04%) (Refer Fig 5-1)

### 5.1.6 Aputuogya white

The Aputuogya sand was very white in colour compared to sand from adagya. This was also meant to be used for plastering purposes but was being used for sandcrete blocks. Aputuogya white sand had (56.19%) as fine, (34.40%) as medium and the residue (1.95%) (Fig 5.1). The organic matter content in the sand was mainly weeds by visual inspection.

### 5.1.7 Aputuogya all purpose

As the name implies the Aputuogya all purpose sand is used for all purposes, as in the making of sandcrete blocks, plastering, filling of pits. The fines after sieving was (55.57%), (32.25%) for medium and (2.14%) for coarse. Comparatively, Aputuogya all purpose and Aputuogya white had almost all their particles sizes being almost the same (see Fig 5-1).

Out of all the sand samples, Adagya plaster had higher amount of fine particles (95.37%) than any of the sands. Esreso plastering had the least coarse particles of (0.68%). This can be seen in the graph (Fig 5-1) and also in the table in the appendices.

### 5.1.8 Ghacem standard

Ghacem standard which is sand used by Ghacem company Ltd was also analyzed. The sand after sieving had the coarse aggregate to be very high (48.28%) followed by the fine (32.84%) and then the medium (19.40%) ( As shown in Fig 5-1).

From this analysis it was observed that none of the sand from the winning sites in Atwima Kwanwoma district of Ashanti region had even its coarse particle size reaching half of the sand used by Ghacem Company for making their mortar.

## 5.2    COLD CRUSHING STRENGTH ANALYSIS (C.C.S)

On the graphs (Fig 5-2, 5-3, 5-4 and 5-5) it can be seen that air dried samples had the higher value of C.C.S than the water cured samples.
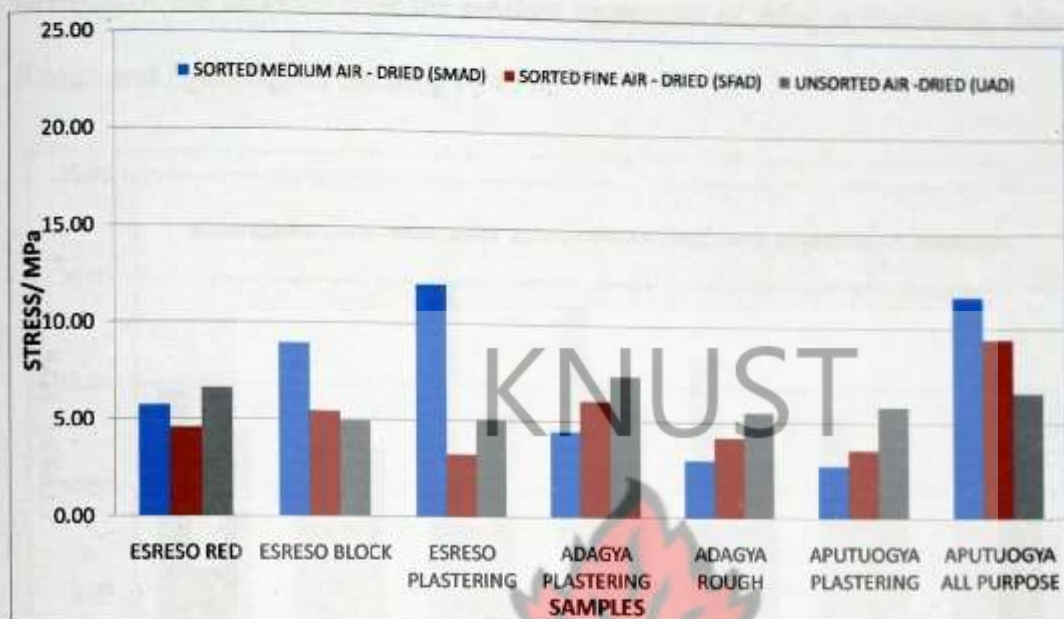


Figure 5-2: A graph showing the cold crushing strength of Sorted Medium Air-Dried (SMAD), Sorted Fine Air-Dried (SFAD) and unsorted Air-Dried (UAD) for the various sandcrete samples in the 6:1 mix.

Comparing all the samples, the strength of UAD of all the samples ranged from 5 MPa to 7 MPa. The disparities were not much. This may be attributed to the fact that a mixture of different particle sizes in different proportions bind well with each other. This is because; the smaller aggregates are able to fill in the pores in the mixture. Samples of medium aggregates had their strength also varying in the range of as low as 3 MPa to as high as 12MPa. This tells us that medium aggregates are able to bond well to give high strength when mixed with cement. Samples of fine aggregates also had their strengths varying from between 3MPa to 9MPa which is low compared to

57

unsorted and medium samples. This can also be given the reason that small particle sizes alone do not bind well with cement. From Esreso Plastering medium, there was 137% increase in strength over the unsorted. But generally, there was increment in strength of the unsorted over the medium aggregates of Adagya Plastering, Adagya Rough and Aputuogya Plastering by 87%.
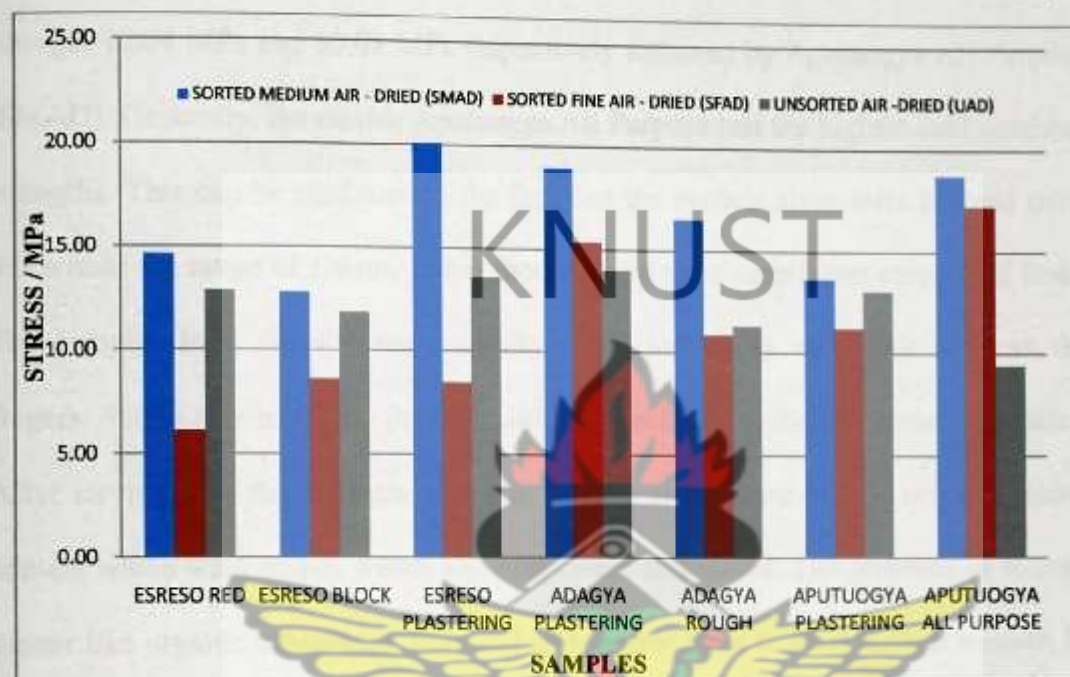


Figure 5-3: A graph showing the cold crushing strength of Sorted Medium Air-Dried (SMAD), Sorted Fine Air-Dried and unsorted Air-Dried (UAD), for the various sandcrete samples in the 3:1 mix.

