ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

STUDY OF PLASTIC SOIL CEMENT FOR FLOORING APPLICATION

A thesis submitted to the School of Graduate Studies of the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
(Construction Technology and Management)

By; Selam Yazew
Advisor: Professor Dr.-Ing Abebe Dinku

August 2015

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DECLARATION

I hereby declare that this research has been carried out under the supervision of Prof. Abebe Dinku, School of Civil and Environmental Engineering, Addis Ababa University as part of Maters of Science program in Construction Technology and Management. In Addition I declare that this research is my original work, the findings presented are not found in any other previous work.

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August 2015

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ABSTRACT

Earth as a building material is available everywhere. In developing countries, earth construction is economically the most efficient means to house the greatest number of people with the least demand of resources. This research is intended to provide detailed technical information on the production of soil stabilized with cement as a flooring material. These include information on suitable soil type, percentage of cement to soil or other ingredients and investigation on its mechanical properties.

Review of related literatures show that soil types and proportions between soil and cement will affect the strength and other properties of the material. The mix proportion is directly related to the type of soil used which will also be a critical point for the thesis.

Using Ordinary Portland Cement manufactured in Ethiopia, soil brought from Kara, North of Addis Ababa city, natural and manufactured sand two mix series were prepared containing the above ingredients. The properties of these mixes have then been assessed in the laboratory on the hardened soil cement mix.

The results of the hardened soil cement paste have shown that with an increase in soil to sand ratio, there is a gradual decrease in compressive strength .Similarly, the increase in amount of cement results in increase in compressive strength and in water absorption. It was found that by using 20% cement content and 50% soil from the total volume the soil product was shown to have a compressive strength of 16 MPa.This shows that by adding soil with half volume a reasonably quality flooring material can be produced.

Key words: Compressive Strength, Soil Cement, Soil stabilization, Water Absorption.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ANNEXES

ABBREVIATION

USBR	United States Bureau of Reclamation
OPC	Ordinary Portland Cement
SSA	Specific surface area
PSD	Particle size distribution
µm	Micro meter
gm	gram
Kg	Kilo gram
KN	Kilo Newton
MPa	Mega Pascal

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND OF THE RESEARCH

Historically, it is well known that earth has been the most widely known and used building material in construction. According to some studies recorded cases of the use of earth bricks dates back to Mesopotamia "around 8000 BC". Recent reports indicated that, about half of the world's populations are still living in earth buildings [1].

Where there is a demand for improving traditional building material made of raw earth which will decrease the cost and also has a direct impact on the environment the introduction of soil cement will come into picture which is mostly concerned with establishing a new relationship to the built-environment and the Earth.

The traditional building material using earth is common in developing countries. Unstabilized soil construction is a widespread construction material in rural areas but is generally seen as undesirable being the bottom rung of the materials ladder. This view is pronounced in South Africa, Kenya and Zimbabwe. Unstabilized soil is not classified as a permanent material under current building regulations which prevents its legal use in urban districts, leaving the home occupier vulnerable to dispossession and the dwelling vulnerable to demolition. None of the above listed countries define urban unstabilized soil construction as permanent. Finance organizations are highly unlikely to lend money for the construction of any property built from material not classified as permanent [2].

Since unstabilized soil has a strength and durability problem stabilization comes into picture. There are various methods that can be used to stabilize soil but the most common technique is by using cement. Ever since 1915 cement stabilized soil has been used in the construction industry for different purpose. It is commonly used for highways to provide uniform strong support for the pavement. It is also used for riprap and low-permeability lining material and in building construction technology, it has commonly been used as a wall making material.

In this research the possibility of using soil cement as a flooring material will be investigated in detail.

1.2 AIMS AND OBJECTIVES

The objectives of this thesis are;

- To produce material using plastic soil cement and experimentally study the effect of altering composition of important constituents like: soil, cement and fine aggregate on the mechanical property.
- To check suitability of the material for flooring with respect to economy and strength.

1.3 METHODOLOGY

The following methodology has been employed to achieve the objectives of the research:

1. Literature survey: The study started off with setting an outline of the research by assessing information from secondary resource regarding soil cement stabilization, its application, constituent materials, mechanism of soil cement stabilization and the factors that affect it were reviewed from books, research papers, journals, etc.

2. Sample preparation: At this stage of the research the constituent materials were arranged and samples were prepared by varying the percentage of constituent materials.

3. Test: Different tests were done on the sample of constituent material and also on the final product of the mixing process. For the specific soil that is going to be used on the research different physical property tests were done in the laboratory. The chemical composition study was also carried out in Ethiopian geological survey laboratory. For other constituent materials the necessary test were done inside AAiT laboratory. The final product i.e the hardened soil cement compressive strength for 7 or 14 days and 28 days were carried out including the water absorption property. Water absorption of the hardened material was also measured as the last stage of the research.

4. Analysis and discussion: from the test results analysis of the findings were presented in graphical form and interpretation and discussion were made on the research findings.

5. And finally formulation of conclusions and recommendations based on the results obtained were forwarded.

1.4 STRUCTURE OF THE THESIS

The body of this thesis consists of five chapters. The organization of the chapters is as follows:

CHAPTER ONE provides an introduction to the whole thesis. It discusses the background to the research and the context in which it is based. This Chapter also summarizes the main aims and objectives of the research and explains the different methodologies that had to be used for the research. Chapter 1 ends by providing guidelines on the organization and structure of the thesis as a whole including the ordering of the main parts and chapters. These are now described each in turn.

CHAPTER TWO introduces the fundamental theoretical concepts of soil stabilization and its principle. This Chapter identifies the main constituent materials in soil cement flooring product and discuss in detail about their property. It further gives introduction regarding mechanism of soil cement stabilization and factors that affect it.

CHAPTER THREE describes the main experimental design and sample preparation methods used for laboratory tests. It explains the mix proportions and the type of material used in the research.

CHAPTER FOUR this chapter presents the results of all the experiments that were carried out and the necessary data to support the conclusions of the experiments. This chapter also shows relationship between properties of the hardened soil cement mass with varying ingredients.

CHAPTER FIVE this section of the thesis discusses about the cost comparison of plastic soil cement flooring material with concrete flooring.

CHAPTER SIX the final chapter of the thesis integrates and summarizes the study. It provides conclusions, recommendations and highlights the implications of the research findings

CHAPTER TWO
LITERATURE REVIEW

2.1 SOIL CEMENT STABILIZATION

2.1.1 Soil Cement: Definition

Soil is one of the oldest building materials. It has been used for centuries in all parts of the world. Ancient temples, fortifications, and pyramids as well as part of the Great Wall of China were built with soil. Natural, compacted soil has good insulating and resistant qualities. It is, however, vulnerable to moisture and the erosive effects of weather [3]. Soil is composed of microscopic or macroscopic discrete particles, which are not strongly bonded together as crystals. Additives such as asphalts, cements, and other compounds, including salts, syrups, oils, and powders, stabilize soil in varying degrees.

Soil cement is a construction material, a mix of natural soil with small amount of Portland cement and water. It is a hard, semi-rigid durable material which is formed by hydration of the cement particles. As the cement reacts, or hydrates, the mixture gains strength and improves the engineering properties of the raw soil .Soil cement can be further defined as a material produced by blending, compacting, and curing a mixture of soil/aggregate, Portland cement, possibly admixtures and water to form a hardened material with specific engineering properties.

2.1.2 History

Probably one of the first homes man lived in after he came out of cave was made of earth. Primitive man did little more than stick mud on poles woven closely together. But even with this he found shelter that was better than anything else he had. He also had the advantage of being able to move around, he could live wherever he wanted to [3].

Soil has been the basic construction material for house for centuries. Walls constructed out of soil, if well compacted, have adequate compressive strength under dry conditions. However they will lose strength under adverse moisture movements. Alternative wetting and drying will erode and deteriorate walls.

Gradually, Primitive man learned that some kinds of mud made better houses than others. And some of the best ones lasted his whole lifetime. Today, with the advances made in the science of soil mechanics, what soils will do under many different conditions can be predicted and controlled. Soil stabilization has also a great impact in advancement of using cement as a construction material.

Different literatures specify different times as to when Soil-cement was first used, according to Portland cement association it was first used in 1915 to improve the road bed for State Highway near Johnsonville, South Carolina. Since that time, Portland cement has been used to stabilize soils and aggregates for pavement applications on thousands of miles of roadway all over the world [4].Since then it has been used in different places in the construction industry.

Many workers in the field of low cost housing have raised using soil cement as a building material. Infact several housing schemes have been completed employing this material for walls, foundations or floor in various parts of the world [5].

2.1.3 Application of Stabilized Soil

Portland cement association has described that engineers and contractors have been using soil cement to pave roads, streets airports and parking areas and its performance has been outstanding. The Portland cement association also stated that soil cement is low- cost and the ease of construction by utilizing a local or in place soil make such application economical, practical and environmentally friendly.

A different type of soil cement mixes have been used in the construction industry for various purposes having different properties.

The common application of soil cement mixes are;

a) Pavements: Since 1915, when a street in Sarasota, Florida was constructed using a mixture of shells, sand, and Portland cement mixed with a plow, soil cement has become one of the most widely used forms of soil stabilization for highways. It is used mainly as a base for road, street, and airport paving. Under concrete pavements, soil cement is used as a base to prevent pumping of fine-grained sub grade soils under wet conditions and heavy truck traffic [6].

Furthermore, a soil-cement base provides a uniform, strong support for the pavement, which will not consolidate under traffic and will provide increased load transfer at pavement joints. It also serves as a firm, stable working platform for construction equipment during concrete placement.

b) Slope protection: The U.S. Bureau of Reclamation (USBR) initiated a major research effort to study the suitability of soil cement as an alternative to conventional riprap. Based on laboratory studies that indicated, soil cement made with sandy soils could produce a durable erosion-resistant facing [6].

The USBR constructed a full-scale test section in 1951.A test-section located along the southeast shore of Bonny Reservoir in eastern Colorado was selected to check the suitability of soil cement for soil stabilization. The reason for selection of this reservoir was that it contains severe natural service conditions created by waves, ice, and more than 100 freeze-thaw cycles per year. After 10 years of observing the test section, the USBR was convinced of its suitability and specified soil cement in 1961 as an alternative to riprap for slope protection on Merritt Dam, Nebraska, and later at Cheney Dam, Kansas. Soil cement was bid at less than 50 percent of the cost of riprap for the projects [6].

c) Structural fills: Reports by ACI journal shows that depending upon the strength requirements, a soil cement mix can be used for foundation support. Compressive strengths can vary from 0.7 MPa to 8.3 MPa depending upon application. In the case of weak soils, it can distribute the structure's load over a greater area. For uneven or nonuniform subgrades under foundation footings and slabs, this material can provide a uniform and level surface and because of its strength, soil cement may reduce the required thickness or strength requirements of the slab [7].

d) Backfills: Plastic Soil cement can be readily placed into a trench, hole or other cavity. Following severe settlement problems of soil backfill in utility trenches, the city of Peoria, in 1988 plastic soil cement was tried as an alternative backfill material. The plastic soil cement was placed in trenches up to 2.7 m deep. Although fluid at time of placement, the plastic soil cement hardened to the extent that a person's weight could be supported within 2 to 3 hr. Very few shrinkage cracks were observed [7].

e) Conduit bedding: Plastic Soil cement provides an excellent bedding material for pipe, electrical, telephone, and other types of conduits. The flowable characteristic of the material allows the plastic soil cement to fill voids beneath the conduit and provide a uniform support [7].

f) Erosion control: soil cement is also used in riprap for embankment protection and in spilling basins below dam spillways, to hold rock pieces in place and resist erosion. It is used to fill flexible fabric mattresses placed along embankments for erosion protection, thereby increasing their strength and weight [7].

g) Lining irrigation canals: Researches reported that in unlined irrigation canal systems seepage losses are so high that in several systems the quantity of water delivered to the fields may be less than 50% of that drawn in the head. In the circumstances, some research showed that soil-cement tiles of 20 to 25 mm thickness if constructed with a cement contents to satisfy the criteria as mentioned below is durable in the irrigation field to withstand the stresses induced by the sun and rain.

h) Rammed earth wall construction: Rammed earth is another name for soil cement used to construct wall systems for residential housing. Rammed-earth walls, which are generally 6 cm thick, are constructed by placing the damp soil cement into forms commonly made of plywood held together by a system of clamps and whalers. The soil cement is then compacted in 12 to 18cm thick lifts with a pneumatic tamper [6].

i) Cement-stabilized building blocks: A cement-stabilized building block is used as a generic name to cover a wide range of building materials. A cement-stabilized building block is defined 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 stabilized block will 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 [9].

j) Soil cement flooring material: Different literatures mention that soil cement can be used to make affordable floors and patios. For floor tiles make a richer soil-cement mix by adding 20 percent of cement to the soil for greater strength and resistance to erosion [3].

2.2 SOIL CEMENT STABILIZATION PRINCIPLE

2.2.1 Back Ground

The stabilization of soil to improve its properties for building purposes is an ancient practice. The procedures were passed on from generation to generation without necessarily understanding the main mechanisms involved. It was only from the 1920s that systematic scientific approaches were emerged [2].

This use of stabilizers such as cement has derived out of a need to improve wet strength and erosion resistance in very exposed walls. In Australia and USA, cement stabilization has become accepted routine practice to stabilize soil and use it as a road bed material[8].

Soil requires to be stabilized because the material as found in its natural state is not durable for long-term use in buildings. By properly modifying the properties of soil, its long-term performance can be significantly improved. The Soil stabilization processes focus on altering its phase structure, namely the soil-water-air interphase. The general goal is to reduce the volume of interstitial voids, fill empty voids, and improve bonding between the soil grains. In this way better mechanical property, reduced porosity, limited dimensional changes, and enhanced resistance to normal and severe exposure conditions can be achieved [2].

Some of the methods used to modify soil can result in irreversible changes, while others may result in reversible changes. The latter are likely to occur due to the lack of resistance offered by soil to environmental agents, especially water. Problems of this type can be effectively overcome by properly stabilizing the soil. Addition of a suitable stabilizer, especially a binder, can enable the soil retain its shape and dimensions. The soil will also gain compressive strength and durability [2].

As several input variables are involved, soil stabilization is likely to remain a complex process. There are several options for stabilizing soil, but the method which is more effective should be considered that will have target on its void and improvement of the bond between particles.

By improving the cohesion and bonding in a soil, action is taken to cement and link the soil particles together. The method also ensures that changes in volume that would normally occur due to shrinkage and swelling are significantly reduced. Improved bonding also minimizes the vulnerability of the soil to surface abrasion and erosions [2].

2.2.2 Soil Stabilization Methods

Current soil stabilization methods can be broadly categorized as follows:

i. Mechanical stabilization (by using a compressor)
ii. Physical stabilization (by improving the soil grading)
iii. Chemical stabilization (by using a binder to improve bonding between the soil particles) [2].

2.2.2.1 Mechanical Stabilization

Involves compressing the soil particles together to increase density and reduce porosity. Compression leads to the redistribution and rearrangement of soil particles. It is the compaction energy used which forces the particles together and in the process most of the air is eliminated from the soil voids. Compaction is best achieved when the grain size distribution of a soil is continuous, not uniform or gap graded. The presence of grains of different sizes facilitates the occupation of voids left by other soil particles. Unfortunately, the effect of mechanical stabilization when used alone is easily reversed, especially when the soil comes into contact with water. Water causes the lubrication of the soil grains, forcing them to move about within the otherwise densified but still unbound fabric. It therefore follows that in addition to densification, the use of a binder will normally be required mainly to overcome the reversible effect of contact with water [2].

2.2.2.2 Physical Stabilization

It involves modification of soil properties by introducing the missing size fractions in the soil particle size distribution. The texture of a soil can be altered by calculated and controlled mixing of the different fractions of soil particles together. When this is done, most of the voids that existed prior to physical stabilization are closed due to closer packing of the grains. An anisotropic network is created limiting the movement of the grains in a soil .Unfortunately, as was the case with mechanical stabilization, the effect of physical stabilization alone is not permanent. On saturation with water, soil grains are easily dispersed, or washed away. For better results, physical stabilization of soil should therefore be combined with the other two methods [2].

2.2.2.3 Chemical Stabilization

It involves the addition of a binder or bonding agent to a soil. The binder modifies the soil properties through cementation or linkage of its particles .Both cementation and linkage are a result of chemical reactions involving the binder and water. Cementation creates a strong and inert matrix that can appreciably limit movement in a soil. The voids in the soil are also filled with insoluble by-products of the hydration reaction while some soil particles are coated and firmly held together by the binder [2].

The main categories of binders used for earth construction are Portland cement, lime, bitumen and chemical solution such as silicates [8].

2.2.2.3.1 Cement Stabilization

There are various advantages when using cement as a stabilizer. Soil samples gain strength from both the formation of a cement gel matrix that binds together the soil particles and the bonding of the surface-active particles, like clay, within the soil [8].

Cement is typically used in proportions between 4% and 15%, with between 6% and 10% the most commonly specified. Increased cement content improves strength and erosion resistance. The amount of cement required will depend on grading and other soil characteristics. Presence of clay generally impedes effectiveness of cement stabilization and, therefore should be generally minimized [8].

2.2.2.3.2 Lime Stabilization

Unlike cement, which works with the coarse particles of a soil, non-hydraulic lime works with the clay minerals in a soil. Tests have indicated that there is an optimum lime dosage for a soil beyond which compressive strength decreases. The likely dosages are between 6-12% Lime by dry weight and will increase as clay content increases [8].

Lime stabilization is ideally suited for stabilization of expansive soils .Lime achieves its final strength more slowly than cement and therefore the curing period should be at least three times more than the one used for cement [6].

The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals to form a variety of cementitious compounds, which bind the soil particles together. Lime can also reduce the degree, to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability [10].

2.2.2.3.3 Sodium Silicate Stabilization

Sodium silicate is used at quantities of around 5% to act as a binding agent to increase compressive strength in sandy and silty soils. According to Houben and Guillaud (1994), a curing period of about 7 days is advisable [8].

Sodium silicate has diverse application as a raw material in the production of adhesives and cement, pulp and paper production, detergent and soap etc. Sodium silicate has also applications in sealing concrete products.

2.2.2.3.4 Bitumen Stabilization

There are two ways whereby bitumen can stabilize soil. The first way is a binding process that increases soil strength particularly in granular soils. Generally, small amounts of bitumen (2% to 6%) give the soil cohesion. When these percentages are exceeded the bitumen tends to act as a lubricant separating the particles and thus reducing the strength. The second way is when the bitumen acts as a water repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil. Soils suitable for bituminous stabilization are sandy soils. Clays need a larger amount for good results [10].

2.2.2.4 Other Stabilizers

Traditionally, many stabilizers such as animal dung, ant hill materials, bird droppings, plant extracts and animal blood, have been used for the manufacture of compressed stabilized earth building blocks. These waste materials generally consist of nitrogenous organic compounds, which help bind together soil grains. Chopped straw, grasses and natural organic fibers, although not active stabilizers, they are used as reinforcement materials to reduce linear shrinkage problems, which occur with soil that has high clay content [10].

2.3 PRACTICES AND APPLICATION OF EARTH IN BUILDING CONSTRUCTION

Adobe Blocks: Walls made from adobe blocks are probably the most popular and one of the oldest forms of earth housing. Adobe blocks are made by placing a wet mud in boxes called "forms" .The forms are removed a short time after the blocks are made and the adobe blocks are allowed to dry (or cure) for about a month before they are used to build a wall. The blocks are held together in the wall with a mortar which can be the same mud used for making the blocks.

The main advantage adobe has over the other methods is that it is the simplest method, and a satisfactory dwelling can be built with the least amount of construction skill. If it's done right, and it can be strong walls that is relatively free from cracks. Adobe has several disadvantages. Adobe blocks are likely to be "rough looking" and chip easily. Adobe is usually not suited to climates that have high rainfall [20].Fig 2.1 shows a picture of one part of a wall of a building that is located in Addis Ababa.

Fig 2.1 Adobe Earth House (Gullele Botanic Garden)

RAMMED EARTH: In this method, continuous walls are built by ramming moist soil into position between heavy wooden forms. When a short section of wall is completed the forms are moved upwards or sideways and the process is repeated until the walls are completed. The ramming may be done with either hand or pneumatic tampers, but either way the soil has to be rammed until it becomes dense and extremely firm. Pneumatic tampers require more skill for successful use than hand tampers. A well made rammed earth wall is one of the most durable earth walls that can be made. Some have lasted for centuries. Rammed earth has the following disadvantages, it is-not easy to do well and the heavy wooden forms take time, money and some skill to build [19].Fig 2.2 shows a picture of Jasmine cottage located in Blakeney, United kingdom constructed from stabilized rammed earth having external and internal load bearing walls.

Fig 2.2 Rammed Earth House under construction, (Source: Review of Rammed Earth construction)

MACHINE-MADE OR PRESSED EARTH BLOCKS: Recently, several simple and inexpensive machines have been made for pressing soil into bricks or blocks. These earth blocks have many advantages. They have approximately the strength and durability of rammed earth. Some blocks which have had stabilizers (or chemicals) added to them are nearly as satisfactory as burnt brick or certain other building materials. At the same time, walls can be built as easily as adobe block walls. The pressed blocks dry and shrink in the sun before they are laid so that walls essentially crack free, can be built even with soils that shrink a little. Walls made of pressed blocks have a very pleasing appearance and it is not necessary to use surface coatings as long as the right soils are used. It nevertheless must be remembered that much hard work is required for handling and mixing the soil and transporting the finished blocks [19].

COB*:* In the cob method of construction, stiff mud is molded into balls somewhat larger than a person's head. These balls are then piled up in thick layers to form the wall directly without the use of any kind of forms. The mud must be stiff enough so that it will not have a tendency to slump. If some slumping or spreading does occur, the mud is put back in place with a trowel or else the excess mud is sliced off and placed on top. The wall must be constructed slowly so that each layer has a chance to harden before more mud is stacked on top of it. Workers usually stand or sit astride the walls so that scaffolding is not needed. The advantages that cob houses have are that they are easy to build and need very little construction equipment. However, shrinkage cracks can usually be expected and they may be serious [20].The beautiful house shown on Fig 2.3 is constructed by members of cobworks and the cob is located on Mayne island, Canada.