From the graph, it can be seen that Esreso Plastering of medium aggregates had a very high strength of 20 MPa. Again, it can be seen that samples of medium aggregates have very high strengths. In the 3:1 sand – cement mix, the strengths were very high due to the increase in cement. The more cement in the mix, the higher the compressive strength because there is increase in cementation. On the average,

unsorted samples had their compressive strengths for all samples between 9 MPa to 14 MPa. Fine aggregates for the samples were low compared to unsorted and medium samples but for samples from Adagya Rough and Aputuogya All Purpose.

From the 6:1 and 3:1, Esreso Plastering (SMAD) had the highest cold crushing strength 12.04 MPa and 20.09 MPa respectively followed by Aputuogya All Purpose (SMAD). Generally, the sample Aputuogya All Purpose had the highest cold crushing strengths. This can be attributed to the fact that the particle sizes were big and most fell within the range of 1.4mm -2mm though there were significant amount of fines. The samples from the site are generally rough and sharp when felt between the fingers. When this happens, they are able to bond well with the cement particles. After sieving into the medium and fine particle sizes, most of the organic matter content which were mostly weeds and twigs were eliminated. The presence of foreign matter like organic substances, salts and undesirable fines in sand tend to weaken its overall performance. Since, it is impossible to get rid of all these materials, it is always necessary to give an indication of the extent of these undesirables in crucial tests.

The varying compressive strengths of samples from various locations could be attributed to the make of sand. Adagya Rough had the highest coarse compared to all samples taken from the winning sites. This could be due to weathering of the parent rocks from which the sand came from. Generally, Esreso Red and Esreso Block recorded the lowest compressive strengths on the average because of clay suspected.

The clay content in the sand was done by visual inspection. (With this, samples of the sand is griped in the palms and squeezed for a few seconds, the palms becomes sticky with the sand this shows that clay is present). Clay and cement have binding properties on their own but clay and cement in the same mixture weakens the strength of mortar. Clay interferes with the bond between aggregate and cement paste. Since good bond is essential to ensure satisfactory stength and durability of concrete, limits are usually set on how much clay and fine silt can be accepted in sand used for civil engineering works.British Standards 882 specifies a clay and fine silt content of not more than 3 per cent. Concrete news, pointed out that there are reasonable concerns regarding unnecessary high strength. It suggests that since there's no direct correlation between compressive strength and water/cement ratio, the two should not be combined in specifications. So the understanding of this statement is that a given water/cement ratio will not necessarily produce the same compressive strength using raw materials from different sources. Specifications that are strength-driven may require a different amount of cement [42].

From fig 5-1 and 5-2, it can be seen that the 3:1 mix had a higher compressive strength than the 6:1 mix. The differences between the compressive strength of mixes is mainly due to the increase in cement content of the 3:1 mix. The more cement in the mix, the higher the compressive strength because there is increase in cementation and also as cement content is increased, compressive strength also increases but also makes the material more brittle.

The anomalies (some having high strengths and others having low strengths) in the 6:1 mixes air drying is attributed to the fact that the UAD for most of the samples

were relatively high compared to SMAD and SFAD because the sand was used just as it was brought from the sites therefore contained both fines and medium which fill (better packing) well into pores thereby creating strong bond between the particles but on the contrary, it contained organic matter content which were mainly weeds. When weeds are in the mixture, they leave large pores in the sandcrete. These pores coalesce to form large pores and thereby the low strengths when tested. After sieving into medium and fine particle sizes most of the organic matter content were removed. The SMAD recorded low compressive strengths for Adagya Plastering and Aputuogya Plastering because of the type of sand. The sand itself is made up of fine particle sizes and therefore the fines constituted greater portion of the sample.

### 5.2.1 Effect of sand gradation on compressive strength

Refer to fig 5-4 and 5-5, it is assumed that bigger particle sizes have a stronger bond when mixed with cement. Since one of the objective was to determine which size of sand particles used to make bricks would be strongest, it was found from the differences in Unsorted Air Dried, Sorted Medium Air Dried and Sorted Fine Air Dried, that larger particle sizes would make the strongest brick from the high compressive strengths results.

The sand particles between 0.5 mm and 1.4 mm have the greatest impact on mortar properties. It is again noted that most variations have little impact on strength in both air drying and water curing. Water demand for cubes increases when finer material is increased substantially or when coarser material is removed. With cube water content, the effects of sand changes on the water needed for the correct flow of mortar to make

61

cubes. Situations that lead to a greater proportion of fine sand particles increase the water demand. The amount of water to be added to the mix is critical knowing that the drier the mix, the stronger their result. Water is usually 1 to 1.5 times the volume of the cement.
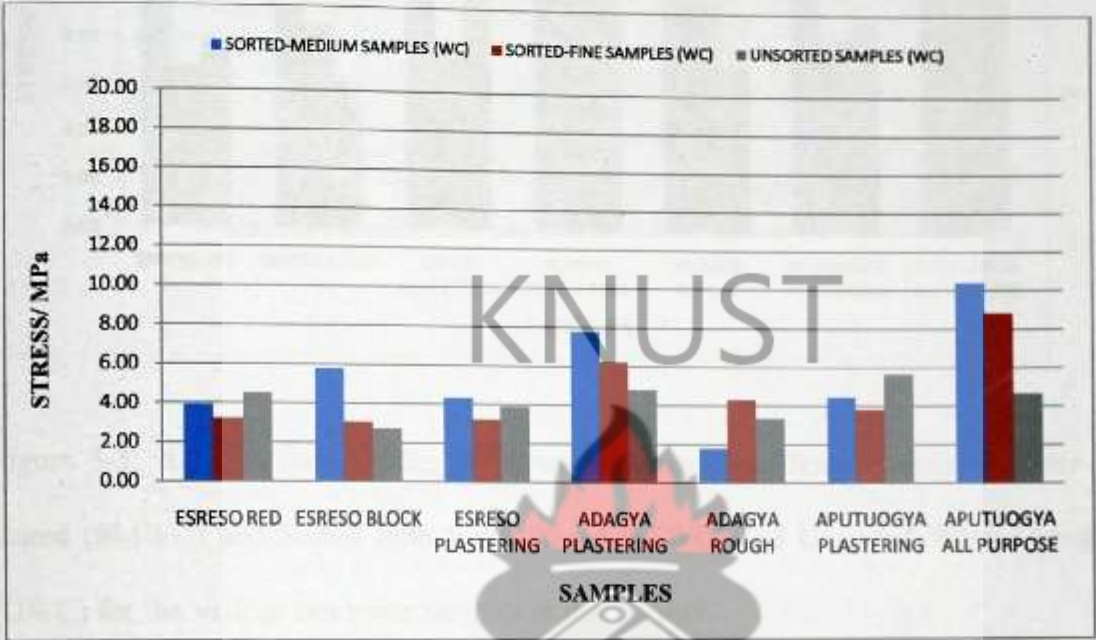


Figure 5-4: A graph showing the cold crushing strength of Sorted Medium Water-Cured (SMWC), Sorted Fine Water-Cured (SFWC) and Unsorted Water-Cured (UWC) for the various sandcrete samples in the 6:1 mix.
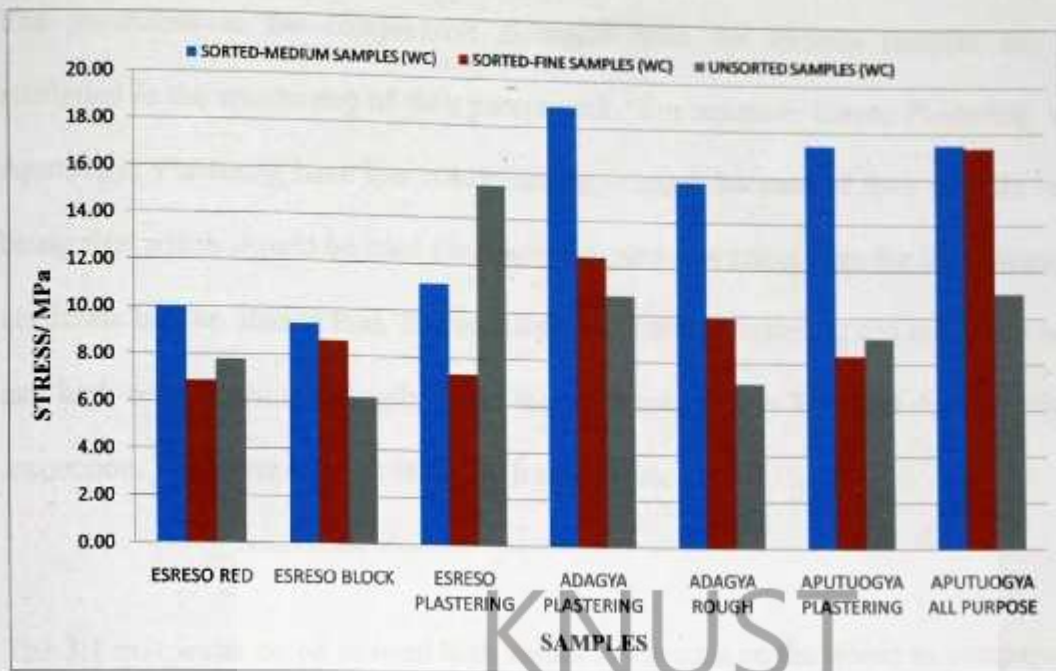
**Figure 5-5:** A graph showing the cold crushing strength of Sorted Medium Water-Cured (SMWC) and Sorted Fine Water-Cured (SFWC) and Unsorted Water-Cured (UWC) for the various sandcrete samples in the 3:1 mix.

### 5.2.2 Water curing analysis

From the graphs (as shown in Fig 5-4 and Fig 5-5), Adagya Plastering and Aputuogya All Purpose proved to have highest compressive strength in the 6:1 mix but this time for water-cured. For the same reason given for air-dried; the samples from the sites were generally rough. The particle sizes were rough when felt between the fingers. The highest compressive strengths for Adagya Plastering and Aputuogya All Purpose can be attributed to the size (big sizes) of the sand particles as brought from the sites. This affirms the fact that larger particle size makes the strongest bricks.

The anomalies in the compressive strengths from the various samples can be attributed to the weathering of their parent rock. For instance, Esreso Plastering and Aputuogya Plastering have low cold crushing strength because of their particle sizes being fine which should be used for plastering purposes rather than for the making of sandcrete blocks. Esreso Red, Esreso Block and Esreso Plastering did not really have any high cold crushing strength due to the presence of clay. This was done by visual inspection. These are all samples taken from Esreso.

The 3:1 mix water cured showed high values in the c.c.s on the whole as compared to the 6:1 mix water cured. This is due to the reason that, the increase in the concentration of cement is accompanied by an increase in the c.c.s It will be noted from the trend of these graphs that in most of the sandcrete an increase in cement content initially increases the compressive strength and this increase will get less rapid at higher concentrations of cement because too much concentrations in cement makes the cube brittle [18].

The development of strength with the same concentration of cement for different sand is different and this is influenced by the grading and the mineral composition in sand.

With the effect of age on the development of strength, the sandcrete samples cured at a constant room temperature showed that sandcrete strengths progressively increases after 28 days curing. Also, sand having no organic matter would normally go on increasing in strength with age [1].

64

## 5.3 AIR DRY AND WATER-CURED COLD CRUSHING STRENGTH ANALYSIS FOR 6:1 SAND- CEMENT MIX

From the graphs, it can be seen that air dried samples had a high cold crushing strength (ccs) than the water-cured samples. This is because less water is needed for cementation to occur. A lot of water weakens the sandcrete and this could be the reason why most sandcrete bricks spall under water. And another reason is that samples are cured in water which is believed to give the weakest of results so naturally from the experiments air dried samples were to give higher results than water cured samples. The behaviour of strength fluctuation is generally attributed to the mineralogical and structural changes which take place during curing.

## 5.4 AIR DRY AND WATER-CURED COLD CRUSHING STRENGTH ANALYSIS FOR 3:1 SAND- CEMENT MIX

From the graphs, it can also be seen here again that air dried samples had a high ccs than water cured samples. The highest ccs for the medium sample for air dried was 20 MPa compared to 18 MPa for medium samples for water – cured though they are of different sand samples. (Refer Fig 5-3 and Fig 5-5)
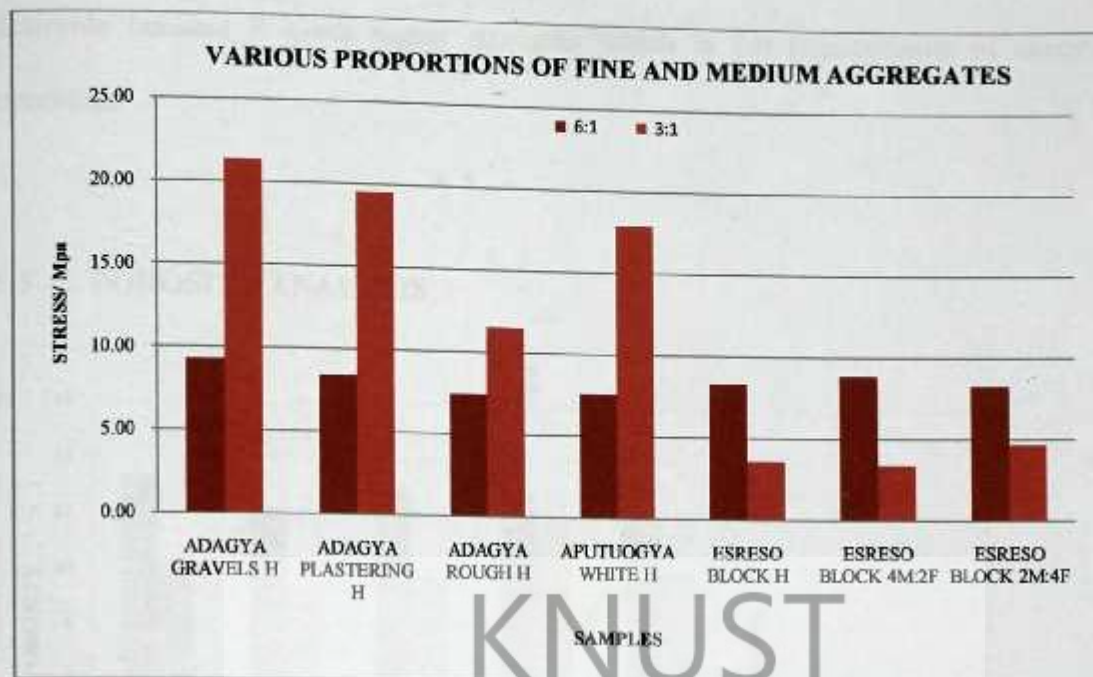
**Figure 5-6:** A graph showing the cold crushing strength of samples in **different** proportions.