Fig 2.3 Cob House, (Source: Cobworks)

SOIL CEMENT FLOORING MATERIAL: Pathways are a necessity in most landscapes in order to easily walk around and move equipment. Often pathways are a means to get from the front yard to backyard, particularly from the garage. Surface materials can range from colored stamped concrete to crushed rock. Concrete is the most formal material and expensive walkway surface. Asphalt has good durability and traction (for steep slopes) and is surprisingly cost-effective. Soil mixed with cement can also be used as a pathway material [21].Fig 2.4 and Fig 2.5 shows the application of soil cement as a jointing material and as an outdoor flooring material.

Fig 2. 4 Flagstone pathways with soil cement between joints (Source: Blue fox farm)

Fig 2.5 Soil cement path meandering through yard (Source: Blue fox farm)

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Soil cement can also be used as indoor flooring material. Soil cement floor can be softer and more comfortable than a conventional concrete slab and if it is done properly, it’s less expensive.

Soil cement is softer under foot because it is less dense than concrete. Soil cement is also warmer, more forgiving and just easy to maintain as concrete. Structural concrete is a controlled mixture of sand, gravel, Portland cement and water. Its strength and limits are well documented. Soil Cement on the other hand, is not carefully controlled mixture of soil, Portland cement and water .The strength and limits of soil cement are highly variable, just as soil itself is variable. A coarse, gravelly soil might yield soil cement that is almost as strong and dense as concrete [22]. For application as floor tiles, a richer soil cement mix can be made by adding 20 percent of cement to the soil (or 1:5) for greater strength and resistance to erosion [3].

Fig2.6 Soil Cement floor [22]

2.4 MAIN CONSTITUENT MATERIALS USED IN THE PRODUCTION OF SOIL CEMENT FLOOR MATERIAL

The major variables that control the properties and characteristics of soil-cement mixtures are the type of soil or aggregate material, the proportion of cement in the mix and the moisture conditions [2]. The main constituent materials used in the production of soil cement mixture are;

- Cement (for binding the soil particles).
- Soil (for the skeletal structure).
- Water (for the hydration of cement and lubrication of soil particles).

- And others including sand or small gravel.

Each of the construction materials mentioned above has unique properties. Before looking how they are combined to form plastic soil cement a description of their nature and properties should be seen in detail. This approach is considered relevant because it is the property of these materials that will influence the soil cement matrix. The quality of material used and their proportioning can significantly affect the strength, durability and economy of the flooring material. Each material is therefore discussed in turn in Sections 2.4.1, 2.4.2, 2.4.3 and 2.4.4.

2.4.1 Ordinary Portland cement as a binder

Cement is to be the primary means of chemically stabilizing the soil samples during this research project. Consequently a good understanding of how cement works and how it forms cemetitious bonds with soil and fine aggregate would be most desirable. This research will briefly outline what cement is made of, its function in soil cement, physical properties of cement likely to affect its performance, basic chemical constituents of cement and hydration reaction of cement following the addition of water.

As a stabilizing material cement is well researched, well understood and its properties clearly defined. Cement can simply be described as being a mixture of lime and clay which is heated to about 1,500°C, resulting in clinker. Gypsum is added and the sum is then ground to very fine powder.

Ordinary Portland cement is an important ingredient and variable in a soil cement flooring material. The function of OPC is to strongly bind the constituent materials together, in a dense, strong, dimensionally stable and durable unit [2].OPC is selected in this thesis because it has a unique and superior binding capacity. Besides ordinary Portland cement other types of cements can also be used for stabilizing soil.

The hydration reaction happens when water is added to unreacted OPC. The grains of the cement follow two distinct phases when this reaction happens: setting followed by hardening, to form a cement paste. The mechanism of the reaction involving the main phases in unreacted cement (C_3S, C_2S, C_3A and C_4AF), occurs at different rates for each phase.

When water is added to the OPC grains, the reaction begins from the surface of the grains, then progresses inwards. This results in the formation of gels and ettringite. The C_3S and C_2S form gels, while the C_3A form ettringite. Due to the increased contact between the formed gels on adjoining grains, and due to the interlocking of the ettringite crystals, cohesion develops signifying the start of the setting period (initial setting). This occurs within about 45-60 minutes of water being added [2]. When this happens the soil particles start to be covered with the gel which in turn forms a stiff material when it hardens.

The water continues to diffuse into the gels, causing pressure to build up within, resulting in rupture of the gel. The ruptured gel peels away from the grain, forming gel foils and fibrils as wells tubules in the case of C_3A. This exposes the grain surface locally to further hydration. The process then repeats itself. The final set occurs approximately 12 hours after water was initially added [2].

In order to maximize the green strength of the mixture one needs to ensure that the free-water content is as small as possible and to leave the mixture untouched for as long as possible to permit the cementitous action to bond the particles together[13].

Two of the most important physical properties of OPC are its: Specific surface area (SSA), and Particle size distribution (PSD). The SSA and PSD of cement are important to because they govern the manner in which the binder stabilizes soils. These physical properties are directly related to the process of manufacture of the binder. Since the hydration reaction of cement while stabilizing soils starts from the surface of the grains and then proceeds inwards, the higher the SSA, the faster can the rate of reaction to be expected. The particle size distribution of OPC is characterized by an almost uniform type of grading (or packing characteristics). Cement grains do not contain every size fraction between the maximum and minimum particle sizes. Approximately 90% of the cement grains in OPC measure more than about 5µm, with only 1% measuring less than about 90 µm [2].

2.4.2 Characteristics and selection of soil in the soil cement mix

2.4.2.1 General Geotechnical Properties of Soil

The materials that constitute the earth's crust are rather arbitrarily divided into two categories, soil and rock. Soil is a natural aggregate of mineral grains, with or without organic constituents that can be separated by mechanical means. Whereas rock is considered to be a natural aggregate of mineral grains connected by strong and permanent cohesive forces.

Rocks are classified according to their mode of formation as follows:

i. Igneous Rocks: - are formed by cooling and solidification of magma within or on the surface of the earth's crust e.g. granite, basalt and dolerite.
ii. Sedimentary Rocks: - are formed by consolidation and cementation of sediments deposited under water e.g. limestone, sandstone, shale, dolomite, mudstone.
iii. Metamorphic Rocks: - are formed from older rocks when they are subjected to increased temperature, pressure and shearing stresses at considerable depth in the earth's crust e.g. slate, schist, marble and quartzite.

Soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition. When rock surface gets exposed to atmosphere for an appreciable time it disintegrates or decomposes into small particles and thus soil is formed [11].

Soil may be considered as an incidental material obtained from the geological cycle which goes on continuously in nature. Soils are formed either by physical disintegration or chemical decomposition of rocks [11].

A. Physical Disintegration

Physical disintegration or mechanical weathering of rocks occurs due to the following physical process [11].

i. Temperature change: Temperature fluctuation can cause unequal expansion and contraction within the rock mass resulting in the spilling of the layers of rocks causing disintegration.
ii. Freezing action of water: water that enters the pores and small cracks freezes during cold periods. As the water freezes it increases the volume there by exerting pressure against the sides of the cracks. This enlarges the cracks and loosens particles of rocks.
iii. Wedging action of plant roots: Small rootlets of trees and shrubs may grow into cracks in rocks in search of moisture and plant food. As these rootlets grow, they act as wedges which gradually force the rock segments apart.
iv. Impact action: The impact action of flowing water, ice and of wind borne sand particles serve to scour and erode rock fragments.

B. Chemical weathering

Chemical weathering or chemical decomposition is a result of attack on rock minerals by water, oxygen, alkaline or acidic materials dissolved in solid water. Carbon dioxide from the air and organic matter in the top soil are common source of such dissolved acids. The original rock minerals are transformed into new minerals by chemical reaction. The soil formed will not have the properties of the parent rock. The chemical process generally occurs in nature and some of them are oxidation in which oxygen unites with the rock minerals, carbonation in which the rock minerals are attacked by carbonic acids, etc [12]

2.4.2.1.1 Common Soil Types

Depending upon the weathered rocks and the different methods of transportation and deposition, different soils are formed. These soils have been differently named. Some of the soil types found in general practice are [12]

- Sand, gravel, cobbles and boulders are coarse-grained cohesionless soils. Their grain size ranges are used to distinguish between them. Particles of size from 0.075 to 4.75mm are referred to as sand and those with a size from 4.75 to 80mm as gravel. Fragments with diameters more than 80mm and less than 300mm are known as cobbles and those with a size greater than 300mm are categorized as boulders.

- Silt is a fine grained soil, having particle size between 0.002mm to 0.075mm. Inorganic silt has little or no plasticity and is cohesionless .Organic silt contains a mixture of organic matter. These particles are not visible to naked eye.
- Clay is composed of microscopic particles of weathered rock within a wide range of water content, clay exhibits plasticity. It contains a large quantity of clay minerals. It is a cohesive fine-grained soil and the particle size is less than 0.002mm.Organic clay contains some finely divided organic matter and is usually dark grey or black in color. Organic clays are highly compressible when saturated and their dry strength is very high.
- Black cotton soil is a residual soil containing a high percentage of the clay mineral montomorillonite. The soil has high shrinkage and expansive characteristics. Its color varies from dark grey to black.
- Hardpan is a term often used to describe any hard cemented layers, which are not softening when wet. These are generally dense, well graded, cohesive aggregates of mineral particles.
- Peat is an organic soil having fibrous aggregate of macroscopic and microscopic particles. It is formed from vegetal matter under conditions of excess moisture, such as in swamps.
- Top soil is surface soil that supports plants. It contains a large quantity of organic matter.
- Lateritic soil is residual soil formed in tropical region. It is formed by decomposition of rock, removal of bases and silica, and accumulation of iron oxide and aluminum oxide. The presence of iron oxide gives this soil the characteristics red or pink color. The lateritic soil is soft and can be cut with a chisel when wet. However, it becomes hard after long exposure. Hardness is due to cementing action of iron oxide and aluminum oxide. A hard crust of gravel size particles, known as lateritic, exists near the ground surface.
- Loam is a mixture of sand, silt and clay.

2.4.2.1.2 Soil Classification

To determine the suitability of any soil for stabilization, it is necessary to understand soil classification. Knowledge of the soil type and properties can facilitate the optimum amount of soil and stabilizer that can be used.

Soil classification is the arrangement of soils into different groups such that the soils in a particular group have similar behavior. It is a sort of labeling of soils with different labels. As there is a wide variety of soils covering the earth it is desirable to systematize or classify the soils into broad groups of similar behavior [11].

Soils are classified in various ways depending on the prevailing local or regional standards in the particular part of the world. Whatever the geographic location, however, some common procedures are usually adopted in the classification of soils [2].Soil classification methods are based on either one or a combination of the following: particle size distribution, plasticity, compactability, cohesion, and organic matter content.

2.4.2.1.2.1 Particle Size Distribution Classification System

The term particle refers to an individual mineral grain within the disturbed soil mass. According to this system, the following size ranges are given on Table 2.1 (BS 1377: Part 2, 1990):

Table 2.1: Soil classification according to particle size distribution (BS 1377 Part 2 1990)

Name	Subdivision	Diameter of Particles(mm)	
		Maximum	Minimum
Gravel	Course	60	20
	Medium	20	6.0
	Fine	6.0	2.0
Sand	Course	2.0	0.6

	Medium	0.6	0.2
	Fine	0.2	0.06
Silt	Course	0.06	0.02
	Medium	0.02	0.006
	Fine	0.006	0.002
Clay			< 0.002

A particle size analysis will determine the fraction of a soil's particles that fall within each of the above size bands. If dense block is to be produced, it is important that the soil used is "well graded" [10].

The value of a well-graded soil for soil cement is that such a distribution of sizes gives a dense structure with a low specific surface area. A dense structure is important for several reasons. A densely packed arrangement will have a higher number of contacting particles, giving a better load-bearing skeleton. The number and size of the inter-particle voids will be reduced as will the number of linked voids, these will reduce the porosity of the soil and hence also its permeability, thereby reducing susceptibility to water penetration. As the interlocking calcium silicate matrix extends through the soil voids, a more compact void system requires less cement to provide a matrix of equal efficiency [10].

Such a system is useful to classify soils of the same grain size. It also serves as an input for other more elaborate classification systems. However since soil is usually an aggregate of a range of sizes, this system has a very limited use.

The normal natural state of soil is such that it is composed of grains from two or more particle size ranges. For example, a soil may be described as sandy clay, implying that the soil has significant amounts of sand and clay size ranges.

The soil that is used should be well graded with a continuous or dense gradation. It should be neither gapgraded nor uniformly graded. Gravel is not usually used in soil- cement production, as the large particle size may lead to a poor (rough) surface finish. A suitable soil will contain a mixture of sand, silt and clay sized particles. The properties of each of these three fractions influence the properties of the soil cement mix.

2.4.2.1.2.2 Unified Soil Classification system

The unified system of soil classification was originally proposed by A. Casagrande in 1942 and was then revised in 1952 by the Corps of Engineers and the U.S. Bureau of Reclamation. The system has also been adopted by American Society of Testing Material (ASTM). The system is most popular for use in all types of engineering problems involving soils [11].

The system employs visual inspection; grain-size analysis and Atterberg limit tests in classifying soils. The coarse soils are classified by their grain sizes and fine grained soils are classified with the aid of plasticity chart [12].

The system uses both the particle size analysis and plasticity characteristics of soils. In this system, there are two major soil categories:

A. Coarse-grained soils: These are gravelly and sandy in nature with less than 50% passing through the No. 200 sieve. The group symbols start with prefixes of either G or S. G stands for gravel or gravelly soil, and S for sand or sandy soil.
   The coarse grained soils are designated as grave (G) if 50% or more of coarse fraction is retained on 4.75mm sieve; otherwise it is termed as sandy soil.
B. Fine grained soils: with 50% or more passing through the No. 200 sieves. The group symbols start with prefixes of M, which stands for inorganic silt, C for inorganic clay, and O for organic silts and clays. The symbol Pt is used for peat, muck, and other highly organic soils.

Table 2.2 Symbol used in USC system

	Symbol	Description
Primary	G	Gravel
	S	Sand
	M	Silt
	C	Clay

	O	Organic
	Pt	Peat
Secondary	W	Well-graded
	P	Poorly graded
	M	Non-plastic fines
	C	Plastic fines
	L	Low Plasticity
	H	High plasticity

2.4.2.1.2.3 Soil Plasticity Classification System

Soil is identified by its behavior when in contact with water. The system is mostly used for the finer fraction of a soil, i.e. clays and silts smaller than the 425µ m sieve only [2].The quantity of fines may be measured by using one of the sedimentation tests; however, the clay type present is very difficult to determine without highly complex tests. In fact it is not necessary to know the clay type present but it is important to know the properties exhibited by the clay.

Atterburg tests defining liquid limit, plastic limit and plasticity index are used to quantify the plasticity of the finer fraction of a soil (only particles less than 0.425 mm are tested). These tests measure the percentage water contents at which the soil passes from a liquid state to a plastic state (liquid limit) and from a plastic state to a solid state (plastic limit). The numerical difference between the liquid and plastic limit (the plasticity index) thus gives the range of water content over which the soil may be considered plastic. As plasticity is dependent on the soil cohesion, it has been found that this index reflects the cohesive characteristics of the soil. Furthermore as cohesion is largely dependent on the specific surface area of the fines, these plasticity limits also reflects the expansiveness of the soil. A soil with a low plasticity index will display low cohesion and usually low expansion on wetting, while a high index soil will display the reverse [10].

Use of both the particle size and plasticity based classification systems are recommended in analyzing soils for cement suitability. The crucial point is that either system should be able to describe the soil in a manner clearly understandable by engineers. The identification of a particular soil can be considered complete with the inclusion of its color, particle shape and composition, soil name based on its grading and plasticity, and the soil group symbol. The approach is useful in that it clearly recognizes the difference between the coarse and fine soil fractions [2].

2.4.2.2 Characteristics and selection of soil in the soil cement mix

According to the ideal specifications given by the United Nations, in "Soil-cement: Its use in Building, (1964)", the best soil composition for soil-cement is as follows; 75% sand, 25% silt and clay, of which more than 10% is clay. This composition will yield a sandcrete product if mixed with cement and will exhibit good structural characteristics. Unfortunately, soil with these exact characteristics will not be found easily near every potential building site and so one of the two things must be done either the soil is tested and the required parts added to make the ideal soil, or a compromise is made and a slightly higher percentage of cement is used to ensure a satisfactory outcome whatever the type of soil is used [13].

There is an underlying problem with randomly mixing cement with any type of soil, and it is to do with the clay fraction of the soil. Clay consists of the finest particles in the soil and, can in same way that cement does, coat the other particles when mixed with water and causes a significant cohesion after the mixture is dried.

Clay and cement will work against one another if the quantities are not carefully monitored. Too much clay will result in the cement not coating all the particles sufficiently and subsequent wetting will cause expansion of the formed mixture breaking apart the cement crystals and causing breakdown. As cement is not strong in tension and the expansion of the clay particles cause internal expansion working against the cementitous bonds. Also because clay is very small it is difficult for the cement to successfully coat the clay particles. Therefore a high composition of clay in a soil that is to be stabilized with a very small quantity of cement makes it unacceptable [13].

The moisture of the soil-cement mixture needs to be carefully controlled. There needs to be sufficient moisture for the cement to fully hydrate but no excess of water which would reduce the final density, increase porosity and reduce final strength.

The dry soil is to be mixed with the cement and the required water added. The mixture then needs to be formed and left in a 100% humidity environment within 30 to 45 minutes of mixing the cement and soil with the water. This is to ensure that the cement has sufficient water to hydrate and also that the mixture is not manipulated again after the critical time [13].

The greatest effectiveness of cement in comparison to other stabilizers is shown with low clay content soils such as sands, sandy and silty soils, and clay soils of low to medium plasticity. Soils unsuitable for treatment with any stabilizer include organic soils, clean gravels and sands, and highly plastic clays.

The results of Bryan suggests that measures of plasticity are inferior to textural properties in discriminating soil suitability for cement stabilization. In contrast, the results of this study indicate that LS and PI should be regarded as the primary discriminators of soil suitability for cement and/or lime stabilization [14].

If the percentage of fine (i.e. silt and clay) is too small there will not be enough cohesion to handle the soil cement mix immediately after mixing. And if the proportion of the fines (especially clay) percent is too high both soil mixing and compacted density will be low [5].

The general suitability of soil materials for soil cement can be judged before they are tested on the basis of their gradation and their position in the soil profile.

Gradation: On the basis of gradation, soil materials for soil cement can be divided into three broad groups:

- Well graded sandy and gravelly soil with about 10 to 35% of non-plastic fines have the most favorable characteristics and generally require the least amount of cement for adequate hardening.
- Sandy soil deficient in fines as an example windblown sand make a good soil-cement though the amount of cement needed for adequate hardening usually is slightly greater than with the material in the first group.
- Silty and clayey soils can make a satisfactory soil cement, but those containing high silt and clay will require higher percentage of cement to harden.

Soil profile: A soil profile is a vertical cross section of the earth's surface that exposes the different or layers. Each soil horizon is generally of different texture, structure and color. Color indicates the soil's chemical makeup. For instance, a red soil indicates the presence of iron and generally reacts exceptionally well with cement. Conversely, a black farmland soil may react rather poorly with cement because of the presence of organic material [15].

Different literatures specify liquid limit, plastic limit and plasticity index value for suitable soil cement mix, the values identified by literatures have different range but the average values for theses soil classification criteria's are 28-44%, 20-30% and 6-25% respectively.

2.4.3 Fine Aggregate

Aggregate can be classified as natural or artificial depending on their sources. Natural aggregates are obtained from quarries by processing crushed rocks or from riverbeds while artificial aggregates are obtained from industrial by product such as blast furnace slag [23].

The geological formation of Addis Ababa soils is dominantly igneous rock. This is due to the volcanic activity the area undergoes in geological time. The most abundant rock types are basalt and trachyte. The red ash, which is found in the near vicinity of the city, is just oxidized form of the basalt during eruptions [23].

Fine aggregates (sand), is a product of natural or artificial disintegration of rocks or minerals. Sand is usually obtained from glacial, river, lake, marine, residual and wind-blown (very fine sand) deposits. These deposits, however, do not provide pure sand. The construction industry utilizes sand mainly from streambeds, which are commonly derived from quartzo-feldspathic basement rocks, sandy marine sediments and alluvial deposits.

When using crushed aggregates for mix one thing that we should consider besides particles size and gradation is aggregate shape, aggregates which contain an irregular and flaky shape will have an influence on workability and in turn the compressive strength of the hardened mix.

Soil cement can be made with eight up to ten percent cement and plain earth. Many soils are compatible with cement directly without adding sand. To improve the property manufactured sand and small gravel can also be added. Soil cement develops about one half the strength of concrete if the proportion and the property of the ingredient materials is suitable which is sufficient for most foot and automobile traffic and it gives and natural look [22].

2.4.4 Water for mixing and curing

The water used in the soil cement mix plays an important role both in placing the material and in achieving strength. The quantity of water used is typically calculated from a fixed amount of water-cement ratio.

Water is also added in the soil cement mix for promotion of hydration and reduction of shrinkage. Therefore, water is one of the important elements of soil cement mix.

2.5 MECHANISM OF SOIL CEMENT STABILIZATION

Cement is to be the primary means of chemically stabilizing the soil samples during this research project. Consequently a good understanding of how cement works and how it forms cemetitious bonds with other particles would be most desirable.

As a stabilizing material cement is well researched, well understood and its properties clearly defined. Portland cement is readily available in most urban areas, and usually available in semi-urban areas, as it is one of the major components for any building construction. [12].

There are different factors which are responsible for ensuring a good bond between the cement and the particles mixed within it. These requirements not only affect the components of the mixture used, how it is prepared, delivered into its final state, but also subsequent curing times and environmental conditions of the finished product [13].

When cement is mixed with a cohesive soil, the calcium ions released during the initial cement hydration reaction are marked to reduce the soil plasticity. The mechanism is most likely the cation exchange or crowding of additional cations onto the soil. These processes that change the electrical charge density around the soil particle cause changes in the behavior of the aggregated soil [16].

When soil-cement is compacted, chemical bonds develop between adjacent cement grain surfaces and between cement grain and soil particle interfaces. In fine grained silty and clayey soils, cement hydration develops strong linkages between the mineral and the aggregates to form a honeycomb-type structure whereby the particles of soil can no longer slide over each other. Not only does cement destroy the soil plasticity, it also increases the shear strength and reduces the water holding capacity of clayey soils. Because of these properties of cement, it prevents the soil from swelling and softening from absorption of the moisture [16].

Portland cement is composed of calcium-silicates and calcium-aluminates that, when combined with water, hydrate to form the cementing compounds of calcium-silicatehydrate and calcium-aluminate-hydrate, as well as excess calcium hydroxide. Because of the cementitious material, as well as the calcium hydroxide (lime) formed, Portland cement may be successful in stabilizing both granular and fine-grained soils, as well as aggregates and miscellaneous materials. A pozzolanic reaction between the calcium hydroxide released during hydration and soil alumina and soil silica occurs in fine-grained clay soils and is an important aspect of the stabilization of these soils. The permeability of cement stabilized material is greatly reduced. The result is a moisture-resistant material that is highly durable and resistant to leaching over the long term [17].

Like concrete, soil-cement continues to increase in strength with increasing age. The chemical composition of particular soils includes substances that react differently with the cement. Soils that present organic matter may cause delayed setting and soils that present sulfates may cause swelling or reduction in strength [16].

Soil stabilization depends on soil classification and the type of structure to be built. Understanding the properties of various soils will make it easier to select the highest quality soil possible [3].

2.6 FACTORS AFFECTING SOIL CEMENT STABILIZATION

There are several factors that affect the properties of cement-treated soil: The nature of the soil and the proportion of the mixing (soil, cement, and water), compaction, curing, and any added admixtures can influence these properties [18].Factors which affect soil cement stabilization are listed on Table 2.3.

Table 2.3 Factors affecting soil cement stabilization

Characteristics of stabilizing agent	• Type of binder • Quality and Quantity of binder • Mixing water and additives
Characteristics and condition of soil	• Physical chemical and mineralogical properties of soil • Nature and amount of organic content • PH
Mixing condition	• Laboratory and field mixing • Quantity of stabilizing agent etc...
Curing condition and compaction preloading	• Temperature • Curing time • Freezing and thawing • Compaction etc...

2.6.1 Characteristics of stabilizing agent

Binder characteristics and chemical reaction are important in order to understand the effect of these binders on stabilization. Depending on the type of binder the characteristics of the stabilized soil may vary with time.

Type of cement will have an effect on compressive strength in some soils. For normal and air entraining cement, results indicated that high alkali content is beneficial to strength if the soil contains a relatively high proportion of clay-free quartz surfaces. For high-early-strength cement, results similar to those for Ordinary Portland Cement will be obtained at optimum water contents and maximum density. The only difference is the rate of gain of compressive strength [16].

High early strength cement does not have the same influence on compressive strength for all soils. For silty clay, the strength when using high early strength cement is slightly greater than for ordinary Portland cement cement. Clayey, sandy silt cement-treated soil mixed with high early strength cement acquires 1.5 times the seven day strength as when mixed with Ordinary Portland Cement and 1.3 times the strength at 28 days [1].

2.6.2 Characteristics and condition of soil

Like concrete, soil-cement continues to increase in strength with increasing age. The chemical composition of particular soil includes the substances that react differently with the cement. Soils that present organic matter may cause delayed setting and soils that present sulfates may cause swelling or reduction in strength [15]. Also In terms of clay content the stabilizing material or cement effectiveness decrease with an increase in clay content [18].

2.6.3 Mixing condition

Homogeneous mixing of binder with soil both in the laboratory and in the field is required to achieve the optimum effectiveness of binder. Many researchers point out that attainment of good mixing of stabilizers with soil is the most important factor affecting the quality of results. Both degree of mixing and time of mixing affect the property of the mix.

2.6.4 Water-Cement Ratio and the Degree of Hydration

These factors are known to determine the strength of a cement matrix [25]. It can be expected that the lower the effective water cement ratio and the higher the degree of hydration, the lower the capillary porosity and the stronger the block [2].

2.6.5 Curing condition

It's well known that water is required for lubrication purpose in the mixed ingredients and it is also needed for strength development as it is a major input for hydration reaction.

2.6.6 Age

The age of the green hardened soil cement influences its strength since the degree of hydration of the OPC stabilizer is known to increase with time. During the early stages of production, the degree of hydration within a block increases with curing age, and so does its strength. This phenomenon is investigated experimentally in this thesis. Soil cement paste is therefore likely to continue to gain strength for many years. The rate of increase in strength is however known to decrease after some years [2].

CHAPTER THREE

EXPERIMENTAL METHODOLOGY

3.1 INTRODUCTION

In this section the materials used in the investigation are described with respect to their physical and chemical properties. Furthermore, mix proportioning and sample preparation techniques and procedures undertaken in this research are discussed in detail. Laboratory investigations on soil and other ingredients were carried out in the Geotechnical Engineering and Construction materials Laboratory of Addis Ababa institute of Technology. The chemical composition test was performed at Geological Survey of Ethiopia; Geochemical laboratory.

3.2 MATERIALS

3.2.1 Cement

The cement used in all the mixes was locally manufactured Messobo OPC which was produced in accordance with EN 196 and BS 1370.

3.2.2 Soil

Soil samples were prepared by drying and sieving to the required size. The soil used in this study was brought from Kara area, which is around 15km East of Addis Ababa. The laboratory tests conducted helps to establish numerical values for the soil sample parameters, primarily the percentage distribution of the different sizes of the soil particles present and the plasticity limits.

These values are subsequently used to determine the suitability of the soil sample for soil cement flooring material. The physical composition and chemical properties of the soil are given in Table 3.1 and Table 3.2 respectively. The detail test results are given on Annex One.

Table 3.1 Physical properties of the soil

NO	Physical Properties	Values
1	Specific gravity	2.63
2	Natural moisture content	17.91%
3	Maximum dry density	1800 kg/m^3
4	Liquid limit	30.48%
5	Plastic limit	24.69%
6	Plasticity index	5.79

Table 3.2 Chemical composition of the soil used for the research

Chemical Composition (%)	Percentage (%)
SiO_2	65.86
Al_2O_3	13.82
Fe_2O_3	7.84
CaO	0.46
MgO	0.58
Na_2O	2.06
K_2O	3.62
MnO	0.38

P_2O_5	0.05
TiO_2	0.87
H_2O	1.10
LOI	4.12

3.2.2.1 Classification of soil

The soil sample is generally characterized in three ways, by a particle size distribution analysis, by plasticity index and unified soil classification system. The particle size analysis gives information on the soil ability to pack in to a dense structure and the quantity of fines present (combined silt and clay fraction), while the plasticity index gives an idea of the cohesion of the fines.

3.2.2.1.1 Particle size distribution

The sieving test done on a representative soil sample showed the particle size distribution and soil particles grading. The result of the test is plotted in Figure 3.1 below. Detail test results are given in Annex1.3.

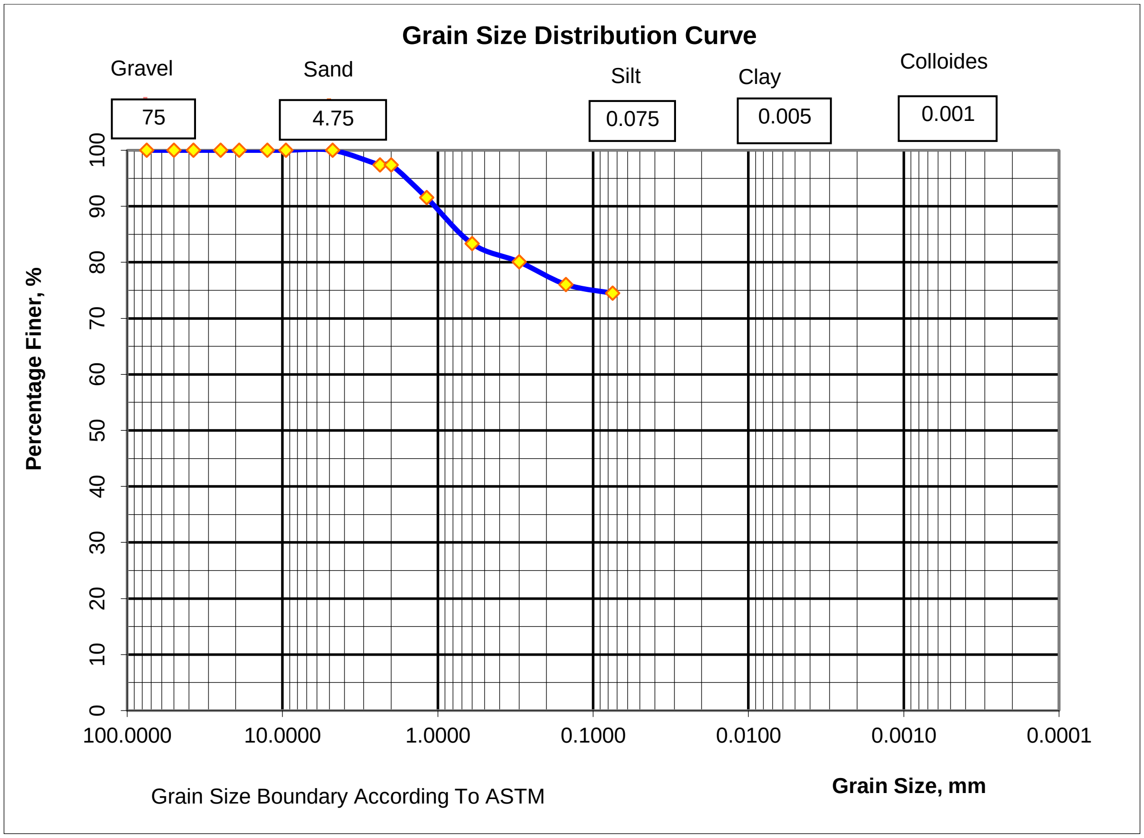

Fig 3.1 Particle size distribution of soil sample

From the test result shown with the above curve the composition of the soil is grouped as follows: Sand 76%, Silt and Clay 24%.Which is acceptable according to the given soil property given by literatures. The best soil composition for soil-cement is as follows; 75% sand, 25% silt and clay, of which more than 10% is clay.[13]

3.2.2.1.2 Unified Soil Classification system

Based on the results of the particles size analysis less than 50% passing through the No. 200 sieve out of which 50% or more of coarse fraction is not retained on 4.75mm sieve which will make the soil a sandy soil.

3.2.2.1.3 Soil Plasticity Classification System

The plastic limit and liquid limit tests described in the Annex 1.3 and Annex 1.4 are prepared by using method of ASTM D 2216-92.The results show that the values are within the advisable range. Atterburg limit test results of soil sample are shown on Table 3.3.

Table 3.3 Atterburg limit test results of soil sample

Atterburg limits	Value
Plastic limit	24.69%
Liquid limit	30.48%
Plasticity index	5.79

3.2.3 Aggregates

3.2.3.1 Natural Sand

The fine aggregate used for this research was brought from Langano as reported by the suppliers. The silt content of the original sample was found to be 11% which is above the permissible limit. As EBCS recommends the material was washed, dried and kept in the laboratory. Then required tests were performed on the sand which is shown in Table 3.4.

3.2.3.2 Crushed Sand

The crushed sand was produced from crushing of basaltic stone. As the original silt content of the crushed sand is more than the allowable limit it was then washed which made the silt content to be 5%. Different tests which show the physical properties were done and are shown in the Table 3.4.

Table 3.4: Physical properties of fine aggregates

Item	Test Description	Fine aggregate	Test Result
1	Silt Content	Natural sand	3.23%
		Crushed sand	5%
2	Moisture content	Natural sand	6.38%
		Crushed sand	7%
3	Absorption capacity	Natural sand	5.3%
		Crushed sand	2.9%
4	Specific gravity (Bulk)	Natural sand	2.35
		Crushed sand	2.4
5	Specific gravity(SSD)	Natural sand	2.41
		Crushed sand	2.53
6	Fineness modulus	Natural sand	3.01
		Crushed sand	2.84

The summaries of gradation of both natural and crushed sand are shown in Fig 3.2 and 3.3, respectively.

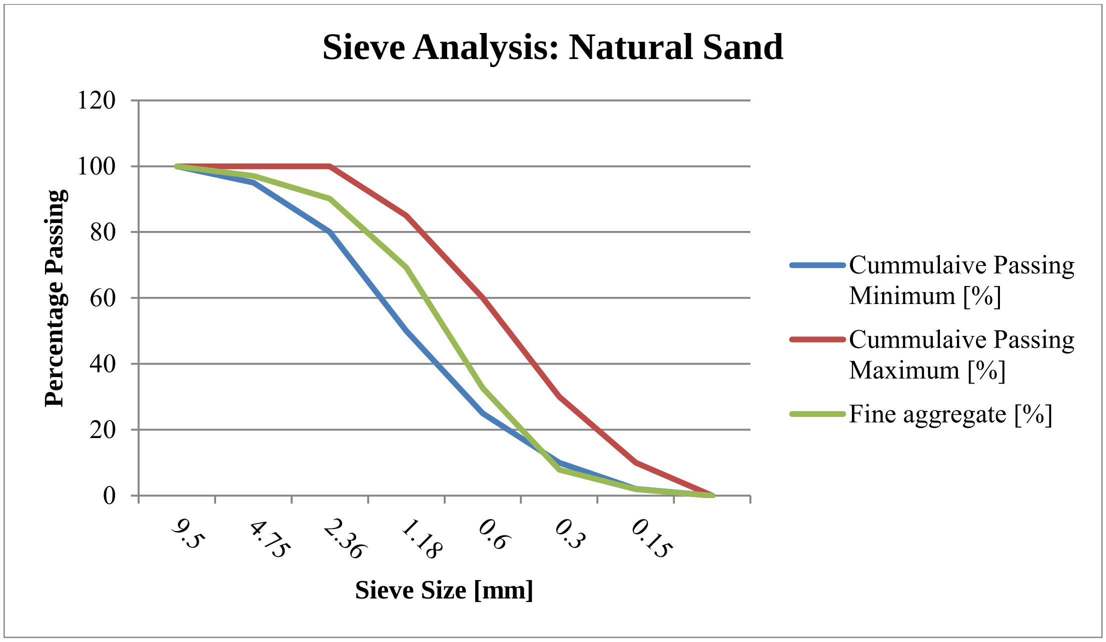

Fig 3.2 Gradation curve for the natural sand

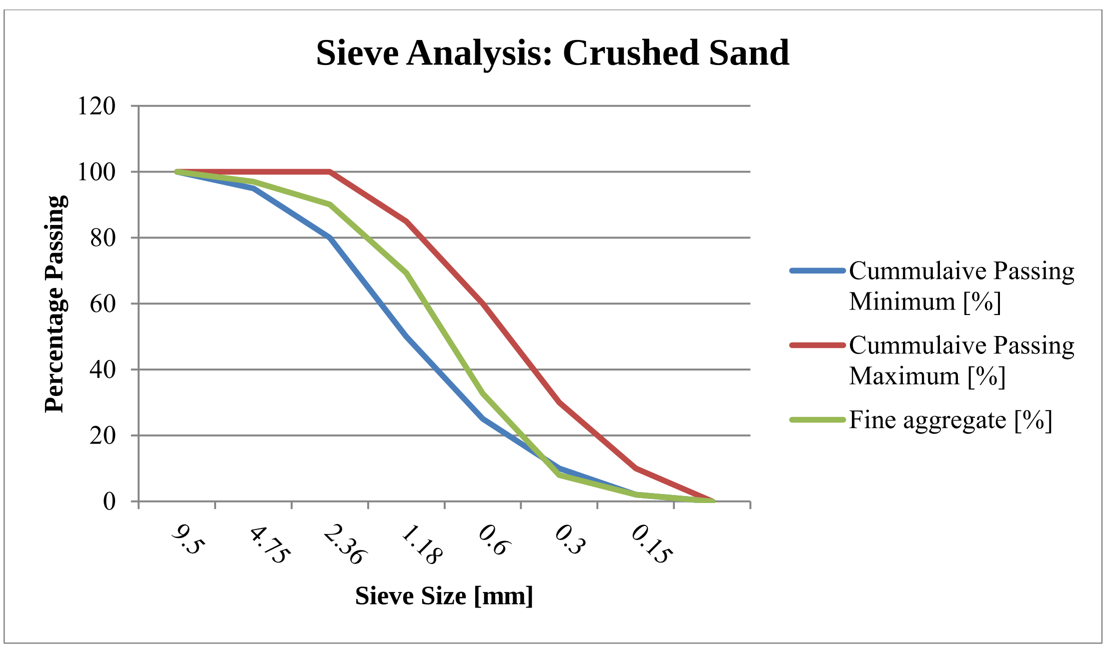

Fig 3.3 Gradation curve for the Crushed Sand

3.2.4 Water

A tap water, which is supplied from the Addis Ababa water supply and sewerage Authority, has been used for all mixes.

3.3 MIX PROPORTIONING AND SAMPLE DESIGNATION

The basic purpose of this investigation is to arrive at a suitable mix ratio which satisfies technical property and economy for manufacturing of flooring material using soil cement. Furthermore the effect of varying the percentage of cement, soil and fine aggregates will be discussed in detail. In order to analyze the effects of contents of cement, soil and fine aggregates two mix series were prepared.

1. The first series of mixes (25 in number) were done on three independent variables which are cement, sand and soil to compare values of compressive strength with soil to sand ratio keeping the W/C ratio constant. In this mix cement content of 20%, 15% and 10% by the total wet volume were kept constant and other ingredients varied accordingly. The Mix proportions are given in Table 3.5. The mixes are designated in such a way that the first, second and third letters describe cement, sand and soil consecutively and the superscripts describe volume portion of the designated material. For instance, $C_{20}S_{60}D_{20}$ is considered as a soil cement mix series I with 20% cement contend, 60% sand content and 20% soil content.

Table 3.5 Mix proportions for Mix Series I (25 mixes)

Cement (%)	Mix Designation	Material	Percent (%)	Soil-sand ratio	W/C Ratio	Water (Kg/m^3)	Weight (Kg/m^3)
	Control-1	C	20	0.00	0.5	239.54	479.09
		S	80				1460.08
		D	0				0.00
	$C_{20}S_{70}D_{10}$	C	20	0.14	0.5	239.54	479.09
		S	70				1277.57
		D	10				190.11
	$C_{20}S_{60}D_{20}$	C	20	0.33	0.5	239.54	479.09
		S	60				1095.06
		D	20				380.23

C-20%	$C_{20}S_{50}D_{30}$	C	20	0.60	0.5	239.54	479.09
		S	50				912.55
		D	30				570.34
	$C_{20}S_{40}D_{40}$	C	20	1.00	0.5	239.54	479.09
		S	40				730.04
		D	40				760.46
	$C_{20}S_{30}D_{50}$	C	20	1.67	0.5	239.54	479.09
		S	30				547.53
		D	50				950.57
	$C_{20}S_{20}D_{60}$	C	20	3.00	0.5	239.54	479.09
		S	20				365.02
		D	60				1140.68
	$C_{20}S_{10}D_{70}$	C	20	7.00	0.5	239.54	479.09
		S	10				182.51
		D	70				1330.80
Cement 15%	Control-2	C	15	0.00	0.5	191.10	382.20
		S	85				1650.15
		D	0				0.00
	$C_{15}S_{75}D_{10}$	C	15	0.13	0.5	191.10	382.20
		S	75				1456.02
		D	10				202.22
	$C_{15}S_{65}D_{20}$	C	15	0.31	0.5	191.10	382.20
		S	65				1261.88
		D	20				404.45
	$C_{15}S_{55}D_{30}$	C	15	0.55	0.5	191.10	382.20
		S	55				1067.75
		D	30				606.67
	$C_{15}S_{45}D_{40}$	C	15	0.89	0.5	191.10	382.20
		S	45				873.61
		D	40				808.90
	$C_{15}S_{35}D_{50}$	C	15	1.43	0.5	191.10	382.20
		S	35				679.47
		D	50				1011.12
	$C_{15}S_{25}D_{60}$	C	15	2.40	0.5	191.10	382.20
		S	25				485.34
		D	60				1213.35

	$C_{15}S_{15}D_{70}$	C	15	4.67	0.5	191.10	382.20
		S	15				291.20
		D	70				1415.57
Cement 10%	Control-3	C	10	0.00	0.5	136.07	272.14
		S	90				1866.09
		D	0				0.00
	$C_{10}S_{80}D_{10}$	C	10	0.13	0.5	136.07	272.14
		S	80				1658.75
		D	10				215.98
	$C_{10}S_{70}D_{20}$	C	10	0.29	0.5	136.07	272.14
		S	70				1451.40
		D	20				431.97
	$C_{10}S_{60}D_{30}$	C	10	0.50	0.5	136.07	272.14
		S	60				1244.06
		D	30				647.95
	$C_{10}S_{50}D_{40}$	C	10	0.80	0.5	136.07	272.14
		S	50				1036.72
		D	40				863.93
	$C_{10}S_{40}D_{50}$	C	10	1.25	0.5	136.07	272.14
		S	40				829.37
		D	50				1079.91
	$C_{10}S_{30}D_{60}$	C	10	2.00	0.5	136.07	272.14
		S	30				622.03
		D	60				1295.90
	$C_{10}S_{20}D_{70}$	C	10	3.50	0.5	136.07	272.14
		S	20				414.69
		D	70				1511.88
	$C_{10}S_{10}D_{80}$	C	10	8.00	0.5	136.07	272.14
		S	10				207.34
		D	80				1727.86

2. The second series of mixes (14 in number) were done on four independent variables which are cement, sand, soil and crushed sand. The mixes are conducted to compare the difference in compressive strength values with age and to study the water absorption with varying percentage and values of the variables. The mixes are made with 20% and 15% cement content as shown in Table 3.6. The mixes are conduct with crushed sand amount of 20% for

both 20% and 15% cement content and additional 10% crushed sand amount is experimented for 15% cement content. The mixes are designated in such a way that the first, second, third and fourth letters describe cement, sand, soil and crushed sand amount successively and the superscripts describe volume portion of the designated material. For example $C_{20}S_{20}D_{40}M_{20}$ is considered as a mix with cement content of 20%, sand content 20%, soil content 40% and crushed sand amount of 20% from the total volume of wet mix.