Samples having 'H' attached to it are samples of equal proportions that is, equal proportions of medium and fine aggregates. From the graph (Fig 5-6) it can be seen that, when the medium and the fine aggregates were mixed together in equal proportions for the 6:1 mix, their strengths were low compared to the 3:1 mix which were very high. This can be explained with the reason that, there was more cement in the 3:1 mix. It can also be recommended that, when equal amount of fines and medium aggregates are mixed, the concentration of cement should be increased. Surprisingly, when the aggregates were mixed in different ratios for samples from Esreso, the 6:1 mix recorded higher strengths than the 3:1 mix. Fine aggregates fill in the pores in the medium aggregates thereby giving it high strengths. It can be concluded that equal proportions of fine and medium aggregates in 3:1 is much

desirable because it gives higher strengths which is the requirements of many structures.

## 5.5 POROSITY ANALYSIS



Figure 5-7: Graph showing the various sandcrete samples (unsorted) and their porosities for 3:1 and 6:1 mix.

From Fig 5-7, it can be seen that, the 6:1 mix had a higher porosity than the 3:1 mix for the unsorted samples just as it was brought from the site. This is due to the increased hydration of cement paste in the 3:1 mix, caused by increase in cement content. The nature of the C-S-H in cement reaction process leads to efficient pore-filling and consequent enhancement of mechanical performance (low porosity pastes are stronger than high porosity pastes).

67

Still, from the graph (Fig 5-8 and 5-9), it can also be seen that even when the samples are sorted into fine and medium, the 6: 1 mix of the fine samples gave high porosity than the 3:1 mix.

### 5.5.1 Medium samples

The cement paste formed by the hydration reactions always contain interconnected pores of different sizes. Larger pores of dimensions up to a few mm are the result of the air entrapped during mixing and not removed by compaction of fresh concrete. Air bubbles with diameters of about 0.05-0.2 mm may also be introduced in the cement paste intentionally by means of air-entraining admixtures so as to produce resistance. Both capillary pores and entrapped air are relevant to the durability of concrete and its protection of the rebars. Entrapped air can be reduced by providing adequate workability to the fresh concrete and proper compaction.

The decrease in capillary porosity increases the mechanical strength of cement paste and reduces the permeability of the hydrated cement paste. A distinction should be made between capillary pores of larger dimensions and pores of smaller dimensions. The reduction in porosity resulting of both larger and smaller pores plays an essential role in increasing mechanical strength.

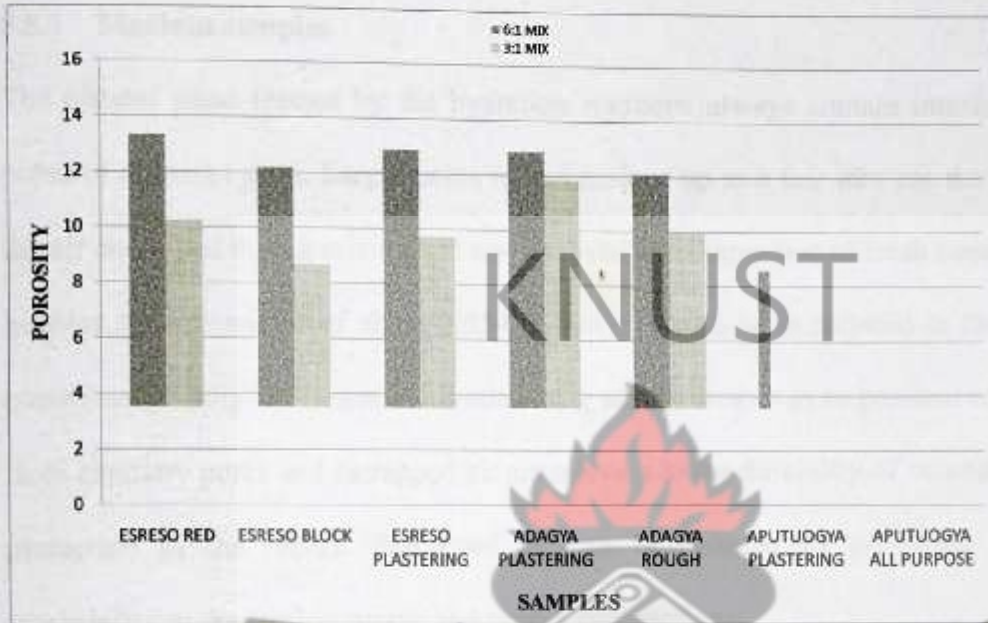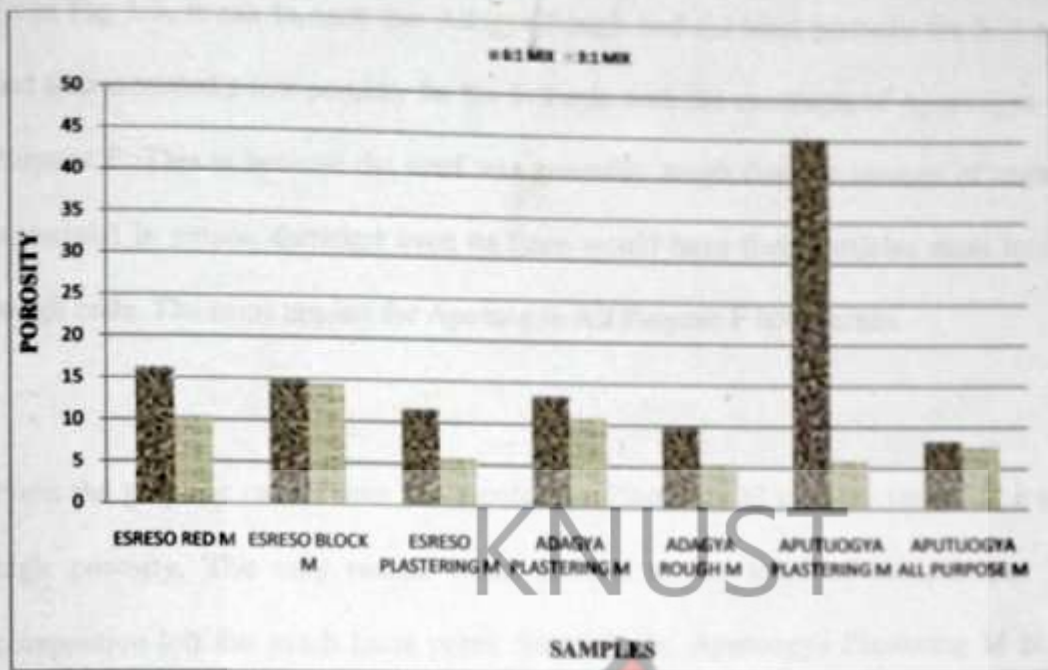**Figure 5-8:** A graph showing the various sand samples (sorted medium) and their porosities for 3:1 and 6:1 mix
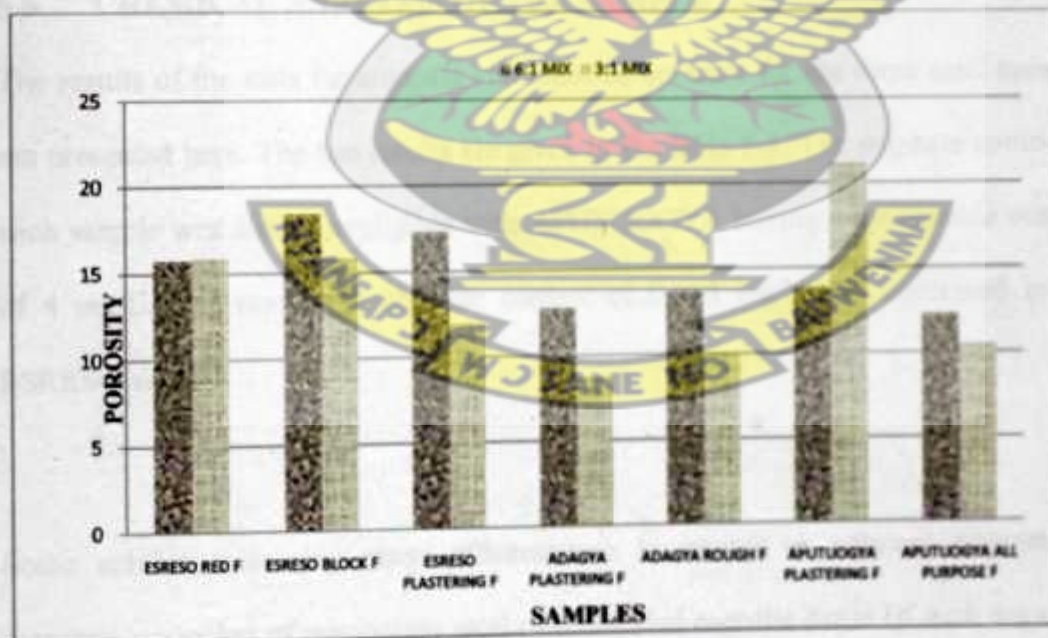