Table 3.6 Mix proportions for Mix Series II (14 mixes)

Cement Percentage	Mix Designation	Material	Percent (%)	Soil to Sand ratio	W/C Ratio	Water (Kg/m^3)	Weight (Kg/m^3)
Cement- 20%	Control-1	C	20	0.00	0.5	239.54	479.09
		M	20				403.04
		S	60				1095.06
		D	0				0.00
	$C_{20}S_{40}D_{20}M_{20}$	C	20	0.5	0.5	239.54	479.09
		M	20				403.04
		S	40				730.04
		D	20				380.23
	$C_{20}S_{20}D_{40}M_{20}$	C	20	2	0.5	239.54	479.09
		M	20				403.04
		S	20				365.02
		D	40				760.46
	$C_{20}S_{1}D_{59}M_{20}$	C	20	59	0.5	239.54	479.09
		M	20				403.04
		S	1				18.25
		D	59				1121.67
	Control-2	C	15	0.00	0.5	191.10	382.28
		M	20				428.80

Cement- 15% Crushed Sand -20%		S	65				1262.14
		D	0				0.00
	$C_{15}S_{60}D_{5}M_{20}$	C	15	0.08	0.5	191.10	382.28
		M	20				428.80
		S	60				1165.05
		D	5				101.13
	$C_{15}S_{40}D_{25}M_{20}$	C	15	0.63	0.5	191.10	382.28
		M	20				428.80
		S	40				776.70
		D	25				505.66
	$C_{15}S_{20}D_{45}M_{20}$	C	15	2.25	0.5	191.10	382.28
		M	20				428.80
		S	20				388.35
		D	45				910.19
	$C_{15}S_{1}D_{64}M_{20}$	C	15	64.00	0.5	191.10	382.28
		M	20				428.80
		S	1				19.42
		D	64				1294.50
Cement- 15% Crushed Sand -15%	Control-3	C	15	0.00	0.5	191.10	382.28
		M	10				214.40
		S	75				1456.31
		D	0				0.00
	$C_{15}S_{60}D_{15}M_{10}$	C	15	0.25	0.5	191.10	382.28
		M	10				214.40
		S	60				1165.05
		D	15				303.40
	$C_{15}S_{40}D_{35}M_{10}$	C	15	0.88	0.5	191.10	382.28
		M	10				214.40
		S	40				776.70
		D	35				707.93

	$C_{15}S_{20}D_{55}M_{10}$	C	15	2.75	0.5	191.10	382.28
		M	10				214.40
		S	20				388.35
		D	55				1112.46
	$C_{15}S_{1}D_{74}M_{10}$	C	15	14.00	0.5	191.10	382.28
		M	10				214.40
		S	1				19.42
		D	74				1496.76

3.4 SPECIMENS PREPARATION

After determining the mix ratio for both series of mixes shown in Table 3.5 and Table 3.6 the materials were batched using weight method and water was added to adjust for moisture. The aggregate was left for some time so that it can reach saturated surface dry condition. Materials were dry mixed for one minute followed by the addition of two third of the total mixing water. After one minute of mixing remaining water was added, Mixing was ceased after three minutes of mixing for all mixes.

The specimens for the two mix series were cast in two layers using the appropriate moulds. For mix series I six 50 mm cubes were prepared for each of the 25 mixes, for the other mix series six 150mm cubes and three 100mm cubes were cast for all 14 mix types. The 50 mm and 150mm cubes were used for determination of 7^{th} or 14^{th} and 28^{th} day compressive strength, the absorption capacity of the material was checked using 100mm cube sample.

3.5 CURING

The specimens were left in the mould for 24hr as they were casted with releasing agent they were easily remolded.

Any building material composed of soil-cement (whether rammed earth or block pressed) must cure slowly until hard taking into consideration this concept the samples were first cured by covering until 3 days and after that they were placed in a pond until the desired test date that is 7 or 14 and 28 days.

3.6 TESTS ON HARDENED SOIL CEMENT

In this research two basic tests are performed to study the properties of the hardened soil cement mix. The tests include compressive strength tests and water absorption test.

The compressive strength gives an indication of quality of the hardened soil cement mix. Literatures and suppliers mention different amount of minimum compressive strength value for flooring material. The International Building code 2006, New Jersey edition specifies the minimum amount of compressive strength that should be satisfied with flooring concrete to be 17 MPa. From experience of the Ethiopian building construction industry the commonly specified compressive strength value for ground floors is 15MPa.

Water is one of the major factors that contribute to the deformation and deterioration of cementaitous structures. The top surface of structures such as slabs or pavements on the ground can be subject to external drying, and the bottom surface can be in contact with water from ineffective drainage. Knowledge of moisture distribution significantly improves durability prediction. The water-to-cement ratio, the environment relative humidity (RH), and the moisture transport properties of concrete affect moisture distribution in ground floor. The water absorption capacity also identifies the nature of a flooring material with regard to its internal structure, which is directly related to mechanical strength. The percentage moisture absorption by weight was calculated from the formula:

$$M_c = \left(\frac{Ww - Wd}{Wd}\right) * 100(\%) \qquad \text{[Eq3.1]}$$

Where:

M_c = percentage moisture absorption (%)

W_w= mass of wetted sample (g)

W_d = mass of dry sample (g)

CHAPTER FOUR

TEST RESULTS AND DISCUSSION

4.1 INTRODUCTION

It was stated that the main objective of the research was to study the effect of altering composition of important constituents like: soil, cement and fine aggregate, and to produce a material using plastic soil cement and study its mechanical property. Accordingly two mixes series were prepared and specimens were arranged and tests were conducted, this section reports and shows a detail analysis of the performed tests.

Below is shown a tabulated result of the average compressive strength of tested specimen for both mix series. The first table i.e. Table 4.1 shows the result of the tests done on Mix series I containing around 25 mixes. The second table ,Table 4.2 shows a result of the second Mix series having 14 mix types and all the raw data's of cube compressive strength results are presented in a tabulated form in Annex Three.

Table 4.1 Average 7 and 28 days compressive strength result for Mix series I

Cement Content	Mix Designation	Soil/sand ratio	W/C Ratio	7 day Avg. Comp. Strength (MPa)	28 day Avg. Comp. Strength (MPa)
Cement-20%	Control-1	0.00	0.5	17.73	24.38
	$C_{20}S_{70}D_{10}$	0.14	0.5	20.05	26.35
	$C_{20}S_{60}D_{20}$	0.33	0.5	16.18	22.11
	$C_{20}S_{50}D_{30}$	0.60	0.5	16.82	22.65
	$C_{20}S_{40}D_{40}$	1.00	0.5	13.58	20.93
	$C_{20}S_{30}D_{50}$	1.67	0.5	9.50	16.03
	$C_{20}S_{20}D_{60}$	3.00	0.5	9.64	12.92
	$C_{20}S_{10}D_{70}$	7.00	0.5	8.26	12.04
Cement-15%	Control-2	0.00	0.5	11.20	20.71
	$C_{15}S_{75}D_{10}$	0.13	0.5	13.52	20.52
	$C_{15}S_{65}D_{20}$	0.31	0.5	11.06	14.78
	$C_{15}S_{55}D_{30}$	0.55	0.5	8.10	12.77
	$C_{15}S_{45}D_{40}$	0.89	0.5	8.02	12.37
	$C_{15}S_{35}D_{50}$	1.43	0.5	6.34	10.23
	$C_{15}S_{25}D_{60}$	2.40	0.5	5.79	7.94
	$C_{15}S_{15}D_{70}$	4.67	0.5	6.68	10.26
Cement-10%	Control-3	0.00	0.5	6.12	8.10
	$C_{10}S_{80}D_{10}$	0.13	0.5	5.04	7.94
	$C_{10}S_{70}D_{20}$	0.29	0.5	6.65	10.85
	$C_{10}S_{60}D_{30}$	0.50	0.5	6.75	8.22
	$C_{10}S_{50}D_{40}$	0.80	0.5	6.37	8.73
	$C_{10}S_{40}D_{50}$	1.25	0.5	5.44	8.45
	$C_{10}S_{30}D_{60}$	2.00	0.5	4.25	5.94
	$C_{10}S_{20}D_{70}$	3.50	0.5	4.23	6.33
	$C_{10}S_{10}D_{80}$	8.00	0.5	3.93	5.49

Table 4.2 Average 14 and 28 days compressive strength result for Mix series II

Cement Content	Mix Designation	Soil/sand ratio	W/C Ratio	14 day Avg. Comp. Strength (MPa)	28 day Avg. Comp. Strength (MPa)
Cement-20%	Control-1	0.00	0.5	21.30	27.79
	$C_{20}S_{40}D_{20}M_{20}$	0.5	0.5	20.55	24.95
	$C_{20}S_{20}D_{40}M_{20}$	2	0.5	15.48	18.54
	$C_{20}S_{1}D_{59}M_{20}$	59	0.5	13.50	16.29
Cement-15%	Control-2	0.00	0.5	7.53	10.47
	$C_{15}S_{60}D_{5}M_{20}$	0.08	0.5	6.31	8.14
	$C_{15}S_{40}D_{25}M_{20}$	0.63	0.5	5.75	7.34
	$C_{15}S_{20}D_{45}M_{20}$	2.25	0.5	4.02	5.45
	$C_{15}S_{1}D_{64}M_{20}$	64.00	0.5	3.07	3.99
Cement-15%	Control-3	0.00	0.5	16.45	19.94
	$C_{15}S_{60}D_{15}M_{10}$	0.25	0.5	14.70	16.48
	$C_{15}S_{40}D_{35}M_{10}$	0.88	0.5	13.68	15.76
	$C_{15}S_{20}D_{55}M_{10}$	2.75	0.5	5.61	10.39
	$C_{15}S_{1}D_{74}M_{10}$	14.00	0.5	5.61	7.49

4.2 RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND SOIL TO SAND RATIO WITH CONSTANT CEMENT CONTENT

The compressive strength of the soil cement mixes has been determined at the ages of 7th or 14th and 28 days. At each age a minimum of three specimens were tested .

4.2.1 Mix Series 1

Among the several factors that affect the compressive strength properties of the hardened cement mix this part shows effect of soil to sand ratio with cement content of 20%, 15% and 10%.As it was discussed earlier in section 3.3 this mix series contain three basic variables Cement, Soil and Sand, the mix series were developed by varying the percentage of these variables.

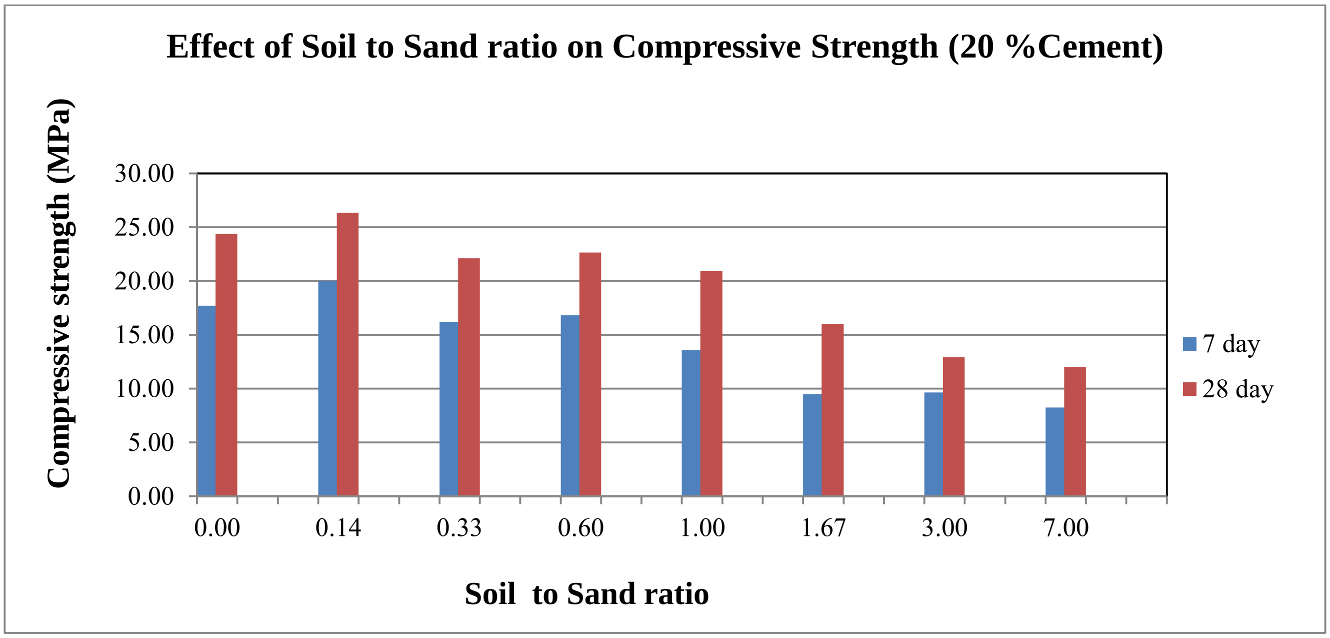

Fig 4.1 Relationship between soil to sand ratio and compressive strength (20% cement content)

The average value of 7th and 28th day compressive strength for mix series I are shown in Table 4.1. As it can be seen in Table 4.1 and Figure 4.1, 4.2 and 4.3 a general trends can be recognized. For the tested cement content i.e. 20%, 15% and 10% with an increase in soil to sand ratio there is a decrease in compressive strength of the specimen. It would be reasonable to conclude that when the amount of soil present in the mix increases the compressive strength will gradually decrease. In Fig 4.1 the peak value of compressive strength is observed at a soil to sand ratio of 0.14($C_{20}S_{70}D_{10}$) both for 7 day and 28 day compressive strength which is 20.5MPa and 26.35 MPa respectively, this mix ratio contains 70% sand and 10% soil content. But when this peak value is compared to the control mix which has no added soil the value shows an increase in compressive strength by 13.08% and 8% for 7th and 28th day respectively. The probable reason for this increase in compressive strength may be that since the compressive strength of the mix depends on workability and void percentage with addition of small percentage of soil, the soil cement has enhanced workability and the voids were easily filled with the fine particles of the soil grains.

The compressive strength test result for the hardened soil cement with cement content of 20% at the 7th day showed on average about 70% of the 28th compressive strength. Similarly for cement content of 10 % the 7th day compressive strength showed about 75% of the 28th day compressive strength ; while for 15% cement content the 7th day compressive strength become on average 65% of the 28th day compressive strength.

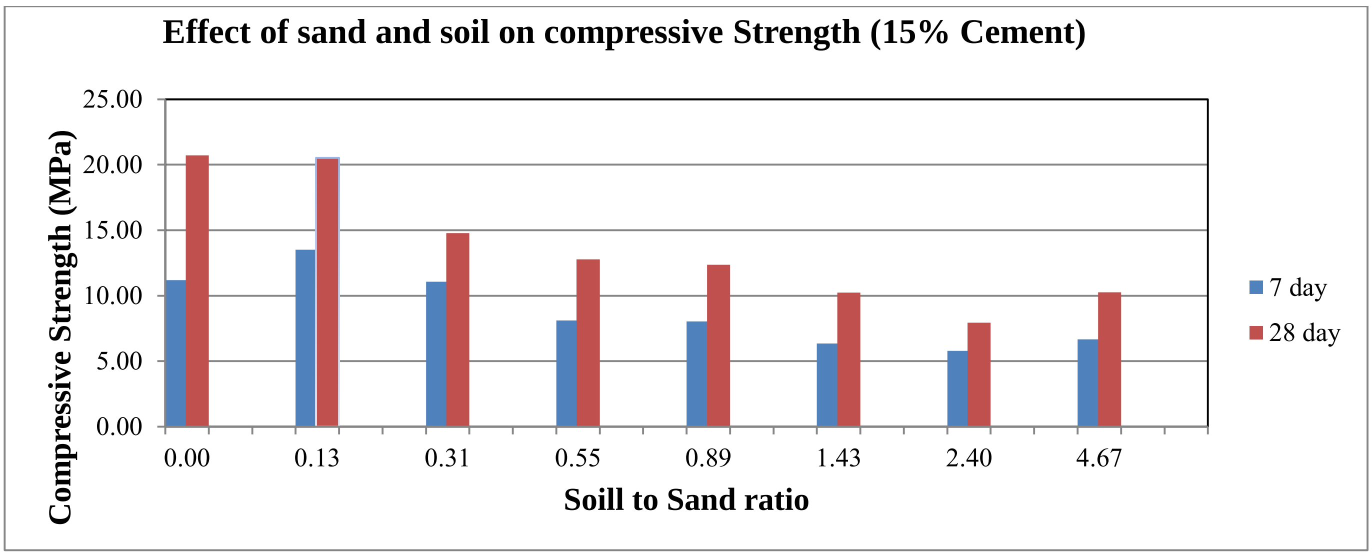

Fig 4.2 Relationship between soil to sand ratio and compressive strength (15% cement content)

For cement content of 15 % shown in Fig 4.2 the peak value of compressive strength is observed at a soil to sand ratio of 0.13 for 7th day and at 0 for 28th day, but the difference in percentage between the two ratios for 28th day is below 1% therefore the prediction for gain in strength with addition of soil is going to be the same as the previous figure.

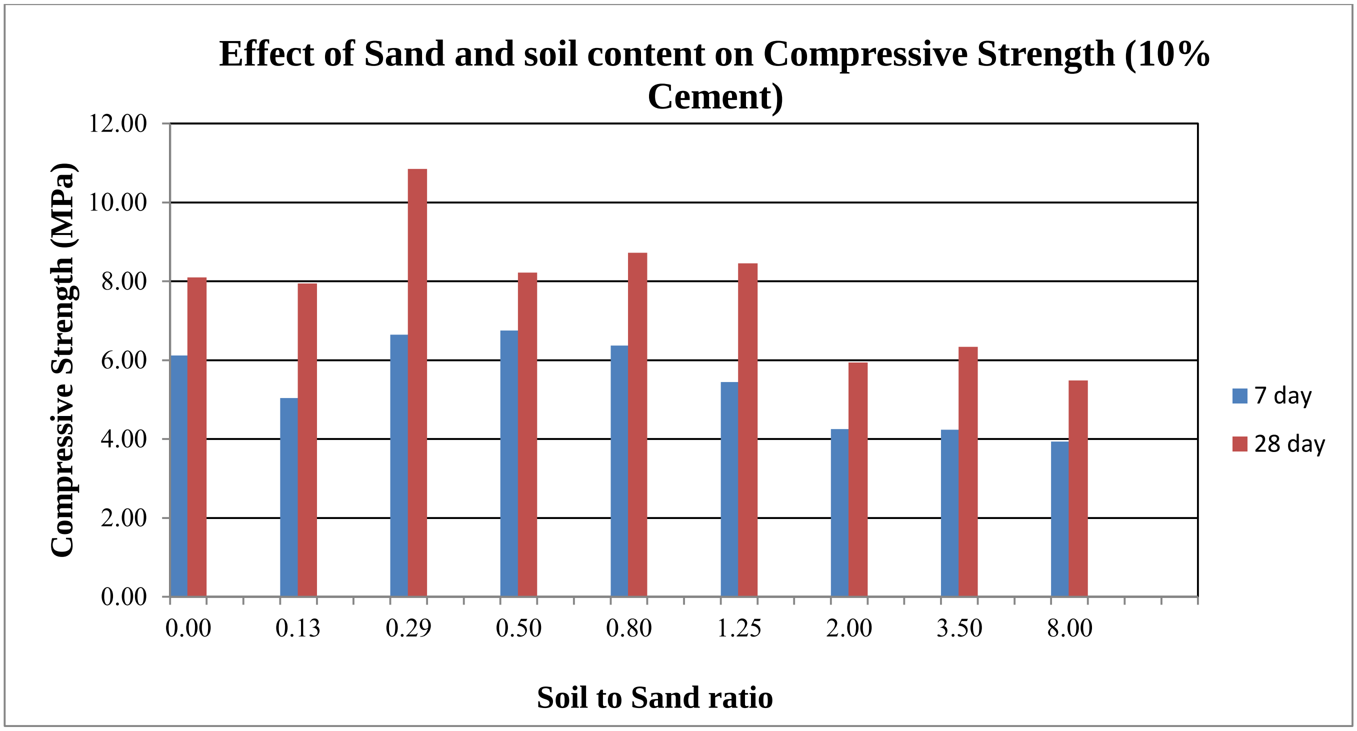

Fig 4.3 Relationship between soil to sand ratio and compressive strength (10% cement content)

4.2.2 Mix Series II

In this part different test results on mix series II containing constant values of cement and crushed aggregate amount are presented and analyzed. The average values are given on Table 4.2 and the graphical representation of compressive strength with respect to soil to sand ratio is shown in Fig 4.4 for cement content of 20% and crushed sand amount of 20%, Fig4.5 for a cement content of 15 % and crushed sand 15% and Fig 4.6 for cement content of 15% and 10% of crushed sand.

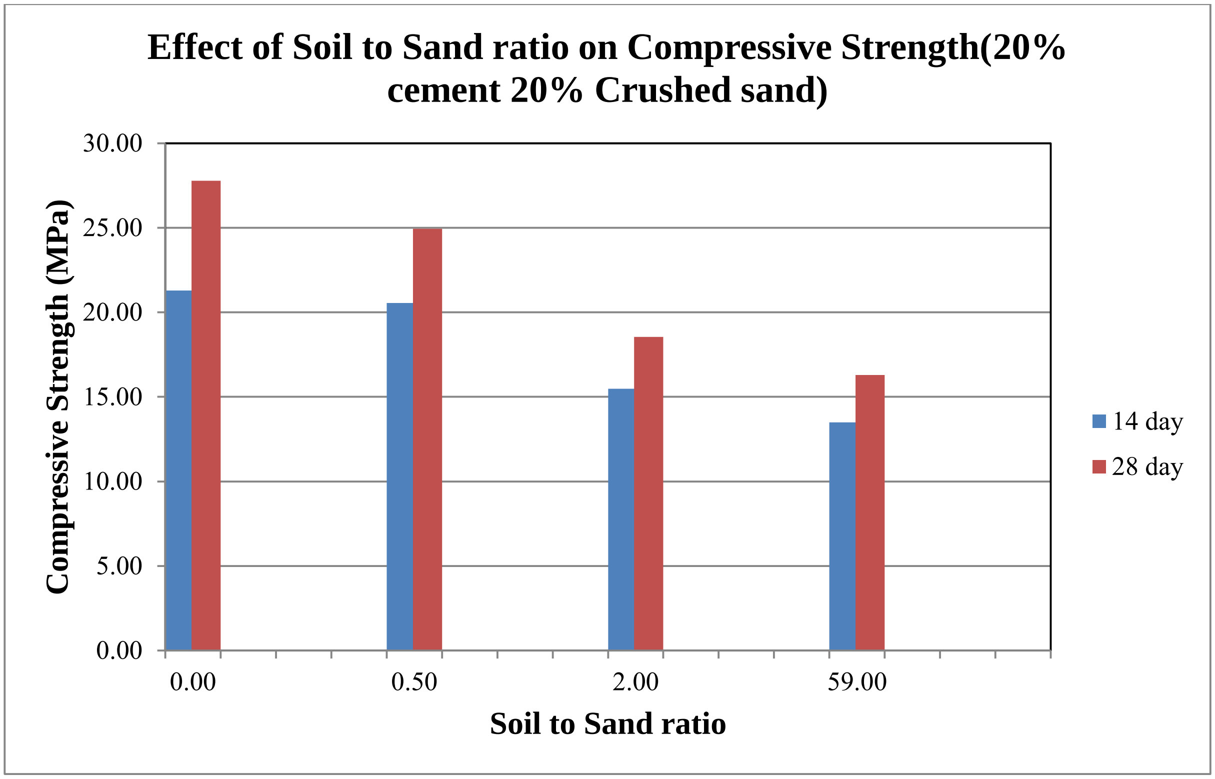

Fig 4.4 Relationship between soil to sand ratio and compressive strength (20% cement and 20% crushed sand content)

Fig 4.4 represents the relation between soil to sand ratio and 14th and 28th day compressive strength with 20% cement and 20% crushed sand content. The graph shows that for the specified cement and crushed sand content the values of compressive strength decrease with an increase in soil to sand ratio. The maximum compressive strength value was observed for the control mix which has a 60% sand content and soil content of Zero. The compressive strengths were 21.47 Mpa and 27.79 MPa for 14th and 28th days strength consecutively. The minimum value of compressive strength for the 14th and 28th day is observed for a mix containing 59 as a soil to sand ratio($C_{20}S_1D_{59}M_{20}$) which has a value of 13.5MPa and 16.29 MPa for 14th and 28th day , this mix has almost 60 % of its material, soil by volume.

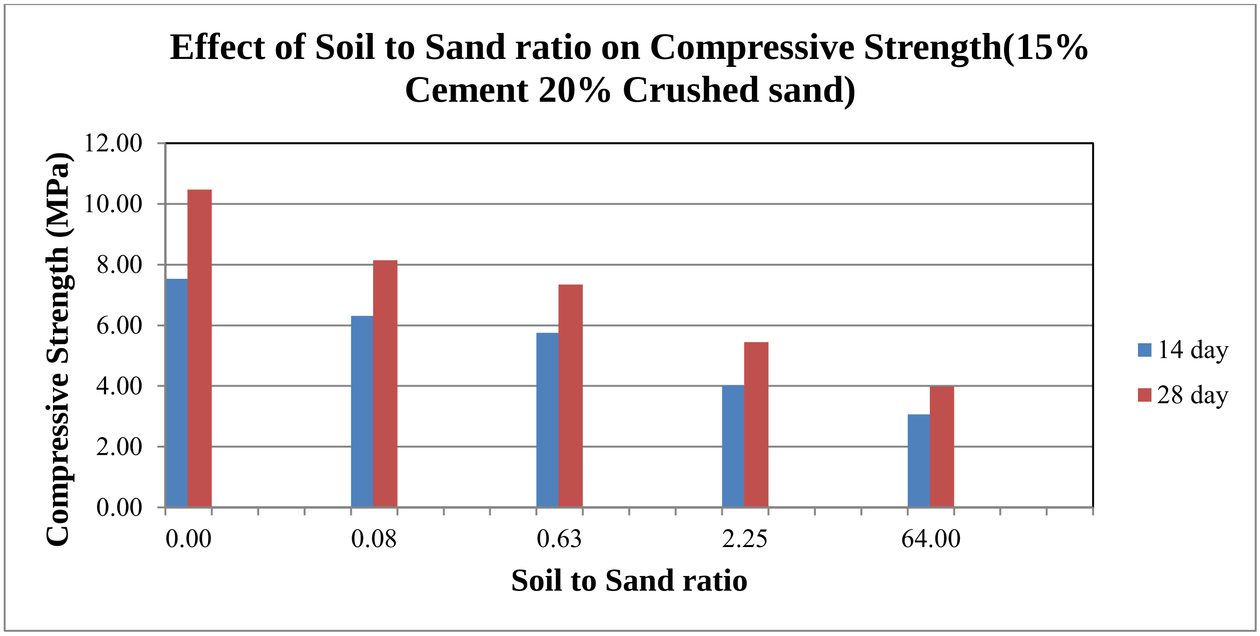

Fig 4.5 Relationship between soil to sand ratio and compressive strength (15% cement and 20% crushed sand content)

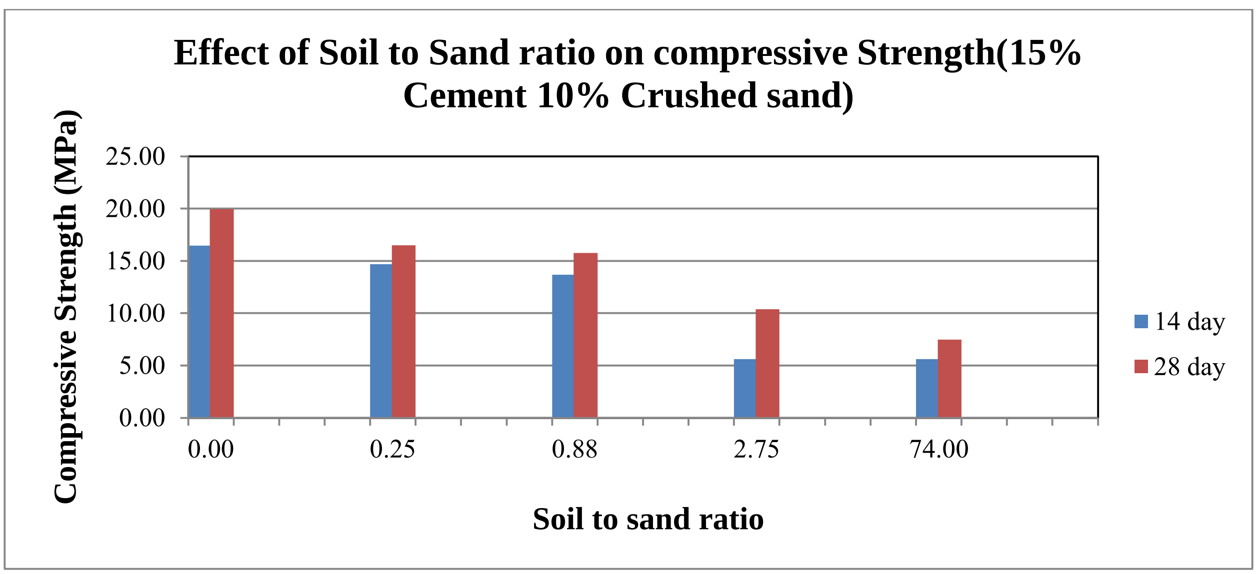

Fig 4.6 Relationship between soil to sand ratio and compressive strength (15% cement and 10% crushed sand content)

The above Figures show the relation between soil to sand ratio and compressive strength for 15% cement and 20% crushed sand content and 15% cement and 10% crushed sand content. As it can be seen from the three figures an increase in soil content has reduced the strength of the mass and an increase in percentage of sand will enhance the compressive strength of the hardened soil cement paste.

4.3 RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND SOIL TO SAND RATIO WITH VARYING CEMENT CONTENT

4.3.1 Mix Series I

From the literature, it was found out that increasing the cement content will have a significant effect on compressive strength of the soil cement product. Fig 4.7 and Fig 4.8 show the 7th and 28th compressive strength with respect to soil to sand ratio. From the shown graph it can be noted than the increase in cement content has a positive effect on compressive strength. This percentage increase in cement content results in deposition of cement gel between soil particles. The interlocking cement gel between the soil particles binds the soil particles together and creates high strength.

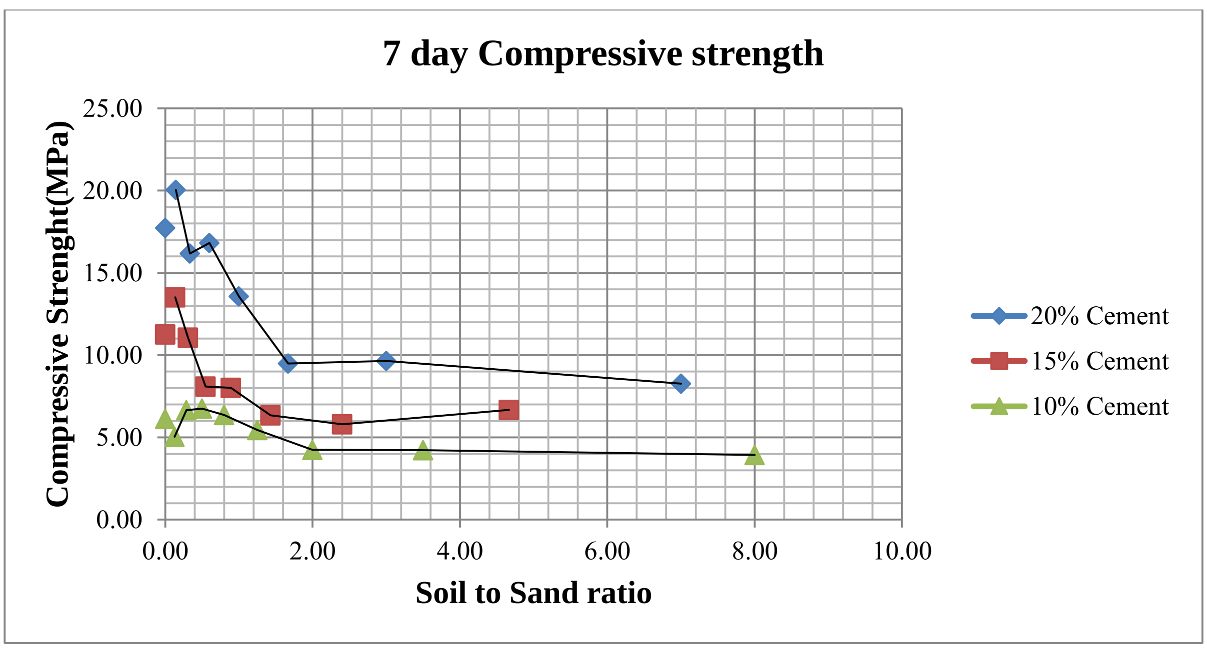

Fig 4.7 Relationship between soil to sand ratio and 7 day compressive strength to show effect of cement content (Mix Series I)

The effect of cement content on compressive strength can be shown by taking one specific soil to sand ratio, for example with soil to sand ratio of 1.0 for cement content of 20 % the 7th day compressive strength is 13.58MPa, for cement content of 15 % the compressive strength is 11.9 MPa, for cement content of 10% the compressive strength 8.6 MPa. The same goes for 28th day compressive strength increase pattern with cement content, therefore it can be concluded that when the percentage of cement increase the compressive strength will increase.

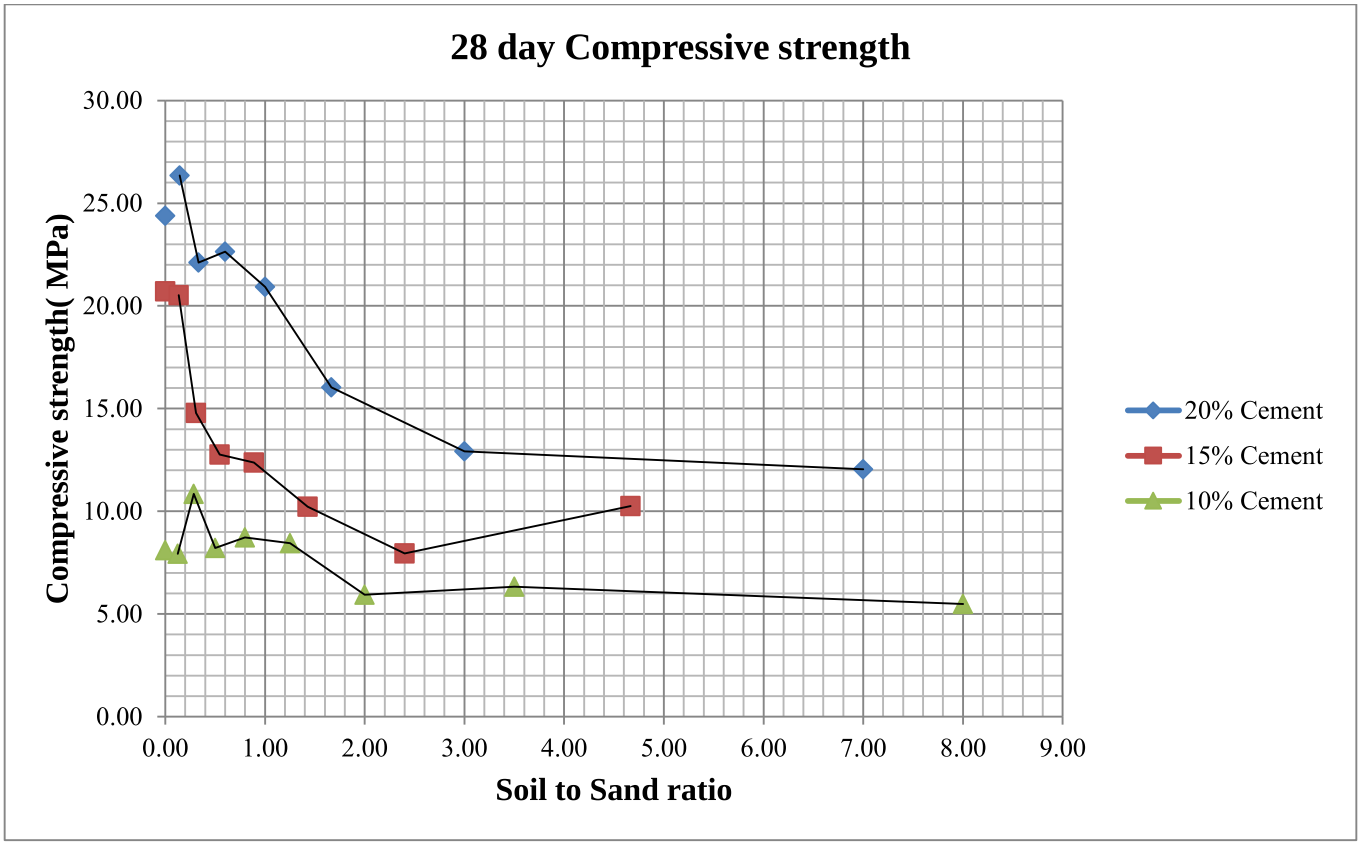

Fig 4.8 Relationship between soil to sand ratio and 28 day compressive strength to show effect of cement content (Mix Series I)

4.3.2 Mix Series II

For the mix series II which contains cement, soil, sand and crushed aggregate from Fig 4.9 to Fig 4.10 show how the percentage increase in crushed sand content will affect the compressive strength and from Fig 4.11 up to Fig 4.12 show the effect of cement content on compressive strength with respect to soil to sand ratio.

Fig 4.9 and Fig 4.10 show the 14th and 28th day compressive strength relationship to soil to sand ratio for a mix containing constant 15% cement content with varying crushed sand content the first one with 20% crushed sand the other with 10 % crushed sand.

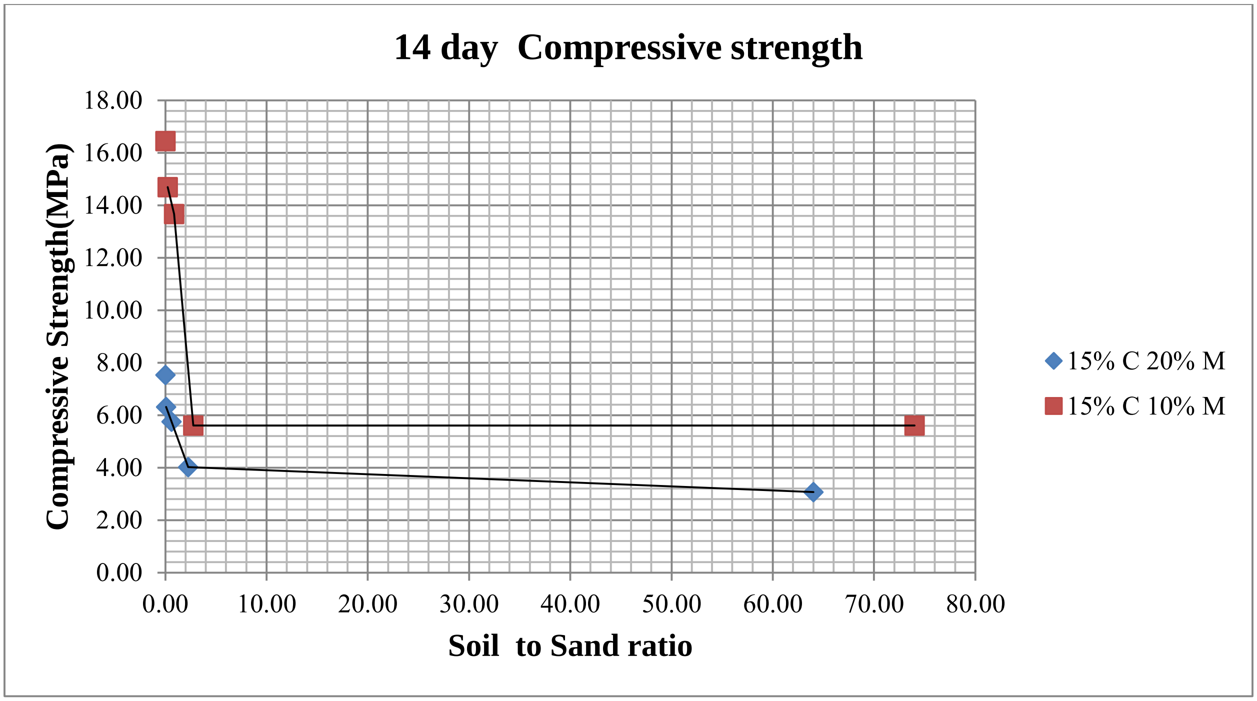

Fig 4.9 Relationship between soil to sand ratio and 14 day compressive strength to show effect of crushed sand content (Mix Series II)

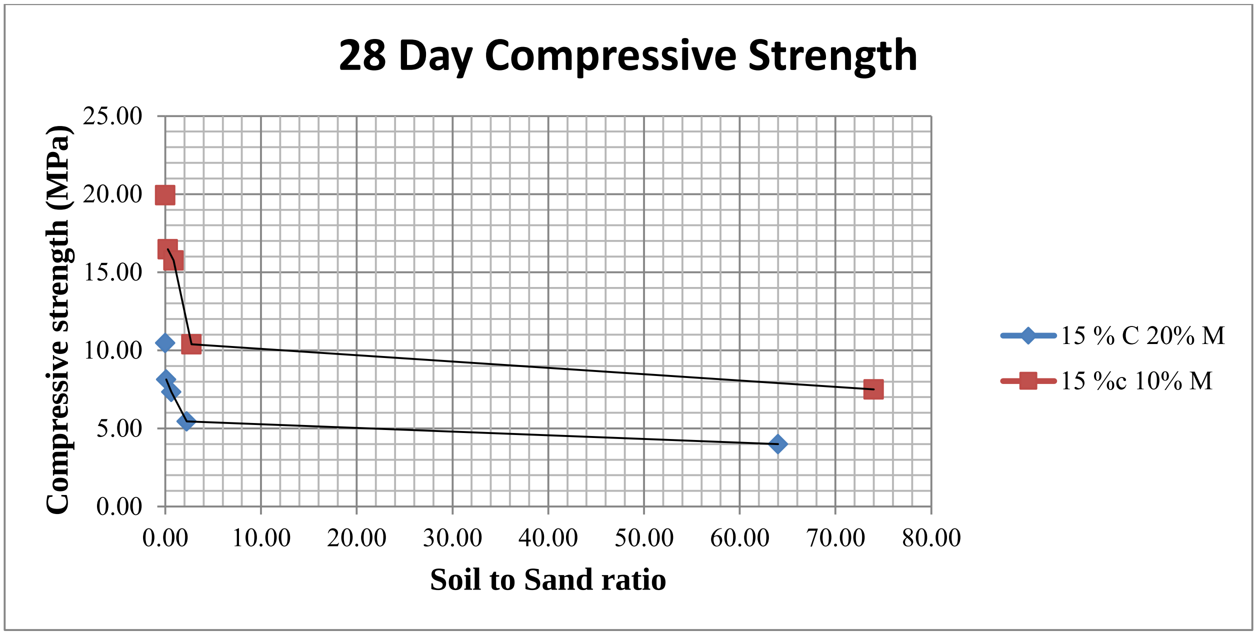

Fig 4.10 Relationship between soil to sand ratio and 14 day compressive strength to show effect of crushed sand content (Mix Series II)

As it can be seen from the above graphs while the percentage of cement being constant the soil cement product has shown reduction in compressive strength when the amount of crushed sand increased. The mix which has 10% crushed sand has higher compressive strength than the mix which contains 20% crushed sand amount. For instance for soil to sand ratio of 0.6 for the 20% crushed sand the compressive strength is around 7.3MPa and for crushed sand percentage of 10% for the same soil to sand ratio the compressive strength is around 16.1MPa.Therefore it can be concluded that the addition of crushed sand amount has a negative impact on compressive strength of the product. In section 2.4.3 of this research it was pointed out that introducing crushed sand will reduce the workability of the mix since workability affects the compressive strength of the product; the likely reason for decrease in compressive strength could be the loss of workability with the addition of crushed sand, during mixing of the specimen visible reduction of workability was noticed.