Figure 5-9: A graph showing the various sand samples (sorted fine) and their porosities for 3:1 and 6:1 mix

From Fig 5-9, it can be seen that Adagya Rough had the least porosity for 3: 1 mix and also recorded a low porosity for the 6: 1 mix with the exception of Aputuogya All Purpose F. This is because the sand was generally rough (had an amount of organic materials) in nature, therefore even its fines would have their particles sizes having rough ends. The same applies for Aputuogya All Purpose F both mixes.

From the graph, it can be seen that Aputuogya Plastering M in the 6:1mix had a very high porosity. The only reason could be due to the level of compaction. The compaction left too much loose pores. Surprisingly, Aputuogya Plastering M in the 3:1 mix has a low porosity of 5.847145 compared to that of Aputuogya Plastering M in the 6:1 mix which recorded a porosity of 45.2767.

## 5.6 CHEMICAL ANALYSIS OF THE SAMPLE

The results of the tests for sulphate and chloride contents for the three sand samples are presented here. The test results are given in the table 5-1. The sulphate content in each sample was almost negligible with APUTUOGYA having a measurable content of 4 mg/L. The maximum chloride content of 0.065 mg/L was contained in the ESRESO sample.

Some soluble salts may cause efflorescence in mortar or adjacent concrete or masonry, corrosion of reinforcing steel or embedded metallic items (if such are used) or disintegration of the mass of the mortar. Permissible levels of soluble salts are

70

generally expressed as the proportion of the relevant ion present in the mortar by mass of mortar or by mass of Portland cement. Sulphate can result in the loss of strength of bricks and concrete, or cracking of concrete. Cement type and mix proportions are keys to the resistance of mortar and concrete against chemical attack.

The chloride ion content of sand determined quantitatively in accordance with AS 1012.20 should be reported if in excess of 0.01 %. A combination of sands where the total chloride salt content (expressed as Cl⁻) exceeds 0.04 % should not be used in reinforced mortar or mortar in contact with embedded metallic fittings. A combination of sands where the total chloride salt content exceeds 0.15 % should not be used in plain mortar.

The sulphate ion content of sand determined quantitatively in accordance with AS 1012.20 should be reported if in excess of 0.01 %. Sand should not be used which, when tested in accordance with AS 1012.20, contain sulphates (expressed as $SO_3$) in proportions which result in the sulphate content of the mortar exceeding 5.0% by mass of Portland cement.

From previous tests done at Brri, CSIR in Kumasi, it was found out that wherever sulphates were predominant, chloride was also predominant. High amount of sulphates and chlorides were high in areas which were densely populated and in the mining areas.

From the tests conducted it can also be concluded that, since the chloride and the sulphate content in the sands were not even up to one- third the amount required by ASTM, it could not have affected the strengths of the sandcrete blocks in any significant way.

**Table 5-1: A table of the various sand (unwashed) and their chemical contents**

| UNWASHED SAND | | | | |
|---|---|---|---|---|
| TEST | ADAGYA | APUTUOGYA | ESRESO | ASTM REQUIREMENT |
| TOTAL CHLORIDE,mg/L | 0.03 | 0.032 | 0.065 | ≤500 mg/L |
| TOTAL SULPHATE ,mg/L | 3.5 | 4 | 0.5 | ≤500 mg/L |
| ORGANIC MATTER % | 5.5 | 5 | 4 | ≤10 % |

**Table 5-2: A table of Adagya sand (washed) and their chemical contents**

| WASHED SAND | | |
|---|---|---|
| TEST | ADAGYA | ASTM REQUIREMENT |
| TOTAL CHLORIDE,mg/L | 0.015 | ≤500 mg/L |
| TOTAL SULPHATE ,mg/L | 0.02 | ≤500 mg/L |
| ORGANIC MATTER % | 2.5 | ≤10 % |

### 5.6.1 Organic matter

Traces of organic matter were detected in all the various sand samples. Since not all organic matter may is harmful, it is usual to check its effect by making actual test cubes and comparing the strength with mortar cubes of the same mix proportions but known quality. In this analysis no standard cubes were made but strength of cubes using the tested sand are compared with strengths usually specified for concrete works in civil engineering contracts. The type of impurity can also affect the cement performance and limits have been established for clay and organic material content of 1.2% and 0.2% respectively. The limits for organic content are permitted to be relaxed to 0.50% where 'adequate' tests and practical experience have shown it to be suitable for use in cement.

### 5.6.2 Results of test of washed Adagya sand

The results of the tests for sulphate and chloride contents for the washed sand was very negligible compared to that of the unwashed ADAGYA sand. The organic matter detected was also very negligible. It can also be concluded that when the sand is washed before used, it eliminates so many undesirable matter from the sand. This can be seen from the results of the washed Adagya sand.

### CONCLUSIONS

From the findings in this project it can be concluded adequately that sand used in sandcrete and other products should be free from chemicals like chloride and sulphate. And also, the constituents in the mixture should be used in the right

73

proportions to attain the maximum strength required for the purpose for which it will be used. It can also be concluded that when the sandcrete blocks are made, there should be maximum packing of the grains to eliminate voids which reduces strength. It is recommended that sand won in the Atwima Kwawoma Distict in the Ashanti can be used for sandcrete only if the coarse aggregates outweigh the fine aggregates and also sand to cement ratio used for the purpose of sandcrete should be 3:1.

# REFERENCES

1. E. Atiemo, The Effect of temperature on accelerated curing of cement products and prediction of their 28-day compressive strength, 1999, BRRI, Pg 1-2.

2. " http://www.1911encyclopaedia.org/sand"

3. " http://en.wikipedia.org/wiki/sand"

4. Classic Encyclopedia, 11th Edition of the Encyclopaedia Britannica (Published 1911).

5. J. Atkinson, City University, London and L. Davison, University of the West of England, Bristol. Soil description and classification. Based on part of the Geotechnical reference package, 2000, Pg 5-6

6. http://www.cement.org/basics/concretebasics_faqa.asp

7. F.M. Lea, The chemistry of Cement and Concrete. Third Edition Formerly Director of Building Research. Edward Arnold (Publishers) ltd, 1970, Pg 170-177.

8. Ghana Statistical Service, 2002, Pg 62.

9. T.A. Grow, Construction, A Guide for the Professionals, McGraw-Hill, 1938.

10. A.M. Neville, Properties of Concrete, Pearson Education Asia, 2000

11. A.M. Neville, Properties of Aggregates, Pitman Books Limited, 1981

12. A.M. Neville, M. Chatterton, Concrete Technologies and Building Design, Longman Inc., 1979.

13. A.W. Hendry, B.P Sinha, S.R Davies, Load Bearing Brickwork Design, Ellis Horwood, 1987.

14. M. Abdullahi, Civil Engineering Department, Federal University of Technology, Minna, Niger State, Nigeria. Properties of Some Natural Fine Aggregates in Minna, Nigeria and Environs. Pg 1-5.

15. K. A. Andam. "Bricks, Blocks and the Future Administrative Capital of Ghana". A paper presented at the British Council Hall, Accra, 2004, Pg 2-6.

16. K. Sandlin, Civil Engineering Department, Laud University, Sweden Mortars for Masonry and Rendering, Choice and Application. 1974, Vol 7 Number 3 Pg7-8.

17. B.K Baiden and M.M. Tuuli, Impact of Quality Control Practices in Sandcrete Blocks Production, Masters Thesis, Dept. Of Building Technology, Kwame Nkrumah University of Science and Technology.. Kumasi, Ghana. 2004, Pg 1

18. H.S. Bhatia. A material of construction for Road and Airfield Pavements. Kumasi- Ghana, 1998.

19. http://www.crystal-netbook.info/index_eng.html

20. www.lmcc.com/news/spring2004/spring2004-02.asp

21. C. Busck, Principal of Busck Consult P/L, SAND FOR MORTAR. Prepared for NATSPEC//Construction Information. Pg 2-7.

22. Research report ICAR 102-F. Austin, Texas: International Center for Aggregates Research, University of Texas, An experimental study on the guidelines for using higher contents of aggregate microfines in Portland Cement Concrete, 2001.

23. H.Haynes, R.O'Neil and P.K Mehta, Concrete deterioration from physical attack by salts, *Concrete International*, **18**(1), 1996, Pg 63–68.

24. H.T Cao, L. Bucea, and O. Ferguson, Sulfate resistance of cementitious materials - mechanisms of attack, deterioration processes, testing and materials selection, Proc. Concrete Institute of Australia - Concrete 97 Conference, Adelaide, Australia, 1997, Pg 263-268 and 14-16.

25. V. Sirivivatnanon, and H.T Cao, An Engineered Model for Service Life of Marine Concrete Structures, Proceedings of the Durability of Building Materials and Components 8 – Service Life and Asset Management, Vol. 1, Vancouver, Canada, 1999, Pg 94-104,

26. P.K Mehta, Mechanism of sulfate attack on portland cement concrete – another look, *Cement & Concrete Research*, **13**(3), 1983, Pg 401–406.

27. F.P Glasser, Reactions between cement paste components and sulfate ions, Proc. Seminar on Sulfate Attack Mechanisms, Quebec, Canada, 1998, pg. 99–122.

28. V. Sirivivatnanon, and R.P Khatri, Performance Based Specification for Sulphate Resisting Concrete, Proceedings of International Conference on a Vision for the Next Millennium, Sheffield, 1999, U.K, Pg 1097-1106.

29. R.P Khatri, V. Sirivivatnanon and J.L Yang, "Role of permeability in Sulphate Attack", Cement and Concrete Research, 27 (8), 1997, Pg 1179-1189.

30. O.S.B Al–Amoudi, M. Maslehuddin, and Y.A.B Abdul–Al, Role of chloride ions on expansion and strength reduction in plain and blended cements in

sulfate environments, *Construction & Building Materials*, **9**(1), 1995, Pg 25–33.

31. O.S.B Al–Amoudi, Attack on plain and blended cements exposed to aggressive sulfate environments, *Cement & Concrete Composites*, **24**, 2002, Pg 305–316.

32. D.E. Gooding and T.H. Thomas. The potential of cement-stabilized building blocks as an urban building material in developing countries. DTU working paper, No.44, 1995, Pg 6-7.

33. D.E.M. Gooding, Soil Testing for soil-cement blocks production- working paper No.38 Coventry, Development Technology Unit, University of Warwick 1992.

34. O.G. Ingles and J.B. Metcaf, Soil Stabilization Principles and Practice. London, Butterworths 1972, Pg 4-5.

35. ApproTec: A sub sectoral Analysis of Walling and Roofing Materials in Nairobi and the Environs. (ApproTEC, p.o.box 10973, Nairobi, 1993, Pg 9-11.

36. J. Sutcliff, Quality Assurance of stabilized soil-cement blocks. Third year undergraduate engineering project conducted at the University of Warwick, 1994, Pg 34-38.