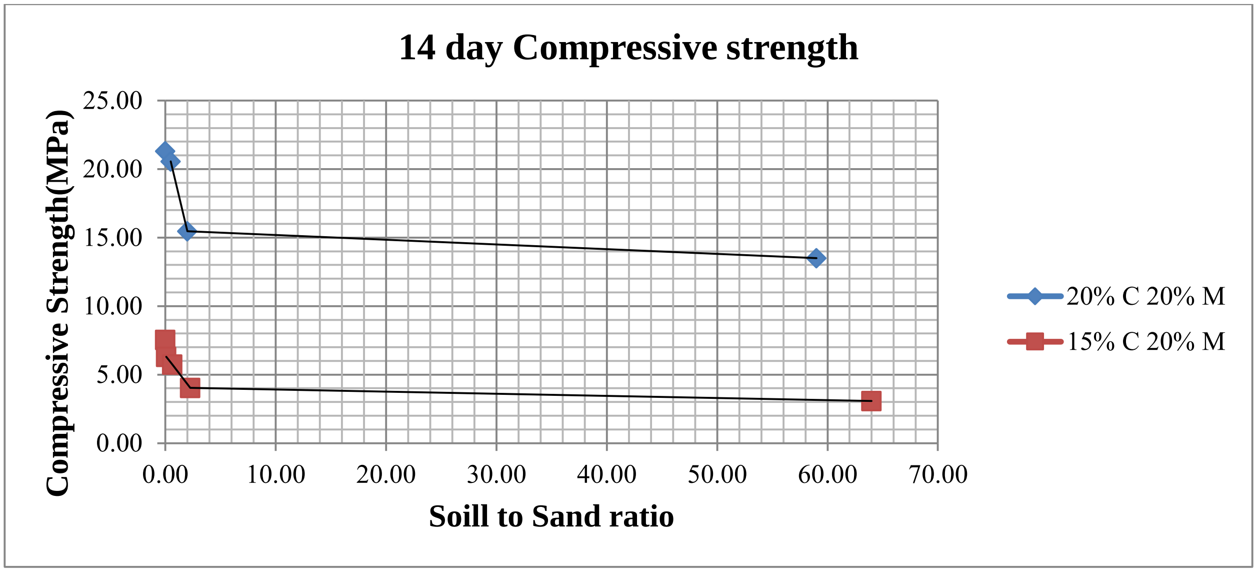

Fig 4.11 Relationship between soil to sand ratio and 14 day compressive strength to show effect of cement content (Mix Series II)

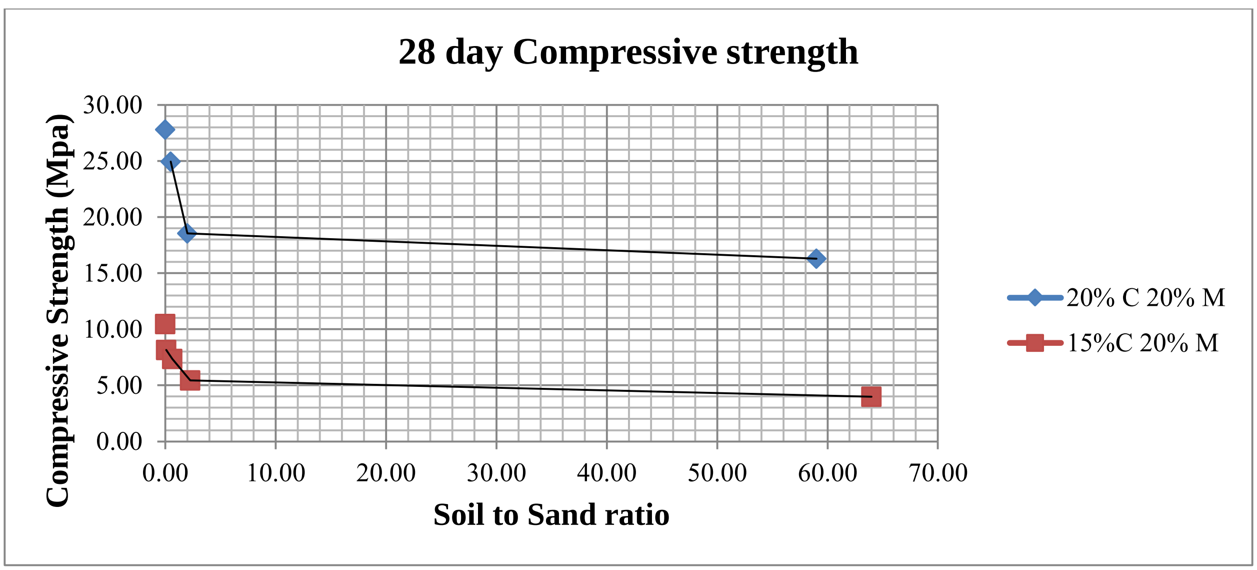

Fig 4.12 Relationship between soil to sand ratio and 28 day compressive strength to show effect of cement content (Mix Series II)

Fig 4.11 and Fig 4.12 shows 14th and 28th compressive strength of soil cement product with 20% crushed sand one with 20 % cement content the other with 15 % cement content. The trend that can be observed form the figures is that with an increase in cement content the compressive strength increases.

4.4 RELATIONSHIP BETWEEN WATER ABSORPTION AND SOIL TO SAND RATIO

28 days water absorption test was done for mix series II having varying cement content and soil to sand ratio the average value of water absorption results is shown in Table 4.3. The experimental results of the water absorption test for mix series are also tabulated in Annex Four and Shown in a graphical form from Fig 4.13-Fig 4.15 . The figures show the effect of varying the percentage of the ingredients with fixed percentage of cement content. From the results average water absorption values varies from 7.34% to 17.92% depending on the ingredients.

Table 4.3 Average water absorption for mix series II

Cement Content	Mix Designation	Soil/sand ratio	Average water absorption (%)
Cement-20%	Control-1	0.00	7.34
	$C_{20}S_{40}D_{20}M_{20}$	0.5	10.57
	$C_{20}S_{20}D_{40}M_{20}$	2	11.23
	$C_{20}S_{1}D_{59}M_{20}$	59	12.18
Cement-15%	Control-2	0.00	11.76
	$C_{15}S_{60}D_{5}M_{20}$	0.08	12.28
	$C_{15}S_{40}D_{25}M_{20}$	0.63	12.42
	$C_{15}S_{20}D_{45}M_{20}$	2.25	12.75
	$C_{15}S_{1}D_{64}M_{20}$	64.00	13.10
Cement-15%	Control-3	0.00	11.89
	$C_{15}S_{60}D_{15}M_{10}$	0.25	12.05
	$C_{15}S_{40}D_{35}M_{10}$	0.88	13.61
	$C_{15}S_{20}D_{55}M_{10}$	2.75	13.79
	$C_{15}S_{1}D_{74}M_{10}$	14.00	17.92

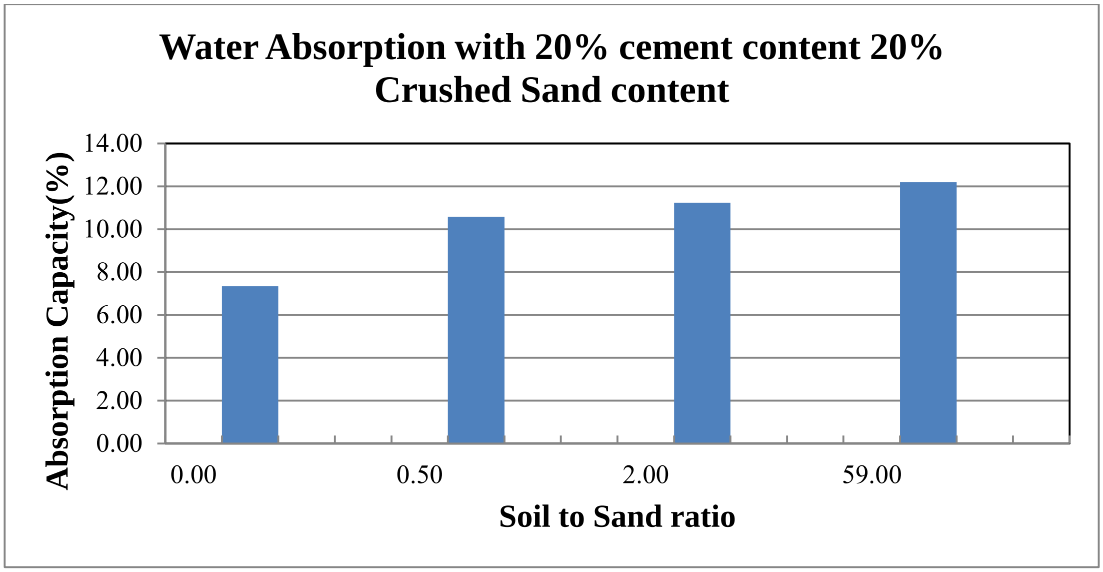

Fig 4.13 Relationship between Water absorption and Soil to sand ratio (20% cement content20 % crushed sand content Mix Series II)

As it can be seen on Fig 4.13 for control mix having 20 % cement content, 20% manufactured sand and 60% natural sand with no added soil content the percentage of water absorption is 7.34%. With addition of soil in the mix the percentage of water absorption increases gradually. For soil sand ratio of 0.5 having 20% soil content the water absorption is around10.5% with a replacement of sand with soil by 20% the water absorption amount increase by 44%. For soil to sand ratio of 2 ($C_{20}S_{20}D_{40}M_{20}$) the water absorption becomes 11.23% when this amount is compared with the control mix the variation is around 53% this indicates that replacement of sand with soil by 40% can result in an increase in water absorption percentage almost by half .

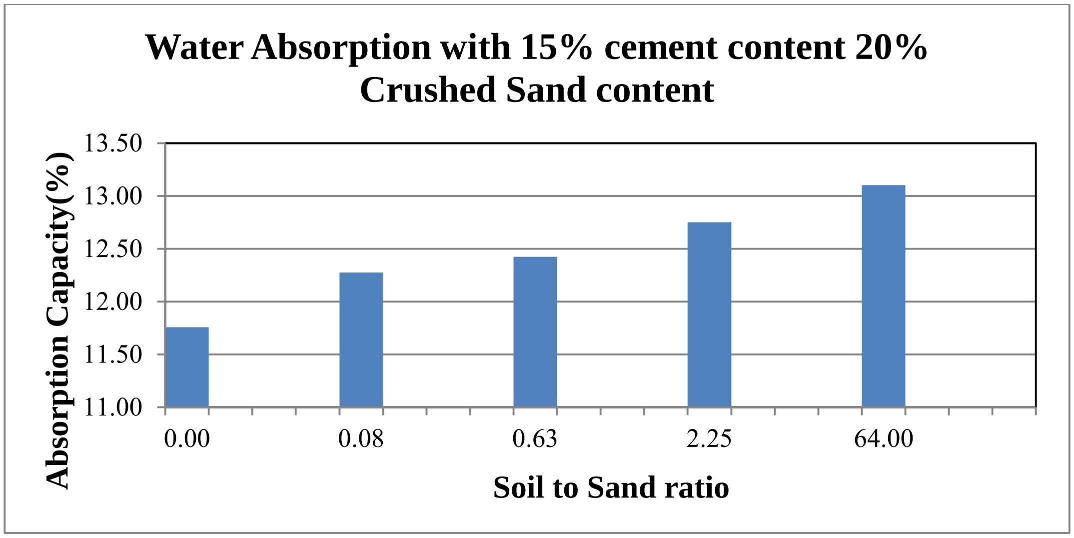

Fig 4.14 Relationship between Water absorption and Soil to sand ratio (15% cement content20 % crushed sand content Mix Series II)

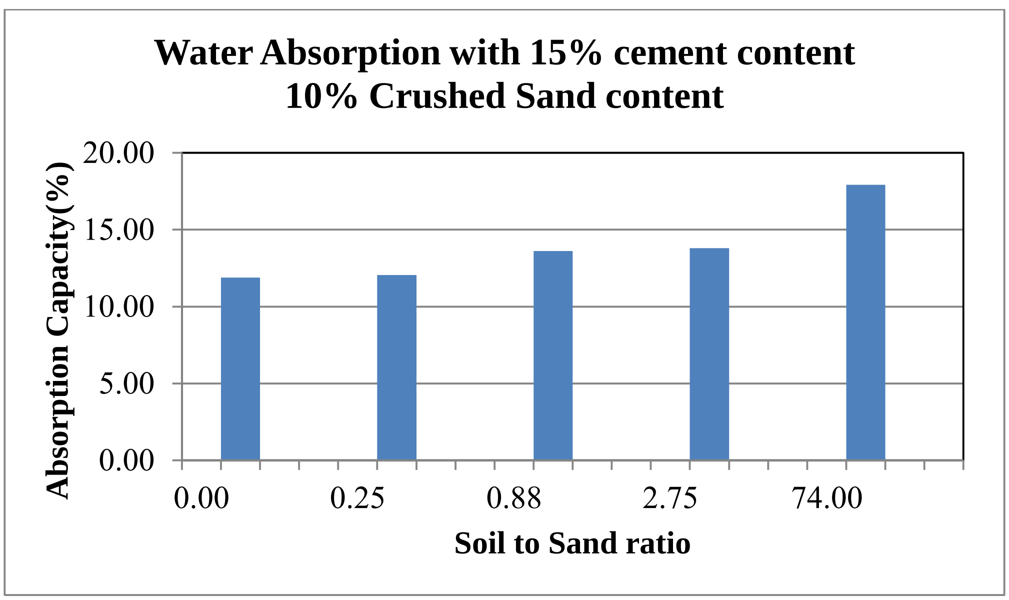

Fig 4.15 Relationship between Water absorption and Soil to sand ratio (15% cement content15% crushed sand content Mix Series II)

The test results indicate that as the value of soil increases the water absorption increases. For example for cement content of 15% and crushed sand content of 20% the control mix, shown on Fig 4.14, which doesn't have soil as in its ingredients with 65% natural sand the water absorption value is 11.76 %. For a mix having the 64% of soil with almost no content of sand ($C_{15}S_1D_{64}M_{20}$) the water absorption value is around 13.1 %. When looking at the percentage increase of water absorption with substitution of the whole natural sand with soil the variation becomes 1.34%.

The increase in water absorption is an indication of an increase in the presence of pore space in the hardened material. For the mix ratio containing 15% cement content and 10% crushed sand as it can be seen from Fig 4.15 with an increase in soil to sand ratio there is an increase in water absorption value. When the absorption value of the control mix with 0 soil to sand ratio having 74% natural sand is compared with the mix containing soil to sand ratio of 74 the variation of absorption capacity is found to be 6.03% which shows the effect of replacement of soil with natural sand.

4.5 RELATIONSHIP BETWEEN WATER ABSORPTION AND CEMENT CONTENT

Results show that there a significant improvement in water absorption with an increase in cement. The Fig 4.16 shows the effect of cement content on water absorption. For the comparison purpose a mix containing 20% cement with 20% crushed sand and mix having 15% cement content with 20% crushed sand is reviewed. The cement hydrates when water is added; the reaction produces a cementitious gel that is independent of the soil. This gel when it hardens it fills void between the aggregates or soil and gives strength to the mix.

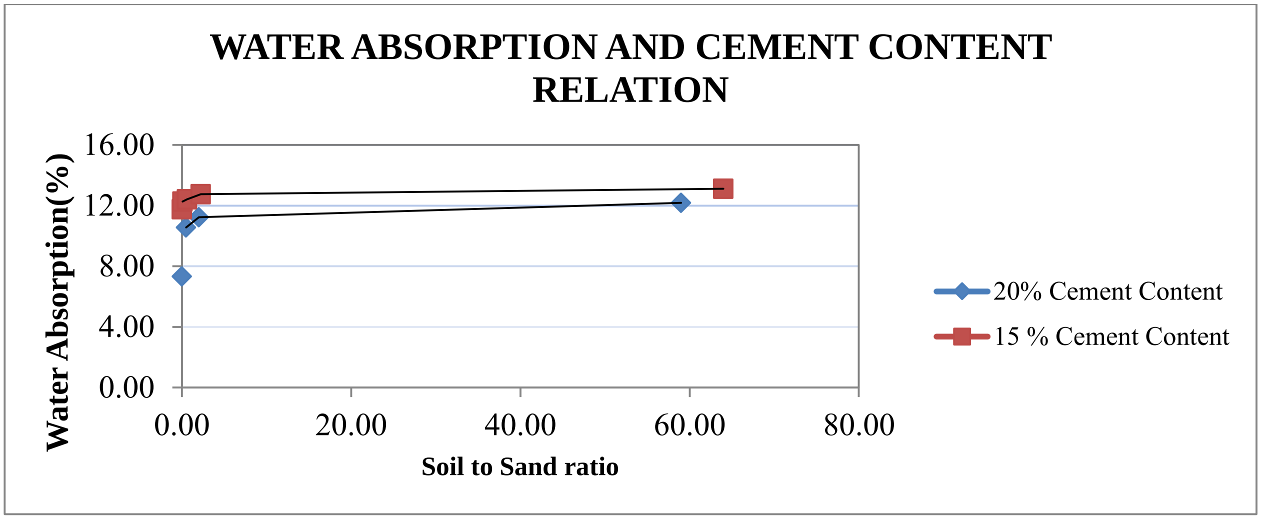

Fig 4.16 Relationship between water absorption and soil to cement content

From the graph it can be seen that high amount of cement has a way of reducing voids in the hardened mix or decreasing the water absorption property.

4.6 RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND WATER ABSORPTION

For the hardened soil cement one of the factors that affect the strength is pore structure which ultimately affects the water absorption property. The experimental results obtained for 28^{th} day compressive strength are plotted against those for 28-day water absorption for mix series II on Fig 4.17 up to Fig 4.19.

For mix series II with different cement, gravel, soil and sand content relationship between compressive strength and water absorption seems to show a uniform trend, it can be seen that with an increase in water absorption there is a decrease in compressive strength.

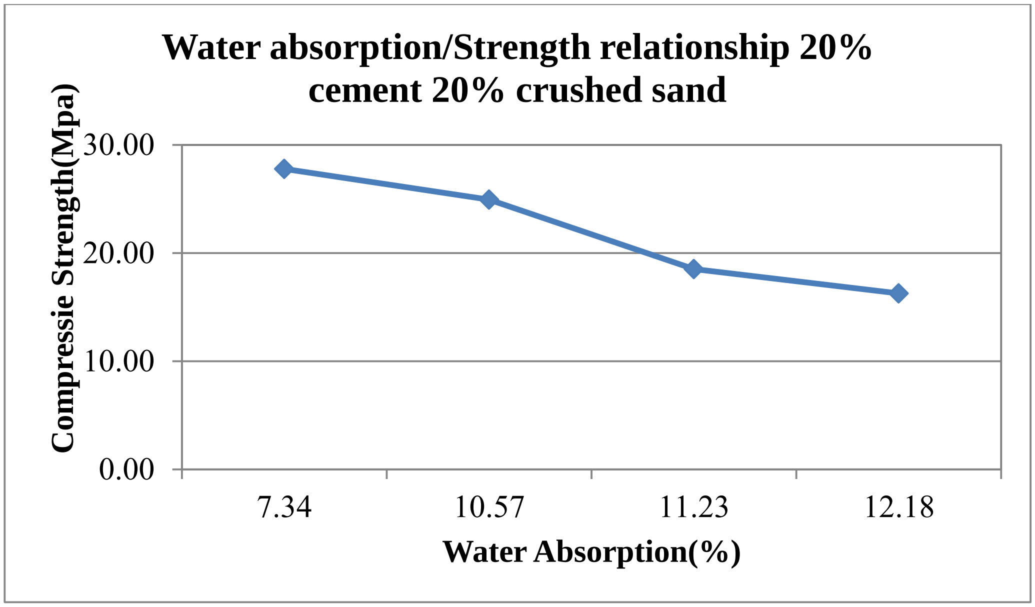

Fig 4.17 Relationship between 28 day compressive strength and water absorption for 20% cement content 20% crushed sand content.

For the mix containing 20% cement and 20% crushed sand content as shown on Fig 4.17 the relationship between water absorption and strength shows that with an increase in water absorption amount there is a decrease in compressive strength value. For the control mix with no added soil content having 60% sand the water absorption value is 7.34% having the highest amount of compressive strength (27.79Mpa). The mix ratio which contains water absorption value of 12.18% has a minimum amount of compressive strength which is around 16.3Mpa. By looking at the relationship of the two mixes for strength reduction of 41.37% the increases in water absorption is found to be 65.9%.