37. J. Petersen, Experiments with Sample Testing Procedures for stabilised soil blocks. (Rural Industries Innovation Centre, Kanye, Botswana, 1991)

38. R. A. Flinn, P. K. Trojan, Engineering materials and their application, Pub. Houghton Mifflin Company, Boston, 1981, Pg. 465-476.

39. M. F. Ashby, Engineering materials 2, Pub. Butterworth-Heinemann, London, 1998, Pg. 266- 274.

40. R. L. Mott, Applied strength of materials. Third edition, Pub. Prentice-Hall, New Jersey, 1996. Pg. 67-70.

41. C. Bimel's article, fall 2001 edition of L&M concrete news, Pg 1-2.

# APPENDICES

## APPENDIX A

**BS 1377**

### 9 Determination of particle size distribution

#### 9.1 General

Two methods of sieving are specified. Wet sieving is the definitive method applicable to essentially cohesionless soils. Dry sieving is suitable only for soils containing insignificant quantities of silt and clay. Two methods of determining the size distribution of fine particles down to the clay size by sedimentation are specified, namely the pipette method and the hydrometer method, in both of which the density of the soil suspension at various intervals is measured. Combined sieving and sedimentation procedures enable a continuous particle size distribution curve of a soil to be plotted from the size of the coarsest particles down to the clay size.

#### 9.2 Wet sieving method

**9.2.1** *General.* This method covers the quantitative determination of the particle size distribution in an essentially cohesionless soil, down to the fine sand size. The combined silt and clay fraction can be obtained by difference. The procedure given involves preparation of the sample by wet sieving to remove silt and clay-sized particles, which are rejected, followed by dry sieving of the remaining coarser material. If the soil does not contain particles retained on a 2 mm test sieve in significant quantity, the method specified in **9.4** or **9.5** can be used. The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

80

## 9.3 Dry sieving method

**9.3.1 *General.*** This method covers the quantitative determination of the particle size distribution in a cohesionless soil down to the fine-sand size. This method shall not be used unless it has been shown that for the type of material under test it gives the same results as the method of analysis by wet sieving. In cases of doubt the method shall not be used. The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

## 9.4 Sedimentation by the pipette method

**9.4.1 *General.*** This method covers the quantitative determination of the particle size distribution in a soil from the coarse sand size to the clay size (about 2 μm). (See note.) The procedure enables the percentages of coarse, medium and fine silt, and clay, to be determined. These percentages can be linked to the curve obtained by sieving to provide a single curve for the whole material. The analysis of data requires that the particle density of the soil specimen is known or can be assumed. The test as specified is not usually necessary if less than 10 % of the material passes the 63 μm test sieve as specified in **9.2**.

NOTE If the sample has been wet sieved down to the 63 μm test sieve size then only the material passing the 63 μm test sieve need be used to carry out this test, thus eliminating the necessity of repeating the determinations of the same fractions. The requirements of Part 1 of this standard, where appropriate, shall apply to this test method.

# APPENDIX B

## BS 882

## 5 Grading

### 5.1 Coarse aggregate

When determined in accordance with BS 812-103.1 using test sieves of the sizes given in Table 3, complying with BS 410, full tolerance, the grading of the coarse aggregate shall be within the appropriate limits given in Table 3.

### 5.2 Sand

### 5.2.1 General

When determined in accordance with BS 812-103.1, using test sieves of the sizes given in Table 4 complying with BS 10, full tolerance, the grading of the sand shall comply with the overall limits given in Table 4. Additionally, not more than one in ten consecutive samples shall have a grading outside the limits for any one of the gradings C, M or F, given in Table 4.

### 5.2.2 Heavy duty concrete floor finishes

For heavy duty concrete floor finishes, the sand shall comply with C or M given in Table 4.

Table 4 — Sand

| Sieve size | Percentage by mass passing BS sieve | | | |
|---|---|---|---|---|
| | Overall limits | Additional limits for grading | | |
| | | C | M | F |
| 10.00 mm | 100 | — | — | — |
| 5.00 mm | 89 to 100 | — | — | — |
| 2.36 mm | 60 to 100 | 60 to 100 | 65 to 100 | 80 to 100 |
| 1.18 mm | 30 to 100 | 30 to 90 | 45 to 100 | 70 to 100 |
| 600 μm | 15 to 100 | 15 to 54 | 25 to 80 | 55 to 100 |
| 300 μm | 5 to 70 | 5 to 40 | 5 to 48 | 5 to 70 |
| 150 μm | 0 to 15[a] | — | — | — |

NOTE   Individual sands may comply with the requirements of more than one grading. Alternatively some sands may satisfy the overall limits but may not fall within any one of the additional limits C, M or F. In this case and where sands do not comply with Table 4 an agreed grading envelope may also be used provided that the supplier can satisfy the purchaser that such materials can produce concrete of the required quality.

[a] Increased to 20 % for crushed rock fines, except when they are used for heavy duty floors.

## 5.3 All-in aggregate

When determined in accordance with BS 812-103.1 using test sieves of the sizes given in Table 5 complying with BS 410, full tolerance, the grading of all-in aggregate for concrete shall be within the appropriate limits given in Table 5.

## Table 5 — All-in aggregate

| Sieve size | Percentage by mass passing BS sieves for nominal sizes | | | |
|---|---|---|---|---|
| | 40 mm | 20 mm | 10 mm | 5 mm[a] |
| 50.0 mm | 100 | — | — | — |
| 37.5 mm | 95 to 100 | 100 | — | — |
| 20.0 mm | 45 to 80 | 95 to 100 | — | — |
| 14.0 mm | — | — | 100 | — |
| 10.0 mm | — | — | 95 to 100 | 100 |
| 5.00 mm | 25 to 50 | 35 to 55 | 30 to 65 | 70 to 100 |
| 2.36 mm | — | — | 20 to 50 | 25 to 100 |
| 1.18 mm | — | — | 15 to 40 | 15 to 45 |
| 600 μm | 8 to 30 | 10 to 35 | 10 to 30 | 5 to 25 |
| 300 μm | — | — | 5 to 15 | 3 to 20 |
| 150 μm | 0 to 8[b] | 0 to 8[b] | 0 to 8[b] | 0 to 15 |

[a] Used mainly in precast concrete products.
[b] Increased to 10 % for crushed rock sand.

## 5.4 Fines

When determined in accordance with **7.2.1** of **BS** 812-103.1:1985, the **amount of** material passing the 75 _m sieve shall **not exceed the** quantities given in Table 6.

## Table 6 — Fines

| Aggregate type | Percentage by mass passing 75 μm sieve (max.) |
|---|---|
| Uncrushed, partially crushed, or crushed gravel coarse aggregate | 2 |
| Crushed rock aggregate | 4 |
| Uncrushed, partially crushed or crushed gravel sand | 4 |
| Crushed rock sand | 16 (9 for use in heavy duty floor finishes) |
| Gravel all-in aggregate | 3 |
| Crushed rock all-in aggregate | 11 |

NOTE   The nature of the fines can vary between different aggregates. The limits given above are appropriate for most aggregates found in the UK. Evidence of performance in use or the result of trial mixes may be used to justify the adoption of higher or lower limits.