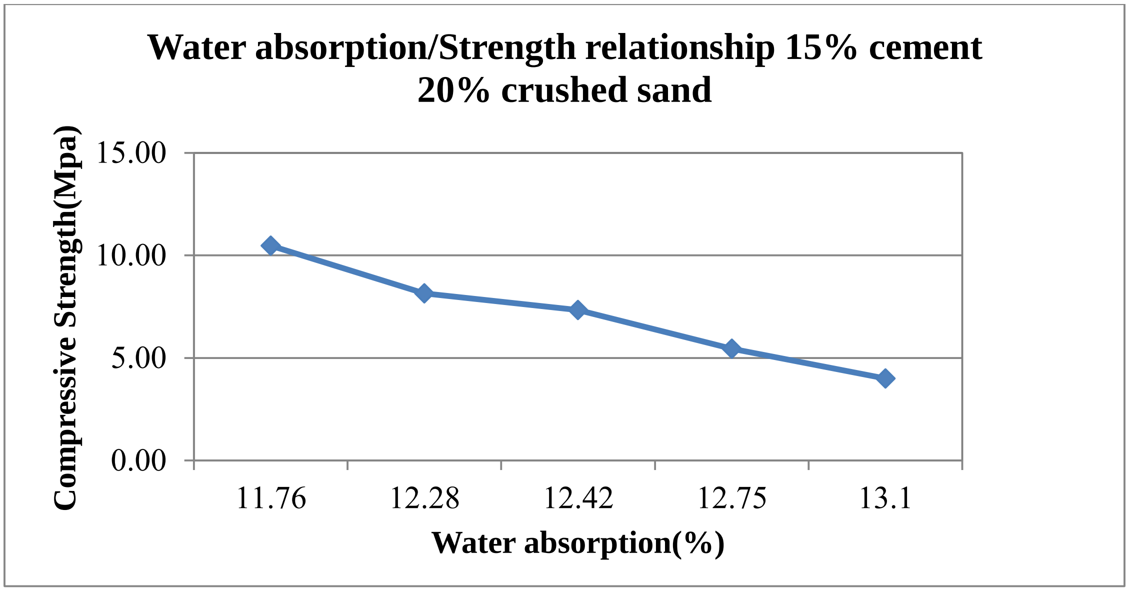

Fig 4.18 Relationship between 28 day compressive strength and water absorption for 15% cement content 20% crushed sand content

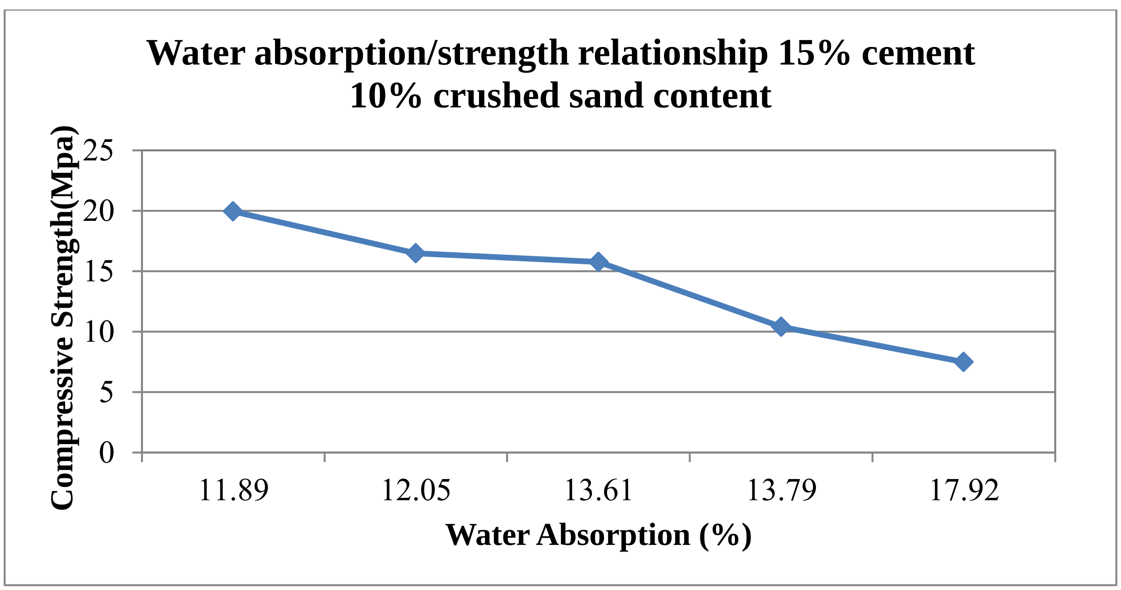

Fig 4.19 Relationship between 28 day compressive strength and water absorption for 15% cement content 10% crushed sand content.

The above figures shows a relationship between compressive strength and water absorption value for mix containing 15% cement 20% crushed sand content on Fig4.18 and 15% cement 20% crushed sand content on Fig 4.19 . These graphs also indicate that as the water absorption value shows increment as the compressive strength value shows a reduction.

CHAPTER FIVE
ECONOMIC ANALYSIS

5.1 INTRODUCTION

This section of the thesis discusses cost comparison of soil cement flooring material with conventional concrete floor. The cost analysis is made on ground floor having 15 MPa and 10 Mpa. For the cost analysis different parameters are considered such as material cost, labor cost and equipment cost. Considering the production of the flooring material for both cases i.e. with soil cement and with concrete the labor cost and the equipment cost are assumed to be the same.

5.2 EQUIPMENT COST

For production of flooring with cement based mixtures different equipments are required starting from batching up to finishing stage. The main equipments required are mixer, vibrator, handling and finishing equipment. As the production process is similar for the plastic soil cement and concrete flooring the equipments that are going to be required are the same. Therefore, equipment cost can be considered equal.

5.3 LABOR COST

For producing ground floor using concrete labor is required from batching to finishing stage. As the soil cement mix contains similar properties as concrete the labor cost included for both materials can also be considered the same.

5.4 MATERIAL COST

For the concrete and soil cement flooring that is going to be considered in this thesis cost variation solely depends on cost of the constituent material. In this section details for cost calculation is done considering the current price index and with mix ratios having the same compressive strength for both materials. For the analysis cost of soil is taken to be equal to the labor required to dig up and prepare the soil assuming the soil is going to be dug up near to the production location. A typical concrete ground floor slab having compressive strength of 15 MPa and 10 MPa, which is used for ground floor construction, is employed for comparison for both mix series I and mix series II. The amount of materials in the concrete floor is calculated by EBCS2 1995 [26]. The values of the comparison are shown on Table 5.1 and Table 5.2.

Table 5.1 Cost analysis calculation for 15 MPa Compressive Strength

Soil Cement Floor Mix				
Material	Quantity(Kg/m^3)	Volume (m^3)	Unit Price (Birr)	Total Price (Birr)
Mix I (20% Cement content) ($C_{20}S_{30}D_{50}$)				
Cement	479	4.79	270	1293.3
Soil	950	0.38	60	22.8
Sand	547	0.23	500	113.95
			Total	**1430.05**
Mix I (15% Cement content) ($C_{15}S_{35}D_{50}$)				
Cement	382	3.82	270	1031.4
Soil	404	0.16	60	9.696
Sand	1261.9	0.52	500	262.89
			Total	**1303.99**
Mix II(20% Cement content) ($C_{20}S_1D_{59}M_{20}$)				

Cement	479	4.79	270	1293.3
Soil	1121.07	0.44	60	26.90568
Sand	18.25	0.0076	500	3.80
Manufactured Sand	403.00	0.16	500.00	77.50
			Total	**1401.50**
Mix II (15% Cement content) ($C_{15}S_{40}D_{35}M_{10}$)				
Cement	382.00	3.82	270.00	1031.40
Soil	707.00	0.28	60.00	16.97
Sand	776.00	0.32	500.00	161.67
Manufactured Sand	214.00	0.08	500.00	41.15
			Total	**1251.19**
Concrete Floor				
Cement	280	2.8	270	756
Sand	756	0.315	500	157.5
Gravel	1044	0.39	500	196.98
			Total	**1110.48**

From the above cost analysis it can be concluded that for trial mixes of soil cement having different percentage of ingredients the one which satisfies the compressive strength 15 MPa for flooring material has high cost or almost equal cost with that of concrete.

For the 20% cement content the mix which satisfies the compressive strength property for ground flooring material in mix series I have a cost of 1430.05 birr per m^3 which is 28.73% higher than the concrete floor. For the 15% cement content the soil cement mix showed a noticeable change in the cost because of the decrease in the cement content, the variation in cost with concrete becomes 17.38 %. Form both mix series the lower cement content mixes (i.e 10%) don’t satisfy the strength requirement so it can’t be used as flooring material with 15 MPa .It can be seen from the cost analysis much of the cost value goes to cement therefore, unless the cost for this ingredient is reduced using soil cement for flooring material with 15Mpa will not be feasible in relation to economy.

For cost comparison of concrete ground floor with 10 MPa and soil cement floor, the cost analysis which is listed on Table 5.2 shows the values of price in birr for mixes which were chosen from Mix series I and Mix series II and for the concrete floor. The values in the table show that for the 20% cement content in Mix Series I the price of material for soil cement flooring is 1171.66 birr which is 13 % higher than the concrete floor, when this value is compared with 15 MPa the cost difference in percentage reduces almost by half. For cement content of 10% and 15 % in Mix series I the cost of soil cement is 938.34 birr and 973.24 birr consecutively which is less value than that of the concrete which will make soil cement as an economical alternative flooring material. For mix Series II having 10% of manufactured sand the cost of the soil cement is the same as that of the concrete.

Table 5.2 Cost analysis calculation for 10 MPa Compressive Strength

Soil Cement Floor Mix				
Material	Quantity(Kg/m^3)	Volume(m^3)	Unit Price (Birr)	Total Price (Birr)
Mix I (20% Cement content) ($C_{20}S_{10}D_{70}$)				
Cement	479.00	4.79	230.00	1101.70
Soil	1330.80	0.53	60.00	31.94
Sand	182.51	0.08	500.00	38.02
			Total	**1171.66**
Mix I (15 % Cement content) ($C_{15}S_{15}D_{70}$)				
Cement	382.00	3.82	230.00	878.60
Soil	1415.57	0.57	60.00	33.97
Sand	291.20	0.12	500.00	60.67
			Total	**973.24**
Mix I (10% Cement content) ($C_{10}S_{70}D_{20}$)				
Cement	272.00	2.72	230.00	625.60
Soil	431.99	0.17	60.00	10.37
Sand	1451.40	0.60	500.00	302.38
			Total	**938.34**
Mix (II)(15% Cement content) ($C_{15}S_{20}D_{55}M_{10}$)				
Cement	382.00	3.82	230.00	878.60
Soil	1112.46	0.44	60.00	26.70
Sand	388.35	0.16	500.00	80.91

Manufactured Sand	214.00	0.08	500.00	41.15
			Total	**1027.36**
Concrete Floor				
Cement	225.00	2.25	230.00	517.50
Sand	714.00	0.30	500.00	148.75
Gravel	1919.00	0.72	500.00	362.08
			Total	**1028.33**

Therefore, it can be concluded from Table 5.1 and Table 5.2 that the higher percentage of cost is contributed by the cement cost and if this value decreases or if other alternative cement replacing materials have been used the cost of soil cement flooring material will decrease making it a good alternative for flooring material.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

In this research experimental work was carried out to assess the applicability of soil cement as a flooring material by studying the ingredients in soil cement mix and by investigating their effect on hardened mass. On the basis of the results obtained the following conclusions are drawn:

1. An increase in soil content will reduced the strength of the mass and an increase in percentage of sand enhances the compressive strength of the hardened soil cement paste.
2. From the result and discussion it can be noted that the increase in cement content has a positive effect on compressive strength, For example with soil to sand ratio of 1.0 and cement content of 20 % the 7th day compressive strength is 13.58MPa, for cement content of 15 % the compressive strength is 11.9 MPa, for cement content of 10% the compressive strength is 8.6 MPa which shows a gradual change in compressive strength value.
3. While the percentage of cement being constant the soil cement product has shown reduction in compressive strength when the amount of crushed sand increased. This might be due to loss

in compactability property of the freshly mixed soil cement that has resulted in loss of compressive strength.

4. Based on the study, it is possible to deduce that when the soil to sand ratio increases the amount of water absorption capacity increases.
5. The research results indicate that the water absorption value shows increment as the compressive strength value reduces.
6. For application as a floor making material with compressive strength of 15 MPa from mix series I $C_{20}S_{30}D_{50}$ and $C_{15}S_{35}D_{50}$, from mix series II $C_{20}S_{1}D_{59}M_{20}$ and $C_{15}S_{40}D_{35}M_{10}$ can be used, as these mixes contain maximum amount of soil which can satisfy the strength requirement with 15 MPa.
7. In mix series I for cement content of 10% and 15 %, with a required compressive strength of 10MPa the cost of plastic soil cement has a reduced cost than that of the concrete flooring.
8. The cost comparison has revealed that higher percentage of cost is due to addition of cement.

6.2 RECOMMENDATIONS

Based on the findings of this research the following recommendations are drawn;

1. Since the use of soil is not a common trend in the construction industry and given that it is a new concept, detail research regarding the durability property is needed to have confidence in its application.
2. For this research, soil with a chemical composition containing SiO_2 65.8%, Al_2O_3 13.82% and Fe_2O_3 7.84% was used in the mix, Further investigation with other soil types is needs to be done to reach at a more comprehensive conclusion on application of soil cement as a flooring material.
3. Since cement is the most expensive material in the prepared mix, other researches can be done on mixes using cement replacing materials and other cement types having lower cost like Pozzolanic Portland Cement and Portland Lime Stone Cement.
4. Further research is needed to test the hardened soil cement for leaching since the main constituent material is soil which might make the soil cement flooring susceptible to leaching.

REFERENCES

[1] Abdulrahman Y. K. and Al-Sakkaf, Durability Properties of Stabilized Earth Blocks, PhD thesis, University Sains Malaysia, 2009.

[2] Anthony Geoffrey Kerali, Durability Of Compressed And Cement-Stabilized building Blocks, PhD thesis , University of Warwick, Coventry, England , 2001.

[3] Bush A., Understanding Stabilized Earth Construction, Virginia, USA, 1984.

[4] Portland Cement Association, Soil-Cement Technology for Pavements: Different Products for Different Applications, Illinois, 2005.

[5] Moriarty J.P., Svare T.I. and Therkildsen O.K., Soil- Cement for low cost Housing, Dares Salaam, 2008.

[6] ACI Committee 230, Report on Soil Cement, ACI 230.1R-90, 2009.

[7] ACI Committee 229, Controlled Low-Strength Materials, ACI 229R-99, 2005.

[8] Vasilios Maniatidis and Peter Walker, A Review of Rammed Earth Construction, University of Bath, 2003.

[9] Gooding D.E. and Thomas T. H., The Potential of Cement-Stabilised Building Blocks as an Urban Building Material in Developing Countries, 1995.

[10] Asmamaw Tadege, Study of Compressed Cement Stabilized Soil Block as an Alternative Wall Making Material, MSc thesis, School of Civil and Environmental Engineering, AAU, Addis Ababa, 2007.

[11] Arora K. R., Soil Mechanics and Foundation Engineering, Sixth Edition, New Delhi, 2003.

[12] Alemayehu Teferra and Mesfin Leikun, Soil Mechanics, Addis Ababa University, 1999.

[13] Montgomery D. E., How does cement stabilisation work?, University of Warwick, United Kingdom, 1998.

[14] Steve Burroughs, Soil Property Criteria for Rammed Earth Stabilization, Journal Of Materials In Civil Engineering, American Society of Civil Enngineers,2008.

[15] Engineering Bulletin, Soil Cement Construction Hand Book, Portland cement Association, 1995.

[16] Tawan Limprasert, Behavior of Soil , Soil-Cement and Soil-Cement-Fiber ,MSc. Thesis, The Faculty of the Russ College of Engineering and Technology Ohio University, Ohio Athens,1995.

[17] Dallas N. Little, Eric H. Males , Jan R. Prusinski and Barry Stewart , Cementitious Stabilization, Committee on Cementitious Stabilization, Louisiana State University, 2006.

[18] Mamunul Hassan, Engineering Characteristics Cement Stabilized Soft Finish Clay- A Laboratory Study, Helsinki University of Technology ,MSc. Thesis, Department of Civil and Environmental Engineering , 2009.

[19] Peace Corps, Handbook for building homes of earth, Washington, DC, USA, 1981.

[20] Lyle A. Wolfskill, Wayne A. Dunlap ¿and Bob M. Gallaway, Handbook For Building Homes of Earth, Texas Transportation Institute, Texas, 1996.

[21] http://www.bluefoxfarm.com/patio-blocks.html

[22] David Easton, Dirt-cheap dirt floor, popular science, California, 1982.

[23] Abebe Dinku , Standardization of concrete making materials in Ethiopia, A paper presented on the 3rd EAF-EARO International Symposium on development studies in Ethiopia, Addis Ababa, Ehtiopia, 2005.

[24] Ehitabezahu Nigussie, Evaluation of Sodium Silicate and Its Combination with Cement/Lime for Soil Stabilization MSc thesis, School of Civil and Environmental Engineering, AAU, Addis Ababa, 2011.

[25] Neville A.M., Properties of concrete, Second edition, 1995.

[26] EBCS 2, Ethiopian Building Code Standard, Structural use of Concrete, Ministry of Works & Urban Development, Addis Ababa, 1995.

ANNEX ONE: SOIL PROPERTIES

Annex 1.1 Specific Gravity Test

Determination No	**1**	**2**	**3**
weight of pychnometer(w_p) g	49.06	45.23	47.62
weight of pychnometer+Soil (w_{ps}) g	78.9	74.7	43.67
weight of pychnometer+water(w_{pw}) g	153.2	149.6	146.77
weight of pycnometer+soil+water(w_{psw})	167.91	165.82	165.62
Temprature ^{0}C	22	22	22
specific gravity	2.63	2.62	2.64
	2.63		

Annex 1.2 Moisture content

Determination No	**1**	**2**	**3**
weight of can, g	15.31	15.62	15.57
weight of can+ dry Soil (w_{cds}), g	45.54	40.21	42.56
weight of can +moist soil (w_{cws}) g	50.26	42.62	49.29
weight of water(w_w)	5.02	4.41	6.73
weight of dry soil (w_s) g	30.23	24.59	27.29
Moisture content	17.67	18.23	17.82
	17.91		

Annex 1.3 particle size distributions

Sieve size (mm)	Weight of Sieve	Weight of soil + sieve	Weight of soil retained (gm)	Cumulative weight retained	Percentage Retained (%)
4.75	1264	0	0	0	0
2.36	990.3	1016.3	26	26	8.38
1.18	894.9	953.6	58.7	84.7	18.92
0.6	831.1	913.3	82.2	140.9	26.50
0.425	788.1	832	43.9	126.1	14.15
0.3	753.4	785.6	32.2	76.1	10.38

0.15	777.5	817.8	40.3	72.5	12.99
0.075	764.8	780.3	15.5	55.8	5.00
Pan	735.9	747.3	11.4	26.9	3.68
		Σ	310.2		

Annex 1.4 Plastic Limit determination

Determination No	1	2	3	4
Can no.	109	B6	HS2	HS0
weight of can, g	15.7	15.6	15.7	15.4
weight of can +moist soil (w_{cws}) g	22.2	29.8	28.7	24.3
weight of can+ dry Soil (w_{cds}), g	21	27	26	22.5
weight of water(w_w)	1.2	2.8	2.7	1.8
weight of dry soil (w_s) g	5.3	11.4	10.3	7.1
Moisture content	22.64	24.56	26.21	25.35
Mean	**24.69 %**			

Annex 1.5 Liquid Limit determination

Determination No	1	2	3	4
Number of drops	35	22	15	26
Can no.	G-3	SM3	T2	6
Weight of can(w_c), g	15.8	15.5	15.8	15.6
Weight of can + moist soil (w_{cws}) g	26.9	24.2	33.5	29.8
Weight of can+ dry Soil (w_{cds}), g	25.3	22.4	28.2	26.02
Weight of water(w_w)	1.6	1.8	5.3	3.78
Weight of dry soil (w_s) g	9.5	6.9	12.4	10.42

Moisture content	16.84	26.09	42.74	36.28
Mean	**30.48**			

Annex 1.6 Chemical Analysis Test Result

Geological Survey of Ethiopia; Geoscience Laboratory Directorate Form G0004
Geochemical Laboratory Complete Silicate Analysis Report Format
FILE ID :- 19173/14 GOV Originator :- SELAM YAZEW(AA.T)
Sample type:- SOIL Date submmitted:- 26/09/2014
Preparation: -200 MESH **Element to be determined Major Oxides & Minor Oxides**
NUMBER OF SAMPLES: 1
Analytical Method: LIBO2 FUSION , HFattack,GRAVIMETERIC and AAS
Analytical Results in PERCENT

FIELD NO	Lab No	SiO2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
SS-01	19173/14	65.86	13.82	7.84	0.46	0.58	2.06	3.62	0.38	0.05	0.87	1.10	4.12

Analysts	**Checked By**	**Approved by**	**QUALITY CONTROL**	**DATE REPORTED**
Mengizam Tsegaye Tizta Zemene Getahun Bikila Hailegebriel Asmare GOSA HAILE	Mengizam Tsegaye	Worede Sahilu	Kedir Bedasso Analytical Process Quality Monitoring Case Team Co-orinator	2/12/2014

ANNEX TWO: AGGREGATE SIEVE ANALYSIS RESULT

Annex 2.1 Sieve analysis result for natural sand

Sieve size (mm)	Weight of Sieve (g)	Wt. of Sieve+ Wt of Retained (g)	Wt. Retained (g)	Percent Retained (%)	Cum. Coarser (%)	Cum. Passing (%)	Cum. Passing (%)	Cum. Passing (%)
9.50	585	585.00	0.00	0.00	0.00	100.00	100.00	100.00
4.75	430	445.00	15.00	2.97	2.97	97.03	95.00	100.00
2.36	385	420.00	35.00	6.93	9.90	90.10	80.00	100.00
1.18	355	460.00	105.00	20.79	30.69	69.31	50.00	85.00
0.60	325	510.00	185.00	36.63	67.33	32.67	25.00	60.00
0.30	300	425.00	125.00	24.75	92.08	7.92	10.00	30.00
0.15	460	490.00	30.00	5.94	98.02	1.98	2.00	10.00
pan	255	265.00	10.00	1.98	100.00	0.00	0.00	0.00
		Σ	505.00	100.00	400.99			