# APPENDIX C

## COLD CRUSHING STRENGTH (CCS) VALUES FOR AIR DRIED SAMPLES FOR 6:1 AND 3:1 MIXES

| SORTED MEDIUM AIR - DRIED | STRESS (MPa) FOR 6:1 | STRESS (MPa) FOR 3:1 |
|---|---|---|
| ESRESO RED | 5.74 | 14.64 |
| ESRESO BLOCK | 8.98 | 12.80 |
| ESRESO PLASTERING | 12.04 | 20.09 |
| ADAGYA PLASTERING | 4.45 | 18.94 |
| ADAGYA ROUGH | 3.00 | 16.51 |
| APUTUOGYA PLASTERING | 2.76 | 13.64 |
| APUTUOGYA ALL PURPOSE | 11.66 | 18.73 |

| SORTED FINE AIR - DRIED | STRESS (MPa) FOR 6:1 | STRESS (MPa) FOR 3:1 |
|---|---|---|
| ESRESO RED | 4.55 | 6.13 |
| ESRESO BLOCK | 5.43 | 8.61 |
| ESRESO PLASTERING | 3.26 | 8.48 |
| ADAGYA PLASTERING | 6.07 | 15.34 |
| ADAGYA ROUGH | 4.24 | 10.87 |
| APUTUOGYA PLASTERING | 3.60 | 11.24 |
| APUTUOGYA ALL PURPOSE | 9.45 | 17.22 |

| UNSORTED AIR -DRIED | STRESS (MPa) FOR 6:1 | STRESS (MPa) FOR 3:1 |
|---|---|---|
| ESRESO RED | 6.62 | 12.88 |
| ESRESO BLOCK | 4.97 | 11.84 |
| ESRESO PLASTERING | 5.06 | 13.61 |
| ADAGYA PLASTERING | 7.37 | 13.96 |
| ADAGYA ROUGH | 5.54 | 11.34 |
| APUTUOGYA PLASTERING | 5.85 | 13.05 |
| APUTUOGYA ALL PURPOSE | 6.58 | 9.41 |

## APPENDIX D

COLD CRUSHING STRENGTH (CCS) VALUES FOR WATER CURING SAMPLES FOR 6:1 AND 3:1 MIX

| SORTED-MEDIUM AIR-DRIED | STRESS (MPa) FOR 6:1 | STRESS (MPa) FOR 3:1 |
|---|---|---|
| ESRESO RED | 3.91 | 10.00 |
| ESRESO BLOCK | 5.78 | 9.32 |
| ESRESO PLASTERING | 4.32 | 11.15 |
| ADAGYA PLASTERING | 7.80 | 18.90 |
| ADAGYA ROUGH | 1.77 | 15.74 |
| APUTUOGYA PLASTERING | 4.44 | 17.41 |
| APUTUOGYA ALL PURPOSE | 10.41 | 17.48 |

| SORTED-FINE AIR-DRIED | STRESS (MPa) FOR 6:1 | STRESS (MPa) FOR 3:1 |
|---|---|---|
| ESRESO RED | 3.21 | 6.88 |
| ESRESO BLOCK | 3.04 | 8.61 |
| ESRESO PLASTERING | 3.21 | 7.31 |
| ADAGYA PLASTERING | 6.21 | 12.43 |
| ADAGYA ROUGH | 4.29 | 9.91 |
| APUTUOGYA PLASTERING | 3.81 | 8.33 |
| APUTUOGYA ALL PURPOSE | 8.82 | 17.35 |

| UNSORTED AIR-DRIED | STRESS (MPa) FOR 6:1 | STRESS (MPa) FOR 3:1 |
|---|---|---|
| ESRESO RED | 4.53 | 7.79 |
| ESRESO BLOCK | 2.74 | 6.22 |
| ESRESO PLASTERING | 3.89 | 15.43 |
| ADAGYA PLASTERING | 4.80 | 10.80 |
| ADAGYA ROUGH | 3.33 | 7.08 |
| APUTUOGYA PLASTERING | 5.65 | 9.08 |
| APUTUOGYA ALL PURPOSE | 4.67 | 11.05 |

## APPENDIX E

### COLD CRUSHING STRENGTHS (CCS) OF EQUAL PROPORTIONS OF FINE AND MEDIUM AGGREGATES OF SAMPLES

| SAMPLES | STRESS (Mpa) FOR 6:1 | STRESS (Mpa) FOR 3:1 |
| --- | --- | --- |
| ADAGYA GRAVELS H | 9.27 | 21.35 |
| ADAGYA PLASTERING H | 8.36 | 19.56 |
| ADAGYA ROUGH H | 7.42 | 11.53 |
| APUTUOGYA WHITE H | 7.56 | 17.88 |
| ESRESO BLOCK H | 8.31 | 3.60 |
| ESRESO BLOCK 4M:2F | 8.85 | 3.35 |
| ESRESO BLOCK 2M:4F | 8.24 | 4.68 |

## APPENDIX F

### VALUES OF POROSITY FOR UNSORTED SAMPLES FOR 6:1 AND 3:1 MIX

| SAMPLES | 6:1 MIX | 3:1 MIX |
|---|---|---|
| ESRESO RED | 13.33946642 | 10.22522523 |
| ESRESO BLOCK | 12.1751026 | 8.676005423 |
| ESRESO PLASTERING | 12.88848263 | 9.704830054 |
| ADAGYA PLASTERING | 12.87534122 | 11.84636742 |
| ADAGYA ROUGH | 12.07444394 | 10.0228833 |
| APUTUOGYA PLASTERING | 8.598726115 | 7.998192499 |
| APUTUOGYA ALL PURPOSE | 8.854404382 | 9.062218215 |

88

APPENDIX G

VALUES FOR POROSITY FOR SORTED MEDIUM SAMPLES FOR 6:1 AND 3:1

MIX

| SAMPLES | 6:1 MIX | 3:1 MIX |
|---|---|---|
| ESRESO RED M | 16.22727273 | 10.40178571 |
| ESRESO BLOCK M | 14.85765125 | 14.47016919 |
| ESRESO PLASTERING M | 11.64383562 | 5.701754386 |
| ADAGYA PLASTERING M | 13.43216532 | 10.83408885 |
| ADAGYA ROUGH M | 9.833795014 | 5.366726297 |
| APUTUOGYA PLASTERING M | 45.27639661 | 5.847145488 |
| APUTUOGYA ALL PURPOSE M | 8.329560887 | 7.637338097 |

## VALUES OF POROSITY FOR SORTED FINE SAMPLES FOR 6:1 AND 3:1 MIX

| SAMPLES | 6:1 MIX | 3:1 MIX |
|---|---|---|
| ESRESO RED F | 15.76837 | 15.87085 |
| ESRESO BLOCK F | 18.42105 | 15.86207 |
| ESRESO PLASTERING F | 17.30856 | 11.94232 |
| ADAGYA ROUGH F | 12.79279 | 8.699552 |
| ADAGYA ROUGH F | 13.69801 | 9.968708 |
| APUTUOGYA PLASTERING F | 13.86482 | 21.15541 |
| APUTUOGYA ALL PURPOSE F | 12.25033 | 10.43711 |