Annex 2.1 Sieve analysis result for Crushed sand

Sieve size (mm)	Weight of Sieve (g)	Wt. of Sieve+ Wt of Retained (g)	Wt. Retained(g)	Percent Retained (%)	Cumulative coarser (%)	Cumulative Passing (%)	Cumulative Passing (%)	Cumulative Passing (%)
9.50	1365	1365.00	0.00	0.00	0.00	100.00	100.00	100.00
4.75	1264	1268.00	4.00	0.76	0.76	99.24	95.00	100.00
2.36	990	1009.40	19.10	3.65	4.42	95.58	80.00	100.00
1.18	894	1050.00	155.10	29.64	34.06	65.94	50.00	85.00
0.60	831	961.20	130.10	24.87	58.93	41.07	25.00	60.00
0.30	753	905.20	151.80	29.01	87.94	12.06	10.00	30.00
0.15	777	831.30	53.80	10.28	98.22	1.78	2.00	10.00
pan	735	745.20	9.30	1.78	100.00	0.00	0.00	0.00
		Σ	523.20	100.00	384.33			

ANNEX THREE: COMPRESSIVE STRENGTH RESULT

Annex 3.1 7th day compressive strength result for mix series I

Cement (%)	Mix Designation	Soil-sand ratio	Weight (kg)	Dimension (mm)			Volume (mm^3)	Failure Load (kN)	Comp. Strength (MPa)	Avg. Comp. Strength (MPa)
C-20%	Control	0.00	271	50.3	51.9	50	130528.50	45.55	18.22	18.37
			262	49.0	48.6	50	119070.00	32.52	13.01	
			281	50.7	50.7	50	128524.50	46.29	18.51	
	$C_{20}S_{70}D_{10}$	0.14	264	49.9	51	50	127245.00	31.98	12.79	20.61
			270	52.0	49.5	50	128700.00	52.38	20.95	
			266	50.3	51	50	128265.00	50.65	20.26	
	$C_{20}S_{60}D_{20}$	0.33	285	50.9	50.8	50	129286.00	43.76	17.5	17.23
			267	53.6	50.8	50	136144.00	46.03	18.41	
			276	53.3	50.3	50	134049.50	39.46	15.79	
	$C_{20}S_{50}D_{30}$	0.60	278	51.0	54.7	50.2	140042.94	50.81	20.32	17.93
			279	53.3	50	50.2	133783.00	44.89	17.96	
			267	51.0	49.3	50.2	126217.86	38.74	15.5	
	$C_{20}S_{40}D_{40}$	1.00	266	50.5	53	50.2	134360.30	35.56	14.22	14.16
			273	53.0	49.4	50.2	131433.64	36.48	14.59	
			261	48.8	51.8	50.2	126897.57	34.15	13.66	
	$C_{20}S_{30}D_{50}$	1.67	265	51.7	51.3	50.2	133140.94	28.95	11.58	10.12
			269	53.7	49.7	50.2	133978.28	22.65	9.06	
			274	54.5	49	50.2	134059.10	24.28	9.71	
	$C_{20}S_{20}D_{60}$	3.00	282	52.6	52.8	50.2	139419.46	28.74	11	9.91
			243	50.1	45	50.2	113062.95	20.32	8.13	
			278	56.0	49.5	50.2	139154.40	26.51	10.61	

	$C_{20}S_{10}D_{70}$	7.00	267	51.0	55	50.2	140811.00	23.14	9.26	9.02
			260	53.6	49.5	50.2	133190.64	21.96	8.78	
C-15%	Control	0.00	280	51.0	53	50.2	135690.60	28.31	11.33	11.66
			264	50.7	52	50.2	132347.28	28.78	11.51	
			264	47.0	52	50.2	122688.80	30.34	12.14	
	$C_{15}S_{75}D_{10}$	0.13	279	50.5	52.5	50.2	133092.75	34.44	13.78	14.32
			281	50.5	52.5	50.2	133092.75	34.1	13.64	
			262	50.0	52.8	50.2	132528.00	38.81	15.54	
	$C_{15}S_{65}D_{20}$	0.31	282	51.0	51.6	50.2	132106.32	26.54	10.62	11.41
			265	50.0	53	50.2	133030.00	29.01	11.6	
			251	49.0	50.5	50.2	124219.90	30.05	12.02	
	$C_{15}S_{55}D_{30}$	0.55	267	52.0	49.8	50.2	129867.40	19.85	7.94	8.36
			266	49.0	52	50.2	127909.60	18.92	7.57	
			245	52.0	48	50.2	125299.20	22.95	9.58	
	$C_{15}S_{45}D_{40}$	0.89	266	51.3	51	50.2	131338.26	20.91	8.36	8.36
			266	51.0	51.5	50.2	131850.30	20.3	8.12	
			263	51.0	50.5	50.2	129290.10	21.5	8.6	
	$C_{15}S_{35}D_{50}$	1.43	267	50.8	52.5	50.2	133883.40	17.08	6.83	6.71
			267	51.0	52	50.2	133130.40	18.31	7.33	
			265	50.4	51.8	50.2	131058.14	14.93	5.97	
	$C_{15}S_{25}D_{60}$	2.40	247	48.7	50	50.2	122237.00	14.38	5.75	5.76
			245	51.0	50.5	50.2	129290.10	14.67	5.87	
			247	48.0	51	50.2	122889.60	14.15	5.66	
	$C_{15}S_{15}D_{70}$	4.67	255	49.0	51.5	50.2	126679.70	16.87	6.75	6.72
			233	50.5	50.5	50.2	128022.55	17	6.8	
			264	50.5	51	50.2	129290.10	26.53	6.61	

C-10%	Control	0.00	271	52.1	51	50.2	133386.42	16.44	6.57	6.35
			267	48.8	51	50.2	125040.17	15.44	6.17	
			273	52.0	50.8	50.2	132608.32	15.8	6.32	
	$C_{10}S_{80}D_{10}$	0.13	267	50.0	52	50.2	130520.00	11.98	4.79	5.25
			259	48.5	53	50.2	129039.10	13.79	5.52	
			264	53.0	49.5	50.2	131699.70	13.5	5.45	
	$C_{10}S_{70}D_{20}$	0.29	262	52.0	51.5	50.2	134435.60	15.36	6.14	7.21
			260	50.0	51.5	50.2	129265.00	17.88	7.51	
			261	52.8	52	50.2	137829.12	19.95	7.98	
	$C_{10}S_{60}D_{30}$	0.50	258	48.7	51.3	50.2	125415.16	15.99	6.4	7.18
			251	51.6	52.8	50.2	136768.90	19.48	7.79	
			269	51.9	52.8	50.2	137564.06	18.39	7.36	
	$C_{10}S_{50}D_{40}$	0.80	262	52.5	49.6	50.2	130720.80	16.66	6.66	6.83
			250	50.6	53.5	50.2	135976.99	16.91	6.76	
			259	51.1	53.3	50.2	136726.23	17.64	7.06	
	$C_{10}S_{40}D_{50}$	1.25	259	52.8	51.4	50.2	136238.78	14.73	5.89	5.85
			260	49.5	52.5	50.2	130457.25	14.27	5.71	
			255	52.5	52.5	50.2	138363.75	14.91	5.96	
	$C_{10}S_{30}D_{60}$	2.00	250	50.6	53.8	50.2	136550.43	11.13	4.45	4.61
			273	51.3	54.6	50.2	140472.15	12.41	4.96	
			257	49.0	53.4	50.2	131353.32	11.04	4.42	
	$C_{10}S_{20}D_{70}$	3.50	272	50.2	56	50.2	141122.24	11.5	4.54	4.63
			260	51.0	52.1	50.2	133491.04	11.36	4.62	
			256	53.2	51.4	50.2	137270.90	11.86	4.72	
	$C_{10}S_{10}D_{80}$	8.00	262	49.3	53	50.2	131167.58	11.48	4.59	2.90
			251	50.4	51.6	50.2	130552.13	10.31	4.12	
			251	54.0	51	50.2	138250.80	9.48	3.79	

Annex 3.2 14th day compressive strength result for mix series II

Cement (%)	Mix Designation	Soil to Sand ratio	Weight (g)	Volume (cm3)	Failure Load (kN)	Compressive strength (MPa)	Avg. Comp. Strength(MPa)
C 20%	Control-1	0.00	7217	3375	474.1	21.07	21.30
			7276	3375	487.9	21.68	
			7139	3375	475.8	21.15	
	$C_{20}S_{40}D_{20}M_{20}$	0.50	7136	3375	462.7	20.57	20.55
			7136	3375	462.7	20.56	
			7192	3375	461.8	20.52	
	$C_{20}S_{20}D_{40}M_{20}$	2.00	6900	3375	340.5	15.13	15.48
			6934	3375	351	15.6	
			6858	3375	353.4	15.7	
	$C_{20}S_{1}D_{59}M_{20}$	59.00	6815	3375	312.9	13.91	13.50
			6850	3375	305.1	13.56	
			6799	3375	293.4	13.04	
C 15%	Control-2	0.00	7096	3375	166.5	7.4	7.53
			7225	3375	168.1	7.47	
			7175	3375	173	7.72	
	$C_{15}S_{60}D_{5}M_{20}$	0.08	7093	3375	139.7	6.21	6.31
			7107	3375	144.9	6.44	
			7087	3375	141.5	6.29	
	$C_{15}S_{40}D_{25}M_{20}$	0.63	6958	3375	132	5.87	5.75
			6993	3375	126.1	5.6	
			6947	3375	130.1	5.78	
	$C_{15}S_{20}D_{45}M_{20}$	2.25	6773	3375	92.8	4.12	4.02
			6778	3375	89.7	3.98	

			6777	3375	89.3	3.97	
	$C_{15}S_{1}D_{64}M_{20}$	64.00	6620	3375	68.9	3.06	3.07
			6603	3375	70	3.11	
			6593	3375	68.2	3.03	
C 15%	Control-3	0.00	7216	3375	365.3	16.23	16.45
			7275	3375	387.8	17.24	
			7166	3375	355	15.89	
	$C_{15}S_{60}D_{15}M_{10}$	0.25	7089	3375	347	15.42	14.70
			7142	3375	335.1	14.89	
			7065	3375	310	13.78	
	$C_{15}S_{40}D_{35}M_{10}$	0.88	7055	3375	309.5	13.76	13.68
			7037	3375	296.3	13.17	
			6989	3375	317.3	14.1	
	$C_{15}S_{20}D_{55}M_{10}$	2.75	6870	3375	129	5.73	5.61
			6848	3375	120	5.35	
			6869	3375	129.3	5.75	
	$C_{15}S_{1}D_{74}M_{10}$	74.00	6553	3375	129	5.73	5.61
			6570	3375	120	5.35	
			6552	3375	129.3	5.75	

Annex 3.3 28th day compressive strength result for mix series I

Cement (%)	Code	Weight (g)	Soil/sand ratio	Dimension			Volume (mm^3)	Failure Load (kN)	Comp. Strength (MPa)	Comp. Strength (MPa)
C-20%	Control	280	0.00	50.2	48	50.1	120720.96	48.7	19.5	23.72
		274		50.2	48	50	120480	32.64	13.06	
		278		50.2	49	50	122990	69.84	27.93	
	$C_{20}S_{70}D_{10}$	271	0.14	50.2	50.1	48	120720.96	77.79	31.12	25.61
		278		50.2	50	50	125500	54.43	21.77	
		263		50.2	50	48	120480	59.85	23.94	
	$C_{20}S_{60}D_{20}$	270	0.33	50.2	48	52	125299.2	45.7	18.31	21.64
		268		50.2	49	49	120530.2	53.02	21.21	
		270		50.2	49	50	122990	63.52	25.41	
	$C_{20}S_{50}D_{30}$	290	0.60	50.2	53	48	127708.8	54.79	21.92	23.23
		275		50.2	50	52	130520	59.87	23.95	
		279		50.2	49	52	127909.6	59.55	23.82	
	$C_{20}S_{40}D_{40}$	268	1.00	50.2	52	48	125299.2	50.1	20.04	20.63
		264		50.2	48	50.1	120720.96	51.67	20.67	
		275		50.2	48	52	125299.2	52.97	21.19	
	$C_{20}S_{30}D_{50}$	270	1.67	50.2	50	52	130520	41.98	16.79	16.38
		270		50.2	51	48	122889.6	34.89	13.95	
		266		50.2	50	52	130520	46.01	18.4	
	$C_{20}S_{20}D_{60}$	261	3.00	50.2	50	48	120480	35	14	12.76
		263		50.2	49	51	125449.8	39.56	15.82	
		270		50.2	48	53	127708.8	21.2	8.47	
		253		50.2	51	49	125449.8	33.4	13.6	

	$C_{20}S_{10}D_{70}$	244	7.00	50.2	51	49	125449.8	26.8	10.47	12.04
				50.2						
C-15%	Control	281	0.00	50.2	50	49	122990	55.07	22.03	20.77
		289		50.2	49	52	127909.6	47.31	18.92	
		283		50.2	51	49	125449.8	52.71	21.37	
	$C_{15}S_{75}D_{10}$	298	0.13	50.2	50	51	128010	50.9	20.37	20.67
		281		50.2	51	50	128010	54.8	21.93	
		275		50.2	50	49	122990	49.3	19.72	
	$C_{15}S_{65}D_{20}$	273	0.31	50.2	50	51	128010	45.26	18.1	14.72
		261		50.2	49	50	122990	30.9	12.36	
		263		50.2	48	51	122889.6	34.25	13.71	
	$C_{15}S_{55}D_{30}$	260	0.55	50.2	51	49	125449.8	34.73	13.89	12.60
		265		50.2	49	49	120530.2	29.55	11.82	
		263		50.2	49	51	125449.8	30.23	12.09	
	$C_{15}S_{45}D_{40}$	264	0.89	50.2	50	50	125500	32.75	13.1	12.14
		263		50.2	51	50	128010	30.77	12.31	
		251		50.2	48	48	115660.8	27.53	11.01	
	$C_{15}S_{35}D_{50}$	247	1.43	50.2	51	48	122889.6	23.68	9.47	10.09
		259		50.2	49	49	120530.2	25.22	10.09	
		250		50.2	51	50	128010	26.8	10.72	
	$C_{15}S_{25}D_{60}$	250	2.40	50.2	49	51	125449.8	17.74	7.09	7.88
		250		50.2	51	49	125449.8	20.84	8.33	
		255		50.2	50	49	122990	20.56	8.22	
	$C_{15}S_{15}D_{70}$	256	4.67	50.2	50	49	122990	26.78	10.71	10.12
		250		50.2	50	50	125500	23.56	9.42	
		245		50.2	50	49	122990	25.55	10.22	
	Control	278		50.2	50	48	120480	15	6.12	

C-10%		270	0.00	50.2	47	50	117970	20.29	8.12	7.02
		263		50.2	50	45	112950	17.03	6.81	
	$C_{10}S_{80}D_{10}$	280	0.13	50.2	50	51	128010	17.37	6.95	7.79
		258		50.2	48	48	115660.8	17.74	7.1	
		278		50.2	50	50	125500	23.28	9.31	
	$C_{10}S_{70}D_{20}$	272	0.29	50.2	50	50	125500	31.58	12.63	10.85
		279		50.2	50	50	125500	26.32	10.53	
		276		50.2	50	50	125500	23.49	9.4	
	$C_{10}S_{60}D_{30}$	266	0.50	50.2	50	50	125500	20.78	8.31	8.04
		271		50.2	50	49	122990	17.58	7.02	
		272		50.2	48	50	120480	21.99	8.79	
	$C_{10}S_{50}D_{40}$	267	0.80	50.2	50	49	122990	19.51	7.8	8.61
		269		50.2	50	50	125500	24.12	9.65	
		269		50.2	48	51	122889.6	20.97	8.39	
	$C_{10}S_{40}D_{50}$	260	1.25	50.2	49	50	122990	22.21	8.48	8.14
		273		50.2	50	50	125500	19.61	7.66	
		272		50.2	49	50	122990	20.71	8.28	
	$C_{10}S_{30}D_{60}$	272	2.00	50.2	52	49	127909.6	15.37	6.15	6.16
		278		50.2	54	49	132829.2	15.44	6.17	
		275		50.2	48	54	130118.4	15.4	6.16	
	$C_{10}S_{20}D_{70}$	262	3.50	50.2	49	52	127909.6	15.5	6.2	6.33
		267		50.2	51	50	128010	17.01	6.8	
		267		50.2	48	52	125299.2	15.6	6	
	$C_{10}S_{10}D_{80}$	250	8.00	50.2	50	50	125500	13.3	5.32	5.27
		262		50.2	51	50	128010	11.25	4.5	
		262		50.2	48	51	122889.6	14.89	5.95	
		263		50.2	48	51	122889.6	15.01	6	

Annex 3.4 28th day compressive strength result for mix series II

Cement (%)	Mix Designation	Soil-sand ratio	Weight (g)	Volume (cm^3)	Failure Load (kN)	Compressive strength (MPa)	Avg. Comp. Strength (MPa)
C- 20%	Control-1	0.00	7231	3375	630.2	28.01	27.79
			7248	3375	570.5	25.36	
			7260	3375	675	30	
	$C_{20}S_{40}D_{20}M_{20}$	0.50	7151	3375	554.4	24.64	24.95
			7155	3375	570.8	25.37	
			7204	3375	558.7	24.83	
	$C_{20}S_{20}D_{40}M_{20}$	2.00	6924	3375	420	18.67	18.54
			6926	3375	424.4	18.86	
			7001	3375	407	18.09	
	$C_{20}S_{1}D_{59}M_{20}$	59.00	6866	3375	353.4	15.7	16.29
			6837	3375	363.3	16.15	
			6907	3375	383.2	17.03	
` C-15%	Control-2	0.00	7253	3375	235	10.45	10.47
			7090	3375	232.6	10.34	
			7244	3375	239.2	10.63	
	$C_{15}S_{60}D_{5}M_{20}$	0.08	7080	3375	179.1	7.96	8.14
			7125	3375	185.9	8.26	
			7113	3375	184.5	8.2	
	$C_{15}S_{40}D_{25}M_{20}$	0.63	7116	3375	159.4	7.08	7.34
			7025	3375	162.9	7.24	
			7143	3375	173.33	7.7	
			6859	3375	123.6	5.49	

	$C_{15}S_{20}D_{45}M_{20}$	2.25	6839	3375	122.9	5.46	5.45
			6812	3375	121.3	5.39	
	$C_{15}S_{1}D_{64}M_{20}$	64.00	6637	3375	90.9	4.04	3.99
			6660	3375	90.3	4	
			6627	3375	88.3	3.92	
C-15 %	Control- 3	0.00	7213	3375	377.9	20.02	19.94
			7221	3375	365.5	19.04	
			7237	3375	362.6	20.75	
	$C_{15}S_{60}D_{15}M_{10}$	0.25	7113	3375	358.2	16.79	16.48
			7108	3375	357.5	16.24	
			7176	3375	347.9	16.41	
	$C_{15}S_{40}D_{35}M_{10}$	0.88	7041	3375	450.4	15.92	15.76
			7045	3375	428.5	15.89	
			7030	3375	466.8	15.46	
	$C_{15}S_{20}D_{55}M_{10}$	2.75	6947	3375	211	9.38	10.39
			6855	3375	246.9	10.97	
			6863	3375	243.2	10.81	
	$C_{15}S_{1}D_{74}M_{10}$	74.00	6616	3375	177.1	7.6	7.49
			6569	3375	163.1	7.27	
			6619	3375	171.1	7.6	

ANNEX FOUR: WATER ABSORPTION TEST RESULTS

APPENDIX 4.1 WATER ABSORPTION MIX SERIES II

	Code	Soil to Sand ratio		Weight of cube oven dry (gm)	Weight of cube saturated surface dry (gm)	Water absorption (%)	Average Water absorption (%)
C- 20%	Control-1	0.00	1	2078	2174	4.62	7.34
			2	1990	2155	8.29	
			3	1999	2181	9.10	
	$C_{20}S_{40}D_{20}M_{20}$	0.50	1	1974	2160	9.42	10.57
			2	1925	2123	10.29	
			3	1934	2166	12.00	
	$C_{20}S_{20}D_{40}M_{20}$	2.00	1	1830	2056	12.35	11.23
			2	1875	2060	9.87	
			3	1901	2077	9.26	
			4	1816	2060	13.44	
	$C_{20}S_{1}D_{59}M_{20}$	59.00	1	1792	2041	13.90	12.18
			2	1855	2051	10.57	
			3	1837	2059	12.08	
C -15%	Control-2	0.00	1	1917	2138	11.53	11.76
			2	1874	2101	12.11	
			3	1892	2113	11.68	
			4	1887	2108	11.71	
	$C_{15}S_{60}D_{5}M_{20}$	0.08	1	1816	2078	14.43	12.28
			2	1847	2063	11.69	
			3	1880	2090	11.17	
			4	1863	2083	11.81	
	$C_{15}S_{40}D_{25}M_{20}$	0.63	1	1876	2085	11.14	12.42
			2	1926	2190	13.71	

	$C_{15}S_{20}D_{45}M_{20}$	2.25	1	1871	2081	11.22	12.75
			2	1793	2049	14.28	
	$C_{15}S_{1}D_{64}M_{20}$	64.00	1	1709	1976	15.62	13.10
			2	1786	1975	10.58	
C-15%	Control- 3	0.00	1	1899	2130	12.16	11.89
			2	1901	2122	11.63	
	$C_{15}S_{60}D_{15}M_{10}$	0.25	1	1890	2100	11.11	12.05
			2	1902	2149	12.99	
	$C_{15}S_{40}D_{35}M_{10}$	0.88	1	1849	2106	13.90	13.61
			2	1900	2153	13.32	
	$C_{15}S_{20}D_{55}M_{10}$	2.75	1	1783	2032	13.97	13.79
			2	1769	2010	13.62	
	$C_{15}S_{1}D_{74}M_{10}$	74.00	1	1570	1868	18.98	17.92
			2	1601	1871	16.86	